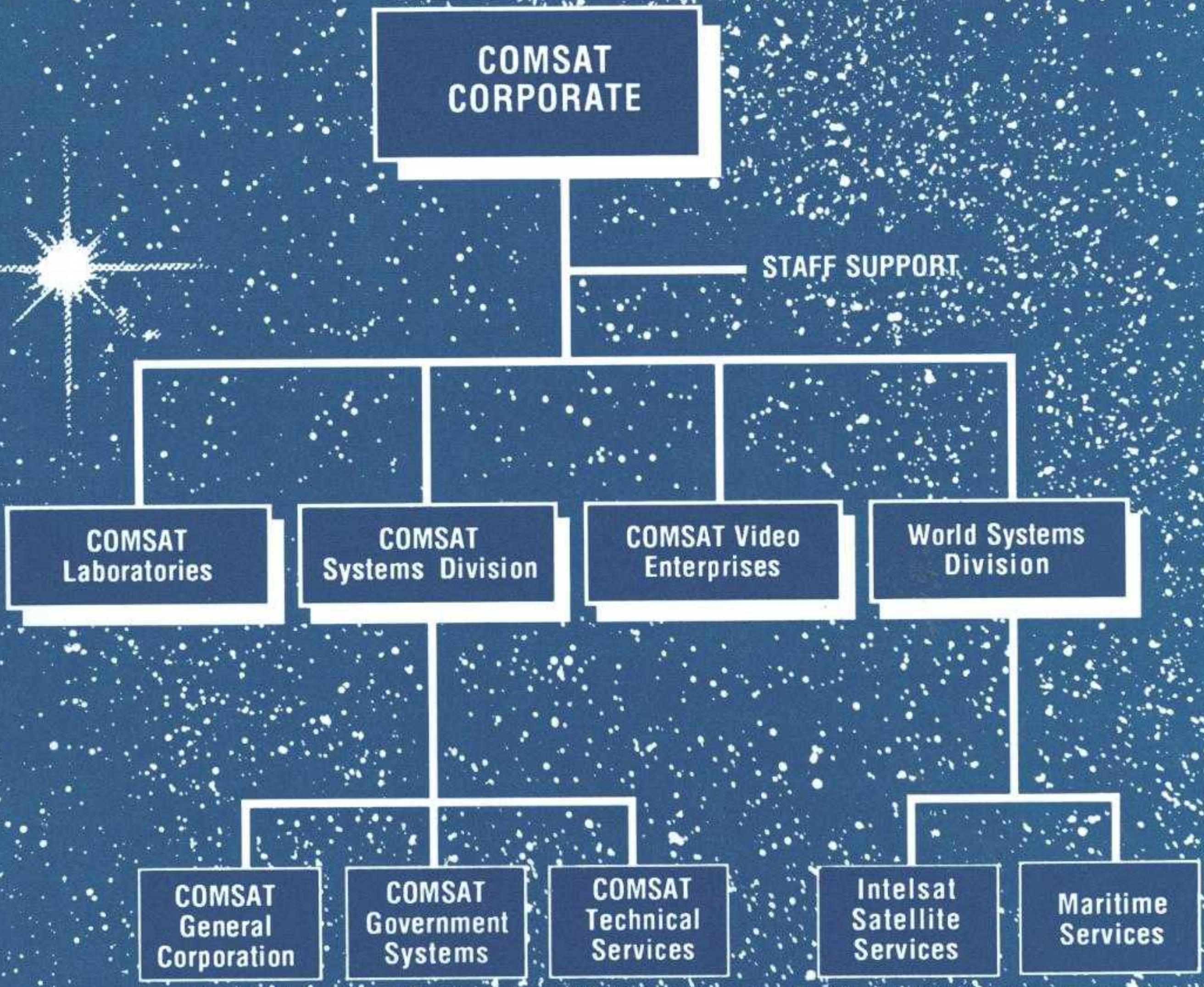
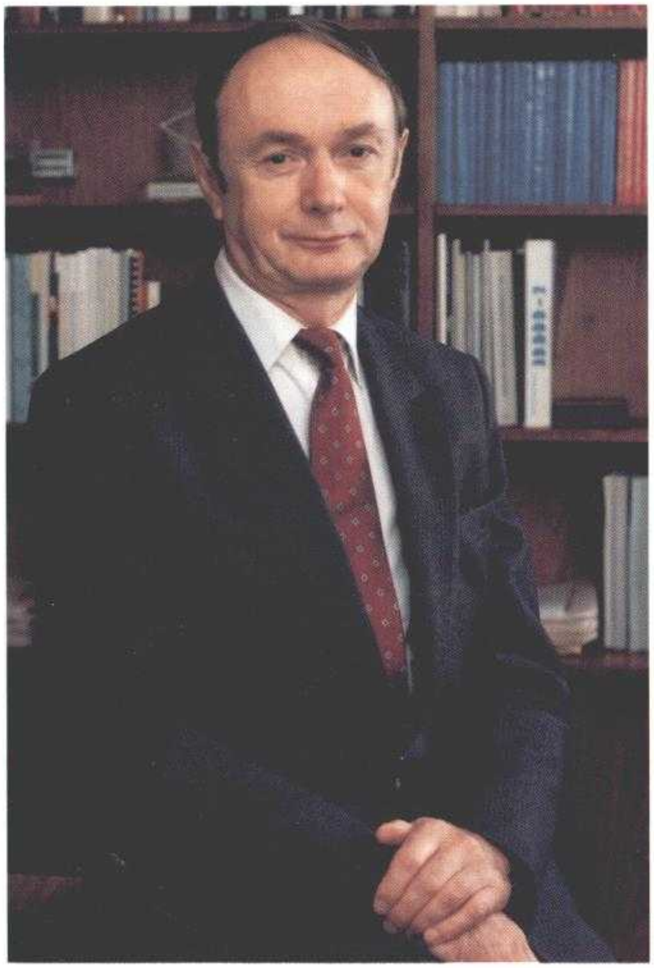
COMSAT LABORATORIES

Annual Report 1988



COMMUNICATIONS SATELLITE CORPORATION 1988



COMSAT Laboratories conducts a program of basic research and development to advance satellite communications technology. Elements of the program are funded by Intelsat Satellite Services and Maritime Services (both part of COMSAT's World Systems Division), and are paid for from revenues derived from international communications services carried via the INTELSAT and INMARSAT organizations. Other work is funded by nonregulated components of the Corporation. Documentation concerning jurisdictional work (that is, work wholly or partially funded by the rate payer) is made available to the public through a catalog that announces the availability of published papers and reports.

During 1988 COMSAT Laboratories had an operating budget of $36 million, of which almost 60 percent came from Corporate sources and the balance from outside. Approximately 30 percent of the Corporate funding (20 percent of the total) supported an applied research program with the goal of creating new technology which has the potential for improving communications systems over the long term. A further 45 percent of the Corporate funding paid for development projects, which were undertaken by the Laboratories for elements of the Corporation on a contract-like basis, and had nearer term applications. The balance of the Corporate funding was for technical support on various projects, studies, and technical issues. The largest effort undertaken for an external customer was for the NASA Advanced Communications Technology Satellite (ACTS) program, although the Laboratories continues to perform a significant amount of development and technical support work for INTELSAT.

Commencing with calendar year 1983 we have published an Annual Report summarizing the results of our research and development program. This report, the sixth in the series, summarizes all the R&D work undertaken with Corporate support during 1988.

J.V. Evans

John V. Evans
March 1989

COMSAT Corporation was created in 1963 following the passage of the Communications Satellite Act, which President Kennedy signed into law in late 1962. Subsequently, in 1964, INTELSAT was established to facilitate international communications between fixed points by satellite, and COMSAT was named U.S. Signatory. Initially, INTELSAT had 11 participants. This has since grown to 115 member countries, and the organization presently provides service to 170 nations.

Until 1979, COMSAT also acted as technical manager of INTELSAT. In this role COMSAT encountered many technical problems, and COMSAT Laboratories was formed in 1967 to help meet these challenges. Initially located in Washington, D.C., the Laboratories moved to its present quarters in Clarksburg, Maryland, in 1969. COMSAT Laboratories presently has a staff of approximately 300 and occupies buildings which afford about 250,000 square feet of space. These facilities are located on a 210-acre tract along Route I-270 north of Gaithersburg, Maryland.

In 1973, COMSAT formed the COMSAT General Corporation with the expectation of branching into domestic satellite communications. In 1975, in partnership with IBM and Aetna Casualty Co., the Satellite Business Systems Corporation was formed. In 1979, as a result of successful demonstrations using the MARISAT system of maritime mobile satellite communications, COMSAT and the U.S. State Department joined with other nations to form INMARSAT, for which COMSAT again serves as U.S. Signatory and representative.

In 1987 COMSAT was reorganized into five divisions, namely the World Systems Division (WSD), which serves as the U.S. Signatory to INTELSAT and INMARSAT; COMSAT International Communications (CICI); COMSAT Video Enterprises (CVE), a business that delivers TV to hotels in the U.S. via satellite; the Laboratories and the Information Systems Division (into which COMSAT General and COMSAT's manufacturing divisions were all grouped). Subsequently, as a result of the sale of CICI and the manufacturing businesses, the Laboratories was reduced in size during 1988 to 300 people. Also in 1988, the Information Systems Division was renamed COMSAT Systems Division (CSD).

In 1988, the largest part of the work at COMSAT Laboratories was that performed for the regulated activity of international satellite communications, either directly for COMSAT or indirectly for INTELSAT. Additional work was performed for CSD and CVE, mostly with support from the Corporate shareholders. Efforts funded entirely by sources outside of COMSAT/INTELSAT included activities for the Federal Government, and the largest part of this was the work performed on the NASA Advanced Communications Technology Satellite (ACTS) program.

During 1988 the Laboratories remained organized into six technical divisions: Applied Technologies, Communications Technology, Microelectronics, Microwave Technology, Network Technology, and System Development. Of these, the first five divisions participate in a research program funded by the Corporation. This program constituted about one-fifth of the Laboratories' activities and included jurisdictional (WSD) business, as well as the nonjurisdictional activities of COMSAT. The former must, perforce, be made public, while the latter is held proprietary.

The balance of the Laboratories' support came from projects performed for and directed by various corporate elements, INTELSAT, INMARSAT, or other outside organizations. Each project is separately negotiated and has specified deliverables and delivery dates. The System Development Division, which is chiefly occupied in writing computer software, works almost exclusively on such specific tasks.

This report summarizes the Laboratories' Research and Development (R&D) activities in 1988. It is organized by technology, as defined by the six technical areas represented by each division. The work is further subdivided into the following categories:

- jurisdictional research and development
- nonjurisdictional research and development
- support work performed for various COMSAT divisions in response to specific requests
- work performed for INTELSAT
- other work.

The Microwave Technology Division (MTD) of COMSAT Laboratories carries out research, development, and support functions in a number of technical areas of importance to the Corporation, including technologies for an advanced communications satellite concept with many pencil beams and on-board processing. Specifically, a phased-array satellite antenna, including monolithic microwave integrated circuits (MMICs), is being developed. Significant progress has been made toward the completion of a 64-element, Ku-band phased-array proof-of-concept antenna. A lightweight, broadband 4 x 4 microwave switch matrix (MSM) for C-band use has been assembled and successfully tested. A multiplexer using quadrupole-mode filters for each channel has been breadboarded, reducing the per-filter mass by two thirds as compared with a dual-mode design. A lightweight reflector-type microstrip radiator, whose flight-qualified mass is about a quarter that of a typical waveguide radiator, has been developed. Support work has continued on MIC and waveguide filters, satellite monitoring and in-orbit testing, new earth station antennas and feeds, microwave propagation studies, and antenna modifications at the Southbury earth station.

COMSAT JURISDICTIONAL R&D

Multimode Microwave Filters

Work on multimode waveguide cavity filters continued in 1988. A study of forced-mode degeneracies in cylindrical cavities led to the concept and design of a single-cavity fifth-order elliptic filter. The realized prototype exhibited a spurious coupling between two of the modes, which prevented accurate tuning of the unit to the desired filter response. Further studies revealed that an extra degree of freedom in the geometry of the cavity would be necessary to independently tune and couple each degenerate mode. New software was developed that accounts for geometries other than cylindrical in the mode analysis. Results obtained so far encourage attempts to realize degeneracies of up to sixth-order.

In the area of high-power filters, a study was completed on the effects of thermal gradients on dual-mode dielectric-loaded cavity filters. Different geometries were analyzed in terms of heat dissipation, insertion loss, and temperature coefficient. Special materials were ordered and several test cavities were designed and built. High-power tests of these units are scheduled for 1989.

Superconducting Filters

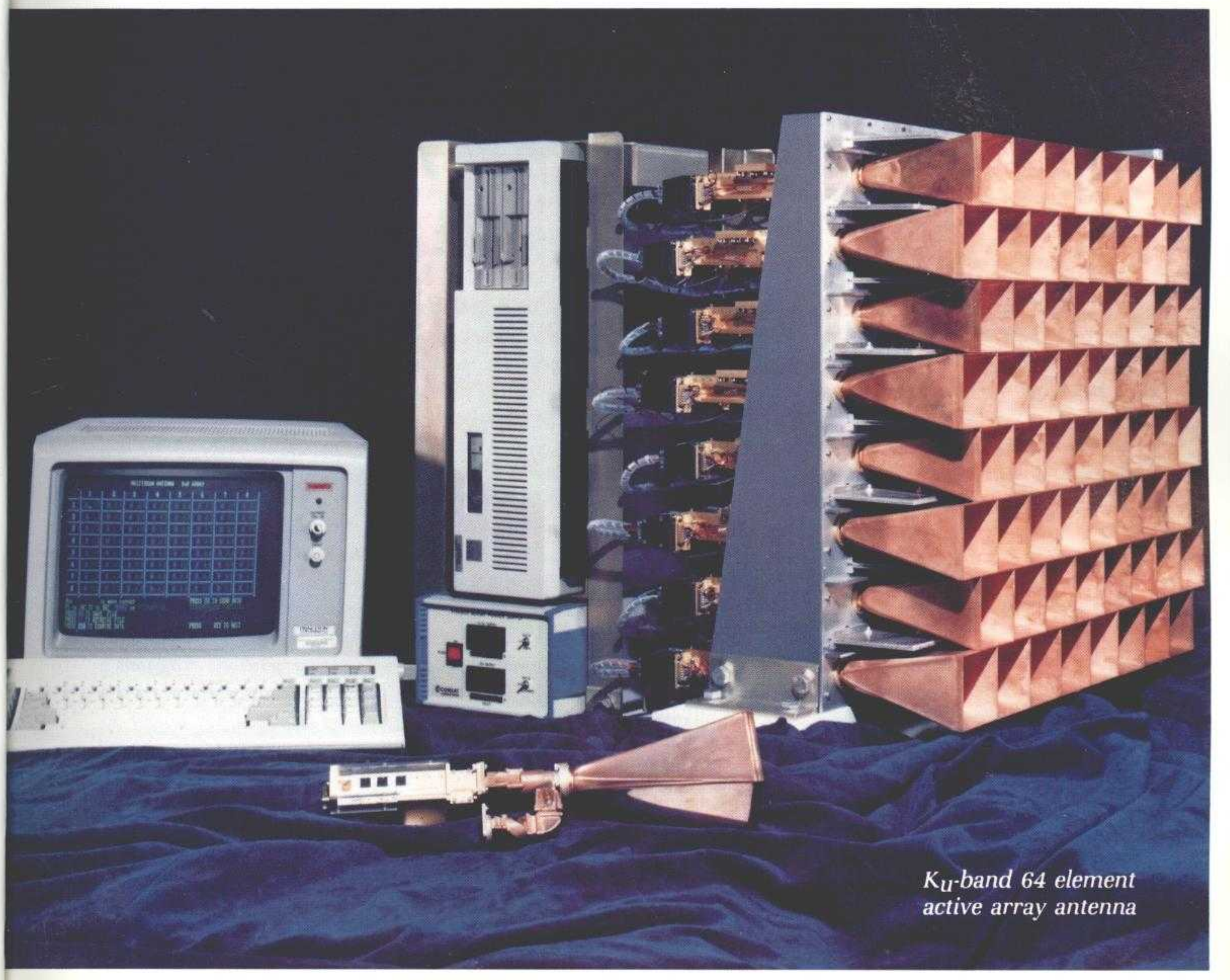
During 1988 MTD instituted a program to keep abreast of fast-moving superconducting filter technology and to carry out microwave conductivity measurements on high critical temperature ($T_c > 77$ K) samples. In May 1988, during a workshop on this subject organized by COMSAT for the International Microwave Symposium in New York, current results and projections were discussed by an audience of over 150 scientists and engineers.

Propagation Studies

COMSAT Laboratories performs a number of radiowave propagation studies applied to satellite communications. A variety of slant-path propagation impairment models have been developed and applied to the design of operating satellite communications systems. Sample calculations of rain impairments for a typical INTELSAT Business Services link between New York and London, assuming a satellite located at 53°W, are displayed in Figure 1. In addition, methods of impairment mitigation such as up-link power control, site diversity, and depolarization compensation have been studied. Several types of data are collected at the Laboratories for model testing; equipment development programs are also pursued.

An investigation of low-cost propagation measurement techniques was initiated in 1988. Preliminary evaluations of several candidate approaches were performed, including monolithic microwave integrated circuit/miniaturized microwave active circuit (MMIC/MMAC) implementations of wideband radiometric noise

MICROWAVE TECHNOLOGY



K_u-band 64 element active array antenna receivers, use of PIN-diode switches in Dicke-switched radiometers, and application of commercial devices in narrow-band beacon receivers. Substantial progress was achieved, particularly in the latter category, with the identification of several commercially based beacon-receive approaches for subsequent testing.

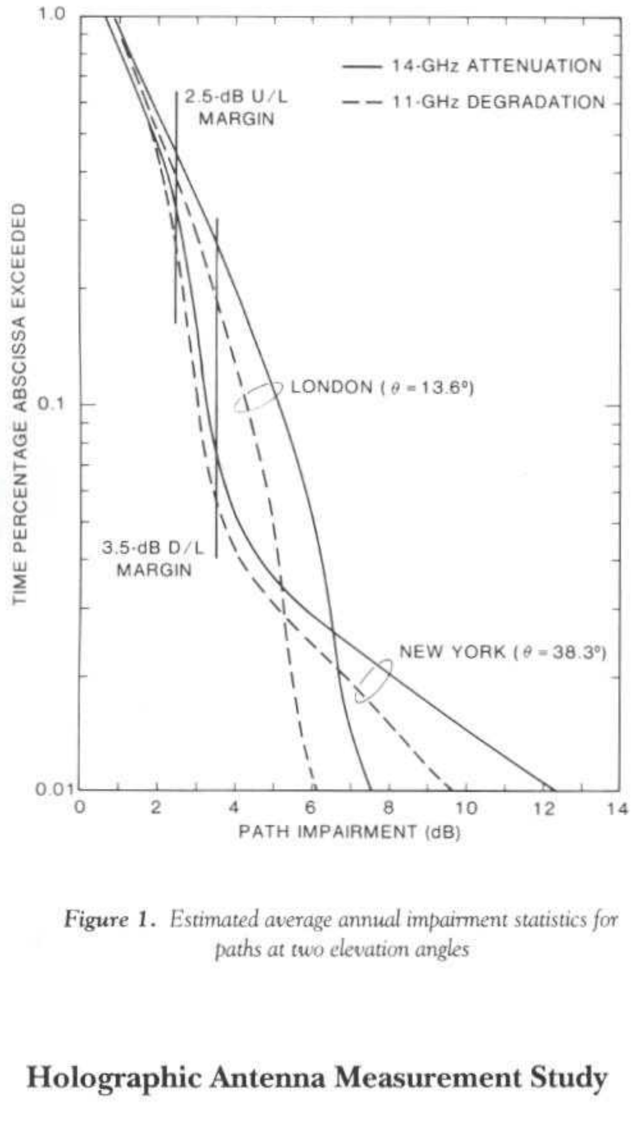


Figure 1. *Estimated average annual impairment statistics for paths at two elevation angles*

Holographic Antenna Measurement Study

For several years, the Laboratories has applied microwave holographic techniques, based on the Fourier-transform relationship between the antenna radiation pattern and the field distribution of the antenna aperture, for accurate diagnosis of antenna surface characteristics. In 1988, several improvements were incorporated into the holographic antenna measurement system to further enhance performance. A new Scientific Atlanta positioner/controller, used for accurate control of antenna position during antenna scans, was purchased to replace the existing unit. (Installation of the controller and conversion of the operating software are planned for 1989.) Data communication extender boxes, which formerly linked the receive equipment to the source antenna and the controlling computer via interface buses, were replaced with faster, more reliable units. Two essential computer programs were transferred from HP-1000 computers to MTD's faster and more reliable HP-840 computer, and the graphics interfaces were rewritten to remove all dependence on specific terminal type. These equipment upgrades have resulted in a faster, more reliable, less complex system for making holographic antenna measurements.

Figure 2 shows the amplitude excitation of a prototype flat-plate phased array as measured by the holographic system. These measurements aided in the array development process by supplying data on the performance of the dividing network.

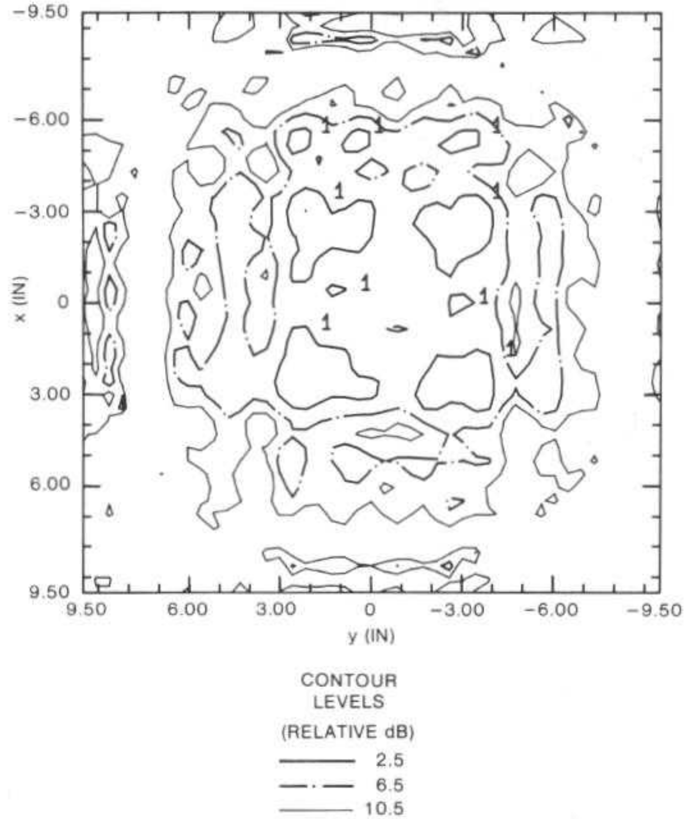


Figure 2. *Amplitude of aperture field (element excitation)*

Component Modeling

Realization of semi-lumped capacitive elements using radial stubs can reduce the size of MMIC modules. However, accurate models for such elements are not available in the literature. Hence, a generalized model for a radial capacitive element was developed.

The radial stubs were modeled as a cascade of several step-transmission lines of equal length, with progressively increasing widths. End effects were modeled by using, for the last step, an open-ended step-transmission line with width equal to the circumference of the radial stub.

Previously, in 1987, a programmable Ku-band linear phase shifter (constant group delay) module had been developed for the active antenna task. To reduce chip sizes, capacitive elements of the low-pass filters that provided the constant group delays were realized with radial stubs. However, the measured phase shifts were found to be almost one-half of the expected values. As part of the 1988 effort, these circuits were redesigned using the radial-stub model described above. Measured data for the new modules were found to be in very good agreement with predictions, confirming the accuracy of the new model.

Broadband Low–Loss Analog Phase Shifters

A low-cost, broadband analog phase shifter, capable of a complete 360° phase-shift capability at 12 GHz, is being designed. The projected chip area, minimized to reduce the cost, is no larger than 90 x 90 mil, significantly smaller than reported phase shifters in this frequency range. Other factors, such as circuit complexity and sensitivity to manufacturing tolerances, also affect cost through wafer yield and must be kept in mind during the design process.

The approach is based on a reflection phase shifter design, in which the phase shift function is produced by a change in the reflection coefficient of a varactor diode circuit as the diode bias is varied. As the voltage level can be varied continuously by an external control circuit, analog phase shift operation is produced. Since the diodes are always reverse biased, the power required to drive the phase-shifter chip is extremely small.

Possible applications of this MMIC phase shifter include flat-plate antennas and future communications satellite antenna systems. In the case of the flat-plate antenna, a series of phase shifters could be integrated into each antenna to permit electronic beam pointing. Therefore, a stationary antenna could be electronically pointed to many different satellite locations.

Computer-Assisted Microwave Measurement Techniques

For many years, COMSAT Laboratories has designed and developed In-Orbit Test (IOT) systems to measure the communications performance of satellites subsequent to launch. These systems are controlled by very sophisticated software that embodies over 20 years of COMSAT's measurement expertise. Recently, the trend toward multiuser systems with remote terminals has required a new operating system. In 1987, implementation of a computer operating system (MPCP II), which provides a "platform" for the development of user-friendly, efficient software to control microwave instrumentation, was started. This system is based on a previous single-terminal system that was used in several IOT projects. Unlike the previous single-terminal system, the new MPCP II accommodates multiple users (several workstations) within a computer network. The new system is based on UNIX and utilizes the industry standard X-window interface. The kernel of MPCP II was completed in 1987 under proprietary R&D and was reported last year.

It was recognized in 1988 that this system could be used to advantage in our antenna characterization facility that is used for in-house measurements on jurisdictionally funded programs. To this end, a set of microwave instrument drivers was developed and is now operational under MPCP II.

SSPA Development

The design of the three-stage, 4-GHz, 2-W amplifier developed in 1987 was modified to facilitate its implementation on a silicon motherboard. A modified circuit layout, which allows the realization of the complete three-stage structure on a single substrate, was completed. In this approach, MMICs, discrete field effect transistors (FETs), and passive components will cohabit the same substrate. The silicon motherboard has the potential advantages of improving reliability and reproducibility and reducing manufacturing costs. A process developed for the etching of via-holes and device recesses preserves the low-loss properties of the high-resistivity silicon being used.

Designs at 11 GHz were completed for the complete 5-stage, 2-W solid-state power amplifier (SSPA) which will be used to populate the high-power array being developed in the laboratory. The amplifier consists of a cascade of single- and two-stage MMIC chips followed by a quasi-monolithic two-stage high-power amplifier (HPA). Masks for the MMIC chips have been fabricated and circuit processing has started. Mask layout for the quasi-monolithic HPA is in progress.

Substantial progress was demonstrated during 1988 in the development of high-efficiency power FETs. As shown in Table 1, power-added efficiencies of over 40 percent, associated with more than 0.5 W per FET cell, have been measured at 12 GHz on several wafers. These results are essentially at the state of the art. This accomplishment resulted from a better understanding of the effects of surface states and how to measure them, as well as the development of techniques to limit the surface state density to an acceptable level while keeping the breakdown voltage high.

Table 1. *Associated Power and Power-Added Efficiency for 1.45-mm Power FET*

Date	Power (mW)	Power-Added Efficiency (%)	Frequency (GHz)
1987	340	Low	12
Feb 1988	277	40.7	12
Apr 1988	313	47.6	12
Aug 1988	533	42.8	12
Oct 1988	658	43.0	12
1988	572	62.8	6

In 1988, significant progress was also made in the development of a high-voltage MMIC amplifier. In

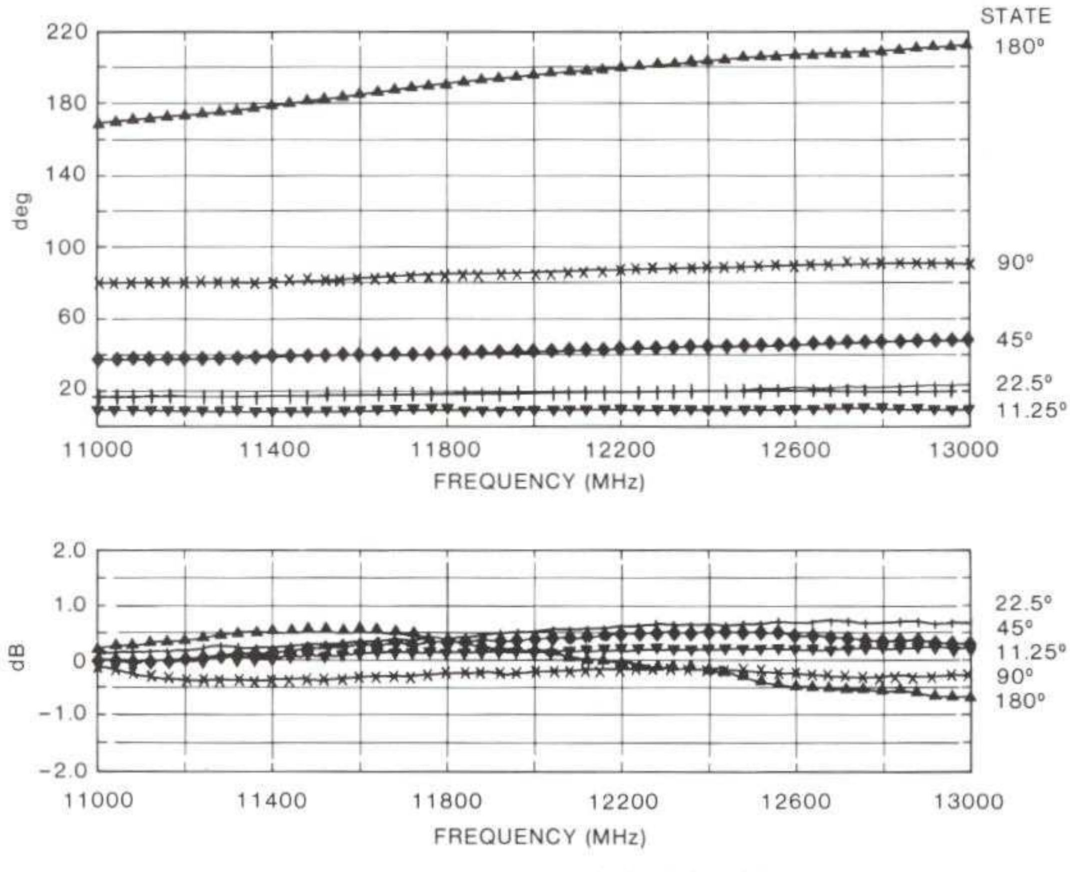


Figure 3. *Performance data of 5-bit digital phase shifter*

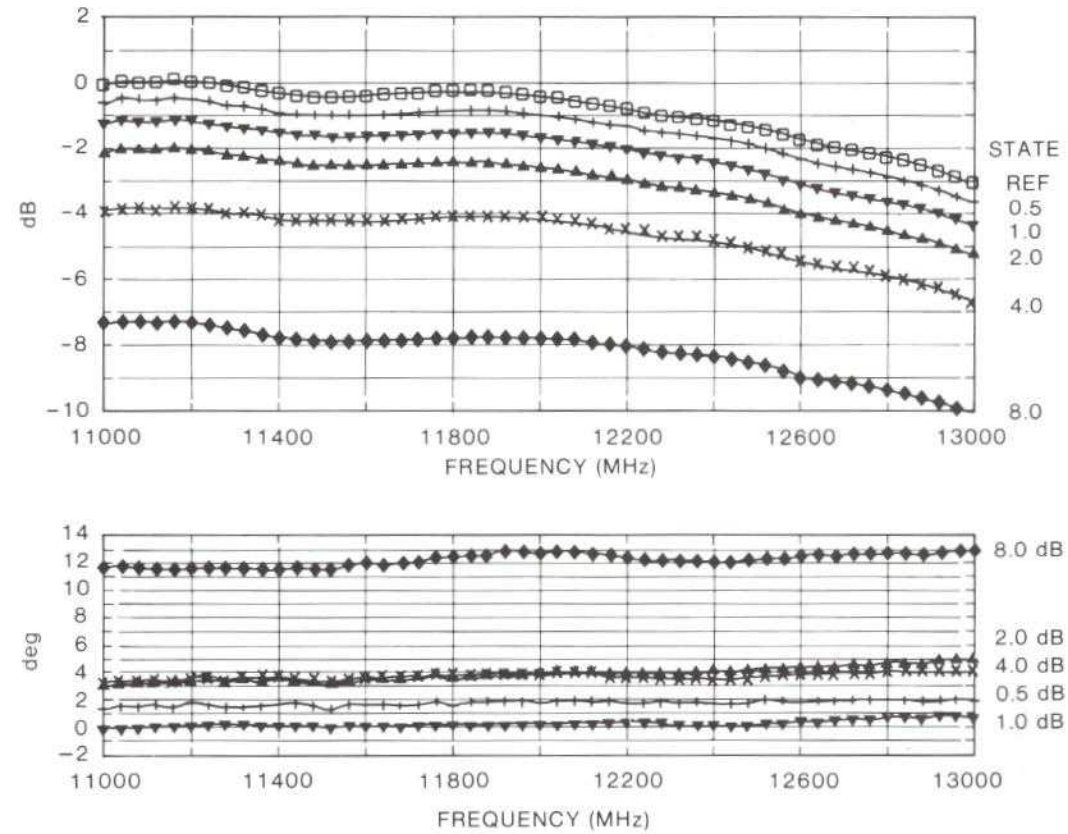


Figure 4. *Individual amplitude and phase performance of active circuit modules for the low-power array*

conjunction with the Microelectronics Division, a two-cell FET MMIC, which can be operated using a 20-VDC bias supply, and a four-cell FET MMIC, which can be operated using a 40-VDC bias supply, have been developed. Both two- and four-cell MMICs achieved 1-W output power at X-band. These are the first high-voltage FET MMICs reported. A 40-V SSPA can improve satellite transmitter efficiency by as much as 15 percent relative to a conventional 10-V SSPA, resulting in substantial weight savings.

At the beginning of 1988, a decision was made to realize the fast FET switch, intended to turn the HPA on and off in order to save power, using a simple hybrid switch rather than an MMIC configuration. A breadboard of the hybrid switch was fabricated and tested, demonstrating good performance.

Multibeam Phased-Array Antenna

Two active phased arrays are under development. The low-power array consists of 64 horns. Each horn is fed by a module containing a digitally controlled phase shifter and attenuator, and driver and buffer amplifiers, all in MMIC form, plus the necessary digital control circuitry and the power supply. The high-power array contains digitally controlled phase shifters, as well as HPAs, to control the beam direction and provide the power needed to achieve the required e.i.r.p. A thermal control system is required in addition to the other systems contained in the low-power array. These arrays are intended as a test bed for future multibeam antennas (with or without reflector systems) generating shaped hopping and scanning beams.

A key component in the MMIC module for both the low- and high-power arrays is the 5-bit digital phase shifter. During the first quarter of 1988, the major causes of observed performance anomalies were identified and resolved. This effort resulted in a phase shifter with performance very close to that predicted. Figure 3 shows performance data for the phase shifter.

In the low-power array, 64 active circuit modules (consisting of MMIC low-power driver and buffer amplifiers, a 5-bit digital phase shifter, a 5-bit digital

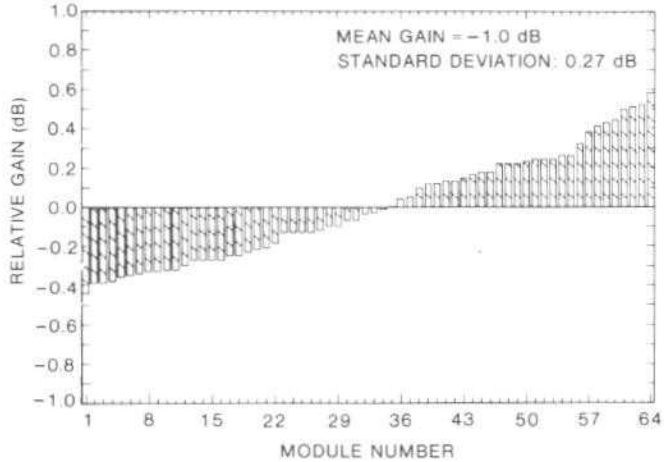


Figure 5. *Gain of 64 active modules at band center (12.2 GHz) relative to mean value (modules sorted from measurement maximum gain)*

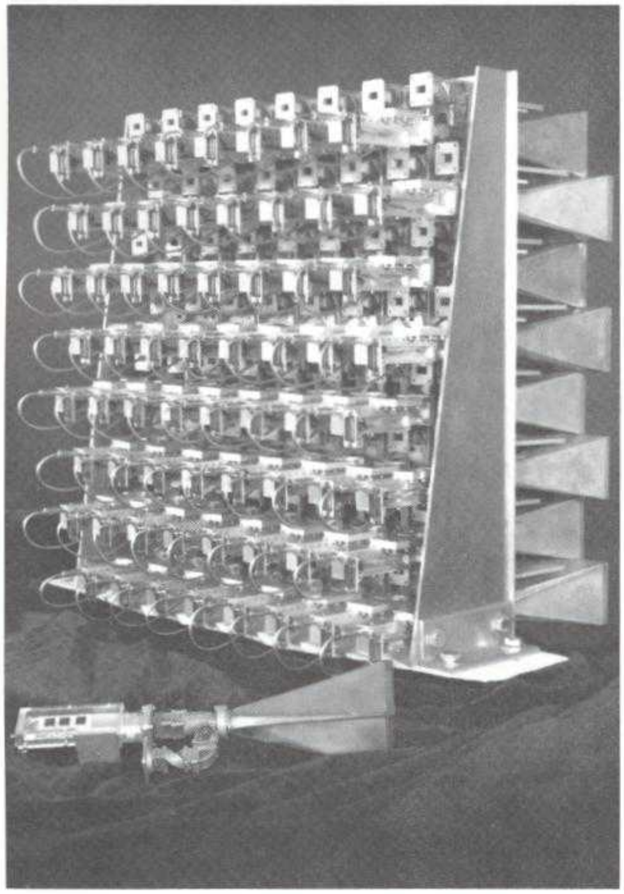


Figure 6. *Complete low-power array*

attenuator, an MMIC-to-waveguide transition, and a local control module) were integrated and tested. The measured performance of these modules has met the design goals. In addition to the 64 modules needed for the array, a number of spare modules were also fabricated. Figure 4 presents data for the amplitude and phase performance of the individual modules. Statistics for all 64 elements are provided in Figure 5.

Other subsystems within the low-power array were completed early in 1988, including the power supply and harness for the control and power lines. Minor modifications were made in the mechanical design of the active-circuit module box. The complete array is now assembled, and testing for reconfigurable beams, as well as scanning beams, will be done during the first part of 1989. Figure 6 shows the complete array.

The conceptual design of the high-power array went through several iterations in 1988 in order to better serve various traffic situations. The final design, which supports four simultaneous beams, encompasses a beam-forming matrix (BFM), a high-power amplifier assembly (HPAA), orthomode transducers (OMTs) for dual polarizations, and 24 radiating horns. Digital thermal control and power supply systems are parts of the design for the complete array.

For future high-capacity communications satellite applications, a candidate antenna system would consist of a small, active phased array feeding a dual-reflector antenna system. The reflector system must be designed to provide maximum gain and minimum scan loss over a full-earth coverage of $\pm 9°$. Offset confocal paraboloids have appropriate characteristics when fed by a uniformly excited array aperture. In 1987, a model was thoroughly tested and compared with analytically calculated results. In 1988 the computer program was enhanced to facilitate shaped-reflector analysis (to improve scan loss) and the code was converted to run on the faster HP 840 computer. The agreement between the measurements and the calculations was excellent, considering the complexity of the antenna system geometry. The scan peaks, main beams, and sidelobe structures were accurately predicted by the computer program; even for the severe scan cases, the agreement was acceptable.

On-board Demodulation and Remodulation

During 1988, a miniaturized reverse-modulation loop (RML) was designed and fabricated. The RML, consisting of a demodulator, a remodulator, and a comparator circuit, has been fabricated using a planar quasi-monolithic approach on a 10-mil-thick alumina substrate. The overall dimensions of the circuit are 0.65 x 1.54 in. A GaAs chip with delay less than 0.4 ns has been selected for the comparator circuit, so that delay line lengths and modem overall size can be reduced. A lightweight, removable Kovar carrier and an aluminum test housing have been designed and fabricated. Assembly and some limited testing of these miniaturized components will be done in the near future. The unit is pictured in Figure 7.

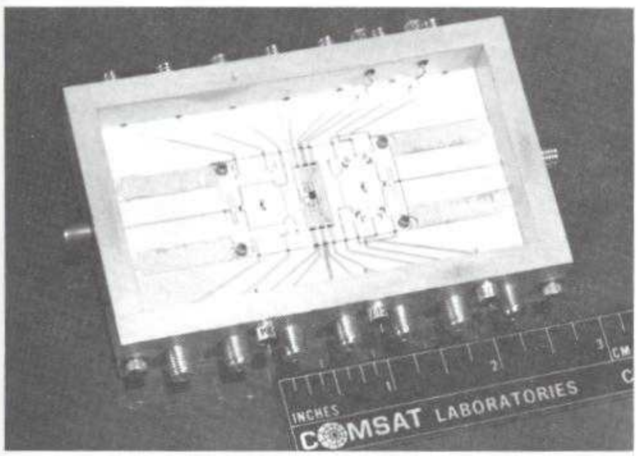


Figure 7. *Miniaturized reverse-modulator loop*

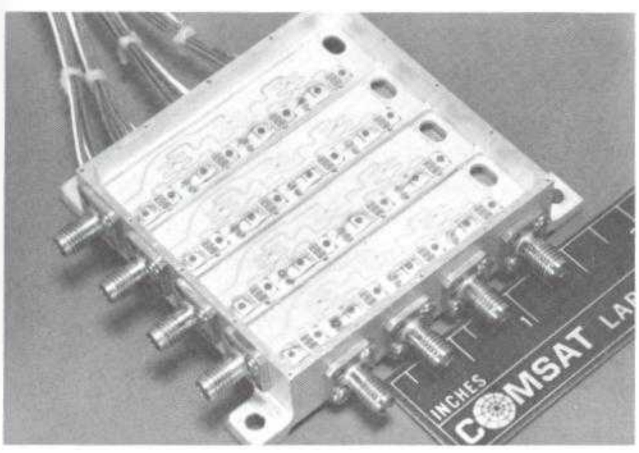


Figure 8. *Microwave switch matrix*

The assembly and RF testing of the broadband, lightweight 4 x 4 MSM have been completed. Measurements show that, over the 3.5- to 6.5-GHz frequency range, on-to-off isolation for all 16 paths is greater than 50 dB. The MSM insertion loss and the path-to-path insertion loss variations are less than 6.25 dB and 1 dB, respectively. Over the down-link band of 3.7 to 4.2 GHz, the path-to-path insertion loss variations are less than 0.6 dB and on-to-off isolation is greater than 60 dB. The return loss at all input and output ports is better than 15 dB. The driver/control circuits for the 4 x 4 MSM switches were fabricated on a 15-mil-thick 1.35- x 1-in. alumina substrate. The mechanical housing for integration of the control circuit with the MSM was also fabricated. The MSM is shown in Figure 8. On-to-off performance ratio data are given in Figure 9.

Low-Mass Filter Multiplexer

During 1988, the design, fabrication, and tuning of a breadboard multiplexer utilizing quadruple-mode filters for each channel were successfully accomplished. Figure 10 is a photograph of the breadboard Quad-Mux unit. The measured and theoretical transmission loss for the three channels and the return loss at the waveguide common output are presented in Figures 11a and 11b, respectively. These results demonstrate the feasibility of the Quad-Mux and its advantages over the conventional dual-mode realization (in terms of lower number of cavities and lower insertion loss). A dual-mode multiplexer would introduce an insertion loss of about 0.6 dB per filter; it is estimated that the engineering model of this multiplexer will introduce losses of the order of 0.3 dB per filter. The final per-filter mass of the engineering model multiplexer, to be completed in 1989, is estimated to be one-third that of the dual-mode realization.

Propagation Measurements in Africa

Several resolutions of the International Telecommunication Union (ITU) have noted the critical shortage of propagation data for tropical regions of the world, and in particular the urgent need for data from Africa. Such data would be especially beneficial to the development of propagation models for tropical and equatorial regions of the world. For the past several years, COMSAT Laboratories has cooperated with INTELSAT, the U.S. Telecommunications Training Institute, the National Telecommunications and Information Administration,

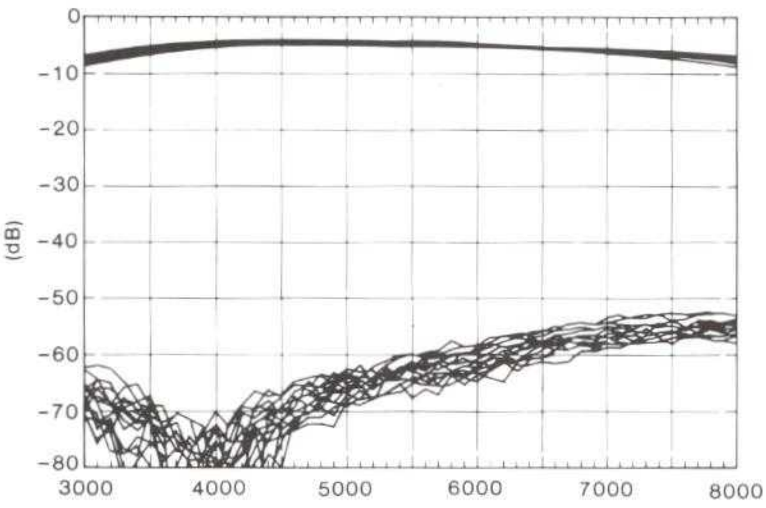


Figure 9. *On-to-off performance ratio for 4 x 4 MSM*

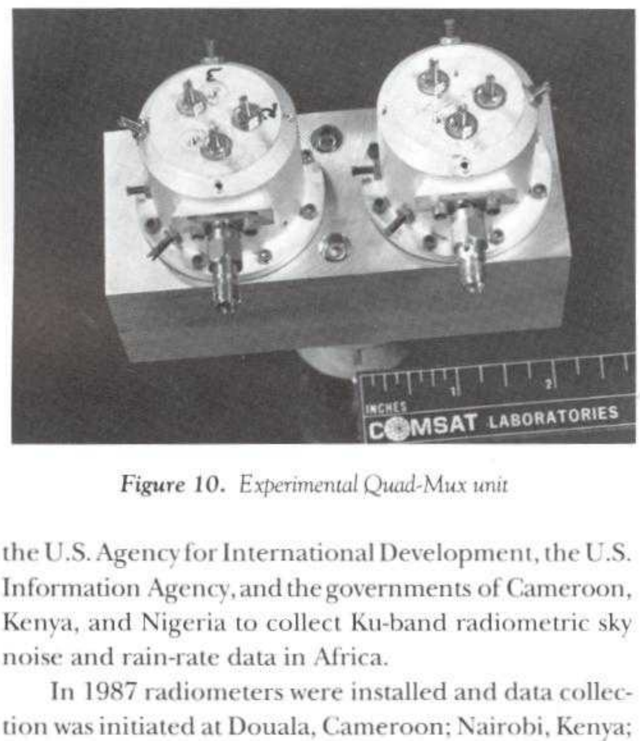


Figure 10. *Experimental Quad-Mux unit*

the U.S. Agency for International Development, the U.S. Information Agency, and the governments of Cameroon, Kenya, and Nigeria to collect Ku-band radiometric sky noise and rain-rate data in Africa.

In 1987 radiometers were installed and data collection was initiated at Douala, Cameroon; Nairobi, Kenya; and Ile-Ife, Nigeria. Under joint COMSAT/INTELSAT funding, COMSAT Laboratories provides a variety of field support, technical consultation, and resupply activities for each of the African experimental facilities. In 1988, agreements were consummated to continue the measurements phase for a second year through mid-1989. Planning was also begun for data analysis and for reporting of the first year of data collected at the sites.

Dual-Band 4/6- to 11/14-GHz Antenna Feed System

A dual-band feed is being developed to provide simultaneous access in both C- and Ku-bands from a single earth station antenna. The design employs a multi-aperture, directional, slotted waveguide array to achieve unity coupling at Ku-band from rectangular waveguides into the C-band (2.125-in.-diameter) circular waveguide. Separate orthogonal sets of waveguides are used to couple the 11- and 14-GHz signals. These slotted arrays have a minimal effect on the 4/6-GHz signals which propagate through the coupling region in the circular waveguide. The advantages of this approach over existing dual-band feed designs (Nippon Electric Company and MELCO) include superior mode purity, reduced weight and size, and reduced fabrication costs.

Most of the effort in the past year has been devoted to achieving unity coupling of the 11/14-GHz energy into the 2.125-in. circular waveguide. A design for the 11-GHz coupler with a worst-case loss of 1 dB and good modal purity was achieved. The swept-frequency response of the 11-GHz coupler is shown in Figure 12. It was found that simple scaling of the 11-GHz multi-aperture array to the 14-GHz band would not give unity coupling without some technique for increasing the slot coupling. Subsequently, an improved geometry using taller coupling slots was investigated. For a given slot length, increasing the slot height yields greater coupling. The increased height slot geometry will provide unity coupling at 14 GHz with a slight increase in coupler length. Figure 13 is a photograph of the partially assembled coupler.

The design for a dual-band corrugated feed horn was investigated. The primary problem is launching the desired hybrid modes in the horn. Therefore, it was necessary to consider only the design of the horn input section. The technique used to design C-band horns was modified such that the corrugations are about three-quarters of a wavelength deep in the 11/14-GHz bands. Satisfactory performance was achieved over all four frequency bands.

The fabrication and testing of a complete dual-band feed is scheduled for 1989.

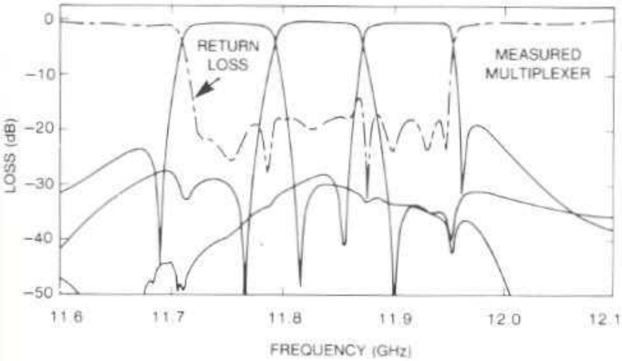


Figure 11a. Measured Quad-Mux transmission and return loss

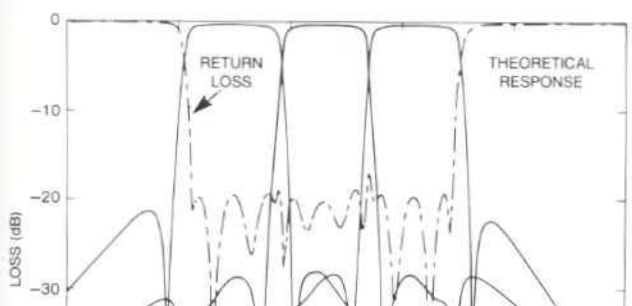


Figure 11b. *Theoretical response of multiplexer optimized with quadrupole-mode filters*

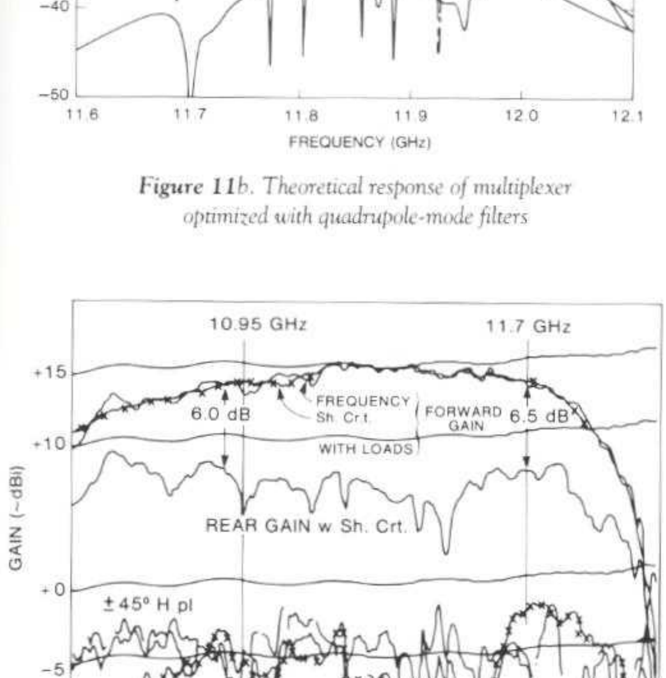


Figure 12. *Swept frequency data for the four-arm coupler*

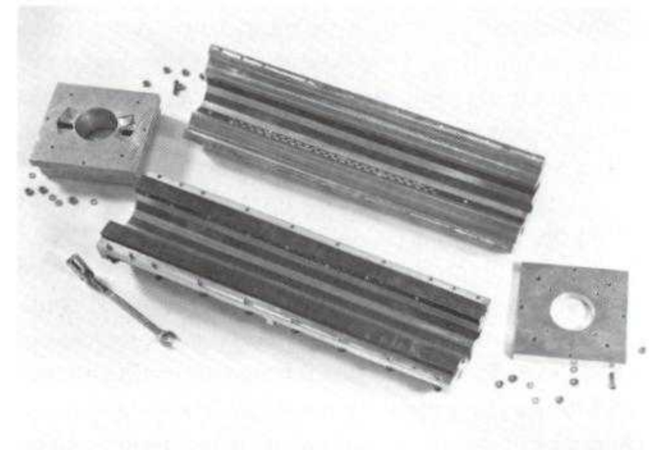


Figure 13. *Partially assembled 11/14-GHz coupler*

Ku-Band Up-Link Power Control Development

Experimental up-link power control (ULPC) systems were implemented and tested at 14/11 GHz in open-loop configurations under a variety of weather conditions at COMSAT Laboratories during 1986 and 1987. Successful performance was demonstrated for rain fade levels up to 7–8 dB, proving the viability of the technique for many Ku-band earth stations. During 1988, the operational principles established under the previous development activities were applied to the design of ULPC systems suitable for implementation or field retrofit in new and existing Ku-band earth terminals, and a basic design was completed. During 1989, ULPC algorithms and practical beacon-monitoring schemes will be evaluated.

Ultra-Low-Cost Earth Station Study

This study examined the feasibility of ultra-low-cost earth station operation in a star network through a global transponder of an INTELSAT V satellite in inclined orbit, with either a Standard A or a Standard B station serving as a hub station. Double-hop operation between small remote terminals and "push-to-talk" voice operations are assumed. This type of network would provide service where none existed before, or where very rudimentary service was previously available.

The study concluded that star-networked double-hop service using a Standard A (30-m antenna) hub station is possible for remote stations with 1.8-m or 2.9-m antennas assembled from "off-the-shelf" parts at a cost of approximately $25,000. Satisfactory voice transmission can be achieved, and low-bit-rate data transmission will perform satisfactorily as long as the voice connection is good. A station with a 1.8-m antenna would not work with a small hub (18-m antenna) due to interference considerations and the need for high remote-station HPA power.

For small-terminal networks of this kind to be cost-effective in the INTELSAT environment, some relaxation in performance requirements for cross-polarization isolation, and possibly also transmit-antenna sidelobe specifications, are necessary. If such relaxation cannot be obtained, spread spectrum techniques can be used with digital transmission to meet spectral density limitations. Although this latter configuration will increase terminal complexity/cost somewhat, it will be less costly than meeting the present, rather stringent, interference criteria.

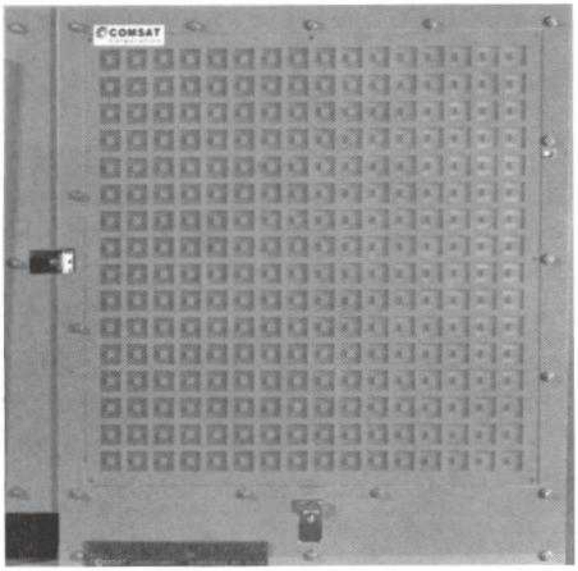


Figure 14. Flat-plate array antenna

NONJURISDICTIONAL R&D

Flat-Plate Antenna

COMSAT and Matsushita Electric Works (MEW) have a joint program to develop and produce low-cost, lightweight, high-efficiency flat-plate array antennas for satellite reception. An improved version of a dual linearly polarized flat-plate array was developed in 1988. Figure 14 depicts one of the units. The array demonstrated greater than 60-percent efficiency in each polarization over a 750-MHz bandwidth. Cross-polarization isolations of greater than 30 dB and port-to-port isolations of better than 25 dB were achieved. A flat-plate array based on this design is presently being developed for the ASTRA market in Europe. The unit will be approximately 0.75 m^2 and will achieve a gain of 37 dBi.

An improved flat-plate feed technique consisting of a stripline-to-waveguide transition has been developed. This feed will replace the coaxial feed presently being employed in the flat-plate array. The transition achieves better than 25 dB of return loss and will improve the overall noise temperature of the array.

Preliminary assembly and testing of an integrated low-noise block (LNB) down-converter began in 1988. This single-substrate circuit contains a low-noise amplifier (LNA), mixer, local oscillator, and IF amplifier on a low-cost glass substrate. The circuit will be placed in a newly developed housing and imbedded into the flat antenna structure to provide a self-contained, flat-panel-type receiver.

Current approaches to the antenna system require the use of external low-noise down-converters, which tend to be relatively large boxes mounted on the back of the antenna unit. In addition to increased size and weight, there is also a degradation in overall system performance due to unavoidable losses in the connection between the antenna and receiver unit. The goal of the LNB project is to overcome these limitations by developing a miniaturized receiver that may be mounted directly into the antenna package.

The selected design accommodates the entire receiver on a single glass substrate approximately 1-in^2 and 0.048-in. thick, a convenient size for integration directly into the antenna with a very-low-loss transition between the antenna stripline and the input to the LNA. This design incorporates a two-stage LNA, MMIC mixer chip, and a two-stage IF amplifier. The remaining portions of the substrate surface are allocated for test purposes, but eventually this area will be used for a built-in local oscillator. Corning 7059 glass has been selected for the substrate because of its low loss and suitable microwave properties. To give the best overall compromise between low cost and low noise figure, the LNA uses a high electron mobility transistor (HEMT) in the first stage and a conventional low-noise FET in the second stage. The entire receiver substrate is implemented in coplanar wavequide to simplify circuit grounding.

COMSAT SUPPORT

INMARSAT III Study

During 1988, COMSAT Laboratories initiated a study on behalf of Maritime Services to investigate the technology appropriate for a third generation INMARSAT III satellite. Specific areas addressed were the spacecraft bus characteristics for 1,260- and 1,860-kg mass, the effect of partial operation during eclipse, $\pm 3^\circ$ N-S stationkeeping, the properties of L-band traveling wave tubes and SSPAs, and the properties of different antenna technologies such as reflectors and phased arrays. These technologies were then modeled into a number of payload designs, and the expected performance as a function of bus size was generated. Various tradeoffs were examined to optimize e.i.r.p. as a function of bus size.

Results from this study showed that for the larger spacecraft bus, it is possible to realize both global and spot beam coverages. A global e.i.r.p. of 39 dBW and spot e.i.r.p. greater than 45 dBW may be achieved if the L-band amplifier is used efficiently and if partial operation is assumed during satellite eclipses.

CCIR Activities

As part of COMSAT's extensive participation in the deliberations of the International Telecommunication Union standards committees, MTD coordinates the Laboratories' activities in the International Radio Consultative Committee (CCIR). Both the Communications Techniques Division (CTD) and MTD play major national and international roles in the CCIR, focusing on Study Group (SG) 4 (Fixed-Satellite Service) and SG 5 (Propagation in Non-ionized Media), with additional attention to SG 6 (Propagation in Ionized Media), SG 8 (Mobile Services), and SGs 10/11 (Broadcast Services). There were several major efforts during 1988.

COMSAT provided U.S. representation at a meeting of SG 5 Interim Working Party 5/3 (Radiometeorology), held in Geneva during January 1988, and sent a delegate to the SG 5 Interim Meeting in Geneva during April 1988. The Laboratories supplies the U.S. representative to Interim Working Party 5/2, who also serves as the chairman of an international testing group for the Slant-Path Mobile and Broadcasting reports of SG 5.

PEACESAT Inclined-Orbit Operation Demonstration

A demonstration using C-band 1.8- and 2.9-m antenna systems with the inclined-orbit Pacific Ocean INTELSAT IV-A (F-3) satellite was conducted for the PEACESAT organization. An inclined-orbit tracking antenna mount and timing-control circuit were developed. The antenna mount was designed so that the movement of a single actuator arm properly moved the antenna in both azimuth and elevation to follow the satellite movement. The actuator arm was controlled by an antenna positioner that was driven by a sidereal crystal time base. A total of 48 positions during a sidereal day can be programmed with this unit.

Maritime Services Antenna Modifications

Two antennas at COMSAT's Southbury INMARSAT shore station were retrofitted to operate with the new and extended frequency bands of the INMARSAT II satellite. The polarizer of one antenna was modified, new LNAs were installed, and complete acceptance tests were conducted. Both antennas now comply with the INMARSAT II specifications. A test report will be sent to INMARSAT to secure qualification of the antennas for operation with the INMARSAT II satellite series.

The C-band 11-m Scientific Atlanta antenna was retrofitted to allow transmission and reception in circular polarization. A 4/6-GHz quarter-wave polarizer designed by COMSAT Laboratories was installed in the antenna. Transmit patterns and radio star gain measurements were also performed during the retrofit program. Alternative approaches to provide L-band capability on this antenna were also evaluated.

INTELSAT CONTRACTS

4/6-GHz Dual-Polarized Feed System Development for C-Band Steerable Spot Beam Antenna

The first-phase design and study of a dual-polarized C-band feed for a steerable spot beam antenna system were completed. The spot beam system consists of an offset reflector antenna and a high-polarization-isolation feed system that can be switched by ground command from dual orthogonal linear polarizations to dual opposing sense circular polarizations. The feed system operates simultaneously in both the INTELSAT transmit and receive frequency bands. This technology is appropriate for the INTELSAT VII satellite series, as well as for future generation satellites.

The second phase, to be completed in 1989, consists of fabricating and testing a flight prototype feed and reflector system.

Compact Feed Development

Efforts to develop lightweight flight-qualified feed elements continued. The goal of the program is to use printed-circuit radiator technology to realize lightweight high-polarization-purity feed elements. These elements would replace existing waveguide horns, OMTs, and polarizers that combine to make the feed large and relatively heavy. In the past year, development concentrated on lightweight, compact, C-band, dual circularly polarized microstrip radiators for communications satellite reflector feed arrays. Two types of microstrip radiators were successfully developed and built: one for reflector feed use, and one for direct-radiating array application.

Figures 15 and 16 show the front and back views of the reflector-type compact radiator, which consists of two parts: the electromagnetically coupled (EMC) patch elements that comprise the radiating portion of the feed, and two microstrip polarizing networks that feed the patches. The entire flight-qualified radiator weighs only 70 g (compared with about 300 g for a typical waveguide radiator), and measures 4.4 x 4.4 in. The radiator exhibits an excellent axial ratio of about 0.3 dB across the operating band, as shown in Figure 17, and has an efficiency of over 75 percent. The return loss of this radiator is

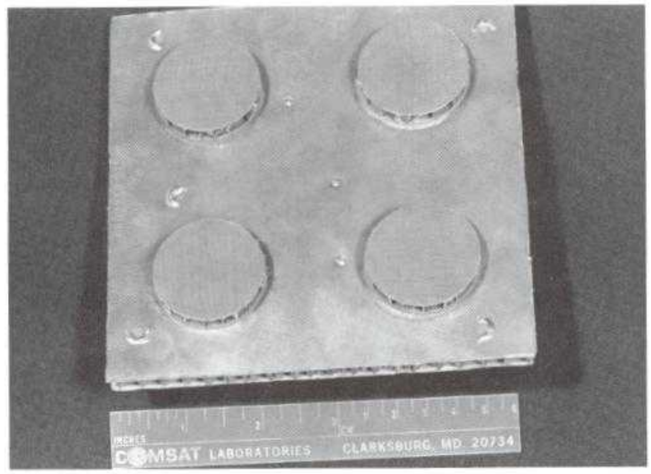


Figure 15. *Reflector-type compact radiator, front view*

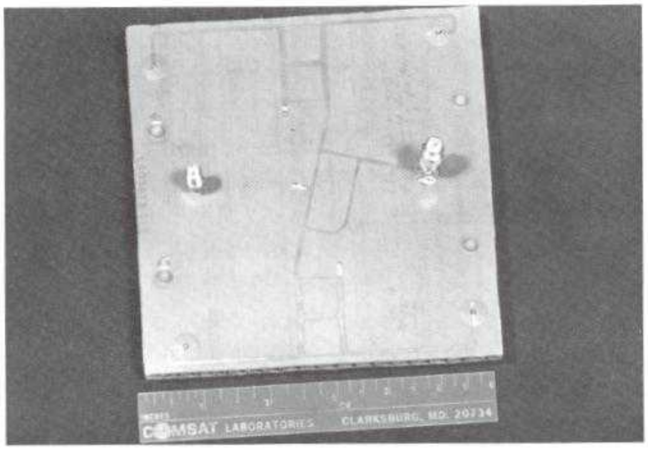


Figure 16. *Reflector-type compact radiator, back view*

shown in Figure 18. The direct-radiating type, which is a similar but larger version of the feed radiator, also has good performance.

In addition to the hardware, a software package to model the compact radiator has been developed. The software model, which is based on a method-of-moments solution to the patch radiator, agrees well with the measured results.

Field Support and Miscellaneous

Under contract to INTELSAT, a variety of field support and consultation services were provided to ra-

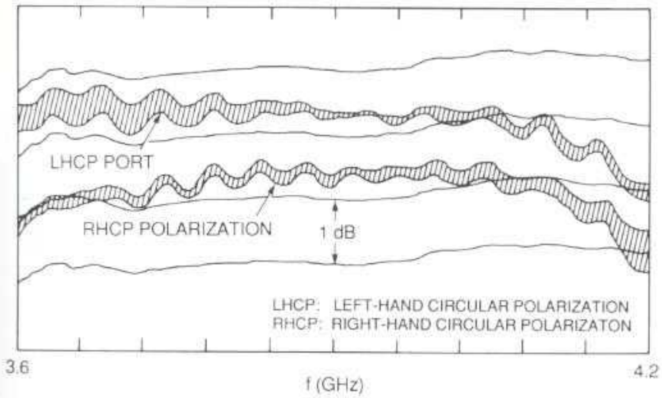


Figure 17. *Compact feed gain/axial ratio on axis for right-hand circular polarization*

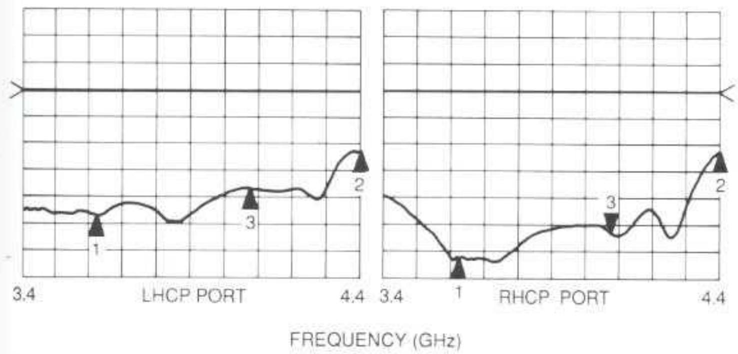


Figure 18. *Compact feed return loss*

diometric measurement sites in Australia, Cameroon, and Nigeria (the latter two as part of the joint INTELSAT/COMSAT African propagation measurements campaign discussed previously). Such services are vital for the successful operation of remote experiments and are an outgrowth of COMSAT's long involvement in the development and deployment of propagation measurements worldwide.

In addition, rainfall parameters in INTELSAT's Propagation Data Base were updated for a set of new earth stations.

OTHER

Active Microwave Filters

During 1988 work began on constructing a 4- to 8-GHz active microwave bandpass MMIC filter for the Naval Research Laboratory. This contract called for a two-phase effort, the first phase requiring a filter rejection of 20 dB and the second requiring a rejection of 60 dB at 3 and 9 GHz. The first-phase design goal was achieved by using a mix of active lumped and distributed circuit elements. MMIC processing of a number of GaAs wafers has begun. It is envisaged that the filter will be available for electrical testing in early 1989.

IOT/ESVA System

In April 1988, COMSAT Laboratories was awarded a contract by EUTELSAT, the European communications satellite consortium, to develop a fully integrated IOT and communications system monitoring system. In addition to the traditional IOT measurements, this system will perform a number of new ones, including measurements in which the IOT station verifies the performance of other earth stations, using a satellite path. Simultaneous measurements can be performed from several remote locations.

The IOT/ESVA system requires a substantial software effort and will use MPCP II, which is currently under development at the Laboratories and is based on the UNIX operating system. The system will have a user-friendly interface, based on the X-window system developed at the Massachusetts Institute of Technology.

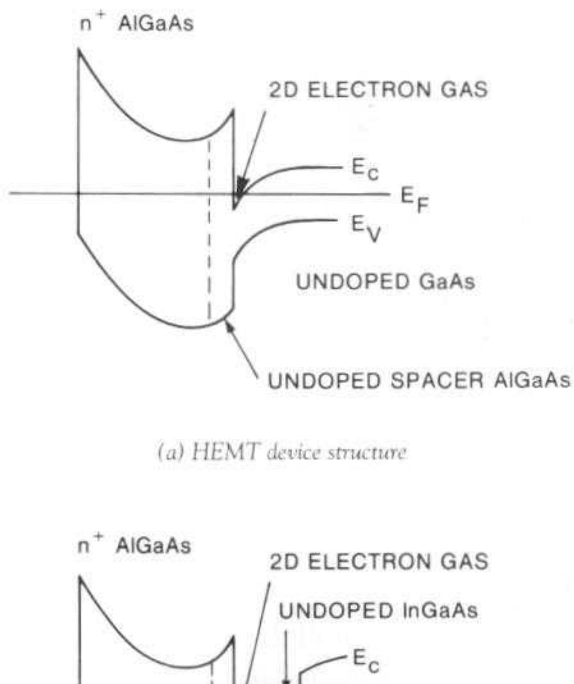
The Microelectronics Division (MED) supports COMSAT Laboratories' need for state-of-the-art microelectronics for use in advancing satellite communications systems and promoting commercial applications. MED performs research and development on discrete components such as field effect transistors (FETs), microwave integrated circuits (MICs), and monolithic MICs (MMICs). General goals are to improve the performance, operating speed, and reliability of these components and circuits. MED capabilities encompass all aspects of this technology from device modeling and materials growth through fabrication, RF and DC characterization, and reliability evaluation. In 1988, MED developed the technology for fabricating individual high-electron-mobility transistors (HEMTs), pseudomorphic HEMTs (P-HEMTs), and MMICs. Dual-stage amplifiers exhibited a noise figure of 5.3 dB at 58 GHz, the lowest reported at that frequency. MED also fabricated power FETs with 40-percent power-added efficiency at 11 GHz and developed technology for fabricating low-resistance tee gates with the highest reported aspect ratios. As part of MED's support in physical and chemical analysis, three phenomena linking traveling wave tube (TWT) cathode failure to chemical composition were identified by means of cathode analysis.

COMSAT JURISDICTIONAL R&D

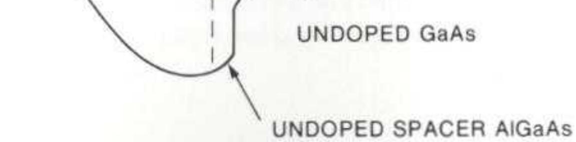
Materials Technology

In 1988, MED continued its research program in millimeter-wave components with the development of HEMT materials and P-HEMT structures using molecular beam epitaxy (MBE). Energy band diagrams for the HEMT and P-HEMT structures are shown in Figure 1. These structures contain AlGaAs heterojunction interfaces that generate two-dimensional electron gases in the GaAs and InGaAs layers, respectively. Because InGaAs has a smaller band gap energy than GaAs, a larger energy band discontinuity exists at the InGaAs/AlGaAs interface and a significantly larger two-dimensional electron density is generated for the P-HEMT structure. A two-dimensional electron density of >2 x $10^{12}/cm^2$ has been achieved at COMSAT Laboratories. The energy band discontinuity at the InGaAs/GaAs heterojunction reduces current injection into the GaAs buffer layer by confining the two-dimensional electron gas to the InGaAs. An enhanced electron saturation velocity is associated with InGaAs. Cutoff frequency measurements made on a COMSAT P-HEMT device with a 0.35-μm gate length indicated an electron saturation velocity of 1.6 x 10^7 cm/s. These features render the P-HEMT structure more suitable than the HEMT structure for microwave and millimeter-wave applications.

Accurate values for the percentage of indium in the alloy and for growth rate were required to prepare a



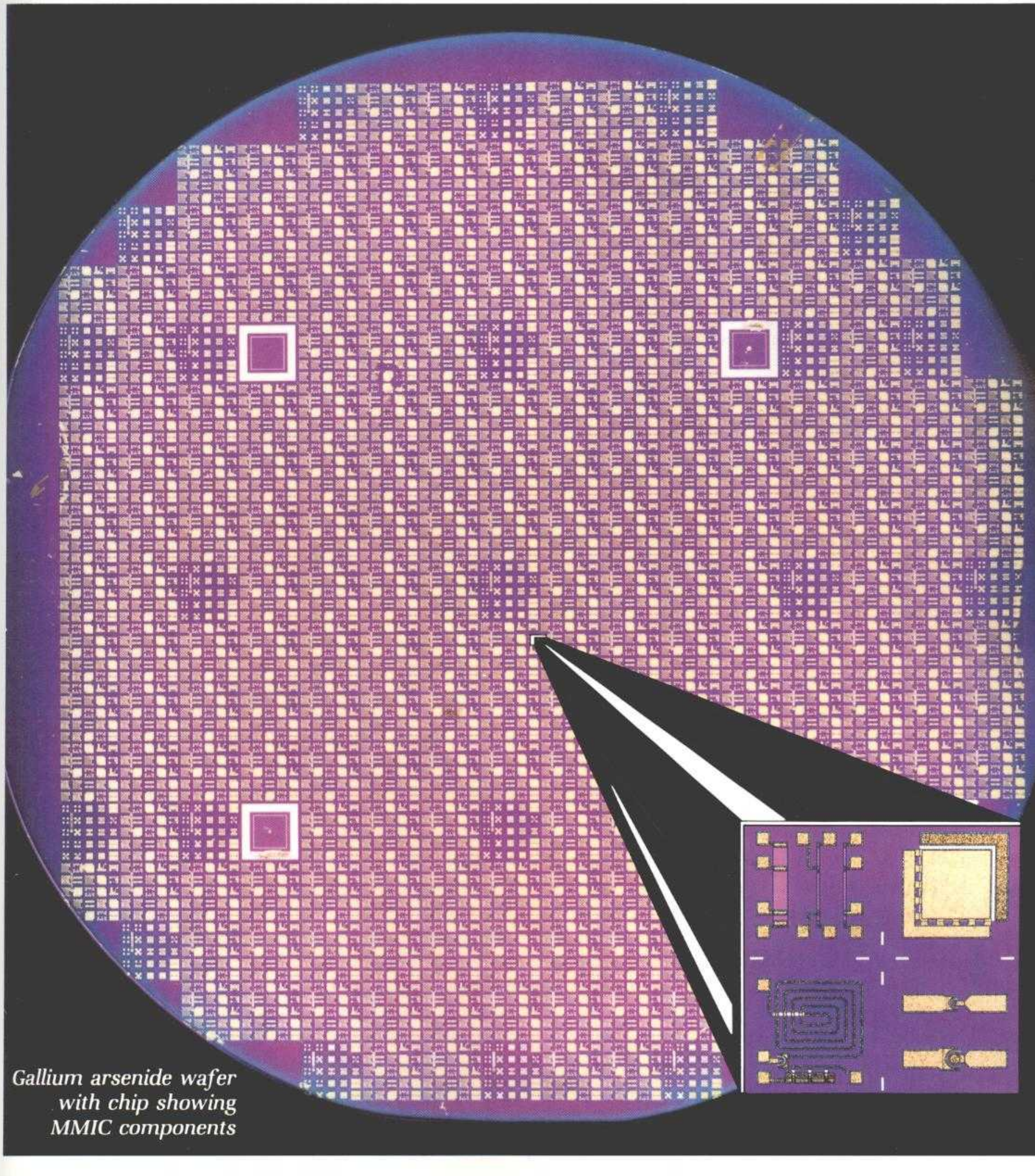
(a) HEMT device structure



(b) P-HEMT device structure

Figure 1. *Energy band diagrams*

MICROELECTRONICS



Gallium arsenide wafer with chip showing MMIC components pseudomorphic layer with superior electrical transport properties. Strain caused by the inequality between the unstressed lattice constants of InGaAs and GaAs is absorbed elastically up to a critical layer thickness that is a function of indium alloy composition. In thicker layers, the strain is relieved by generation of misfit dislocations, which degrade electrical transport properties. To permit measurement of growth rate and alloy composition during growth, a technique based on reflection high-energy electron diffraction (RHEED) intensity oscillations from the material surface was implemented. Growth rates measured for GaAs, AlGaAs, and InGaAs were 3.01, 3.85, and 3.85 Å/s, respectively. The Al and In atomic fractions for the ternaries were both 0.22. The ability to measure growth rates and alloy composition prior to P-HEMT structure formation significantly improved the number of usable structures.

Another yield improvement was obtained by increasing the size of the GaAs substrates processed. During the final quarter of 1988, MBE material was grown on several 3-in.-diameter GaAs wafers. The MBE machine fixturing proved satisfactory, and 3-in. wafers were processed identically to 2-in. wafers. A yield improvement of greater than twice the number of chips was expected to result from the implementation of 3-in. GaAs wafers in the process lines.

An ultra-broadband, monolithic, 5-bit digital attenuator for the Ku-band phased-array antenna being constructed by the Microwave Technology Division (MTD) was developed on ion-implanted GaAs, which provided the required material properties. The MMIC consisted of 36 FET devices and 36 resistors produced by a dual-energy ion implantation process. Experimental work using a 100-keV n^+ implant in combination with a 300-keV n implant produced good agreement between the measured profile and the target profile. Carrier concentration profile reproducibility within about 9 percent for approximately 35 wafers is shown in Figure 2. Variation in sheet resistivity within a wafer was typically ± 3 percent. These data were used to perform a sensitivity analysis on the device characteristics of pinch-off voltage V_p, ungated drain source current I_{dso}, ON-state equivalent drain-to-source resistance, and capacitance. The equivalent resistance and capacitance values did not change by more than 5 percent for fixed values of V_p and ungated I_{dso}. This analysis provided an important link between I_{dso}, which was the process control parameter, and desired device characteristics. The highly reproducible ion-implanted layers resulted in high-yield circuit fabrication and closely matched circuit performance.

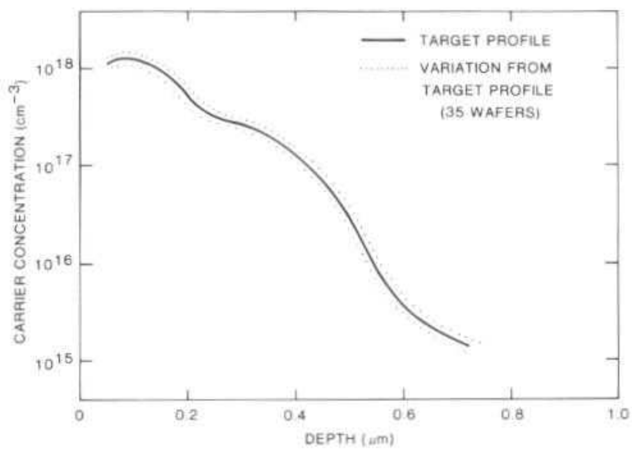


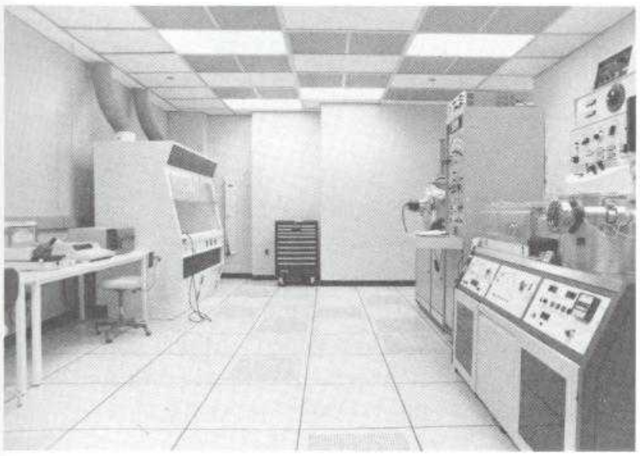
Figure 2. *Design target and experimental variation from design for 35 wafers produced using dual-energy (100/300-keV) ion implantation profiles indicate excellent uniformity*

Device and Circuit Fabrication

Begun in 1985, MED's 5,000-ft² cleanroom fabrication facility dedicated to GaAs fabrication was placed in full operation during 1988. About 1,800 ft² of Class 100 area is dedicated to electron-beam (e-beam) lithography and photolithography operations. The remaining area, which houses wet chemistry, thin film, and plasma process operations, is maintained under Class 1000 conditions. The completed facility permits all MMIC and GaAs FET fabrication to take place in nearly particulate-free environments. Photographs of portions of the Class 100 and Class 1000 areas are shown in Figure 3.

The fabrication of reproducible gate lengths by e-beam lithography was predominantly affected by the pattern writing field size and associated on- and off-axis beam stigmatism and focus. Gate length control with a 3σ value of 0.035 µm for large e-beam writing fields (≈ 3 mm) and 0.020 µm for small e-beam writing fields (<1 mm) was obtained by new procedures and enhancements to system hardware and software for on- and off-axis correction of beam focus and astigmatism. Software techniques were also implemented that permit multi-field writing schemes on the same wafer. Critical dimension features were written at small field sizes and small

(a) Class 100 area



(b) Class 1000 area

Figure 3. *MED's GaAs FET and MMIC fabrication cleanroom*

beam spot size, whereas less critical geometries were written at large field sizes and beam currents, thus maintaining gate length control and increasing system throughput.

Figure 4 shows a 0.25-μm tee gate structure that requires control of the beam focus, stigmatism, and positioning. Two layers of resist having different thickness and sensitivities were exposed with the same beam dosage. The differential development rates produced the resist cross section required to form the metal gate.

The passivation of power metal semiconductor FET (MESFET) channels is critical for eliminating the time-dependent shift in the RF parameters and minimizing handling and environmental damage to the MMIC chip. A low-temperature (250°C) device passivation process using plasma-enhanced chemical vapor deposition (PECVD) of Si_3N_4 has been developed. The films are deposited using $SiH_4 + NH_3$ reactants diluted in He or N_2 carrier gas. The deposited films exhibit a Si/N atomic ratio of 0.75 and oxygen content of less than 1 percent; they are under tensile stress of 10^9 dyne/cm^2.

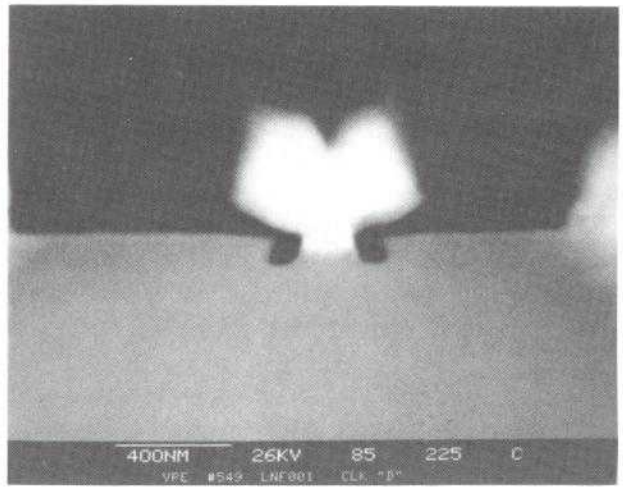


Figure 4. *High-aspect-ratio, 0.25-μm tee gate formed using dual-layer resists of different electron sensitivity*

A combined wet acid and dry plasma cleaning procedure has been developed for surface cleaning before nitride passivation. Figure 5 shows the pulsed, gate-drain current transient measurement of the FET after nitride passivation. I-V characteristic curves, taken at different time intervals after the application of gate voltage (V_g), coincide, indicating that this cleaning procedure removes surface states and does not generate traps in the GaAs devices. The new MESFET passivation using this nitride deposition process produced changes of <10 percent in V_p, saturated source-drain current (I_{dss}), transconductance (g_m), and breakdown voltage (V_{br}) values. Parameter changes of P-HEMT devices similarly passivated were also <10 percent after nitride deposition.

The high reliability of the passivated GaAs devices was demonstrated by changes in the power MESFET device parameters of <5 percent after the devices are annealed at 300°C for 100 hr. Low-noise P-HEMTs showed parameter shifts of nearly 10 percent after similar heating cycles. These shifts are believed to be due to the difference in the material structure of the channel region.

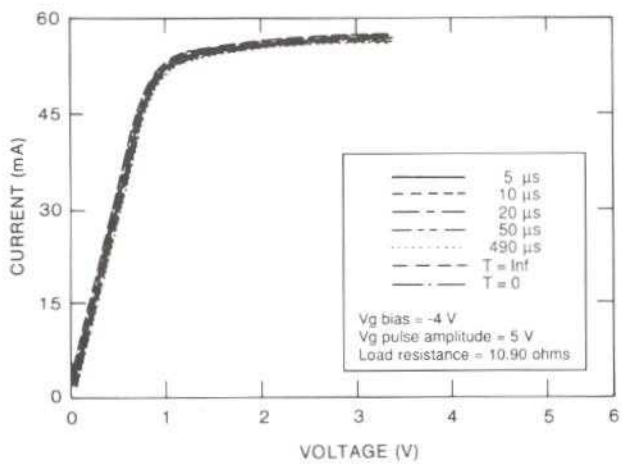


Figure 5. *Pulsed gate-drain current transient measurement after wet/dry cleaning and passivation shows excellent stability under wide differential in pulse length*

Development of enhanced miniature microwave active circuit (MMAC) processing on high-resistivity silicon was initiated for MTD. The silicon MMAC included the following passive components: resistors, capacitors, inductors, air bridges, and in some cases, via-holes through the substrate to ground. Relative to a standard dielectric substrate, the silicon motherboard offers advantages of higher thermal conductivity for power amplifiers and low-inductance via-holes to ground. Wells were formed in the front silicon surface to permit a recess for active devices that reduces the length and inductance of bond wires from the transmission line to the active device. Via-holes etched through to the frontside well provide ground contact to the active device.

Advanced Devices and Circuits

V-band, low-noise, 58-GHz, single- and dual-stage MMICs based on P-HEMTs with 0.35- x 60-μm gates were developed. Measured noise figure and gain performance are shown in Table 1. These data represented the lowest currently reported noise figure at V-band. More importantly, the highly uniform fabrication process allows routine cascading of multiple MMICs for future systems applications while still providing good noise figure and usable gain. Figure 6 shows the dual-stage P-HEMT MMIC.

Table 1. *V-band P-HEMT noise figure and gain performance*

Number of Stages	Noise Figure (dB)	Associated Gain (dB)	Maximum Available Gain (dB)
1	3.9	3.5	7.2
2	5.3	8.2	10.2
4	5.8	18.3	21.1

GaAs monolithic amplifiers based on MESFET technology were developed at V-band for low-noise and low-power applications. These MMICs, which had on-chip DC blocking and bias networks, were fabricated from both vapor phase epitaxy (VPE) and MBE materials. The single-stage power amplifier provided more than 4.5 dB of gain from 57 to 60.5 GHz, with a maximum output power of 95 mW and a corresponding power-added

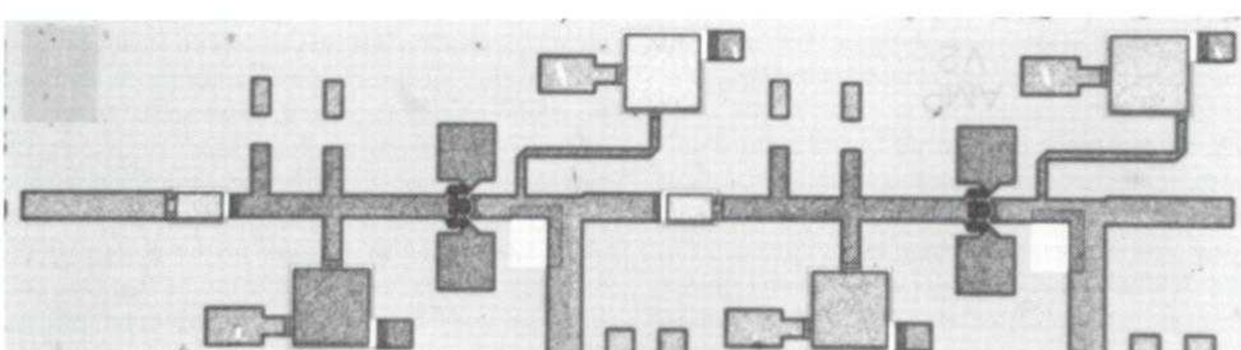


Figure 6. *Dual-stage V-band P-HEMT LNA*

efficiency of 11 percent at 58 GHz. At 73 mW, a maximum power-added efficiency of 15.3 percent was obtained. A cascaded four-stage power amplifier demonstrated stable operation, achieving a gain of 17 dB and output power of 85 mW. In addition, the two-stage balanced amplifier shown in Figure 7 provides output power of 136 mW and linear gain of 7.5 dB at 56.5 to 60 GHz. These results demonstrated that excellent low-noise performance can be obtained from P-HEMT MMICs and that power output is achievable with MESFET MMICs in the 60-GHz band.

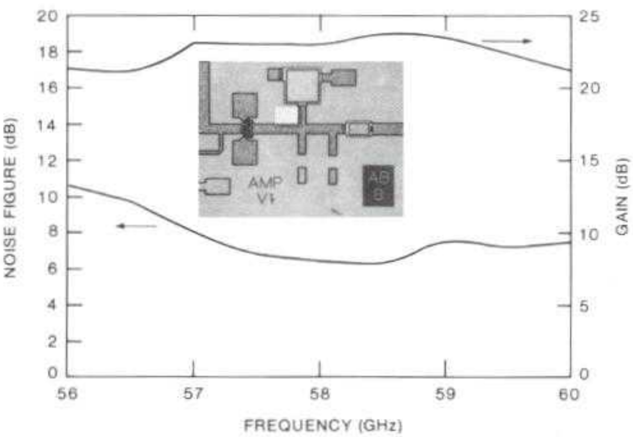


Figure 7. *V-band multistage LNA performance illustrates excellent low-noise characteristic*

A computer program was written to generate DC characteristics and full RF equivalent circuits for both HEMTs and P-HEMTs. Given the physical parameters of the transistor (source, gate, and drain sizes; doping; and layer thickness), the program predicts the current-voltage curves of the device for the bias range of interest and generates the equivalent circuit element values.

MED developed 1-W, discrete, power FETs with power-added efficiency of >40 percent at 11 GHz that promise to be reliable satellite power amplifier alternatives to TWTs. Several of these FETs were combined in a solid-state power amplifier (SSPA) to form an element of a phased-array antenna being developed by MTD.

Ku-band (14- to 14.5-GHz) low-noise amplifiers (LNAs) were developed for satellite applications. These MMIC LNAs were fabricated on VPE and MBE material. Electron-beam lithography achieved a gate dimension of 0.35 µm for improved RF performance. Source series feedback improved circuit stability. Both single- and dual-stage LNAs were fabricated, with the dual-stage LNA containing on-chip interstage matching. Data on these LNAs are presented in Table 2.

Table 2. *Ku-band LNA noise figure and associated gain*

Number of Stages	Noise Figure (dB)	Associated Gain (dB)
1	2.0	7.5
2	2.5	18.0
4	2.8	25.0

Four-cell, high-voltage (HV) MMIC amplifiers were successfully tested at bias conditions up to 40 V. A resistive biasing scheme was implemented that allows operation with a high-voltage supply and a single negative gate bias, eliminating three other gate bias supplies at intermediate voltages. Subsequent testing showed no degradation in performance of individually biased amplifiers. The HVFET MMIC amplifier shown in Figure 8 achieved output power of 28 dBm with power-added efficiency of 20 percent and small-signal gain of 8.5 dB. The two-cell MMIC amplifier achieved output power of 29 dBm and power-added efficiency of 24 percent. These accomplishments demonstrated that SSPAs can indeed be biased at the satellite bus voltage of 28-40 V. This feature led to improved DC-to-RF conversion efficiency by reducing or eliminating DC power losses in the power conditioning circuitry. In 1989, circuit tuning and improved device efficiency will be used to improve amplifier performance.

Measurement and Characterization

Fabrication process changes that increased the value of V_{br} for high-efficiency GaAs power FETs produce a phenomenon associated with FET current transients known as "premature power saturation," in which the FET fails to generate expected microwave power and RF efficiency. Figure 9 shows gate input voltage versus time and the resulting output (drain) current versus time for a FET. The output current is proportional to the input voltage, with a subtractive transient that decays with time. This effect is caused by surface states that gain or lose charge slowly compared with the rate of change of the

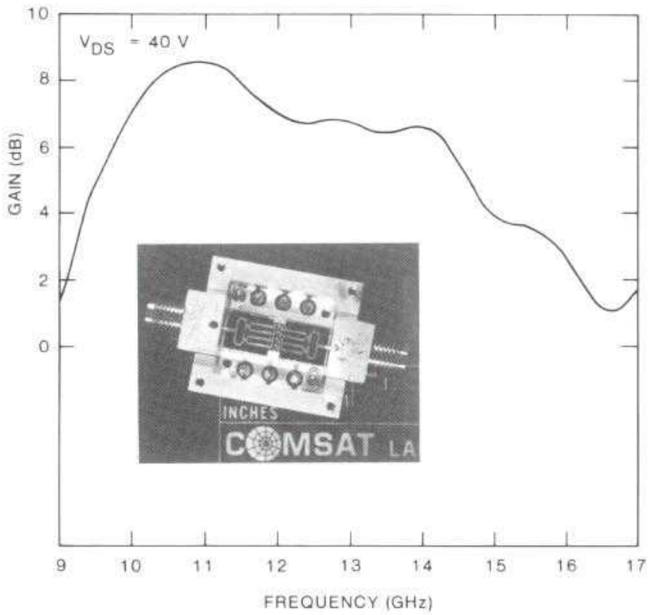


Figure 8. *High-voltage FET MMIC amplifier performance suitable for operation at satellite bus voltage of 28-40 V*

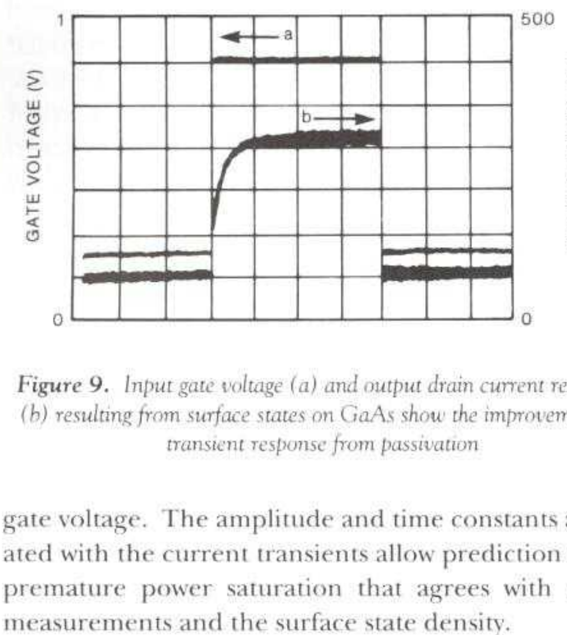


Figure 9. *Input gate voltage (a) and output drain current response (b) resulting from surface states on GaAs show the improvement in transient response from passivation*

gate voltage. The amplitude and time constants associated with the current transients allow prediction of the premature power saturation that agrees with power measurements and the surface state density.

An automated system was set up to measure the output current transients for a large number of DC drain voltages, thus providing a new tool for the study of surface states on GaAs. This tool enabled the development of process technology for realizing high-efficiency FETs.

U-band, 44-GHz, MMIC power amplifiers based on an optimized device structure (0.35- x 800-μm gate) were developed using MBE material and e-beam lithography. The single-stage power amplifier achieved linear gain of 5.5 to 6.5 dB at 42.5 to 45.5 GHz. Output power of 22.5 dBm (175 mW) and associated gain of 4.6 dB were obtained at 42.5 GHz. A cascaded five-stage balanced amplifier was fabricated to achieve usable power gain and output power for system applications as shown in Figure 10. Linear power gain of 15.1 dB and saturated output power of almost 27 dBm (500 mW) were obtained at 42 GHz.

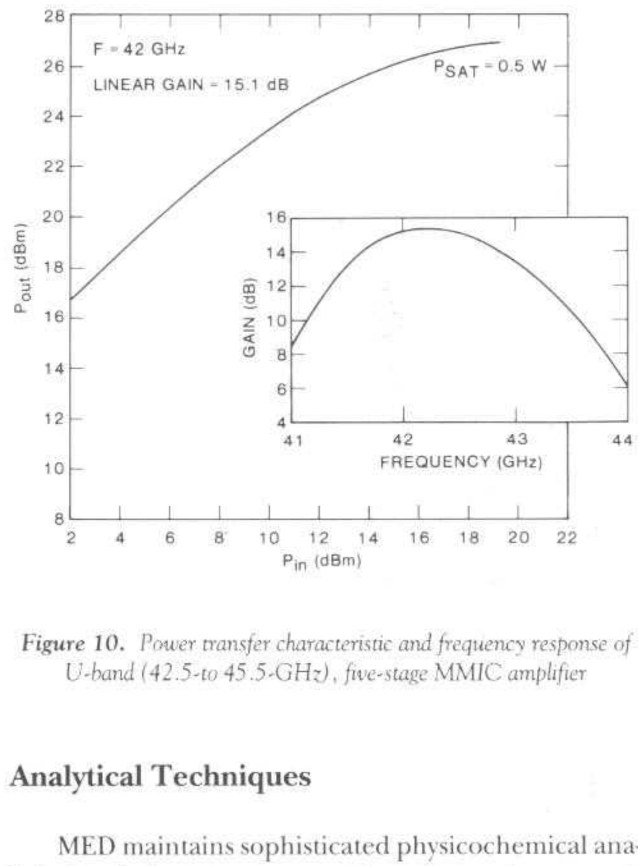
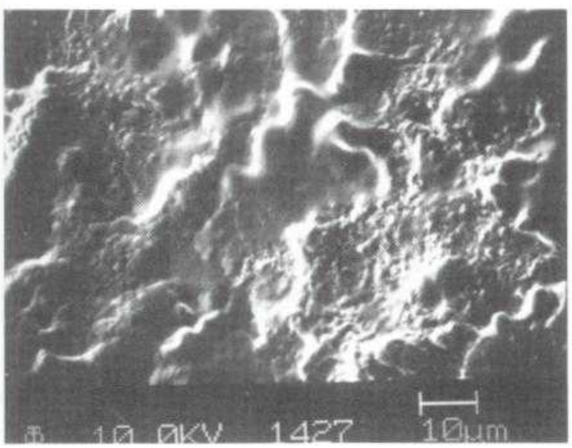


Figure 10. *Power transfer characteristic and frequency response of U-band (42.5-to 45.5-GHz), five-stage MMIC amplifier*

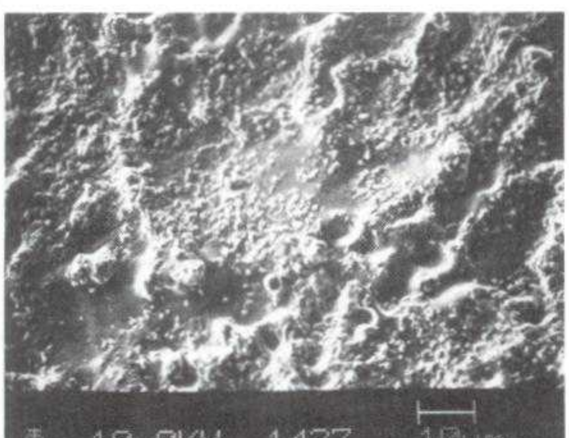
Analytical Techniques

MED maintains sophisticated physicochemical analytical techniques to support microelectronics research and development and to assist the rest of the Laboratories and the Corporation in improving satellite communications technology. The TWT, a major system element on board satellites, is one of the life-limiting components. The state-of-the-art TWT uses an oxide cathode because of its light weight, long life, and ruggedness. There are ongoing efforts in MED to understand the operation of these cathodes and devise methods for improving their reliability.

The following three phenomena linking cathode failure to chemical composition were discovered. First, two distinct morphologies were identified and their composition studied: a glassy phase seen only in regions where the oxide coating delaminated from the underlying cathode nickel button (Figure 11a), and a rough granular or nodular phase strongly associated with adherent regions of the cathodes in both good and failed cathodes (Figure 11b). Surface analysis of the two morphologies verified that the glassy region was composed of a compound of Ni_2Zr that appears to have melted at the operating temperature of the cathode. The cause of the low-melting compound formation remains under investigation. Second, carbon was found in different valence states that represented carbonates or carbides at the oxide-substrate interface. Such material represented incomplete or inadequate oxidation of the coating material during manufacture. Third, elemental contamination by sulfur, a known metal embrittler, was identified as the source of failure in one cathode.



(a) Lifted glassy surface containing Zr-rich granules



(b) Textured surface of Ni granules characteristic of cathode regions under adherent oxide coating

Figure 11. *SEMs of TWT cathode coating*

COMSAT Laboratories has established a facility to test the microwave properties of high-temperature superconductor (HTS) materials, to help guide research on methods of increasing their microwave conductivity, and to determine if improved materials can be used to enhance high-frequency MMIC performance. Using this facility, the quality factors (Q) of an aluminum microwave resonance cavity with an HTS end plate and a copper end plate have been compared at 15-18 GHz. Figure 12 shows an example of Q versus temperature data obtained for several samples of $YBa_2Cu_3O_{7-x}$, an HTS $Bi_2CaSr_2Cu_2$ oxide compound, and a copper disk.

The cylindrical resonance cavity Q depends on the square root of the conductivity of an HTS wafer placed at the end of the cavity. The abrupt increase in Q denoting the transition of the material under test to a

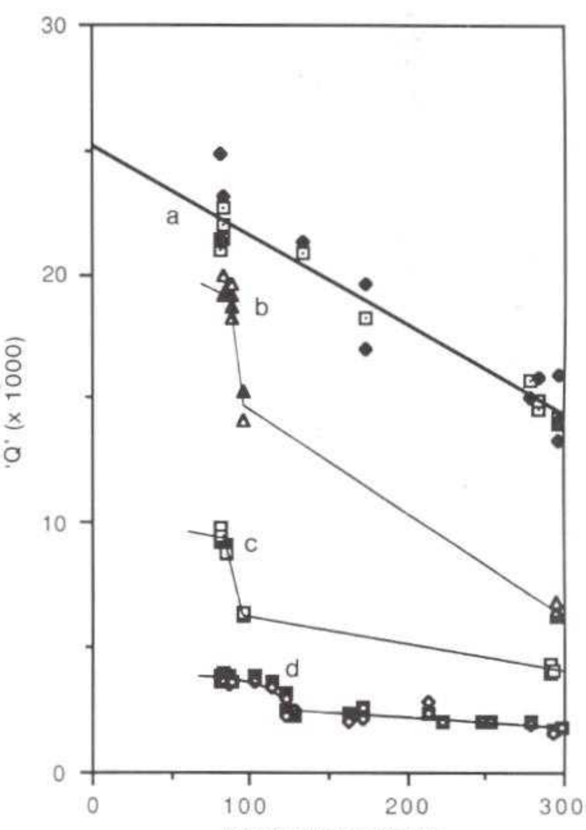
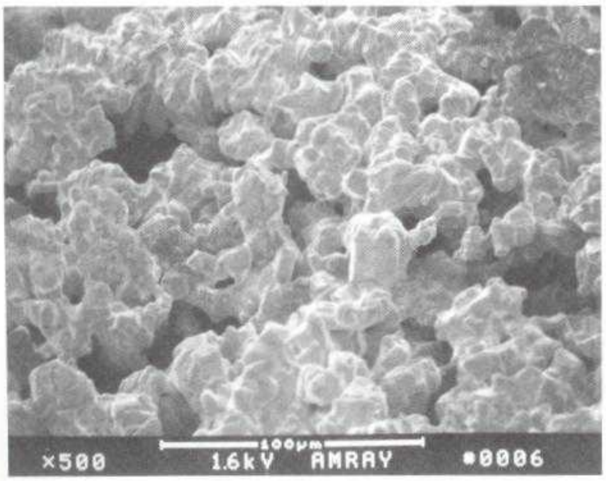
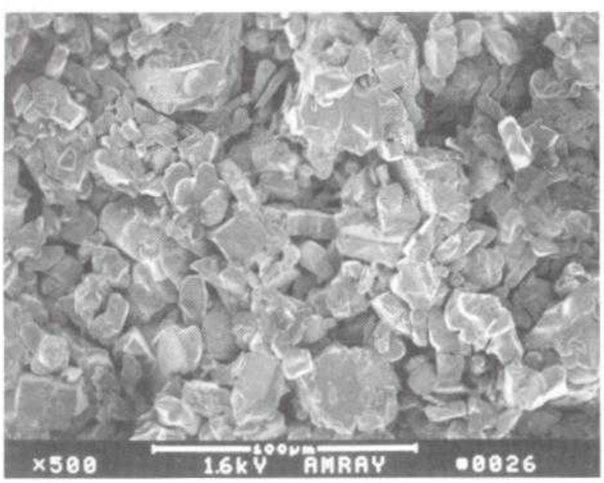


Figure 12. *Cavity Q as function of temperature showing the superconducting transitions for various HTS samples and a copper disk (a: copper disk, b and c: two samples of $YBa_2Cu_3O_{7-x}$, d: $Bi_2CaSr_2Cu_2$ oxide)*

superconducting state, was used to determine the critical temperature T_c. Figure 13 shows the morphological differences resulting from two processing techniques used to fabricate the bulk HTS material. The co-precipitated sample (Figure 13a) appears to have fewer gaps between microcrystallites, thereby providing better microwave conductivity than the hot-pressed sample (Figure 13b) as seen from curves b and c, respectively, in Figure 12.



(a) Co-precipitated $YBa_2Cu_3O_{7-x}$ HTS sample



(b) Hot-pressed $YBa_2Cu_3O_{7-x}$ sample

Figure 13. *Surface morphology*

At COMSAT Laboratories, radiation damage to GaAs devices is presently characterized in terms of atomic displacements or damage from an equivalent fluence. This method differs significantly from the measurement of deposited energy used for silicon devices and circuits. A simple, reliable radiation monitor has been developed for determining the displacement capability of a wide variety of radiation sources. The monitor is based on the extremely linear change in resistance of GaAs as a function of radiation fluence and can be calibrated with a simple ohmmeter. GaAs resistors are mounted in conventional integrated circuit packages for ease of use and tested in a gamma irradiation cell and in an electron accelerator for linearity and precision. This monitor provides a cross-calibration for the many gamma radiation, charged-particle, and neutron radiation sources used in testing GaAs FETs and MMICs.

High-level irradiation ($>10^8$ rads) by Cobalt 60 gamma rays, electrons, and neutrons degrades GaAs FET performance by reducing effective doping levels and carrier mobility in the active channel regions. MED has previously shown that damage from Cobalt 60 gamma rays and 1-MeV electrons are qualitatively similar. The 1988 effort demonstrated that neutrons create a different type of material damage but produce similar device degradation characteristics.

A thermal-stress, accelerated-life test of COMSAT MBE-grown, GaAs-based HEMT devices was conducted to evaluate reliability and lifetime of these promising devices in future satellite applications. HEMT devices were subjected to a series of high-temperature exposures from 175°C to 275°C in steps of 25°C for 48 hr per step. Initial values of I_{dss}, V_p, V_{br}, and g_m were measured on each device and after each thermal step. Device failures were defined as a change of more than 20 percent in any of the measured parameters. Preliminary reliability predictions based on tests of these few devices indicated that mean time to failure (MTTF) exceeds 11,000 years at normal operating temperatures. Further testing on a larger sample is underway to verify these predictions.

Heat, voltage, and radiation are the three primary sources of stress in solid-state devices. Voltage stressing of metal-insulator-metal (MIM) capacitors typical of those used in MMICs creates at least three failure mechanisms. Only infant mortality, tentatively associated with pinholes that arise during device fabrication, is likely to cause failure of MMICs under normal operating conditions. This failure mechanism is easily identified in device characterization tests and preselection criteria were developed.

COMSAT NONJURISDICTIONAL R&D

A dual-gate MESFET variable-power amplifier in the 33-GHz band has been developed. The single-stage amplifier shown in Figure 14 demonstrates linear gain of 9.1 dB and dynamic range of 30 dB. A two-stage balanced amplifier provides linear gain of 16.5 dB and maximum output power of 25.3 dBm at 33 GHz. Minimal variations in the insertion phase and power-added efficiency of the amplifier as a function of second gate control have been demonstrated.

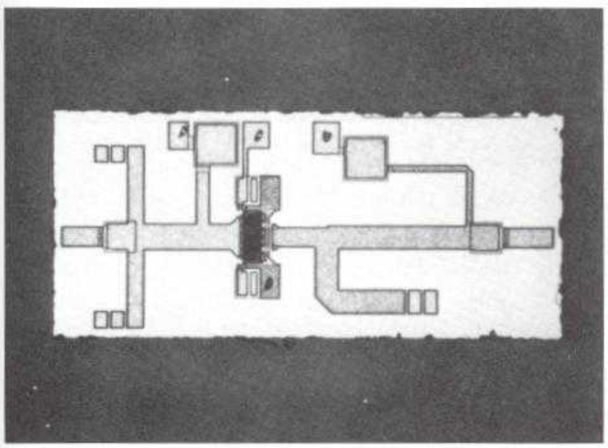


Figure 14a. *Single-stage, dual gate MESFET Ka-band amplifier*

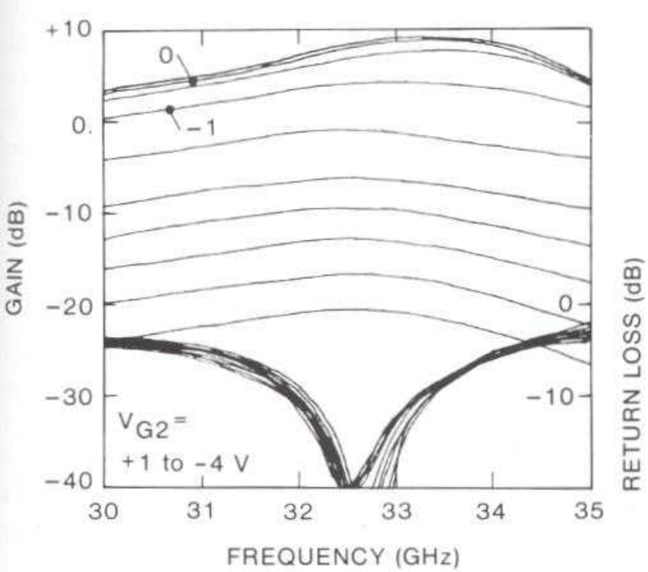


Figure 14b. *Gain and input return loss illustrate the wide range of gate control on gain*

INTELSAT SUPPORT

A new potential failure mechanism was identified in the nickel-hydrogen (NiH_2) batteries used in INTELSAT satellites and other spacecraft programs. This failure mechanism was uncovered during product assurance testing of INTELSAT VI NiH_2 batteries in collaboration with COMSAT's Applied Technologies Division (ATD) and INTELSAT. Real-time and accelerated-life tests simulating eclipse seasons were performed on INTELSAT VI NiH_2 batteries at both COMSAT Laboratories and Hughes Aircraft Co. MED performed microchemical analysis on the cell components, including the positive plates and separators. Electron-beam-excited, energy-dispersive x-ray analysis showed that islands of platinum-rich particles accumulate on the surface of the positive plates, as shown in Figure 15. The presence of platinum on the positive plate leads to local depletion of charge and loss of cell capacity, but only positive plates from INTELSAT VI cells subjected to simulated eclipse cycle testing showed evidence of platinum. The source of platinum on the positive plates of INTELSAT VI cells was traced to migration of particles from the negative plate through the open tricot-woven Zircar separator, which differs from the dense asbestos used on INTELSAT V. Further tests and analytical evaluation were underway to ascertain the impact of this discovery about battery life on the INTELSAT VI program.

In other INTELSAT support work, MED conducted an investigation of potential shorting mechanisms in the INTELSAT V solar array. Metallographic cross sections of solar cell/Kapton/graphite epoxy laminate structures of test coupons were examined. The Kapton insulating layers were intact in all cases. Work will continue in 1989 to determine the probable failure mechanism.

OTHER

NIST Calibration Standard

The National Institute of Standards and Technology (NIST) offers many certified standards to scientists around the world. Among the newest of these is SRM 2135, a nine-layer sandwich of high-purity nickel and chromium on silicon, which acts as a calibration standard for determining the argon ion sputtering rate in

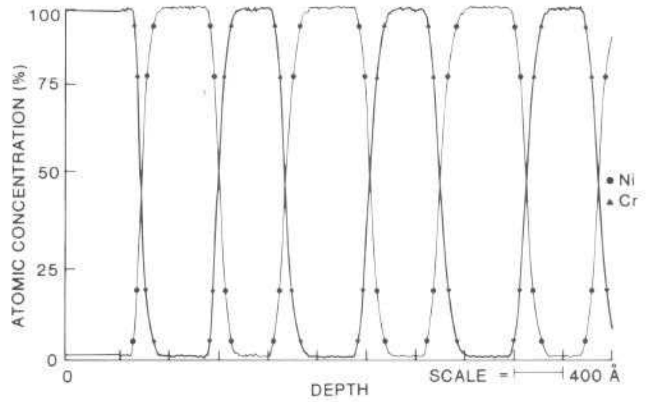
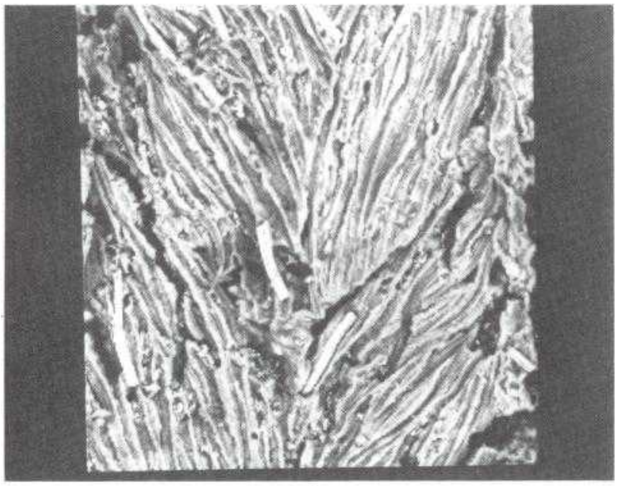
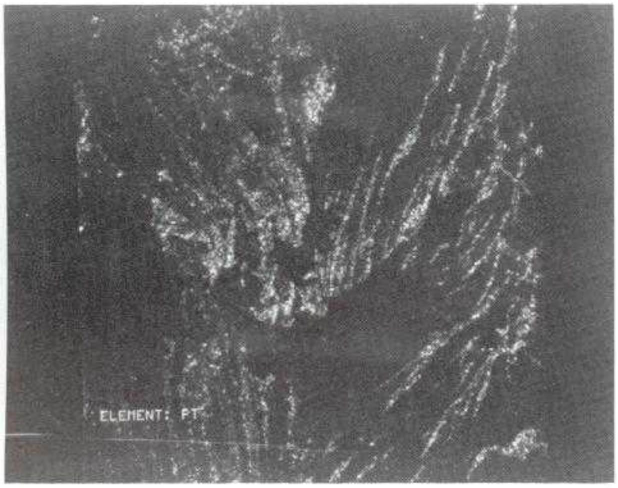


Figure 16. Alternating nickel and chromium layers of SRM 2135 Standard as measured by Auger electron spectroscopy depth profile delineating the high contrast between Ni and Cr layers



(a)



(b)

Figure 15. *Backscattered SEM image (a) and energy-dispersive x-ray map (b) of platinum on the surface of a positive plate from a life-tested INTELSAT VI NiH_2 battery, showing location of the platinum islands*

surface analysis instrumentation. It is fabricated by alternately depositing 640-Å nickel and 580-Å chromium layers onto a silicon substrate within the same vacuum system, thus creating a contamination-free structure of metal layers having very sharp interfaces. In a demonstration structure fabricated at COMSAT, the interface sharpness was decreased from a value of 80 Å (obtained by previous contractors) to 65 Å. The structure was characterized using Auger electron analysis and argon ion sputtering to resolve the layers (Figure 16). Under contract to NIST, MED will prepare a new supply of material for SRM 2135.

Microwave Characterization of Devices and MMICs

COMSAT Laboratories demonstrated and applied for a patent on a method of using laser pulses for microwave characterization of devices and MMICs on GaAs wafers. The technique eliminates the need for electromechanical contact that often damages the MMIC during testing and interferes with accurate circuit parameter determination. A brief pulse of laser light on a photoconductive gap generates a voltage pulse a few picoseconds in width that travels along a transmission line printed on the wafer. The voltage amplitude is sampled as the laser light pulse passes a sampling line separated from the transmission line by a photoconductive gap. This gap is illuminated with a second laser pulse derived from the first by insertion of an optical delay. Many such voltage samples, one per laser pulse, with differing time delays, provide information about the shape of the pulse. The pulse shape is converted to an amplitude versus frequency spectrum by means of a Fourier transform. The microwave performance of an MMIC can be characterized by measuring the pulse shapes before and after the pulses pass through a device or circuit. Figure 17 shows amplifier microwave power gain versus frequency for a GaAs MMIC.

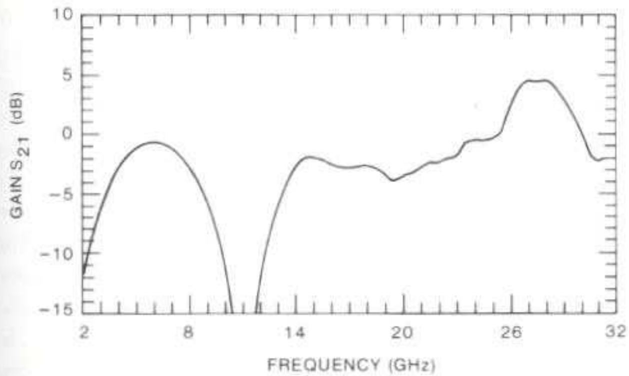


Figure 17. Gain of an MMIC as measured using optically generated and sampled voltage pulses without probe contact to the samples

As a result of this work, COMSAT Laboratories was awarded a subcontract by TRW, under the U.S. Government MIMIC Phase I program, for preliminary study of the technique. More recently, the MIMIC program office awarded a MIMIC Phase III contract to COMSAT Laboratories (with TRW, the University of Maryland, and EE&G as subcontractors) to develop commercial equipment for the optical method of characterizing MMICs on GaAs wafers.

Ion-Implanted Hyperabrupt Varactor Diodes

COMSAT has ongoing programs with Hughes Aircraft Co. and the Naval Research Laboratory to develop ion-implanted hyperabrupt varactor diodes for insertion into a voltage-controlled oscillator (VCO) circuit. A hyperabrupt impurity profile (Figure 18, curve a) is required to produce a varactor with Q of 10, capacitance tuning ratio of 17 to 1, and maximum operating voltage of 3.3 V. Modeling has shown that it is possible to produce a close approximation of this impurity profile using 6-MeV silicon and sulfur ions and low-energy silicon ions (curve b). The experimentally achieved profile is shown by curve c. Work is in progress to produce an ion implant and anneal process that more closely matches the modeled result. MMIC wafers intended to be used as VCOs at frequencies between 14.5 and 26.5 GHz were fabricated for Hughes Aircraft Co. Other devices included an ion-implanted FET, associated inductors, and thin-film capacitors.

Materials Analysis

In 1988, MED continued to provide materials analysis expertise on a contract basis to other laboratories, corporate divisions, and outside customers worldwide. For example, MED provided analytical assistance to the following organizations involved in various aerospace battery programs: British Aerospace PLC, NASA, Messerschmitt-Bölkow-Blohm (MBB), and Aerospatiale. The David Taylor Research Center of the U.S. Navy approached COMSAT for assistance in identifying the cause of premature failures of K-Monel components on submarines. Auger election analysis of fracture surfaces proved the key to understanding the metallurgical nature of the weakness. MED and ATD also combined efforts to supply gold-plated silver solar cell interconnects to a NASA subcontractor for use in the Explorer II platform spacecraft program.

U.S. Air Force Transmit/Receive Modules

MED began work in late 1988 for Unisys Corporation to produce 75 transmit/receive modules for the U.S. Air Force. An LNA for the receiver, a power amplifier, and amplifier driver chips were designed and scheduled for production and testing in 1989. They will be assembled into hermetically sealed packages in 1990.

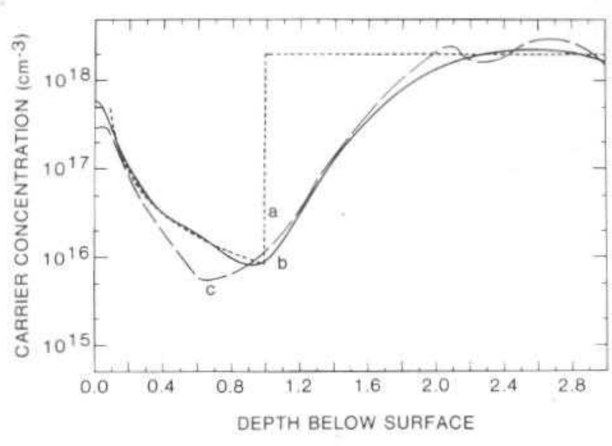


Figure 18. Hyperabrupt ion implant profiles for the VCO showing the excellent agreement between the modeling and the actual device ideal (gamma of 1.5) (a), modeled profile (b), measured device profie (c)

The Applied Technologies Division (ATD) provides a broad range of research and development capabilities in disciplines such as controls; dynamics and propulsion; satellite telemetry, tracking, and command; traveling wave tube amplifiers (TWTAs); structures, mechanisms, and thermal control; power systems, energy conversion and storage; reliability and quality assurance; and environmental and qualification testing. The design and fabrication facilities of COMSAT Laboratories are part of ATD. ATD is responsible for extending satellite lifetime and reliability, and supports development programs in other divisions, such as the multibeam antenna program for Intelsat Satellite Services (ISS) within COMSAT's World Systems Division (WSD). ATD provides engineering support under contract to INTELSAT and for other spacecraft programs, including INMARSAT II on behalf of the COMSAT Systems Division (CSD). In 1988, ATD initiated development of a common pressure vessel nickel-hydrogen (NiH_2) aerospace battery under a joint development with Johnson Controls, Inc.; continued thermal and mechanical design of the multibeam phased-array antenna; and provided major support to ISS, in its role as U.S. Signatory to INTELSAT, in the technical evaluation of proposals for the INTELSAT VII satellite system.

COMSAT JURISDICTIONAL R&D

Analytical Techniques

In 1988, research on analytical techniques continued to improve the overall analytical capabilities of ATD. This improvement was accomplished by adding new software, enhancing and converting existing software, increasing accessibility to local area networks (LANs), and training personnel using the software.

ORBIT and PWFP, two digital computer programs for simulating the dynamics and performance of the roll-yaw control system of a wheel thruster, were developed and validated. They were applied to simulation of the INTELSAT V attitude determination and control subsystem (ADCS). The advanced continuous simulation language (ACSL) program, obtained in 1987, was used to develop these programs.

Several programs widely used in industry were modified and enhanced: NASTRAN, used for finite element structural analysis; SINDA, used for thermal analysis; PATRAN, a pre- and post-processor for NASTRAN and SINDA; CADKEY, a three-dimensional computer-aided design program; MSC-PAL2, used for stress and vibration analysis; and ACSL and CTRL-C, used for control system design, analysis, and simulation. Files and data were transferred between programs and computers by means of in-house and Initial Graphics Exchange Standard (IGES) translators.

Education and training were provided for CADKEY, MSC-PAL2, the INERTA mass properties program, and NBOD2 and DISCOS dynamics programs.

Automated Satellite Command and Control

Satellite command and control center requirements are becoming more severe as the numbers and the different types of satellites increase. For example, in the 1990s, several INTELSAT satellites from three different series will be operational. Despite this changing environment, the operating criteria will remain the same. The satellites must be operated safely, high availability of communications service must be maintained, and the operating cost must be minimized. Automation in the control center is needed to ease the growing conflict between the operating environment and the criteria for good performance.

To organize control center functions that are candidates for automation, three key areas of technology were identified: expert (or knowledge-based) systems, simulators, and computers. Investigation of real-time, parallel computers began with an architecture involving coprocessor boards with a microcomputer or workstation as host. Each coprocessor could contain up to four parallel processors. The processors, designed for high performance and easy integration with other processors, had high-speed processor-to-processor communication links, on-chip high-speed random access memory (RAM),

APPLIED TECHNOLOGIES

NiH_2 Aerospace CPV battery

and on-chip timers. Of several available software development alternatives, parallel FORTRAN (standard FORTRAN augmented with parallel constructs) was selected for initial work to achieve coarse-grain parallelism.

A demonstration project used the parallel computer as a real-time, hardware-in-the-loop simulator. By the end of 1988, the simulator control and monitor software from the Direct Broadcast Satellite simulator was successfully downloaded and modified for the parallel computer. In 1989, the application software will be downloaded and adapted, and the hardware placed in the control of the parallel computer, thus completing the demonstration.

Multibeam Phased-Array Antenna

During 1988, to satisfy the system requirements, a new conceptual design for the high-power, dual-polarized Ku-band array was developed. As in previous configurations, heat pipes were used to transport 875 W of heat dissipated in the multibeam antenna (MBA) to remote radiators for rejection to space. The baseline module comprised the following components and subassemblies:

- 24 feed horns
- 24 orthogonal mode transducers (OMTs)
- 48 high-power amplifiers (HPAs), 24 for each polarization
- 2 beam-forming matrices (BFMs), one for each polarization
- 2 controller assemblies, one for each polarization
- 2 redundant power supplies, one for each polarization
- 6 redundant heat pipe assemblies.

Figure 1 shows the MBA conceptual design. The 24 feed horns are configured in a hexagonal shape (five unequal rows in a staggered pattern) to facilitate the interleaving of MBA modules to form a complete array. The HPAs are mounted as close to the heat pipes as possible to minimize the temperature gradient between the highly heat dissipating field effect transistors (FETs) and the heat pipe vapor. Thermal analysis of the HPAs indicated that the FET junction temperatures were acceptable. The estimated weight of the entire MBA module was 47 kg.

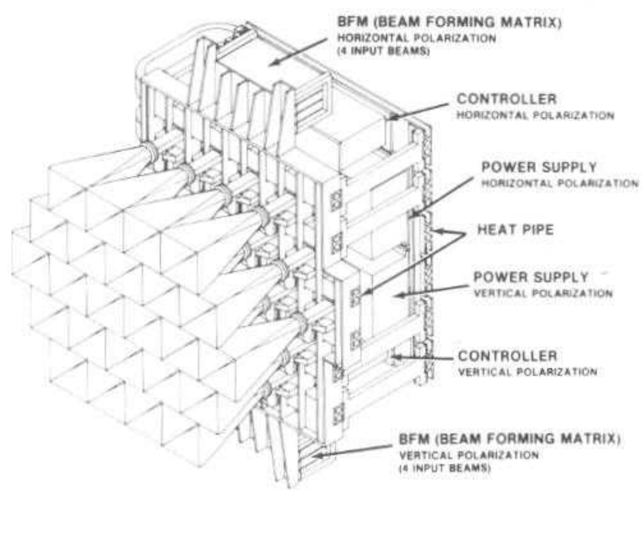


Figure 1. *Multibeam high-power active phased array*

The overall controller for the Ku-band high-power array is a distributed hierarchical controller comprising the executive controller, the data distribution and timing unit (DDTU), the local controller module (LCM) unit, and several monolithic microwave integrated circuit (MMIC) drivers in the BFM unit. In 1988, the controller design was changed to accommodate improvements and system requirements. The controller was in an advanced state of development by the end of 1988. An LCM breadboard was tested, and the computer-aided design of the LCM printed circuit board was completed (Figure 2). In addition, the LCM board and the LCM unit mechanical parts were fabricated. The DDTU was completed, and the executive controller was almost completed.

Work was performed on the controller for the 64-element low-power array. The MMIC drivers for the array were completed. Fabricated on alumina boards, these circuits were integrated with the MMIC circuits.

The performance and functional requirements of the power supply for the Ku-band high-power array, as well as design goals (such as high efficiency, small volume, and low mass), were developed and coordinated with other disciplines. This power supply provides regulated DC power to the high-power solid-state power amplifiers (SSPAs), the BFM MMICs, and the digital controller. It will be mechanically and thermally integrated with the high-power array module.

A design for the SSPA drain voltage supply (350-W total load) was developed using state-of-the-art topology and components (i.e., integrated magnetics and ceramic capacitors).

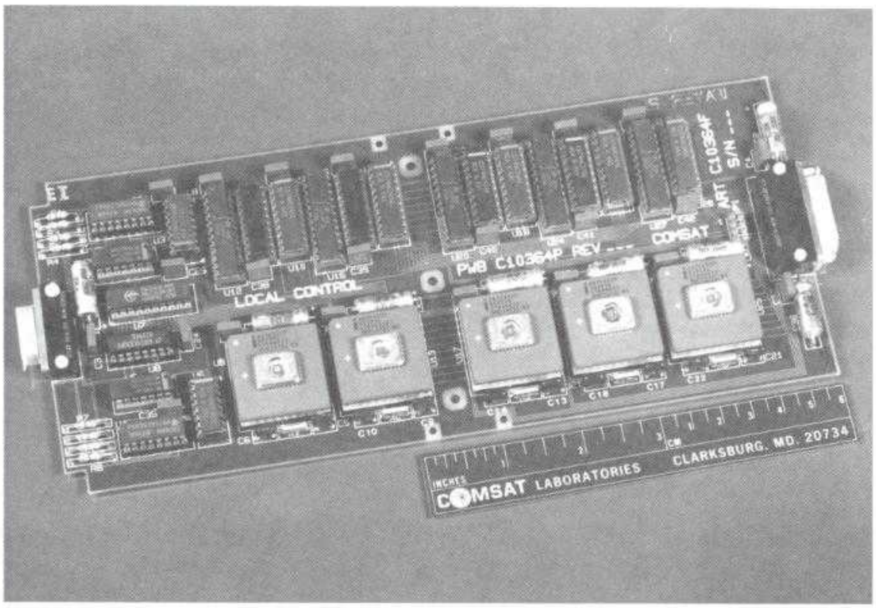


Figure 2. Local control module board for the high-power array

Advanced Satellite Thermal Control

A thermal control design concept was defined and developed for spacecraft with a modularized multibeam phase-array antenna system. A capillary pumped two-phase heat transfer loop (CPL) transports the MBA heat dissipation to spacecraft radiator panels. Design data for the CPL were scaled from a future NASA Goddard flight experiment, TEMP-2C. A spacecraft radiator panel featuring 1.90-cm-diameter axially grooved aluminum/ammonia heat pipes was area- and weight-optimized by varying the heat pipe spacing and thickness of the panel skins. The heat transfer interfaces between the MBA heat pipes and the CPL and between the CPL and the spacecraft radiator panels were analyzed, and design curves of required interface weight versus temperature gradient were generated. Spacecraft area and weight requirements were defined as functions of the required temperature at the MBA amplifier chip interface.

Early Failure Detection of TWTs

The principal reliability risk in space traveling wave tubes (TWTs) remains the thermionic oxide cathode, which is susceptible to subtle processing faults that may result in early failure (3 to 5 years), rather than the theoretical value of 15 years. For the current generation of spacecraft, traditional cathode tests are not satisfactory because a suitable diagnostic test has to be applicable after the TWT has been integrated with its power supply, an electronic power conditioner (EPC), to form a TWT amplifier (TWTA).

In an effort to reduce the number of early failures, time fluctuating (also called noise) properties of the cathode current are being investigated with the goal of demonstrating correlations between characteristic signatures and cathode anomalies. Theory and observation show that physical and chemical irregularities in the oxide or its bonding to the metal substrate can lead to excess noise. Several frequency ranges are being studied; the lowest corresponds to slight variations with time during a life test. In three typical space TWTs, tiny jumps in the filament current have occurred on a daily time scale. It has been concluded that this is a normal, benign effect, probably resulting from slight physical shifting of the filament.

At 50 to 1,000 Hz, enhanced noise termed "flicker noise," which varies with surface conditions, occurs. However, regardless of the high-frequency selectivity of modern spectrum analyzers, the broadband background noise due to the EPC and the environment may mask the cathode signatures corresponding to this small signal. Tests will be performed on a TWT known to demonstrate this effect.

At 10 to 30 MHz, noise is more readily detectable above the background; work will continue to identify signatures in the dependence of this noise level on cathode current and temperature. During the cooling down of a normal cathode after filament power switchoff, sharp increases in noise level have been observed. More work is required to quantify these effects and compare them with the behavior of nonnormal cathodes.

A chemical study of the surface bonding of the oxide cathode is being carried out in COMSAT Laboratories' Microelectronics Division (MED).

Expert Systems Applications

Expert systems applications (ESAs) have been studied with the goals of lowering the cost of satellite operations and minimizing the risk to in-orbit assets and service. This project focuses on the use of knowledge-based (or expert) systems to overcome problems in attitude control, electric power, thermal control, propulsion, and orbit determination and control that occur during either normal or abnormal spacecraft operation.

During 1988, the following goals were accomplished. The design of the first prototype expert system, the ISSESA, which diagnoses the failure of the pitch control loop of a wheel-stabilized spacecraft, was improved and completed. A prototype of the satellite command assistance and monitoring expert system (SATCAM), which treats a planning problem somewhat differently from the ISSESA diagnosis problem, was initiated. A report on the risk and cost reduction benefits of ESAs in satellite control centers was completed. The best architecture was selected for extending the attitude control system simulator by the addition of the selected electrical power system simulator.

The integrated attitude control and electrical power system simulator will be applied to semi-independent but cooperating ESAs that will be investigated in 1989. The SATCAM expert system will be completed in 1989.

Advanced Stationkeeping Techniques

The solid-propellant apogee motor has been supplanted by liquid propulsion systems on many of the newer communications satellites. Additionally, some of these configurations are spun to achieve inertial stiffness during the several motor firings used to raise the satellite from the elliptical transfer orbit to the final, circular, geostationary orbit. The interaction of the spinning spacecraft body and the large liquid mass fraction can result in dynamical anomalies, e.g., spin instability, as the properties of the body change due to liquid consumption during motor fire. This work attempts to analytically predict the dynamic effects of the liquid.

A survey of analysis methods applicable to static stability of spinning spacecraft with tanks partially filled with liquid was completed. Because Guibert's method was the easiest to implement, a computer program was developed to compute the parameters in Guibert's criterion for static stability. The program is being validated using stability results for INMARSAT II developed by British Aerospace. Presently, the capabilities of the program are restricted to analysis of cylindrical tanks with hemispherical ends.

Small Earth Station Tracking

The primary method available for extending the maneuver lifetime of geostationary satellites is to save propellant by eliminating north-south (N-S) stationkeeping. This results in an increase in orbit inclination at the rate of approximately 0.9° per year. As a consequence, earth station antennas, many of which could remain essentially fixed on the satellite in orbit, must now track the satellite motion as seen from the ground. If the satellite is located at the same longitude as the earth station, the motion appears as a figure eight with the amplitude proportional to the satellite inclination. For earth stations offset in longitude, the figure eight is skewed as a function of longitudinal separation.

The performance of large earth stations has been optimized by step tracking in which a satellite-generated beacon signal is used to control the antenna position. Because these systems involve a beacon received in the loop, they are somewhat more costly than a simple open loop programmable system in which the ephemeris data are used to determine satellite position. INTELSAT has eliminated N-S stationkeeping for a number of INTELSAT V satellites.

COMSAT has sponsored a small earth station tracking verification project to study and compare the performance and cost of step tracking and program tracking for small stations in the 4.5-m class. An existing antenna was modified, as shown in Figure 3 to accommodate both types of control. The system was implemented at C-band and is tracking the INTELSAT IV-A satellite, which had an inclination of approximately 3.5° at the start of the evaluation period. Following an extended test period, a report describing results and recommendations for low-cost implementation will be issued.

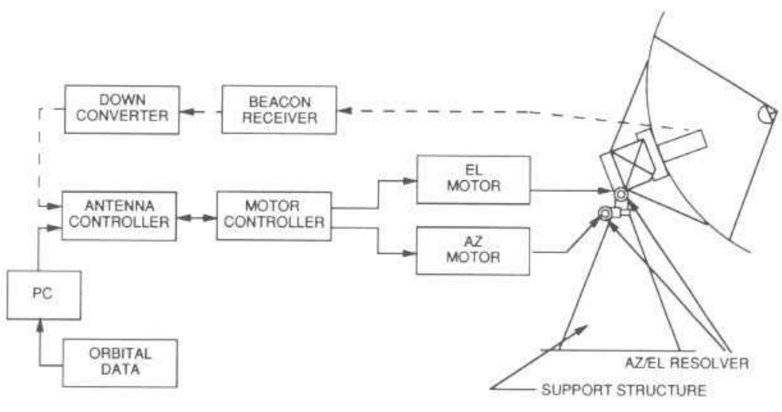


Figure 3. Small earth station tracking configuration

Satellite Life Extension Studies

The possibility of extending INTELSAT spacecraft life up to 15 years encouraged the study of the durability and performance of Ni-Cd and NiH_2 batteries. The battery performance computer model consisted of a multiple linear regression function and an error function. The voltage and life expectancy of all the batteries on board INTELSAT satellites were calculated from orbital data for the 1988 autumnal eclipse season. Efforts are underway to improve the prediction model by modifying the constants in the regression equation to reflect changes in the design of the battery, such as the amounts of potassium hydroxide, separator, and additives. An accelerated cycling test of flight-type NiH_2 cells has been initiated to determine the mean time to failure (MTTF) and thereby refine the prediction model. INTELSAT V and VI cells have completed 4,193 and 4,651 cycles, respectively, without significant change in performance.

COMSAT NONJURISDICTIONAL R&D

NiH_2 Aerospace CPV Battery

During 1988, ATD initiated a project to develop a prototype test module of the NiH_2 common pressure vessel (CPV) aerospace battery. This project is intended to exploit, for aerospace use, technological achievements from a previous Sandia National Laboratory program in which a terrestrial CPV battery was developed. After thermal modeling studies, a cylindrical design was selected that allows for the passive removal of heat. Optimization studies were performed on various CPV diameters with a variable number of cell modules for a wide range of applications. A lightweight Inconel pressure vessel was designed and fabricated, and a laser welding technique was used for final vessel closing. Assembly and testing of this aerospace CPV are scheduled for early 1989. CPV technology offers significant improvements in specific energy (energy per unit weight) and energy density (energy per unit volume).

COMSTAR/SBS Batteries

Batteries representative of those being used in the COMSTAR and Satellite Business Systems (SBS) satellites continue to be life-tested in a charge and discharge cycling regime that simulates real-time battery operation in orbit. Test results provide a database for projecting in-orbit performance and lifetime expectancy on board COMSTAR and SBS satellites. By means of a computer model, the expected end-of-discharge voltage on the longest eclipse day is calculated and performance forecast. The COMSTAR-type batteries have completed 26 eclipse seasons, whereas the SBS-type batteries have completed 17 eclipse seasons. The real-time life test and the performance projections provide a basis for estimating the battery capability for operating these satellites up to and beyond their contractual lifetime.

COMSAT SUPPORT

Technical and Engineering Support

During 1988, ATD provided technical and engineering support to several COMSAT business units, including ISS, Maritime Services (MS), and CSD.

ATD efforts in support of ISS and MS involved technical studies and reviews related to COMSAT's role as U.S. Signatory to INTELSAT and INMARSAT. For ISS, ATD's major effort was technical evaluation of proposals for the development and procurement of the INTELSAT VII spacecraft system. This evaluation aided ISS in establishing its position on the program during INTELSAT's proposal deliberations. ATD led the 25-member evaluation support team, which included experts from COMSAT Laboratories and CSD's New Jersey and California operations. ATD conducted periodic studies and reviews of satellite programs for the U.S. Signatories in their roles as delegates to the INTELSAT and INMARSAT technical committees.

ATD efforts in support of CSD included quality assurance for a Voice of America satellite interconnection system contract, and continuing studies and experiments on ground-based Ni-Cd batteries used for lifetime prediction of their orbiting counterparts. ATD also acted as spacecraft subsystem consultant to the INMARSAT II and INTELSAT contracts being managed by CSD.

INTELSAT CONTRACTS

INTELSAT V and VI Batteries

In life-testing the INTELSAT V NiH_2 battery, ATD discovered that some cells experienced loss of water from their electrode stacks. This water accumulated in the free volume of the cell's pressure vessel. When water is lost from the stack, the concentration of electrolyte increases. Its volume decreases in the stack and the cell voltage is adversely affected by ohmic and electrochemical effects. The affected cells experience a higher ON-charge and lower discharge voltage than normal cells.

Similar anomalous low-voltage performance was subsequently observed for some cells in several of the orbiting INTELSAT V NiH_2 batteries. During 1987, a rejuvenation procedure was developed and then implemented as a test on one battery, in time for the 1988 vernal equinox. Because this procedure produced the desired result of correcting the low-voltage performance of the affected cells, it is presently being used for six additional in-orbit batteries. INTELSAT is considering routine use of the procedure for all INTELSAT V NiH_2 batteries.

INTELSAT VI NiH_2 cells suffer not only a capacity loss when stored for extended periods at room temperature in the open-circuit discharged condition but also a low-voltage second plateau in their discharge profile. In support of INTELSAT VI, ATD continued a study under the Laboratories' Engineering Assistance Contract (LEAC) showing that capacity maintenance characteristics were the same when cells were stored either passively at 0°C in an open-circuit discharged condition or trickle-charged at 0°C at the C/600 rate. Neither of these procedures is suitable for recovering the lost capacity, but the conventional trickle-charge method at C/100 helps in capacity recovery and in eliminating the second plateau.

A life test using two quadrants (two 16-cell batteries) of an INTELSAT VI NiH_2 battery continues to provide data about the operating features of the battery in real-time eclipse simulation. After five seasons of testing, there is no marked difference in change of discharge voltage between the positive precharge and hydrogen precharge batteries; the capacity of the hydrogen precharge battery has increased by 2 Ah and that of the positive precharge battery has decreased by 3 Ah.

INTELSAT VI BAPTA Testing

During a Hughes Aircraft Co. (HAC) life test of the electrical contact ring assembly (ECRA), a failure due to an open in the power circuit occurred. A constant-force negator spring was used in the bearing and power transfer assembly (BAPTA) power section to keep the brushes in intimate contact with the slip rings. The BAPTA, a single-point failure device, is the satellite spun-despun interface that transfers electrical power and telemetry signals by means of slip rings. An ATD BAPTA was retrofitted with the cantilever spring design adapted by HAC to replace the negator spring design. Designs were developed for an overspeed control circuit, as well as analysis and computer simulation of a working speed control circuit for the BAPTA. Both circuits were successfully integrated in the BAPTA control electronics, and a life test was instituted. The primary assemblies in the BAPTA are the bearing assembly and the ECRA (Figure 4). The BAPTA with the new cantilever spring design is being subjected to a real-time life test to assess the long-term performance of the bearing assembly and the ECRA.

The performance of the bearing assembly and the ECRA is critical in sustaining the life of the satellite because neither system has a redundant backup. The BAPTA is being tested in a thermal vacuum environment to simulate in-orbit conditions. An instrumentation system fully monitors and assesses the performance of the ball bearings and ECRA during the life test. Continuously monitored parameters are the drive motor voltage and current, input drive power, temperatures at several locations, bearing lubrication film condition, noise signature generated by the bearing, and power brush noise in the ECRA. The friction torque of the bearing is computed. The BAPTA has demonstrated normal performance since the beginning of the life test.

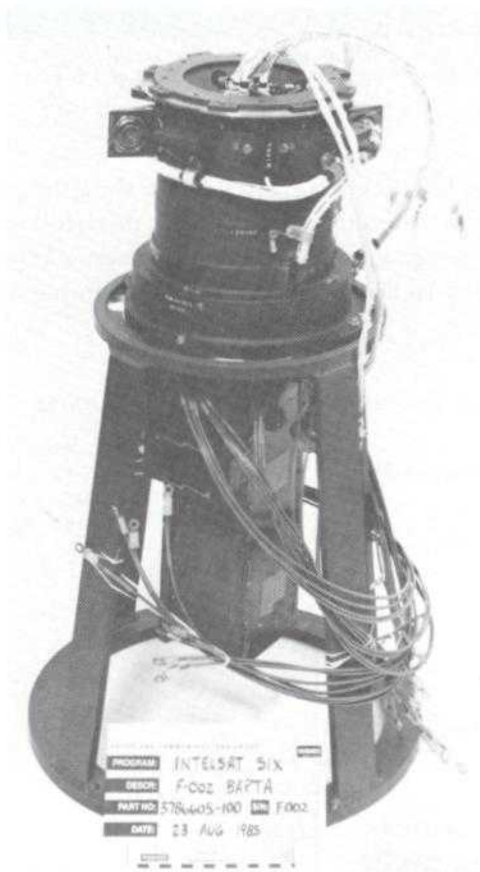


Figure 4. *INTELSAT VI BAPTA*

Under an initial contract with HAC and the LEAC with INTELSAT, ATD is conducting an accelerated life test on the ECRA with the coil spring design. Parallel life testing of both designs provides added assurance that the launch schedule will not be seriously compromised if an ECRA fails. The nominal in-orbit speed of the ECRA is 30 rpm. To accelerate the life test, the ECRA is being run at 300 rpm. The system is being tested in a thermal vacuum chamber to simulate a space environment. Though there have been several interruptions due to instrumentation problems, the ECRA has performed normally in the accelerated life test since July 1988.

INTELSAT VI Thermal Model Conversions

Overall, detailed, analytical thermal computer models of the INTELSAT V and VI spacecraft have been obtained from Aerospatiale and HAC, respectively. Under the LEAC, ATD is converting these models to SINDA thermal analyzer program format for INTELSAT's use. This conversion will allow INTELSAT to assess the thermal consequences of in-orbit anomalies or unusual operation modes. Translators have been written to convert the 10 INTELSAT V models simulating 72 orbital environments.

Conversion of the INTELSAT VI overall model and communications subsystem model, involving 22 thermal models, is in progress.

TWTA Enhanced Reliability

To improve the 10-year long-life reliability of space TWTAs to 15 years, ATD is continuing to perform an experimental program of multiple-stress screening tests on flight-type TWTAs, under contract to INTELSAT. Although manufacture is carried out under the most careful conditions, final acceptance of units as flight models is always based on satisfactory completion of screening tests designed to indicate weaknesses that could lead to premature degradation or failure. In-orbit experience has shown that more rigorous procedures are needed to meet the increasing life requirements of new-generation spacecraft.

In this program, experimental regimes of cyclic operating condition and temperature variations are being applied to a population of 20 Ku-band TWTAs built for the INTELSAT VI spacecraft series. Two units at a time are tested in the apparatus shown in Figure 5, while the temperature is raised and lowered slowly between high and low plateaus, with a cycle time of 12 hr.

Under computer control, the operating RF power, DC voltages, on/off, and other control functions are switched for a period of some days, while all sensitive parameters are being precisely recorded. The variations are chosen either to trigger latent faults or to show anomalies that could indicate reliability problems.

Large volumes of data are collected in such tests. Presentation of these data in a form that would be readily useful in a manufacturing environment is an important element of the program. Typically, in such tests signatures for device parameter variations are developed that are easily seen only in graphic presentations. Figure 6 shows hundreds of data points for three operating parameters plotted by the computer as a function of temperature. The complete data for one test can be presented on three transparencies for easy viewing. Irregularities can be seen at a glance and can be further investigated by comparison with time plots, or if necessary, by more detailed printouts.

Figure 5. *Equipment for multiple stress testing of TWTAs*

The test program is intended to show the practical utility of such multiple-stress testing; this is followed by a life-test program to show whether subsequent behavior can be correlated with observations during the test phase.

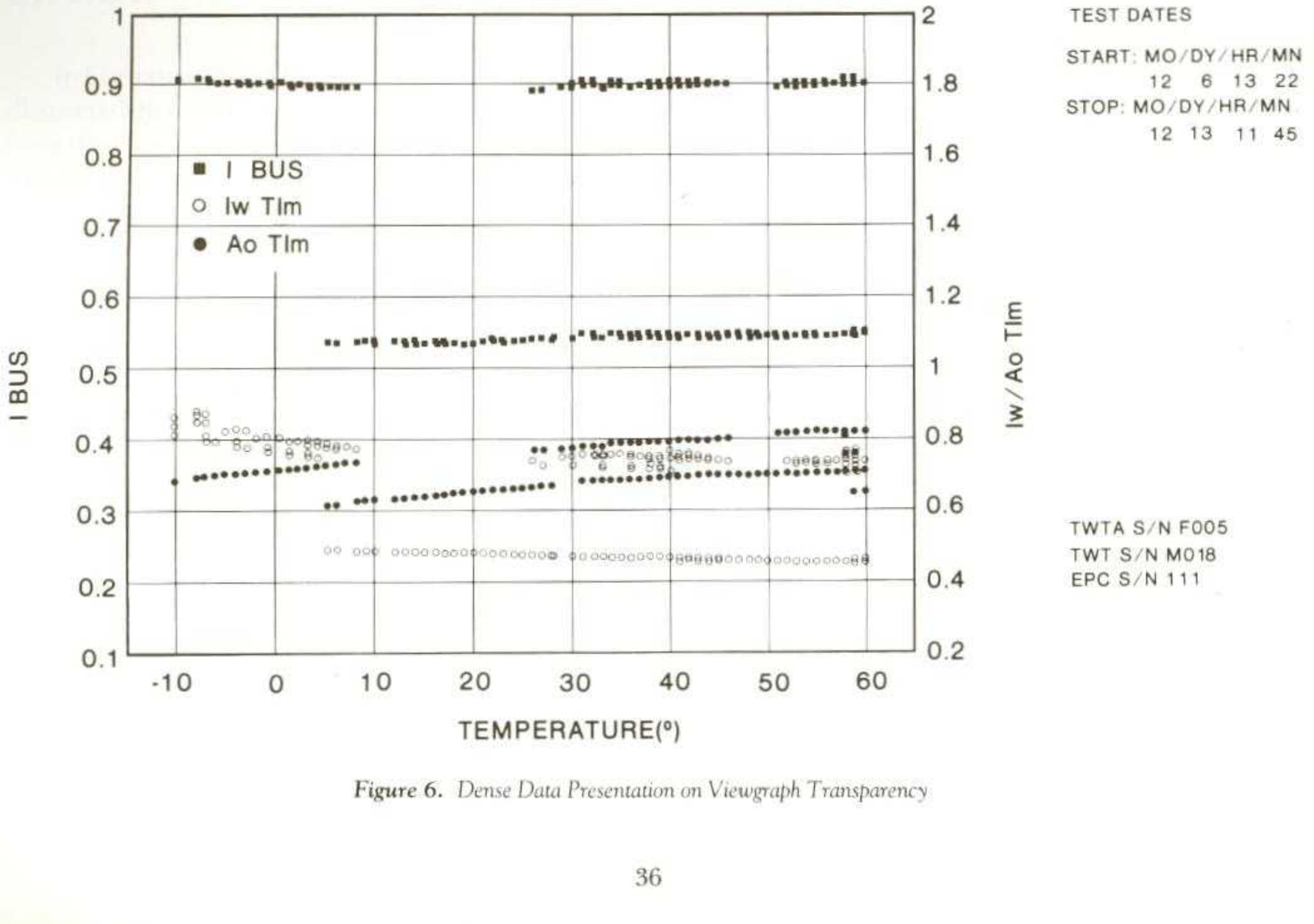


Figure 6. *Dense Data Presentation on Viewgraph Transparency*

OTHER CONTRACTS

Environmental Test Laboratory

ATD operates the Environmental Test Laboratory. During 1988, vibration, shock, temperature, and humidity test services were provided under contract to several customers, including Weinschel Engineering and CONTEL.

Design and Fabrication Center

The design, machining, and plating facility provided services to outside customers for several projects.

An antenna feed system comprising a prime focus feed horn and a four-port, dual, circularly polarized diplexer was designed and fabricated for British Telecom. The feed system was installed in the Goonhilly Aerial No. 1, and the expanded frequency allowed the antenna to operate with both INTELSAT and INMARSAT satellites. Feed systems were also delivered to Dalsat, CONTEL ASC, COMSAT General (for installation in the U.S.S.R.), and American Technical Communications Corporation.

Several large weldments for radar acquisition ranges were supplied to System Planning Corporation for field installation. Above- and below-deck electronics for the MARISAT 9100 communications system were manufactured for Mobile Telesystems, Inc.

The Communications Technology Division (CTD) carries out research and development and provides technical support in transmission, video, and voice-frequency band processing; systems simulation; and systems analysis and synthesis. Advanced communications systems architectures and technologies are used extensively to achieve the lower equipment costs and improved transmission efficiency necessary to maintain the cost-competitiveness of satellite communications relative to other media. These advanced architectures and technologies depend, in turn, on widespread application of digital signal processing techniques. Examples of such developments in 1988 include 4.8- and 16-kbit/s low-rate speech encoding; 140- and 155-Mbit/s modems and codecs constrained to pass signals through the standard 72-MHz satellite transponders; and an on-board multicarrier digital demultiplexer demodulator development. Other significant efforts in 1988 include reduced-complexity decoding techniques, advanced mobile communications technology, digital circuit multiplication equipment (DCME) protocol analyzers, three-channel TV multiplexers, modified National Television System Committee/phase alternating line rate (NTSC/PAL) processors, mobile gateway earth station technology, spread spectrum simulation software, and advanced digital signal processing.

COMSAT JURISDICTIONAL R&D

Advanced On-Board Digital Processing

The objective of this project is to develop a proof-of-concept (POC) model of an integrated, on-board, multichannel demultiplexer/demodulator unit and associated test bed. Such technology will not only improve link signal-to-noise ratio (S/N) efficiency and provide interconnectivity in a multibeam system because individual carriers can be separated and demodulated on board the satellite, but will also make the on-board processor independent of the frequency plan and transparent to ground users. Except for the demultiplexer IF front end, the embodiment is completely digital and thus its frequency plan can be reprogrammed from the ground.

The systems-level architecture, defined in 1986, was refined in 1987. The effort in 1988 focused primarily on hardware development.

The fast Fourier transform (FFT) and inverse FFT (IFFT) subsystems of this on-board processor comprise more than half the on-board hardware. A composite butterfly architecture allows the same general structure to be duplicated and used in several locations in both the FFT and IFFT. In addition, the hardware-intensive delay/switch/delay (DSD) function is implemented in very large-scale integration (VLSI) form. DSD operation requires eight application-specific integrated circuits (ASICs) developed by COMSAT and about 20 off-the-shelf complementary metal oxide semiconductor (CMOS) support chips. Eight DSD ASIC chips, shown in Figure 1, and approximately 20 support chips replace the hardware of three 370-mm x 400-mm boards when discrete ICs are used. In addition to the size reduction with VLSI, the power is also reduced by a factor of 6.4.

The POC model will be completed in December 1989.

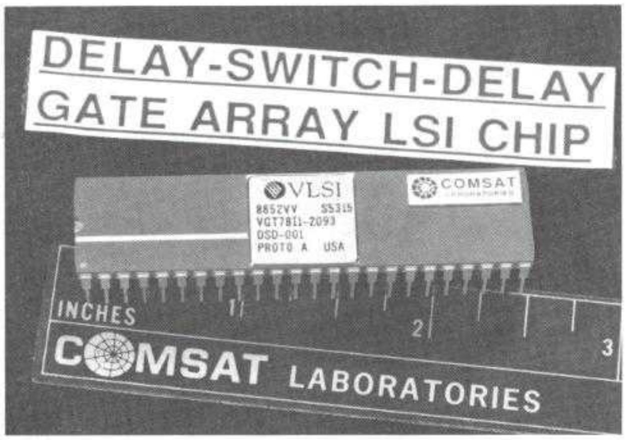
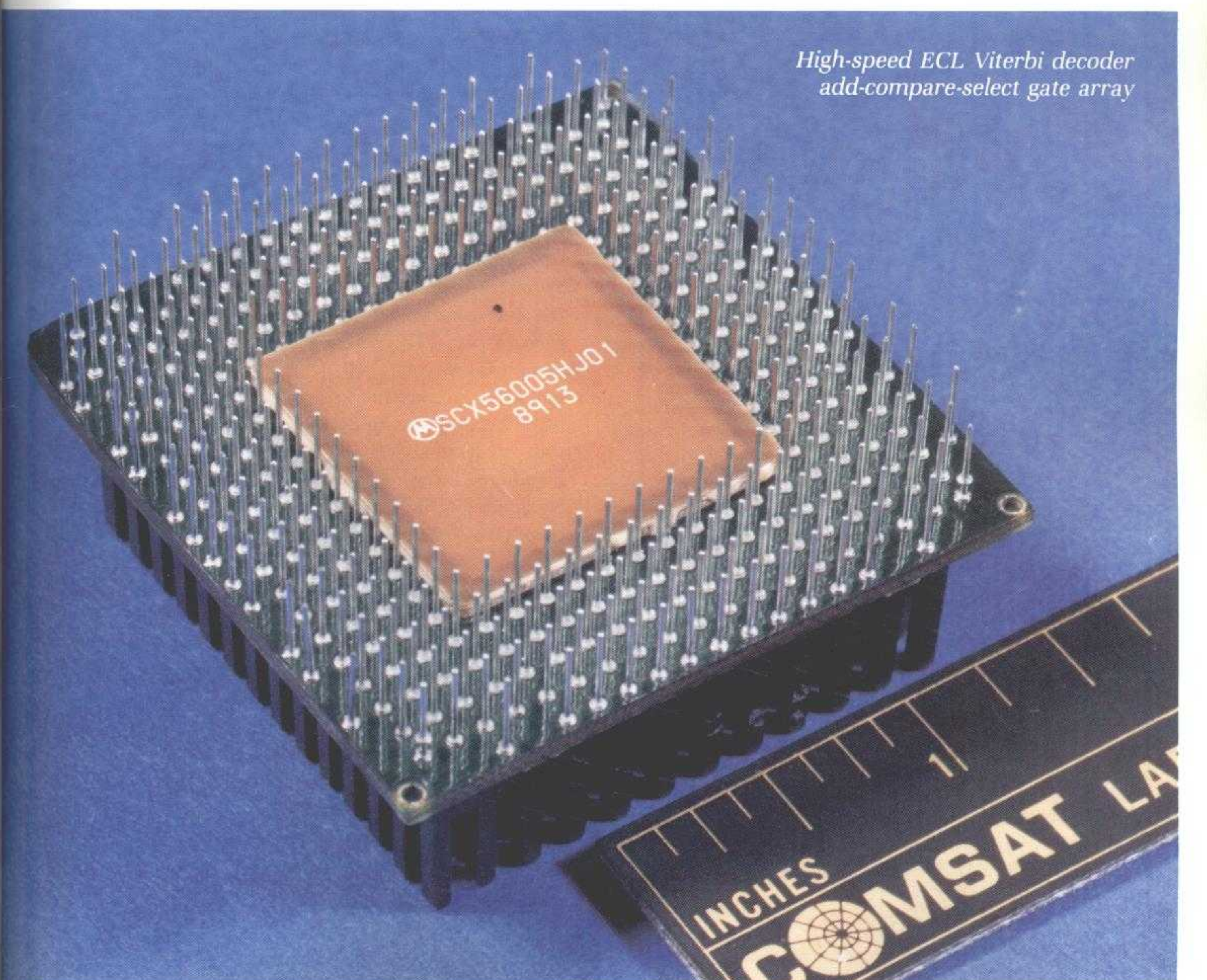


Figure 1. Delay/switch/delay ASIC chip

140-Mbit/s Coded Octal-PSK Field Trials

A system capable of carrying 140 Mbit/s through a standard 72-MHz transponder to allow efficient restoration of the TAT-8 fiber optic cable was completed in 1987

COMMUNICATIONS TECHNOLOGY



High-speed ECL Viterbi decoder add-compare-select gate array and reported in the *COMSAT Laboratories' 1987 Annual Report*. Until this system was developed, the maximum data throughput for this satellite channel bandwidth was 120 Mbit/s. The coded octal phase-shift keyed (COPSK) system consists of an 8-PSK modem combined with a rate 7/9 Viterbi codec. Laboratory testing indicated that this system is capable of providing better bit error rate (BER) performance than the current 120-Mbit/s QPSK system, and providing transmission at the required 140-Mbit/s rate.

During the first half of 1988, COMSAT conducted performance tests of this system between the U.S., the U.K., and France. Two COPSK systems were included in these tests, one belonging to COMSAT's Intelsat Satellite Services (ISS) and the other to INTELSAT. Both units were designed and built at COMSAT Laboratories.

After careful equalization and characterization of the links, BER was measured in both directions for each transmission link. In Figure 2, the results of the Roaring Creek to Pleumeur Bodou measurements are compared with typical 120-Mbit/s satellite loopback performance. The COPSK system is thus capable of providing transmission at 140 Mbit/s with improved BER performance when operating over a nonlinear channel.

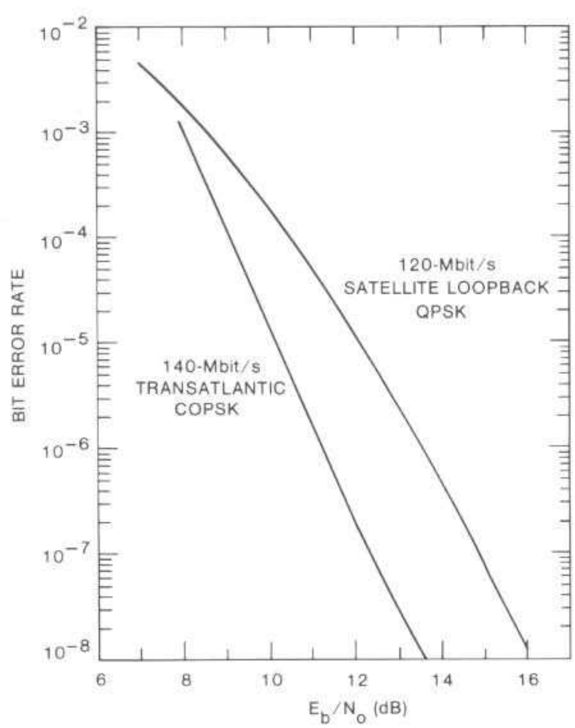


***Figure 2**. Comparison of 140-Mbit/s COPSK with 120-Mbit/s*

Reduced-Complexity Decoding of Convolutional Codes

Since the introduction of the Viterbi algorithm in 1967, many attempts have been made to reduce its computational complexity for decoding long convolutional codes while maintaining a near-optimal BER performance. Reduced-state and reduced-path Viterbi decoding methods have been proposed and extensively investigated. The main drawback of these schemes is the error propagation property. That is, once the correct path or state is eliminated from the set of survivors in the convolutional code trellis, the decoder is unable to resynchronize itself to the correct state, even if the channel remains noiseless afterward. A reduced-complexity decoding algorithm that does not propagate errors was introduced and analyzed. For long codes, its computational complexity and memory requirements are less than with the Viterbi algorithm, while its asymptotic BER performance is equivalent to that of a maximum-likelihood decoder.

Rather than decoding the random sequence of equally likely received channel symbols, the reduced-complexity decoding algorithm computes and processes a syndrome sequence that is an encoded but noisy version of the channel noise. The decoder output, an estimate for channel noise, is used to correct errors in the received sequence. Figure 3 shows the BER (P_b) and event error rate (P_E) performance curves of the reduced-complexity decoder (RCD) for a memory order 13 quick-look-in convolutional code of rate 1/2, processing 64 or 94 paths at each decoding step. At a BER of 10^{-4}, with soft decision decoding, this code gives about 0.4 dB of additional coding gain over the 64-state code with maximum-likelihood decoding. Also, at a P_E of 10^{-4}, more than 0.7 dB of extra coding gain is achievable.

Bidirectional Trellis Decoding

Bidirectional trellis decoding is a reduced-complexity method for soft-decision decoding of block codes. Unlike the Viterbi algorithm, which processes every trellis state, the bidirectional decoding algorithm takes advantage of the code structure to identify and process a small subset of paths in the trellis diagram containing the most likely path. The algorithm examines a received block of channel symbols in the forward and backward directions and selects the most likely codeword as the transmitted message. The bidirectional algorithm requires significantly fewer computations per decoded bit. Extensive analysis and computer simulations indicate that, for special classes of block codes, the BER performance of the bidirectional decoding algorithm is equivalent to that with a maximum-likelihood decoder. This decoding scheme allows simple, low-cost implementation of soft-decision decoders for powerful block codes.

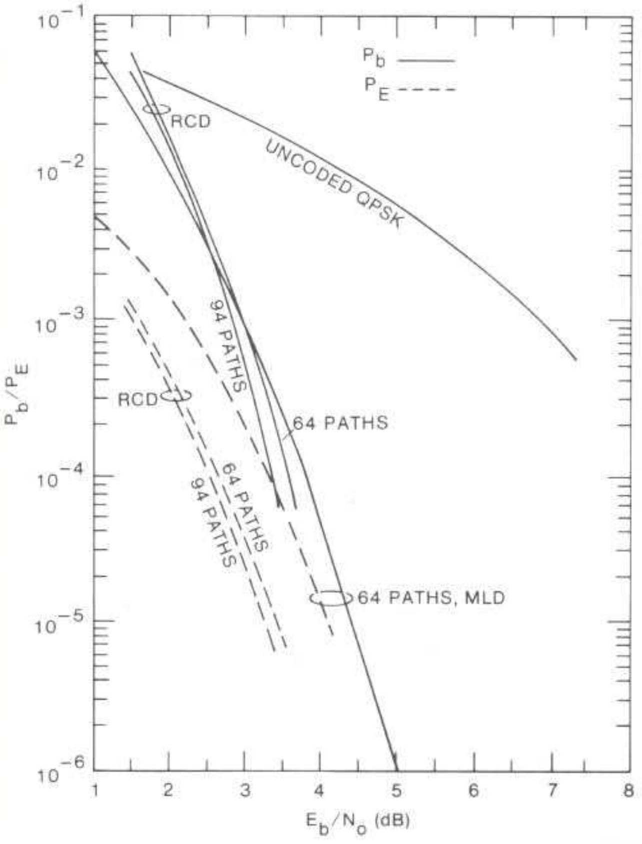


Figure 3. *Performance curves for a memory order 13 convolutional code of rate 1/2 with eight-level soft decision over an additive white Gaussian noise channel*

B-ISDN Compatible Modem/Codec

INTELSAT is expected to provide broadband integrated services such as broadcast TV, high-definition TV, and data transmission at high rates. Modulation and coding schemes have been investigated that can achieve high-quality transmission of information at the broadband integrated services digital network (B-ISDN) rate of 155.52 Mbit/s over 72-MHz transponders. Of particular importance is the hardware realizability of the selected modulation format and code. Several candidate coded modulation schemes have been investigated and analyzed. In particular, a COPSK modulation of rate 31/36 and channel symbol rate of 60 Msymbol/s provide an asymptotic coding gain of 3.5 dB over uncoded QPSK and can readily be implemented with available technology. The channel symbol rate of 60 Msymbol/s was selected because the earth station subsystems have already been designed for operation at this clock rate. The codec is also applicable for transmission of 140 Mbit/s at the same symbol rate while achieving a higher coding gain.

Mobile and Portable Terminal Technology

Because of bandwidth and power limitations in the current maritime mobile satellites, technologies for low-cost maritime mobile, aeronautical mobile, and portable satellite-terminal services must be developed. Development of a 4.8-kbit/s communications-quality vocoder and transmission of the 4.8-kbit/s signal over a 5-kHz multipath fading channel have been studied.

Computer software and efficient algorithms for reducing computational complexity for a code-excited linear predictive (CELP) speech coder were developed. A fast-search method for vector quantizers based on a mean square error (MSE) distortion measure, an adaptive method for transforming predictor coefficients to line-spectrum frequencies, and robust schemes for noisy environment applications were also developed. These schemes included speech activity detection under noisy conditions, and pitch tracking in multiple-talker situations. Informal subjective tests indicated that the reconstructed speech had high intelligibility, excellent speaker recognizability, and natural sound.

Computer simulations were also conducted to test the performance of the modem/codec in transmitting the 4.8-kbit/s voice-coded signal over a Ricean fading channel. The transmission scheme is based on partially coherent detection of a differentially encoded 8-PSK trellis modulation code. A clock synchronization algorithm based on a maximum-likelihood estimator operating on the squared samples was derived and simulated. A frequency acquisition algorithm and a frequency tracking loop were also simulated under worst-case Doppler scenarios. The simulation results indicated that partially coherent detection of the differentially coded 8-PSK trellis modulation with proper frequency synchronization is well suited to the mobile channel. Implementation of the CELP coder and modem/codec with DSP chips is planned for 1989.

16-kbit/s Voice Codec

Initiated in 1985, this effort has reached its final stages with the development of a new technique for speech coding at 16 kbit/s. This technique, called adaptive predictive coding with transform domain quantization (APC-TQ), meets the basic requirements of being amenable to variable transmission rate operation and delivering high speech quality, while providing satisfactory performance on sine waves, signaling waveforms, and low-rate modem signals.

The APC-TQ coder is a predictive coder in which waveform quantization of the residual signal is performed in the frequency domain. At the encoder, short-term redundancies due to vocal tract resonances are removed from the speech signal, long-term redundancies arising from the pitch periodic nature of speech are removed, and the residual signal is processed in the frequency domain by means of a discrete cosine transform. A bit allocation algorithm then determines the optimal use of available bits for transmission over the digital channel, so that the distortion at the decoder is masked by the signal itself. The frequency domain coefficients are quantized and transmitted to the decoder, along with the parameters for the predictors and the quantizer.

In 1988, a full-duplex APC-TQ codec was implemented on a single Analog Devices ADSP-2100 digital signal processor. Informal listening tests indicated that the speech quality is approximately equivalent to that of 7-bit/sample log-PCM transmission. Furthermore, CCITT-5 dual-tone multifrequency (DTMF) sine waves at 400 to 2,400 Hz and modem signals at 300, 1,200, and 2,400 bit/s pass satisfactorily through the codec. A total algorithm plus implementation delay of 60 ms is introduced by the codec.

During 1989, formal subjective and objective tests will be conducted to assess the performance of the APC-TQ codec.

Digital Circuit Multiplication Equipment (DCME) Protocol Analyzer

INTELSAT approved a 32-kbit/s low-rate encoding, digital speech interpolation (LRE/DSI) DCME specification that was sufficiently detailed to provide interoperability between equipment built by various manufacturers. The DCME protocol analyzer is a test bed for

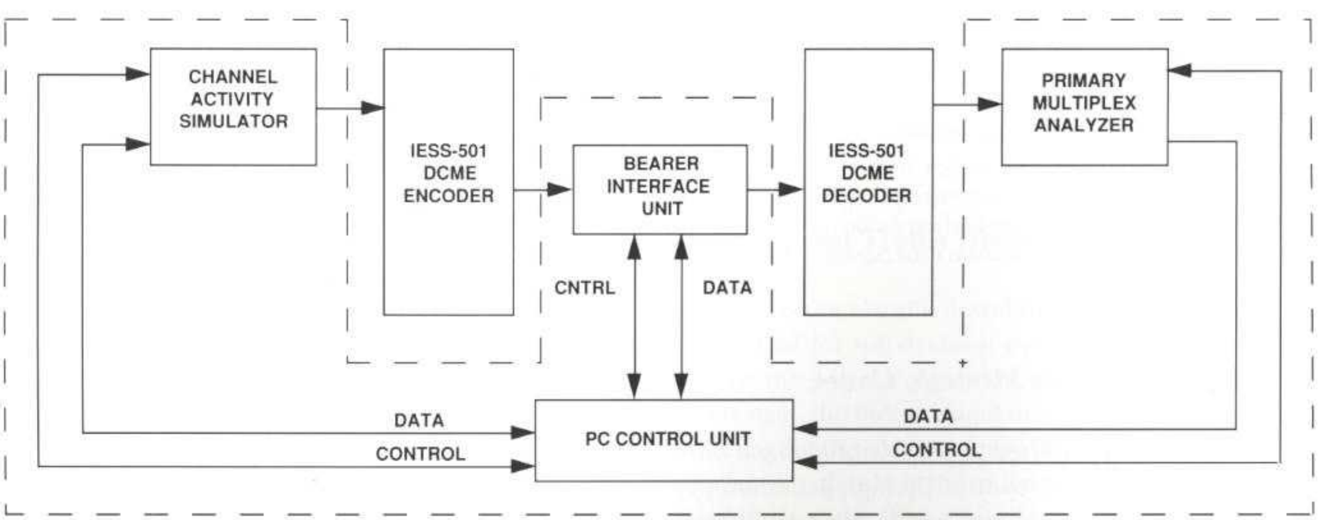


Figure 4. DCME protocol analyzer

verifying the functional compliance of DCME built in accordance with the INTELSAT specification and is also a maintenance tool for DCME users.

The DCME protocol analyzer is a PC-driven automated test scenario generation and monitoring system that is programmed by the operator to precisely load the DCME input trunks with known channel activity, monitor the assignment message channel (AMC), and confirm proper output trunk connectivity at the DCME receiver. As shown in Figure 4, the DCME protocol analyzer consists of the following functional blocks:

- bearer interface unit (BIU)
- PC control unit
- channel activity simulator
- primary multiplex analyzer.

The BIU interfaces with the DCME at its standard 2.048-Mbit/s bearer ports and allows the operator real-time access to the assignment messages carried in the DCME encoder AMC. The BIU may be programmed to trigger on specific assignment messages and either store them for subsequent analysis or modify them to initiate specific DCME decoder responses. The BIU may also be programmed to generate known AMC patterns for testing the DCME decoder under isolated conditions.

Future plans include transfer of this technology to a special-purpose test instrument manufacturing company.

Modified NTSC/PAL Video Processor Testing

As reported in the *1987 COMSAT Laboratories Annual Report*, a modified NTSC/PAL video processor has been developed by COMSAT Laboratories. In this equipment, digital techniques enhance the performance of INTELSAT half-transponder video transmissions. Modified NTSC/PAL video signals can maintain video synchronization at very low receive carrier-to-noise (C/N) ratios (e.g., -3 dB). The modified NTSC/PAL processor can also support a single high-rate digital channel (~2 Mbit/s for NTSC, ~1 Mbit/s for PAL), and four or eight high-quality digital audio channels for PAL or NTSC, respectively.

In 1988, the video performance of the modified NTSC/PAL processor was measured in the laboratory for an IF loopback and a nonlinear channel configuration. A 17.5-MHz channel was used for the IF loopback testing, and two adjacent 17.5-MHz channels in a 41-MHz hardware-simulated satellite transponder were used for nonlinear channel testing. The nonlinear channel operating parameters were those specified for standard INTELSAT half-transponder video signals.

In general, the modified NTSC signal exhibited performance that was objectively superior to that of the modified PAL. The nonlinear channel results showed increased degradation relative to the IF loopback case, as expected. The peak video deviation during these measurements was equivalent to that for standard INTELSAT half-transponder video, and therefore the unweighted video S/N ratio was equivalent to that of a standard INTELSAT half-transponder video signal. For the nonlinear channel configuration, objective measurements of video crosstalk from one modified NTSC carrier to another showed that this crosstalk level is no worse than that for standard INTELSAT half-transponder NTSC carriers.

COMSAT NONJURISDICTIONAL DEVELOPMENT

Mobile Gateway Earth Station Technology

This project was initiated in 1988 to develop the hardware technology for mobile satellite communications networks with earth stations as gateways between mobile users and a central mobile network operations center. The hardware will reside at the gateway earth station and function as the data collection and transmitting terminal that communicates with the geographically distributed mobile terminals at 600 and 1,200 bit/s.

The technology development addresses technical problems associated with the signaling and message channel packet formats. The major technological challenges under severely adverse conditions are as follows:

- the preambleless demodulator process for short signaling channel packets
- low operating E_s/N_o ratio

- large frequency offsets that exceed those of the symbol rate, Doppler frequency shifts, and multipath fading
- the message channel demodulation process under the same conditions but with variable packet sizes and a short acquisition preamble
- the complex signal processing functions associated with a distributed unique word and a variable interleaver size for the message channel.

During 1988, these problems were addressed by developing sophisticated simulation programs to evaluate the demodulation algorithms for the signaling and message channel demodulators. Hardware and software developed in 1988 included initial system design; IF up/down-conversion chains that interface the channel units with the earth station; and major segments of link processor software; link processor hardware for the signaling and message channels that perform scrambling, encoding, cyclic redundancy check (CRC), and interleaving functions.

Work scheduled for 1989 will include multiple DSP based hardware design and construction of the signaling and message demodulators, parameter optimization and software development to implement the demodulation algorithms, design and construction of the interfacing hardware to the system controller, and final integration and test.

Spread-Spectrum System Simulation Software

During 1988, studies of spread-spectrum (SS) communications systems have concentrated on modulation-coding tradeoffs and on development and test of flexible simulation facility software to evaluate the performance of SS systems. The simulator has been implemented as the SPREAD program that models either direct-sequence pseudonoise (DSPN) or frequency hopping (FH) signal formats. Figure 5 is a flowchart of the general structure of SPREAD. After generation, signals are operated on by conventional channel elements (filters, nonlinearities) and are available for corruption by interference or jamming, as shown in Figure 6, or for signal analysis to evaluate low-probability-of-intercept (LPI) designs. Algorithms are also available to introduce signal fading effects.

A final step in the simulation is correlation and demodulation to evaluate BER. Considerable effort was directed toward different receiver implementations for fast FH. Because of the extremely large time-bandwidth products that must be represented in the SS simulation, computer run time becomes a serious problem. Importance sampling, implemented as an option in the program, resulted in a significant saving in CPU time.

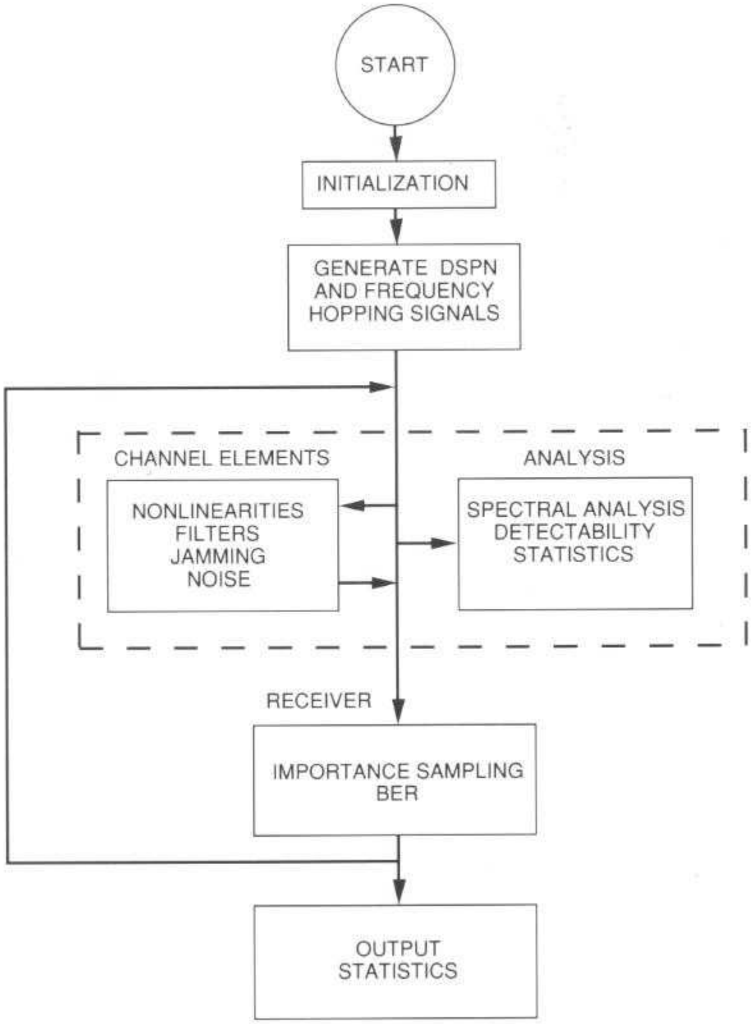


***Figure 5**. Flowchart for SPREAD simulation program*

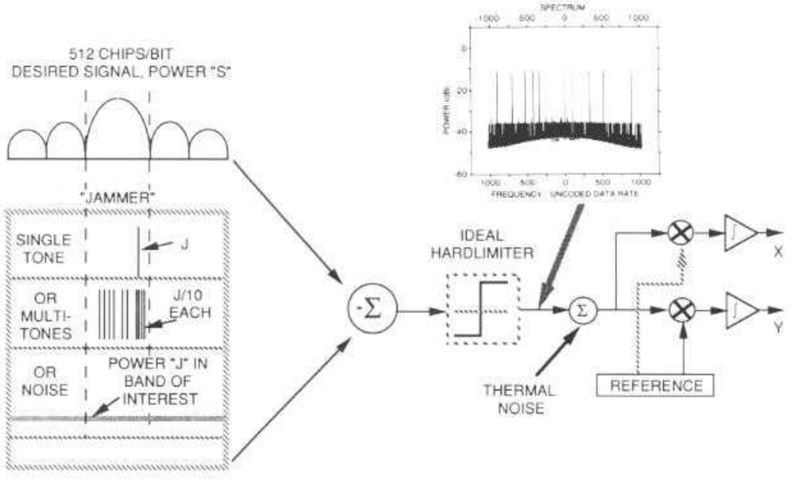


Figure 6. Test case for one DSPN signal with various jammers

Advanced Signal Processing

The continuing demand for increasingly faster communications and signal processing capabilities requires parallel processors that execute multiple operations simultaneously. A class of matrix processors well suited for performing multiple tasks was investigated. Discrete Fourier transforms, Viterbi decoders, and vector quantizers were examined, with emphasis on fault-tolerant algorithms and architectures.

The residue number system (RNS) was investigated because of its modularity due to its carry-free property, and the ease of incorporating fault tolerance in RNS-based systems.

Computer software was developed to emulate the function of several matrix processors and to study their dynamic range and precision requirements.

COMSAT SUPPORT

Standards Activities

COMSAT's standards activities support the development of standards and recommendations compatible with satellite communications systems operation. CTD activities focus primarily on three study groups of the CCITT: SG XII, Quality; SG XV, Transmission Systems; and SG XVIII, Networking. Lower level activities occur in SG VII, Data Transmission, and SG XI, Switching. The CCITT works on a 4-year cycle, and 1988 was the final year of the current study period.

The primary effort in SGXII involved improving Recommendation G.114 to relax constraints on mean one-way propagation time (MOPT). COMSAT successfully led the effort to remove the obsolete echo suppressor performance data from Annex A, and to add test results, produced by COMSAT, showing satisfactory subjective performance for circuits with 500-ms MOPT equipped with echo cancellers. The body of the recommendation was not changed, but a note was included indicating that circuits with MOPT greater than 400 ms may provide satisfactory service when echo cancellers are used on the circuits.

In SG XV, COMSAT held the Special Rapporteur chair and led the drafting of a functional recommendation on DCME (Recommendation G.763). The development of an equipment recommendation, based on INTELSAT Specification IESS-501, with sufficient detail to provide compatibility between different manufacturers' DCME is planned for the next study period.

In SG XVIII, COMSAT was influential in defining the mandatory and optional features of a 32-kbit/s DCME and helped to reduce its system complexity. In other areas, an interest in standardizing a 16-kbit/s algorithm has developed, and COMSAT's contributions have established it as a leading participant in this effort.

In SG VII, important work was accomplished in the area of data transmission quality of service (QOS), for which three new draft or modified recommendations were approved. Because of COMSAT's participation, these new or revised recommendations are compatible with satellite systems issues regarding delay and availability.

In U.S. Committee T1, COMSAT chairs the subgroup that is drafting a DCME specification. INTELSAT Specification IESS-501 for DCME was adopted as the basis for the T1Y1.2 Draft American National DCME Standard. Throughout 1988, the T1Y1.2 Committee conducted a detailed review of the draft DCME standard, which is expected to be submitted for letter ballot in early 1989.

Digital HDTV Transmission Over SBS Satellites

In the spring of 1988, COMSAT Laboratories tested and demonstrated the Canon DITS-120 TV codec, which provides high-definition television (HDTV) at 120 Mbit/s. In the satellite transmission demonstration (see Figure 7), two 60-Mbit/s modems transmitted a signal via a 4.5-m antenna at COMSAT Laboratories through two transponders in the SBS-III satellite for reception by the same antenna and display on a high-definition monitor. Objective tests of codec performance and loopback testing preceded this final demonstration.

Transmission of HDTV (1,125 lines, 60 Hz, and 2:1 field interlaced), with 20 MHz of luminance bandwidth, 6 MHz of chrominance bandwidth, and 8-bit PCM, requires approximately 650 Mbit/s. With digital processing, the DITS-120 codec achieves reductions of 20 percent by removing blanking intervals, 50 percent by line offset sampling, and another 50 percent by 4-bit differential PCM, resulting in a bit rate of 120 to 140 Mbit/s. Such bit rates are compatible with QPSK transmission in the 72-MHz satellite transponders available on INTELSAT satellites, but require more than one transponder in most U.S. domestic satellites.

For the experiment, the Laboratories constructed the necessary 2:1 demultiplexer/multiplexer and timing skew compensator to interface a pair of 60-Mbit/s modems to the 120-Mbit/s video codec. Because of the very effective error correction/detection coding within the DITS-120 codec, an impairment-free picture was transmitted via satellite as long as the received BER was less than 10^{-4}. This robust transmission format required some compromise in picture quality to achieve the 120-Mbit/s transmission rate. The technique has possible application, for example, for private network transmission of HDTV as an alternative to conventional FM/TV transmission, such as COMSAT Video Enterprises' distribution system.

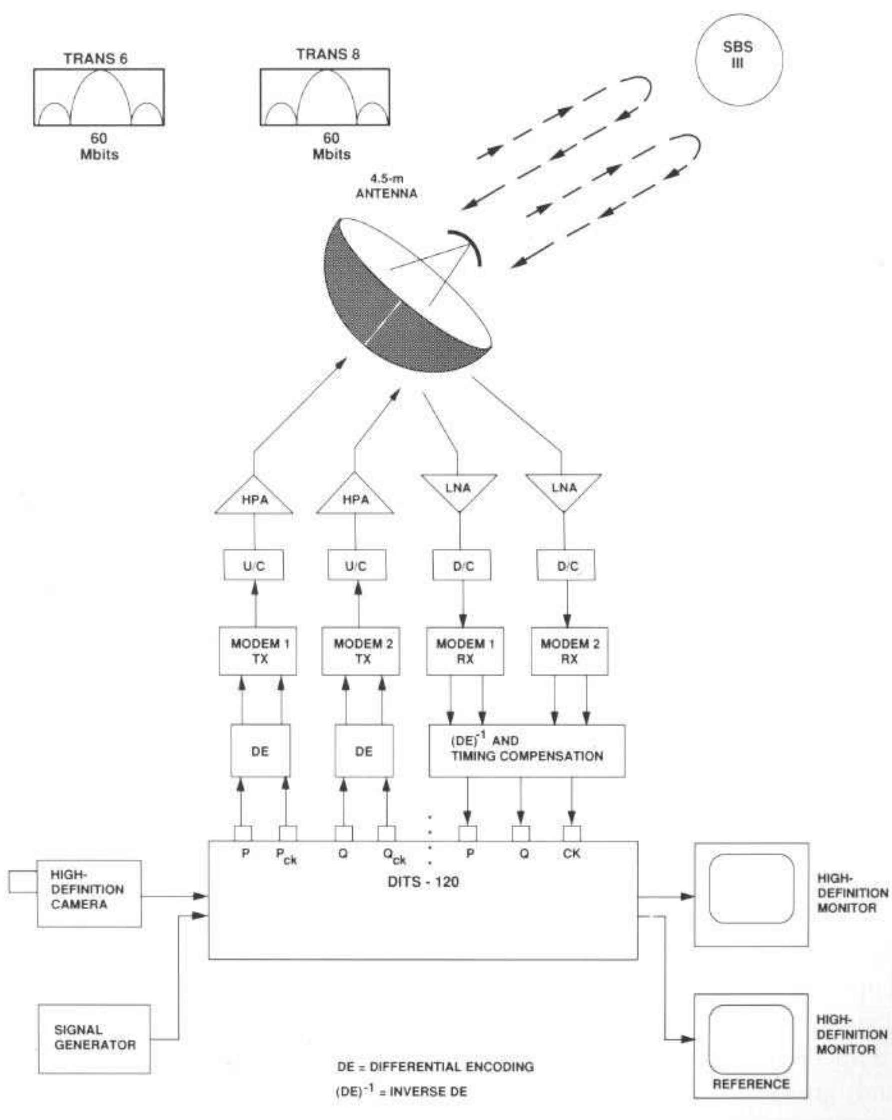


Figure 7. Satellite transmission demonstration

International Satellite ISDN Demonstrations

In 1988, support was provided to the World Systems Division (WSD) for ISDN demonstrations via international satellites. Demonstrations were held at the INTELSAT Global Traffic Meeting (May 4-6) and the Expo China 1988 Trade Fair in Beijing, Peoples Republic of China (October 27-31).

The ISDN switch and associated applications—digital telephony, computer file transfer, facsimile, slow-scan television, and color picture telephone—were located in the lobby of INTELSAT headquarters in Washington, D.C., the site of the Global Traffic Meeting. The switch worked with a host exchange located in Liverpool, U.K. Access to the INTELSAT V 307°E spacecraft was accomplished with a transportable Ku-band earth station located at INTELSAT headquarters, and via the London teleport, with a terrestrial connection between London and Liverpool. This demonstration included the first intercontinental ISDN-compatible color picture telephone.

For the demonstration that supported the Expo China 1988 Trade Fair, the ISDN switch was located at COMSAT headquarters at L'Enfant Plaza in Washington, D.C. COMSAT also provided a node of the network located at the trade fair in Beijing. This demonstration was the first double-hop configuration. The digital telephony, computer file transfer, facsimile, and slow-scan video all performed properly despite extra delay due to the double-hop satellite configuration. Figure 8 is a schematic diagram of the network configuration for this demonstration.

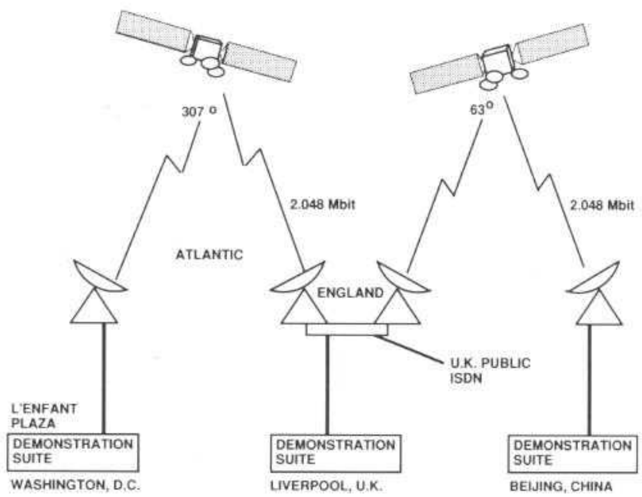


***Figure 8**. Global ISDN demonstration network*

U.S. Armed Forces Radio and Television Service

The U.S. Armed Forces Radio and Television Service (AFRTS) has been distributing radio programming to U.S. forces at sea and in remote land locations by means of the INMARSAT system. To provide satisfactory service to AFRTS receive-only stations, the receive signal was required to remain within 200 Hz of its assigned frequency. This requirement, combined with increased transmitter frequency stability, relaxed the receive-only station stability and frequency tracking specifications, considerably lowering the unit cost of these stations.

To meet the receive frequency stability requirement through the INMARSAT system, COMSAT Maritime Services modified its two coastal earth stations (CESs). COMSAT Laboratories' involvement in this modification consisted of the design, development, and installation of an automatic frequency control (AFC) system that provided frequency stability by controlling the frequency output of the AFRTS up-link. Figure 9 is a block diagram of this system.

The AFRTS signal from the satellite is received at the CES and is input to an INMARSAT Standard-A receiver. The frequency of the Standard-A receiver IF output is measured by a frequency counter and monitored by the microprocessor-based AFRTS AFC system controller. When the controller determines that the AFRTS receive frequency has exceeded some preset error limit, it commands the frequency synthesizer to move to a new frequency.

The frequency synthesizer output drives the AFRTS transmit up-converter and hence controls the AFRTS transmit frequency. The magnitude of the receive frequency error is reduced by this adjustment of the AFRTS transmit frequency.

The COMSAT CES serving the Pacific Ocean Region (POR) was modified during the last quarter of 1988. Since then, AFRTS has been successfully using the INMARSAT system to distribute its programming to receive-only stations in the POR. The COMSAT CES serving the Atlantic Ocean Region (AOR) will receive the same modification during the second quarter of 1989.

Inclined-Orbit Satellite TV Receive-Only Demonstration for the National Association of Broadcasters Convention

In April 1988, during the National Association of Broadcasters (NAB) Convention, CTD supported

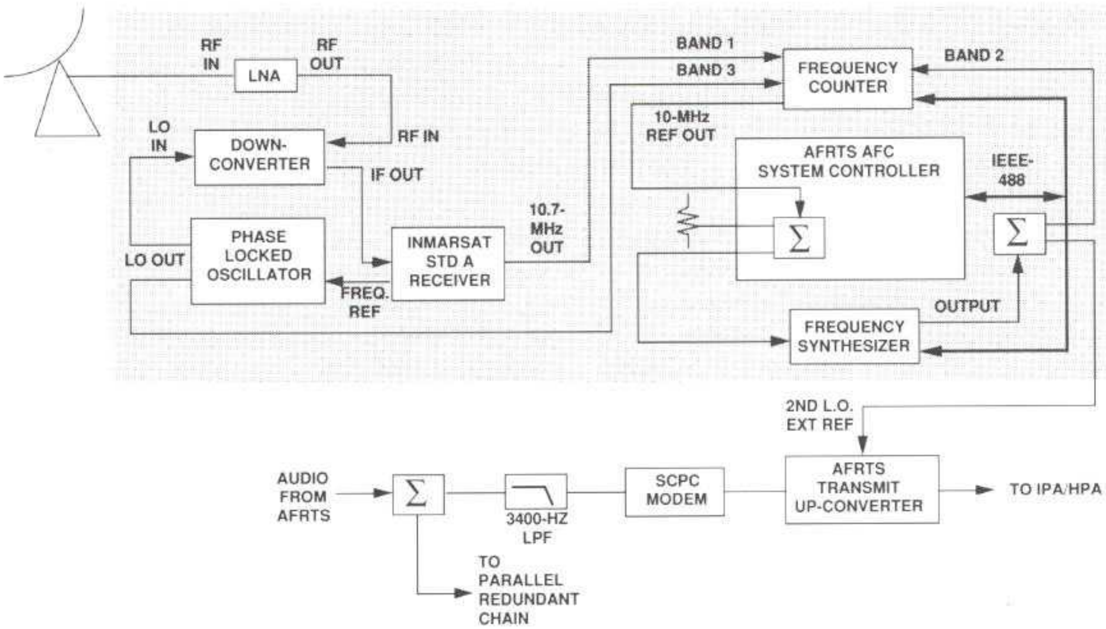


***Figure 9**. AFRTS AFC system block diagram*

COMSAT's WSD in demonstrating TV transmission via an inclined-orbit satellite. This demonstration, conducted with the Australian Overseas Telecommunications Corporation, used the INTELSAT IV-A spacecraft located at 177°E over the Pacific Ocean. The transmission originated from an earth station in Perth, Australia, and was received at the NAB Convention by an earth station in the parking lot of the Las Vegas Convention Center. Program tracking updated the position of the antenna every 15 minutes and tracked the spacecraft, which moved ±3° every 24 hours. A fiber optic cable carried the received signal from the parking lot to the COMSAT display within the Convention Center.

The transmission had the following INTELSAT full-transponder parameter values for NTSC transmission: 4.2-MHz top baseband frequency, 10.75-MHz peak video deviation, and single 6.6-MHz audio subcarrier. The received video had a 51-dB ratio of peak-to-peak luminance to rms-weighted noise. No impulsive noise was encountered in either the video or the audio, and no degradation due to satellite motion or pointing errors was detected. Figure 10 is a photograph of the earth station in use during the convention.

***Figure 10**. Earth station in use during NAB Convention*

Wireless Local Interconnect Systems for Satellite Transmission

Satellites provide a cost-effective means of establishing communications with remote locations. Furthermore, if the end users are not located at the earth station site and if there is no local telephone system, a wireless local interconnect system may be more practical than a conventional wireline system in terms of both cost and installation time.

A study was undertaken for ISS to determine the design and cost of wireless local communications systems connected to the outside world by satellite. Information was gathered on the characteristics and costs of currently available local wireless and satellite transmission systems, primarily in terms of the costs of using available equipment and services. Network considerations were briefly investigated.

Potential applications for this type of system include private networks for which government or commercial organizations need to rapidly establish communications in a remote area; thin-route public communications systems in remote areas; and centralized switching and control services for small regional cellular systems.

Although cellular mobile technology was satisfactory for some local interconnect systems, two-way radio and rural radio telephony systems were more appropriate for certain system requirements. Eight wireless systems were compared. In some cases, specific technical requirements dictated a preference for a particular system, but in general the preferred system depended on the size of subscriber pool it served.

Because it is likely that a regional wireless communications system will require only 1 to 12 circuits, small earth stations are suitable. Much of the satellite transmission data in this study was based on the INTELSAT VISTA service, which is designed for low-density traffic systems, uses small earth stations, and is currently operational.

Results of the study led to technical and cost guidelines for wireless local communications systems and the satellite systems that serve them.

INTELSAT AND INMARSAT

Architecture Study for Processing Payloads

In this recently completed INTELSAT-sponsored study, the application of on-board processing technology in the INTELSAT system was considered as a means of increasing system flexibility and reducing the overall service cost to the INTELSAT user. The study, a joint effort of CTD and the Network Technology Division (NTD), provides an updated assessment of the potential benefits of on-board processing based on technological forecasts and traffic projections for the 1990s.

To accurately assess the overall benefits that may be derived by introducing on-board processing technology in the INTELSAT system, the study begins by examining projected INTELSAT traffic requirements up to year 2000. On the basis of these requirements, several candidate satellite system concepts are initially defined. Three concepts are selected for further definition and analysis: an INTELSAT VI satellite (Concept 1), an INTELSAT V satellite (Concept 2), and a multi-spot-beam satellite with 13 spot beams at C-band and 53 spot beams at Ku-band (Concept 3). Within this framework, several baseband processing architectures are defined for the following on-board processing elements: carrier demultiplexing, demodulation, decoding, baseband demultiplexing, baseband switching, baseband remultiplexing and reformatting (rate conversion), recoding, and remodulation.

Transmission analyses and link budget tradeoffs are performed to analyze effects of on-board regeneration parametrically and to optimize transmission parameters for the candidate satellite system concepts. Baseband processing architectures for each concept are then defined to a level that shows the major components of the design. Detailed description of the technology needed to implement each major component of the on-board baseband processor is provided. Current and forecast statuses of the technology for such major components as demultiplexers, demodulators, baseband switches, and on-board buffers are examined.

Detailed cost-benefit analysis of these concepts and technologies, for both space and earth segments, indicates the following:

a. Detailed link analysis demonstrates that on-board regeneration results in substantial savings in satellite power, earth station gain-to-noise temperature ratio (G/T), and high-power amplifier (HPA) power.

b. The cost of adding on-board processing (OBP) components to a satellite payload is nearly offset by the cost savings derived from the inclusion of on-board regeneration to reduce satellite transmit power.

c. Although on-board processing in itself does not lead to significant reductions in spacecraft cost, the increased flexibility it allows creates appreciable ground segment cost savings. This is most pronounced for services such as INTELSAT's IDR and IBS, with frequency-division multiple access (FDMA) transmission in which each station in the network can operate single transmit and receive carriers. For time-division multiple access (TDMA), the benefits of on-board processing include simplification of TDMA equipment through elimination of frequency hopping and multiple-burst transmissions. Increased space segment capacity is derived by reducing the number of bursts per frame (and associated guard times and preambles).

d. On-board processing with rate conversion permits efficient and cost-effective interconnection of diverse earth station types. Thus earth stations can be designed and optimized according to their own traffic requirements rather than those of their correspondents.

e. When multi-spot beams are used with on-board processing as in Concept 3, there is a significant reduction in space segment cost relative to Concepts 1 and 2, which use more conventional beam coverage patterns.

Figure 11 shows potential savings in total link (space and earth segment) cost, derivable from on-board processing. The substantial savings achieved with Concepts 1 and 2 (OBP-1 AND OBP-2) compared with the non-processing satellite are primarily due to earth station cost reduction. The additional savings shown for Concept 3 (OBP-3) include space segment cost savings derived from multispot beam coverage.

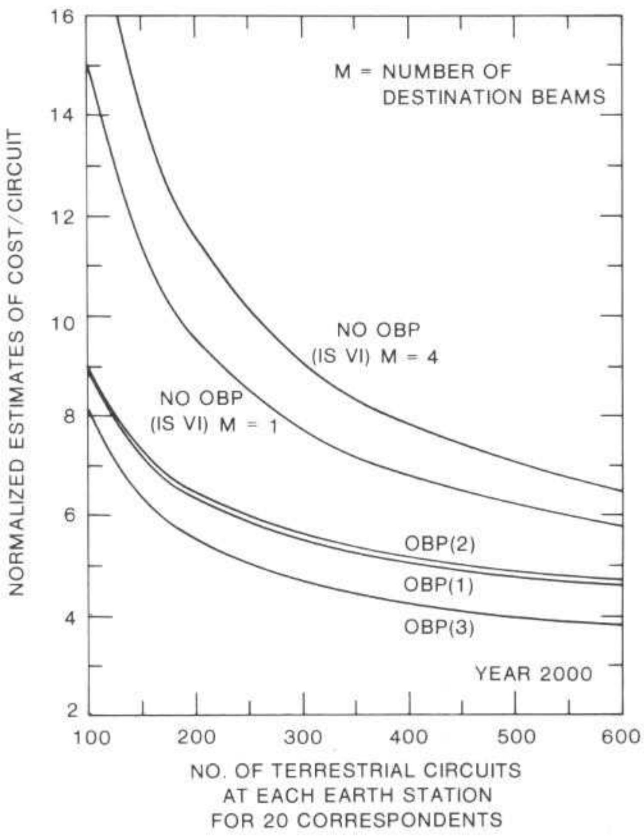


Figure 11. *Example of link cost estimates for IDR system using F-3 earth stations*

On-board Multicarrier Digital Demultiplexer Study

Under INMARSAT contract, COMSAT Laboratories performed a study of on-board multicarrier digital demultiplexing for INMARSAT's third-generation satellites. The proposed demultiplexer will process signals in both forward (ship-to-shore) and return (shore-to-ship) directions for a possible third-generation satellite with spot-beam coverages at L-band, while complying with the following INMARSAT specifications: Standard-B4 channel, 20-kHz channel spacing, offset QPSK modulation, 24-kbit/s transmission rate, 6-MHz available bandwidth, and 12 spot beams. The baseline architecture demultiplexes a 6-MHz band into 300 20-kHz slots.

The transponder configuration achieves flexibility in bandwidth allocation while minimizing spectrum losses due to guard band. In the forward direction, the processor rearranges the arriving carriers, by assigned frequency slots, into destination beam groupings. In the return direction, the processor eliminates all bands for which no carrier is present and collapses the 12 partially filled spectra into a single 6-MHz band.

A total power of 190 W and mass of 75 lb are estimated using 1988 technology for forward and return links. To further reduce power dissipation, the total processed bandwidth, number of beams, and maximum capacity of each beam may be scaled down. For 1990, radiation-hardened CMOS and CMOS/SOS (silicon on sapphire) are the most appropriate technology choices. ASICs will be necessary for power conservation.

By analysis and computer simulation, the feasibility of on-board digital multicarrier demultiplexers was demonstrated for INMARSAT's third-generation satellites.

Analytical formulas and simulations determined the design parameters. Implementation with FFT methods combined computational efficiency and operational flexibility. Figure 12 is a block diagram of the forward link signal processor; Figure 13 shows the FFT pipeline (the central part of the overall processor).

(APC) and a 1-kbit/s signaling channel data stream are rate 3/4 encoded and multiplexed with dummy bits to form an 80-ms frame. Offset QPSK modulation at a 24-kbit/s modulation data rate is used for burst (voice-activated) and continuous modes. A new preamble length was defined for the voice-activated burst mode. The pro-

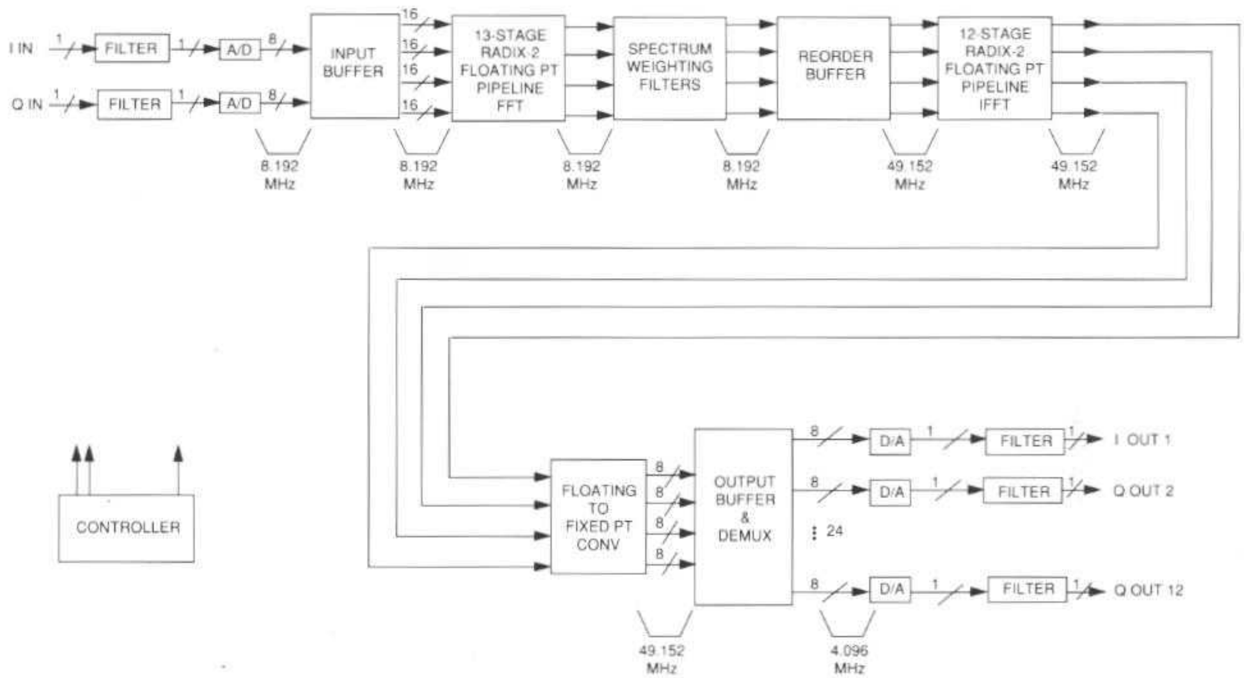


Figure 12. Forward link signal processor

INMARSAT Standard-B Test Bed

During 1985-1987, COMSAT Laboratories designed and constructed a versatile test bed communications subsystem for INMARSAT Standard-B and aeronautical modes. The test bed was successfully tested under additive white Gaussian noise (AWGN), adjacent channel interference (ACI), and multipath fading conditions. During 1988, existing discrete logic-based transmit and receive frame synchronizers in the CES drawer, originally developed for the Standard-B mode, were replaced with new microprocessor-based (Zilog Super8 and Texas Instruments TMS32010) frame synchronizers that implemented the Standard-B voice channel format.

Figure 14 is a photograph of the completed unit. A 16-kbit/s voice stream with adaptive predictive coding grammable 24-kbit/s offset QPSK modem, Viterbi decoder, and up/down-converters with wideband AGC remain as before, with minor changes in the demodulator software for the new preamble.

To assist INMARSAT in evaluating the performance of the new 80-ms voice frame format for burst and continuous modes, special test mode formats were implemented in the frame synchronizers to provide measurement data for the following:

- miss and false detection probabilities of the unique word, framing bit, and end-of-data patterns, including a test feature limiting searches to the 0° pattern
- burst detection probabilities and mean time to cycle slip

- cyclic redundancy check miss and false detections to evaluate packet error performance for the 80-bit signaling channel packet unit in each 80-ms frame
- frame reacquisition times after a sustained loss of signal.

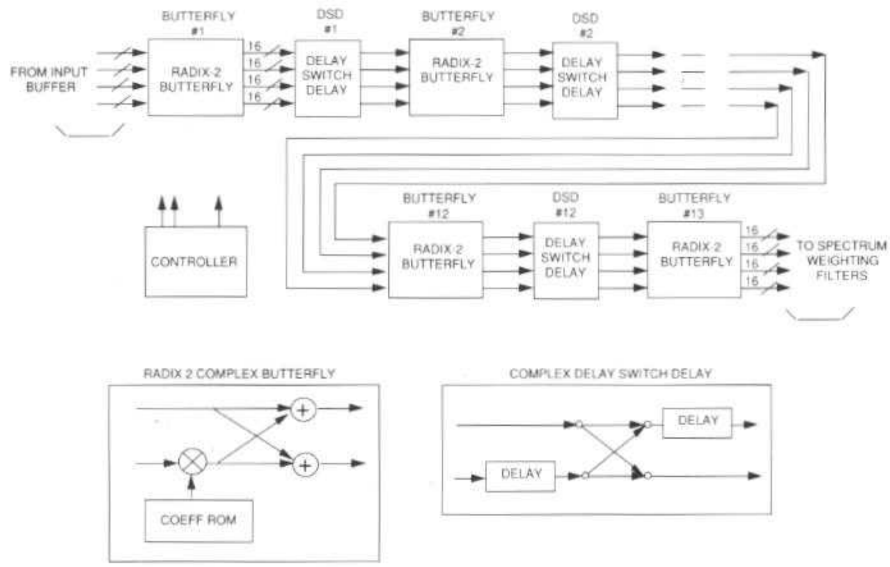


Figure 13. FFT processor

Test results show that the BER and miss and false probability data are in good agreement with theory, with insignificant degradations at the specified frequency offsets of ±1 kHz. The uncoded and rate 3/4 coded BER performance curves are shown in Figure 15. Subjective burst and continuous-mode voice code performance with an INMARSAT-supplied 16-kbit APC vocoder was also satisfactory. The modified CES drawer has already passed the in-plant and final acceptance tests. The modified Standard-B test bed communications subsystem hardware has been delivered to INMARSAT.

INMARSAT Standard-B Facsimile Interface Units

In 1988, a contract was awarded to COMSAT to study an approach for accommodating Group 3 facsimile traffic via the INMARSAT Standard B 16-kbit/s digital channel. COMSAT considered an approach whereby the analog facsimile signals would be intercepted, demodulated, and carried in the baseband at 9.6-kbit/s net transmission rate. Channel dedicated facsimile interface units (FIUs) located at the CESs and SESs would perform these processes.

The concepts incorporated in this study permit facsimile communication between equipment conforming to CCITT Recommendation T.30 with intervening real-time demodulation/remodulation of the facsimile signals. Special techniques allow each FIU to interpret the nature of all facsimile signals, issue separate responses to transmitting facsimile terminals, and dynamically determine and introduce signal-dependent transmission delays in order to preserve the tight timing relationship between facsimile signal pairs encoded according to the same or different modulation schemes. Such a real-time approach enabled the extension of communications to circuits with one-way propagation delays up to 920 ms, and the enhancement of Group 3 capability to broadcast messages to ship-based terminals by means of terrestrially based facsimile equipment.

Time-Multiplexed Analog TV

The time-multiplexed analog TV (TMATV) technology was initially reported in the *1985 COMSAT Laboratories Annual Report* and later in the *1987 Annual Report*. In 1988, a TMATV demonstration unit (Figure 16) was completed under an INTELSAT contract. By reducing the diagonal resolution of the TV signals and introducing time multiplexing, the unit was capable of transmitting three TV signals and six program audio signals through a single 36-MHz satellite transponder, as opposed to only two television signals with conventional methods. Although only one video channel and two audio channels were fully implemented, the unit demonstrated the signal quality achievable with the

TMATV technique for all three channels with a 36- or 40-MHz transponder. When the IF carrier at the FM modulator output was gated on only during active signal transmission, the unit also successfully simulated the receiver burst acquisition of TMATV signals from multiple uplinks transmitted in TDMA mode.

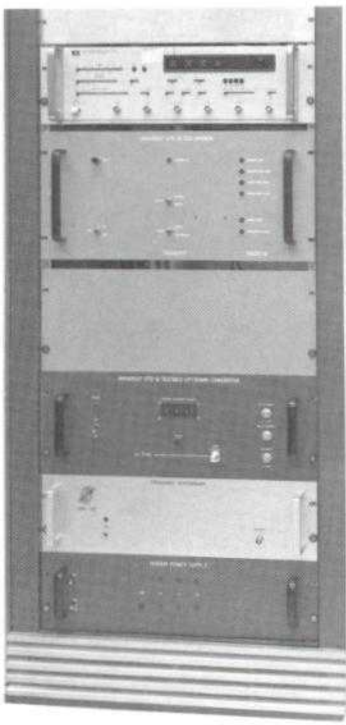


Figure 14. Modified CES drawer with existing Standard-B test bed components

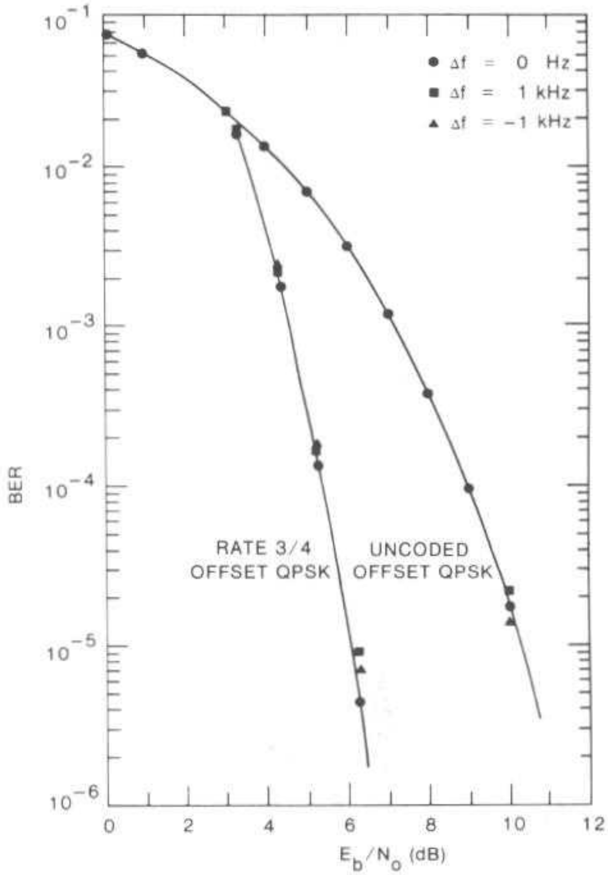


Figure 15. Measured continuous-mode BER performance with the modified CES drawer

An informal subjective evaluation of TMATV performance was conducted. The video and audio signals before TMATV transmission were the reference, while the signals after TMATV processing at the receive side were evaluated at normal viewing distance, with the IF loop simulating the satellite link. When compared with the unprocessed reference signal under normal operation in the CCIR five-grade scale, both video and audio signal degradation were rated between imperceptible and barely perceptible.

The video signal was also compared against a signal transmitted through another IF loop simulating the INTELSAT half-transponder TV. The TMATV signal was rated consistently better than the half-transponder TV, particularly during severe fading.

OTHER

NASA Advanced Modem/Codec Technology Development

To advance the state-of-the-art bandwidth and power efficiency of digital transmission via satellite, COMSAT developed two POC models of FEC decoders at an information rate of 200 Mbit/s under contract to the NASA Lewis Research Center. The decoders are intended for use in a combined trellis-coded modulation system that uses 16-quadrature amplitude modulation (QAM) and rate 3/4 convolutional code for the up-link (satellite), and 8-PSK modulation and time-varying rate 8/9 convolutional code for the down-link (earth station). A bandwidth efficiency of more than 2 bit/s/Hz is achieved in both links. The up/down-link decoders were both constructed and partially tested during 1987.

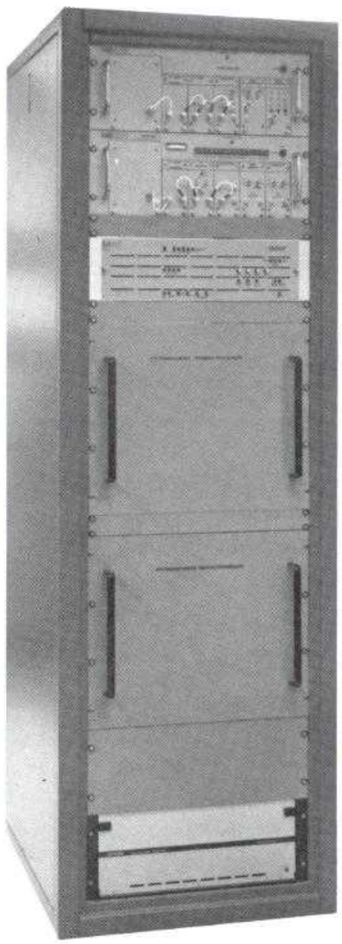


Figure 16. TMATV demonstration unit

During 1988, performance testing of these decoders at the 200-Mbit/s information rate was completed in a back-to-back, noise-free environment and over a digital AWGN channel. To measure performance over the AWGN channel, COMSAT developed a special test set that operates at the full symbol rate (Figure 17) and generates quantized AWGN noise samples which closely match the effect of AWGN in an ideal modem. The test set includes a symbol-mapping function, the digital AWGN generator, and a digital signal combiner. The symbol-mapping function replaces the modem function in the actual channel by mapping encoded symbols into the associated coordinates in the in-phase and quadrature (I, Q) phase plane. The digital AWGN generator consists of PN sequence generators whose outputs form the addresses of two independent AWGN memories, one for each coordinate in the phase plane. The memory contents are loaded off-line with AWGN vectors at the desired ratio of energy per information bit to one-sided noise spectral density E_b/N_o.

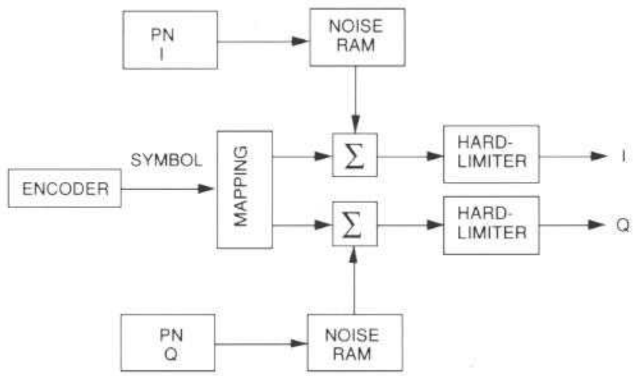


Figure 17. Block diagram of the self-test board

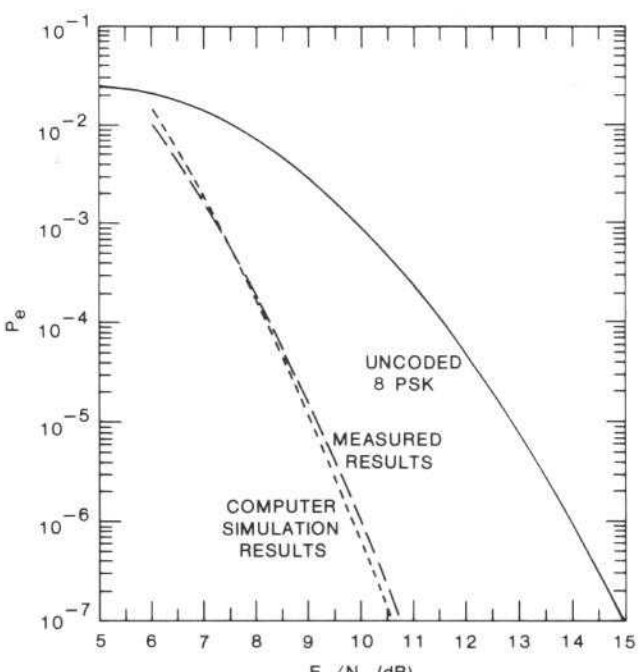


Figure 18. Rate 3/4 code AWGN curves

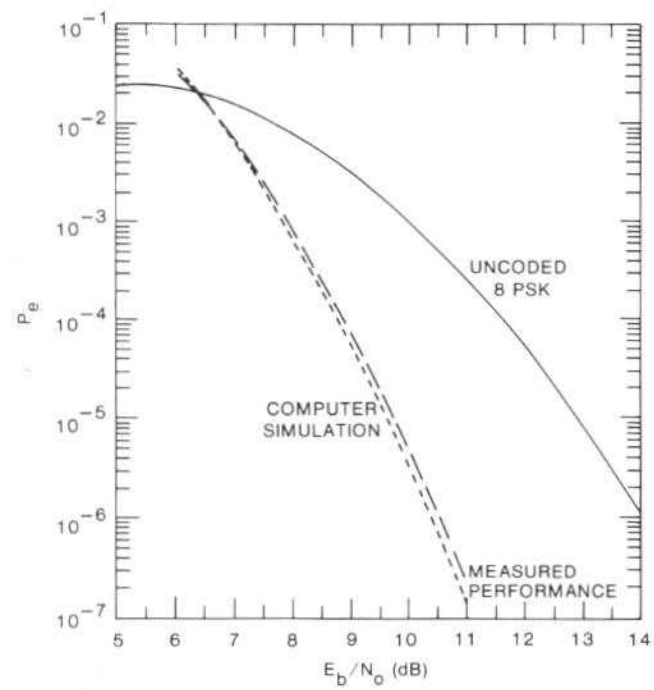


Figure 19. *Rate 8/9 code AWGN curves*

Figures 18 and 19 show the measured BER performance of the rate 3/4 and rate 8/9 Viterbi decoders, respectively. As shown in Figure 18, the rate 3/4 convolutional codec is capable of providing a BER of 10^{-6} at an E_b/N_o of 10 dB. This compares favorably with uncoded ideal 8PSK, which requires approximately 14 dB to give the same error rate performance. Similarly, Figure 19 shows that the rate 8/9 time-varying code provides a BER of 10^{-6} at an E_b/N_o of 10.6 dB.

To demonstrate the coded system performance of the rate 8/9 codec, COMSAT has developed an 8-PSK burst mode modem also under contract for NASA Lewis Research Center. This modem allows complete characterization of the coded modulation system operating at a bit rate of 160 Mbit/s in burst mode.

The modem design, fabrication, testing, and development of special test equipment for overall system operation have been completed. Measured BER performance of the 8-PSK modem is shown in Figure 20 for both continuous and worst-case burst modes. After integration of the modem and codec in 1989, performance testing of the completed system will be conducted and the results compared to those achieved using the digital noise test set.

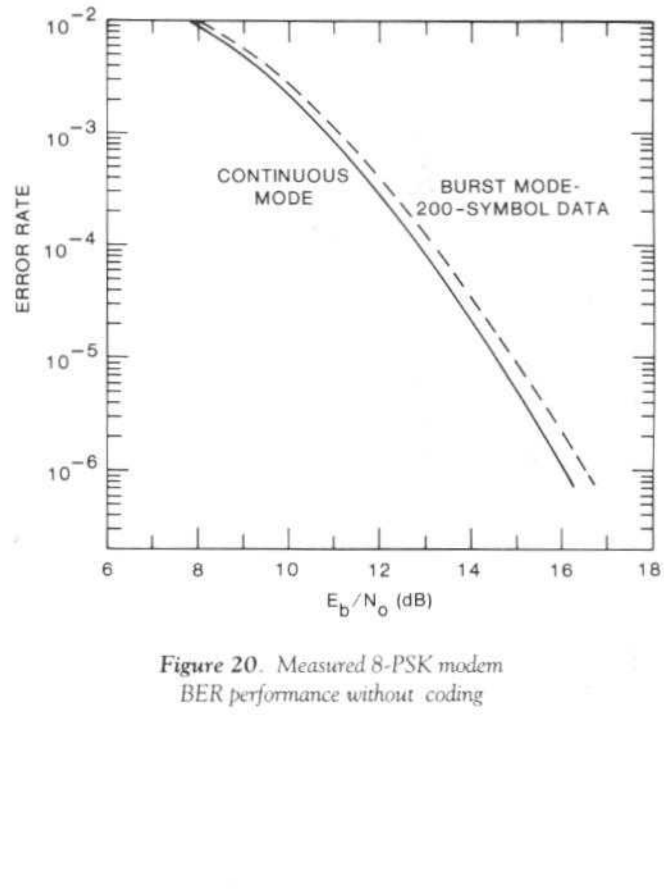


Figure 20. *Measured 8-PSK modem BER performance without coding*

The Network Technology Division (NTD) conducts research and development activities and provides technical support in various facets of networking, from the design and system architecture of networks to the detailed development and implementation of relevant software and hardware components. For several years, NTD has been at the forefront of developing and applying hardware and software technology and expert system technology to communications networks. During 1988, various satellite, data communications, fiber optic, and integrated services digital networks (ISDN) were investigated. For satellite networks, architectural alternatives for the design of an on-board baseband switch, along with detailed implementation tradeoffs, on-board processing architectures, and network control strategies such as synchronization of digital intersatellite links (ISLs), were investigated. Other significant efforts in 1988 included modifying data communications protocols, implementing them over satellite links, and obtaining U.S. support to incorporate these changes in the International Standards, thus ensuring the development of satellite-compatible ISDN standards. Other activities included conducting an international packet switching experiment, applying expert systems to network control, developing a network management facility for TCP/IP networks, completing key enhancements to NTD's COSMOS operating system, developing a software simulation test-bed for large mixed-media networks, studying network security architectures, and developing a fiber-optic-based intelligent building network. Support was also provided to COMSAT's Maritime Services for aeronautical services.

COMSAT JURISDICTIONAL R&D

Joint COMSAT/NIST OSI Protocol Experiments

The International Standards Organization (ISO) has developed an international standard reference model of open systems interconnection (OSI), as a basis for coordinating standards development for systems interconnection, while allowing existing standards to be placed in perspective within the overall reference model.

Since 1983, COMSAT and the National Institute of Standards and Technology (NIST, formerly the National Bureau of Standards) have conducted a joint program to examine, implement, and test the performance of high-level data communications protocols over satellites links. The investigation first analyzes the relevant protocols and then identifies the parameters and procedures that affect the efficient operation of the protocols over satellite links for different range of transmission speeds and bit error rates. Next, the protocols and any necessary modifications are implemented and tested in the laboratory. Finally, a joint satellite experiment is conducted with NIST, and the results are presented to national and international standards organizations for appropriate modifications of the protocols.

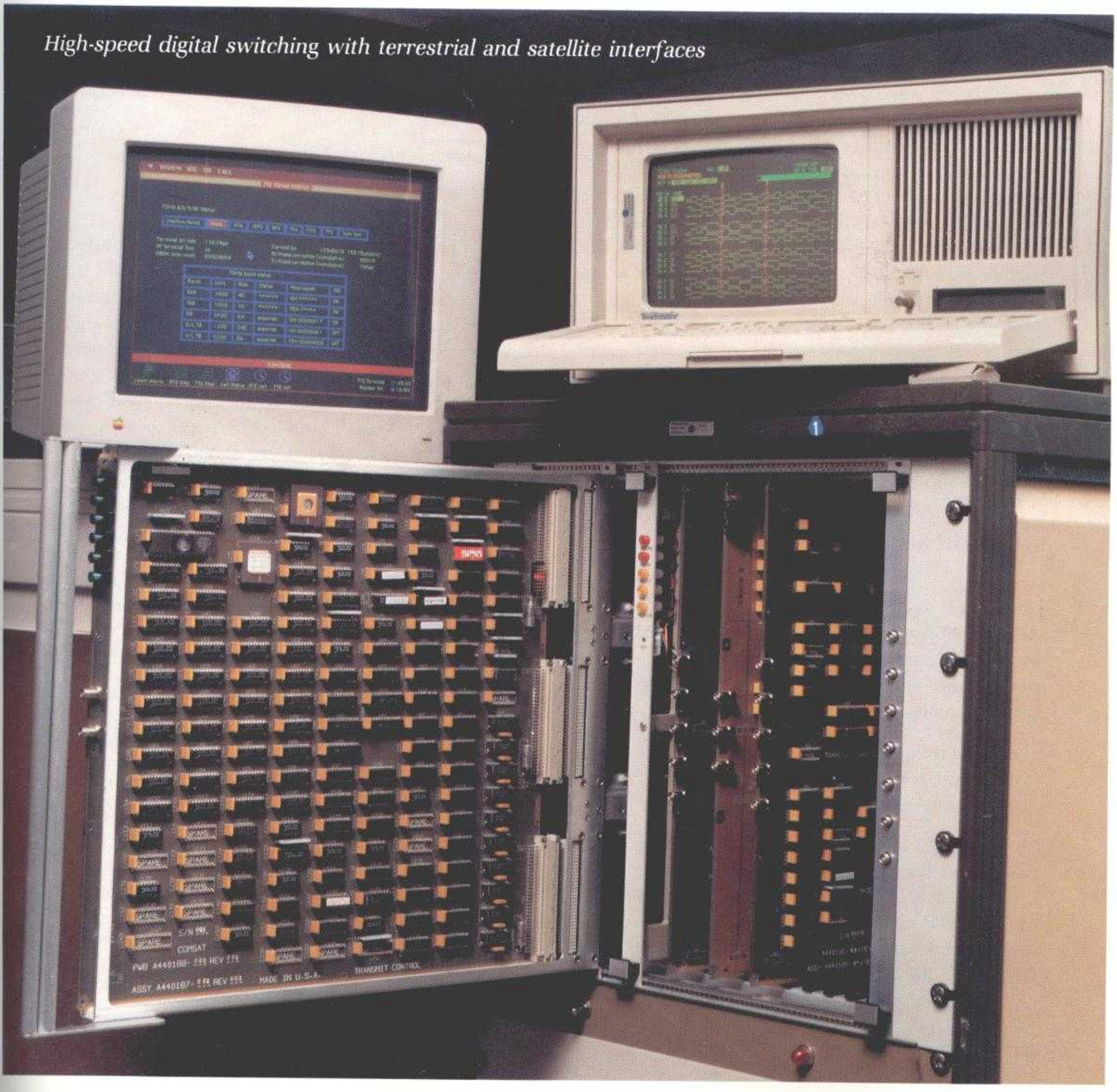
Experiments completed in 1985, 1986, and 1987 by the NTD concerned transport protocol class 4 (TP-4), connectionless network protocol (CLNP), session protocol, and message handling system (X.400) protocols. All relevant modifications to TP-4 are being considered by various subcommittees (ANSI X3S3 and ISO JTC1/SC6) for incorporation in the next release of TP-4 standards.

During 1988, the file transfer, access, and management (FTAM) protocol was investigated. The FTAM protocol enables users to transfer, access, and manage files. The basic protocol supports these file services by means of the association control service element (ACSE) and presentation services.

Although the FTAM protocol is designed with the assumption that the underlying service is reliable, it requires confirmations before proceeding from step to step. For example, opening a file successfully is necessary before reading or writing. Because some confirmations are not necessary (or can be grouped), a new optional enhancement was introduced that reduces the number of confirmation steps in the current file transfer procedure. This procedure considerably decreases the delays associated with operation of FTAM over satellite links.

Specific modifications to FTAM protocols, supported by detailed experimental results, were prepared for presentation to the appropriate subcommittees (ANSI X3T5.5 and X3T5).

NETWORK TECHNOLOGY



High-speed digital switching with terrestrial and satellite interfaces

On-Board Baseband Processor Switching

When used on board the satellite in conjunction with other on-board processing functions such as carrier demultiplexing, demodulation, decoding, and baseband demultiplexing, baseband switching can provide enhanced service capability and flexibility to reduce earth station complexity and cost. In addition, when on-board switching is coupled with multiple spot beams, it can provide interbeam carrier and channel routing in a system architecture which is efficient in terms of the spacecraft mass and power. This in turn can lead to lower spacecraft and launch vehicle costs.

NTD has studied various functional requirements and hardware design alternatives needed to provide such switching on board the satellite. Baseband processing architectures including time-space-time, time-space, space-time, and unified memory switch architectures were studied to determine their compatibility with various system functional requirements (mass, power, size, and device technology). Figure 1 shows four system architectures which compare circuit switching against various implementations of packet switching. Each packet implementation switch shown impacts the relative complexity of the earth station and/or the satellite design. Selection of the on-board switch functions, architectures, and mass/power cost tradeoffs will be completed in 1989 prior to the implementation of the on-board baseband processor switch.

Quality of Service for Packet Connections

CCITT Recommendations X.134 through X.137 define performance objectives for international packet-switched data services. Recommendation X.135 defines performance objectives for three primary data communications functions:

- call setup and call clearing delay
- data packet transfer delay
- throughput capacity.

In 1987, NTD measured the quality of service (QOS) parameters for a national packet-switching network operating via satellite circuits. In continuing that effort in 1988, NTD measured QOS parameters over an international link with two 9.6-kbit/s satellite circuits on the INTELSAT 335.5°E satellite. Other participants were AT&T, Deutsche Bundespost, and INTELSAT. The packet-switching networks for the experiment were the ACCUNET network in the U.S. and the DATEX-P network in West Germany. The experiment was conducted for both one-hop and two-hop scenarios. Figure 2 shows the one-hop configuration. Experimental results demonstrated that satellites can be efficiently used for providing international data services. A CCITT contribution based on the experiment showed that the performance of international packet-switching links that included satellite links is well within the requirements of Recommendation X.135. Results for the throughput and delay tests are shown in Tables 1 and 2, along with the requirements specified in Recommendation X.135.

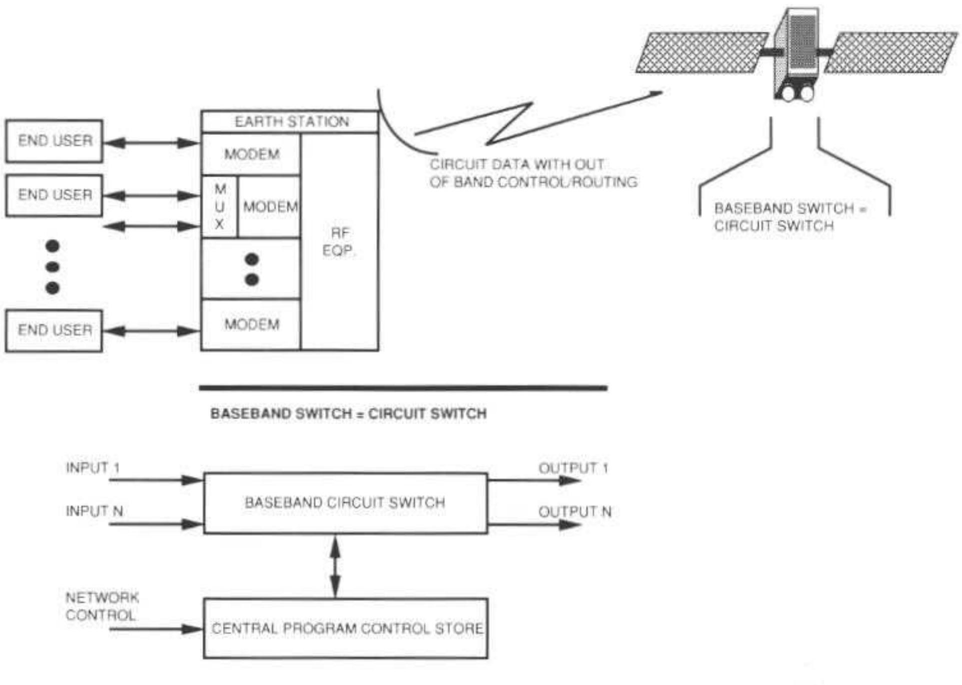
Local Area Network Interconnection by Satellites

NTD has investigated the use of satellites for interconnecting local area networks (LANs) since 1987. In 1988, effects of various parameters on a satellite circuit and a terrestrial link interconnecting two Ethernet segments were compared. The satellite circuit was simulated in the laboratory by a delay simulator and an error simulator. Parameters included link rate, bit error rate (BER), and block size. Link level error recovery provided on the satellite circuit and end-to-end recovery provided by transport protocols were also studied. User throughputs obtained over the satellite link interconnecting the two Ethernet LANs are shown in Figure 3. The experiment demonstrated that satellites can be effectively used for interconnecting LANs and that the choice of optimal protocol parameter values is critical for obtaining high performance.

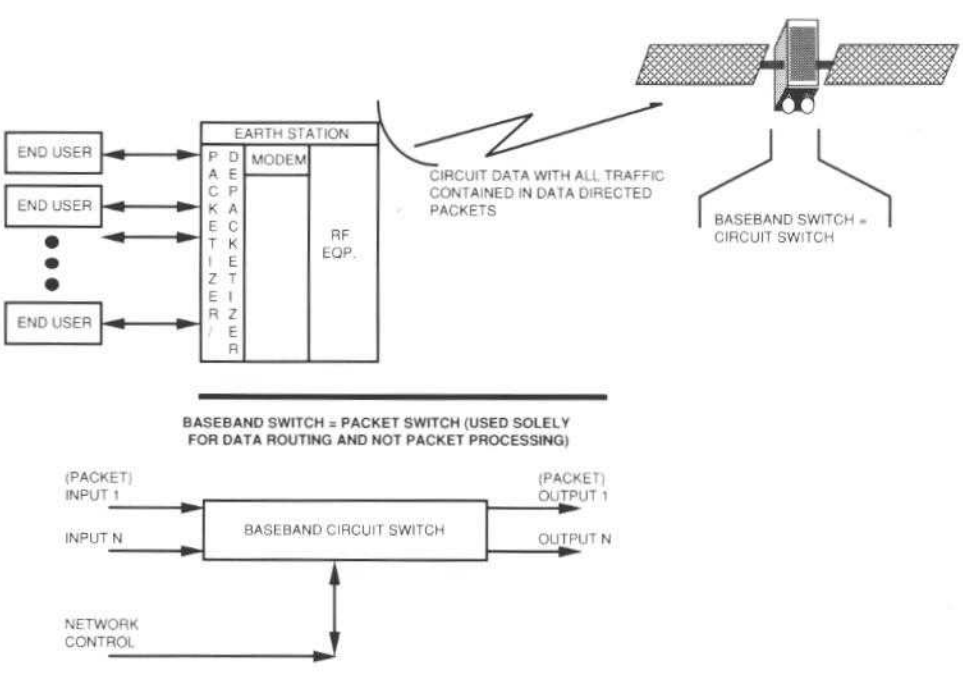
International Fiber Optic Systems

A comprehensive in-depth study focused on three areas:

- the status of fiber optic technology and systems that could have a significant impact on satellite communications
- special issues such as global undersea fiber cable networks, reliability of fiber optic components (and redundancy requirements of systems), and signal quality and standards

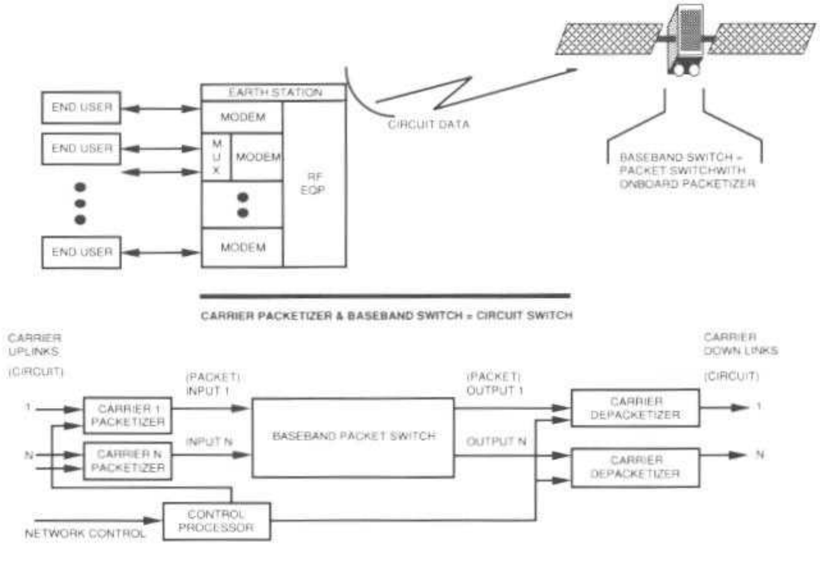


a. On-board baseband circuit switch

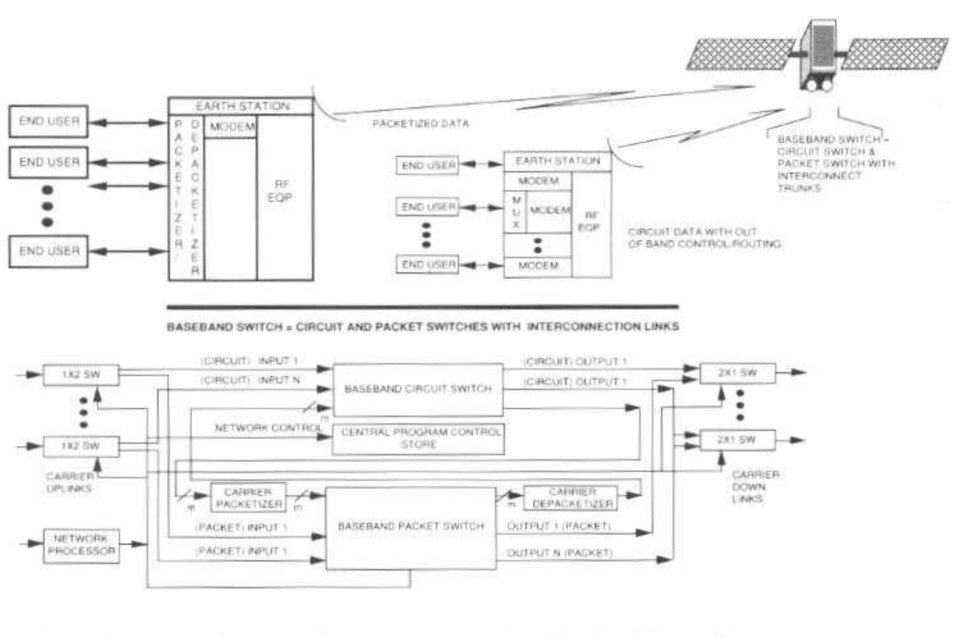


b. On-board baseband packet switch

Figure 1. *Baseband switching alternatives*



c. On-board data packetization and baseband packet switch



d. On-board hybrid packet and circuit switch with limited on-board data packetization

Figure 1. *Baseband switching alternatives (con't)*

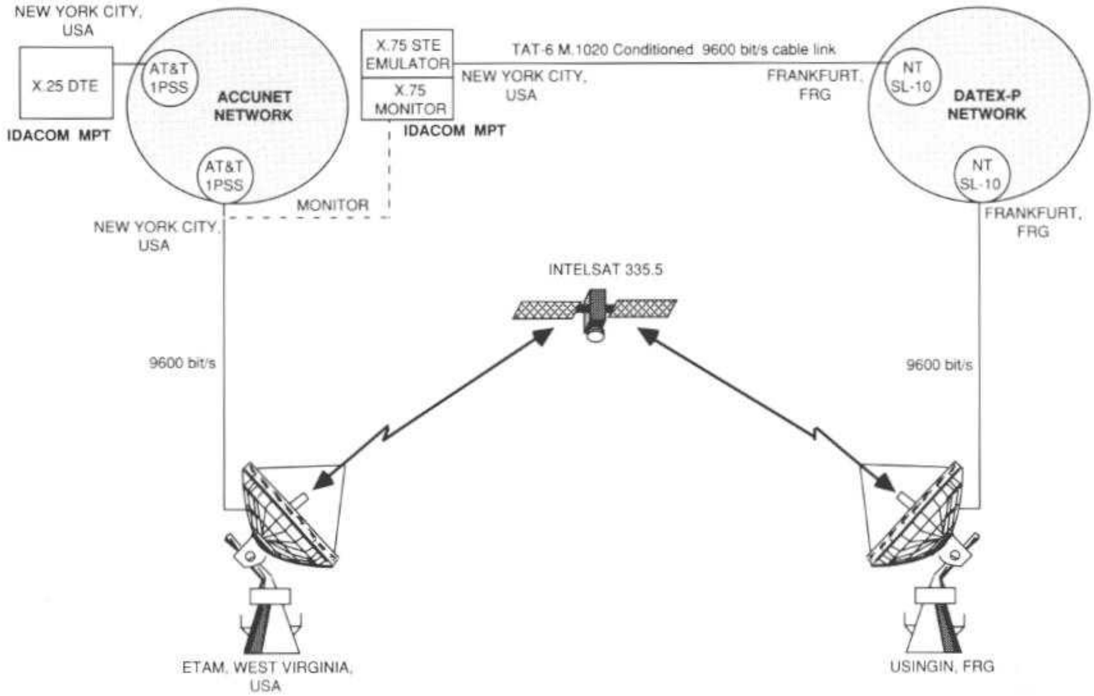


Figure 2. *International quality of service experiment*

Table 1. *Measured Call Setup, Data Transfer, and Call Clearing Delays (ms)*

	Configuration 1				Configuration 2				Recommendation X.135	
	Min	Mean	95%	Max	Min	Mean	95%	Max	Mean	95%
Call Setup	1,111	1,168	1,235	1,450	1,558	1,593	1,620	1,702	2,000	3,000
Call Clearing	400	421	440	568	662	630	635	668	900	1,200
Data Transfer										
32 octets	400	447	460	580	654	661	675	697		
64 octets	467	508	530	684	714	721	730	753		
128 octets	586	624	640	746	832	839	845	917	900	1,200

Table 2. ***Measured Throughput (bit/s)***

No. of Logical Channels	Configuration 1				Configuration 2			
	Min	Mean	95%	Max	Min	Mean	95%	Max
4	7,667	8,218	7,733	9,022	8,650	8,824	8,803	8,958
8	9,102	9,406	9,140	9,471	8,785	8,880	8,792	9,102

- selected technology and network architecture evaluation.

The final report provided a technical assessment of fiber optic technology and systems and indicated that the problem of missing or less reliable services in the worldwide intelligent fiber cable network is being rectified rapidly by ongoing technology improvement, innovative approaches, and high-reliability systems implementation.

The current status of global undersea fiber cable networks reflects this intense activity by both common carriers and private owners or operators of cables. Evolving fiber optic technologies include dispersion-flattened fibers, narrow-linewidth single-frequency lasers, broad-bandwidth photodetectors, optoelectronic integrated circuits, fiber amplifiers, external integrated optical modulators and switches, all-optical repeaters, and wet-mux/active undersea branching devices for high-speed, long-haul operation and improved reliability. The synergy between these technologies and standards activities worldwide will allow improved services and extended networking in future undersea cable systems. Also, the progress of several fiber-to-home projects for broadband multichannel subscriber services has improved the prospects for global all-fiber networks. The possible impacts of this technology on future satellite communications must be investigated.

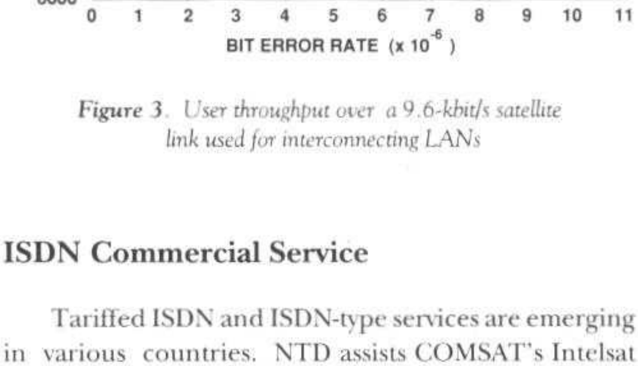


Figure 3. User throughput over a 9.6-kbit/s satellite link used for interconnecting LANs

ISDN Commercial Service

Tariffed ISDN and ISDN-type services are emerging in various countries. NTD assists COMSAT's Intelsat Satellite Services (ISS) in facilitating introduction of these services over the INTELSAT system. The division is actively detailing the requirements for extending ISDN service developments of European countries to private networks in the U.S. and will likewise extend U.S. ISDN service developments to private networks in Europe and Asia.

This project involves system engineering tasks related to commercially available switches and private branch exchanges (PBXs) and the use of these subsystems in accessing the INTELSAT system via either Intelsat Business Service (IBS) or public-switched intermediate data rate (IDR) earth stations. Detailed requirements are associated with basic- and primary-rate customer access protocols used in the switches and PBXs. The gradual introduction of CCITT Signaling System No. 7 (and its national variants) in national public networks and the extent to which such out-of-band signaling can facilitate the introduction of ISDN services over the INTELSAT system are also being investigated.

COMSAT NONJURISDICTIONAL

Software Technology

Software is a critical and often expensive element in data communications today and will be increasingly so in the future. NTD has long recognized the need for software development methodologies and architectures that allow rapid development of high-quality and high-performance software, that exploit parallel and multiprocessor hardware architectures and the inherent pipelined structure of data communications software, and that allow rapid construction of experimental systems for exploring new networking technologies. Ongoing research in software technology has produced a mature set of architectural and design principles, a large library of reusable software components and tools, and several successful implementations of data and voice communications systems.

A cornerstone of this development is the COSMOS operating system and its corresponding large library of data communications software. COSMOS is a highly efficient, portable, multiprocessor, real-time operating system that allows rapid development of high-performance communications systems. Currently, COSMOS supports the Motorola 680x0 series of microprocessors; it can be very easily ported to other processors because most of it is written in the C programming language. It supports many commercially available Multibus and VME bus boards and input/output (I/O) devices. COSMOS is more than just an operating system; it embodies a set of coherent principles that are used throughout the life cycle of the systems design: specification, design, implementation, testing, and maintenance. Although networking and systems applications are not part of COSMOS, their design is influenced by its architecture, and all non-special-purpose software becomes part of the COSMOS library.

In 1988, important software development and management tools were added to COSMOS. The new packages aid the design of unattended network nodes. A new memory-based file system allows systems to save important information (code, parameters, and error logs) in battery-backed memory. The PROM-based debugger was enhanced to allow booting of system software from code saved in nonvolatile memory. Several important run-time diagnostic checks were added. During normal operations, the system can detect hardware and software failures such as infinite loops, stuck interrupts, I/O chip failures, and memory errors. Also in 1988, COSMOS software development was transferred from the VAX system to the Sun system. All proprietary development tools were ported to run on the Sun system. Tools were developed to transfer code from Sun systems to target processors over Ethernet.

A new tool called "mkmk" was developed to automate the process of software compilation and linking, and to provide advanced configuration management functions (see Figure 4). Software compilations and linking are normally done under the control of the Unix MAKE command. The MAKE command files, called "makefiles," contain commands to compile and link files and contain dependencies among files, so that a change in one file causes all dependent files to be compiled. Mkmk automates and greatly simplifies the creation of makefiles. It has built-in rules to automatically generate most makefiles such as those for creating object libraries from source files and for creating executables from object libraries. Built on top of the MAKE system, all facilities of the mkmk system are available to the programmer, a feature that can be useful for creating nonstandard makefiles. As a result, makefiles are always accurate and up-to-date. Mkmk also produces rules for certain standard maintenance operations, such as updating libraries, deleting all recreatable files, and running lint on source files.

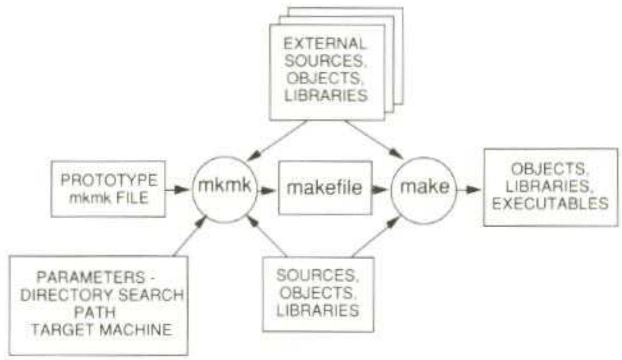


Figure 4. *Architecture of mkmk, the makefile generator*

Mkmk also finds foreign files such as include files, object files, and libraries on the basis of a user-specified directory search order and inserts their full path names in the makefile. This feature facilitates the management of different versions of a system and allows systems to be created from a hierarchy of versions by appropriately specifying the search order. It is also useful during system development and maintenance, when a small subset of a large stable system must be modified. Mkmk generates makefiles for 680x0 cross development and for native host software development for both the VAX and Sun systems. This feature improves portability of the software because makefiles in general are not portable across machines. In all cases, appropriate commands are generated for the correct tools (such as compilers), along with the proper options and flags.

Although COSMOS is a real-time system, several applications require low-cost, large-capacity stable storage systems. Examples are systems that produce large amounts of data that need post-processing or analysis, and network management systems. To meet this requirement in COSMOS, support for small computer systems interface (SCSI) based disks was added. SCSI is a versatile interface to which a number of peripheral devices besides disk drives can be attached. It operates at transfer rates of 1.5 to 4 Mbyte/s; these rates are expected to increase in the future. A commercial, high-performance VME bus-based board acts as the interface to the SCSI bus. Performance close to the limits of the disk system was obtained during testing. This development brings an important functionality to COSMOS because many peripherals use the SCSI bus interface. SCSI can also be used for interprocessor communications and the building of adapters to high-speed LANs.

Network Management

NTD has an ongoing research program to investigate, evaluate, and implement data communications and network technologies. Various network architectures and communications protocols have been implemented, yielding an abundance of information, experience, development tools, and expertise.

Data communications technology and protocols have made steady progress over the last several years. The number of public and private data networks is increasing rapidly and so are the sizes and complexity of each network. Coupled with the increase in complexity is the additional factor of multivendor equipment within the same network. Management of these large complex networks is a problem area which has largely been ignored until recently. NTD has embarked on a research program to investigate and implement network management strategies.

A number of areas within the umbrella of network management have been identified—network administration (network configuration and definition), fault management, problem management, statistics and reports (including billing and accounting), network planning, and design tools. One of the design goals of the network management system has been that the network operator should not be overloaded with information about the network; instead, the network management should handle most routine (and some not so routine) problems automatically; the operator is involved only with problems that the system cannot handle (yet). Of course, all information is available to the operator, when needed.

NTD has performed research and development in network design and implementation for a number of years. The multimicroprocessor-based network interface processor (NIP), developed by NTD, is the primary vehicle for network node implementation. COSMOS remains the primary software vehicle for implementation of communications systems software.

NEWNET, an NTD packet network, is used as a research tool for experimental networking architectures, protocols, and network management strategies. It provides automated solutions to traditionally difficult network management problems. It enhances network reliability against failures and outages by means of a routing and congestion algorithm, without manual intervention from network operators. The adaptive distributed routing protocol (ADRP) optimally routes traffic through the network on the basis of the current availability of network nodes and current traffic levels. ADRP is executed in unison by all nodes in the network. Each node exchanges information about traffic levels with its immediately connected nodes. Through this exchange, an optimal and consistent set of routes is generated, independently by each node, for each destination node. As traffic levels change and nodes fail, the routes are regenerated by all nodes; traffic is routed around congested or failed nodes or areas. The algorithm, transparent to end users, increases performance and availability of the network.

All NEWNET configuration information and software for a node are kept at a central network management center (NMC), where operators can define and modify it. On power-up, each node fetches this information from the NMC using a neighboring node as an intermediary. If a copy is available in battery-backed memory in the node, the information is fetched only if it has changed in the NMC. This facility eases installation and configuration of nodes and software upgrades.

The NMC node accesses files and databases on disks and uses a Macintosh terminal as a display terminal. The virtual console system (VCS) software enables the Macintosh to be an intelligent terminal for any host system, including a COSMOS-based NIP. Application programs residing in the NMC access high-level facilities common to most Macintosh-based applications, such as pull-down menus, multiple windows, and dialog boxes. The result is a highly interactive and user-friendly operator interface, based on color graphics and familiar Macintosh objects. Prototype NMC applications allow graphic display of network status and statistics at various levels of detail.

As part of the network management task, NTD has also been investigating management of multivendor, multiprotocol networks. Protocol architectures currently in widespread use include TCP/IP, DECNET, X.25, SNA, AppleTalk, and PC-NET. Most protocol suites have varying amounts of support for network management functions. OSI, whose protocols are soon expected to dominate the networking world, is defining a comprehensive set of network management protocols. In addition to keeping pace with ongoing developments in protocol families, NTD also has a keen interest in implementing a strategy that can be used to manage a network operating with multiple protocols from a unified NMC.

Development of a prototype NMC that initially will manage TCP/IP networks, but will be enhanced to manage OSI, SNA, AppleTalk, PC-NET, and vendor-proprietary networks, is underway. This NMC operates under the simple network management protocol (SNMP), recently standardized for TCP/IP networks, and which will eventually evolve into OSI protocols. The NMC is based on a Sun workstation with color graphics display and X-window display system. The Ingres database management system supports network configuration management. Standardized protocols and software tools have been chosen to enhance customer acceptance of the system.

Expert systems technology has been enlisted to solve certain network management problems. Expert system prototypes have addressed problems in optimal network design and network fault diagnosis. A prototype expert system that performs network fault diagnosis for TCP/IP networks is under development. This system is hosted on a Symbolics workstation, uses the knowledge engineering environment (KEE) expert system shell, and interfaces with the Sun-based NMC over Ethernet. Figure 5 shows the implementation architecture of the NMC and the expert system.

The Generic Network Simulator for Intelligent Systems (GENESIS) simulates distributed computing systems. It is currently used to simulate and evaluate the performance of communications protocols in large networks, and to test network management protocols. It consists of a set of design rules and a library of functions that rapidly create simulation models for networking functions that rely on a message-passing paradigm. Models have been created for simulating serial links, Ethernet, DoD Internet Protocol (IP), DoD User Data Protocol (UDP), Routing Information Protocol (RIP), Network File Service (NFS), and protocols for narrowband ISDN supplementary bearer services. GENESIS is written in the SIMSCRIPT simulation language; its compiler is available for several computing platforms.

Artificial Intelligence in Network Control

Packet networks are subject to traffic surges and focused loads that create congestion, overwhelm network resources, cause increased delays and reduced throughput, and create deadlocks. Because of the increasing complexity of large multivendor, multimedia networks, and the large spectrum of possible causes of congestion, devising control strategies that limit congestion is becoming unmanageable. A knowledge-based expert system can reduce the number of possible solutions and render control more manageable. Network control mechanisms for most communications standards are moving toward distributed implementation for each layer of the protocol suite. Such controls, although having a limited view of the network, are self-reliant and able to operate without a centralized network control center.

NTD developed the Artificial Learning Intelligence for Congestion Identification and Avoidance (ALICIA) program, a distributed cooperative expert system that resides at each switch in a packet-switched network and that identifies and avoids congestion.

Each switch analyzes the data traffic passing through it, the control traffic from neighbors, current connectivity, and its own buffer utilization. From this information, the switch regulates the incoming rates on its links according to heuristics that pertain to globally efficient use of its resources, fair allocation of resources among its neighbors, deadlock prevention conditions for the impact of congestion on end-to-end flow controls, and the behavioral model for congestion control mechanisms of neighboring switches. The switch communicates requests and allocations for communication bandwidth using a transaction protocol that establishes a cooperative congestion control architecture.

GENESIS, which allows a quick implementation of packet-switched protocols, is used to test the control architecture. This package has been used to simulate the DoD internet suite of protocols, as well as some narrowband ISDN protocols.

Fiber Optic Based Data Networking

In this project, use of optical fiber cables in an intelligent building (IB) network was investigated. With its large bandwidth, optical fiber can easily accommodate the presently available shared tenant services of an IB network. In fact, optical fiber provides a safeguard against future obsolescence when much higher speed services will be required. Additionally, optical fiber cable is small, lightweight, and free of electromagnetic interference (EMI).

Connectivity and channelization schemes for integrating voice, video, and data services in an IB network have been investigated, taking into consideration necessary fiber optic parameters. Optical components needed for the architectures have been identified and their performance and price evaluated. A cost comparison of these architectures has also been performed.

On the basis of these studies, a low-cost fiber optic architecture has been recommended for an IB network (see Figure 6). IB wiring uses conventional star-structured systems with wiring closets on every floor and a service center from which the backbone riser cable is distributed. Star couplers, typically situated in such a service center, form the hub of the IB network. Each cable section that starts from the hub shares the riser cable conduits for the normal building wiring system. Because the optical cable is light and free of EMI, it can share conduit space with the existing wiring. The cable sections end in a distribution panel on every floor (or every other floor), where with the use of wavelength division multiplexing (WDM) the horizontal system branches out into T1, video, and Ethernet channels.

An Ethernet Multistar-based unit can allow further extension of Ethernet LAN segments on each floor. Each of these LAN segments can operate on any wiring medium, allowing a variety of subsystems to be mixed and matched. The T1 channel can be connected to CB or PBX equipment, and circuit-switched voice and data services can be provided throughout the building. Low-speed telemetry signals for energy management and security can be transmitted on DS0 channels by means of the CB/PBX arrangement. Finally, the video channel can support CCTV surveillance, video monitoring of equipment, and videoconferencing. A small-scale prototype of such a fiber optic IB network architecture has been designed, installed, and successfully tested by NTD.

It is envisioned that such a fiber optic network can be easily upgraded to higher speed networks such as the100-Mbit/s fiber distributed data interface (FDDI) network when they become available.

Crisis Briefing System

The crisis briefing system task explored technology for establishing a coordinated crisis management system for improving communications between crisis managers. Potential applications for this technology include nuclear reactor incidents, forest fires, law enforcement, and intelligence operations. The system consists of

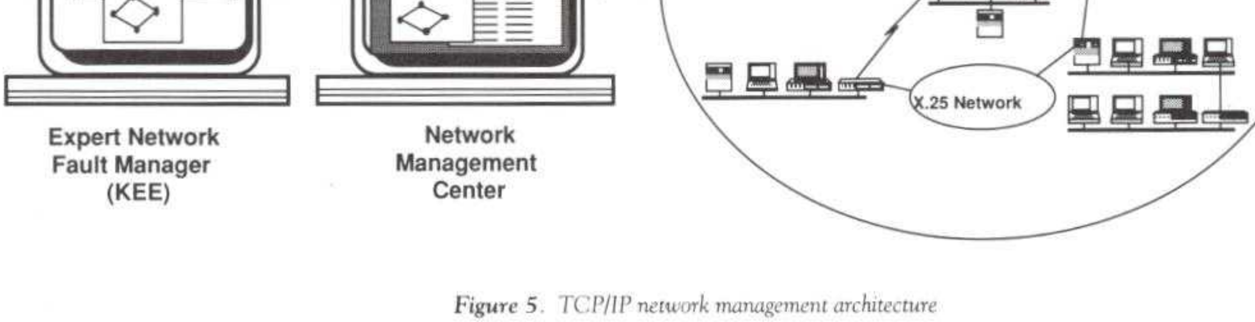


Figure 5. TCP/IP network management architecture

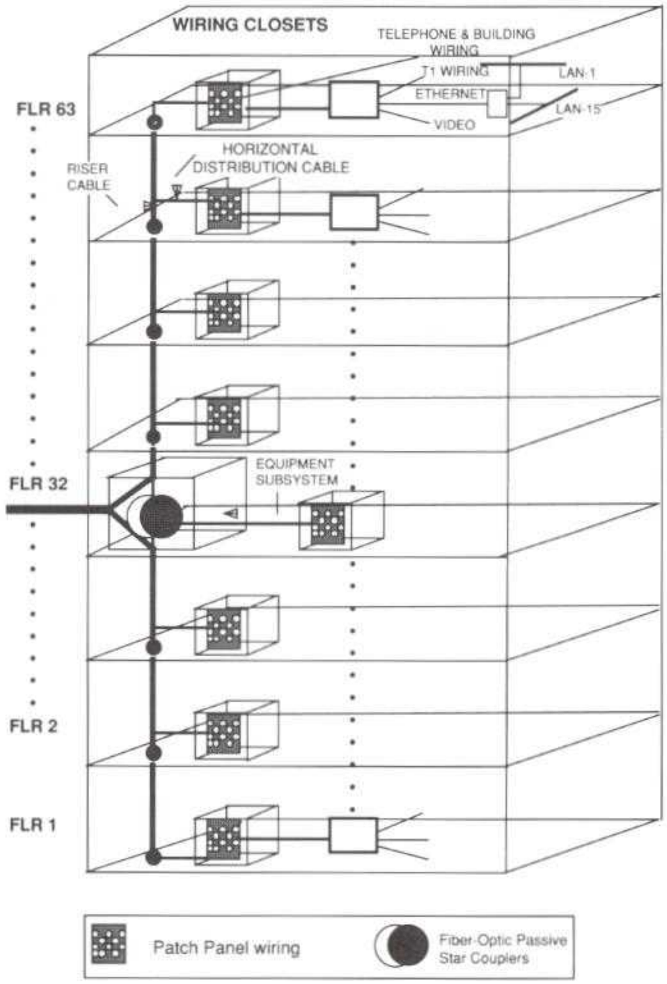


Figure 6. Fiber optic network for an intelligent building

normal telephone service and advanced workstations connected to a data network to provide voice, data, and image communications in interactive sessions between users at various geographical locations. The telephone establishes conference calls for a group of users, who then initiate a shared workstation environment. Connections to the workstations can be provided by either private or public data facilities. Each workstation connected for a briefing system has a window that can display a variety of the same graphic material, e.g., drawings, maps, data tables, curves, and text, to all users. The user can readily display overlays containing text, graphic outlines, and pointers. The system also provides a real-time pointer that appears on all screens.

Crisis management consists of the following four elements:

- appraisal of the situation
- development of options to handle the crisis
- decision dissemination and coordination
- post-crisis analysis.

The workstation supports both analysis and communications between users. To demonstrate the capabilities of such a system with readily available hardware and software, Sun Model 3 workstations and TCP/IP network connections have been integrated. Either a Sun workstation or a local Macintosh computer can prepare materials for the briefing system. The demonstration can display text, object graphics, bit-mapped graphics, data tables, and curves.

In the current demonstration, an NTD Ethernet network can initiate a conference session between three workstations. Participants in the conference are invited to join the session and enter a password to accept the invitation. A conference window appears when the invitation is accepted. All users view the same window. A separate window displays the names of conference participants, and indicated which user has the "floor." Any user can request control of the floor by clicking a mouse button, and when in control, can point to objects on the screen with the mouse, and alter the window contents. The system has not been tested between users on different networks, but this function is supported by system components.

INTELSAT

On-Board Processing

Under an INTELSAT contract, members of NTD and CTD investigated alternative on-board processing architectures and network control strategies that minimized ground terminal and on-board processing complexity and cost while providing maximum traffic routing capability, reconfiguration flexibility, and link performance. The study was divided into four phases:

- Phase 1. Architecture tradeoffs
- Phase 2. Technology definition
- Phase 3. Cost/benefit analysis
- Phase 4. Synchronization of digital inter-satellite links (ISLs)

Phase 1, 2, and 3 are described in the CTD section of this Annual Report. The work carried out under Phase 4 is briefly described in the following paragraphs.

The ISL study included calculation of ISL range rate and range variation, ISL processor architecture and their impact on ground terminals, internetwork TDMA synchronization, and optical ISL transmission analysis and tradeoffs.

Worst-case range rate and range variation were computed for a satellite longitudinal separation of 60° to 120°. The worst-case range rate and range variation occurred at 60°. With this separation, a range variation of 261 to 432 km for an orbital inclination angle, i, of 0.1° to 3.0° (assuming longitudinal drift of ±0.1°) and a range rate value of 5.6 m/s (i = 0.1°) to 21.9 m/s (i = 3.0°) were possible. In comparison, earth station range variation was 73 km (i = 0.1°) to 708 km (i = 3.0°); earth station range rate was 2.4 to 25.9 m/s. Minimum buffer requirements set by earth station and ISL range variations were determined on the basis of these values. Other buffer components such as frame alignment and clock drift were also estimated.

ISL transmission architectures were examined, and various alternatives for on-board processing of ISL signals were presented. Within the context of transmission architectures, both TDMA and TDM/FDMA systems were considered with 120-Mbit/s (TDM or TDMA) ISL transmission. Available on-board processing alternatives for these systems, including no processing (transparent link), regeneration, IF switching, baseband switching, and baseband processing, were examined. ISL payload interconnection options were also considered for satellites with either the same or different ISL payload configurations (Figure 7).

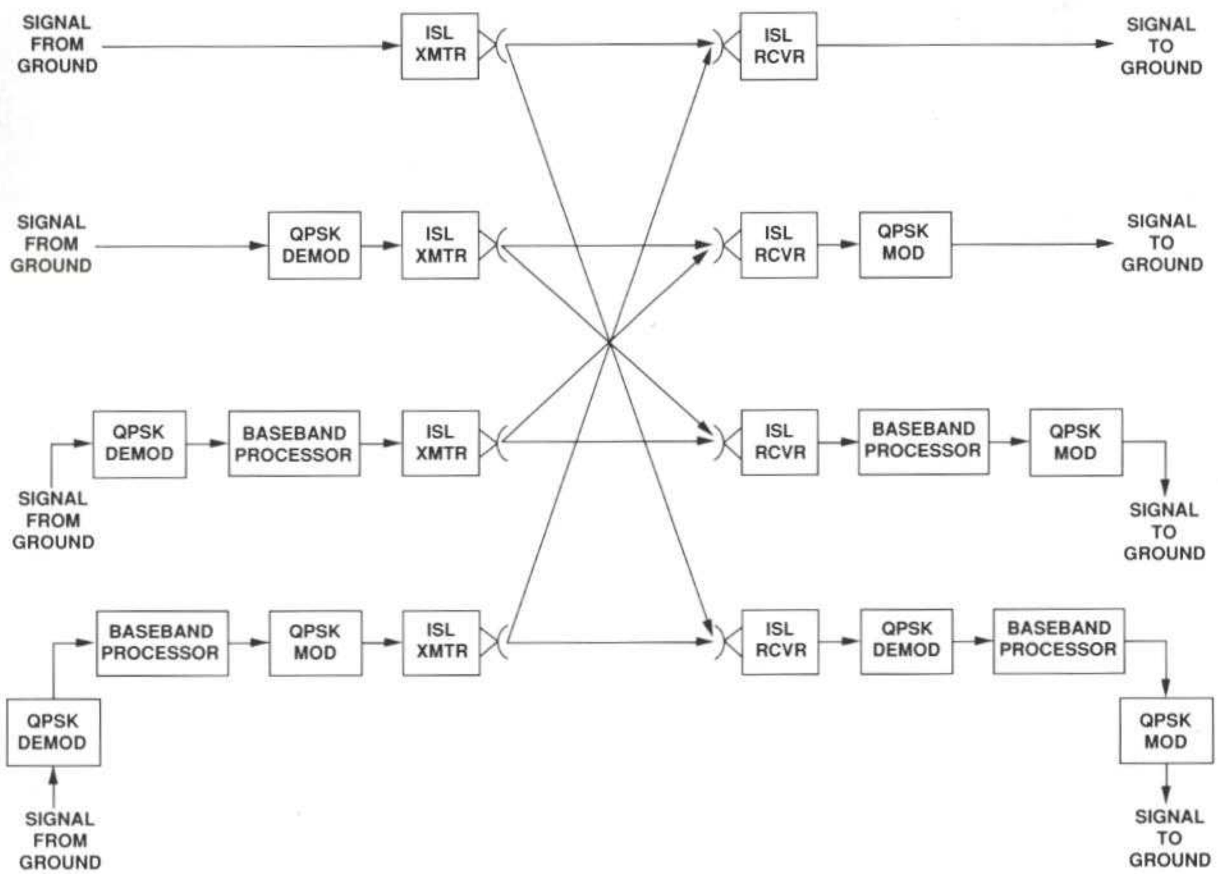


Figure 7. ISL payload interconnection options

The major part of the study focused on ISL TDMA network synchronization, identifying on-board processing requirements, impacts on earth station design, and buffer requirements for the ISL subsystem and earth station. Both ground- and on-board based timing techniques were considered.

For synchronization of multiple-TDMA networks interconnected by ISLs, several network timing alternatives were studied in conjunction with ground reference and on-board reference timing. These included independent network timing (networks operating with different satellites are independently synchronized to their own reference clocks), synchronized on-board timing (one control station provides reference timing to both local and remote networks), and synchronized ground timing (identical to independent network timing except that ground reference clocks are synchronized using a terrestrial link). In addition, a minimum on-board hardware configuration (Figure 8) was investigated in which ISL synchronization and processing functions are transferred to the traffic terminals to simplify the on-board hardware at the expense of more complicated ground processing.

After examining the alternatives, it was concluded that independent network timing is the simplest to implement and results in reliable network operation. Slight enhancements at the reference stations (such as adding synchronization circuitry and a terrestrial link between the reference stations) will provide synchronous operation of the TDMA networks.

For an optical ISL transmission analysis, the optical ISL transmission subsystem and parameters, optical power budget tradeoffs, and ISL BER considerations were defined. Based on the ISL transmission rate requirements and the level of maturity of various optical technologies, it was concluded that GaAlAs technology was promising

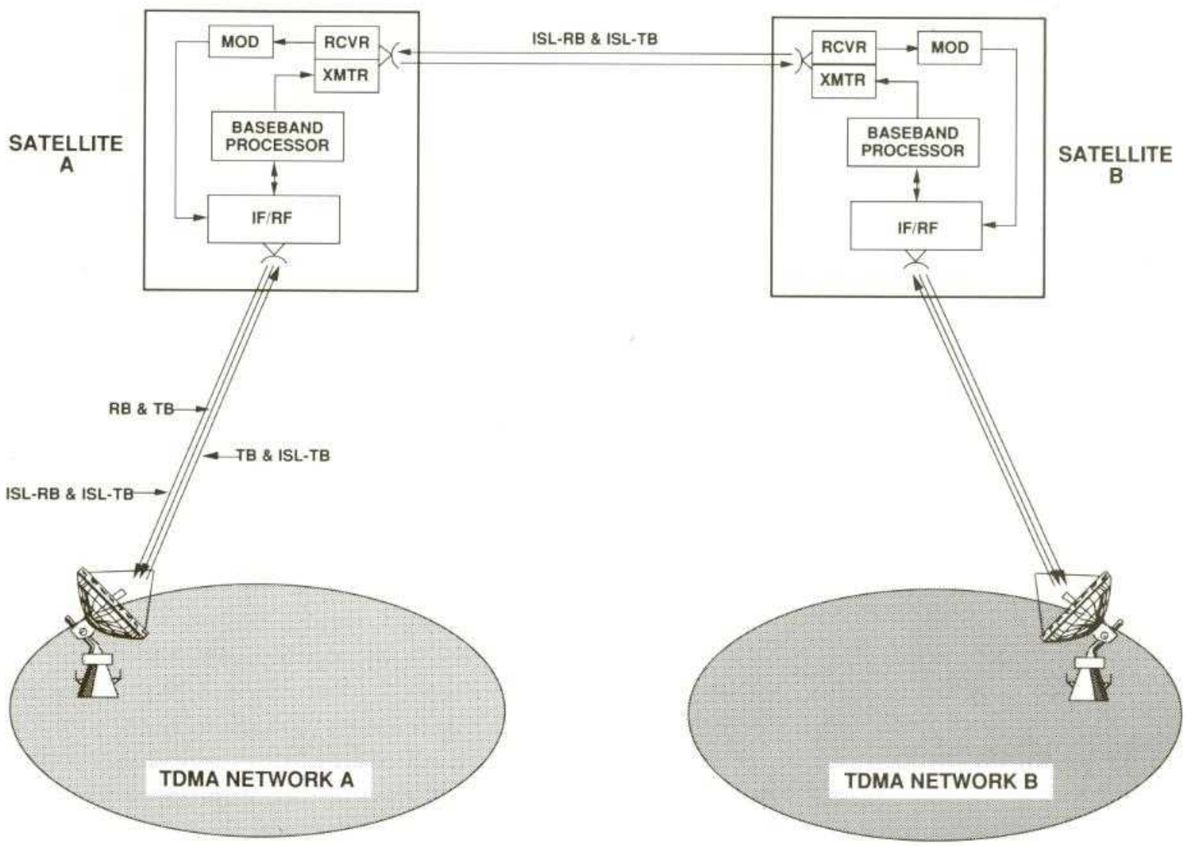


Figure 8. *ISL TDMA transmission configuration requiring minimal on-board hardware*

for this particular application. Parametric results showing ISL BER versus optical antenna diameter were presented as a function of ISL separation angle for two levels of transmitter power (50 and 200 mW). An example of the study results is shown in Figure 9. ISL BER requirements for 120-Mbit/s transmission were also determined with and without the application of forward error correction (FEC) coding. For FEC coding, both end-to-end and on-board decoding and recoding were considered. ISL-BER curves (link BER = 10^{-7}) for both cases were presented.

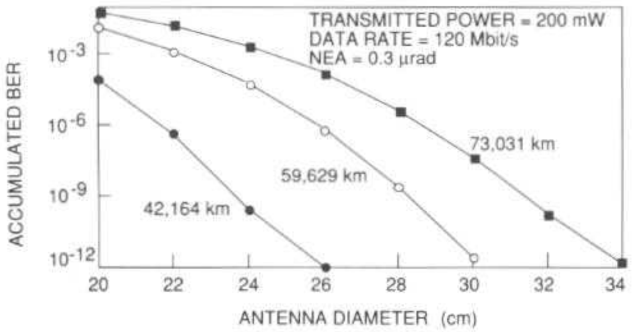


Figure 9. *Accumulated BER vs antenna diameter (ISL optical link budget)*

Packet Switching Experiment

NTD supported INTELSAT in determining the QOS of an international packet-switching link that included at least one satellite hop. The data gathered from the experiment were analyzed in detail. The resulting report contained recommendations on choice of optimal protocol parameter values when satellite links carry packet-switched data.

CORPORATE SUPPORT

CCITT and T1 Activities

NTD has actively participated in international and national standards organizations dealing with ISDNs and data communications issues. Members of NTD have participated in Study Groups XI and XVIII of the CCITT and in subcommittees of the ANSI T1 Committee on Telecommunication. These efforts have been directed toward ensuring that satellite system characteristics are accommodated in the development of national and international standards.

Ensuring the compatibility of satellite communications with ISDN standards development required analysis of issues ranging from simple timer parameters to detailed protocol procedures. Interworking (Recommendation I.515), additional packet mode bearer services (Recommendation I.122), broadband ISDN (Recommendation I.121), asynchronous transfer mode (ATM), non-D channel application of link access protocol-D (LAPD), and multipoint broadcast services were some of the specific topics which were investigated in detail.

Recommendation I.515 defines the parameter exchange for ISDN interworking. Typical examples in which parameter exchange takes place include terminal adaption compatibility establishment, modem type selection, and voice encoding compatibility establishment. The time parameter N_{pid} bounds the time interval allowed for completing the parameter exchange. The proposed value of 500 ms would have ruled out satellite links for interworking situations. N_{pid} is now the implementer's choice.

Recommendation I.122 defines frame relaying 1, frame relaying 2, frame switching, and X.25-based packet mode bearer services. Differences between these services arise from the different applicable user-plane functions. (In the control-plane, all signaling capabilities for call control, parameter negotiation, etc., are based on a common set of protocols, e.g., Recommendation I.451.) In 1989, it is expected that some bearer services will be deleted and not considered further for standardization.

In the frame relaying 1 service, both the user and network perform I.441 core functions, whereas in the frame relaying 2 service, the user terminal performs I.441 protocol, whereas the network performs only I.441 core functions. In the frame switching service, both the user and the network perform full I.441 protocol functions. In the X.25-based additional packet mode bearer service, both the user and network perform full I.441 protocol and the data transfer part (DTP) of X.25 packet layer protocol (PLP). The core functions of I.441 are frame delimiting, frame multiplexing/demultiplexing, error detection, and frame inspection.

The difference between frame relay and frame switching protocols is that no flow control or local retransmission is performed in the former schemes. As a result, an additional congestion control technique is needed in the frame relay protocols to prevent users from flooding the network. The proposed congestion control scheme (reduction of windows to one) will not perform well over satellite links because they typically operate with large windows. In the COMSAT scheme proposed to the subcommittee T1S1, the multiplicative decrease in the window size upon user-perceived congestion is considerably better for satellite links. Frame switching and X.25-based services have no such problems.

LAPD is being modified for non-D channels. NTD has been participating in this development to ensure its compatibility with satellite technology.

Recommendation I.121 defines the broadband aspects of ISDN. Broadband refers to digital rates higher than T1 rates (1.544 Mbit/s, or CEPT, 2.048 Mbit/s), and can be as high as 150 to 600 Mbit/s. These digital rates are intended to be supported over fiber optic transmission media, but so far the specification of standards has been kept independent of transmission media. NTD has been active in ensuring that satellite-based services are an integral part of B-ISDN.

Maritime Services Support

Maritime Services announced its intention to offer transoceanic aeronautical communications systems using satellites in the INMARSAT System. These services will greatly enhance the capabilities of air traffic control (ATC), resulting in fuel cost savings. They will also provide efficient tracking, permit instant emergency communications, and provide airline company and public correspondence (both voice and data) to and from the aircraft. NTD supported Maritime Services in specifying the interface between the aeronautical ground station and the packet network operated by ARINC. NTD also contributed to ARINC-741, an international standard for the aviation satellite communications system. Specific recommendations for the standard improved the available throughput and made possible the external measurement of delays through the network. NTD also assisted in specifying the requirements for an early-services ground station and in writing a request for proposal (RFP) for the full-services ground station.

Computer Network Security

Sponsored by CSD, a study in computer network security has been undertaken to expand COMSAT's understanding of this rapidly growing field. Various security features and mechanisms to implement them, as well as security requirements of the defense, civilian, and private sectors, were examined. This work included reviews of the trusted computer system evaluation criteria (TCSEC) and the trusted network interpretation (TNI) systems developed by DoD as a guideline for specifying, providing, and evaluating security functions in automated data processing equipment. Security architectures and functions of the protocols in the Secure Data Network System (SDNS) were also studied. SDNS is an outgrowth of the work done by National Security Agency's (NSA's) Development Center for Embedded Comsec Products (DCECP). Also evaluated was the impact of providing various security functions at different layers of the ISO-OSI model.

The System Development Division (SDD) is responsible for system design and development activities in support of COMSAT lines of business, INTELSAT, and other COMSAT clients. SDD projects encompass development of computer-based systems, including design and implementation of software and the selection, acquisition, installation, and integration of hardware. Other SDD activities involve development of digital hardware and microprocessor firmware for prototype equipment produced by COMSAT Laboratories, and development of analysis and simulation techniques and computer software for evaluation and optimization of satellite communications systems and subsystems. State-of-the-art software development techniques, including advanced methodologies, computer languages, and computer hardware, are investigated and applied. During 1988, SDD continued development of several major systems analysis programs, expanded the database of satellite system information, implemented a computer network to support program management activities, and initiated a research program in lightweight satellite technology.

COMSAT JURISDICTIONAL R&D

Interactive Channel Modeling Program

As reported in the *1987 COMSAT Laboratories Annual Report,* a baseline version of the Interactive Channel Modeling Program (ICHAMP) was developed in 1987. An enhanced version was developed jointly with the Communications Technology Division (CTD) in 1988. ICHAMP is a time-domain simulation program that runs on the IBM 3083 processor under the CMS operating system. Although designed primarily for simulation of satellite communications channels, ICHAMP can also be used for analyzing terrestrial communications systems and as a general software package for digital signal processing.

ICHAMP simulates the steady-state transmission of digital signals over a satellite channel, and generates performance measures such as bit error rate (BER) and signal-to-noise ratio (S/N). Graphical outputs of signal envelopes, eye patterns, scatter diagrams, phase-plane trajectories, and power spectral density plots can be generated at any point along the channel. The analysis algorithms used in ICHAMP originated in the Channel Modeling Program (CHAMP).

ICHAMP enables a user to graphically describe digital or FM communications channel configurations in block diagram form by means of a menu-driven interface (Figure 1). Icons representing filters, amplifiers, signal generators, and signal operators are used to

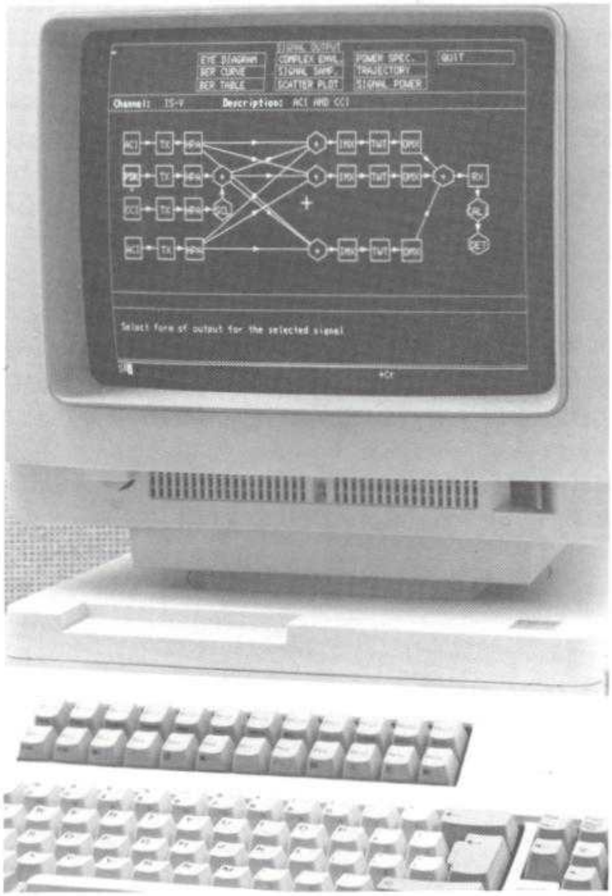
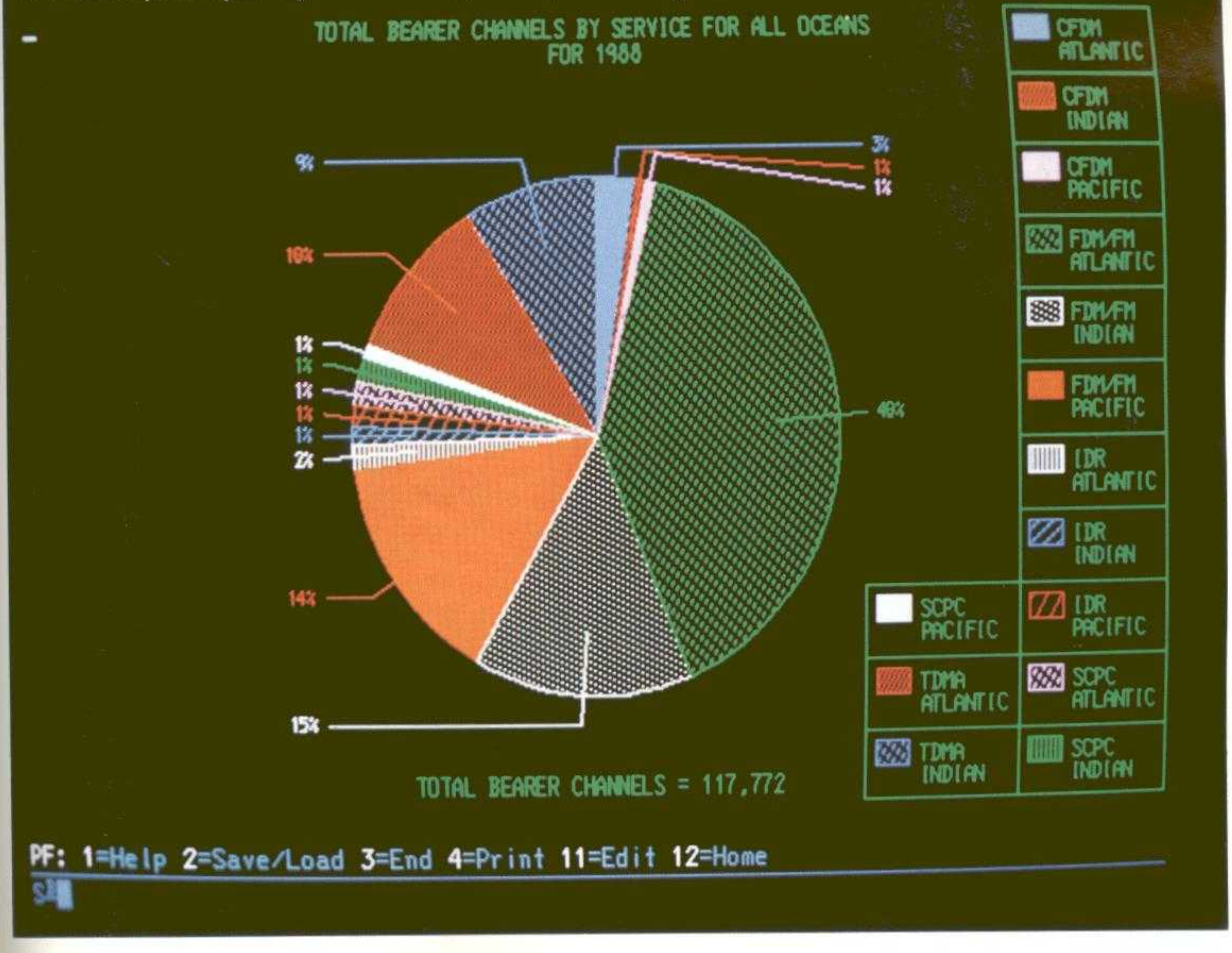


Figure 1. *Block diagram of a satellite channel in ICHAMP*

SYSTEM DEVELOPMENT

SDD develops analysis software and engineering data base facilities



build the diagram. Multiple channels may be defined in order to model adjacent channel interference (ACI). Individual channel component parameters stored in a component database may be retrieved and used to construct specific channel models. The channel block diagram is stored in a channel database that may be edited by the user.

Integration and testing of the enhanced version of ICHAMP were completed in 1988. The simulation results were validated against CHAMP and known theoretical results. An ICHAMP user's manual, programmer's manual, and theoretical manual were prepared.

Network Analysis Program

The Network Analysis Program (NAP) is an analytical tool for evaluating the quality of service of a packet-switched network which has been augmented and revised since 1987. Network performance is defined by the throughput and end-to-end delay incurred in sending messages from a source node to a destination node. Network performance may also be evaluated by introducing network component failures. An availability analysis of the complete network may be carried out on the basis of the mean time between failures (MTBF) and the mean time to repair (MTTR) for each link and node.

Components of the network model include network nodes; processes residing at each node; communications links between nodes, traffic sources, and distributions; and link level protocols used over each link. A description of each of these components serves as program input. NAP runs on the IBM 3083 processor under the CMS operating system and also on the HP 9000/320 under UNIX. Program output includes tabular listings of network parameters, node connectivity, and performance of various network components.

NAP has been tested and its documentation updated. A user's manual, programmer's manual, and theoretical manual are available.

General Antenna Program

Development of an integrated version of the General Antenna Program (GAP) for modeling a reflector antenna system continued in 1988. GAP can analyze reflector antenna systems with multiple feeds and multiple reflecting surfaces with diffractive rim boundaries. It performs surface and aperture integration, geometrical diffraction theory calculations, and sampling and reconstruction techniques to predict radiation patterns of a variety of reflector antennas.

GAP creates an input file describing the antenna geometry, invokes a ray trace of the radiated field, performs far-field or near-field integration, and then produces a plot of the radiation field on a graphics terminal. The far-field radiation pattern shown in Figure 2 was generated by a dual reflector system with four feeds. To analyze the performance of an antenna system, the user may iteratively adjust parameters describing the antenna geometry and repeat the analysis.

Developed on an IBM mainframe, GAP was transferred in 1988 to the HP-9000 (Series 840) computer. Both versions of the program are currently operational within COMSAT Laboratories. Supporting documentation for GAP was also generated.

In 1989, restructuring of GAP to make it more efficient and easier to use and maintain will be initiated.

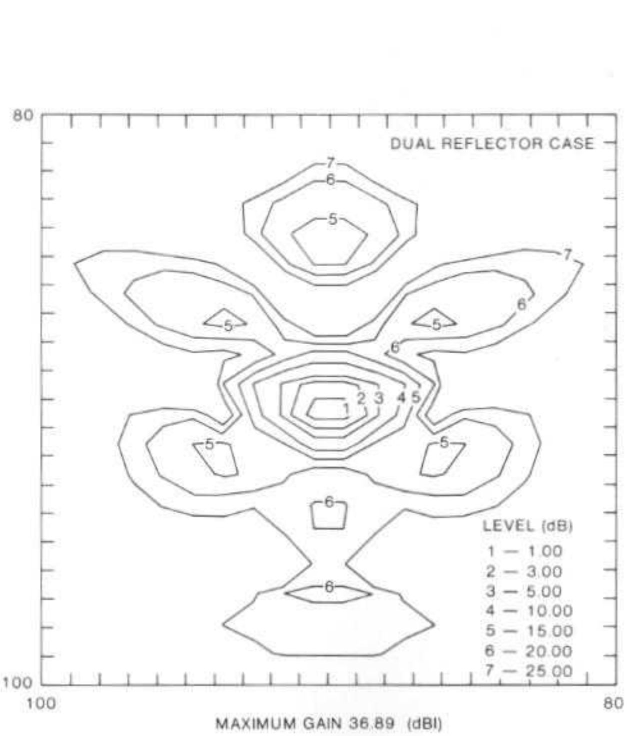


Figure 2. Far-field radiation pattern generated by GAP

COMSAT NONJURISDICTIONAL R&D

Lightweight Satellite Technology Research

There has been considerable interest recently in potential applications for lightweight, low-orbit satellites using contemporary technology. COMSAT Laboratories has actively followed developments in this area to plan for the application of SDD's technical capabilities in systems engineering, on-board microcomputing, solid-state RF and digital electronics, flat-plate antennas, and efficient long-life batteries.

SDD led an internal, multidivisional study to survey appropriate applications for lightweight, low-orbit satellites, and to develop corresponding system concepts that made effective use of the applicable base of laboratory-demonstrated technology. In the study, SDD chose to explore the next step beyond individual small spacecraft operating independently. That is, SDD concentrated on designing efficient networks with modest numbers (tens) of lightweight low-orbit satellites, interconnected by millimeter-wave intersatellite links (ISLs), to provide data relay coverage of a local area anywhere on earth, plus longer range connectivity if required.

The resulting COMSAT Lightsat Network concept, with satellites autonomously positioned relative to each other in polar orbit planes, provides full-time communications coverage (without gaps in time or in space) that is immediately available to a military commander anywhere, at any time. Figure 3 shows a typical configuration with eight satellites in each of four polar orbit planes.

The SDD study avoided a single-point design for the system or any component, but rather attempted to explore the range of parameters over which the basic concept was applicable and to develop selected design examples. For instance, SDD found that the concept is attractive at orbit altitudes between 500 and 2,000 km and at spacecraft weights of 400 to 500 lb. Figure 4 is a top-level block diagram of a suitable communications payload. ISL data rates of several megabits per second were feasible, but they could be increased to 100 Mbits by the more advanced component technology that has been demonstrated in the laboratory.

Studies of Lightsat applications and applicable technology will continue in 1989.

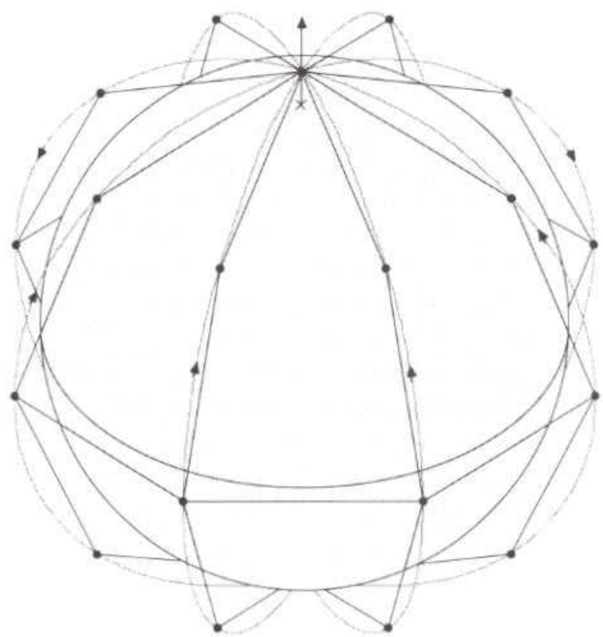


Figure 3. *Lightweight satellite constellation*

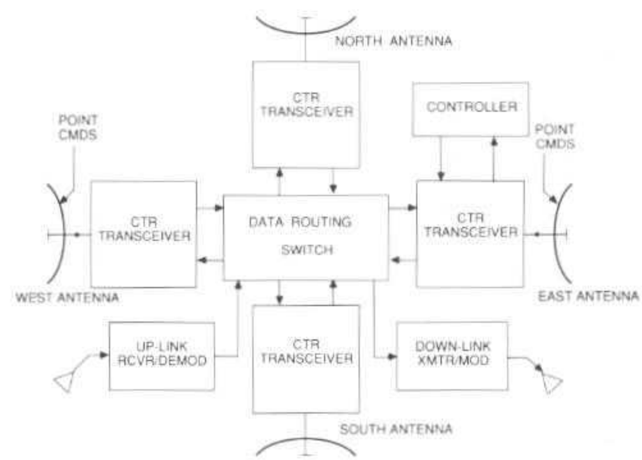


Figure 4. *Lightweight satellite block diagram*

COMSAT SUPPORT

Communications System Planning Model

The Communications System Planning Model (CSPM), begun in 1987, is an interactive computer program that facilitates the planning of a satellite communications system. The need for CSPM stemmed from the large amount of data involved in the planning process and the desire to examine many system alternatives.

CSPM contains a number of analysis algorithms for performing time-consuming and iterative operations. Implementation of the model entailed focusing not only on these analysis algorithms, but also on the user interface in order to design and implement a package for a system planner.

CSPM is a flexible and expandable software program. To ensure the most general model possible, predefined parameters and size limitations were avoided. CSPM allows for multiple ocean regions, each containing several satellites.

Current satellite communications systems accommodate numerous communications services within a single satellite, and often within a single transponder, all of which are supported by CSPM's algorithms. The model addresses both system capacity and costs. Parameters and data are easy to change, simplifying the process of iterative analysis.

In using the CSPM model, a systems planner defines all the basic parameters of a satellite communications system, including earth stations (network nodes), oceans, satellite deployment data, transponder configurations, beam coverage regions, earth station equipment, and service categories. Traffic requirements, in the form of traffic matrices, represent actual or forecast traffic for each communications service. By

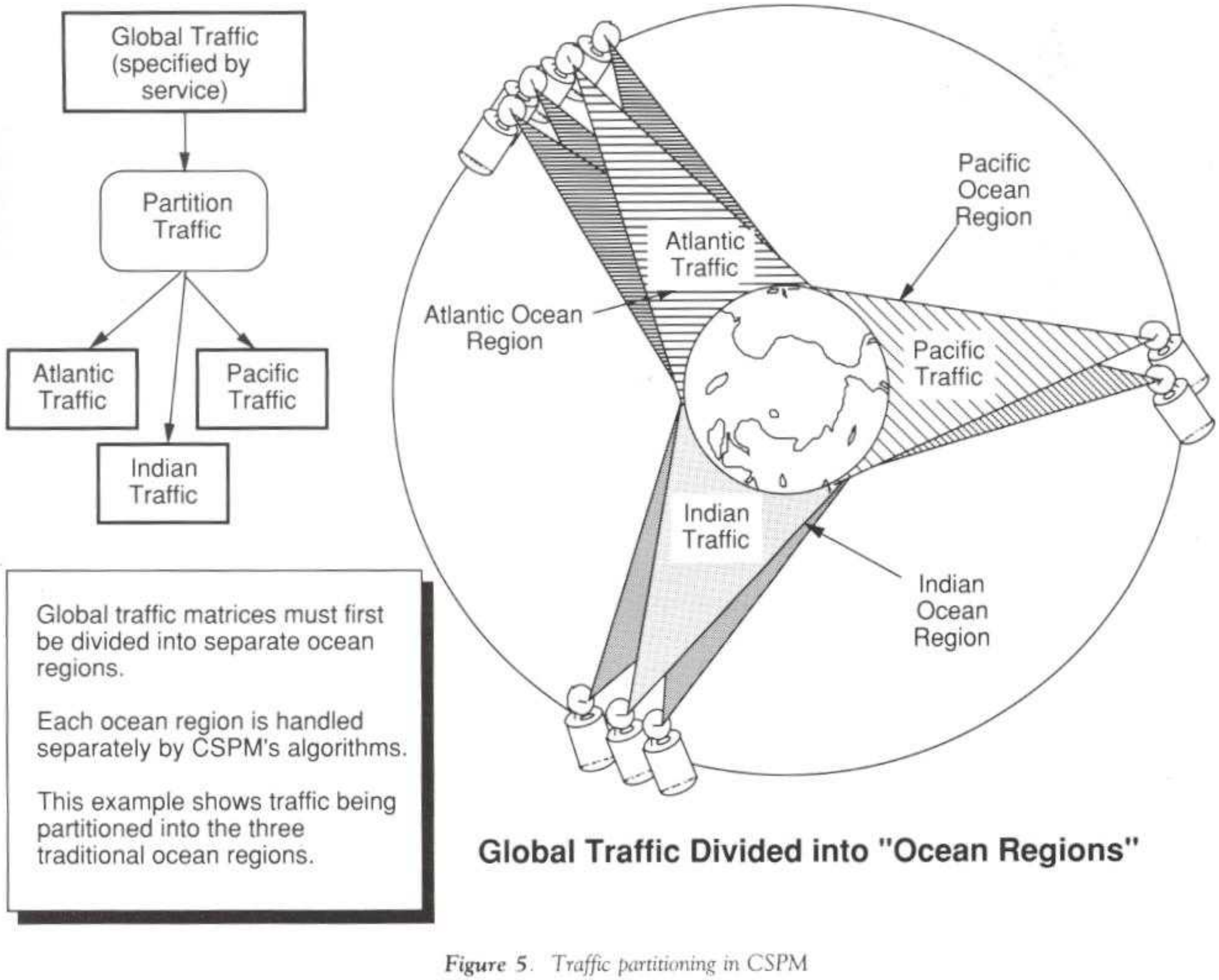


Figure 5. Traffic partitioning in CSPM

editing and manipulating the system and traffic data, the planner creates system configurations that are tested for feasibility or analyzed for performance (e.g., capacity) and cost. CSPM stores, manipulates, and analyzes all of these data.

Several analysis algorithms were implemented for CSPM. Traffic manipulation algorithms provide manipulation functions for traffic data including the addition, subtraction, scaling, and partitioning of traffic matrices (see Figure 5). A traffic routing algorithm divides system-wide traffic between the defined satellites in an ocean region to create traffic matrices for individual satellites. A traffic assignment algorithm assigns a satellite's traffic to specific transponders, resulting in a transponder loading plan and a summary report on capacity utilization. Finally, an economic model produces reports of revenue requirements and net present value.

An interface to the INTELSAT Satellite Services (ISS) Database Management Facility (IDBMF) allows the CSPM user to retrieve data from the central ISS database. The IDBMF contains actual and forecast traffic, as well as many of the basic parameters needed for describing a communications system. The ability to retrieve data from the ISS database significantly reduces the amount of data that must be entered by the CSPM user.

The CSPM software was implemented on an IBM mainframe using the Graphical Kernel System (GKS). The user accesses the program from a standard (unintelligent) graphics terminal. The user interface design incorporates many features commonly associated with intelligent workstations, including split screens, pop-up dialogs, scroll bars, and drop-down menus (Figure 6). The screens for CSPM that form the basis of its interface have control buttons, selection buttons, and editable fields. Each screen can view and edit a specific category of satellite system data or analysis algorithm parameters.

Most functions and commands are invoked using a drop-down menu system, but the user can invoke other frequently used functions related to viewing and editing the tables of data by selecting control buttons displayed on the screen. Scroll bars allow searching through the numerous tables of satellite system data. Several functions incorporated into the scroll bar make this process quick and easy.

Development of CSPM began in 1987 and the first version was completed at the end of 1988. During 1988, the CSPM interface was refined, links to the IDBMF were implemented, analysis algorithms for CSPM were completed, and the software helped to evaluate the new INTELSAT VII satellites proposed for the Pacific Ocean Region.

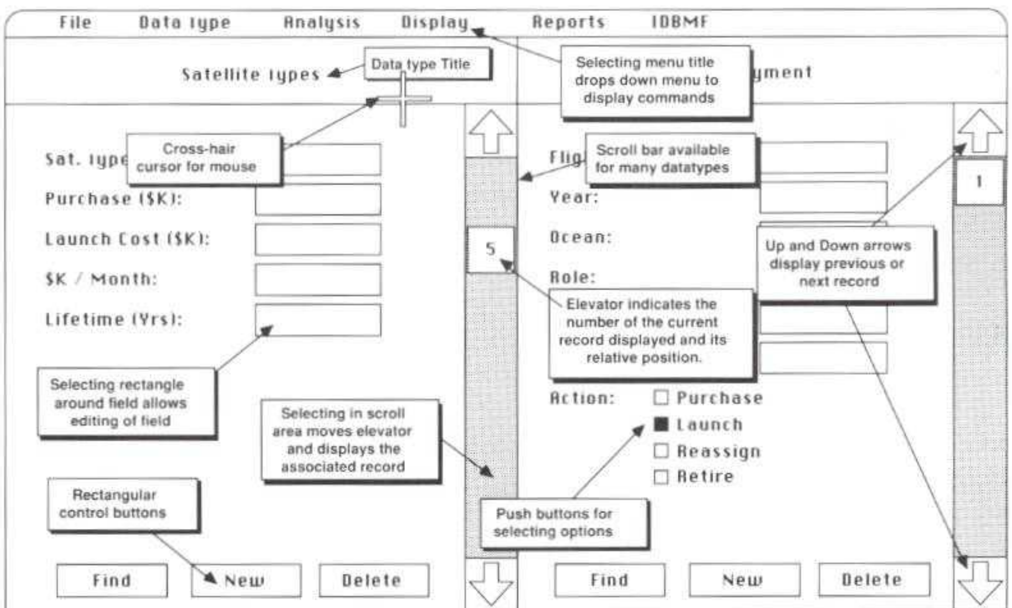


Figure 6. *Typical CSPM input screen*

ISS Database Management Facility

The IDBMF, as developed on an IBM mainframe, is the central repository for satellite system data within ISS, providing the ISS staff with current and accurate data for many planning, engineering, and marketing tasks. It also provides a set of defined reports and high-quality graphs for use in presentations and published documents, and supplies data directly to the CSPM.

Planning of the IDBMF was initiated and completed in 1987. In 1988, the system was implemented and made available for use.

Currently, the ISS database contains the following categories of data:

- Assistant Governor data
- Alternate Governor data
- country names and ITU codes
- Signatory data
- Board representation groups
- INTELSAT traffic actuals
- INTELSAT short-range traffic estimates
- INTELSAT long-range traffic estimates
- earth station data
- earth station antenna systems
- earth station standards
- satellite data
- satellite cost data
- satellite deployment records
- satellite configurations
- configuration descriptions
- orbital station data.

Many charts and reports based on data from one or more categories have been defined and are available to the user (Figure 7).

In 1989, augmentation of IDBMF is expected to include extension of existing categories as well as user support.

COMSAT Orbit Inclination Analysis Program

During 1988, SDD developed a baseline version of a software program to compute the effects of orbital inclination buildup for INTELSAT satellites by determining if a specified satellite in inclined orbit is visible to the

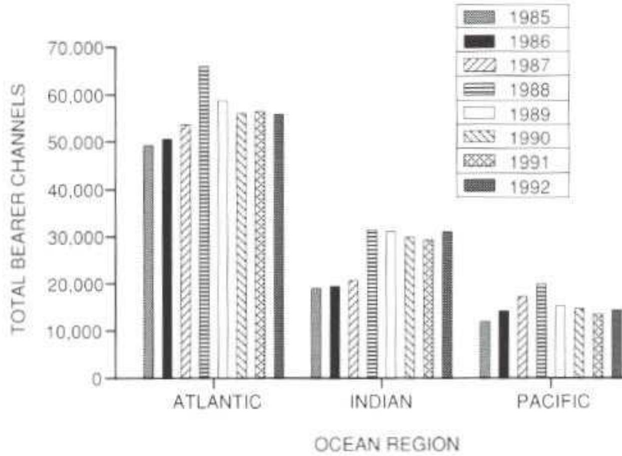


Figure 7. Chart generated by IDBMF

earth stations accessing it. The COMSAT Orbit Inclination (COIN) analysis program computes the elevation angles for these earth stations at regular periods over one complete orbit and compares these angles with a minimum acceptable elevation angle criterion.

In the baseline version of COIN, the user specifies only the satellite longitude and inclination, which the program uses to model a circular orbit with an arbitrary time origin. The program also reads a database of earth station descriptions that contains the locations of the earth stations accessing the specified satellite. Program output consists of a report listing those earth stations at which the elevation angles fall below the specified minimum acceptable angle at any time during one orbit. A distribution plot shows the earth stations that lose access to the satellite as a function of inclination. Plans have been proposed for extending the baseline version of COIN to accurately model inclination growth over time by more precisely modeling the satellite's orbit.

Interactive versions of COIN (written in PASCAL, with GKS to generate plots) have been developed for the IBM 370 VM/CMS system and for IBM PC-DOS computers.

ISS Software Support

SDD personnel often apply existing systems analysis tools to current problems to assist ISS staff with its daily tasks. Programs are often modified to produce special analyses or report formats. In addition, SDD provides training in the use of these tools to new ISS software users, and maintains a library of existing software tools and associated documentation for ISS.

In 1988 ISS published an INTELSAT Satellite Coverage Notebook that consisted of maps showing the antenna beam coverages for each of the current and planned satellites in the INTELSAT system. The coverage maps (as shown in Figure 8) were produced at the Laboratories using the Antenna Coverage Program (ACP). This task involved gathering data such as antenna pointing biases for each of the spacecraft and antenna gain data and modifying ACP to read this specially formatted data. SDD assisted ISS with formatting this notebook for publication. ACP also plotted INTELSAT VII coverages to aid in evaluating INTELSAT VII proposals.

INTELSAT VII transponder loading plans were developed using CSPM and verified that the new spacecraft had sufficient capacity to meet the projected INTELSAT traffic requirements. Tailored reports were frequently generated for traffic or earth station data contained in the IDBMF.

SDD also supported ISS in determining requirements for migrating existing systems analysis software to new computer systems.

Figure 8. *Plot from the Antenna Coverage Notebook*

Integrated Project Support Environment

During 1988, SDD developed a comprehensive, integrated environment for the management of major engineering development projects undertaken by COMSAT Systems Division (CSD) and COMSAT Laboratories. This Integrated Project Support Environment (IPSE) will assist project managers and staff members to ensure that the following objectives are met:

- All projects are completed on schedule and within budget.
- All applicable standards for development, documentation, and status reporting are followed.
- Complete records are kept for each project, including the deliverable documentation list, material list, module status reports, design and code walkthrough reports, test reports, discrepancy reports, action items, and project correspondence.
- An accurate list of system requirements is maintained, with each requirement traceable to one or more specific system components and to one or more specific test cases.
- All deliverable documents adhere to a common accepted standard for style and content, and the current version of each document is kept on-line and protected from unauthorized changes.

Thus, IPSE facilitates the tasks of each project team member and serves as a means of communication between them.

The IPSE environment consists of a network of Macintosh workstations, a VAX host computer, and a set of software tools residing on each. The IPSE local area network includes an Ethernet network interconnected with an AppleTalk network. The Ethernet network links the VAX host with CRT terminals, and permits the terminals to communicate with each other and with the VAX host. The AppleTalk network links the Macintosh workstations with each other and with a Macintosh file server and laser printers. An asynchronous server attached to the AppleTalk network permits remote users to access the network through a dial-up telephone line. A gateway is provided to link the AppleTalk network with the Ethernet network.

Users of the IPSE system are provided with a comprehensive set of software tools, including tools for software implementation, project management, analysis, and documentation. These resources reside on the IPSE workstations, the scanner station, the Macintosh file server, or the VAX host computer.

SCOPE

The user interface to the Macintosh workstations is provided by the SCOPE program, which was developed by SDD using HyperCard, an icon-based information management facility. In HyperCard, information is stored on cards, which are organized into stacks. Figure 9 shows the stacks included in SCOPE, along with application programs that are invoked and the documents associated with each application. The format of a typical SCOPE stack is shown in Figure 10.

SCOPE provides easy access to all IPSE functions, while maintaining a database of all project information. For proposal preparation, SCOPE maintains the resumes of all technical personnel in the resumes stack on the file server. The current labor rates (including overhead and G&A) for each labor category within each technical organization are stored on the labor rates stack, which is also kept on the file server. The proposal manager and cost account managers have access to these

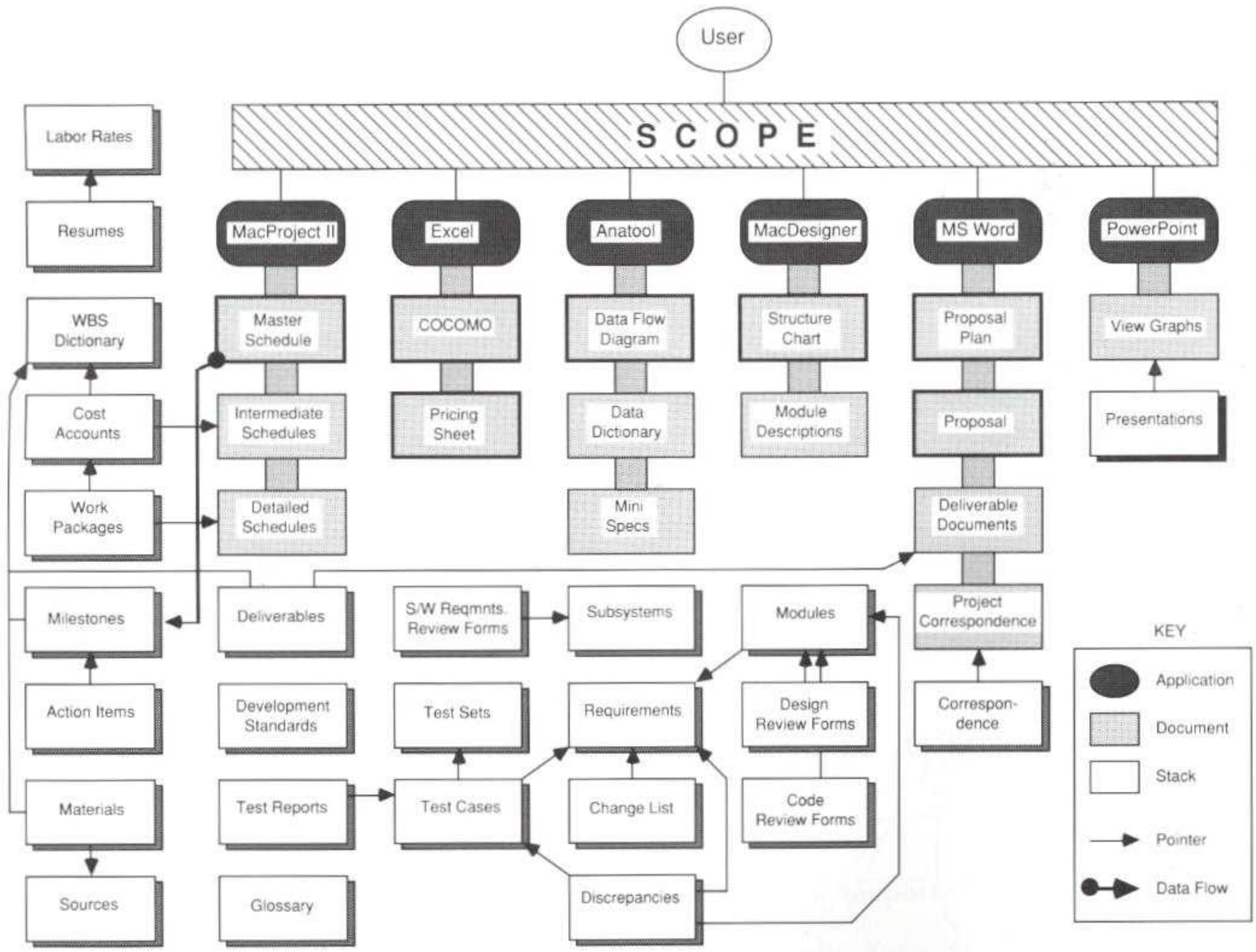


Figure 9. SCOPE overview

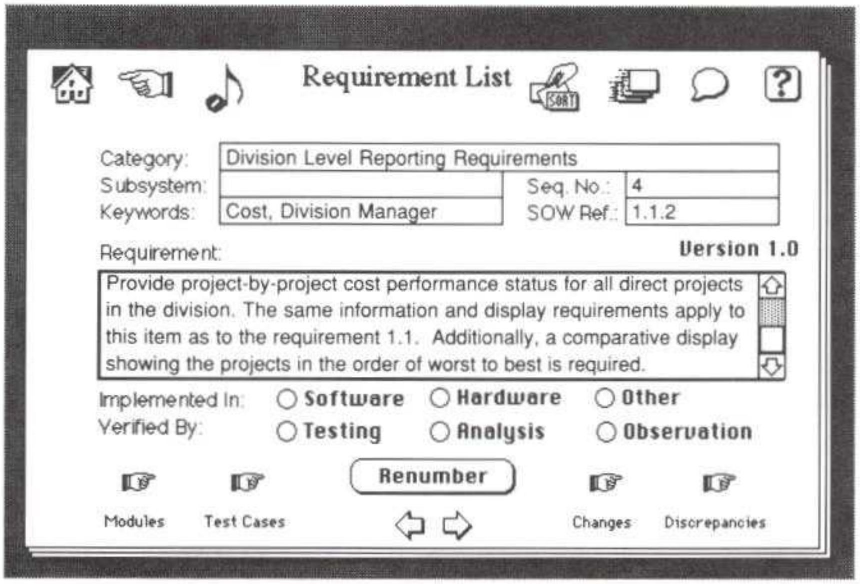


Figure 10. *Typical SCOPE stack*

rates when filling in the pricing sheets, which are Excel documents accessed through SCOPE.

The Constructive Cost Model (COCOMO) is maintained on another Excel document that is accessed through SCOPE. The proposal manager can use COCOMO to obtain an estimate of software development costs and schedule for any project involving software development.

The proposal manager has on-line access through SCOPE to all documents generated in the proposal phase, including the proposal plan, the technical proposal, and the management proposal. SCOPE can store and maintain common (boilerplate) information for these documents on the file server.

SCOPE maintains current descriptions of development standards in the development standards stack on the file server. The name of each distinct project phase is identified in the phases stack, along with a list of the activities to be performed during that phase and the deliverables required at the end of that phase. For each activity identified in the phases stack, a brief description is provided in the activities stack, along with references to any relevant development standard documents. In addition, a brief description of each deliverable identified in the phases stack is provided in the deliverables stack, along with references to any relevant development standard documents. The software coding standards are defined in the coding standards stack.

At the start of the project, the project manager can prepare a project plan that identifies the activities to be performed and the resources to be applied to the project. The project organization chart is maintained on a MacDraw document accessed through SCOPE. Standard project management tools such as MacProject and ARTEMIS are accessed through SCOPE as well. SCOPE also maintains a list of major project milestones in the milestones stack, which can be automatically updated with information from the project management tool. SCOPE contains additional stacks for entering the work breakdown structure (WBS) dictionary, cost accounts, and work packages.

The proposal manager can generate a complete list of system requirements and enter them in the SCOPE requirements stack. Changes to the requirements after contract award are entered in the change list stack, along with pointers to the requirements affected. SCOPE has a facility for verifying that:

- for each system requirement implemented in soft ware, one or more software modules are specified that address this requirement
- for each system requirement verified by testing, one or more test cases are specified that address this requirement.

SCOPE's action item stack maintains a list of action items arising from formal meetings with the customer or informal requests by the customer as well as action items generated by the project staff. A list of all contract deliverables is kept in the deliverables stack. All deliverable documents adhere to the standard style defined in the SCOPE document template. The project manager maintains a list of all materials to be acquired and delivered to the customer in the material list stack. A list of manufacturers and vendors is found in the equipment sources stack maintained on the file server.

SCOPE provides a number of tools and stacks to facilitate the software development phase. Software requirements analysis is performed by AnaTool, which generates a hierarchical set of data flow diagrams, a data dictionary, and a set of standard specifications. Software design is performed by MacDesigner, which generates a hierarchical set of structure charts, module prologues, and program design language (PDL) descriptions of each module.

All software subsystems identified in the data flow diagrams are included in the subsystems stack, which can track the status of software requirements analysis for each subsystem. Software modules identified in the structure charts are included in the modules stack, which can track the status of design and coding for each module. The software QA manager invokes the review forms stack to enter the results of each internal review (analysis, design, or code walkthrough) and to track the status of changes requested during the review.

A number of implementation tools are provided on the VAX host, including source code templates, language-sensitive editors, and program analyzers.

The integration and test manager enters each test case and test procedure in the test cases stack and enters the results of all formal (witnessed or unwitnessed) tests in the test reports stack. Separate test cases and test reports stacks are maintained for each phase of testing. All discrepancy (or trouble) reports are entered in the discrepancies stack, and this list is updated with information regarding the status of the discrepancy report .

The IPSE system, including SCOPE, has been installed at COMSAT in Clarksburg and currently serves users in both SDD and COMSAT Systems Division (CSD). Experience gained in applying SCOPE to current development projects determines whether further enhancements are required, and also whether COMSAT will make SCOPE available to external users.

Ada Software Development Environment

Ada is a modern computer language designated by the Department of Defense (DoD) as the official language for all future software projects. Ada supports two basic software engineering principles: abstraction and information hiding. Ada is a strongly typed language (with respect to definitions of variables) and has strict cross-checking of interfaces. Furthermore, it is a highly portable language that provides a software development environment that is independent of the computer and the operating system. Thus, software developed in Ada tends to be error free, highly modular, and reusable, which significantly increases software productivity and decreases maintenance costs.

COMSAT will soon develop Ada software or integrate software developed by subcontractors or supplied by vendors. In any case, COMSAT must acquire expertise in managing all aspects of an Ada software project. A fully integrated Ada Project Support Environment (APSE), including an appropriate software engineering methodology, is the first step toward this goal.

By the end of 1988, COMSAT personnel had received Ada language training and attended several seminars on Ada project management, DoD requirements for Ada software, and Ada software design methodologies. Several Ada compilers were tested to select a compiler suited to COMSAT's needs and two medium-sized Ada programs were written and tested to gain some practical experience in Ada software development. Finally, a preliminary report was prepared that surveyed existing Ada software development methodologies, including Object Oriented Design (OOD), the Process Abstraction Method for Large Embedded Applications (PAMELA), and the Extended Buhr Development Method (EBDM).

INTELSAT SUPPORT

Fixed TDMA Burst Time Plan Software

SDD continued to maintain and enhance the fixed TDMA Burst Time Plan Generation (BTPGEN) software system for INTELSAT in 1988. This system consists of four programs used to develop network burst time plans, individual earth station master time plans (MTPs), and condensed time plans (CTPs) for the INTELSAT fixed TDMA system. Major developments in 1988 consisted of modifying the software to accommodate direct digital interface (DDI) modules and digital circuit multiplication equipment (DCME). In addition, all documentation on the software system was revised and reissued.

Satellite-Switched TDMA Burst Time Plan Software

SDD began developing the Satellite-Switched Master Time Plan/Condensed Time Plan (SSMTP/SSCTP) software system for use with the forthcoming INTELSAT SS/TDMA system (Figure 11). The SSMTP/SSCTP software system consists of two programs used to generate MTPs and CTPs for each individual earth station, a switch state time plan (SSTP), and a diagnostic processor time plan (DPTP) for an INTELSAT SS/TDMA network. The software is being developed on INTELSAT's IBM mainframe under the MVS/TSO operating system. The Generate Satellite-Switched Parameters (GSSPARM) program was developed to generate simulated SS/TDMA network parameters that are required by the SSMTP/SSCTP software.

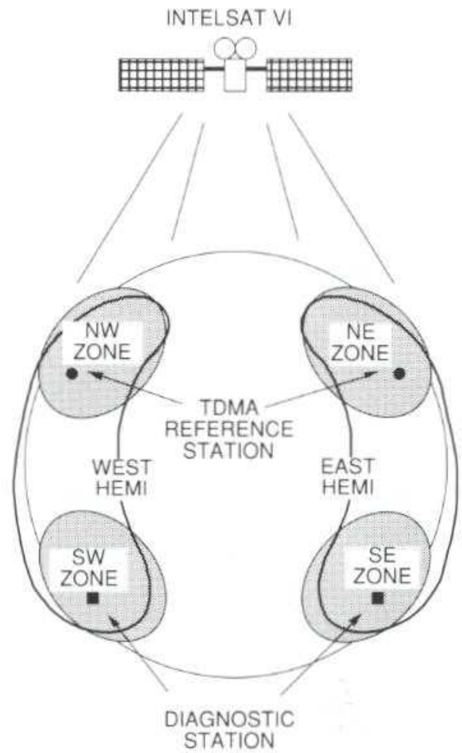


Figure 11. INTELSAT SS/TDMA coverage areas

Since 1984, the Advanced Communications Technology Satellite (ACTS) program has been under development by the National Aeronautics and Space Administration (NASA). Under direct contract to NASA, COMSAT is responsible for developing the NASA ground station (NGS) and the master control station (MCS). Signficant accomplishments recorded in 1988 include the NGS/MCS hardware and software developments required to implement the ground control and operational equipment needed at NASA Lewis Research Center (LeRC). General Electric's (GE's) AstroSpace Division, the spacecraft contractor, is well on the way to meeting its requirements. The overall goal of developing basic technologies to ensure the continuing preeminence of U.S. technology in the satellite communications industry is being realized. By combining its outstanding technical resources with a highly effective program management team, COMSAT Laboratories is demonstrating that it is capable of assembling and managing a large systems development and integration program.

ACTS PROGRAM MANAGEMENT OFFICE

In January 1988, NASA restructured the entire ACTS program in order to streamline relationships with contractors and to control costs. In accordance with Congressional direction, the program cost was capped, with each contractor to assume all responsibility for any cost exposure that exceeded the cap.

NASA established a reporting relationship with COMSAT as prime contractor (NAS3-25084) for the NGS and MCS that replaced COMSAT's subcontractor relationship through GE's AstroSpace Division. However, the COMSAT subcontract with Motorola for the ground modem equipment was assigned directly to GE.

In conjunction with these changes, NASA modified the program schedule. The launch date was postponed to May 1992; delivery of the NGS/MCS to GE and subsequently to NASA's Lewis Research Center was delayed accordingly.

COMSAT completely reestimated the cost of the restructured program in order to establish a cap value and to determine the effect on cost of the delay in delivery of equipment and subsequent launch of the satellite.

Work remaining on each technical element of the program was reexamined and replanned to minimize cost and to coincide with the delayed schedule. A revised program plan was prepared and submitted to NASA in the third quarter of the year. COMSAT has been working according to this new plan since July 1, 1988.

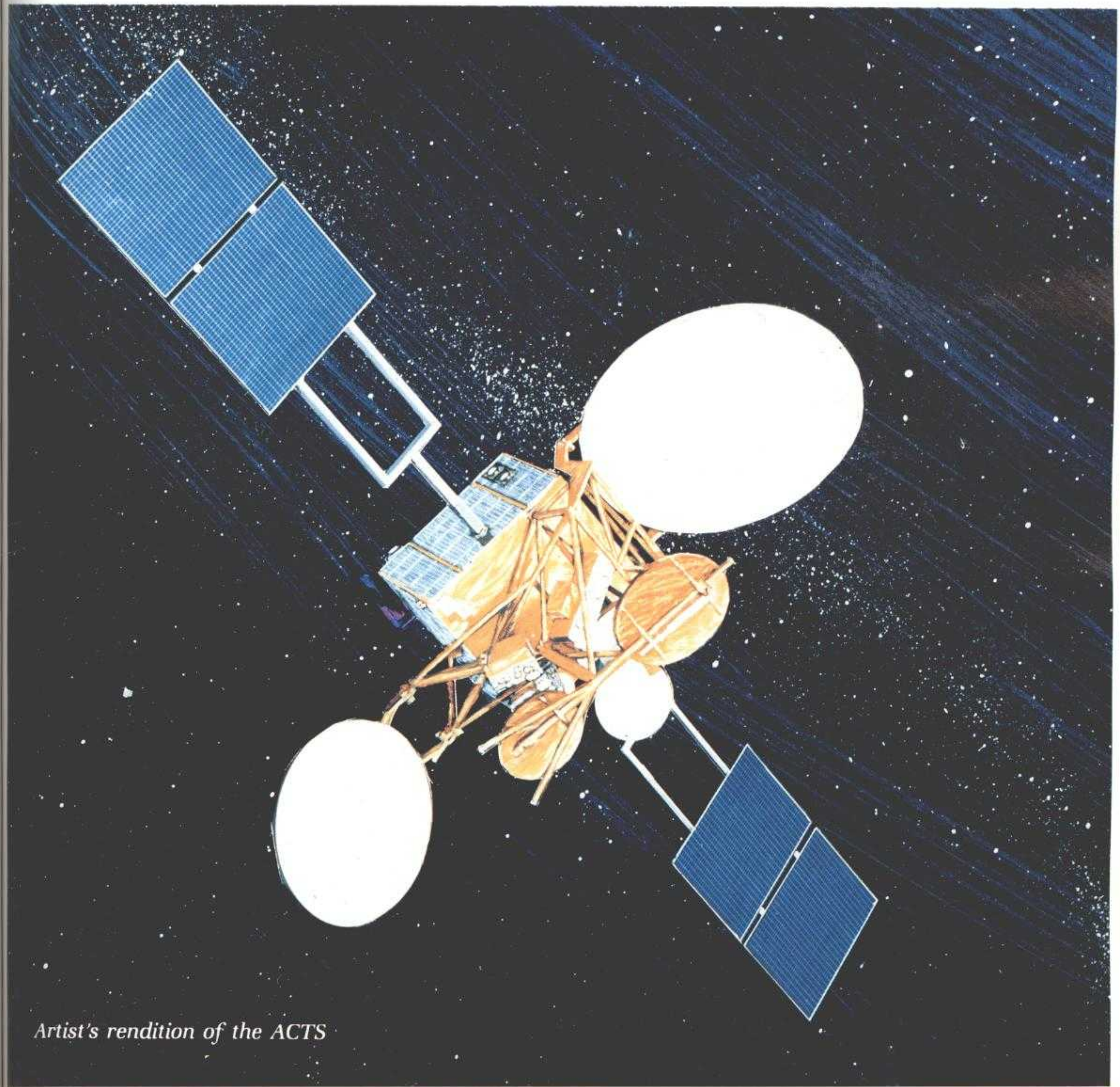
The ACTS Program Management Office (PMO) directs the program within COMSAT Laboratories, and manages the interface NASA. The PMO includes the technical managers of each of the major elements of the program, as well as cost and schedule control managers and staff.

Technical managers operate with counterparts in the various functional organizations, defining and scheduling the work to be accomplished and the resources required. Upon agreement, these parameters are entered into a computer-based ARTEMIS cost and schedule control system, which produces system and subsystem schedule networks and detailed cost projections for each element of the program. This information is continually monitored and updated, distributed to various COMSAT management levels, and reported on a regular basis to the customer.

The PMO was instrumental in directing, coordinating, and supporting the development of this plan. Completely new schedule networks were constructed and refined until all timetable constraints were met. New cost estimates were developed for each segment of the work breakdown structure to determine new budget and estimate-at-completion amounts associated with increasing the duration of the program.

Because of the uncertainty surrounding the NASA course of action and the new ground rules associated with the restructured program, the COMSAT staffing levels were deliberately held in check until new cost and schedule estimates could be developed. Consequently, instead of the work effort reaching a peak during 1988, staff levels remained relatively constant vis-a-vis 1987 levels, with approximately 20 percent of the total Laboratories' staff engaged in ACTS-related activities.

ACTS



Artist's rendition of the ACTS

Systems Engineering

COMSAT's systems engineering role in the ACTS program includes responsibility for the engineering, analysis, integration, and testing associated with COMSAT's deliverable hardware and software. A second responsibility is the direct engineering and analytical support of NASA as prime contractor, a role that involves substantial interaction on technical matters with NASA and other program subcontractors. Both roles draw heavily on the Laboratories' technical resources and have led to significant engineering and analytical contributions.

During 1988, with the restructuring of the ACTS program, NASA formalized the technical interactions among subcontractors by instituting working groups to coordinate the implementation of the overall ACTS system. Each working group is chaired by NASA and focuses on a specific technical area, e.g., the programming and control of the multibeam communications package aboard the ACTS spacecraft. The working group provides a forum in which technical interface issues are discussed and resolved. Related contractual issues are resolved separately between subcontractor PMOs. Each working group also maintains an interface control document (ICD) as the governing document over the technical area for which the group is responsible. In 1988, COMSAT was heavily involved both in the initiation of the several working groups relating to the ACTS ground segment and as a participant in them. As the implementation of the ACTS system proceeds, the critical system engineering coordination function performed by the working groups will continue to grow in importance.

With system development efforts nearing completion, the systems engineering focus has shifted toward the integration and test (I&T) phase, which will lead to the verification of system performance. A major effort has been the ongoing development of a comprehensive I&T plan for the COMSAT portion of the ACTS Ground Segment. Because of the unique complexities of evaluating a satellite-switched communications system, COMSAT's test activities are significant to the total ACTS program. Whereas analog repeater systems permit the loopback of test signals through spacecraft transponders, satellite-switched systems, with their essentially independent up- and down-links, place new demands on communications systems test programs and require rethinking of classical spacecraft communications test techniques. The technical challenge is further compounded by the hopped spot-beam antenna coverages and the digital regenerative repeaters of the ACTS spacecraft.

In the I&T process, the major subsystems will be tested separately by the internal COMSAT engineering groups developing them, prior to delivery of the subsystems to the system I&T process. When delivered, the subsystem elements will be integrated into the NGS/MCS system residing in the ACTS system test facility at COMSAT Laboratories. The equipment ensemble will include the Ka-band RF terminal equipment developed by the Microwave Technology Division (MTD), the MCS computer equipment and software, developed by the System Development Division (SDD), and two sets of TDMA terminal equipment developed by the Network Technology Division (NTD).

The equipment ensemble will also include government-furnished equipment (GFE) produced by other ACTS subcontractors. This equipment, required to exercise and test the COMSAT ground segment equipment, includes modems produced by Motorola for use with the low burst rate (LBR) TDMA subsystem, special test equipment for those modems, a spacecraft simulator produced by GE and TRW (the engineering model of the ACTS spacecraft communications payload), and support equipment for the spacecraft simulator to permit monitoring and control of the simulator via a simulated TT&C channel.

The functionality and correctness of the interfaces between subsystem elements will be verified as these elements are integrated into the system. When the integration process has been completed, the entire ensemble of equipment will be exercised together in a series of functional and performance verification tests designed to verify compliance of the COMSAT ground segment equipment with the requirements of the ground segment performance specification.

The I&T tests at COMSAT will verify the complex, multifaceted operation of the LBR network, including MCS control of network and spacecraft functions, dynamic message routing and demand assignment of channel capacity, fade compensation and housekeeping functions of status monitoring and data logging for ground segment equipment, space segment equipment, and network operations. This test approach provides preliminary data on the functioning of the overall ACTS

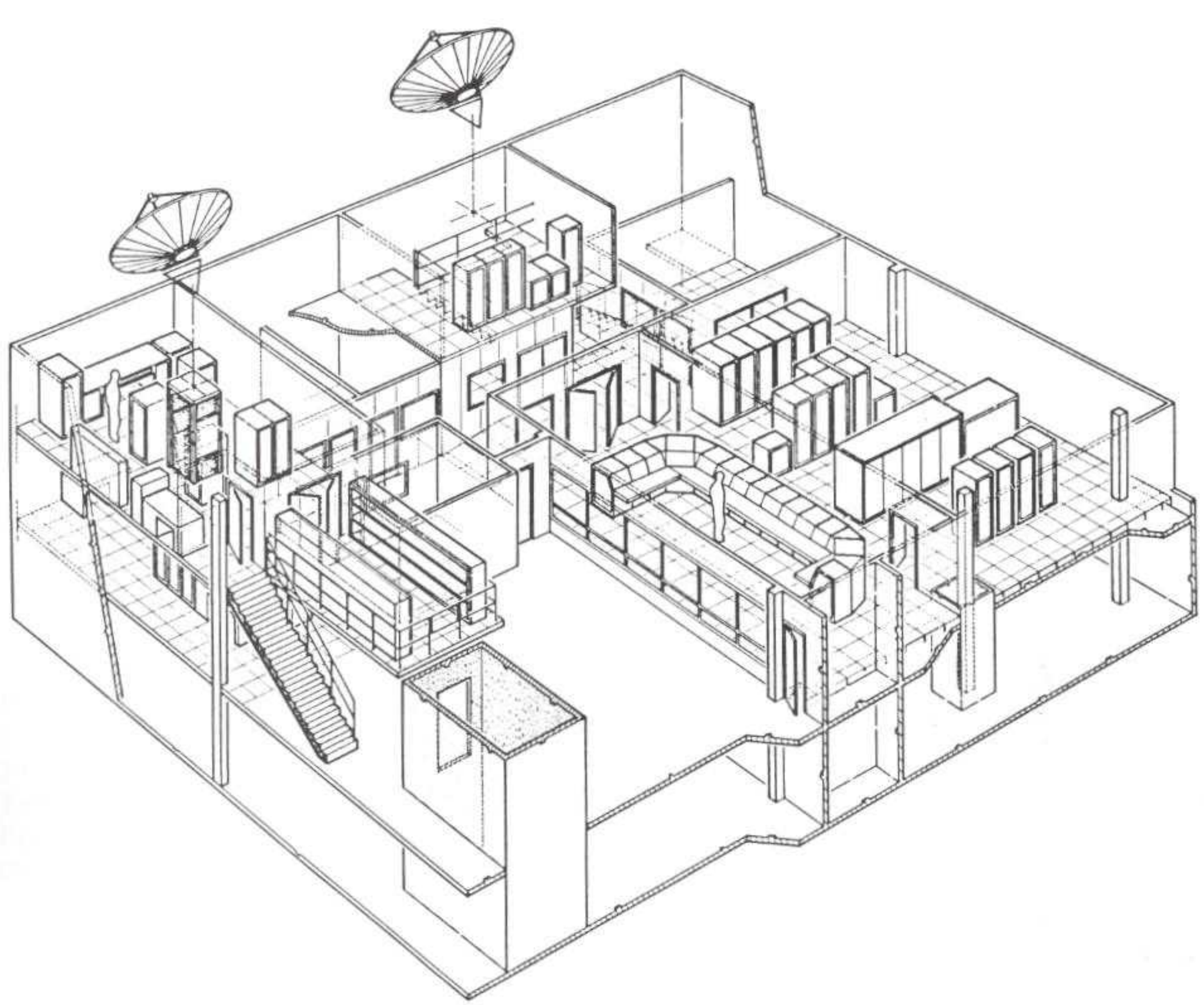


Figure 1. NGS/MCS equipment layout at NASA LeRC

eight deliverable subassemblies were complete, including all the operational up- and down-converters for both the communications and TT&C signals.

Figure 2 shows assembly work in progress on the second production command up-converter plate. This up-converts a 70-MHz signal to the 29.975-GHz transmit frequency. Figure 3 shows testing of the production LBR up-converter, which up-converts the 3-GHz output from the modulators to the 29.26-GHz transmit frequency.

The design, assembly, and test of the loopback subassemblies have been ongoing activities this year. These loopback subsystems will be used to complete all the signal paths that are incomplete in the absence of the spacecraft. They will be used to test and troubleshoot the completed station. In addition, they will be used extensively during the station I&T phase, when the satellite signals are not available.

As the number of completed subassemblies increased, work began on the RFT I&T phase. Racks that ultimately will be installed at LeRC were procured, rack layouts were developed, and equipment was installed in the racks.

The need to measure rain fade attenuation using signals transmitted from the spacecraft has presented special challenges. Measurements of rain fade attenuation using spacecraft signals generally employ dedicated beacons. In the ACTS system, the requirement is for two of the three rain fade attenuation measurements to utilize modulated spacecraft carriers and beacons. The modulation may be that associated with digital telemetry, analog telemetry, or ranging tones. The need to extract fade data from these modulated carriers over a wide dynamic range has required the development of innovative circuits and techniques that were completed in early 1988.

During 1988, changes to characteristics of these down-link fade beacons were made by the customer. Using new measurement technology developed as part of an R&D program, COMSAT was able to respond to these changes and, concurrently, to simplify the original design. Following COMSAT's new approach, commercially available equipment could accommodate the customer changes and, in addition, could perform functions for which, in the previous plan, specialized custom circuitry was required. The change reduced the technical risks to the program and simplified the hardware to be fabricated.

The RFT performs many of its functions, and is monitored, under computer control. The functions are controlled by the RFT supervisor, an HP 9000/350C computer. Other elements of the digital circuitry are located in the rain fade measurement equipment, antenna control unit, and experiment measurement equipment. Most of the hardware has been procured, and the software is under development.

Parts of the RFT were developed outside COMSAT in parallel with hardware being developed at COMSAT Laboratories. Subcontracts being monitored by COMSAT for modem equipment and for LBR transmitters were in place at the beginning of 1988. During the year, GE assumed the modem subcontract responsibility. However, COMSAT will still be involved in monitoring the progress of the modems until they are delivered to COMSAT as GFE.

The LBR transmitter subcontract came close to completion with the delivery to COMSAT of three 50-W, 30-GHz transmitters at year's end from Hughes Aircraft Co. During 1988, significant work was done in planning the procurement of, and seeking potential vendors for, the command transmitter, with the objective of placing a subcontract for that transmitter. During 1988, NASA reduced the command transmitter e.i.r.p., permitting the command function to be performed by a transmitter conforming essentially to the LBR design. Consequently,

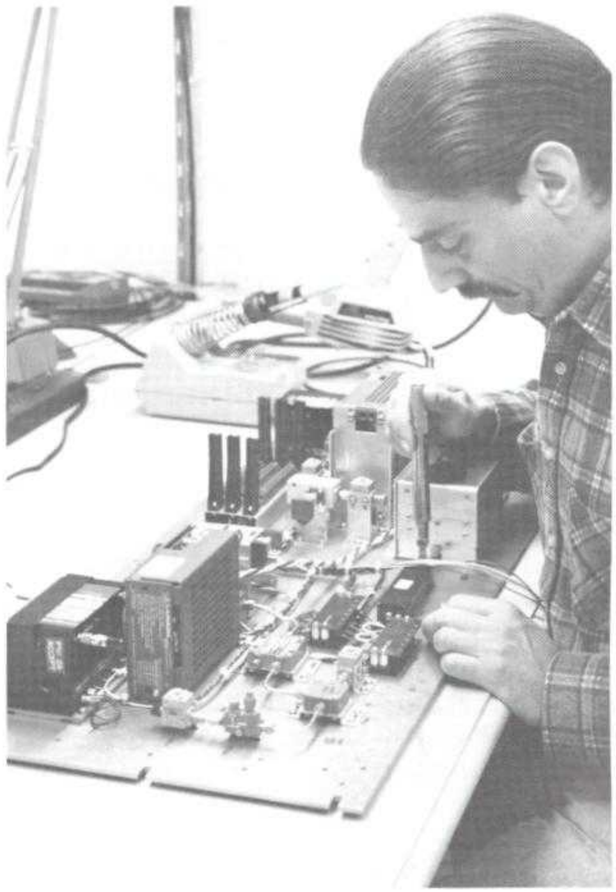


Figure 2. *Assembly of a command up-converter*

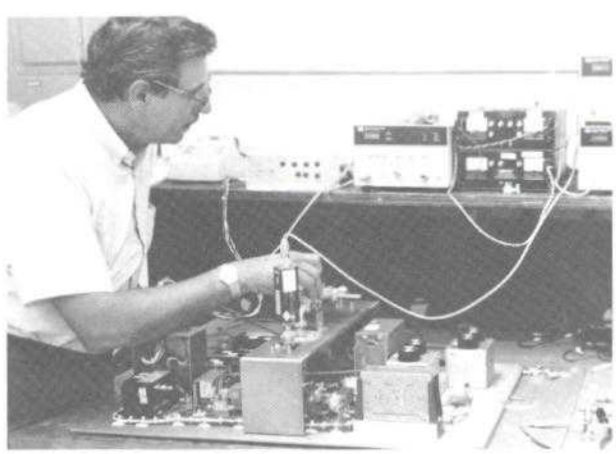


Figure 3. *Testing of the LBR up-converter*

the separate LBR and command transmitter rack designs were combined into a single rack, and a new subcontract for a command transmitter became unnecessary.

TDMA TERMINAL DEVELOPMENT

COMSAT Laboratories is developing two TDMA terminals that will be integrated into the ACTS NGS: a 110-Msymbol/s TDMA terminal serving as both the LBR reference terminal and as a traffic terminal; and a 27.5-Msymbol/s TDMA terminal serving as a stand-alone traffic terminal. The reference terminal acquires and synchronizes to the satellite's baseband processor (BBP) generated TDMA frame to transfer the MCS control and status orderwire channels to the BBP and to the LBR terminals. The reference terminal preprocesses these orderwire channels, which have a combined maximum rate of 1.476 Mbit/s. The reference terminal also continuously compares the BBP on-board clock drift to a local frequency standard, and periodically reports deviations to the MCS. The MCS then up-links frequency corrections to the BBP to maintain network clock stability.

The traffic terminals acquire and synchronize to the BBP TDMA frame to interconnect experimenter terrestrial circuits to the LBR network. The 110-Msymbol/s terminal provides service for eight T1 interfaces operating at 1.544 Mbit/s and six interfaces operating at 6.312 Mbit/s. The 27.5-Msymbol/s terminal provides service for four T1 interfaces and two 6.312-Mbit/s interfaces. Together, the terminals can interface 1,072 64-kbit/s equivalent voice channels to the LBR network. Call-processing functions within the terminals provide for both single-channel dynamic routing using dial digits and multichannel trunk routing in either point-to-point or broadcast connections.

NTD has primary responsibility for TDMA terminal development, ranging from architectural concept, through design and production and subsystem acceptance testing. NTD will also provide support during system integration and acceptance testing.

The design of the forward error correction (FEC) decoder module was developed by CTD. This module uses an large scale integration (LSI) decoder circuit and provides some on-board self-testing features.

NTD has developed a TDMA design and documentation methodology that is structured in a six-level, top-down hierarchy. The highest levels include external interface specifications and major subsystem functional partitioning. Middle levels include analyses to derive lowest level functional elements in terms of hardware/software partitioning and trade-offs to map functional requirements into the physical implementation. The lowest levels include detailed electrical design of hardware using computer-aided engineering work stations, logical design and coding of embedded microprocessor software, and overall I&T of the terminals. This meticulous top-down approach ensures that the design implementation fulfills all program requirements.

Figure 4 is a functional block diagram of the 110-Msymbol/s terminal design. The 27.5-Msymbol/s design is identical except for deletion of the transmit and receive MCS interfaces. The terminals are partitioned into two major subsystems, the terrestrial interface equipment (TIE) and a TDMA burst controller. The major functional requirements for each are as follows:

TIE

- *T1 and 6.312-Mbit/s Interfaces.* Provide terrestrial line interface, plesiochronous buffering of channel data, and T1 supervisory signaling processing.
- *Transmit and Receive Bus Controllers.* Provide digital switching of channel data to/from the burst controller or the signaling extraction/signaling generation (SXU/SGU) hardware under call processor control.
- *SXU/SGUs.* Provide dual-tone multifrequency selective signaling reception/transmission to/from experimenter channels for dynamic single-channel routing in the LBR network.
- *Receive and Transmit Traffic Buffer Interfaces.* Buffer channel data for high-speed transfer to/from the TDMA burst controller.
- *Demand-Assigned Multiple-Access Call Processor.* Processes supervisory and address signaling to/from experimenter channels, sends and receives orderwire messages to/from the MCS to acquire and release satellite capacity, dynamically routes channel data to/from the burst controller, and maintains call records for operator status display.

TDMA Burst Controller

- *Receive and Transmit MCS Interfaces.* Provide high-speed transfer and preprocessing of orderwire

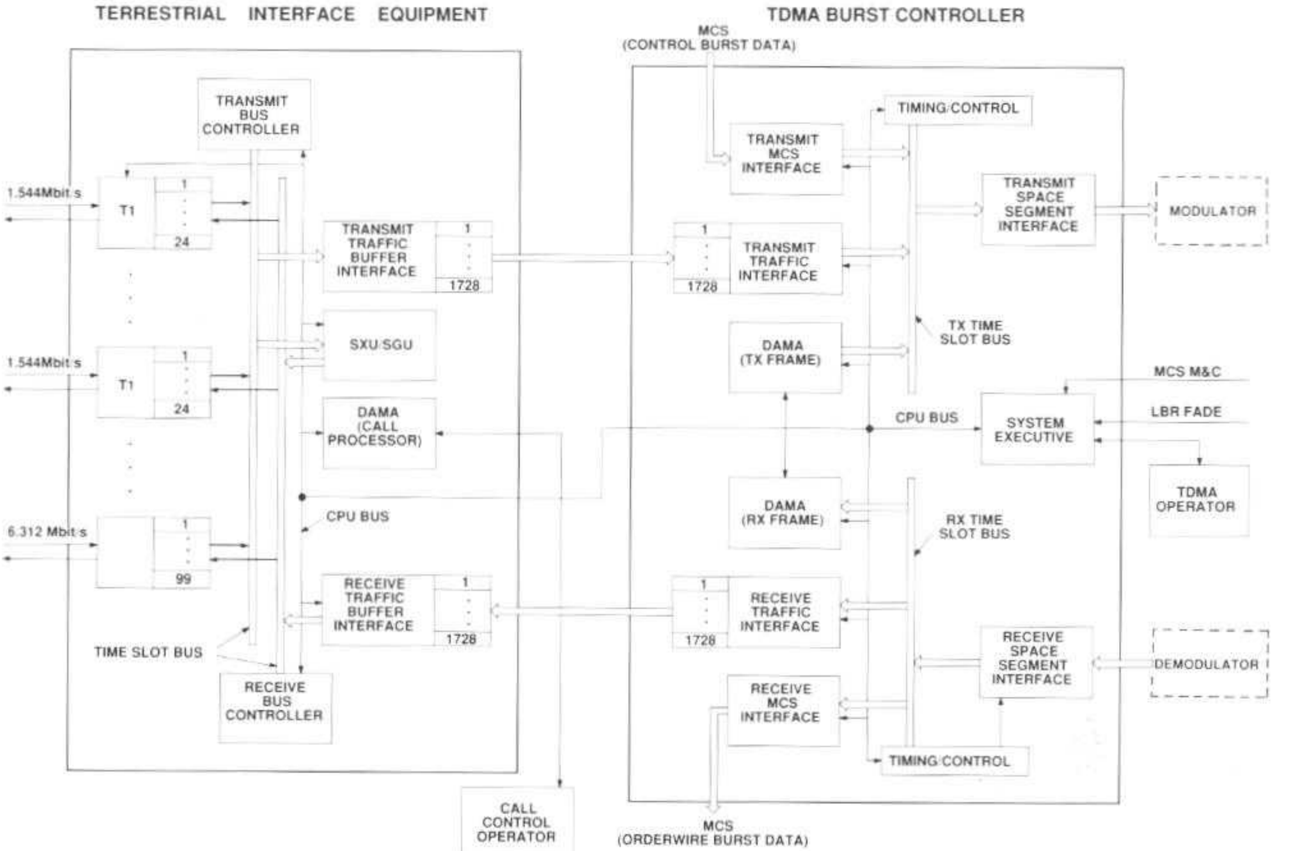


Figure 4. *NGS TDMA terminal functional block diagram*

channels to/from the MCS, as well as the BBP and traffic terminal network.

- *Receive and Transmit Traffic Interfaces.* Buffer channel data to/from the TIE and route channels into MCS-assigned satellite slots.
- *DAMA (Receive and Transmit Frame Management).* Dynamically alters TDMA frame structure and traffic slot assignments in response to MCS orderwire commands, and performs synchronous burst time plan changes.
- *Receive and Transmit Timing and Control.* Acquires and maintains synchronization to the BBP TDMA frame.
- *Receive and Transmit Space Segment Interfaces.* Multiplex/demultiplex channel data to/from the TDMA bursts at either the 110- or 27.5 Msymbol/s serial rates, and provide FEC encoding/decoding at rate = 1/2 and constraint length, k = 5.
- *System Executive.* Provides overall terminal monitoring and control, processes MCS monitor/control and LBR fade data links, and interfaces to the terminal operator for commands and status displays.

The terminal design presented in Figure 4 represents a carefully balanced selection of digital hardware and microprocessor software components. High-speed digital logic and carefully engineered digital interconnection backplanes ensure error-free and reliable performance. The extensive use of programmable array logic (PAL) hardware and microprocessor software ensures a design that can be easily adapted to the needs of NASA's experimental program, as well as to the operational requirements of future commercial terminals in the ACTS system.

Overall, the TDMA terminal design requires 45 unique hardware module designs and 78 software processes. During 1988, over 60 percent of the hardware schematic designs were completed. Fabrication and assembly of hardware modules began in 1988 and will continue throughout 1989. Figure 5 shows testing progress on three modules in a prototype chassis. The TDMA subrack backplanes were designed, fabricated, assembled, and tested. This monolithic printed circuit backplane is a COMSAT design based on the VME-Bus standard. Figure 6 shows the mechanical CAD design and physical

Figure 5. *TDMA build-1 testing*

Figure 6. *TDMA subrack chassis*

realization of the burst controller backplane mounted in a subrack chassis. This backplane simultaneously passes transmit and receive data at rates up to 110-Mbit/s. Testing showed error-free performance.

A test set for the FEC decoder was completed by CTD. This test set permits extensive systematic testing of the error correction performance for the ACTS downlink FEC decoder module.

Sixty-five percent of the program description language for the firmware modules was completed in 1988. Firmware coding is 48 percent complete and 20 percent of the code has been tested. This coding uses an NTD-developed State Machine Generator utility program that has proven highly successful in creating C-language code from high-level state machine descriptions. All code for ACTS TDMA microprocessors is designed to run in the COSMOS (an NTD-developed real-time executive program) operating environment.

TDMA terminal operator consoles are based on NTD's Virtual Console System (VCS) and Macintosh II computers.

MCS DEVELOPMENT

Figure 7 is a functional block diagram of the MCS, which is responsible for the real-time control and monitoring of the ACTS LBR communications networks, as well as associated control of the ACTS payload, including the BBP. It also supports ACTS experiments by controlling system configuration parameters and managing recorded data.

The MCS, implemented entirely in software hosted on a VAX 8600 super-minicomputer consists of the following software subsystems:

- *LBR Network Control.* Provides real-time monitoring and control of ACTS LBR networks, call-by-call DAMA functions, adaptive fade compensation, control of terminal acquisition, and recording of network performance data.
- *MCP Telemetry and Control.* Provides real-time monitoring and control of the ACTS MCP (including the BBP, the scanning beam antenna, and the MCP master oscillator), and operates in conjunction with the LBR network control subsystem.
- *RFT Interface.* Records RF measurements made by the NGS RFT.
- *Experiment Configuration Support.* Provides off-line functions to configure the MCS and MCP for specific experiments.
- *Experiment Data Processing.* Provides off-line management of data recorded by the MCS during ACTS experiments.
- *Executive and Utilities.* Controls the startup and shutdown of the MCS, and provides a library of reusable utility routines.
- *Test Support Software.* Provides nonoperational test software consisting of simulators used in testing the LBR, MCP, and RFT subsystems.

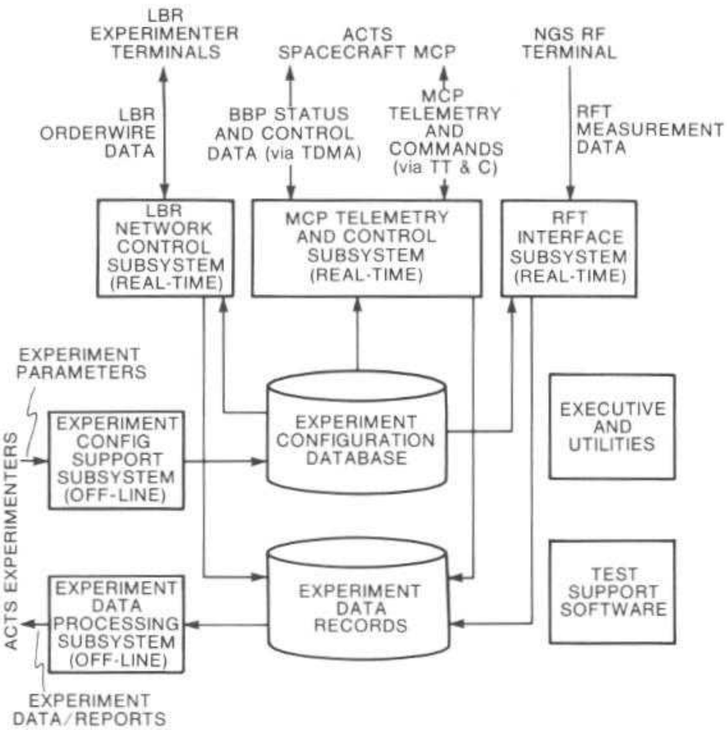


Figure 7. *MCS functional block diagram*

The DAMA functions performed by the MCS use several algorithms, depending on the type of connection required (single- or multichannel, single- or multidestination, etc.). The development of these algorithms required careful consideration of conflicting objectives and constraints, including response time, frame utilization, BBP operational constraints, recovery from errors in control messages, experimental flexibility, and implementation cost.

In particular, the requirement to provide call setup times on the order of 3 to 5 seconds, and the complexities of programming the BBP, offered significant technical challenges to the ACTS MCS and TDMA teams. Several simulation programs were developed to test and refine alternative approaches to the DAMA problem. The resulting system design and algorithms developed by COMSAT will fully demonstrate the flexibility and efficiency available in a TDMA network with an on-board baseband switch . A first release of the MCS DAMA software was completed and tested by the end of 1987. This release provided the DAMA functions associated with initialization and acquisition of the reference terminal equipment and TDMA traffic terminals. The second (and final) release of the MCS DAMA software was coded by the end of 1988, and will be tested by mid-1989. This software release provides all DAMA functions, including network startup, network shutdown, and on-demand call connect/disconnect services.

Associated with the LBR network are control and programming functions of the BBP. The BBP is essentially a TDMA terminal in the sky, under the complete control of the MCS. The MCS generates the BBP micro-code-level instructions and transmits them to the BBP via a 576-kbit/s LBR command channel provided by the TDMA reference terminal. Because the BBP must be reprogrammed approximately every 3 seconds, a feed-forward protocol is used on the command channel to eliminate the need for a time-consuming command acknowledgment. This protocol was designed to ensure that the BBP will be reliably programmed, even in the event of bit errors in the command channel. By the end of 1988, all of the software associated with the programming of the BBP was coded and tested.

The experiment configuration support software allows the user to set up satellite communications-related experiments. A full LBR network experiment can be configured to include the reference terminal and up to 40 traffic terminals, whereas an MCP-only experiment will not include any traffic terminals. An experiment is set up by selecting options and choosing desired values for LBR network parameters and MCP parameters. The resulting configuration is validated by the experiment configuration support software. An initial burst time plan is created and the experiment is stored in a library of experiments that can be later run as needed. By the end of 1988, the experiment configuration support software was coded except for the program that validates the MCP configuration.

The operator interfaces to the MCS consist of textual and graphic displays implemented on color graphic CRT terminals. Because all control and monitoring functions are associated with the operator interface, these programs are among the largest and most complex in the MCS. Figure 8 depicts a series of LBR burst time plan displays, showing the location of the scanning beam dwell periods and traffic bursts within each LBR TDMA frame. Figure 8a shows the dwell schedules for each of the four

TDMA frames. Figure 8b shows the bursts located in the first dwell in the west scan up-link frame, and Figure 8c shows the contents of the first burst in the dwell shown in Figure 8b. By the end of 1988, software was coded for the LBR subsystem operator interface, the MCP subsystem operator interface, and the experiment configuration support subsystem interface.

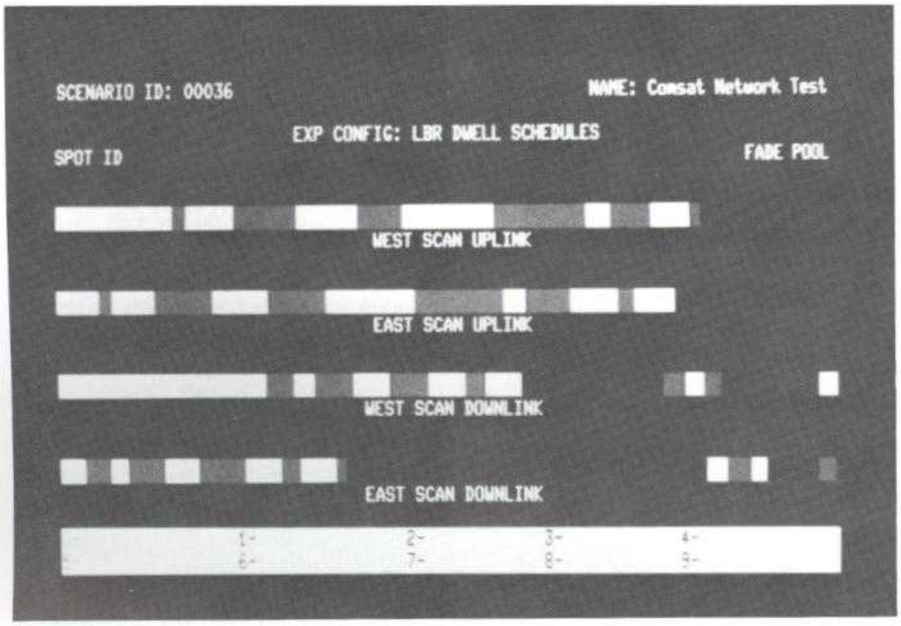


***Figure 8a**. LBR dwell schedule display*

For the total MCS project, approximately 130,000 lines of code (LOC) of an anticipated 165,000 LOC for the entire system were produced by year's end, and 73 of 101 programs were completed. Six subsystem builds, including five LBR subsystem builds and one MCP subsystem build, were successfully integrated. The five LBR builds included the LBR subsystem software which controls the startup of an LBR network. The MCP build included software that receives and displays the MCP telemetry. As currently defined, the MCS integrates 21 builds, each of which comprises two or more programs. This incremental development/integration approach provides for early testing and demonstration of key features of the system, and permits maximum use of parallel development activities, shortening the total project schedule.

Work on the MCS project has been performed by COMSAT Laboratories' Systems Development Division (SDD), which has brought to bear its well-established methodology, including software design, coding, testing, and documentation standards; an effective configuration management/software performance assurance (PA) system; and an ever-expanding set of sophisticated software development tools and reusable utility software. Measured productivity for the MCS project is approximately 38 percent higher than the industry norm.

PERFORMANCE ASSURANCE

During 1988, the COMSAT PA team focused on the actual performance of "hands on work" as it applies to hardware, software and firmware built or purchased for the ACTS program. The team's activities included design reviews, component and subsystem procurement reviews, inspections, manufacturing engineering, production planning, configuration management, product assurance, and product safety.

The quality assurance methods, quality engineering, and inspections used on procured and in-house fabricated items have proven to be effective and have continued to operate well. The controls exercised over the ACTS stockrooms have produced positive results, in that the inventory of products is accurate and quickly accessed for accountability and preparation of complete as-built kits. In-house fabrication inspections were performed on both the RFT and TDMA units. This process resulted in assemblies that were compliant with contracted requirements and quality standards.

Meetings of the key PA program control groups (the Configuration Control Board, the Software Review Board, and the Material Review Board) have continued. Formal PA reviews have been held for both in-house manufacturing and out-of-house procurements. These reviews

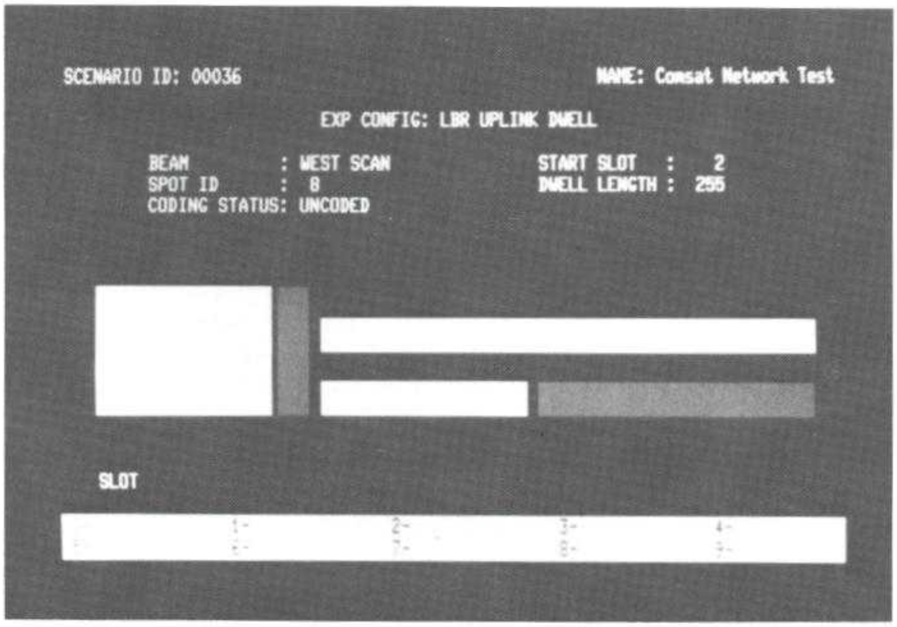


Figure 8b. Dwell contents display

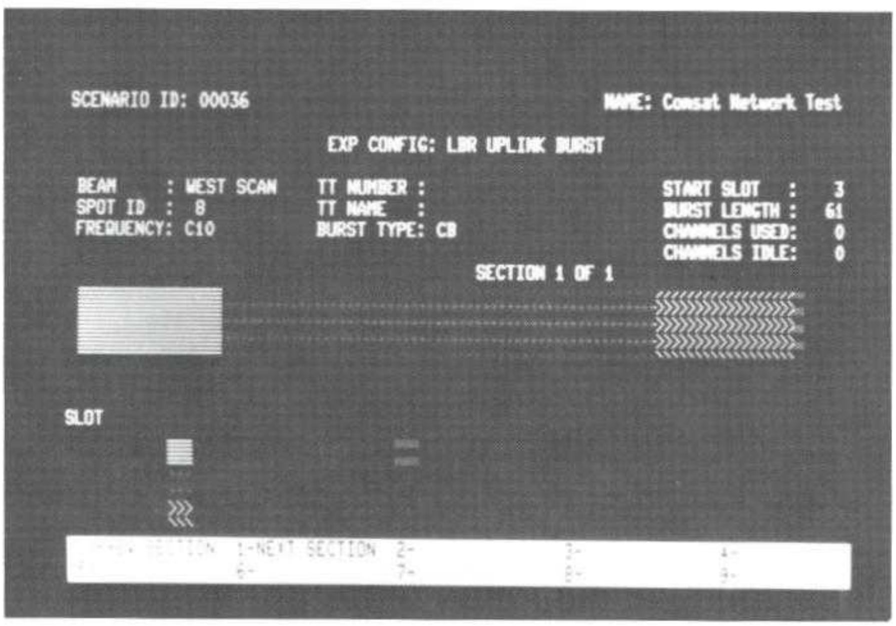


Figure 8c. Burst contents display

will continue through the entire build cycle and through system-level integration and test of the ground system. Hazard and safety analysis procedures have been implemented to support parts procurement and assembly build and test.

The change management procedures for both in-house and out-of-house activities have established the standard level of control necessary for this type of comprehensive program. Drawings and hardware and software configuration control have been merged into one operational control system.

Software PA personnel have implemented the configuration control database for all related MCS software, and are now receiving RFT and TDMA inputs for appropriate application. At year's end, the CMS library contained 5,000 of a projected 6,000 ASCII source and test files related to the LBR, test support, and MCP subsystems. The module management system database stores the executables and binary files associated with these subsystems.

In the areas of manufacturing and fabrication, the PA team continued to control and monitor the preparation of subassemblies, assemblies, and subsystem hardware (both in- and out-of-house). The procedures developed to manage ACTS hardware and software deliverables have been implemented and are in continuous use. The management procedures implemented encompass the entire hardware build cycle from design, procurement of parts and components, inventory control, kit assembly, and fabrication, through final test and checkout.

The guideline documents and methods developed earlier for program safety and maintainability have been implemented, with positive results achieved.

PUBLICATIONS AND PATENTS

The following is a list of 1988 publications and patents by authors at COMSAT Laboratories. Copies of the publications may be obtained by contacting the COMSAT authors at COMSAT Laboratories, 22300 Comsat Drive, Clarksburg, MD 20871-9475.

PUBLICATIONS

ANDERSON, W. T.,* Meulenberg, A., Beall, J. M.,* Kazi, A. H.,* Harrison, R. C.,* Gerdes, J.,* and Mittleman, S. D.,* "Radiation Induced Displacement Damage in GaAs Devices," *Gallium Arsenide and Related Compounds 1987,* A. Christou and H. S. Rupprecht, eds., Bristol, England: IOP Publishing, 1988, pp. 471–474.

ASSAL, F. T., and Mahle, C. E., "Hardware Development for Future Commercial Communications Satellites," AIAA 12th International Communication Satellite Systems Conference, Arlington, VA, March 1988, *A Collection of Technical Papers,* pp. 332–349. AIAA Paper No.88-0815.

ASSAL, F. T., Zaghloul, A. I., and Sorbello, R. M., "Multiple Spot Beam Systems for Satellite Communications," AIAA 12th International Communication Satellite Systems Conference, Arlington, VA, March 1988, *A Collection of Technical Papers,* pp. 322–331. AIAA Paper No. 88-0814.

ASSAL, F. T., Zaghloul, A. I., and Sorbello, R. M., "Active Phased Arrays for Multibeam Communications Applications," IEEE Military Communications Conference (MILCOM), San Diego, CA, October 1988, *Conference Record,* Classified Session No. 29.

BARGELLINI, P. L., and Hyde, G., "Electrical Communications Systems Approaching the Year 2000," *Satellite Integrated Communications Networks,* E. Del Re, P. Bartholomé, and P. P. Nuspl, eds., Amsterdam: Elsevier Science, 1988, pp. 11–21.

BONETTI, R. R., and Williams, A. E., "A TE Triple-Mode Filter," IEEE MTT-S International Microwave Symposium, New York, NY, May 1988, Digest, pp. 511–514.

CAMPANELLA, S. J., "Satellite Switches," *Satellite Integrated Communications Networks,* E. Del Re, P. Bartholomé, and P. P. Nuspl, eds., Amsterdam: Elsevier Science, 1988, pp. 57–64.

CAMPANELLA, S. J., and Pontano, B. A., "Economic Comparison of Cables and Satellites," *Satellite Integrated Communications Networks,* E. Del Re, P. Bartholomé, and P. P. Nuspl, eds., Amsterdam: Elsevier Science, 1988, pp. 35–46.

CAMPANELLA, S. J., and Sayegh, S. I., "A Flexible On-Board Demultiplexer/Demodulator," AIAA 12th International Communication Satellite Systems Conference, Arlington, VA, March 1988, *A Collection of Technical Papers,* pp. 299–303. AIAA Paper No. 88-0811.

CAMPANELLA, S. J., and Dimolitsas, S., "Digital Voice Transmission Techniques for Aeronautical Communications," Radio Technical Commission for Aeronautics (RTCA) Annual Assembly Meeting and Technical Symposium, Washington, DC, November 1988, *Proc.,* pp. 51–73. RTCA Paper No. 405-88/AS-349.

CHITRE, D. M., "ISDN Challenges to Satellite Communications" (Abstract) IEEE 21st Electronics and Aerospace Conference (EASCON), Arlington, VA, November 1988, *Proc.,* p. 107.

CHITRE, D. M., and McCoskey, J. S., "VSAT Networks: Architectures, Protocols and Management," *IEEE Communications Magazine,* Vol. 26, No. 7, July 1988, pp. 28–38.

CONEY, T. A.,* Dobyns, T. R., Chitre, D. M., and Lindstrom, R., "Service Offerings and Interfaces for the ACTS Network of Earth Stations," AIAA 12th International Communication Satellite Systems Conference, Arlington, VA, March 1988, *A Collection of Technical Papers,* pp. 247–258. AIAA Paper No. 88-0800.

DIMOLITSAS, S., and Gunn, J. E.,* "A Modular, Off-Line, Full Duplex Telephone Channel Simulator for High Speed Data Transciever Evaluation," *Proc. IEE, Part F: Communications, Radar and Signal Processing,* Vol. 135, No. 2, April 1988, pp. 155–160.

FANG, R. J. F., and Budinger, J.,* "Bandwidth-Efficient High-Speed Coded Trellis Modulation," AIAA 12th International Communication Satellite Systems Conference, Arlington, VA, March 1988, *A Collection of Technical Papers,* pp. 313–321. AIAA Paper No. 88-0813.

GELLER, B., and Goettle, P., "Quasi-Monolithic 4-GHz Power Amplifiers With 65-percent Power-Added Efficiency," IEEE MTT-S International Microwave Symposium, New York, NY, May 1988, *Digest,* pp. 835–838.

GUPTA, R., Reynolds, J., and McNally, P., "Modeling and CAD of an Ultra-Broadband Monolithic 5-bit Digital Attenuator," 18th European Microwave Conference, Stockholm, Sweden, September 1988, *Proc.,* pp. 151–155.

GUPTA, R., Gerson. H., Ross, P., and Assal, F., "Design and Packaging Approach for MMIC Insertion in a Broadband 4 x 4 Microwave Switch Matrix," IEEE GaAs IC Symposium, Nashville, TN, November 1988, *Digest,* pp. 261–264.

HAMPSCH, T., "Digital Controller for High-Speed Multibeam Antennas," *COMSAT Technical Review,* Vol. 18, No. 2, Fall 1988, pp. 255–268 [CTR88/337].

HEGAZI, G., Hung, H-L., Phelleps, F., Holdeman, L., Cornfeld, A., Smith, T., Allison, J., and Huang, H., "V-Band Monolithic Power MESFET Amplifiers," IEEE MTT-S International Microwave Symposium, New York, NY, May 1988, *Digest,* pp. 409–412.

HEMMATI, F., "Closest Coset Decoding," IEEE International Conference on Communications (ICC-88), Philadelphia, PA, June 1988, *Proc.,* pp. 21.2.1–21.2.5.

HEMMATI, F., "Reduced-Complexity Decoding of Convolutional Codes," *COMSAT Technical Review,* Vol. 18, No. 2, Fall 1988, pp. 239–253 [CTR88/336].

* Non-COMSAT author.

HULLEY, M. A., "Ion-Noise Sidebands as a Possible Quality Control Tool in TWTs," Advisory Group on Electronic Devices (AGED) and IEEE Microwave Power Tube Conference, Monterey, CA, May 1988, *Proc.*, p. 3D.2.

HUNG, H-L. A., Lee, T. T., Phelleps, F. R., Singer, J. F., Bass, J. F., Noble, T. F., and Huang, H. C., "60-GHz GaAs MMIC Low-Noise Amplifiers," IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium, New York, NY, May 1988, *Digest*, pp. 87–90.

HUNG, H-L. A., Hegazi, G. M., Peterson, K. E., and Huang, H. C., "Design and Performance of MESFET Power Amplifiers at K- and K_a-Band," *Microwave Journal*, Vol.31, No. 6, June 1988, pp. 177–190.

HUNG, H-L. A., Hegazi, G., Peterson, K. E., Phelleps, F. R., and Huang, H. C., "Monolithic Dual-Gate MESFET Power Amplifiers," IEEE GaAs IC Symposium, Nashville, TN, November 1988, *Digest*, pp. 41–44.

HUNG, H-L. A., Hegazi, G., Lee, T., Phelleps, F., Singer, J., and Huang, H., "V-Band MMIC Low-Noise and Power Amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-36. No. 12, December 1988, pp. 1966–1975.

INUKAI, T., Jupin, D., Lindstrom, R., and Meadows, D., "ACTS TDMA Network Control Architecture," AIAA 12th International Communication Satellite Systems Conference, Arlington, VA, March 1988, *A Collection of Technical Papers*, pp. 225–239. AIAA Paper No. 88-0798.

KELLY, W. H., Reisenweber, J. H., Robinson, J. A., and Abercrombie, D. B.,* "Program Overview and In-Orbit Performance Evaluation of the INTELSAT V Spacecraft Thermal Control Subsystem," AIAA Thermophysics, Plasmadynamics and Lasers Conference, June 1988, San Antonio, TX. AIAA Paper No. 88-2690.

LEE, B. S., Zaghloul, A. I., and Sorbello, R. M., "Performance Comparison for Scanning and Hopping Beam Satellite Antennas" (Abstract), URSI Radio Science Meeting, Syracuse, NY, June 1988, *Program and Abstracts.*, p. 435.

LEE, T. T., Hung, H-L. A., Cornfeld, A., Phelleps, F. R., Singer, J. L., Bass, J. F., and Huang, H. C., "GaAs MBE Monolithic Amplifiers for Millimeter-Wave Applications," Government Microcircuits Applications Conference (GOMAC), Las Vegas, NV, November 1988, *Digest*, pp. 369–372.

MAHLE, C. E., Geller, B. D., Potukuchi, J. R., and Hyde, G., "Advanced Communications Satellite Technology," IEEE 21st Electronics and Aerospace Conference (EASCON), Arlington, VA, November 1988, *Proc.*, pp. 207–211.

MARSHALEK, R. G., "Comparison of Optical Technologies for Intersatellite Link Payloads. Part I: Mass, Prime Power, and Volume Estimates," *COMSAT Technical Review*, Vol. 18, No. 2, Fall 1988, pp. 191–214 [CTR88/335].

MARSHALEK, R. G., and Paul, D. K., "Annotated Bibliography of Optical Intersatellite Link Technology 1970-1988," *COMSAT Technical Review*, Vol. 18, No. 2, Fall 1988, pp. 283–348 [CTR88/339].

McNALLY, P. J., and Cregger, B. B., "Ion-Implanted Hyperabrupt Varactor Diodes for GaAs MMICs," *COMSAT Technical Review*, Vol. 18, No. 1, Spring 1988, pp. 1–20 [CTR88/330].

MEULENBERG, A., "Radiation-Hardened Deposited Oxides," *COMSAT Technical Review*, Vol. 18, No. 2, Fall 1988, pp. 269–282 [CTR88/338].

MEULENBERG, A., Hung, H-L. A., Peterson, K. E., and Anderson, W. T.,* "Total Dose and Transient Radiation Effects on GaAs MMICs," *IEEE Transactions on Electron Devices*, Special Issue on Reliability, Vol. ED-35, No. 12, December 1988, pp.2125–2132.

MEULENBERG, A., Hung, H-L. A., and Tough, G., "Microwave Characterization of Bulk and Powdered High-T_c Superconductors," SPIE 13th International Conference on Infrared and Millimeter Waves, Honolulu, HI, December 1988, *Digest*, pp. 259–260.

MOTT, R. C., Potukuchi, J. R., Gupta, R. K., Zaghloul, A. I., Siddiqi, S., and Gourley, S. E., "Monolithic Transmit Modules for a Multibeam K_u-Band Phased Array Antenna," 18th European Microwave Conference, Stockholm, Sweden, September 1988, *Proc.*, pp. 759–763.

NADERI, F. M.,* and Campanella, S. J., "NASA's Advanced Communications Technology Satellite (ACTS): An Overview of the Satellite, the Network, and the Underlying Technologies," AIAA 12th International Communication Satellite Systems Conference, Arlington, VA, March 1988, *A Collection of Technical Papers*, pp. 204–224. AIAA Paper No. 88-0797.

ONUFRY, M., "The New Challenges of DCME," *ITU Telecommunication Journal*, Special Issue on Speech Processing, Vol. 55, No. 12, December 1988, pp. 831–837.

PALMER, L. C., and Chang, P. Y., "Simulation of a Random-Access-With-Notification Protocol for VSAT Applications," *COMSAT Technical Review*, Vol. 18, No. 1, Spring 1988, pp. 21–53 [CTR88/331].

PALMER, L., and White, L., "Demand Assignment in the ACTS LBR System," IEEE International Conference on Communications, Philadelphia, PA, June 1988, Proc., pp. 16.3.1–16.3.6.

PAUL, D. K., "Status and Trends in Fiber Optic Communications," Guest Editorial in *Laser Focus Fall Product Bulletin*, August 1988, p. 20.

PAUL, D. K., "Reliable Fiber Optics" (Summary of the panel session), Fiber Optics Reliability: Benign and Adverse Environments II, Boston, MA, September 1988, *Proc. SPIE*, Vol. 992, D. K. Paul, R. A. Greenwell, and S. Wadekar, eds., pp. 223–229.

PAUL, D. K., "Broadband Analog Capability Opens Up New Fiber Optic Applications," Guest Editorial in *Laser Focus Magazine*, Annual Fiber Optics Review Edition, Vol. 24, No. 10, October 1988, p. 136.

PAUL, D. K., "Comparison of Optical Technologies for Intersatellite Link Payloads. Part II: Impact of Reliability Considerations on Technology Selection," *COMSAT Technical Review*, Vol. 18, No. 2, Fall 1988, pp. 215–238 [CTR88/335].

* Non-COMSAT author.

POLAK-DINGELS, P.,* Hung, H-L. A., Smith, T., Huang, H. C., Webb, K. J.,* and Lee, C. H.,* "On-Wafer Characterization of Monolithic Millimeter-Wave Integrated Circuits by a Picosecond Optical Electronic Technique," IEEE MTT-S International Microwave Symposium, New York, NY, May 1988, *Digest*, pp. 237–240.

POLAK-DINGELS, P.,* Hung, H-L. A., Webb, K. J.,* Lee, T. T., Smith, T., and Lee, C. H.,* "An Optoelectronic Technique for S-Parameter Measurements of GaAs Monolithic Integrated Circuits," SPIE 13th International Conference on Infrared and Millimeter Waves, Honolulu, HI, December 1988, *Digest*, pp. 69–70.

POTUKUCHI, J. R., Gupta, R. K., Assal, F. T., Holdeman, L. B., Mott, R. C., and Zaghloul, A. I., "MMIC Modules for Active Phased-Array Applications in Communications Satellites," *Microwave Systems News*, Vol. 18, No. 11, November 1988, pp. 20–27.

ROGERS, D. V., "Radio-Wave Propagation," Chapter 1, *Electronic Communications Handbook*, A. F. Inglis, ed., New York: McGraw-Hill, 1988.

SAYEGH, S. I., Assal, F. T., and Inukai, T., "On-Board Processing Architectures and Technology," IEEE 21st Electronics and Aerospace Conference (EASCON), Arlington, VA, November 1988, *Proc.*, pp. 217–223.

SCHMIDT, W. D., "The ACTS LBR System: A Technology Testbed for Future VSAT/TDMA Networking Applications," AIAA 12th International Communication Satellite Systems Conference, Arlington, VA, March 1988, *A Collection of Technical Papers*, pp. 259–263. AIAA Paper No. 88-0801.

SORBELLO, R. M., "Advanced Satellite Antenna Developments for the 1990s," AIAA 12th International Communication Satellite Systems Conference, Arlington, VA, March 1988, *A Collection of Technical Papers*, pp. 652–659. AIAA Paper No. 88-0873.

SORBELLO, R. M., Zaghloul, A. I., Effland, J. E., and DiFonzo, D. F., "An Efficient Flat Plate Antenna for Direct Broadcast Applications," 18th European Microwave Conference, Stockholm, Sweden, September 1988, *Proc.*, pp. 295–299.

SUYDERHOUD, H. G., "Dependence of Mean Opinion Scores on Differences in Lingual Interpretation," *COMSAT Technical Review*, Vol. 18, No. 1, Spring 1988, pp. 55–64 [CTR88/332].

SUYDERHOUD, H. G., and Dimolitsas, S., "Impact of Noise and Encoder Decoder Mistracking in ADPCM System Performance," IEEE International Conference on Acoustics, Speech and Signal Processing, New York, NY, April 1988, *Proc.*, pp. 16.S6.4.1–16.S6.4.4.

TZENG, F. F., "Multipulse Excitation Codebook Design and Fast Search Methods for CELP Speech Coding," IEEE Global Telecommunications Conference, Hollywood, FL, November 1988, *Conference Record*, Vol. 1, pp. 18.6.1–18.6.5.

VAIDYANATHAN, H., "Long-Term Storage of Nickel-Hydrogen Cells," *Journal of Power Sources*, Vol. 22, 1988, pp. 221–228.

VAIDYANATHAN, H., and Earl, M. W., "Capacity and Pressure Variation of INTELSAT VI Nickel-Hydrogen Cells With Storage and Cycling," 23rd Intersociety Energy Conversion Engineering Conference, Denver, CO, July–August 1988, *Proc.*, D. Groswami, ed., The American Society of Mechanical Engineers, New York, NY, pp. 471–475.

WILLIAMS, A. E., and Bonetti, R. R., "A Mixed Dual-Quadruple Mode 10-Pole Filter," 18th European Microwave Conference, Stockholm, Sweden, September 1988, *Proc.*, pp. 966–968.

WISE, P. C.,* Kelly, W. H., and Sharma, S. P., "Critique of the Thermal Design Verification Program for a High-Power Communications Spacecraft," AIAA Thermophysics, Plasmadynamics and Lasers Conference, June 1988, San Antonio, TX. AIAA Paper No. 88-2648.

ZAGHLOUL, A. I., Sorbello, R. M., and Assal, F. T., "Development of Active Phased Arrays for Reconfigurable Satellite Antennas," European Space Agency COST 213/KUL Phased Array Workshop, Leuven, Belgium, October 1988, *Proc.*, pp. 135–150.

PATENTS

The following patents were issued to employees (or former employees) of COMSAT Laboratories in 1988.

CAMPANELLA, S. J., and Inukai, T., "Satellite Clock System," U. S. Patent No. 4,792,963, issued December 20, 1988.

GUPTA, V., Onufry, M., Suyderhoud, H., and Virupaksha, K., "Variable Bit Rate Speech Codec With Backward-Type Prediction and Quantization," U. S. Patent No. 4,751,736, issued June 14, 1988.

ZAGHLOUL, A. I., "Electromagnetically Coupled Microstrip Antennas Having Feeding Patches Capacitively Coupled to Feedlines," U. S. Patent No. 4,761,654, issued August 2, 1988.

The patent listing below was inadvertently omitted from the 1987 Annual Report.

GELLER, B. D., and Zaghloul, A. I., "General Technique for the Integration of MIC/MMIC's With Waveguides," U. S. Patent No. 4,636,753, issued January 13, 1987.

* Non-COMSAT author.

HONORS AND AWARDS

COMSAT Laboratories is pleased to acknowledge those of its scientists who were recognized in 1988 for their significant contributions to the field of satellite technology.

Dr. R. J. F. Fang

EXCEPTIONAL INVENTION AWARD

Dr. L-N. Lee

For the second time in its history, COMSAT Laboratories presented the Exceptional Invention Award to two COMSAT researchers. This award recognizes COMSAT engineers whose patented inventions are the basis for substantial savings or income for the corporation. This year, **Dr. Russell J. F. Fang** and **Dr. Lin-Nan Lee** of the Communications Technology Division were awarded $5,000 each for their invention, "Security System for SSTV," U.S. Patent No. 4,484,654, an encryption system that prevents unauthorized reception of the visual or audio segments of a TV signal. This system formed the basis for a security system design that is licensed to Scientific Atlanta (S/A) and incorporated into the S/A B-MAC video transmission system—the premier video scrambling system in the video transmission and distribution industry, and the only one that has not been compromised, even though more than 70,000 decoders have been in operation worldwide. The corporation receives a steady royalty revenue through B-MAC sales as a result of this invention.

Dr. K. Pande

IEEE FELLOW

The Institute of Electrical and Electronic Engineers (IEEE) this year awarded the grade of Fellow to **Dr. Krishna Pande** for his outstanding scientific research. Dr. Pande received his Fellow for contributions to III-V semiconductor materials and device technology, and particularly for advancing the new area of indium-phosphide field-effect transistor (FET) technology. FETs fabricated with indium-phosphide have the potential to be at least two and a half times faster than FETs made using gallium arsenide (GaAs).

RESEARCH AWARDS

Four outstanding research projects carried out at the Laboratories over the past several years have been named winners of the COMSAT Laboratories Research Award for their valuable contributions to the state of the art of communications technology and their strategic importance to the corporation. Winners share a cash prize and their names are added to a plaque listing the recipients of this annual award.

85 The 1985 Research Award was presented to **Lin-Nan Lee**, **Neal D. Becker**, **Yih-Sien Kao**, and **Mark D. Redman** for their work in developing a COMSAT version of a multiplexed analog component (MAC) video transmission system. This work contributed to a video encryption system and represented substantial progress in video transmission techniques, which find application in high-definition television (HDTV) and video multiplexing.

86 Two Research Awards were presented for two exceptional pieces of work performed in 1986. **Jack H. Rieser**, **Michael Onufry, Jr.**, **Krishnamoorthy Virupaksha**, **Henri G. Suyderhoud**, and **Vaikunth N. Gupta** were honored for contributing key concepts to the development of the INTELSAT 32-kbit/s low-rate encoded, digital circuit multiplication equipment (LRE/DCME), which is now being built into the global satellite system. DCME allows as many as four telephone conversations to be carried on a single circuit, and is an essential feature in INTELSAT's program to compete successfully with fiber optic cable.

A 1986 Research Award was also presented to **Robert M. Sorbello, Amir I. Zaghloul, John E. Effland, Daniel F. DiFonzo**, and **Henry B. Williams** for their contributions to the design of a flat-plate antenna for use with direct broadcast satellites (DBS). This device targets the DBS TV market and is expected to yield significant royalty revenues. Embodying a number of technical innovations, this inexpensive and attractive antenna can be used in situations and locations where larger parabolic antennas are impractical.

87 The 1987 Research Award was granted for the development of a coded modulation system that enables eight satellite transponders to handle the same amount of traffic, at the same digital transmission rates, as can be carried by the entire TAT-8 fiber optic cable. **Russell J. F. Fang**, **Farhad Hemmati**, **Neal D. Becker**, and **William J. Hersey III** were cited as innovators and developers of the 140-Mbit/s coded octal phase-shift keying (COPSK) modulation technique . The system has been successfully demonstrated over INTELSAT 72-MHz bandwidth transponders and was employed for sending 140-Mbit/s HDTV between the U.S. and Japan.