COMSAT Laboratories

1986 Annual Report

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September 1987

COMSAT Laboratories
Communications Satellite Corporation
22300 COMSAT Drive
Clarksburg, MD 20871

PERSPECTIVE

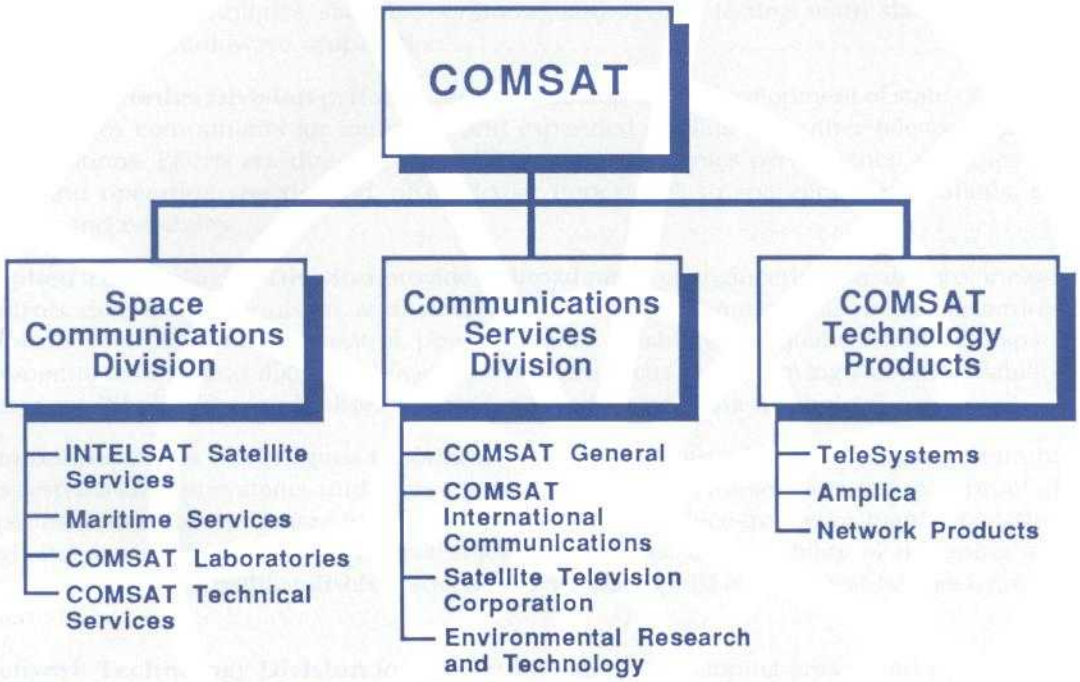
COMSAT Laboratories conducts a program of basic research and development to advance satellite communications technology. Elements of the program are funded by the Intelsat Satellite Services and Maritime Services divisions (all parts of the World Systems Division), and together with COMSAT International Communications Corporation (which operates the large multipurpose earth stations) 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 partly funded by the rate-payer) is made available to the public through a catalog that announces the availability of published papers and reports. In addition, a précis is published to summarize the scope of all jurisdictional projects being undertaken in each calendar year.

During 1984 the Federal Communications Commission ruled (in its Structure Order dated April 20, 1984) that the program of basic research previously funded wholly by the rate-payer must henceforth be paid for in part by the rate-payers and in part by the Corporation's shareholders. The prescribed formula that sets the ratio between these sources results in two-thirds of the cost being assigned to the shareholders. Since this work still must be put in the public domain, it affords the shareholders no proprietary advantage. The result has been a steady decrease in the overall size of the research program. In 1986 the Laboratories' funding for research fell to 20 percent of its total budget (approximately $40 million) and the balance of the effort consisted of work undertaken for Corporate and external customers approximately equally. The largest effort undertaken for external customers is our involvement in the NASA Advanced Communications Technology Satellite (ACTS) Program.

Commencing with calendar year 1983 we began publishing an Annual Report summarizing the results of our research and development program. This report provides a summary of all of the R&D work undertaken with Corporate support during 1986 and is the fourth in the series.

J.V. Evans

J.V. Evans
September 1987



COMMUNICATIONS SATELLITE CORPORATION
Organization 1986

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This report summarizes the research and development activities of **COMSAT Laboratories** for 1986, including Corporate research and support, INTELSAT support, and work funded by the Federal Government and other outside sources **1**

The **Microwave Technology Division** performs research, development, and support functions over aspects of satellite communications that include monolithic microwave integrated circuits (MMICs) for both satellite and earth station applications, MIC and waveguide filters, on-board repeater processing techniques, satellite monitoring and in-orbit testing, earth station and satellite antennas, and radiowave propagation **3**

The **Microelectronics Division** performs research leading to the development of state-of-the-art microelectronics components for improved and expanded satellite and other telecommunications applications. Efforts are directed toward improved electronics performance at higher frequencies and operating speeds, and, of particular importance to spacecraft applications, enhanced life and reliability **17**

The **Applied Technologies Division** provides a broad range of engineering capabilities, including controls, dynamics, propulsion, and telemetry, tracking and command, as well as structures, mechanisms, materials, thermal control, power systems, reliability and quality assurance, space environmental testing, and flight qualification. Programs focus on improving satellite reliability, extending satellite lifetime, and advancing communications antenna technology **25**

The **Communications Techniques Division** conducts exploratory investigations of communications systems and subsystems, undertakes system analyses, and implements and tests proof-of-concept and prototype equipment for transmission, video, and voice-frequency band processing. Through the increasing use of microelectronics components, the capability of designing and implementing complex, highly reliable systems with increasing cost effectiveness has been greatly extended **37**

The **Network Technology Division** focuses on the rapidly developing area called networking, from systems and architectures to software and hardware. The division performs basic technology development, development of proof-of-concept prototypes, and support to COMSAT's lines of business. Development projects promote COMSAT's leadership role in communications services and products by applying the results of basic research to projects sponsored by Corporate R&D, lines of business, and outside customers **53**

The **System Development Division** activities encompass the development of computer-based systems, including the design and implementation of software and the acquisition, installation, and integration of hardware. Other projects involve the development of digital hardware and microprocessing firmware, analysis and simulation techniques, distributed processing systems, and the establishment of standards and methodologies for software products **59**

The **Advanced Communications Technology Satellite (ACTS) Program** team continued working on the refinement of the architecture of the NASA ground station/master control station, and had its work presented at the Ground Segment Preliminary Design Review. Following RCA/NASA approval, design-level specifications were begun **67**

COMSAT Laboratories **Publications and Patents** encompass all aspects of satellite communications technology **79**

COMSAT Laboratories employees received **Honors and Awards** for their work **83**

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 as a result of efforts by COMSAT and the U.S. State Department to facilitate international communications between fixed points by satellite. Initially, INTELSAT had 11 participants. This has since grown to 114 member countries, and the organization presently provides service to 170 nations. COMSAT is the U.S. Signatory and representative to INTELSAT.

Until 1978, 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 400, and occupies buildings which afford approximately 400,000 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. The Satellite Television Corporation was formed in 1980 to promote direct broadcast television. The Corporation exited from the SBS partnership in late 1984.

In 1986 COMSAT was reorganized into four operating divisions. The World Systems Division (WSD) consisted of the units handling the INTELSAT and INMARSAT businesses (Intelsat Satellite Services and Maritime Services). The Communications Services Division, incorporating COMSAT General and COMSAT International Communications Corporation, was formed to provide private network services. The Space Communications Division incorporated COMSAT's consulting engineering function (COMSAT Technical Services), the Laboratories and the microwave amplifier manufacturing business (Amplica). Finally, COMSAT Technology Products continued as the division carrying out the manufacture of telephone equipment, TDMA terminals and mobile equipment.

In 1986, 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 COMSAT General, and COMSAT's manufacturing arm, Technology Products. Effort funded entirely by sources outside of COMSAT/INTELSAT includes activities for the Federal Government (NASA or DARPA) or for commercial companies, and in particular, a significant amount of work performed on the Advanced Communications Technology Satellite (ACTS) ground segment program.

During 1986, the Laboratories remained organized into six technical divisions: Communications Techniques, Microelectronics, Microwave Technology, Network Technology, Applied 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 includes jurisdictional (WSD) business, as well as the non-jurisdictional activities of COMSAT. The former must, perforce, be made public while the latter can be held proprietary. The balance of the Laboratories' support comes from projects performed for and directed by various corporate elements, INTELSAT, INMARSAT, or other outside organizations, each of which 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' R&D activities in 1986. It is organized by technology, as defined by the six technical areas represented by each of its constituent divisions. The work is further subdivided into the following categories:

- Jurisdictional Research and Development;
- Non-Jurisdictional Research and Development;
- Support work performed for various COMSAT divisions in response to specific requests;
- Work performed for INTELSAT; and
- Other work.

Of these categories the most advanced work is that undertaken as part of the research program. This program is decided upon through a process of Laboratory management review of ongoing efforts and proposed new ones leading to a tentative program that is subject to critique by the WSD and the approval of COMSAT's Corporate R&D Committee—a subcommittee of the COMSAT Board of Directors.

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. A substantial part of the effort is devoted to the development of 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 realization of a 64-element and K_u-band phased-array proof-of-concept antenna. All design engineering for the active and passive circuits for this antenna has been completed and the feed array assembled.

A multi-coupled cavity filter using four electrical modes in one cavity has been demonstrated, and an engineering model of a 120-Mbit/s QPSK demodulator for satellite on-board processing has been completed and has met all applicable INTELSAT performance requirements. In addition, work has continued on MIC and waveguide filters, satellite monitoring and in-orbit testing, new earth station antennas and feeds, and microwave propagation studies.

Support efforts for other parts of the Corporation have included antenna modifications at the Southbury and Santa Paula earth stations, and antenna measurements at the Washington INTELSAT Business Services (IBS) station.

COMSAT POOLED R&D

Multimode Microwave Filters

Work on multimode filters continued in two areas: development of the quadrupole filter in cylindrical cavities, and modal analysis of dielectric loaded cylindrical cavities.

In 1985, a four-pole elliptic function filter response was realized in a cylindrical cavity having four degenerate modes. This work has continued during 1986 with the design and tuning of an eight-pole, two-cavity filter. Experimental results on a 50-MHz-bandwidth, 12-GHz, quasi-elliptic filter (couplings 1-8, 2-7, and 3-6 = 0) are shown in Figure 1. Excellent agreement with the predicted response was obtained and an average cavity Q of 9,000 was realized. The measured out-of-band response gives adjacent resonant spurious modes at their predicted locations, approximately ±800 MHz about the filter center frequency. Figure 2 is a photograph of the eight-pole filter.

During 1986, significant progress was also made in analyzing the theoretical resonances of a cylindrical metal cavity partially loaded with a dielectric cylinder. Experimental measurements showed good correlation with theoretical results. Triple mode and quadruple mode degeneracies were identified, and work next year will concentrate on using these results to further miniaturize microwave filters.

MMIC Design Technology

The long-range goals for this technology include the development of monolithic satellite receivers, microwave switch matrices (MSMs), and active elements for multibeam phased-array antennas. The basic building blocks of these subsystems are low-noise amplifiers (LNAs), fixed and variable gain blocks, mixers, oscillators, switches, variable attenuators, and phase shifters. Many of these modules were realized in fully monolithic form in 1986.

A two-stage, 6-GHz monolithic (MMIC) self-biased LNA was developed on gallium arsenide (GaAs) with a measured noise figure of 1.7 dB and associated gain of 21 dB, as shown in Figure 3. The measured in-band amplifier gain was within 1 dB of that predicted. Similarly, the measured in-band minimum noise figure of 1.7 dB was within 0.2 dB of the value predicted using a COMSAT-developed

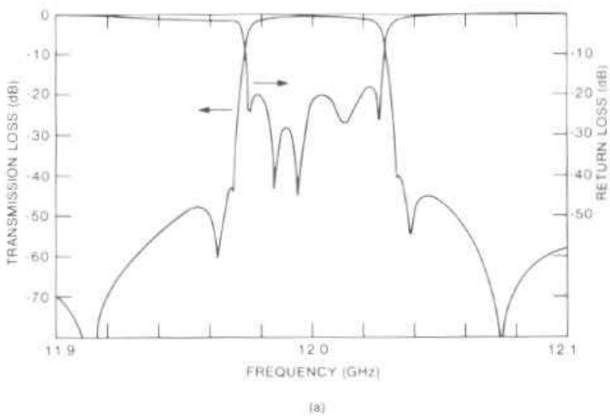


Figure 1. *Measured response of 12-GHz, 8-pole quadruple-mode filter*

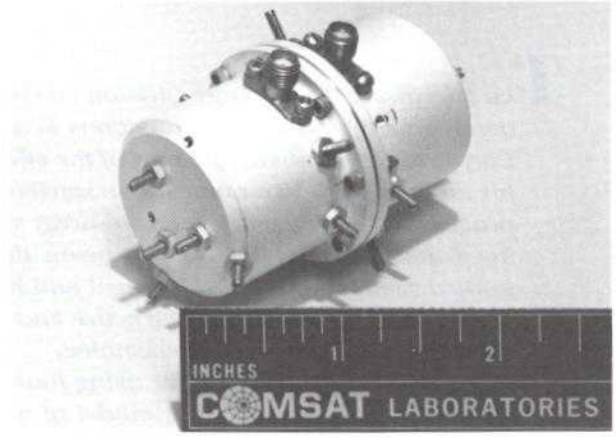


Figure 2. *8-pole, quadruple-mode filter*

noise parameter estimation process. The LNA measures 2 × 3.5 mm and utilizes selective ion-implant processing.

A two-stage, 2- to 6-GHz MMIC amplifier was realized using feedback techniques. The amplifier has a gain of 9.0 ± 0.7 dB and input and output return losses better than 17 dB over 2 to 6 GHz, as shown in Figure 4. The excellent agreement between measured and predicted performance validates the field effect transistor (FET) models derived from ion-implant profiles and peak doping density.

Interference Cancellation

The object of this task was to investigate techniques for cancelling interference at earth station antennas from adjacent satellites or from terrestrial sources. A technique was studied which uses an adjustable panel on the reflector surface to cancel an interfering transmission from an adjacent satellite. This panel consists of approximately 10 small flat plates which are individually adjustable to cancel the interference. This technique provides cancellation over a relatively wide frequency band and does not require auxiliary antennas or electronics.

Simulation Studies of Slant Path Site Diversity Effects

COMSAT Laboratories performs a variety of propagation studies, including global modeling of slant path propagation impairments and evaluation of impairment mitigation techniques such as transmit power control, depolarization compensation, and site diversity. One such model simulates a distributed population of rain cells of varying heights and diameters to provide estimates

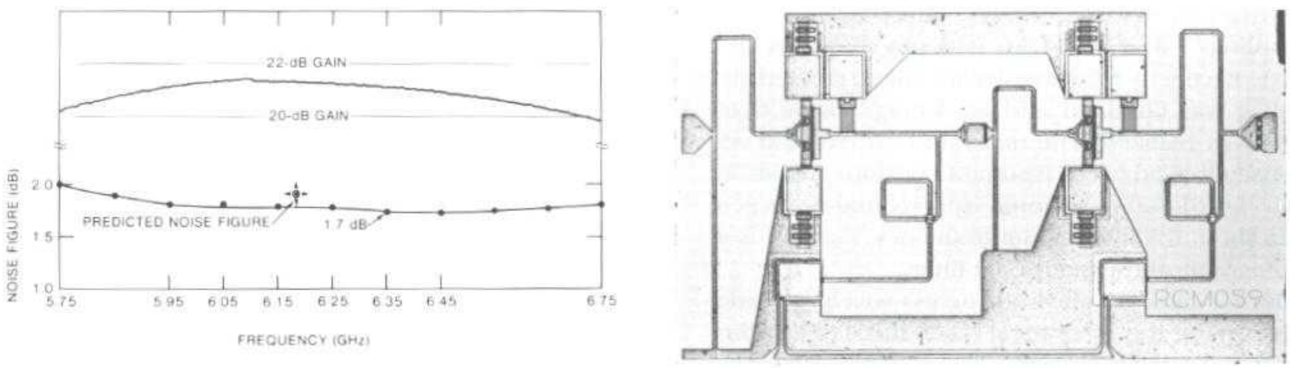


Figure 3. *6-GHz MMIC LNA and measured response*

of single- and dual-path diversity rain fade statistics. During 1986, this model was enhanced by comparison with measured data. The capabilities of the refined model were demonstrated for a variety of single-path and diversity configurations in several rain climates.

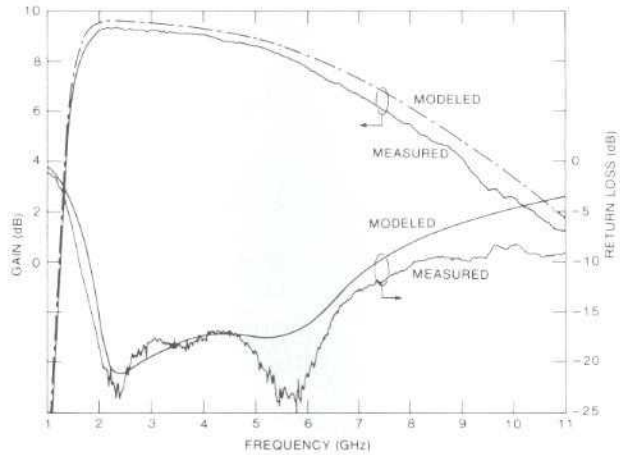


Figure 4. *Measured and modeled response of MMIC feedback amplifier*

While the model is relatively complex and requires moderate computing facilities to perform the rain simulations, it is a valuable tool for investigating the physical basis of rain attenuation and for exploring the influence of rain climate on path impairments. It is now being used to evaluate the relative importance of path geometry, wave frequency, and climate type on site diversity performance. These studies will aid in the development of a simpler, meteorologically based, site diversity prediction method. In addition, the simulation approach may provide a model of the rain environment that can be applied to other propagation problems, such as rain scatter interference and fade duration modeling.

COMSAT JURISDICTIONAL DEVELOPMENT

4-GHz SSPA Development

The purpose of this task is to develop highly miniaturized amplifier circuits with linearity and efficiency characteristics suitable for satellite applications. One use for these circuits is the phased-array antenna, which requires many small, reliable, inexpensive, lightweight amplifiers.

In 1986, a C-band, 0.5-W, single-ended class AB amplifier and a C-band, 1-W, push-pull class AB amplifier were designed, built, and tested. These amplifiers use a combination of lumped and distributed element matching to achieve small size and high efficiency. The single-ended amplifier, measuring 2.5 × 3.0 mm, has a maximum efficiency of 46 percent and gain of 9.9 dB for a single-tone output power of 26.9 dBm (0.49 W). For a total two-tone output power of 25.7 dBm, third-order intermodulation distortion (IMD) of -17 dB has been measured. The push-pull amplifier (9.9 × 22.8 mm) has a measured efficiency of 39 percent and a measured gain of 8.5 dB for a single-tone output power of 29.5 dBm (0.89 W). Losses in the balun circuits, which are required for push-pull operation, cause reduced gain and efficiency (relative to the single-ended amplifier). For a total two-tone output power of 28.6 dBm (25.6 dBm per FET), third-order IMD of -13.1 dB has been measured. Figure 5 is a close-up photograph of the push-pull amplifier without the baluns.

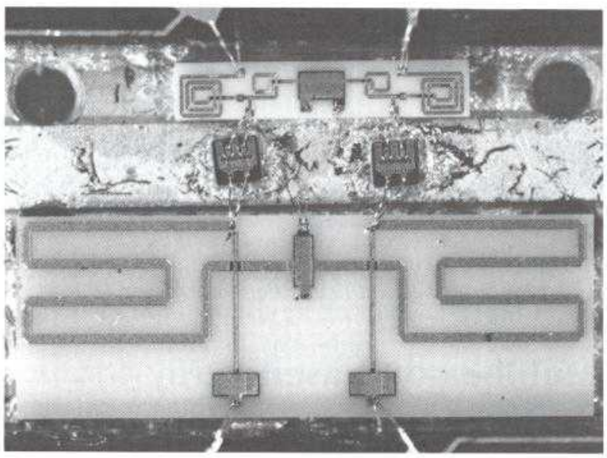


Figure 5. *C-band, 1-W push-pull amplifier*

11-GHz SSPA Development

For the 11-GHz SSPA development project, COMSAT's newly developed high-frequency FET was used to design, fabricate, and test an MIC version of a single-ended 1-W power amplifier. Work in 1986 was aimed at the realization of a multistage monolithic 2-W power amplifier for spaceborne phased-array or scanning beam applications, requiring a large number of identical amplifiers. These amplifiers must be small, lightweight, and exhibit efficient, reliable, and uniform performance. Figure 6 is a photograph of the single-stage, 1-W amplifier, which has an actual size of 5.0 × 10.2 mm. The matching circuit was deposited on a 0.25-mm-thick alumina substrate and the FET (3.0-mm gate width) was mounted on a metal ridge between two substrates. The amplifier typically provides 6.2-±0.2-dB small signal gain across a 3-GHz bandwidth (10 to 13 GHz) with a maximum output power of over 1 W (1.1 W). Six amplifiers have been fabricated and tested. The measured performance of all amplifiers using the same batch of FETs is essentially identical and meets the design goals, except for the power-added efficiency, which is 20 percent.

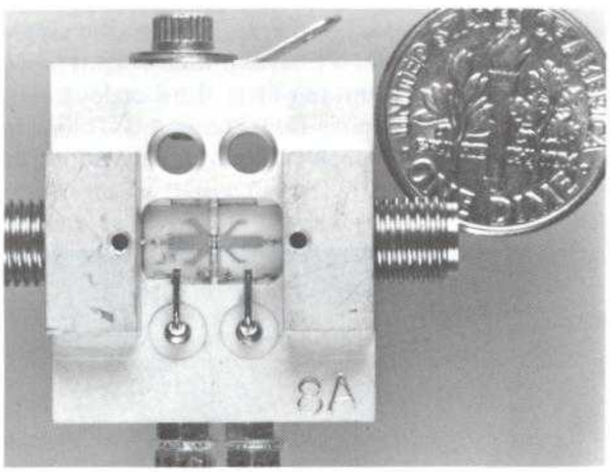


***Figure 6.** K_u-band power amplifier uses COMSAT's newly developed high-frequency power FET*

Multibeam Phased-Array Antenna

A 64-element, K_u-band active array is being built and tested at COMSAT Laboratories. The array, shown in Figure 7, will be used to demonstrate rapidly scanning, hopping, and reconfigurable beam coverages for future high-capacity satellite systems. It incorporates MMIC active circuits to provide complete amplitude and phase control over the aperture.

Figure 7 also depicts the passive array elements, which include waveguide feed horns, orthomode transducers, and a lightweight, stripline beam-forming network. Located behind each element is an active circuit box containing a 5-bit phase shifter, 5-bit digital attenuator, buffer amplifier, driver amplifier, and power amplifier.

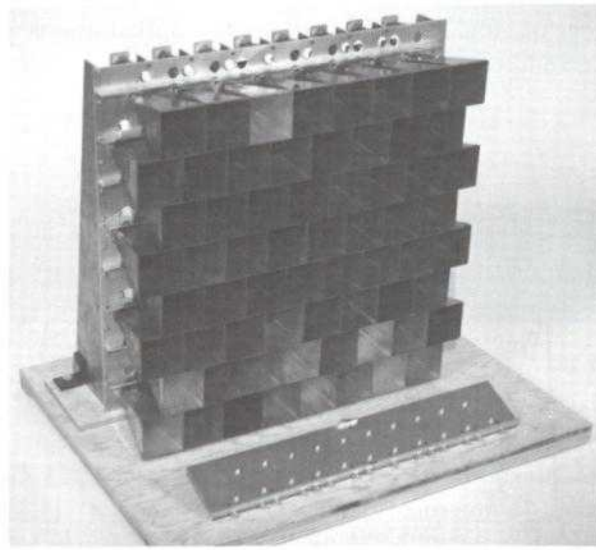


***Figure 7.** Active array and power divider will demonstrate beam coverage for future high-capacity satellite systems*

During 1986, the MMIC circuits were designed and fabrication was initiated. A 5-bit phase shifter (Figure 8) which incorporates a switched delay line approach was designed. The time delay elements use low-pass filters, and the single-pole/double-throw switches are designed to operate over a wide band (2 to 15 GHz).

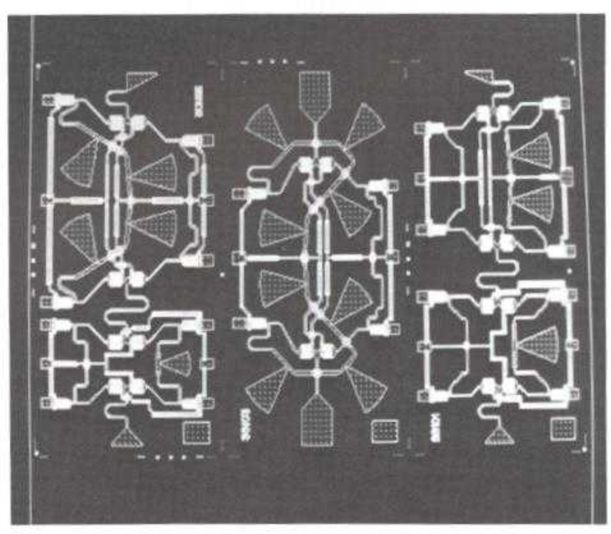
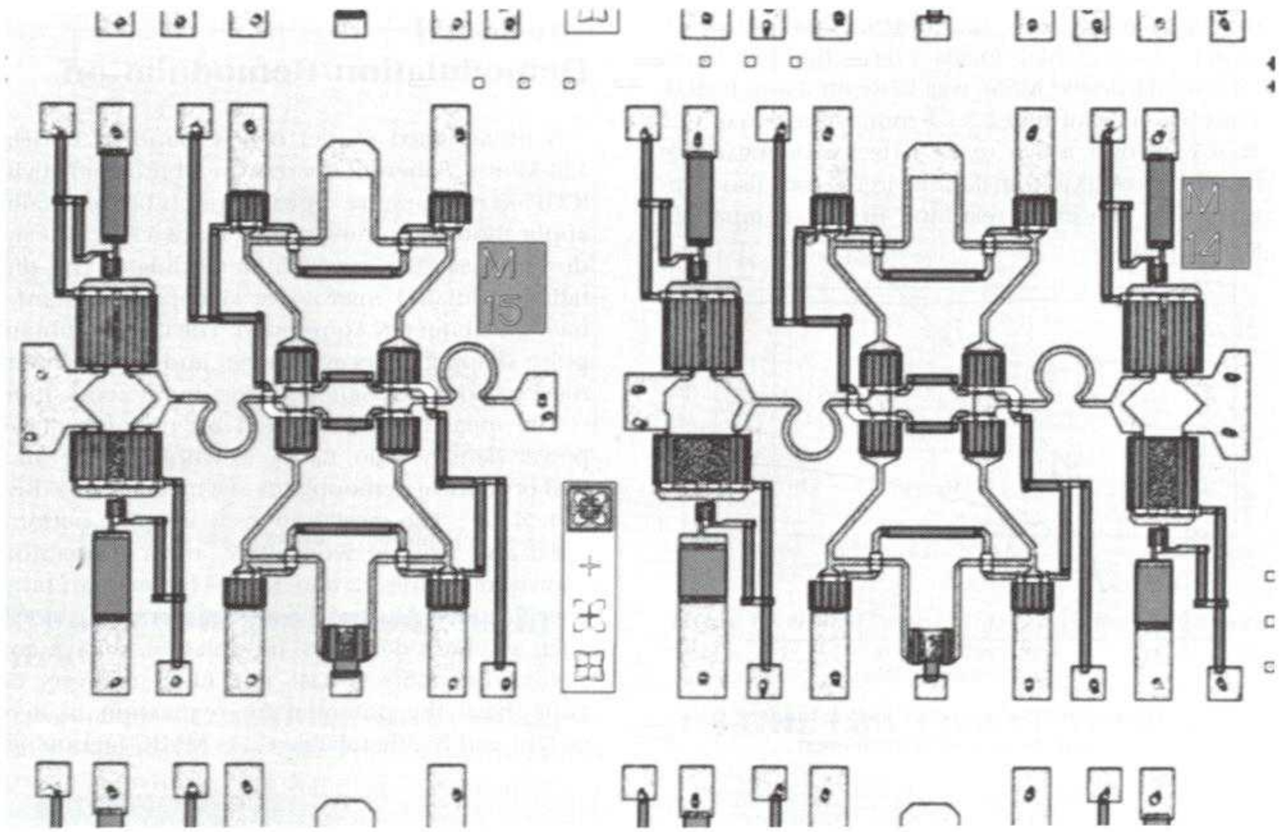


***Figure 8.** K_u-band MMIC phase shifter incorporates switched delay line approach*



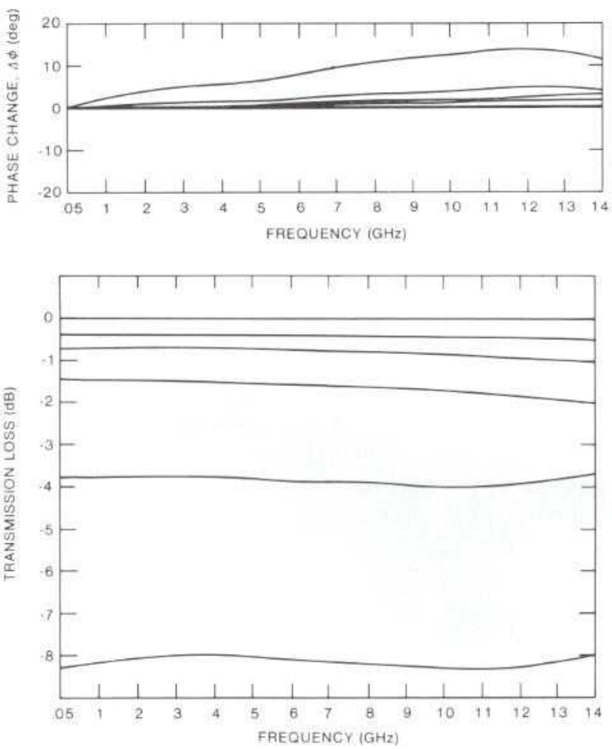


Figure 9. *K_u-band, 5-bit digital attenuator yields broadband performance over 0.05 to 14 GHz.*

A novel, broadband, digitally controlled, 5-bit attenuator measuring 1.3 × 2.6 mm (Figure 9) has been developed in fully monolithic form. This design uses FET devices in passive modes (with no DC power consumption) for attenuation control. Measured results show excellent performance over an operating band of 0.05 to 14 GHz. This design is based on ion-implantation profiles specifically designed to improve the performance of the FET in the passive mode of operation.

An MMIC 12-GHz buffer amplifier and a three-stage driver amplifier have also been designed. The buffer amplifier is designed to provide a gain of 6 dB and an input return loss better than 20 dB across the 11.7 to 12.7-GHz frequency band. The driver amplifier was designed to provide a gain of 16 dB and return loss better than 20 dB across the band. Both amplifiers are self-biased for operation with a single positive power supply.

In addition to the RF designs, the array incorporates a mechanical and thermal design that is consistent with the power handling capabilities of incorporating a 2-W amplifier behind each element.

Development of a highly reliable, compact, lightweight MSM using MMIC technology continued during 1986. A fully monolithic dual-gate FET switch circuit, which forms a basic building block for a miniaturized MSM, was fabricated and tested. The chip, measuring 1.5 × 2.5 mm, has a gain of 11.2 ± 0.5 dB over a 3.5- to 6.5-GHz frequency range (Figure 10). A level translating circuit was also integrated on the chip, resulting in TTL-compatible switch control.

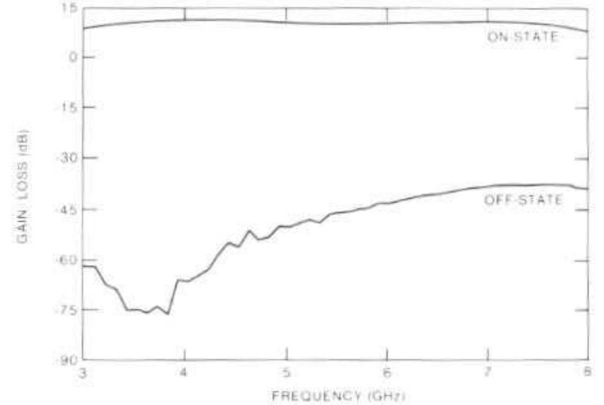


Figure 10. *Dual-gate FET switch module and measured performance*

On-Board Demodulation/Remodulation

A breadboard model of a C-band (3.95-GHz), 120-Mbit/s, coherent quadrature phase shift keying (CQPSK) regenerative repeater for on-board satellite applications was integrated (Figure 11) and tested during 1986. The repeater demodulates the digitally modulated microwave signal without intermediate frequency conversion. The circuit contains pulse shaping filters and carrier and symbol timing recovery loops designed for fast burst acquisition.

The measured modulated bit energy-to-noise power density ratio, E_b/N_o, is within 1 to 2 dB of that of an ideal demodulator at a bit error rate (BER) of 1×10^{-6}. The measured cycle slipping performance and unique word (UW) miss probability, shown in Figures 12 and 13, are better than target specifications. Most of the repeater building blocks, such as phase detectors, modulators, voltage controlled oscillators (VCOs), and clock recovery circuits, have the potential for realization in lightweight and highly reliable GaAs MMIC technology.

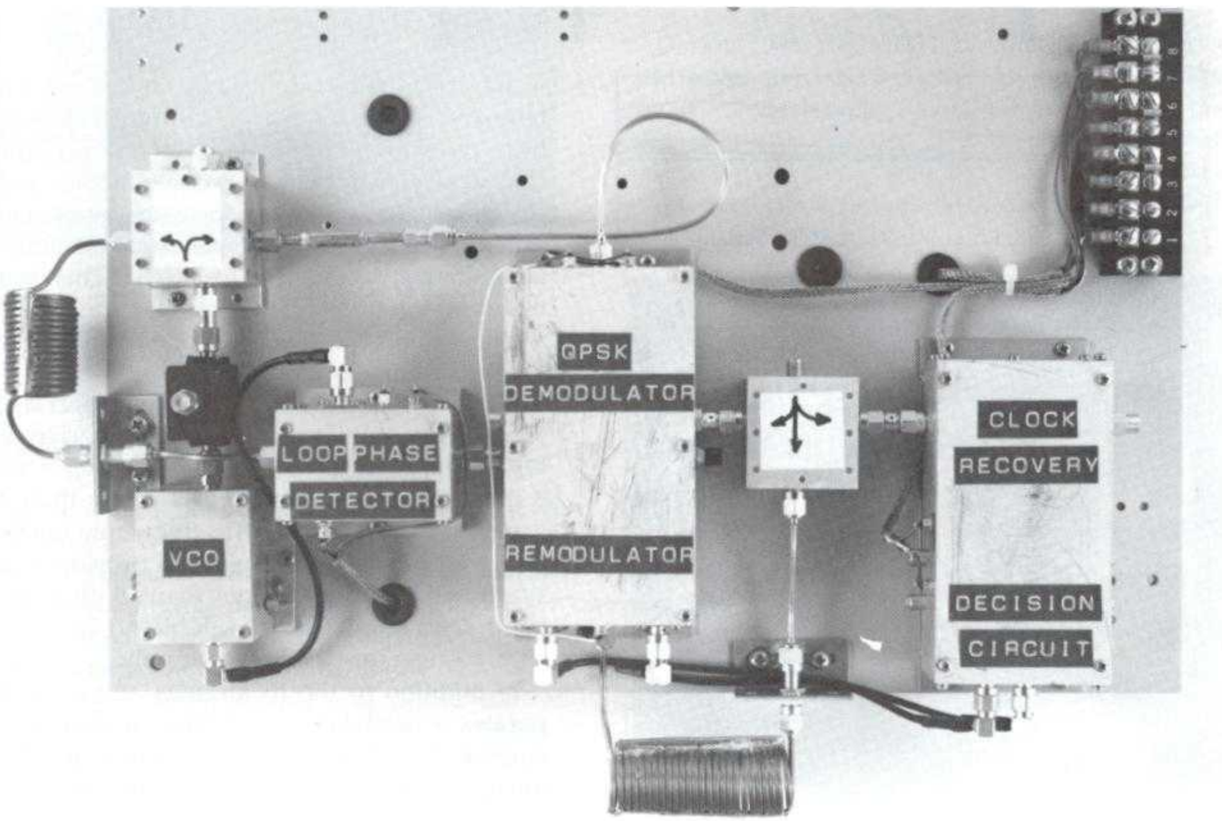


Figure 11. *Integrated C-band CQPSK modem*

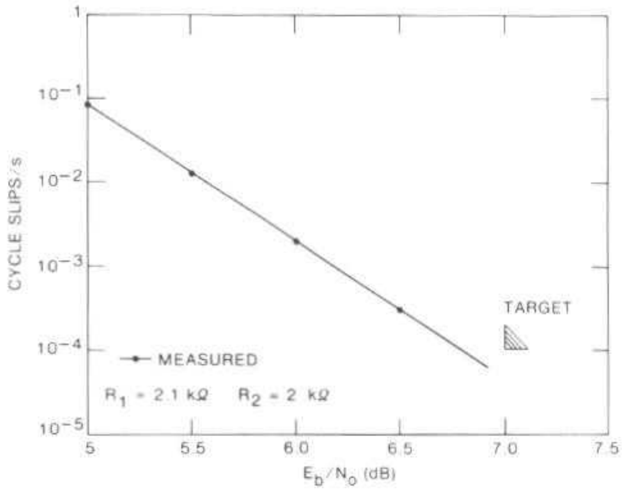


Figure 12. *Demodulator cycle slipping rate*

Propagation Measurements in Africa

During 1986, COMSAT Laboratories cooperated with INTELSAT, the U.S. Telecommunications Training Institute, the National Telecommunications and Information Administration, the U.S. Agency for International Development, the U.S. Information Agency, and the Governments of Cameroon, Kenya, and Nigeria to initiate a radio propagation measurement program in Africa. The goal is to collect annual K_u-band radiometric sky noise statistics and concurrent rain rate data at three sites in Africa. Such data are needed for planning and for developing and evaluating propagation models for tropical and equatorial climates. The locations selected for deployment of the measurement equipment are Douala, Nairobi, and Ile-Ife, each within 10° of the equator.

As part of its responsibilities, COMSAT conducted a 3-month training course at the Laboratories during June through August 1986 for six African engineers, two from each of the African countries. The course covered radiometric measurement techniques, equipment operation and maintenance, and data collection and analysis methods. COMSAT also supplied a radiometric receive terminal and spares for the Kenyan site. (INTELSAT supplied the other two equipment sets, and PC-controlled data acquisition systems for all three locations.) COMSAT and INTELSAT will provide further assistance and field support during the data collection phase.

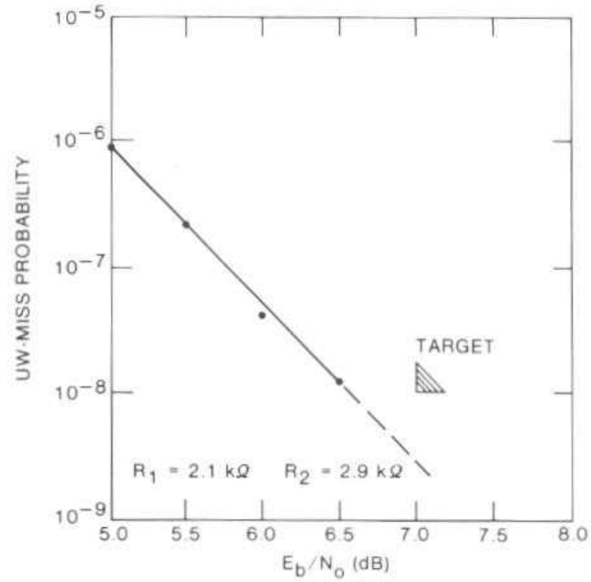


Figure 13. *Demodulator UW miss probability measured in the burst mode*

4/6-GHz Low-Cost CP Diplexer

In 1986, various designs for a low-cost, 4/6-GHz dual-polarized diplexer were investigated for use with small earth terminal antennas in the INTELSAT system. At present, there is no single feed/diplexer system totally compatible with the INTELSAT IBS polarization specifications for small (5- to 7-m class) antennas. The primary constraints on the design were fabrication cost, physical size and weight, and electrical performance. The approaches that were evaluated and breadboarded had to be consistent with all of the program goals.

Various designs involving both balanced and unbalanced 4-GHz receive band junctions were modeled and fabricated. The balanced junctions eliminated undesired TE_{21} mode transmit band energy and excessive receive band port-to-port coupling, but at the expense of substantial mechanical complexity. The unbalanced junctions were much smaller and less expensive to fabricate, but were incapable of meeting specified levels of electrical performance. Based on the analysis and measured results, an approach using concentric, coaxially disposed circular waveguides will be used. This is somewhat similar to the approach used for the present COMSAT Laboratories diplexer, but with substantial reductions in size and cost. During 1987, a breadboard/prototype model will be fabricated and tested.

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

The objective of this project is to develop a feed design appropriate for INTELSAT earth station antennas to allow simultaneous operation in both the existing 4/6- and 11/14-GHz bands. Ideally, the design should be low in cost and compatible with as many reflector antenna types as possible, including retrofits of existing antennas.

Shown in Figure 14, the system developed for this project employs couplers to inject the 11/14-GHz energy into the circular waveguide carrying the 4/6-GHz energy. This permits the 11/14-GHz coupler to be placed between the output of the 4/6-GHz diplexer and the feed horn. The coupling is accomplished by an array of small holes which couple energy from the circular waveguide to a symmetric pair of rectangular waveguides, one pair for each band. The symmetric arrangement is required to couple to the desired fundamental [TE(11)] circular waveguide mode. The advantages of this concept are that it permits the use of an existing 4/6-GHz diplexer design and results in a compact and low-cost approach to the dual band feed.

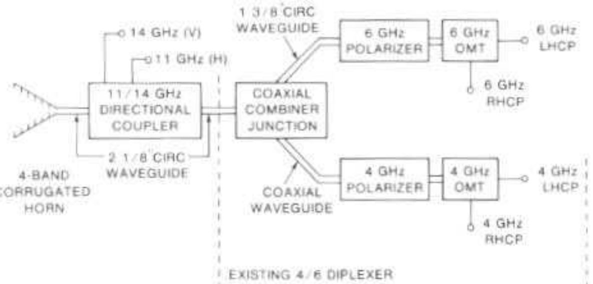


Figure 14. *4/6- and 11/14-GHz antenna feed system*

Emphasis has been placed on the design of the 11/14-GHz coupler since the modifications to the 4/6-GHz diplexer and the design of the four-band horn are believed to be straightforward. Therefore, they can be delayed until the critical item, the 11/14-GHz coupler, is near completion.

Because of the symmetry of the coupling structure, only symmetric modes are generated in the circular waveguide. A coupling hole geometry has been selected which generates only transverse electric (TE) modes in the circular waveguide. Therefore, if adequate symmetry is maintained, there are only four unwanted modes which may be generated in the circular waveguide. These four unwanted modes are suppressed relative to the desired TE(11) mode by the design of the coupling structure. Dielectric loading in the coupled rectangular waveguides is used to match the phase velocity of the fundamental TE(10) mode to the circular TE(11) waveguide mode. Higher order modes are further suppressed by optimizing the coupling taper at the ends of the slot coupling sections.

A method of computing the appropriate coupling and phase velocity has been developed and breadboard test models have been constructed. Measurements on these test models have demonstrated excellent mode purity, return loss, and directivity.

Antenna Diagnosis Using Microwave Holographic Techniques

Microwave holographic measurement capability was added to the antenna pattern range facility in 1986. Microwave holography utilizes the Fourier transform relationship between the antenna radiation pattern and the antenna aperture electromagnetic field distribution. The transform facilitates antenna diagnosis by providing the reflector surface deviation profiles and the illumination/blockage patterns from the measured far field data. Problems such as random surface errors, periodic surface errors, feed illumination errors, blockage, and phase errors on array elements can be quickly and accurately diagnosed. This diagnostic information is useful for various antenna types including prime feed single reflectors, dual reflector antennas, shaped antenna systems, offset antennas, and multifeed and flat plate arrays. The primary advantage of the holographic measurement is that a complete antenna system diagnosis can be performed in a relatively short time. Other methods, such as optical measurement using theodolites, mechanical measurement of reflector surfaces, and analysis of far-field pattern cuts, are less direct and more time consuming.

Figure 15 is a block diagram of the holographic antenna measurement system. A drive file containing the azimuth and elevation angles is used by a computer program which controls the antenna positioner and RF receiver. This program collects the amplitude and phase at the far-field sample points. A second program then plots the far-field contour pattern and processes the data using the fast Fourier transform. The resolution of the processed data can be improved by an iteration process. The data can then be plotted as an aperture amplitude distribution (illumination function including blockage) and an aperture phase contour (due to reflector surface deformations, feed defocusing, and blockage, etc.).

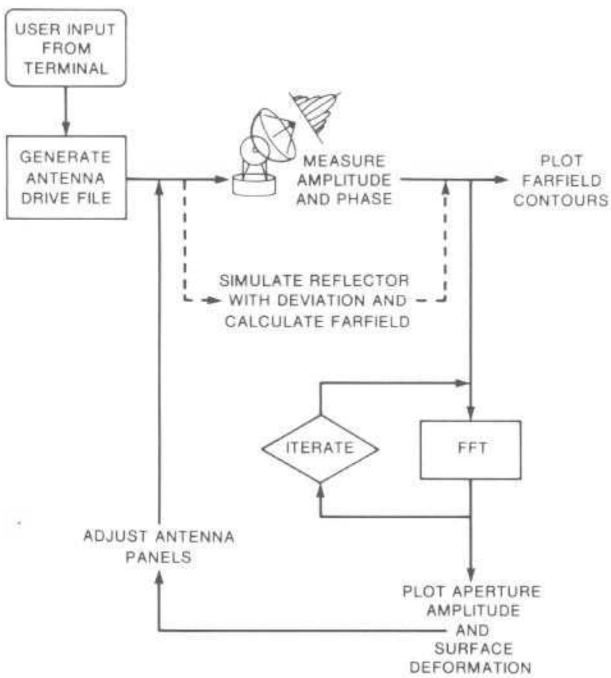


Figure 15. *Block diagram of holographic antenna measurement system*

To facilitate the measurement system, several major software development tasks were completed in 1986. One program contains processing software to perform the Fourier transform and graphically display the results. Another program drives the antenna and reads the receiver data. A program to analytically simulate reflector surface deviations was a'so written.

Figures 16 and 17 show the results of a holographic measurement of a 1.8-m offset fed antenna. As a demonstration, the antenna had an 8.5 × 11-in., 0.040-in.-thick patch purposely located near the center of the reflector. As expected, the amplitude distribution shows an unblocked illumination function with a very minor disturbance in the patch region. The phase contour shows the patch as a phase discontinuity of the expected magnitude. Figure 18 shows a phase profile through the patch.

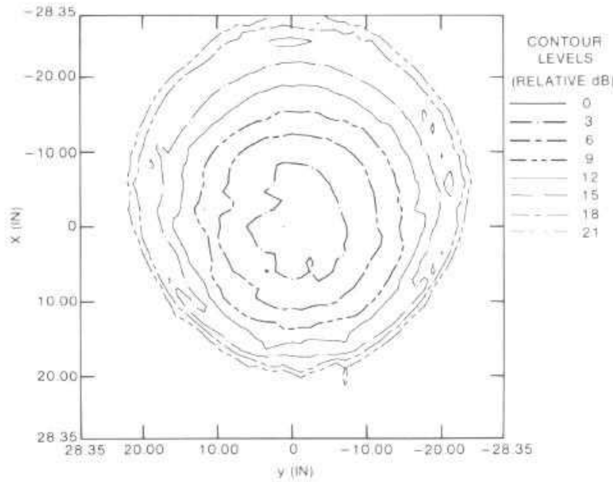


Figure 16. *1.2-m offset reflector antenna with patch, 14.25-GHz amplitude of aperture field (illumination function)*

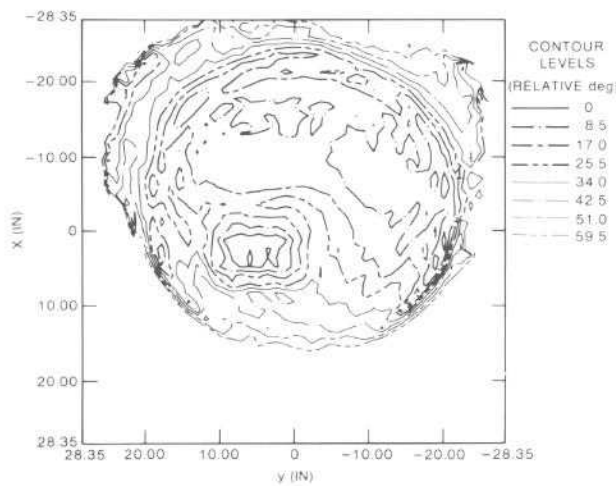


Figure 17. *1.2-m offset reflector antenna with patch, 14.25-GHz phase of aperture field (surface deviation contour)*

K_u-Band Up-Link Power Control Development

A program to develop and demonstrate up-link power control (ULPC) techniques applicable to a wide range of K_u-band satellite communications systems was initiated in 1986. Under certain conditions, implementation of ULPC capability can substantially increase the up-link available time during periods of precipitation. However, a ULPC system must contend with several distinct propagation phenomena, including rain attenuation, gaseous absorption, and tropospheric scintillations. It is also difficult to unambiguously differentiate path effects from system-generated signal level variations that may be caused by gain changes, antenna mispointing, and beacon level variations, for example. The major limitations to effective ULPC implementation are natural variability in the propagation medium, control-signal measurement errors, and imprecision in the control loop. Loop dynamics are also an important consideration.

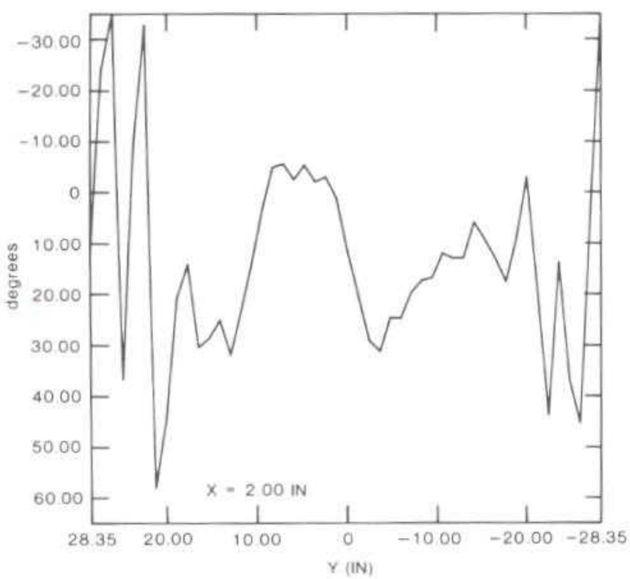


Figure 18. 1.2-m offset reflector antenna with patch, 14.25-GHz phase of aperture field (surface deviation profile)

Analyses of propagation effects led to the conclusion that simply scaling the measured 11-GHz down-link attenuation to 14 GHz with frequency-dependent ratios is sufficiently accurate for a 7-dB range of power control, provided that measurement errors are controlled. Figure 19 shows the theoretical variations in 14/11-GHz scaling ratio as a function of rain type.

Data were collected for several precipitation events (including rain, snow, sleet, and soft hail) by using a K_u-band loopback system implemented at COMSAT Laboratories. A down-link beacon at 11.45 GHz was monitored for the control signal, which was then used to control the up-link transmit power. The level of the looped back carrier relative to the beacon provides verification of the ULPC operation.

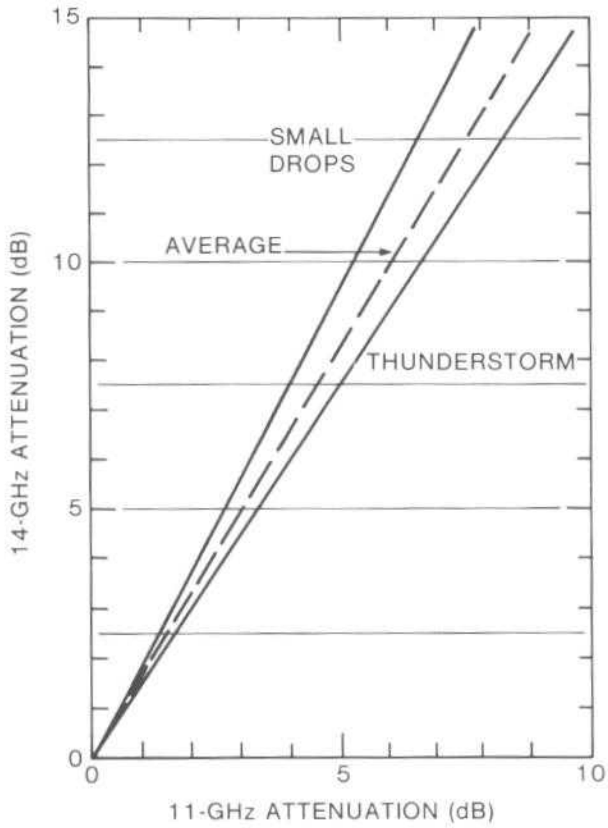


Figure 19. Relation between 14- and 11-GHz rain attenuation for different rain types

COMSAT PROPRIETARY R&D

Flat Plate Antenna

COMSAT has entered into a joint development agreement with Matsushita Electric Works (MEW) to produce low-cost, lightweight, high-efficiency flat plate arrays for satellite reception at K_u-band. The array designs are based on advanced technology developed at COMSAT Laboratories that has led to novel printed circuit radiators that are electromagnetically coupled to the feed line. This type of design lends itself to low cost and high efficiency. COMSAT has built linearly and circularly polarized versions in addition to designs with a fixed beam offset. Figure 20 shows a 1.3-m working model array that demonstrated efficiency greater than 60 percent. This array was used to receive high-quality TV transmissions from a number of domestic K_u-band satellites.

COMSAT PROPRIETARY DEVELOPMENT

1.8-m Offset Reflector and Die Cast Feed System

The design of a 1.8-m offset reflector and feed system was completed. A program for designing feed components that do not require tuning (including pretuned transmit reject and transmit bandpass filters) was also successfully completed. The accuracy and repeatability of the die cast manufacturing process permits the use of pretuned components that reduce the cost of producing the feed. During 1986, 200 deliverable antennas were tested and designs of alternative antenna manufacturers were evaluated.

2.9-m Transportable Earth Terminal Antenna

A 2.9-m transportable antenna system incorporating both C- and K_u-band feeds was developed for COMSAT General. Careful electrical design of the feeds and the control of the mechanical aspects of the reflector surface (including the rms of lightweight graphite epoxy reflector panels and panel alignment mechanisms) have resulted in an antenna system that meets all international and domestic wide-angle sidelobe requirements.

The K_u-band feed operates over both the international and domestic frequency bands. The C-band feed design allows either linear antenna polarization for domestic use or circular antenna polarization for INTELSAT use. The antenna meets the INTELSAT 1.06 voltage axial ratio specification using a recently developed feed that can be easily polarization tuned on site at the operating transmit frequency.

***Figure 20.** K_u-band flat plate array demonstrates efficiency greater than 60 percent*

The antenna system is a "fly away" design: the mount, feeds, and associated solid-state power amplifier (SSPA) and LNAs are foam packed for shock protection in seven boxes that can be shipped on commercial airlines. The mount is designed to adapt to various mounting surfaces and to hold the antenna rigid in winds up to 60 mph. A rear view of the assembled antenna is shown in Figure 21.

The antenna was temporarily installed on the roof of the American Mission in Geneva, Switzerland, awaiting the completion of a permanent installation. This allowed COMSAT International Communications, Inc. (CICI) to complete a K_u-band T-1 link and begin service for the State Department.

Figure 21. 2.9-m transportable antenna system (rear view)

COMSAT SUPPORT

Southbury INMARSAT Antenna Measurements

In 1985, a comprehensive set of measurements was conducted on both the Southbury full-performance and MARISAT earth station antennas to evaluate their performance over the new INMARSAT frequency bands. Tests indicated that they could be used without major modifications. The full-performance antenna had severe mode spikes and resultant gain and noise temperature degradations within the new receive band frequencies. At that time, it was theorized that a half-wave polarizer in the NEC feed was causing the problem and it was further concluded that the antenna could be rendered suitable for use by covering the coupling slots in the polarizer shunt cavity phase compensating network.

During a trip to Southbury in May 1986, the recommended fix was implemented, and as expected, the mode spikes were eliminated. Measurements of the receive gain, using radio star techniques, and the antenna system noise temperature were also conducted. The measurements showed that, with the addition of new LNAs, it will be possible to achieve the specified level of G/T performance. In 1987, a return trip will be made to Southbury to install the amplifiers and to make the final INMARSAT acceptance test measurements on both antennas.

This test program has been successful in accurately determining the capability of the present antennas to meet the new INMARSAT specifications, thereby minimizing retrofit costs.

Washington E3 IBS Earth Station Measurements

Extensive gain and G/T measurements were conducted on CICI's IBS, 9-m, K_u-band antenna located at L'Enfant Plaza. This antenna was designed to operate over a greater frequency range than is currently available from in-orbit satellite testing, which measures gain and G/T over just a portion of the design bandwidth. Radio stars, which are commonly used for measurements on much larger, 30-m class antennas, were used to measure the gain and G/T over the full design bandwidth.

The semiautomated antenna measurement system, developed at COMSAT Laboratories, along with accurate noise injection techniques, measured the signal power from the radio star. Despite an extremely small Y-factor of 0.1 dB, the gain and G/T data agreed well with the calculated antenna gain, and the limited data that were measured using satellites.

INTELSAT CONTRACTS

G/T Measurement Techniques of INTELSAT Standard E and F Earth Stations

INTELSAT Standard E and F business class earth stations are difficult to characterize in terms of gain and figure of merit (G/T). These antennas are generally too small for G/T measurements using standard radio star techniques and conventional test equipment. Satellite testing techniques based on assumed e.i.r.p. levels are often used but with reduced accuracy. In some cases, the antenna manufacturer's predicted performance is offered as proof of performance without adequate testing.

COMSAT Laboratories has developed and refined procedures to accurately measure gain and G/T for these antennas, and, through Purchase Order 21337-0 with INTELSAT, is documenting these techniques for other users of the INTELSAT system. For the larger antennas, measurement accuracy can be significantly improved by comparing signals received from radio stars to that of a known noise power injected at the LNA input. For the smaller antennas, the moon can be used as a known signal source. A simplified, but accurate, moon ephemeris program was written that runs in real-time on small, readily obtainable computers. The antennas can still use satellite techniques to measure G/T, but careful attention to system gain drift, along with the use of a standard gain horn comparison technique, can greatly improve measurement accuracy. All of the applicable test techniques and error bounds are discussed in the final report.

Propagation Model Development

Under Contract INTEL-222 (RAE-207), COMSAT Laboratories developed refined propagation analysis software which incorporates new impairment calculations and also contains improvements to the existing rain degradation model. The new model, intended only for INTELSAT research and development applications until it has been thoroughly tested, provides predictions of gaseous attenuation, tropospheric scintillation, defocusing, rain and cloud attenuation, path depolarization, and down-link degradation for frequencies of 1 to 35 GHz and path elevation angles of 0° to 90°.

Figure 22 provides the modeled annual distribution of 11-GHz tropospheric scintillation fading for an elevation angle of 5 and antenna diameter of 3 m, along with an analytic fit to the curve that is used in the model as a reference distribution. The model predictions have generally provided good agreement with measured data.

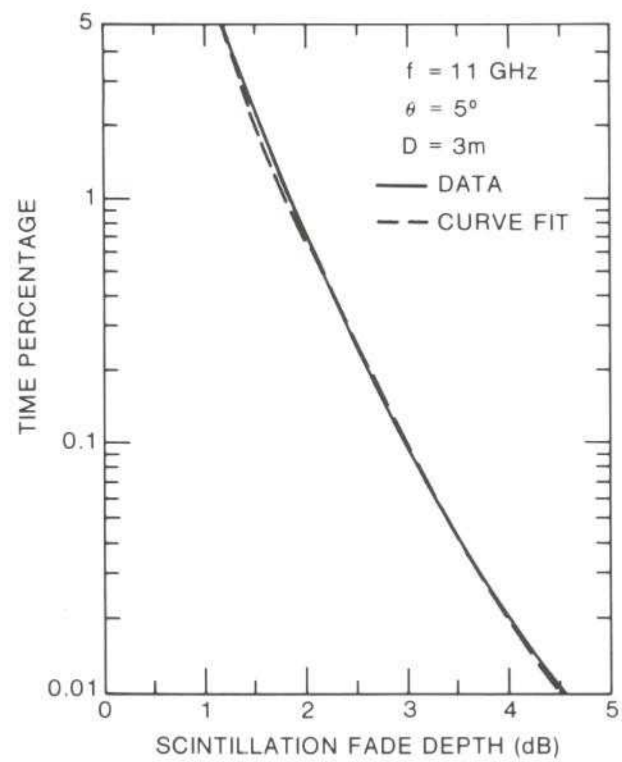


Figure 22. *Modeled scintillation fading statistics*

STLC In-Orbit Test System Upgrade

Software and hardware of the SBS IOT system were upgraded under contract with STLC. The new system is based on an automatic spectrum analyzer and uses synthesized sources for both up-link and injected signals. It is controlled by an HP9000 Series 520 computer rather than the two HP9845s used in the old system. The new system retains all the functionality of the old system and supports any number of different spacecraft models with diverse antennas and channels. However, unlike the old system, contour generation is totally integrated with the measured software. A completely new feature allows verification of the earth station antenna and feed coupler calibration, thus eliminating time consuming and error-prone pretest calibrations.

The objective of Contract INTEL-497 was for COMSAT Laboratories to upgrade the INTELSAT V control software that runs the in-orbit tests (IOT) on the Series V satellites. Both the original hardware and software were implemented by COMSAT Laboratories for INTELSAT. The upgrade allowed INTELSAT to perform IOT for the Series V, as well as the expanded frequency band V-A and V-B business system satellites. The upgrade expanded the existing software to make it compatible with the modified INTELSAT hardware, while maintaining the existing user interface and measurement strategy. The contract was successfully completed in 1986.

The Microelectronics Division (MED) supports the Corporation's needs for state-of-the-art microelectronics components for improved and expanded satellite communications systems, other aerospace applications, and the programs of COMSAT's Amplica Division. Research and development efforts focus on field effect transistors (FETs), microwave integrated circuits (MICs), miniaturized microwave active circuits (MMACs), and monolithic microwave integrated circuits (MMICs). Goals of these efforts include improvement of electrical performance and the achievement of higher operating speeds and frequencies, as well as reliable and long lived products. MED capabilities include semiconductor materials preparation, circuit design and testing, complete fabrication, and reliability assessment (including radiation effects because of their importance to satellite communications). Because of the significance attached to reliability, the division maintains an extensive analytical facility to support its own projects and those of other organizations within the Corporation.

FACILITIES

Construction of the MED's clean-room facility was nearly complete at the end of 1986. Phase I, a class-100 (fewer than 100 half-micrometer particles per cubic foot) clean room for microlithography, became operational in 1985. Phase II, a class-1000 clean room for wet-chemical and thin-film processing, will become operational soon. The class-1000 area will house vapor deposition systems (both electron-beam and resistively heated evaporation sources), sputter deposition systems, and systems for plasma-enhanced chemical vapor deposition (PECVD), ion-beam etching, reactive ion etching, and plasma etching in the thin-film area. The wet-chemistry area will contain multiple clean-bench work stations and an electroplating facility.

Automatic DC measurements can be a low-cost technique for evaluating FETs and MMICs at the wafer level. At COMSAT, an Automated Wafer Probing System and attendant software were developed to allow rapid analysis of DC characteristics of active and passive components and to establish a data base for yield and performance. The system is built around an automatic prober which accommodates probe cards for different test configurations. Measurements are made using a semiconductor parameter analyzer, which has eight measurement ports that can be dynamically switched to any of the 48 pins on the probe card by a switch matrix controller. Data generated during a wafer probing are stored on floppy disk for off-line analysis. The control and analysis software, developed in house, evolved in response to a variety of needs. The output is a mix of relevant statistics and graphic presentations that quickly convey the sense of the data. Figure 1 is a photograph of the probe head of the equipment.

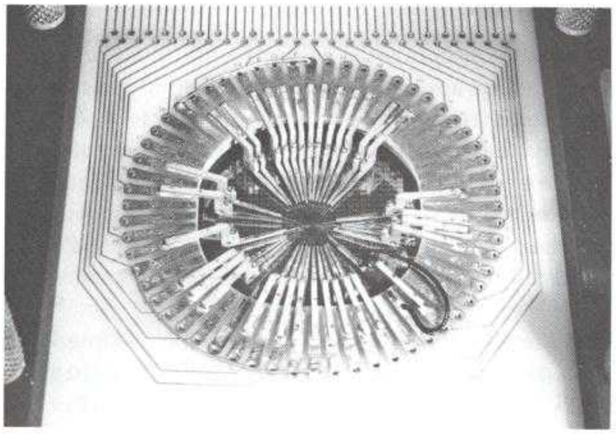


Figure 1. *Automated Wafer Probing System allows rapid analysis of DC characteristics of active and passive components*

The division's molecular beam epitaxy (MBE) reactor was installed in the summer of 1986. Following a conditioning period in which the system underwent extensive baking and outgassing, trial growth runs were initiated to demonstrate that the equipment is capable of producing state-of-the-art material. Acceptance criteria were specified for layer uniformity, Hall mobility for n-type GaAs, and electron mobility in a high electron mobility transistor (HEMT) structure. Specifications for layer uniformity have been met and test runs for carrier mobility determination are in progress.

Two new RF measurement capabilities were added to the MED test and evaluation facilities. A dedicated automated measurement system capable of power and swept-gain measurements at K_u-band frequencies for the FET device qualification program was assembled and is currently operational. Microwave performance of sampled devices from wafer runs is routinely obtained. To support millimeter-wave device and MMIC development, equipment operating in the 40- to 60-GHz band for power, swept gain, return loss, noise figure, and spectrum analysis have been added to the current facility for measurements up to 40 GHz. The new systems are available to evaluate both low-noise and power devices and circuits.

COMSAT JURISDICTIONAL R&D

Materials

The basic semiconductor material used in the MED research programs is gallium arsenide (GaAs). Although substrate wafers are not made in house, the remainder of the materials processing (e.g., epitaxial growth or ion implementation) to obtain the desired active material is done by the MED. GaAs layers grown in the halide reactor can now be produced routinely with very repeatable characteristics for thickness, carrier concentration, and carrier mobility.

More recently, research efforts have been aimed at advances in MBE-grown materials using COMSAT's MBE machine, described in an earlier section of this report. In contrast with the halide system, which operates at pressures of about 1 atmosphere, the MBE system background pressure is of the order of 10^{-13} atmospheres. Such severe restrictions are not often encountered elsewhere, and a special set of laboratory procedures must be developed for working under them. The goal of MBE technology is to achieve materials with properties that cannot be obtained with previously available methods.

A prime example of MBE application is the material structure needed for HEMTs. This structure requires very thin (~100 Å) layers of high purity. Although many of the fabrication steps used with conventional GaAs devices can also be used with HEMTs, new procedures must be developed to make devices from HEMT-type material. In addition to the thin layers, other constraints are imposed by the use of GaAlAs (gallium aluminum arsenide) and the proximity of the active region to the semiconductor surface. In preparation for processing COMSAT-grown HEMT structures, process modifications have been tested on purchased wafers and the successful ones adopted.

Semiconductor Processing

Semiconductor processing encompasses a wide variety of technologies and professional talent. Changes in component design and improvements in materials require continuous adjustment of processing procedures. Descriptions of some of the more interesting advances are given below.

As semiconductor devices and circuits become more sophisticated, their construction results in three-dimensional structures as opposed to planar, or single-surface, units. Consequently, the fabrication of the reverse, or nonactive, side of a wafer requires every bit as much care as does the front side. Back-side processing provides reduced inductance, joule heat dissipation, and ground plane contacts; these features are particularly critical in circuits and power devices. An important feature of this processing is the method of forming the conductive connection (via-hole) between the two surfaces. The thicker the wafer, the more difficult is this fabrication step. The MED has designed and constructed spray etching equipment to improve via-hole processing of substrates as thick as 0.10 mm. Figure 2 is a photograph of via-holes taken from the back side of a power amplifier wafer.

Another step in advancing processing capability was direct-write, electron-beam (e-beam) lithography. Software that permits the operation of the e-beam system in a direct-write mode overnight and on weekends has been completed and tested. Previously, an operator was required for calibrating and initializing the e-beam system at the start of writing every wafer. Now wafers can be loaded into the system and initializing parameters set up for all wafers at the start of a multi-wafer run. The e-beam system then operates completely automatically through loading, initializing, creating job command files, writing wafers, and creating job summary data files for each wafer. The system throughput is now limited only by the number of direct-write wafer chucks available (presently four). Other software has improved wafer throughput by sorting pattern data into high- and low-beam current sections, without compromising between fast writing rates and high resolution.

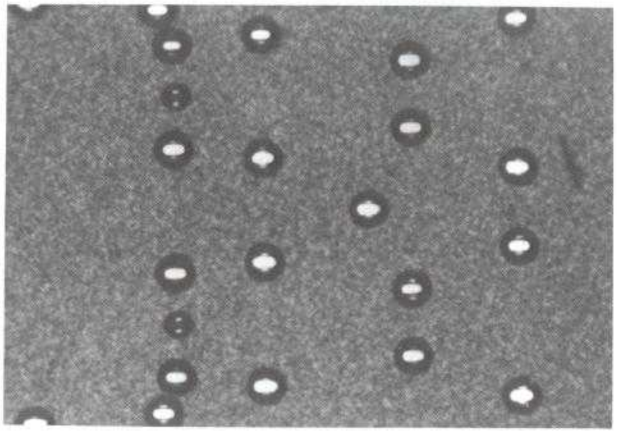


Figure 2. *Improved via-holes are obtained by using spray etching equipment designed and constructed by the MED*

The MED also performs processing as a service for other divisions of the Laboratories. The *COMSAT Laboratories 1985 Annual Report* described the computer-aided design of a 140-Mbit/s, coded octal phase-shift keying (COPSK) modem. Approximately 70 of these hybrid integrated circuits were fabricated for a development project of the Communications Techniques Division. Each circuit consists of a thick-film, two-dielectric-layer and three-metal-layer power and ground back plane, drilled and filled holes (conducting via) through an alumina substrate, and four-layer thin-film front-side circuitry. The circuits contain resistors, two metal layers for signal interconnection, and approximately 1,200 dielectric crossovers for the interconnect lines.

The MED has also successfully fabricated GaAs MMICs for use in phased-array antennas. These circuits, designed by the Microwave Technology Division, are unique in that many new fabrication methods (two-tier capacitor dielectrics, e-beam alignment techniques) and many types of circuits (low-noise amplifiers, broadband amplifiers, single- and dual-gate FETs) and signal translators are embodied in a single maskset. Figure 3 is a chip yield for an MMIC circuit where the accepted devices are shaded.

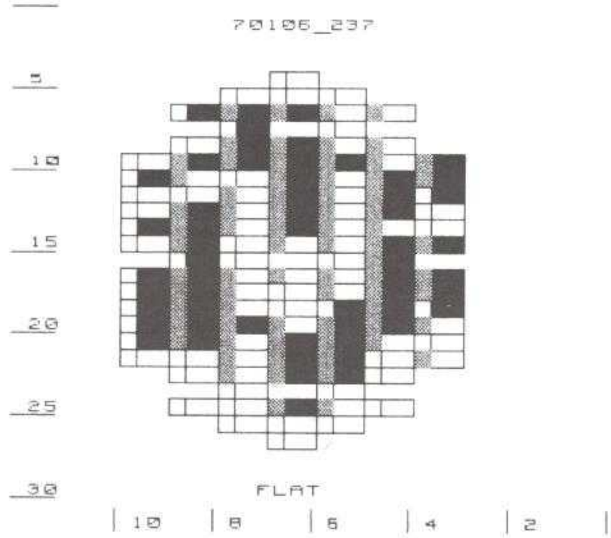


Figure 3. *Chip yield for an MMIC circuit*

MMICs

One of the goals in developing MMICs is to provide a greater degree of reliability and uniformity in satellite circuits. Work was initiated toward achieving a small, space-compatible, two-stage low-noise amplifier (LNA) for the 14.0- to 14.5-GHz fixed satellite service band. Because the FET is usually the most critical feature of an MMIC, low-noise FETs were fabricated. Several state-of-the-art fabrication techniques such as through-substrate via-holes, air bridges, and half-micron gates were used to produce high-gain, low-noise devices. The first fabrication runs yielded FETs which exhibited a noise figure of 1.82 dB and an associated gain of 7.8 dB.

Using equivalent circuit models generated from s-parameters and COMSAT's modeling programs, impedance matching circuits aimed at achieving an optimum noise figure over the 500-MHz band were designed. Two approaches were followed: cascaded single-stage and combined two-stage with interstage matching. Figure 4 shows the CAD layout of the two-stage LNA.

Radiation-Hardened Circuits and Materials

Because satellites are subjected to the space radiation environment, COMSAT Laboratories is continually working to determine the effects of radiation on satellite components. The MED has previously reported on damage to silicon devices from individual energetic ions. This damage has been demonstrated, and its extent measured, by imaging the surface of the device with the COMSAT scanning electron microscope (SEM) operating in the electron-beam-induced-current (EBIC) mode. Figure 5 shows traces of EBIC; the lowest current is generated in the damaged regions. With the increased demand for higher frequency, higher speed components, the dimensions of semiconductor devices have become smaller and the use of new materials (e.g., GaAs) has become necessary. As of this date, repetitions of the above work on GaAs have not shown the same kind of damage that was seen in silicon. Further studies of this type are underway to establish with certainty that GaAs-based devices will not degrade from such single-event failures.

Not all aspects of satellite communications are better served by using GaAs; therefore, there is a need to improve the radiation characteristics of some kinds of silicon devices. The MED has been working on improving the radiation tolerance of oxide layers on silicon. By introducing modifications to PECVD layers, the radiation hardness of both thin (gate) and thick (field) insulators has been extended well beyond that of any others. Gate insulators have exhibited tolerance to 10^7 rad and field oxides to 10^6 rad.

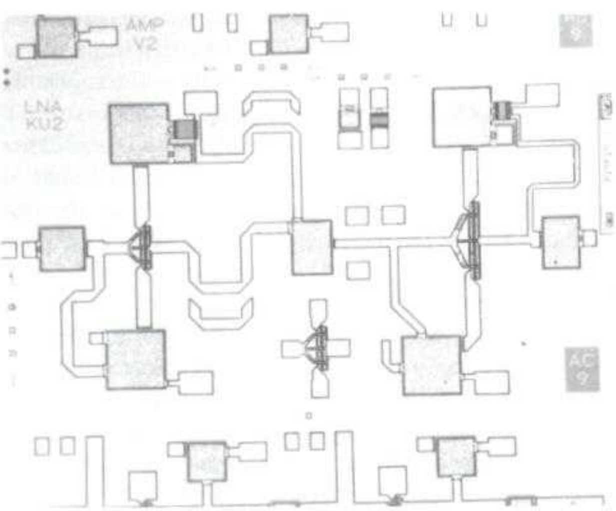


Figure 4. Circuit layout of a two-stage, 14.0- to 14.5-GHz LNA

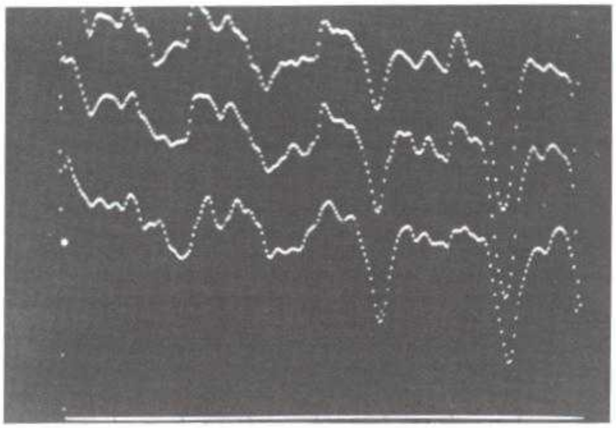


Figure 5. EBIC traces generated by the COMSAT scanning electron microscope measure damage to silicon devices

COMSAT NON-JURISDICTIONAL R&D

Computer-Aided Device Modeling

Physical modeling of GaAs devices, in support of design efforts in the Microwave Technology Division and fabrication and design capability in the MED, is an ongoing activity. The models have been particularly useful in reducing iterations when designing masksets and for troubleshooting problems in the fabrication of devices and in tailoring material characteristics. A recent addition to this capability is a program for designing varactor carrier profiles. Results of this program have been used to develop a 14.5- to 26.5-GHz, MMIC, varactor tuned, voltage controlled oscillator (VCO) for a Hughes Aircraft Company study contract (described subsequently). The MED's efforts in VCO development will also be enhanced by the availability of this program.

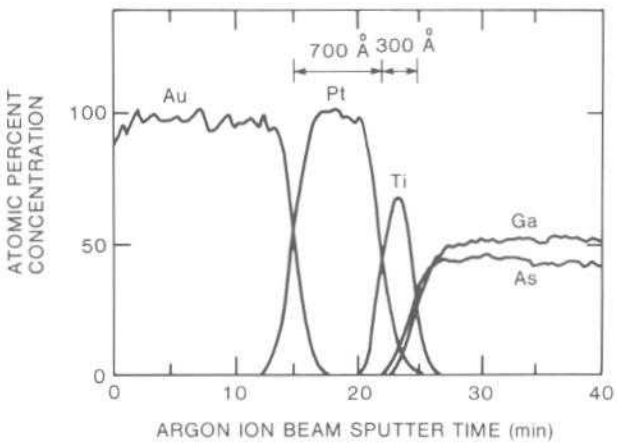
Power Amplifiers and Devices

Whether a circuit is of MIC or MMIC form, the most critical component is usually an FET. The

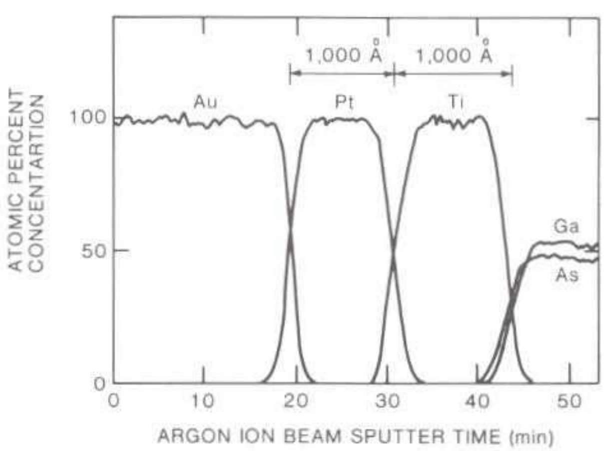
MED had previously announced a state-of-the-art power FET for use at 20 GHz. To ensure the utility of this device in non-laboratory applications, a product assurance program was begun. This program consists of two parts: a wafer qualification procedure and a product reliability assessment.

One of the steps in the qualification procedure is a high-temperature (240°C) bake. Early versions of the FET exhibited a very low yield of devices after this bake and the problem appeared to be at the gate. By employing Auger electron spectroscopy to study the materials in the gate metalization, it was discovered that the titanium (Ti) barrier metal was only marginally thick enough to prevent gold diffusion into the GaAs (see Figure 6a). The Ti thickness was increased (Figure 6b) to about 1,000 Å and the FETs were subjected to the same high-temperature step as before with no measurable degradation of the gates due to metallic diffusion.

Facilities have been installed to address the second part of the product assurance plan, the reliability aspect. Using three separate ovens, up to 30 devices can be evaluated under DC and temperature stress conditions with independent control and computer monitoring of voltage and current on the gate and drain of FETs. Devices can be tested with channel temperatures up to 300°C; this represents a life-acceleration factor of about 20,000 for devices that normally operate at 110°C. These procedures, coupled with results of analysis by SEM and Auger techniques, are used to assess the quality of FETs and to develop processes for fabricating improved devices.

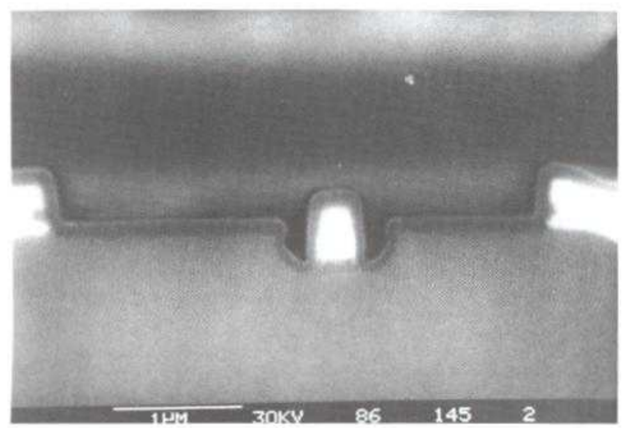


a) Faulty gate structure has thin Ti layer

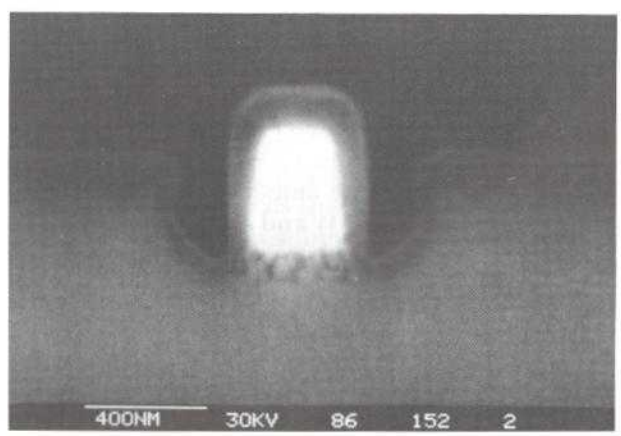


b) Improved gate structure has thick Ti layer

Figure 6. *Auger electron spectroscopy is used to study the materials in the FET gate metalization*



a) Magnification = 17,000 X



b) Magnification = 41,000 X

Figure 7. *Backscatter electron image of the cleaved cross section of a 0.5-W FET*

The backscatter electron image of the cleaved cross section of a 0.5-W FET with sub 0.5-μm gate length and integral glass passivation layer is shown in Figure 7. Devices produced under the FET development and qualification program have been used in circuits such as a 0.5-W, 6- to 18-GHz balanced power amplifier (Figure 8) developed at COMSAT. The COMSAT power FET offers improvements over other commercial devices based on its RF performance and easy-to-match load characteristics for optimal output power across the broad frequency band. Prototype circuits have been forwarded to the Amplica Division of COMSAT for further evaluation and conversion to potential products.

Two K_u-band, solid-state power amplifier modules were developed for the VSAT terminal application. A 1-W amplifier covering the 14- to 14.5-GHz satellite band was designed using low-cost hybrid MIC technology and the COMSAT GaAs power FET. A 2-W version was also developed using two 1-W FETs. A multistage amplifier consisting of two 1-W modules, an isolator, and a 2-W module is shown in Figure 9. The complete amplifier provides an output power exceeding 2 W and a power gain of 16 dB across the 14- to 14.5-GHz band, as illustrated in Figure 10.

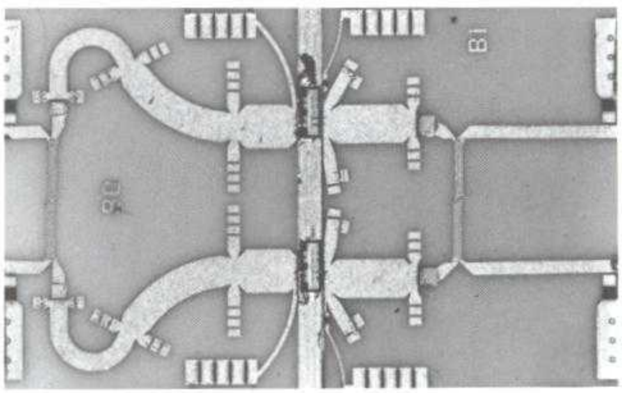


Figure 8. *COMSAT power FET provides optimal output power across the 6- to 18-GHz band*

COMSAT SUPPORT

Support to Amplica in the areas of device/circuit modeling and automated measurements included an improved test fixture de-embedding software, which was developed, installed, and tested on Amplica's HP 8510 automatic network analyzer. An automated amplifier module test workstation was developed and implemented jointly with Amplica personnel. The FASTEST software/hardware system allows quick pass/fail testing of RF performance along with DC parameter testing. The automatic probe station was employed to evaluate the process for fabricating thin-film capacitors of MICs and MMICs. More than 150,000 capacitors were fabricated on a variety of substrates, and breakdown voltages were measured. No significant changes in yield or capacitance value were observed for capacitors aged for 120 hours at 150°C.

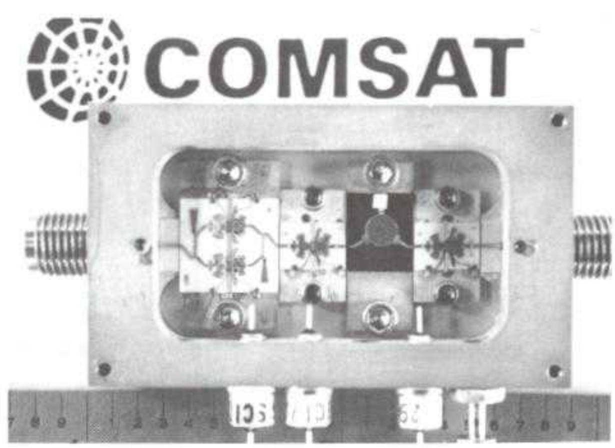


Figure 9. *Multistage amplifier consists of two 1-W modules, an isolator, and a 2-W module*

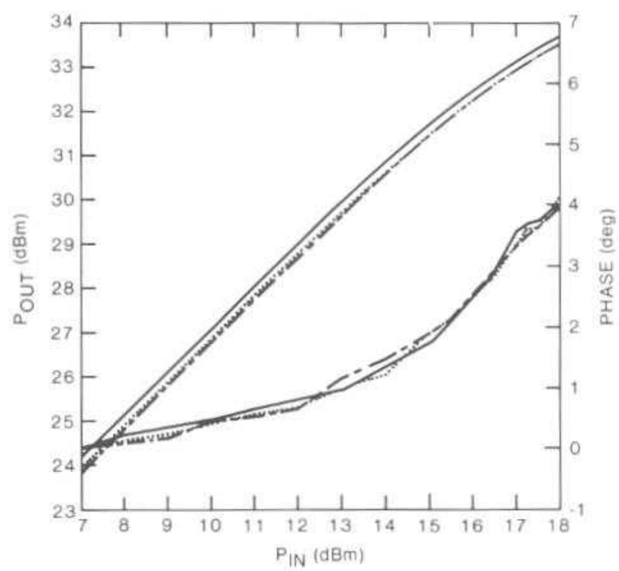


Figure 10. *Output power and gain performance of the COMSAT multistage amplifier*

In a collaborative study with the Applied Technologies Division, the function of zirconium as an emission activator in the oxide-coated cathode used in INTELSAT VI traveling wave tubes (TWTs) (Figure 11) was investigated. Chemical analysis was carried out using high-resolution Auger electron spectroscopy with argon ion milling on a TWT cathode following 40,000 hours on life test. The Auger analysis uncovered an unexpected segregation and concentration of zirconium on the surface of the high-purity nickel base that supports the barium strontium oxide coating on the cathode. Although the zirconium had originally been deposited as a layer of uniform thickness, zirconium concentrations were found in raised areas a few micrometers in size. Low levels of sulfur, a contaminant known to poison oxide cathodes, were also found at nickel grain boundaries. The consequences of these chemical discoveries in terms of involvement in failure mechanisms of TWT cathodes is currently under consideration.

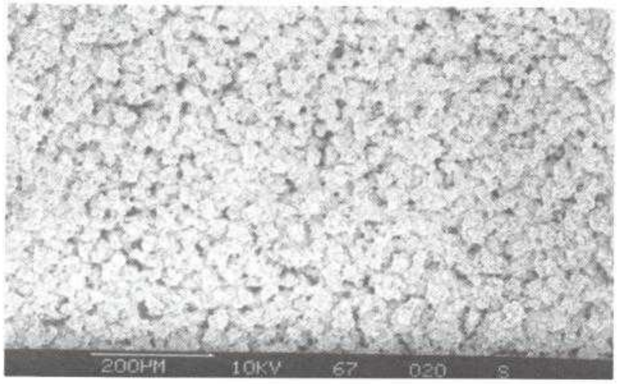


Figure 11. *Scanning electron micrograph shows the analytical area of the oxide-coated cathode used in the INTELSAT VI TWT study*

Analytical support services using inductively coupled plasma emission spectroscopy provided the solution to a problem at the Roaring Creek Earth Station involving a contaminated, high-volume cooling system. Analytical data on samples of coolant and corrosion debris and expert chemical assistance from the Laboratories resulted in an inexpensive chemical treatment procedure that was used to inhibit corrosion in the coolant system without discontinuing operation at the station, which would have resulted in lost revenues to COMSAT.

INTELSAT SUPPORT

The failure of an INTELSAT V TWTA from the shorting of a silicon diode prompted a reliability study of the diodes by the MED. The metallurgical and electrical integrity of flight-qualified diodes, identical to the failed diode, was ascertained by a failure analysis process, involving electrical and thermal measurements, and materials analysis using scanning electron microscopy, energy dispersive X-ray analysis, and Auger electron microanalysis. The results showed that resistance to pull stress of the die bond was low on two of four diodes tested; this would explain the increased forward voltage which was measured. Also, the side of one silicon die, where the junction terminates and the highest electrical field exists, was found to be contaminated with sodium and chlorine. This discovery may explain the failure of the shorted diode in the TWTA. These findings led to improved methods of evaluating diodes for acceptance in the INTELSAT V hardware to minimize the risk of possible failure.

Another task performed to support the INTELSAT program was to identify the cause of blisters on positive plates for the INTELSAT V Ni/H_2 cell. These blisters, which occasionally formed in a region where the thickness had been reduced to one-half the original in a coining step, were shown to cause a separation in the Ni sinter during subsequent plate fabrication steps. Scanning electron microscopy and Auger microanalysis of pull-tested samples of the starting, sintered nickel-plate matrix showed that there was a high concentration of carbon and nitrogen on the fracture surfaces of the Ni particles. This chemistry is associated with thin, brittle boundaries between the Ni particles of the sinter, as manufactured. It was concluded that these brittle particle-to-particle bonds yielded under the shearing forces during compression of the coining operation, resulting in sub-surface crack formation. Closer control of the Ni sintering operation was recommended to limit the formation of a brittle structure, and hence avoid the problem in future plate lots.

INTELSAT CONTRACTS

The MED, in conjunction with the Applied Technologies Division, completed the performance evaluation of 11 C-band TWTAs, 4 K_u-band TWTAs, and 4 C-band SSPAs under contract INTEL-485. Most of the measurements of these INTELSAT VI units were performed on the MED's AMPAC system.

Spacecraft bus voltage interactions, such as bus ripple caused by TDMA operation and modulation sidebands generated by bus ripple, were performed. The measurements verified the manufacturer's data and provided additional information of special interest concerning the use of the amplifier in the INTELSAT VI spacecraft simulator.

The TWTAs and solid-state power amplifiers (SSPAs) were also subjected to thermal soak cycles and their performance recorded. The measured results were analyzed and compared with the INTELSAT VI specifications and the manufacturer data where applicable. The data collected during this program will serve as a reference for the amplifier's performance when used in the spacecraft simulator during the lifetime of the INTELSAT VI program.

OTHER

Early in the year, Hughes Aircraft Company awarded a contract to COMSAT's MED for the development of passive GaAs MMIC components. Working from design rules provided by COMSAT, Hughes engineers designed passive components and circuits for fabrication by COMSAT. COMSAT provided designs for test patterns and alignment marks to be used in a lithographic maskset. The maskset was ordered by Hughes and delivered to the MED, where the passive MMICs were fabricated on 50-mm-diameter GaAs wafers. Features of interest included tantalum nitride resistors, metal-insulator-metal capacitors, air-bridges, through substrate via-holes, and Lange couplers. The program was completed in December 1986 with the delivery of five completed wafers. Figure 12 shows a Lange coupler on one of these wafers.

Figure 12. *Lange coupler on a 50-mm-diameter GaAs wafer delivered to Hughes Aircraft Company*

In October, the University of Maryland, under contract to MIT's Lincoln Laboratory, awarded a subcontract to COMSAT for the fabrication of 10-GHz ultraviolet photomixers and associated test structures. These GaAs photomixers are required to deliver an intermediate frequency (IF) from 1 to 10 GHz when illuminated by two beams of ultraviolet light having a frequency difference equal to the IF. The MED assisted with the design of a new maskset for this program and fabricated test structures using a maskset left over from an earlier University of Maryland program. These test structures were used to measure the frequency response of photoconductivity in GaAs by focusing a subpicosecond laser on a gap between metal conductors on semi-insulating GaAs. The length of the resulting electrical pulse gave the reciprocal of the frequency response. Measurements by the University of Maryland on COMSAT-fabricated test structures showed pulse lengths as short as 13 picoseconds, which is shorter than needed for the 10-GHz photomixers.

At the start of 1986, the Spacecraft Technology Division was renamed, becoming the Applied Technologies Division (ATD). This reflects a change in the division's mission, which has been broadened to encompass the terrestrial activities now being pursued by COMSAT.

The ATD continues to provide a broad range of R&D capabilities from controls, dynamics, and propulsion, to telemetry, tracking, and command, as well as structures, mechanisms, materials, thermal control, power systems, energy conversion and storage, reliability and quality assurance, and environmental and qualification testing. The division conducts R&D studies directed toward extending satellite lifetime and improving reliability, and advancing the technology of communications antennas. Activities include in-depth analyses, laboratory investigations, and on-site test support throughout COMSAT as well as under contract to INTELSAT and other organizations.

Significant activities in 1986 include verification of the temperature control of the monolithic microwave integrated circuit (MMIC) amplifiers to be used in multibeam phased-array antennas, and completion and delivery of attitude control flight simulators for both INTELSAT VI and the Direct Broadcast Satellite. The ATD was instrumental in confirming the validity of the "COMSAT Maneuver" for extending satellite lifetime. The division participated in the DARPA/USAF Multiple Satellite System Program as a support contractor. The ATD is also heavily involved in providing product assurance for the terrestrial segment of the NASA ACTS program and completed a two-year contract for development of an innovative, low-cost terrestrial H_2/NiO battery for the U.S. Department of Energy under a Sandia National Laboratories contract.

COMSAT JURISDICTIONAL R&D

Power Conditioning for SSPAs

In 1986, circuitry was designed to allow gallium arsenide (GaAs) monolithic microwave integrated circuits (MMICs) to be controlled by external transistor-transistor logic (TTL) compatible signals. The development of phased-array antennas has led to the need for a special circuit to switch solid-state power amplifiers (SSPAs) on and off, conserving DC power and reducing thermal dissipation. Figure 1 illustrates a circuit developed by the ATD to perform this task as part of the SSPA project. Using computerized techniques, the circuit was designed and its performance predicted. A developmental circuit utilizing discrete GaAs metal semiconductor field effect transistors (MESFETs) was constructed and subsequent tests with an SSPA verified predicted performance. Design of a monolithic GaAs on/off switch is in progress.

Multibeam Phased-Array Antenna

As reported in the *COMSAT Laboratories 1985 Annual Report*, the ATD is responsible for the thermal and mechanical design of the multibeam phased-array antenna being jointly designed with the Microwave Technology Division (MTD). Thermal control of the multibeam antenna is critical because the SSPAs are located in the waveguide directly behind each of the closely packed feed horns, resulting in a high concentration of dissipated heat. The selected design mounts the SSPA directly to a heat pipe which carries dissipated heat to a remote thermal radiator for rejection to space. As illustrated in Figure 2, it also permits the removal of any element in the array without disassembling the entire feed system. During 1986, mechanical and thermal analyses were performed which proved the design. The critical SSPA heat removal scheme was verified by thermal vacuum testing. This test configuration is shown in Figure 3.

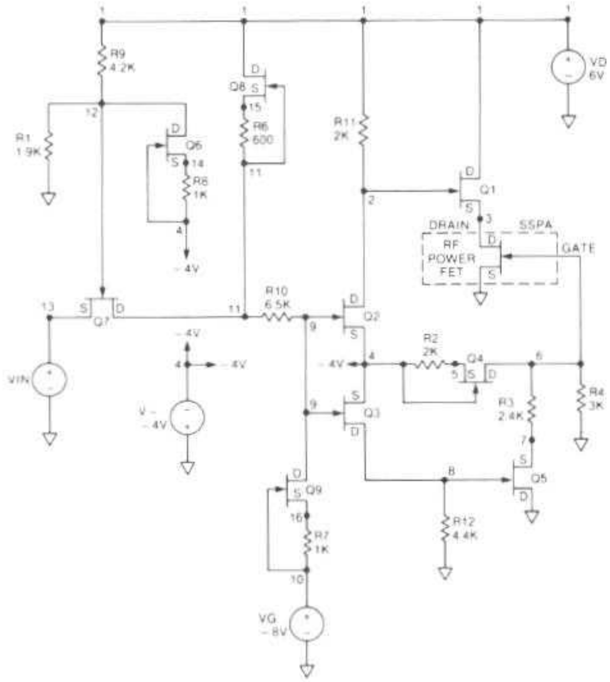


Figure 1. *Power conditioner circuit for SSPAs*

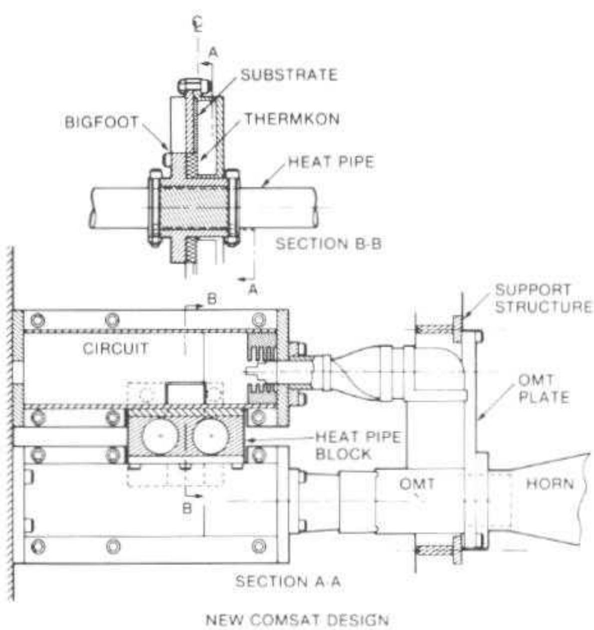


Figure 2. *Multibeam antenna layout*

The ATD also completed a study of power distribution concepts for multiple-beam antennas (MBAs) which determined that redundant, centralized power processing systems have an advantage over decentralized systems with respect to mass and reliability. Design and construction of a centralized power system is presently in progress.

The prototype of the active circuit for the low-power array digital controller was developed and tested. In addition, the top-level design of a distributed controller for a high-power array was completed. The local control module, which represents the lowest level of control in the distributed controller, was breadboarded using programmable logic array parts.

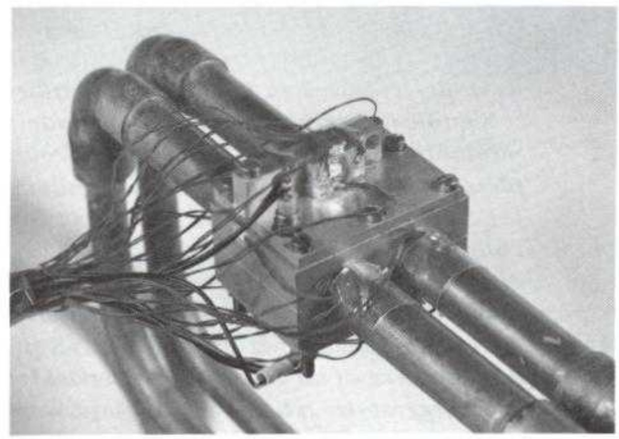


Figure 3. *Thermal test configuration*

Momentum Wheel Bearing Cage Instability

Life expectancy and operating performance of spacecraft momentum wheels are highly dependent on bearing cage stability. In 1986, nine different momentum wheel ball bearing cages were tested to evaluate effects of various design parameters on cage stability. The purpose of these tests was two-fold. The tests validated the cage dynamics predicted by the computer program ADORE (Advanced Dynamics of Rolling Element Bearings). ADORE was used extensively in the earlier study phase of this project, completed in 1985. In addition, these tests provided an opportunity to observe the effects of various design parameters on cage dynamics. As shown in Figure 4, testing was conducted in a fixture which allowed direct viewing of the moving bearing elements. A fiber-optics technique allowed real-time observation of cage motions.

The test program showed that ADORE is an accurate predictor of momentum wheel bearing-cage dynamics. Design and operating parameters that promote cage stability were also identified. Parameters considered included lubricant properties, temperature, cage geometric clearances, mass imbalance, and spacing between balls. A general stability criterion emerged which will aid in designing and screening future ball bearing assemblies for maximum cage stability.

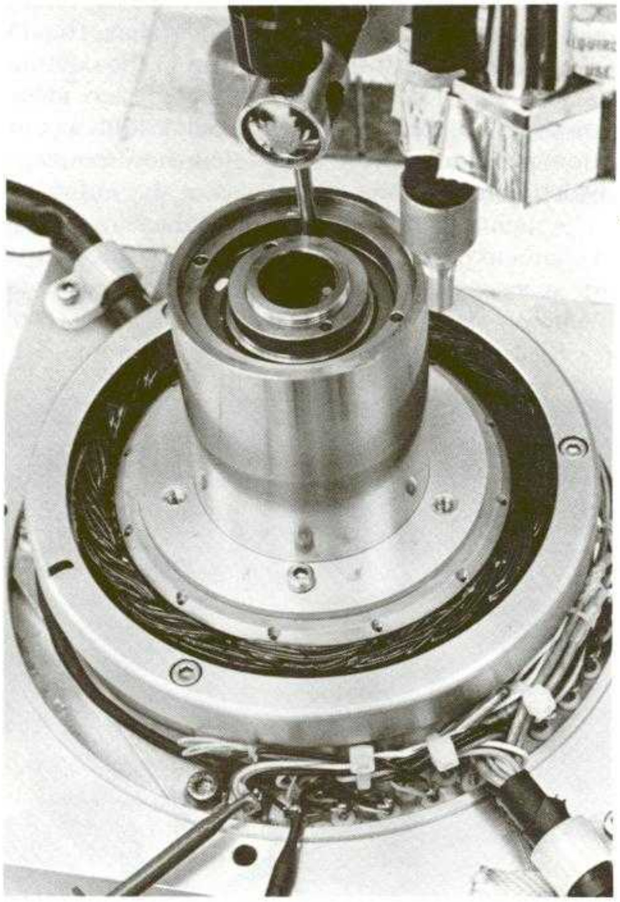


Figure 4. *Momentum wheel bearing test fixture*

TWT Quality Assurance Techniques

The TWT Quality Assurance project was divided into two sets of laboratory investigations with distinct goals:

- to use observations of noise modulation sidebands, due to ionized gas molecules trapped in the TWT electron beam, and to develop techniques which would permit the manufacturer to monitor the quality of TWT exhaust and processing; and
- to test the validity of the current model used for predicting operating lives of oxide cathodes in TWTs.

Regarding the first goal, trapped ions in the electron beam cause a characteristic noise modulation on each side of the carrier frequency. The separation from the carrier is in the range of 300 to 1,000 kHz. It has been shown that the modulation form is almost pure amplitude modulation, as observed in C- and K_u-band TWTs.

When the noise sidebands are visible above the ordinary broadband TWT noise, as seen on a spectrum analyzer, then the residual gas pressure is too high, a sure sign of inadequate manufacturing processing or the presence of a small leak. Laboratory investigations have shown that, when the ion noise level is below the broadband noise, its presence may be made visible by the addition of a small, synchronous voltage modulation of the beam, and it may also be visible in the video spectrum of the helix current.

Experiments have identified the operating conditions under which ion noise may be most readily observed, although these conditions are not equally applicable to all TWT types. As the demands on TWT performance grow and manufacturers install more sophisticated test instrumentation, monitoring of ion noise during manufacture will give the manufacturer useful quality control information on TWT processing.

Under the second goal, six TWTs with oxide-coated cathodes having experienced 45,000 hours of operation were evaluated for six months with the cathode heated but not drawing current. Using a specially devised pulsed-test procedure, it was found that the cathode quality improved by about 20 percent over the first month of operation and then stabilized. This is consistent with the activator diffusion model generally used by manufacturers and counter to the general belief that this mode of standby operation is harmful. One of the cathodes was subsequently subjected to destructive physical analysis and the cathode surface was examined by Auger spectroscopy to seek the buildup of activator chemicals predicted by theory. Instead, it was found that the distribution of surface chemicals was very nonuniform, revealing that the cathode behavior is more complex than that of the manufacturer's model.

Satellite Cost-Cutting Procedures

In the interest of reducing the costs of future INTELSAT satellites, a study of satellite procurement philosophy and practice was conducted. The study indicated that, while no specific procurement practices have a significantly large cost savings potential, the sum of small savings from changes in individual practices can be significant. Among the procurement practices identified as having the potential to reduce costs are design philosophy and margins, contractual documentation and reviews, satellite testing, product assurance, incentives and financial provisions, and the level of subcontractor monitoring.

Low-Cost Satellites

For the next generation of INTELSAT spacecraft, a study of technology-related cost reduction techniques was pursued. A COMSAT cost model revealed how costs were distributed among satellite subsystems. Typical cases were examined for several proposed spacecraft being considered by INTELSAT. The cost advantages of using an existing satellite bus were estimated by eliminating the predicted non-recurring costs for appropriate subsystems.

Subsystems specialists throughout COMSAT Laboratories identified technologies that will lead to lower costs. Guidelines were established for the selection of future R&D projects.

COMSAT NON-JURISDICTIONAL R&D

CPV Battery Development

COMSAT Laboratories successfully completed a cost-shared development program with the Department of Energy (DOE) for the design and development of the H_2/NiO battery under a contract with the Sandia National Laboratories. The objectives of this program are to design and develop an H_2/NiO battery that is cost competitive with an advanced lead-acid battery for terrestrial energy storage applications. Work on this 2-year contract was completed in 1986 and all of the program objectives were met. Johnson Controls Inc., with which COMSAT jointly developed this technology, was awarded a follow-on contract to build a large multi-kilowatt-hour battery for field testing by the DOE.

Under the DOE contract, a new concept evolved using individual cells instead of the six cell monoblock to make up 6-, 12-, or 24-V batteries. The 6-V battery delivered at the conclusion of the contract is shown in Figure 5. The battery design incorporates a number of individual cells within a common pressure vessel (CPV). The new concept, which combines the advantages of the individual cells such as bypass circuitry with the simplicity of a common pressure vessel, offers many advantages for space, as well as terrestrial applications along with very significant cost savings.

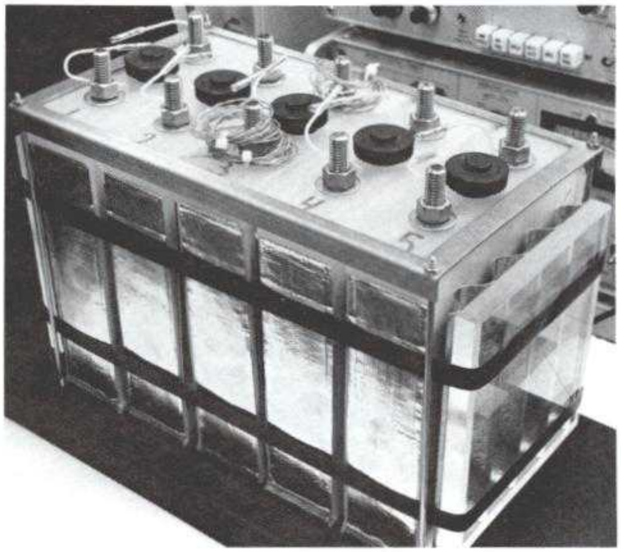


Figure 5. *6-V common pressure vessel battery*

COMSAT SUPPORT

Technical and Engineering Support

During 1986, the ATD provided technical and engineering support to four organizations within the Space Communications Division: Intelsat Satellite Services, Maritime Services, COMSAT Technical Services, and Amplica. The ATD supported Intelsat Satellite Services, as the U.S. Signatory to INTELSAT, on the INTELSAT Board of Governors' Technical and Planning Committees. These efforts included technical studies supporting the U.S. position on matters being considered by the committees, including available satellite bus technology, status of the satellites in orbit, TWT reliability, and predictions of satellite lifetime.

The ATD also provided support to Maritime Services concerning the INMARSAT Advisory Committee on Technical Matters (ACTOM) by conducting technical reviews of progress on the INMARSAT II spacecraft, as well as studying potential spot-beam antenna configurations for later INMARSAT spacecraft.

On behalf of COMSAT Technical Services, the ATD provided engineering support on a number of satellite programs including Direct Broadcast Satellite (DBS), INMARSAT II, ITALSAT, and MCI (SBS). In addition, a product assurance plan was developed for the Voice of America Project. Several examples of these activities are described in the following subsections.

The ATD developed a thermal and mechanical packaging concept for Amplica in support of a winning military hardware proposal. A thermal analysis determined the best approach to thermal control of FET modules for given air flow rates at sea level and 70,000 ft. The design incorporates forced-air cooling within finned channels. The ATD was also responsible for the shock and vibration isolation design and will support Amplica during the program design and implementation phase.

In addition to these activities, the ATD supported the Communications Services Division of COMSAT by assisting with a number of technical investigations for COMSAT General, including various aspects of the COMSAT Maneuver, which was proposed during 1986. Battery lifetime predictions were provided for the COMSTAR and MARISAT satellites, and the proposed spacecraft lifetime extension was evaluated. Thermal specialists also assisted with a technical investigation of a problem on the NBC up-link power amplifiers.

For COMSAT Technology Products, Inc., the ATD assisted COMSAT TeleSystems, Inc. in resolving operational problems in its MCS-9100 shipboard antenna terminal, as described in more detail in a subsequent subsection.

Direct Broadcast Satellites

In 1986, the ATD provided extensive engineering support to COMSAT Technical Services for the qualification test program of the Direct Broadcast Satellites (DBS). Test plans and procedures were reviewed and recommendations for changes were made. During the DBS thermal-vacuum test, a period of approximately five weeks, ATD personnel were responsible for monitoring the satellite thermal control subsystem and for evaluating its performance. Real-time additions and deletions to the test plan were generated while the test was in progress in order to selectively investigate test anomalies.

DBS temperature control is based upon the use of heat pipes to efficiently transport large quantities of waste heat. The DBS heat pipes are fixed-conductance types fabricated from grooved aluminum tubing and use ammonia as the working fluid. The failure mechanisms for heat pipes consist of either leaks in the tubing or the generation of non-condensible gas, which effectively blocks part of the active heat pipe length. Tests were conducted to ascertain whether any ammonia had leaked from the pipes, which would result in a substandard heat transport capability. These tests are part of a continuing effort to characterize the operational performance of heat pipes used on the spacecraft. ATD experiments show that the amount of gas generation and the performance parameters are consistent with the design lifetime of the DBS spacecraft.

ITALSAT Multibeam Antenna Thermal Analysis

On behalf of COMSAT Technical Services, thermal analyses of the ITALSAT spacecraft multibeam antenna and associated hardware were conducted for Selenia Spazio. Transient temperature profiles were computed for the reflector dish for worst-case orbital environmental conditions. The temperature predictions of these analyses were used by Selenia Spazio to calculate the thermal distortion of the antenna system. Contour temperature plots were computer generated to illustrate the reflector temperature distribution at selected sun angle and spacecraft shadowing conditions. Figure 6 shows a typical ITALSAT reflector contour temperature plot.

Temperature specifications for antenna positioning mechanisms and deployment hardware were developed from the results of this analysis.

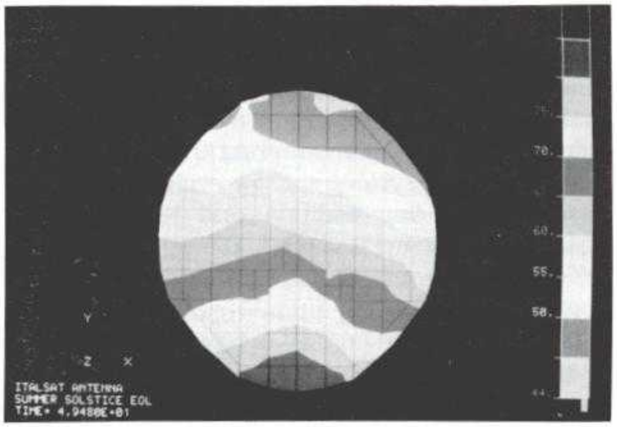


***Figure 6.** ITALSAT reflector contour temperature plot*

Shipboard Environment Test Program

The COMSAT Telesystems, Inc. MCS-9100 shipboard antenna terminal, shown in Figure 7, provides satellite telex and voice communication to the maritime community. To aid in diagnosing operational problems that developed in service, the ATD experimentally measured the shipboard vibration environment, which was suspected to cause structural failures. ATD personnel instrumented a shipboard terminal and measured the environments during the ship's passage from New Orleans to the Gulf of Mexico and on to a final destination at Texas City. Accelerometers were positioned at the base of the terminal and at the radome to record the vibration input to the antenna and its response.

A spectrum analyzer was used to generate frequency response plots characterizing the vibrational environment, under various operating conditions, including low-speed turning maneuvers in the Mississippi River and a full-speed-ahead cruise in the Gulf with a 30-knot wind. These data, along with on-site mechanical engineering inspection, were instrumental in diagnosing the mechanical anomalies, recommending modifications to the environmental qualification testing program, and in leading to successful correction of the problems.

***Figure 7.** MCS-9100 shipboard antenna terminal*

INTELSAT–Laboratory Engineering Assistance Contract

Under the LEAC, INTEL-485, the ATD provides INTELSAT with continuing support for its satellite programs including engineering and testing for the INTELSAT VA and VI series, operational assistance for the INTELSAT V series satellites, and the INTELSAT Exploratory Research and Studies program. Some of the ATD activities are described in the following subsections.

INTELSAT V Battery Investigations

Life tests of the INTELSAT V batteries, begun in 1985, have continued during 1986, simulating real-time battery operation in orbit. The Ni/Cd battery has completed 14 eclipse seasons on test and the

Ni/H_2 battery 10. Results provide a data base for predicting in-orbit performance and lifetime expectancy. Periodically, both the Ni/Cd and Ni/H_2 cells are removed from test analysis to assess degradation mechanisms. A voltage loss of 50 to 150 mV during discharge had been observed on five Ni/H_2 cells in the life-test battery. The same phenomenon has now been observed on several cells in INTELSAT V operational satellites. Experimental investigations have identified an unexplained electrolyte loss mechanism that is currently under investigation.

Three remaining Ni/H_2 flight batteries in storage at Ford Aerospace and Communication Corporation (FACC) showed capacity loss with storage time. FACC has adopted a trickle charge storage mode procedure recommended by the ATD to correct the problem. Two of the three batteries are now showing a recovery of capacity.

INTELSAT VA C-Band 8.5-W TWT Thermal Expansion Test

In 1984, FACC returned several defective TWTs to Hughes Aircraft Corporation (HAC). Atmospheric gas was found to be leaking into these TWTs; this leakage was attributed to small cracks in the collector isolator ceramic. HAC conducted a detailed investigation, including finite element modeling, photomicroscopic inspection and compressive load testing on the collector, to determine the cause of the fissures. This investigation led, in mid 1984, to the conclusion that the cracks were most likely due to internal loads induced in the TWT during low-temperature thermal cycling.

During manufacturing tests, the TWTs are subjected to temperatures between $-30°$ and $-34°C$. The stress on the collector results from differential thermal contraction between the TWT, which is made of stainless steel, and its aluminum baseplate. The problem escalated as a number of TWTAs failed during spacecraft integration.

INTELSAT requested that the ATD develop a test procedure to determine the magnitude of the load developed in the TWT where cracks were developing. Five TWTs were delivered to COMSAT Laboratories for tests during 1986. A test was devised and implemented (see Figure 8). The differential expansion at the TWT collector-isolator interface during thermal cycling and the stiffness of the TWT and the baseplate structure were used to determine the axial load at the collector ceramic cup.

The maximum load was always evident at the lowest temperature ($-34°C$) and the greatest maximum load measured in the COMSAT tests was 140 lb. FACC had, in late 1984, conducted compression tests on 25 samples of brazed joint configurations to determine the load required to induce a crack in the collector isolator ceramic. Results of the COMSAT Laboratories test were compared with the FACC HAC data to determine the margin in the TWTs already mounted on yet-to-be-launched spacecraft.

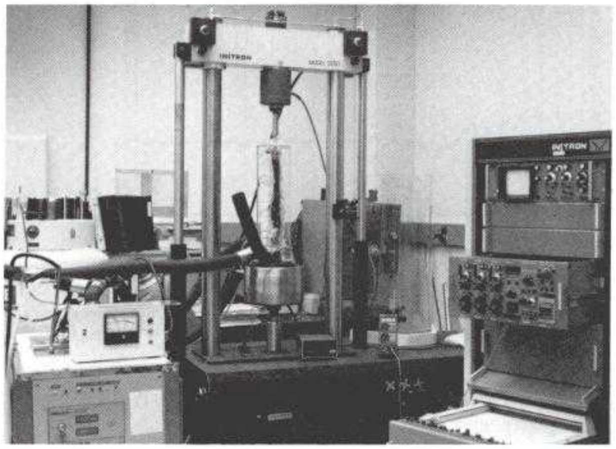


Figure 8. *C-Band TWT stiffness test*

Life Test Assessment of INTELSAT V Momentum Wheels

The performance and lifetime of the INTELSAT V/VA satellites strongly depend on the performance of the momentum wheels. Because the long-term effects of speed and temperature cycling on the momentum wheel motor, electronics, and bearings were not fully known prior to launching the early INTELSAT V satellites, COMSAT Laboratories undertook the task of evaluating the long-term performance of two engineering model (EM) wheels.

As of 1986, the EM wheel life test program has accumulated over 12 wheel-years of running time. One wheel acts as an experimental control by operating at ambient conditions at a nominal 3,500 rpm, while the other wheel is speed and temperature cycled, simulating worst-case, in-orbit conditions. Performance data such as power consumption and reaction torque are collected monthly and added to the data base. Spectral analysis of the torque signals is also performed each month and compared with beginning-of-life baseline spectra. Figure 9 shows the monthly torque and temperature trend of one EM wheel.

These ongoing wheel tests provide an empirical critique of the current generation of momentum wheels. In addition, they have produced a valuable data base upon which to base future momentum wheel designs.

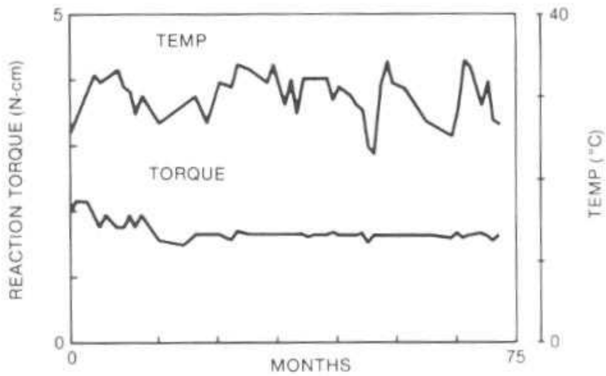


Figure 9. *Torque/Temperature profile for INTELSAT V EM wheel*

INTELSAT VI Battery Support

Storage of activated flight batteries F-1 through F-4 was the major issue to be resolved during 1986. Launch delays required these batteries to be stored for up to 5 years instead of the initial planned maximum of 2 years. The initial room temperature storage mode used by HAC was unacceptable because measured capacities of these flight batteries declined below minimum values specified. Several different storage methods were investigated by the ATD in support of the INTELSAT VI program office. Based on results of these investigations, the program office directed HAC to start using a low temperature storage mode for flight batteries.

The INTELSAT VI Ni/H_2 battery life test was initiated in 1986. By year's end, the test battery had completed acceptance testing, trickle charge storage, and one eclipse season. Initially the capacity was low as described above; however, after trickle charge storage (simulating in-orbit operation between eclipse seasons), a significant increase in capacity was observed. This encouraging result indicates not only that trickle charge at 10°C can be used as a means to recover capacity, but also that in-orbit capacity recovery of flight batteries may be expected after long-term storage at HAC.

INTELSAT VI Solar Cell UV Test

Ultraviolet radiation testing in vacuum of the Spectralab K7 and AEG INTELSAT VI solar cells, begun in 1984, continued in 1986. The objective of this test is to experimentally determine the amount of performance degradation of the solar cells caused by solar ultraviolet irradiation. In the past, predictions of solar cell ultraviolet degradation have been based on 1,000-hour tests. This led to predictions of approximately 2-percent degradation due to ultraviolet irradiation after 10 years in orbit.

At the end of 1986, the cells had been exposed to 13,536 hours of ultraviolet light. For a cylindrical solar panel such as that of INTELSAT VI, this number is multiplied by the configuration factor of π to obtain the equivalent of 42,525 hours or 4.9 years in orbit. The average degradation in short-circuit current of the K7 solar cells at 13,536 hours was 4.01 percent, as illustrated in Figure 10. Based on these experimental data, the predicted degradation in short-circuit current after 14 years in orbit for the K7 solar cells is 4.92 percent. The average degradation in short-circuit current of the AEG solar cell at 13,536 hours was 5.03 percent (see Figure 11). The predicted degradation in short-circuit current after 14 years in orbit for the AEG solar cells is 6.06 percent.

Balloon-Flight Calibration of INTELSAT VI Solar Cells

Two INTELSAT VI K7 standard solar cells were flown on the 1986 Jet Propulsion Laboratory solar cell calibration balloon flight to obtain solar cell electrical measurements at an altitude of approximately 120,000 feet (where atmospheric effects are negligible in terms of solar cell measurements). These data will provide a baseline for calibration of the COMSAT Laboratories solar simulator and for calculation of INTELSAT VI solar array performance in space. Calibration values for short-circuit current were obtained by measuring voltage across a 0.5-ohm resistor connected in parallel with each

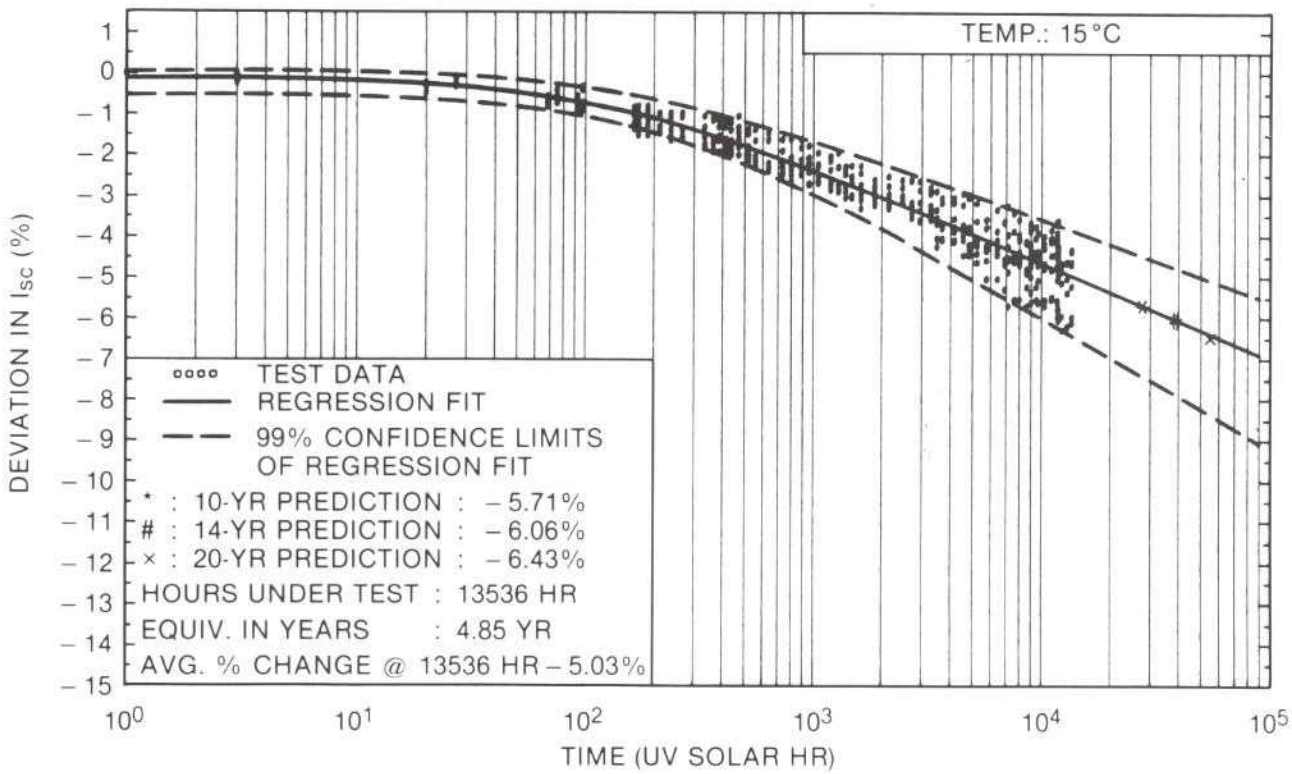


Figure 10. *Solar array degradation (K7)*

solar cell. The 1986 calibration values for one cell decreased by 0.8 percent from the original 1984 flight calibration value of 71.8 mV. The second cell decreased by 1.0 percent from the 1984 value of 71.59 mV. The difference between the 1984 and 1986 results is within the 1.0-percent variation, which has historically been observed from one flight to the next. Thus, the 1986 calibration values are considered to confirm the 1984 results.

INTELSAT VI BAPTA Thermal Test

A thermal-vacuum test was performed on the INTELSAT VI bearing and power transfer assembly (BAPTA) to verify HAC's BAPTA analytical thermal model and to establish temperature boundaries for a long-term performance and life test. To accomplish this objective, the ATD modified the HAC analytical thermal model to represent the test configuration, which consisted of two independently temperature-controlled test shrouds.

The environmental test shrouds and the BAPTA were thermally and electrically instrumented so that the proper boundary conditions, thermal dissipations, and load current could be applied and monitored during the test. The results of the test will be utilized to verify the analytical thermal model. The life test and the thermal model will be used to predict in-orbit performance during nominal operation and other alternate operating conditions. The performance of the BAPTA can be predicted under simulated in-orbit anomalies that may be experienced by any INTELSAT VI satellite.

INTELSAT VI Equipment Evaluation

The ATD completed preparations for extended life testing of three critical INTELSAT VI components: the C-band antenna positioner, the electrical contact ring assembly, and the bearing and power transfer assembly, in 1986. The BAPTA assembly will remain under test throughout the INTELSAT VI program. The INTELSAT IV BAPTA completed 12 years of testing in the chamber that will be used for INTELSAT VI.

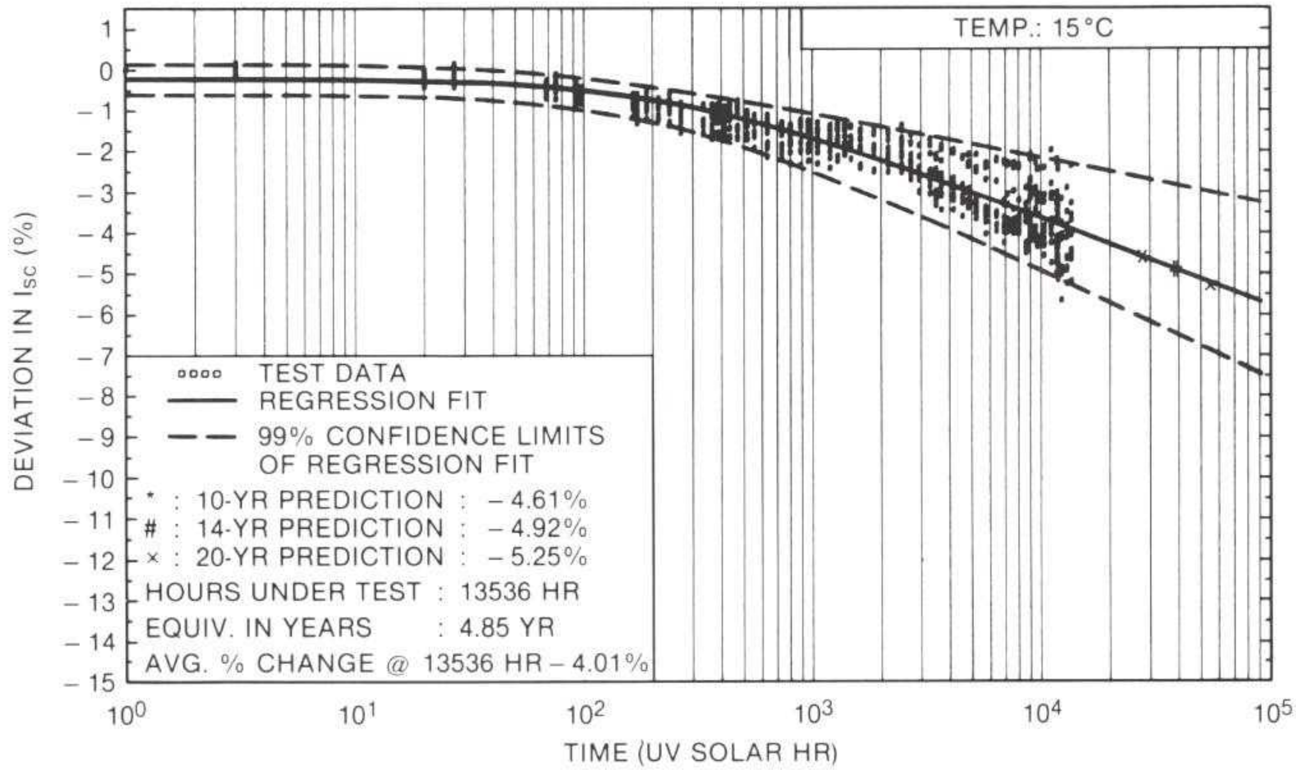


Figure 11. *Solar array degradation (AEG)*

INTELSAT Thermal Model Conversions

The analytical thermal models of the INTELSAT V and VI spacecraft are being acquired by INTELSAT, which will use them to assess the thermal consequences of in-orbit anomalies or unusual operation modes independently of the spacecraft contractor. The ATD is converting these models to SINDA format (thermal analyzer program) for INTELSAT's use. During 1986, 13 INTELSAT thermal models were converted.

INTELSAT V Temperature Trends

In support of the INTELSAT Operations Division, INTELSAT V spacecraft are monitored to evaluate their thermal performance and to identify potential trends in component temperatures. Seasonal estimates of the spacecraft radiator degradation in solar absorptance are used to predict end-of-life spacecraft temperatures. Forecasts of the future operating environment based on these temperature predictions permit better utilization of the in-orbit spacecraft.

Attitude Determination and Control Flight Simulator

In 1986, the ATD completed the development, integration, acceptance test, delivery, and installation of the INTELSAT VI Attitude Determination and Control System (ADCS) flight simulator, and continued to support the operation and maintenance of the INTELSAT V ADCS simulator. These simulators, designed by the ATD, are being used by INTELSAT for training engineers and spacecraft operators, contingency planning, maneuver evaluation, and attitude determination.

These devices allow the operators to gain familiarity with routine maneuver sequences and engineers to develop contingency plans for dealing with in-orbit anomalies. In addition, they provide a test facility in which spacecraft operational procedures may be evaluated, practiced, or optimized.

They are designed to be used with external facilities such as tracking and command data processing equipment or expert systems.

Each of these simulators operates in real-time and incorporates engineering models of attitude control hardware. Their design allows the hardware to be exercised as if it were actually being used on the spacecraft. The rotational dynamics, structural flexibility, attitude sensors, actuators, and disturbance and environmental torques are implemented entirely on a 32-bit minicomputer using FORTRAN and assembly language. The simulators accommodate all mission phases except the spinning phase of the body stabilized INTELSAT V design. All redundancy is modeled, as well as a large number of failures, which can be dynamically inserted and reset at any time during a simulation.

The simulator operator can send commands to the simulated ACS; telemetry from the simulated ACS is displayed on video monitors and strip-chart recorders in the same format as at the T&C control center. In addition, the spacecraft attitude is displayed on a color graphics monitor.

Battery Powered Electric Propulsion: Ni/H_2 Cells

This activity, which started in 1980, was continued in 1986. The objectives were, and still are, to evaluate new design concepts and new components for Ni/H_2 cells. These cells are being evaluated in a test program simulating battery-powered electrical propulsion: two eclipse seasons per year and daily cycling between eclipse seasons. The original five cells have completed six years on test or over 2,000 cycles. Probably the most significant conclusion to date is that the best performing cell is the one with two layers of zircar separator material. Several of the cells are starting to show a second plateau in the discharge profile resulting in capacity loss measured at 1.0 V.

ADDITIONAL INTELSAT CONTRACTS

Analysis of INTELSAT V Launch Data

Under INTELSAT Contract INTEL-523, an extensive evaluation of the INTELSAT V spacecraft launch data was completed in 1986. The measurements were made using accelerometer and strain gauge signals transmitted during eight Atlas Centaur and two Ariane launches of the INTELSAT V satellites. The evaluation of loads data focused on a comparison of coupled loads analysis predictions with statistically based flight loads.

The predictions of axial acceleration at the spacecraft/launch vehicle interface were found to be accurate. However, the lateral loads predicted by the coupled loads analysis were overly conservative. Several discrepancies between the structural analysis and the flight measurements have been revealed. This comparison is important in that it has identified discrepancies resulting from poor assumptions which may affect future satellite programs.

OSR Solar Absorptance

Under INTELSAT Contract INTEL-621, the solar absorptance of optical solar reflectors (OSR) as a function of sun incidence angle was investigated utilizing a radiator coupon similar to the INTELSAT VI OSR radiators. As shown in Figure 12, this coupon was mounted to a test fixture and driven by a stepper motor through incidence angles of 0 to 90°. The entire assembly was placed in the Large Space Simulator at the European Space Agency (ESA)/ESTEC and tested in the solar beam. The results indicate that there is an increase in solar absorptance of approximately 20 percent for the 0° incidence angle (sun normal to the surface) relative to

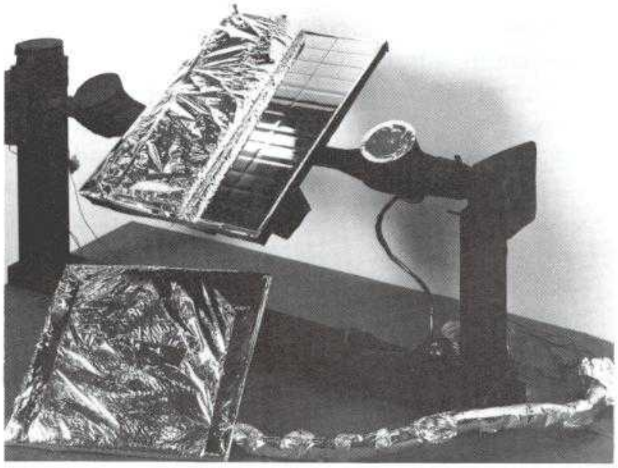


Figure 12. *OSR solar absorptance fixture*

the 66.7° incidence angle. These test data will be useful in designing future spacecraft and predicting performance of in-orbit satellites.

OTHER CONTRACTS

RCA TWTA Cycling Test

Under Purchase Order C-F-03305-0201-80F36 with RCA, this project required qualification thermal cycling and switching of a 220-W K-band TWTA of the type used in the COMSAT DBS. The TWTA, comprising an AEG TL12230 TWT and a Hughes (Electron Dynamics Division) power supply, was subjected to over 700 on/off cycles while operating in a high-vacuum chamber, and to temperature cycling representative of in-orbit conditions on the spacecraft.

The test was designed to simulate the cycling expected during eclipses in a seven-year period in orbit and comprised four months of continuous thermal-vacuum operation. It was controlled by a computer which continuously monitored the operation and recorded all the TWTA operating parameters on magnetic disks for subsequent analysis.

After completion of the qualification program, the TV testing was continued, with variations of the cycling conditions, and at year's end the TWTA has been subjected to nearly 1,000 on/off cycles and over five months of continuous thermal vacuum. No significant changes in TWTA properties have been recorded.

Multiple Satellite System Program

Under contract F30602-86-C-0063, the ATD is studying aspects of the Multiple Satellite System Program (MSSP) for the U.S. Air Force Rome Air Development Center and the Defense Advanced Research Projects Agency (DARPA). The MSSP concept provides a highly survivable communications capability by using a large number of satellites, nominally 240, in low-earth orbit, 740 km. Each spacecraft has a ground link and an intersatellite link for half-duplex packet communications. For an affordable system, the cost of building and launching the spacecraft must be very low. The ATD is performing cost studies and investigating launch and deployment concepts in a search for the lowest cost solution. Expendable launch vehicle candidates as well as the Shuttle are being evaluated. The studies relate the space network cost and earth terminal cost to data rate throughput.

Environmental Test Laboratory

The ATD maintains management responsibility for the Environmental Test Laboratory. Vibration, shock, temperature cycling, and thermal-vacuum test services have been provided under contract to several customers for both ground and aerospace equipment. During 1986, these customers have included COMSAT Technology Products, Weinschel Engineering, and Schonstedt Instrument Co.

The Communications Techniques Division (CTD) pursues research and development activities and provides technical support in transmission, video, and voice-frequency band processing; systems simulation; and systems analysis and synthesis. Work ranges from exploratory investigations through analyses and preliminary designs and measurements of critical subsystems to implementation and testing of proof-of-concept equipment. Extensive use of advanced communications systems architectures and technologies is required 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, in turn, depend upon widespread applications of digital signal processing (DSP) techniques. Examples of such developments in 1986 include 16-kbit/s low-rate encoded voice, advanced on-board digital signal processing (DSP), and DSP-based modem technology applied to INMARSAT Standard-B and Standard-C terminals.

Other significant efforts in 1986 included continued development of coded-phase modems and codecs and systems transmission analysis software, earth station systems studies, advanced forward error correction (FEC) coding and digitally implemented modem investigations, and implementation of an INTELSAT VI simulator.

COMSAT JURISDICTIONAL R&D

HPA Linearizer Characterization and Development

High-power amplifier (HPA) linearizers, using predistortion to limit intermodulation interference (and thereby increase usable HPA output power), have been installed at U.S. Standard-A earth stations operating in the INTELSAT system. However, an improved adjustment procedure was needed to increase the usefulness of these linearizers since readjustment is required after any significant reconfiguration of the transmit carrier.

COMSAT Laboratories conducted a program to develop a procedure for quickly adjusting these linearizers which would produce reliable improvement in intermodulation performance. This jurisdictional work was performed on behalf of COMSAT International Communications, Inc.

Using four unmodulated carriers, a simple-to-implement procedure developed in the laboratory provided a consistently improved level of intermodulation interference, when utilized with a low-power helix TWTA. A series of field trials was undertaken at the COMSAT earth station in Andover, Maine, to evaluate the applicability of this procedure to the high-power coupled-cavity TWTAs typically found at INTELSAT Standard-A facilities. An exhaustive series of measurements characterized the effect of a linearizer adjusted in this fashion upon the carriers transmitted via the linearizer/HPA pair.

It was demonstrated that the procedure improved the total carrier-to-intermodulation ratio for virtually every configuration in which it was applied. The improvement was shown to be a function of both carrier bandwidth and HPA backoff. Figure 1 shows the power transfer characteristic of the HPA both with and without the linearizer. Figure 2, which is a spectral representation of the HPA output for four carriers over a 50-MHz bandwidth, shows the reduced intermodulation level for the linearized case.

It was also discovered that the HPA linearizer introduced an in-band slope in the transmitter frequency response. This effect was more pronounced for wider bandwidths, particularly those above 100 MHz. Additional tests are required to fully characterize the effect of this slope on modulated carrier performance.

The adjustment procedure was demonstrated to the staff of the Andover earth station, which indicated that it was simple enough to be easily adapted to routine operations. Based upon the inputs of the Andover staff and the results of the field trials, a report was generated to explain the implementation of the procedure, provide a step-by-step guide for performing the operation, and recommend guidelines for its application. This report is being circulated to the operational segments of COMSAT so that the procedure may be integrated into daily operations to improve the efficiency with which the available facilities are utilized.

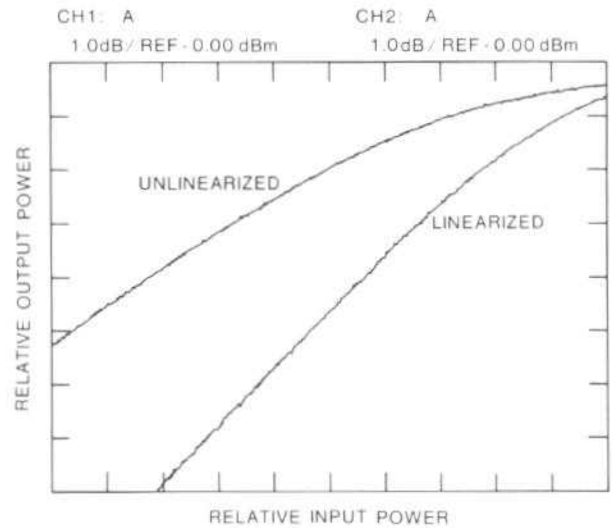


Figure 1. *HPA power transfer characteristic with and without the linearizer*

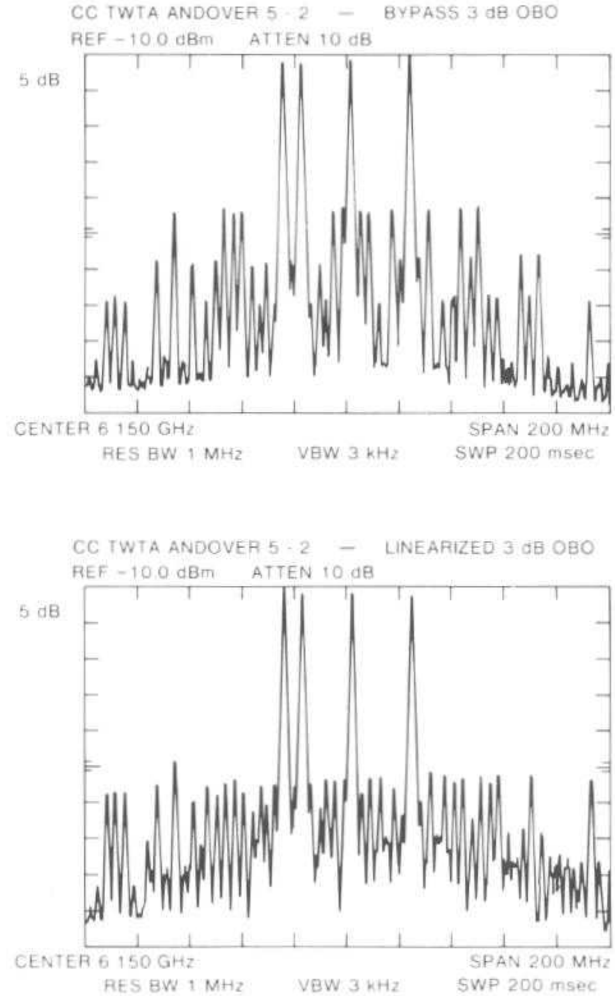


Figure 2. *Intermodulation spectrum of 4-carrier test signal before (top) and after linearization*

COMSAT JURISDICTIONAL R&D (INTELSAT RELATED)

140-Mbit/s COPSK Modem and Codec Development

Major progress was made in the development of the 140-Mbit/s coded octal phase shift keying (COPSK) system, initiated in 1985. This system is composed of an OPSK modem operating at 180 Mbit/s and a rate 7/9 convolutional encoder with a 16-state Viterbi algorithm decoder operating at an information rate of 140 Mbit/s. The 40-Mbit/s redundancy in the system enhances the error-correcting capability of this system, and results in an asymptotic coding gain of almost 3 dB relative to the detection of each information bit. Four such modems and codecs provide capacity equivalent to that of the TAT-8 fiber optic cable using four 72-MHz transponders of the INTELSAT V satellite.

Printed-circuit board construction of the OPSK modem was completed in 1986. Its performance was measured and found to be similar to that of the breadboard version, as reported in the *COMSAT Laboratories 1985 Annual Report*.

Construction of the rate 7/9 high-speed Viterbi codec was completed in 1986 and debugging and testing were initiated. The most critical technology element of the system is the add-compare-select (ACS) unit, 16 of which are employed in the Viterbi algorithm decoder. These ACS units are constructed with hybrid technology. Each unit consists of 22 100K series emitter-coupled logic integrated circuits that are interconnected by thin-film lines on a ceramic substrate shown in Figure 3. The power plane and the ground plane on the back side of the substrate are fabricated with thick-film technology. It is anticipated that work on the codec will be completed and field tests initiated in 1987.

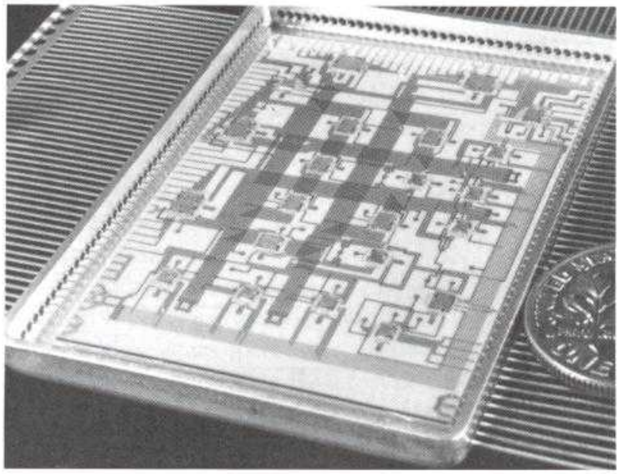


Figure 3. *Sixteen add-select-compare units of this type are employed in the Viterbi algorithm decoder*

16-kbit/s Low-Rate Encoded Voice

Initiated in 1985, the effort to develop toll-quality speech codecs at 16 kbit/s was continued during 1986. The lattice-structured adaptive digital pulse code modulator with both short- and long-term predictors failed to meet the toll-quality objective. A theoretical analysis of the limitations imposed by the quantizer coarseness showed that performance degraded rapidly as pole locations approached the unit circle when the number of steps in the quantizer was reduced. This was seen as one of the factors preventing attainment of toll-quality performance in a waveform codec operating at 16 kbit/s. The effort then turned toward the study of a hybrid of waveform and parametric coding techniques, known as adaptive predictive coding.

The adaptive predictive coder (APC), shown in Figure 4, transmits the predictor parameters, computed from blocks of speech samples, as side information in addition to encoded waveform information. Both short- and long-term predictors are employed. The APC has been combined with a special type of noise feedback to mask the quantization noise by redistributing its power across the frequency spectrum. Since frequencies where signal power is small have proportionately small quantization noise power, the "perceived" noise is substantially reduced.

APC performance was evaluated by using a simulation to process several sentences of male and female speech. The processed speech quality was judged to be superior to that achieved with waveform coding approaches. However, it also fell short of toll quality because a low-level distortion was perceptible. Further investigation revealed that this was due to the poor performance of the simple quantizer employed in the APC. Development of a more sophisticated quantizer is expected to provide a further speech quality improvement.

To optimize several parameters in the APC, development of a real-time version of the APC was initiated. At present a simplified version of the APC exists on a TMS 32010 development system. Completion of this unit will aid in optimizing the APC performance.

32-kbit/s LRE/DSI

Speech signals occurring on telecommunications links are the product of two-way conversations. It is natural for one talker to pause while the other speaks; thus, an active speech signal is present on a transmission channel for only a fraction of the available time. In addition, even when only one talker is speaking, pauses occur between utterances so that there are times when the circuit is idle. Measurements show that speech is present on a telephone channel approximately 35 percent of the time, averaged over a large number of busy trunks. Low-rate encoded/digital speech interpolation (LRE/DSI) systems reduce the transmission capacity needed to handle a multiplicity of telephone channels by a factor of about 4:1. This reduction in transmission capacity is achieved by exploiting the low average channel activity and transmitting active speech using adaptive differential pulse code modulation (ADPCM) techniques.

The development and testing of a 32-kbit/s LRE/DSI system was completed in 1986. A terminal unit, shown in Figure 5, provides a flexible facility for conducting objective and subjective tests as a function of DSI gain, overload usage, variable delay, and other DSI operating parameters to investigate fundamental LRE/DSI technical problems and assess

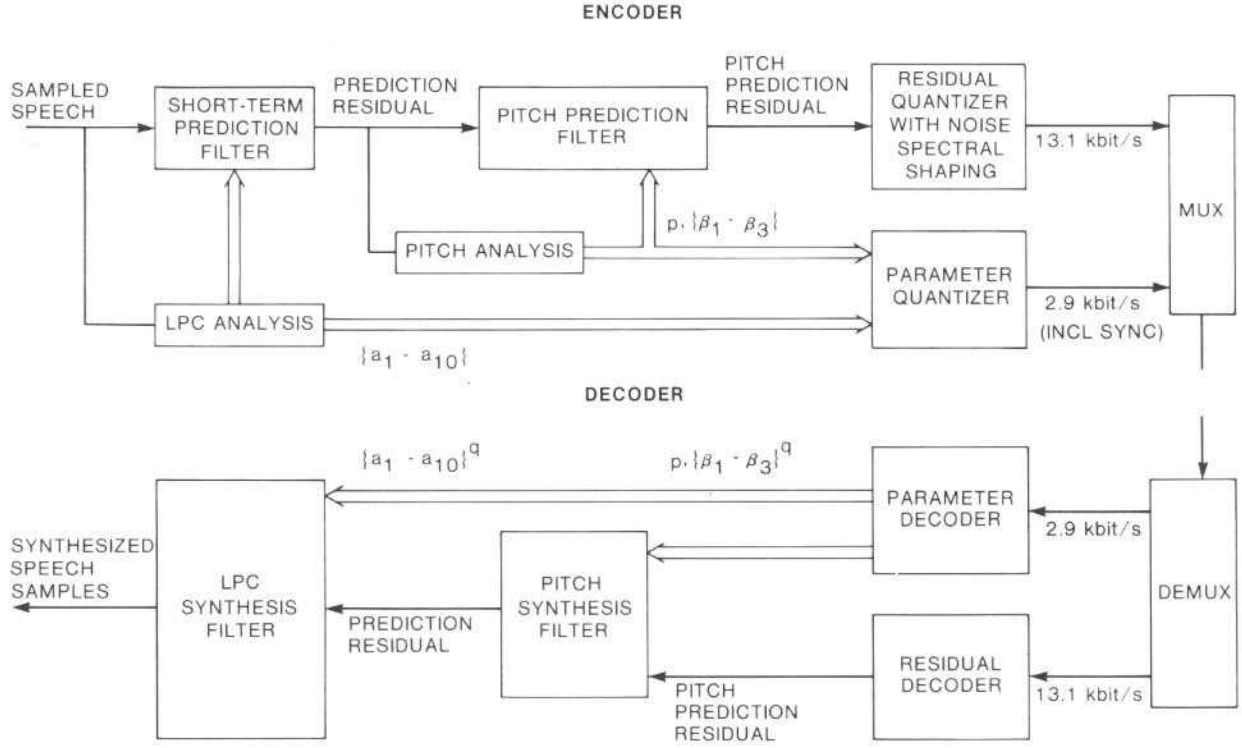


Figure 4. *APC codec masks quantization noise*

the complexity and effectiveness of the solutions. This system includes a means to solve an ADPCM encoder-to-decoder mistracking problem which can arise when encoded information is lost due to competitive clipping. Dynamic switching has been accomplished between 32 and 24 kbit/s, as well as between 32 and 40 kbit/s (the rate used for voiceband data at rates greater than 4800 bit/s). The system has a speech/non-speech discrimination capability as well as a data rate discrimination function, permitting data to be classified as less than, equal to, or greater than 4800 bit/s. For test purposes, the system may be operated without 40-kbit/s or 24-kbit/s channels, and the interpolation pool (the number of digital channel multiplication equipment (DCME) encoder output bearer channels) may be increased or decreased one channel at a time. All system configuration changes are controlled from a menu-driven terminal. In addition, the LRE/DSI development effort has established a technological base for the development and assessment of contributions to national and international LRE/DSI standards-making committees.

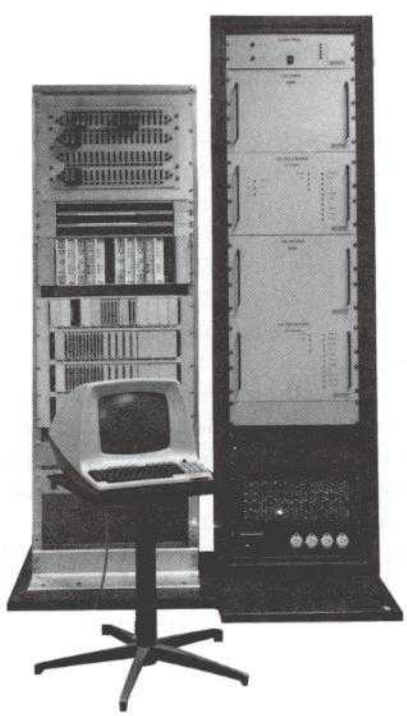


Figure 5. *32-kbit/s LRE/DSI unit*

Systems Transmissions Analysis Programs

The Satellite Transmission Impairments Program (STRIP) is a powerful tool used to evaluate and optimize frequency plans for satellites employing multiple bands and multiple frequency reuse. It computes impairments to FDM/FM, digital, TV, single-channel-per-carrier (SCPC) FM, and companded single-sideband carriers due to thermal noise, interference, and intermodulation noise. In the optimization mode, STRIP automatically computes every earth station up-link's e.i.r.p. so that system performance is maximized.

The enhancements to the STRIP program described below are a continuation of work initiated in previous years and were developed for the Intelsat Satellite Services Division of COMSAT.

During 1986, in a joint effort with the System Development Division, the STRIP program was enhanced in two ways. First, it was recognized that rain impairments are an important consideration for transmission planning, especially at K_u-band but also for frequency reuse carriers of opposite polarization at C-band, where rain depolarization causes increased co-channel interference. The STRIP program was therefore enhanced to analyze the effects of rain impairments on carriers. Now, in addition to clear-weather impairments, rain outage times and performance vs percent time for rain impairments are computed. A model originally developed by the Microwave Technology Division is used to compute these rain impairments. This model computes up-link attenuation, down-link degradation (attenuation plus noise temperature increase), and depolarization due to rain. The modified STRIP program uses these rain impairment values, and the system link and carrier parameters, to compute the effect of rain on an entire set of carriers.

The second 1986 STRIP enhancement was an interactive capability. Figure 6 illustrates the graphics terminal used for this program, with a typical frequency reuse carrier frequency plan displayed on the screen. With this frequency planning tool, the user can rapidly modify frequency plans and interactively assess the impact on system performance. Through the use of a conveniently modified frequency plan display and nearly instantaneous system performance evaluations, system planners can ensure that satellite capacity is fully utilized.

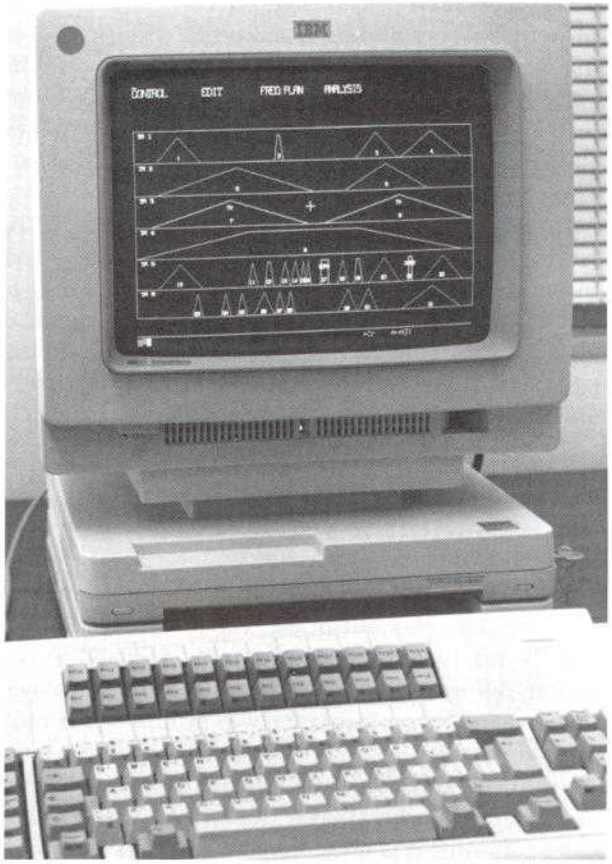


Figure 6. *Example of STRIP output on a workstation screen*

Advanced Transmission Processing

Advanced transmission processing concepts and techniques were investigated for potential applications to international satellite communications. Of particular interest is a rate 7/8 coded 16-PSK modulation system using block FEC coding with a fast Hadamard transform decoder. With this system, the bandwidth efficiency is about 2.63 bits/s/Hz of allocated bandwidth vs only about 1.5 bits/s/Hz for the current INTELSAT time-division multiple-access/quaternary phase shift keying (TDMA/QPSK) system without coding. The power efficiency is theoretically about the same as that of uncoded QPSK.

Also, a class of simplified rate 4/8, 8/14, and 8/11 convolutional codecs was discovered with asymptotical coding gains of 5, 4.5, and 4 dB, respectively. This class of codecs is most suited to high-speed implementation and can offer significant hardware savings relative to the conventional punctured convolutional encoding/Viterbi decoding approach. This class of codecs employs convolutional codes with Reed-Muller codes imbedded in them. The decoder consists of a fast Hadamard transform processor combined with a Viterbi algorithm processor.

In addition, a relative-phase-path decoding technique was examined for low-data-rate transmission over partially coherent channels such as the INMARSAT L-band channels. A coding gain of about 4.8 dB can be obtained by using a rate 1/2, 64-state convolutional code with Viterbi decoding and partially coherent BPSK transmission.

Advanced On-Board Digital Processing

In 1986, research initiated in 1985 was continued into the development phase. As an example of the significant progress in this area, a baseline on-board demultiplexing/demodulation system was defined and its performance was evaluated for multibeam satellite applications. This baseline system employs a channel-by-channel demultiplexing architecture and a shared demodulator approach. Consequently, it is quite flexible and can be readily adapted to the on-board demodulation of carriers arranged in an arbitrary FDMA frequency plan and operating at various symbol rates. Tradeoffs between hardware complexity and system performance were followed by system and subsystem level design. The design of the channel-by-channel demultiplexing unit was based upon a 1024-point FFT processor, which uses the Cooley-Tukey algorithm, and a radix-4 pipeline architecture. The shared demodulator was based upon a variable-length inverse FFT processor, an interpolation filter, and other digital circuitry. Breadboard development of the processor, the demodulator, and a testbed, initiated in 1986, will continue in 1987.

Flexible Digital Module Development

Flexible digital module development was sponsored by COMSAT International Communications, Inc. The purpose of this project is to develop flexible, programmable, low-cost digital baseband subsystems for low- to medium-data rate applications from 16 to 144 kbit/s, by taking advantage of the state-of-the-art LSI and multiprocessor technologies. The basic baseband functions of an earth station have been implemented in a current

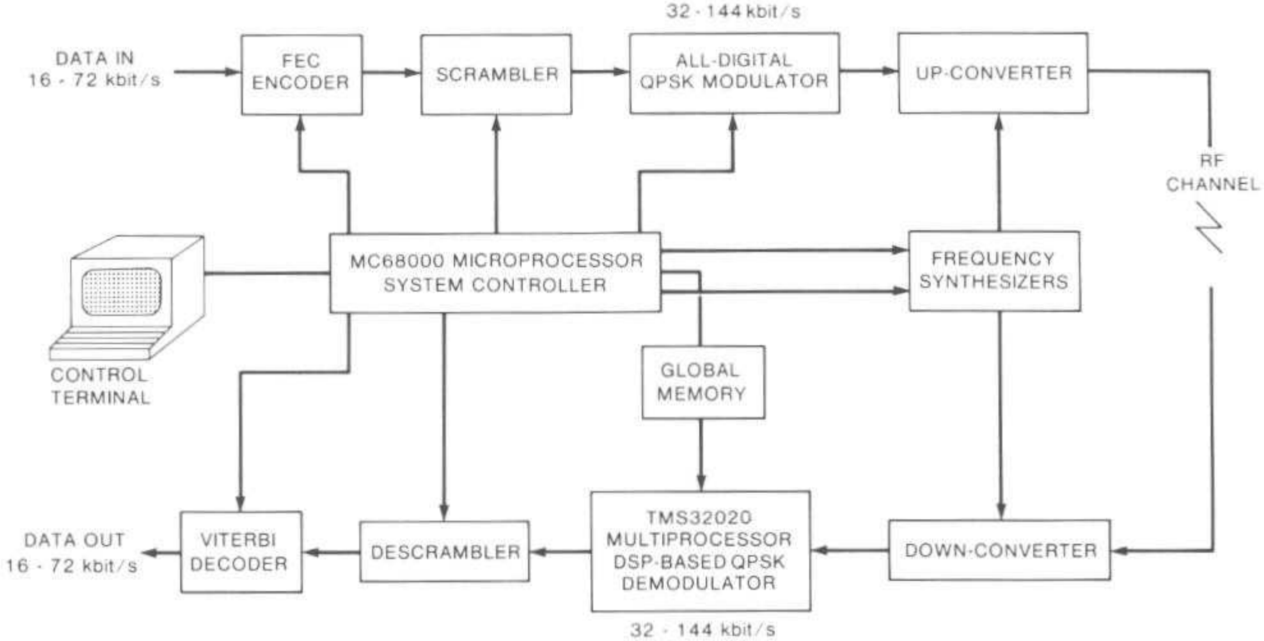


Figure 7. *Flexible digital module prototype unit is based on a modular multiprocessor architecture*

prototype. These include a programmable, all-digital, microprocessor-based continuous mode QPSK modem; a programmable, variable rate (rate 1/2, rate 3/4), constraint length 7, convolutional encoder/Viterbi decoder; a self-synchronizing scrambler/descrambler; up/down-converters; frequency synthesizers; and a control terminal.

The initial work on the system concept and computer simulations of the modem algorithms were performed in 1985. The hardware design and construction and the software development and testing of the prototype were completed in 1986. The design of this prototype terminal, as shown in Figure 7, is based on a modular, multiprocessor architecture built around the industry-standard VME bus. Five processors are used in this unit. A Motorola MC68000 16-bit microprocessor is used as the host processor that controls the system operation and communicates with the user through the control terminal. Four high-speed Texas Instruments TMS 32020 digital signal processor chips operating in parallel are used for the QPSK demodulator. The demodulator board is shown in Figure 8. All interprocessor communication between the host processor and four TI processors takes place through a centralized global memory. The four TMS 32020 chips perform carrier mixing,

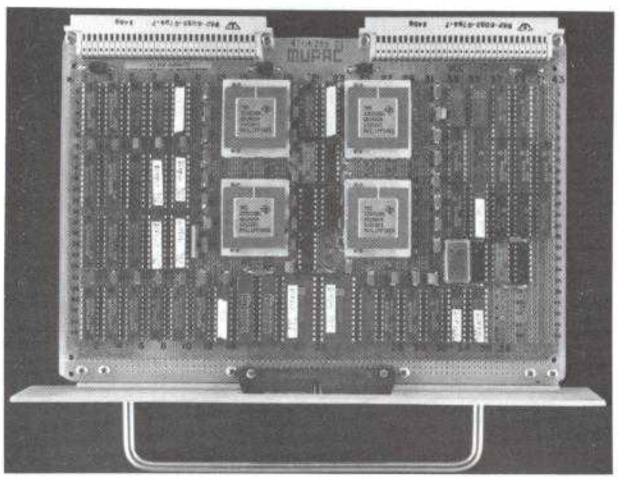


Figure 8. Multiprocessor QPSK demodulator board

carrier recovery, clock recovery, and data detection entirely in software. Extensive use of programmable array logic (PAL) and PROMs/EPROMs in the digital boards has resulted in improved functionality and efficient utilization of the available board areas. Figure 9 shows the measured bit error rate (BER) performance in IF loopback. With the present prototype, the measured modem implementation loss at the highest data rate of 144 kbit/s is 0.2 dB. The coding gain with rate 1/2, constraint length 7, convolutional coding/Viterbi decoding is within 0.3 dB of theoretical.

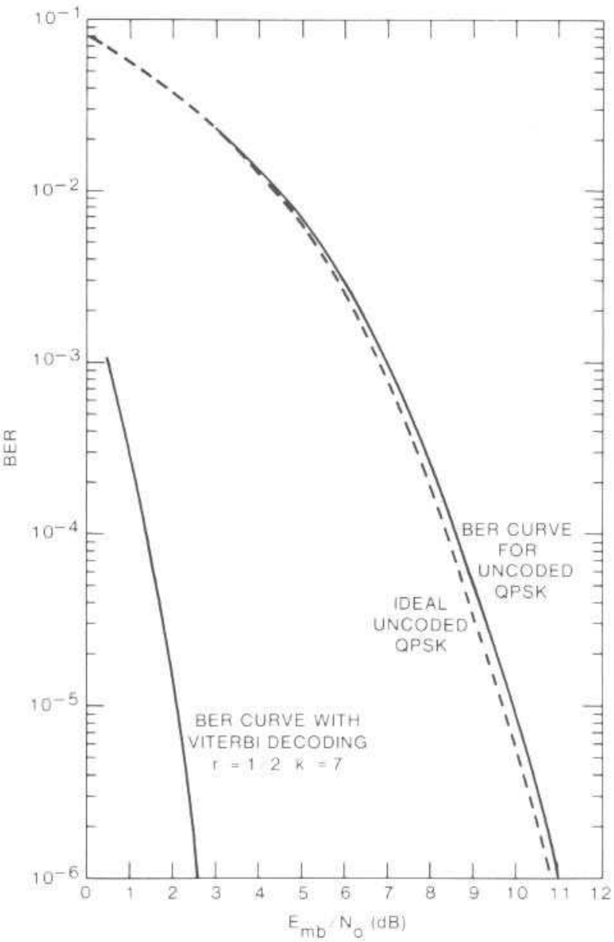


Figure 9. Measured BER performance for uncoded and coded QPSK at a modulation rate of 144 kbit/s

COMSAT JURISDICTIONAL R&D (INMARSAT RELATED)

Standard-C Functional Prototype Development

Early functional prototypes of the INMARSAT Standard-C ship earth station (SES) and the Standard-C coastal earth station (CES) equipment have been developed on behalf of Maritime Systems. The SES, shown in Figure 10, consists of antenna, transceiver, modem, baseband processor, battery-operated computer terminal, and carrying case. The CES equipment consists of IF converters, frequency synthesizers, modem, baseband processor, and a personal computer. The SES is a complete terminal capable of stand-alone operation, and the CES interfaces with existing Standard-A CES equipment at 90 MHz.

The functional prototype can be operated at an information rate of 300 or 600 bit/s. The CES-to-SES transmission is continuous. The SES receives and transmits in half-duplex mode. The operating mode and a frequency pair are menu selected by keyboards at the SES and CES.

Figure 11 is a block diagram of the CES and SES. An RF relay in the SES, under the control of the baseband processor, is used to isolate the transmit and receive chains for half-duplex operation. Also used for half-duplex operation is a single L-band local oscillator shared by both the up- and down-converters. Under processor control, a single frequency synthesizer is switched between a pair of intermediate frequencies for transmission and reception. The SES demodulator is implemented with a Texas Instruments TMS 32010 DSP and must acquire a PSK signal modulated by random data under the influence of severe noise, fading, and a large frequency offset. The baseband functions are realized with two microprocessors. The rate 1/2 Viterbi decoder operates on a microprocessor and has variable constraint lengths ($K = 5$ and $K = 7$). All remaining baseband functions are implemented with a Zilog Z8 microprocessor. The modem and baseband processor circuits are contained in two 8-in. × 7-in. circuit cards. These circuit cards, with their power supply, occupy only a single 1.5-in.-high deck in the carrying case.

Figure 10. *Standard-C SES functional prototype*

The CES design is a conventional full-duplex design. The baseband functions are quite similar to those of the SES, except that both transmit and receive processing must be performed concurrently. Some of the baseband functions are therefore implemented in the personal computer.

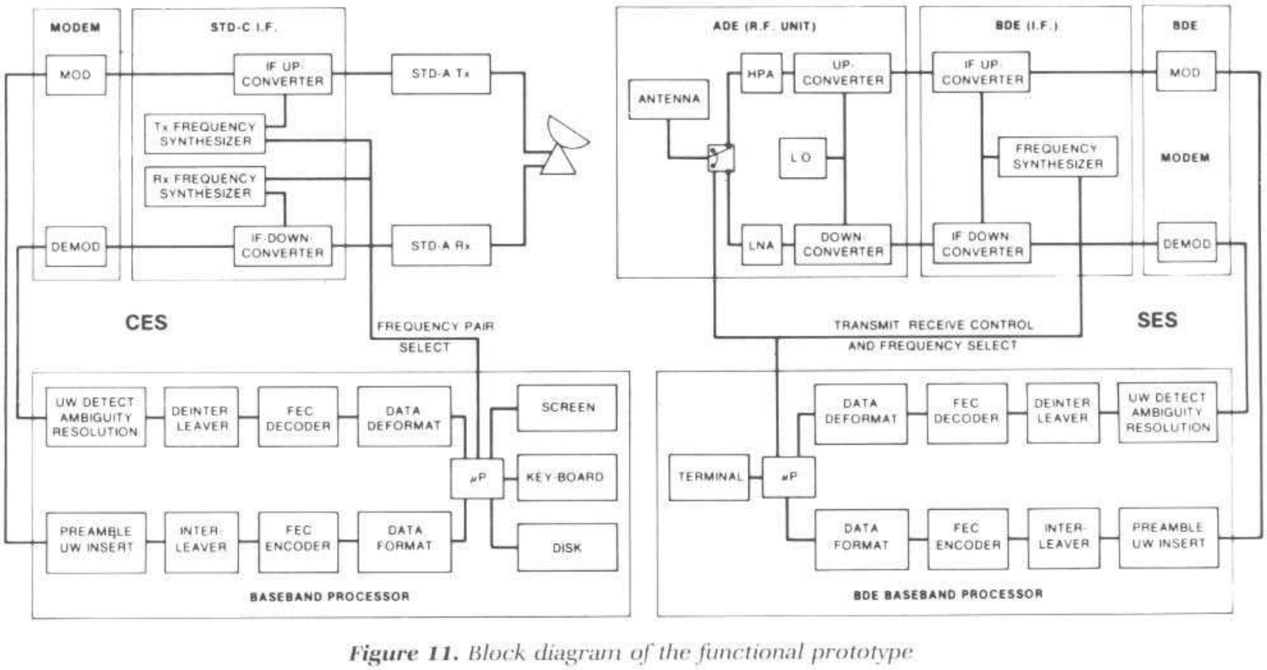


Figure 11. *Block diagram of the functional prototype CES and SES*

The demodulator is implemented with the same hardware as that of the SES, but with additional software for burst acquisition.

The BER performance of the modem operating in half-duplex mode is shown in Figure 12 for the coast-to-ship link. Similar performance is expected for the ship-to-coast direction.

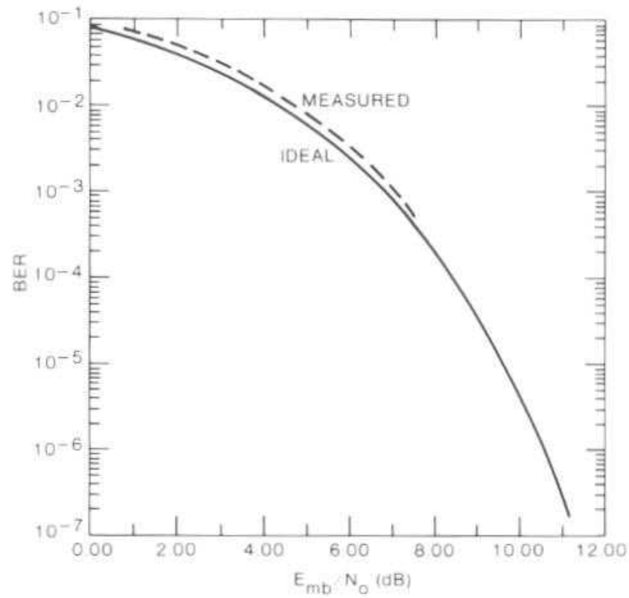


Figure 12. *BER performance of the DSP-based modem on the CES-to-SES link*

COMSAT NON-JURISDICTIONAL R&D

Digitally Implemented Modem—Acquisition Measurements

In recent years, work performed under this task has concentrated on flexible-rate modulator/demodulator (modem) technology. Much of this work has focused on one of the main functions of the demodulator portion of the modem: the way in which the demodulator recovers the transmitted carrier and clock signals.

Phase-locked loop (PLL) carrier and clock recovery circuits are normally chosen for use in continuous mode modem designs because they provide the best overall performance. Although it would be desirable to use PLL-based circuits in burst mode designs as well, a PLL phenomenon known as "hangup" occasionally lengthens the time required to recover the carrier and/or clock, resulting in degraded acquisition performance with respect to non-PLL designs.

Using a digitally implemented, PLL-based burst modem developed at COMSAT Laboratories in 1985, a series of acquisition measurements were made to quantify the effect of hangup on burst mode performance. Some of the parameters which were varied to fully characterize this performance include the following:

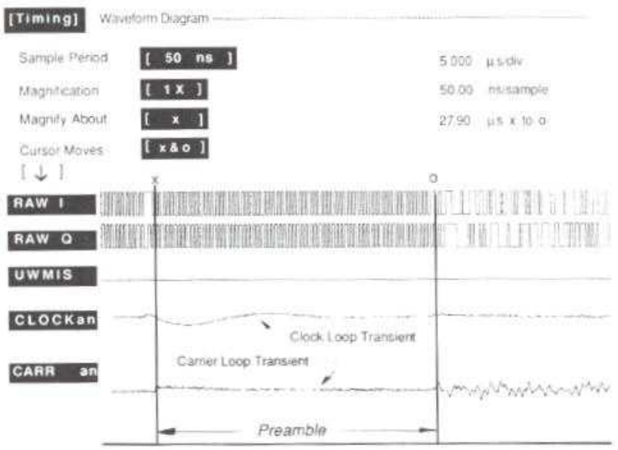
- carrier, clock phase, and frequency offsets between consecutive bursts
- recovery loop bandwidths
- preamble length and pattern
- modulation type (BPSK, QPSK).

Presented in Figure 13 is a direct observation of carrier loop hangup, as evidenced by the equivocating carrier loop transient and absence of data in the upper channel. Hardwiring of the transmit carrier and clock signals to the receive side of the modem indicates that carrier loop hangup, and to a lesser extent, clock loop hangup, are causing substantial degradation in burst acquisition performance, as shown in Figure 14.

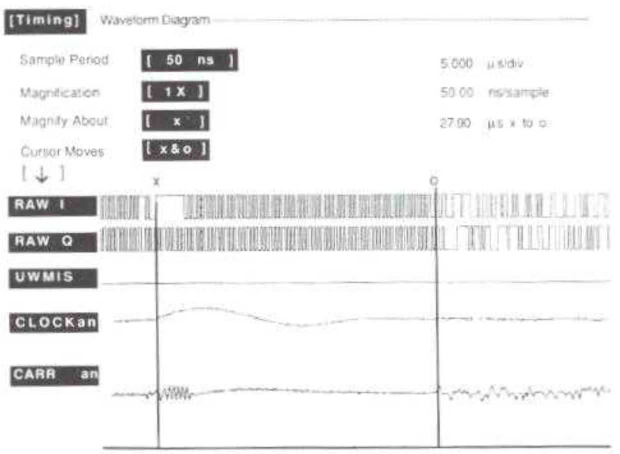
Currently under development are acquisition aid circuits, which are designed to detect and correct for the hangup condition before it can degrade the acquisition performance of the modem. This work consists of joint optimization of performance parameters following short-term error measurements of carrier and symbol timing phase at the start of burst synchronization.

Microprocessor-Based Viterbi Decoder

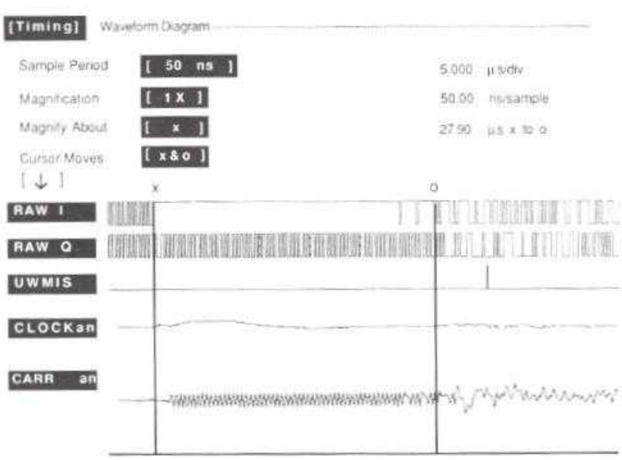
A selectable-constraint-length, rate 1/2 Viterbi decoder, based on a Rockwell 65C02 microprocessor, was developed. This decoder, which is capable of operating at information rates of up to 2400 bit/s with a constraint length of 5, and up to 600 bit/s with a constraint length of 7, allows reliable data communications via satellite at carrier-to-noise density ratios below 40 dB-Hz. It has potential application to INMARSAT Standard-C terminals, aeronautical data link terminals, and land mobile systems. With a total of five memory and interface chips, the decoder is implemented on a 5-in. × 2.5-in. wirewrap card.



(a) No hangup-burst acquired



(b) Partial hangup-burst still acquired



(c) Hangup during entire preamble-burst missed

Figure 13. *Examples of carrier loop hangup in the LR-TDMA modem*

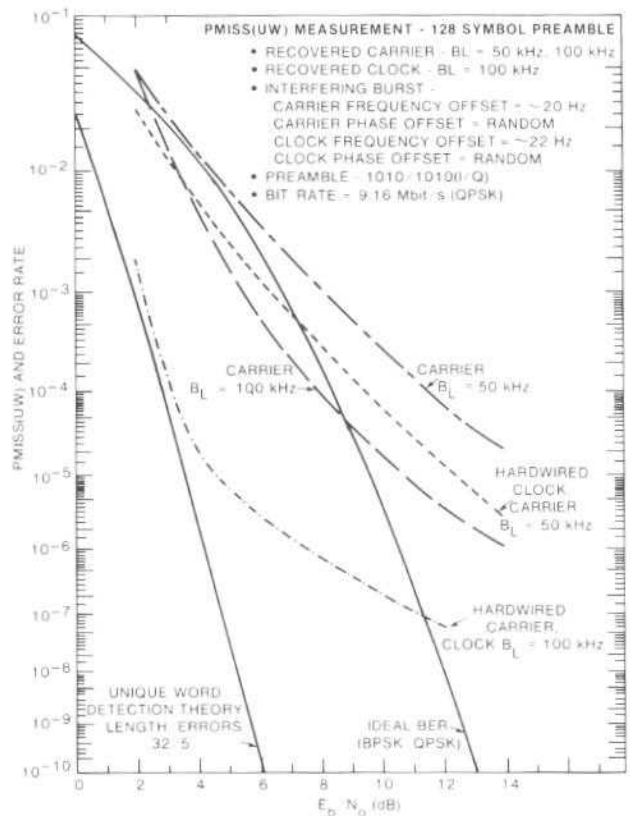


Figure 14. *Acquisition performance with 128-symbol preamble vs E_b/N_o*

COMSAT SUPPORT

64-kbit/s Audio Codec

COMSAT Laboratories has provided COMSAT Technical Services with a 64-kbit/s, 5-kHz program audio codec. CTS will use this codec to improve the transmission quality of the broadcast distribution system and lower system transmission costs for the Voice of America program. To achieve the 64-kbit/s transmission rate, the input program audio signal is bandlimited to 5 kHz and sampled at a 12.4-kHz rate. The samples are then converted to a 16-bit linear signal, which is subsequently processed by a 5-bit/sample ADPCM encoder, yielding a 62-kbit/s encoded signal. The required 64-kbit/s transmission rate is achieved after 2 kbit/s of synchronization information is interleaved with the 62-kbit/s ADPCM encoder output. The ADPCM codec and synchronizer are implemented using Texas Instruments TMS 32010 digital signal processors.

Figure 15, which is a plot of the input signal level vs signal-to-distortion ratio, shows the performance of the program audio codec using 5-bit/sample ADPCM. It can be seen that the signal-to-distortion ratio is at least 45 dB over an input signal level range of 35 dB. An expert listening test using various types of program material has shown that the ADPCM codec performance is nearly equal to that processed by a reference 198.4-kbit/s linear PCM codec.

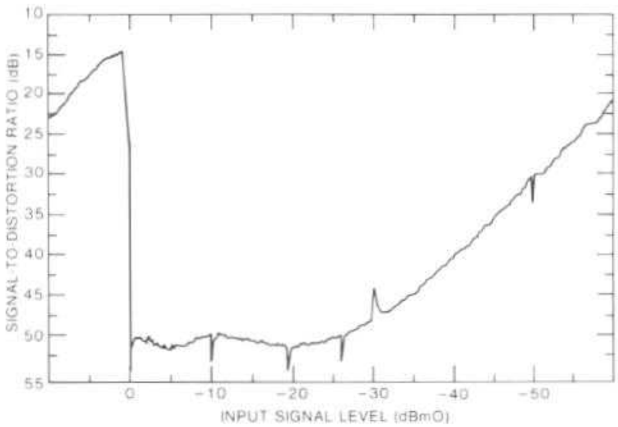


Figure 15. *Signal-to-distortion ratio vs input signal level (1004-Hz sinusoidal signal) for 64-kbit/s audio codec*

Earth Station System Studies

Two studies, one sponsored by Intelsat Satellite Services and the other by COMSAT International Communications, Inc., were conducted in 1986 to examine optimum roles for earth stations of various sizes in the INTELSAT system. The scope, and some of the more salient results of these studies are described below.

With a greater emphasis on reducing end-to-end circuit costs, the use of smaller earth stations in the INTELSAT system has increased. Detailed tradeoffs between space and earth segment costs have identified the minimum cost antenna size for various transmission schemes at both C- and K_u-bands using the INTELSAT V and VI satellites. Cost analyses show that, for operation with an INTELSAT V satellite at C-band, the minimum cost is incurred with an antenna diameter in the range of 5 to 7 m for SCPC circuits, depending on the number of circuits carried, and with an antenna diameter of about 7 m for either FDMA/PSK or low-rate (LR) TDMA. At K_u-band, the minimum earth station cost occurs with an antenna diameter of about 3 to 5 m for SCPC and about 4 m for FDMA/PSK and LR-TDMA.

Comparison of these three transmission techniques indicates that SCPC clearly provides the lowest cost earth station when the number of circuits carried is small, e.g., less than 10. For larger capacity earth stations, either FDMA/PSK or LR-TDMA will provide the lowest cost depending on the number of correspondent stations that must be received by the station. Since the cost of the LR-TDMA system is independent of the number of correspondents that must be received by the station, while the cost of the FDMA/PSK system increases with increasing correspondents because of the need for additional down-converter chains and demodulators, LR-TDMA becomes more cost effective than FDMA/PSK whenever the number of correspondents is greater than about 4 to 6.

Means for reducing earth station cost through a reduction in the earth station's subsystem redundancy show a potential cost savings of the order of 20 to 40 percent depending on the quantity of stations procured. The impact of reduced redundancy on station availability has also been examined. The study shows that a station having only redundant modems and using solid-state HPAs has virtually the same availability as a fully redundant station if the mean time to repair is kept small, on the order of a few hours.

When the complete satellite link costs, i.e., earth station and satellite costs, are taken into account, the earth station antenna diameter which provides the minimum earth station and space segment costs is slightly different from that obtained solely from earth station cost analysis. For INTELSAT V operation at C-band, the minimum cost occurs with an antenna diameter of about 8 to 9 m for all three transmission techniques. At K_u-band the minimum cost occurs with an earth station antenna diameter of about 4 to 5 m. With stations having reduced subsystem redundancy, the minimum cost per circuit occurs for a slightly smaller antenna diameter, e.g., 7 to 8 m at C-band and 3 to 4 m at K_u-band. The optimum satellite backoffs and code rates to obtain the minimum per-circuit costs have also been determined.

A star network such as that shown in Figure 16 has cost advantages when used in the current INTELSAT network to provide service between

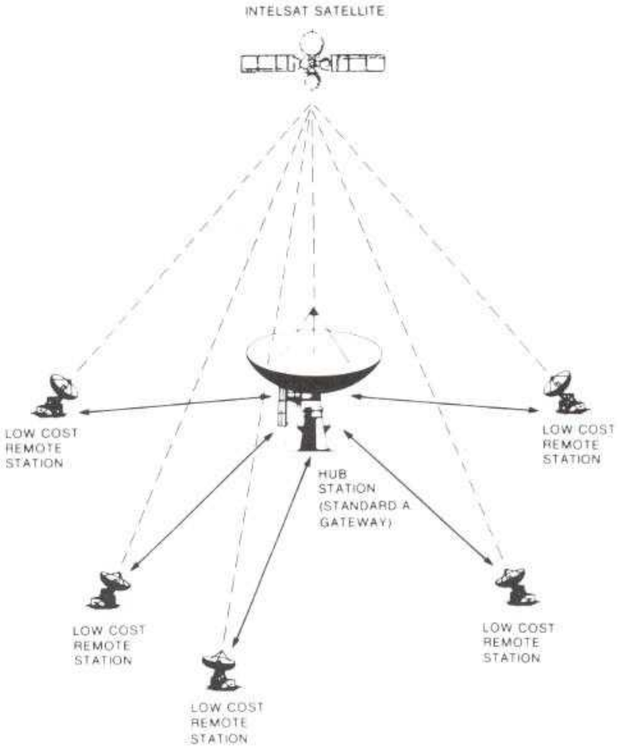


Figure 16. *International "STAR" network with low-cost remote stations*

thin-route remote stations and a major traffic gateway (hub). The use of a large antenna hub station reduces the cost of the remote stations, primarily by reducing the required e.i.r.p., which in turn allows smaller antennas and reduced HPA power. In addition, the space segment cost of the channel that originates at the remote station and terminates at the hub is reduced. For example, for a large network of users, the use of a large hub station and 5-m remote station in a star configuration provides up to 40-percent reduction in the per-circuit cost relative to that for a mesh network with 5-m antennas.

Candidate demand-assignment multiple-access (DAMA) concepts have been studied for application to a star network. The low-cost concept depends upon a number of factors, including the number of circuits carried by the remote earth station. Figure 17 compares the currently used companded FM/FDM/FDMA with three DAMA concepts: SCPC with distributed control (INTELSAT SPADE System), SCPC with centralized DAMA control, and TDM from the hub/TDMA to the hub (TDM/TDMA) with centralized DAMA control. For less than 50 circuits, all three DAMA concepts provide a cost savings over the existing CFM/FDM approach. A cost reduction relative to CFM/FDM ranging between 50 and 80 percent is made possible with use of the lowest cost DAMA star option. It can be seen that, for less than about 18 circuits, SCPC with centralized DAMA control is the lowest cost option, whereas for larger traffic stations, TDM/TDMA with centralized DAMA control provides the lowest end-to-end circuit cost.

Other issues addressed in the earth station system studies include:

- use of cost saving earth station technologies
- network control and monitoring for networks of small earth stations
- network considerations related to issues of traffic reciprocity with foreign correspondents
- impact of small stations on orbit/spectrum utilization
- spurious emission limits for small earth stations.

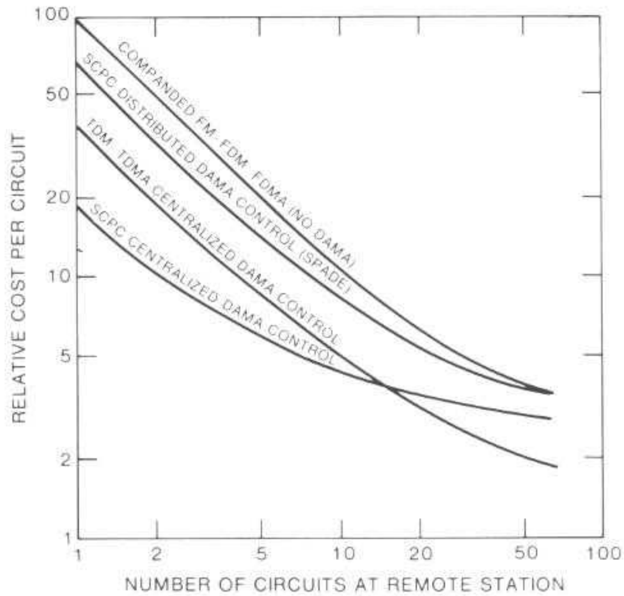


Figure 17. *Comparison of total link cost per circuit for CFM/FDM/FDMA and for "STAR" network with DAMA*

CCITT/CCIR and T1 Committee Activities

Compatibility of international telecommunications systems and services is based on agreements among the participating countries on technical and operational standards. Internationally, the CCITT and CCIR (of the International Telecommunications Union) provide important forums for such agreements, while nationally, the T1 Committee (of ANSI) is a major organization with the same purpose.

The CTD provides ongoing technical support to Intelsat Satellite Services by preparing technical contributions on satellite communications-related issues, actively participating in specialized meetings where these issues are discussed and resolved, and conducting laboratory and field experiments to provide critical data needed for decision making.

During 1986, the CTD acted as host laboratory for critical testing of LRE codecs for the selection of an algorithm suitable for DSI, provided numerous technical contributions, and chaired or attended meetings on the following standardization issues:

- speech coding techniques for LRE and teleconferencing
- system architecture, networking methods, and equipment specifications for DSI [called digital circuit multiplication (CM) by the CCITT]
- compandors for companded FM (CFM) satellite operation
- performance measures for fixed satellite services
- quality of service parameters for international packet networks involving satellite links.

Although international negotiations have progressed slowly, important agreements generally favorable to international satellite communications have resulted.

Shipboard TV Experiment

The *1985 COMSAT Laboratories Annual Report* described the laboratory demonstration of an experimental system for transmitting television to ships at sea. This project, undertaken on behalf of Maritime Systems, continued in 1986 with a field trial of the same video transmission system. The system involves compressing the full-motion NTSC video into a digital bit stream. A Rembrandt video codec, provided by Compression Labs, Inc., produced a 768-kbit/s bit stream which multiplexed limited motion video, its companion audio, and FEC information. This bit stream was modulated by a QPSK modem incorporating rate 1/2 FEC. The QPSK carrier was up-linked from the COMSAT CES at Southbury, Connecticut, to the INMARSAT Atlantic Ocean Region (AOR) Marecs A Satellite. The L-band down-link was received aboard the Cunard luxury liner Queen Elizabeth 2 (QE2) by a 2.2-m stabilized antenna provided by Seatel, Inc., and a modified SES provided by Sperry Marine. The QPSK carrier was demodulated and the bit stream decoded to provide limited-motion NTSC television.

From January 15 through January 21, 1986, a series of test transmissions was made from the Southbury CES to the SES on-board the QE2 at several different locations within the AOR. These test transmissions contained one hour of video programming. This programming was recorded on video cassette for subsequent playback on a large screen projection television system for an audience consisting of passengers and crew. A subjective evaluation survey found that 71 percent of a sample of viewers rated the received video quality as "about the same" as the TV reception at home. The test transmissions continued for almost a month after the initial one-week trial. The highlight of the test transmission period came on January 26, 1986, when approximately 800 passengers and crew aboard the QE2 watched the Super Bowl via INMARSAT while cruising off the coast of Peru.

INTELSAT SUPPORT

INTELSAT VI Simulator

A hardwire simulator of the INTELSAT VI communications subsystem has been designed, built, tested, and delivered to INTELSAT by COMSAT under the LEAC INTEL 1100-1101. As compared to a computer simulation, in which results are predicted by sophisticated mathematical modeling, the simulator built for INTELSAT was constructed using actual receivers, TWTAs, and filters. These components were supplied to COMSAT by the spacecraft manufacturer, and are assumed to be representative of the hardware which will be utilized in constructing the actual spacecraft. The INTELSAT VI simulator is therefore expected to exhibit performance virtually identical to that of the INTELSAT VI spacecraft when it initiates service later in this decade.

Many of the features of the INTELSAT VI communications subsystem have been incorporated into the design of the simulator. The simulator,

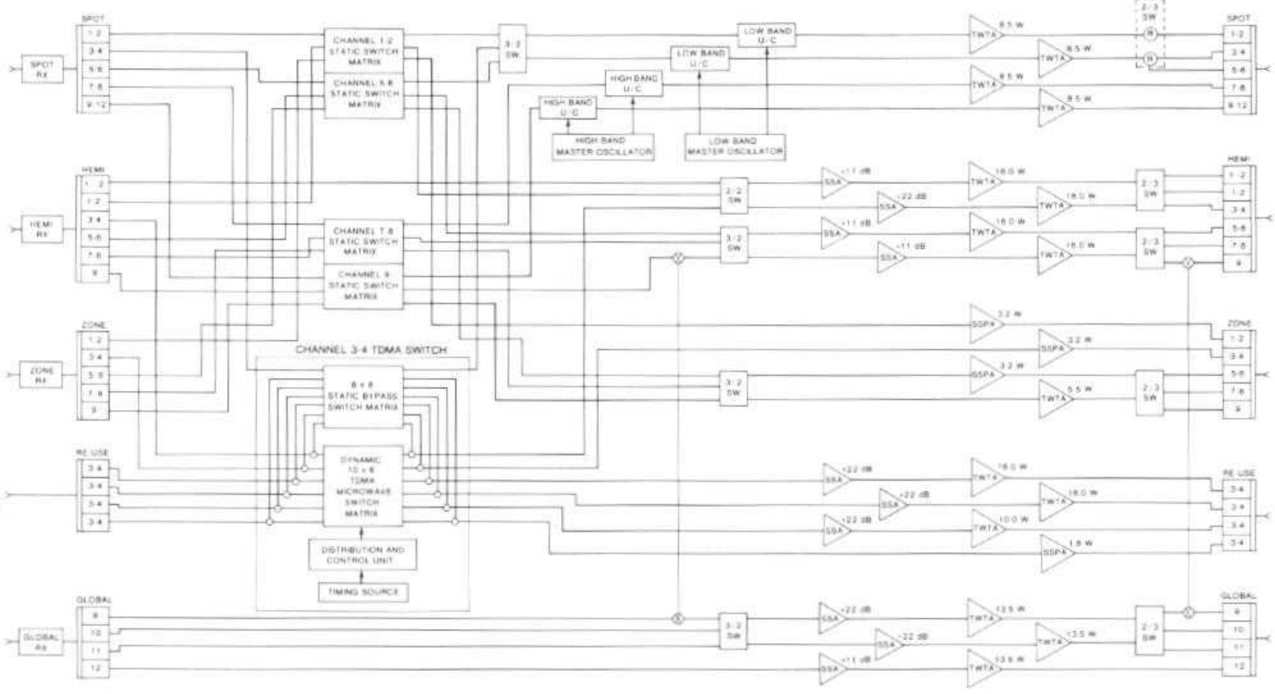


Figure 18. *INTELSAT VI laboratory simulator models end-to-end satellite link operation*

which consists of 5-½ racks of equipment, contains a complete set of spot, hemi, zone, and global transponders. Complete interconnectivity between all of these transponders allows any transponder input to be routed to any transponder output. Full sixfold frequency reuse is available on the INTELSAT VI spacecraft, and this reuse capability has been preserved in the simulator design. The simulator will also be capable of performing satellite-switched TDMA (SS/TDMA) experiments when its dynamic microwave switch matrix (MSM) is incorporated at a later date.

Figure 18 is a block diagram of the INTELSAT VI simulator. The spot, hemi, zone, and global inputs at the left of the diagram are connected to the respective receivers. Although not shown in this simplified diagram, the signal can be examined at the output of the receiver and at several other "monitor" outputs provided at key interim junctions throughout the signal path. Features such as these "excite" and "monitor" ports make this simulator extremely useful to the engineer attempting to gain insight into the operation of an end-to-end satellite link. Following the receivers, the signal passes through the demultiplexing filters to the 8 × 8 static switches, where the signal path can be

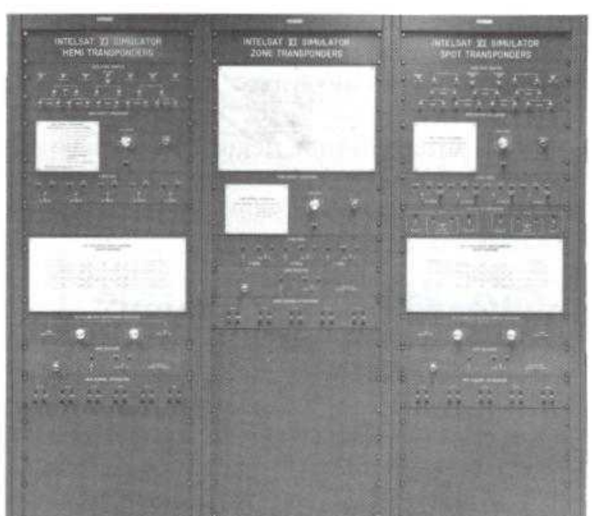


Figure 19. *Front view of spot, hemi, and zone sections of INTELSAT VI laboratory simulator*

selected from the front panel. The outputs of the 8 × 8 static switches eventually enter TWTAs, and then the multiplexing filters at the outputs of the simulator.

The simulator, a portion of which is shown in Figure 19, is the sixth built for INTELSAT. (Simulators were also built for the INTELSAT IV, IV-A, V, V-A, and V-MCS.) Its predecessors were used extensively in experiments conducted at COMSAT Laboratories. It is anticipated that the INTELSAT VI simulator will be equally useful.

OTHER

INMARSAT Standard-B Testbed

The INMARSAT Standard-B Testbed Communications Subsystem was completed in 1986 under Contract INM-84/101. This testbed, shown in Figure 20, includes a CES unit and an SES unit, and is capable of concurrently simulating both the SES-to-CES and CES-to-SES link. Each of the CES and SES units can be operated in nine different modes, as described in Table 1.

Table 1. Standard-B Testbed Operating Modes

Mode	Modulator	FEC Rate	Format	Information Rate (kbit/s)	Channel Rate (kbit/s)
1	BPSK	½	Continuous Data	6	12
2	BPSK	¾	Continuous Data	9	12
3	BPSK	½	Burst Data	6	12
4	QPSK	½	Continuous Data	12	24
5	QPSK	½	Burst Data	12	24
6	QPSK	¾	Burst Voice	18	24
7	O-QPSK	½	Continuous Data	12	24
8	O-QPSK	½	Burst Data	12	24
9	O-QPSK	¾	Burst Voice	18	24

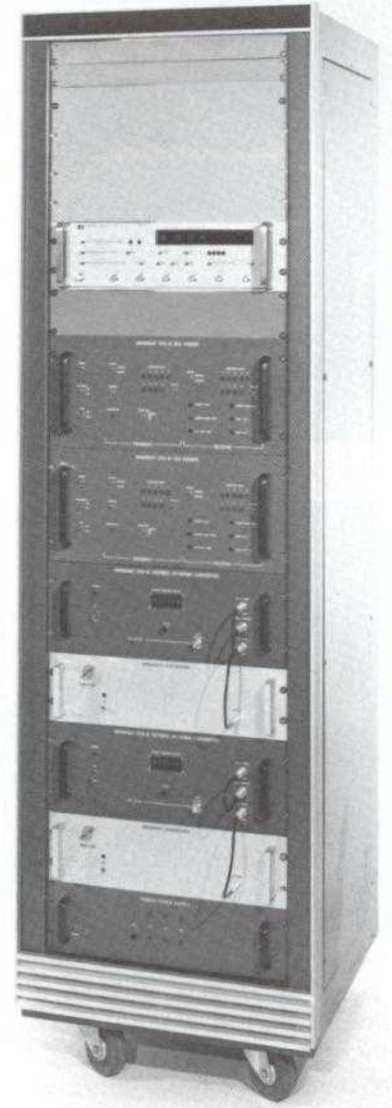
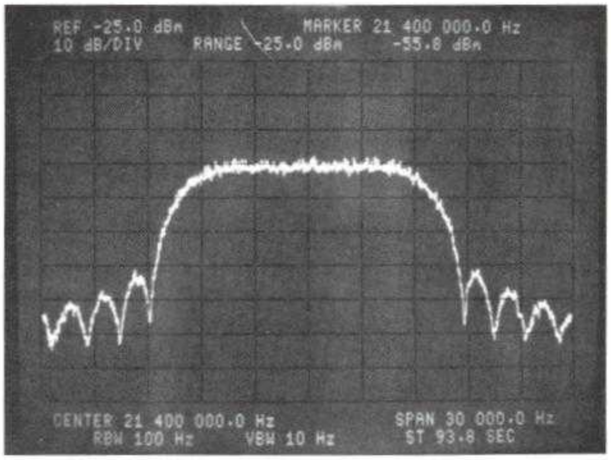
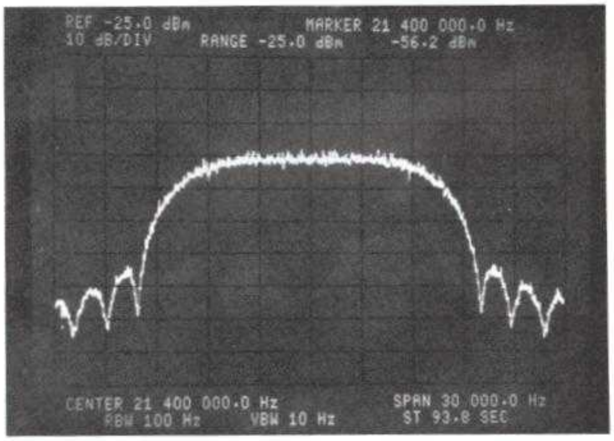


Figure 20. INMARSAT Standard-B testbed concurrently simulates SES-to-CES and CES-to-SES links

Key features of the testbed include two microprocessor-based programmable modems, each capable of operating in six different modes: BPSK, continuous and burst; QPSK, continuous and burst; and offset QPSK (O-QPSK), continuous and burst. The major functions of each modem are accomplished using a single Texas Instruments TMS 32010 digital signal processor. The transmitted spectrum and the BER performance of the modem for the continuous modes, obtained in the in-plant acceptance test over an IF loop at 21.4 MHz, are illustrated in Figures 21 and 22, respectively. It is shown that, due to precise digital implementation of the spectral shaping, the BER performance is very close to the ideal. The testbed also includes a



(a) BPSK and QPSK with 40-percent root-Nyquist filtering



(b) O-QPSK with 60-percent root-Nyquist filtering

Figure 21. *Modulated spectra*

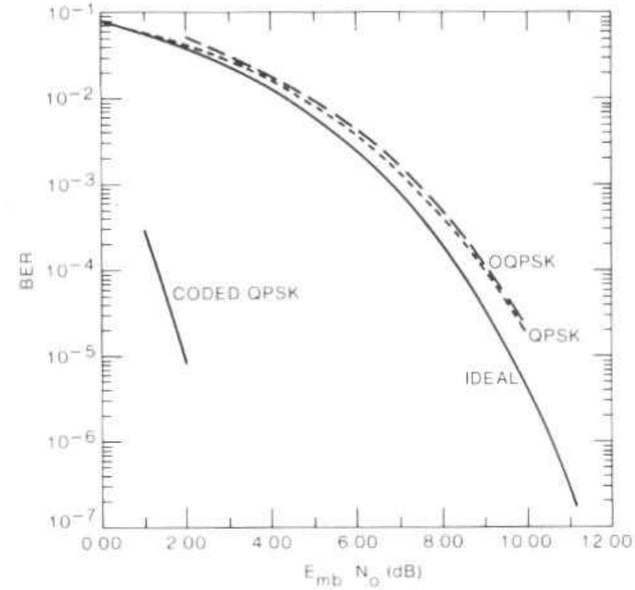


Figure 22. *BER performance of Standard-B testbed IF loopback*

variable-code-rate, variable-constraint-length Viterbi decoder. The coded BER performance for constraint length 7 is shown in Figure 22.

Under two amendments to the original contract, COMSAT Laboratories is currently implementing a new modem and frame synchronizer for aeronautical applications, and in 1987 will be conducting multipath tests for INMARSAT.

Digital transmission and switching technology has led to new forms of networks that provide new services at reduced cost; as a result, networks are evolving at an ever-increasing pace. New network concepts, protocols, systems, and devices are announced almost daily. This rapid development has a positive feedback effect: as more services become available, more users are attracted, resulting in rapid network expansion. These new networks may take the form of local networks within a building or campus-wide complexes, metropolitan area networks, or national and international networks.

The notion of separate telecommunications networks for voice, data, and video is rapidly giving way to the concept of Integrated Services Digital Networks (ISDNs), which are more cost-effective solutions for the explosive "Information Age" needs of customers today and in the next decade. The focus of the Network Technology Division (NTD) is this rapidly developing area called "networking," from systems and architecture to software and hardware. The NTD has applied an integrated approach to this massive task in order to simplify procedures and designs, hence ensuring a manageable network design capable of continuing orderly growth and encouraging the incorporation of future technological advances. While the NTD is primarily concerned with telecommunications networks, special emphasis is placed on exploiting the advantages of satellites in providing new services at competitive cost.

The NTD is responsible for research and development activities pertaining to communications network design, network control, network management, protocol development, satellite multiple access, and fiber optic systems and device development. In addition, hardware and software development conducted by the NTD plays a crucial role in cost-effective network implementation. In these areas of endeavor, the NTD has been engaged in research and development activities in support of the Corporation and its various lines of business.

COMSAT NON-JURISDICTIONAL R&D

Processor Technology

The NTD maintains a continuing research and development program to evaluate new developments in processor technology and to develop multiprocessor architectures using the latest commercially available and custom devices to support various development programs in such areas as fault-tolerant processor networks, network monitoring, management, data processing, and data routing. During 1986, the NTD procured and initiated evaluation of the first commercially available transputer. Transputers are designed for operation in a network of processors (with no common bus and hence no bus capacity limitations) as opposed to common bus multiprocessor systems, and are well suited to a variety of multiprocessor topologies for fault-tolerant architectures, real-time control systems, and large simulations. The basic transputer architecture is presented in Figure 1a. As indicated in the figure, each transputer has four bidirectional 10-Mbit/s physical links, which connect it to another transputer or an input/output device. Figures 1b and 1c show how multiple transponders are connected to form a network. These systems are being evaluated for possible application to networking problems with a detailed trade-off of cost vs performance.

Software Technology

Software is a critical element in the evolution of "intelligent" networking functions today and will become even more critical in the future. It is

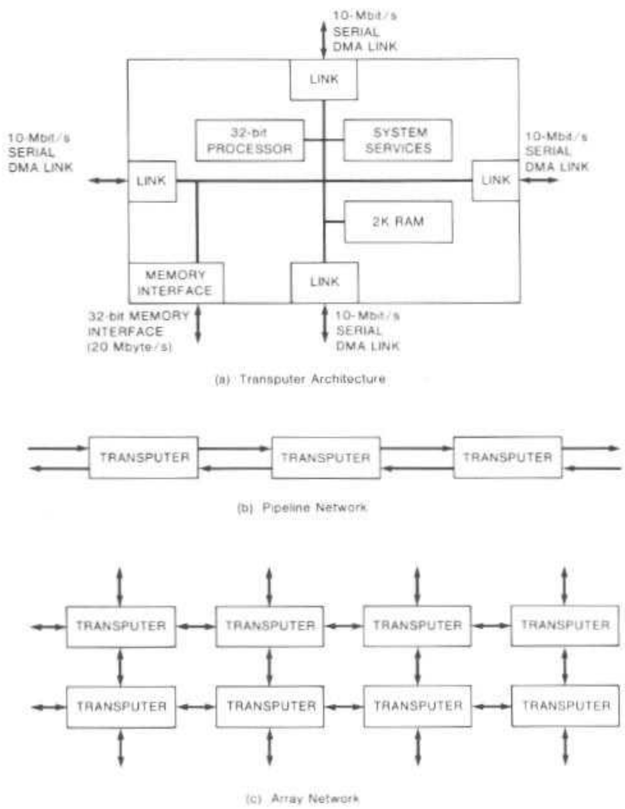


Figure 1. *Transputers are designed for operation in a network of processors with no common bus*

usually the largest bottleneck in terms of development costs and time. The NTD has been attacking this "technological" barrier with a large measure of success and will continue to do so. In this context, the NTD has developed the COMSAT multiprocessor operating system (COSMOS) that forms the basis for most software development tasks carried out by the division. COSMOS consists of an ever-increasing library of software "bricks" and an architecture (rules for synthesis) that allow the synthesis of simple to highly complex software systems from the COSMOS library, and reduces software development to an incremental task. COSMOS has been structured and optimized for efficiency (high speed and low overhead) and transparency in distributed processing environments; however, less stringent environments are also accommodated. A significant advantage of COSMOS is that it allows common hardware and software development for different projects. Over the past several years, the division has developed a large inventory of software that can be applied to division programs. During 1986, the following enhancements were made to COSMOS:

- *Priority Scheduler.* The priority scheduler enhances COSMOS to provide the control needed by real-time software systems to respond to external events within fixed time constraints.
- *Variable-Length Message Header.* This feature has been added to COSMOS to allow a more efficient implementation of the higher layers of data communications protocols (e.g., session, presentation, and application). Since the higher layers can have message headers that vary considerably in length, a variable message header length facilitates their software implementation.
- *Improved Buffer Management Scheme.* This improvement provides an additional level of control in the allocation of buffer resources to the various software tasks running on the microprocessor(s). Buffer capacity can be allocated to specific software tasks as opposed to a common buffer pool that is treated on a first-come, first-served basis. This capability is very desirable for real-time systems where buffer capacity for specific tasks must be available when needed.
- *PROM-Based Debugger/Disassembler.* A PROM-based debugger functions similar to an in-circuit emulator, providing approximately 80 percent of its capability, but at a much lower cost. Therefore, for a system containing a number of microprocessors, PROM-based debuggers are an inexpensive and practical way to test software running in the microprocessor hardware. In addition, the PROM-based debugger is very useful for problem solving in the field. The disassembler translates machine code into assembly language, which is much easier for the software designer to interpret.
- *VAX Implementation.* Implementation of COSMOS on a VAX computer using the UNIX operating system provides three basic enhancements to the NTD's software development capability. First, programs that run in a microprocessor system can gain access to VAX resources, such as the file system, printer, and data bases. Second, the development of incremental software for existing systems is enhanced since the existing software can be located in the microprocessor system, while the new incremental software resides within the VAX. Third, new software can be loaded into a target system in seconds using Ethernet.

Figure 2. *NTD engineers are developing feasibility prototypes of expert and knowledge-based systems*

Expert Systems

Since 1985, the NTD has been involved in applying recent developments in knowledge-based systems and expert systems to various suitable networking problems. Two broad classes of applications have been identified: network management and control, and network planning and design. During 1986, feasibility prototypes of both classes were developed to explore the concepts, as well as the advantages and limitations of the technology (Figure 2).

As an example of the first class, a prototype expert system, called the Intelligent Network Alarms Manager (INAM), has been developed and tested. Within this system, network designers and implementers have embedded knowledge of a low-bit-rate TDMA (LBR-TDMA) multifrequency system and the appropriate inference and decision-making procedures. INAM has the capability to analyze the alarms received at the Network Control Center of the LBR-TDMA system. It can correlate a set of alarms, find the possible causes for the alarms, assign degrees of certainty to the determined causes, and suggest appropriate remedial actions. INAM also has an explanation facility that details its decision-making process.

Other prototype expert systems being developed for network design and planning include the T1 Carrier Planning System (TCAPS), which is a concept feasibility prototype expert system developed to explore the potential for knowledge-based systems in network synthesis and analysis. The problem domain used in this exercise involves configuring an optimal cost T1 network for specified traffic and performance requirements. TCAPS synthesizes cost-optimal topology with appropriate routing using applicable algorithms and rule-based control strategies (with explanation facilities). TCAPS has the capability to adapt to changes in user requirements and has a powerful user interface via windows, menus, and graphics.

As another example of the planning applications, the problem of synthesizing a cost-optimized packet network is being addressed for user/customer-specified traffic and performance requirements. A set of standard techniques and algorithms is used to develop the initial topology, flow, and capacity allocation. A set of heuristic rules is being formulated to modify the initial network design to reduce the cost and to incorporate changes in the user requirements. The user interface via windows, menus, and graphics plays an important role in the formulation of some of these rules.

COMSAT SUPPORT

NBS/COMSAT Data Communications Experiment

Since late 1983, the Space Communications Division of COMSAT and the National Bureau of Standards (NBS) have been engaged in a joint program to examine, implement, and test the performance of data communications protocols [specifically, high-level protocols as specified by the International Standards Organization (ISO)]. The investigation is carried out by first analyzing the relevant protocols and identifying the appropriate parameters and procedures that have an impact on the efficient operation of the protocols over satellite links for different ranges of transmission speeds and bit error rates. Next, the protocols and modifications, if necessary, are implemented and tested in the laboratory and, finally, a joint satellite experiment is conducted with NBS. Results of the experiments are presented to national and international standard bodies for appropriate modifications in the protocols.

Experiments conducted by the NTD in 1985 concerned normal and expedited data flow of ISO Class 4 Transport Protocol (TP-4). The second set of experiments, conducted in 1986, focused on the ISO Internetwork Protocol (IP), a datagram protocol which was implemented and experimentally evaluated over the satellite link between COMSAT and NBS. Specific sets of experiments were selected to investigate the parameters of IP that have an impact on the performance of IP over satellite links. A detailed set of specific recommendations for values of these parameters was obtained based on the experimental results.

The higher-layer protocols, namely, session, presentation, and application, will be investigated in the near future.

CCITT and T1D1 Summary

As described in the *COMSAT Laboratories 1985 Annual Report*, the NTD has been an active participant in Study Groups XI and XVIII of the CCITT (for activities pertaining to the ISDN) and the National Subcommittee for ISDN, T1D1, of the American National Standards Institute (ANSI).

Study Group XI activities within the NTD include ISDN signaling (Q.921, Q.931) and signaling system No. 7 (Q.700 series). Various timer values in these signaling protocols have been chosen to ensure successful operation over a satellite link. NTD participation in Study Group XVIII (ISDN matters) is to ensure that satellite circuits are not excluded from ISDN and that a full range of satellite communications capabilities are included. For example, distributed broadcast services have been offered as part of ISDN services.

The NTD has also been involved in the T1D1 Subcommittee with regard to various aspects of minimal subset recommendations. Specific values for parameters and procedures have been chosen to ensure satellite compatibility. A number of issues relating to the new packet mode protocol for ISDN are being resolved satisfactorily from the point of view of satellite networks.

ISDN Interfaces

A number of detailed reports were generated discussing all existing CCITT Study Group XVIII and XI ISDN-related recommendations in terms of satellite communications. First, a detailed report was prepared on ISDN concepts, principles, and service capabilities, including ISDN interface structures and protocols. Appropriate parameters and procedures for ISDN signaling protocols that have significant impact on satellite communications were identified. A second report described the general architecture of Signal System No. 7 and specific issues related to satellite communications. A third report evaluated the capability of the INTELSAT Business Services (IBS) network to carry ISDN traffic.

Optical Intersatellite Link Technology

In December 1986, a study on optical intersatellite links (ISLs) was completed for the INTELSAT Satellite Services organization of the Space Communications Division. The purpose of this study was to assess optical communications technologies suitable for ISL applications in the

Table 1. Design Parameters for Near-Term and Far-Term ISL Systems

Parameter	System Selection	Transmitter Power (mW)	Modulation Format	Receiver Sensitivity[a] (dBm)	Antenna Diameter[b] (cm)	Non-Redundant Payload Mass (kg)	Non-Redundant Payload Power (W)	Non-Redundant Payload Volume (cm^3)
Near-Term Baseband-Digital Traffic	GaAlAs Single-Carrier, Direct-Detection System	200	On/Off Keying	−46.5	25.6	83.9	120.8	81,000
Near-Term Analog Traffic	GaAlAs WDM, Direct-Detection System	3 Transmitters at 200 mW each	Intensity Modulation with a Frequency Modulated Subcarrier	−47.1	31.6	101.2	135.5	145,500
Far-Term Analog Traffic	GaAlAs Single-Carrier, Heterodyne-Detection System	50	Quaternary Frequency Shift Keying	−54	23.4	83	125.4	66,700
Far-Term Analog Traffic	GaAlAs Single-Carrier, Heterodyne-Detection System	50	Direct Optical Frequency Modulation	−54.6	22.5	82.7	128.7	61,100

[a]For 1×10^{9} BER or 22.9-dB S/N ratio at the receiver output.
[b]With 5-dB beginning-of-life link margin.

INTELSAT global telecommunications network. Six optical systems using carbon dioxide, Nd:YAG, InGaAsP, and GaAlAs lasers were evaluated with respect to their communications performance; the mass, volume, and prime power requirements of an on-board optical transceiver package; and the component and system reliabilities. Furthermore, an in-depth annotated bibliography was compiled, covering both past and present optical ISL activities.

Each of the six technologies was also evaluated with respect to selected criteria relevant to an INTELSAT ISL and the GaAlAs technologies were favored for both near-term and far-term applications. Table 1 gives the major design parameters for the selected near-term and far-term technologies. Finally, additional testing and development procedures required to ensure a timely development of the near-term and far-term optical payloads were identified.

STARCOM Network Control Software

STARCOM is a satellite-based data communications system developed by the Network Products Division of COMSAT Technology Products. The NTD has played a key role in the inception and development of this product. This program represents a significant commitment by COMSAT Laboratories to apply technology developed in the labs to solutions required for satellite data networks.

STARCOM is based on a star network topology, in which a central hub station is linked to numerous low-cost remote stations. Data are transmitted from the hub on multiple 256-kbit/s outbound time-division-multiplexed (TDM) carriers, which are broadcast to all remote stations. Remote stations use multiple 56-kbit/s inbound carriers to send data to the hub; an inbound carrier is either allocated to a specific remote station or shared by multiple stations in a random-access TDMA mode. Under an effective network management system, satellite transmission capacity is dynamically allocated based on the requirements of the remote stations.

User equipment interfaces to this network through standard interfaces. Currently, X.25 and IBM System Network Architecture (SNA) protocols are supported. Highly efficient protocols, developed in prior years by the NTD, are used over the satellite. These protocols are transparent to users, but provide considerably improved performance.

During 1986, the NTD continued to support STARCOM by providing software to enhance the acquisition and synchronization of remote terminals and to allow down-line loading of new software from the central hub (Figure 3).

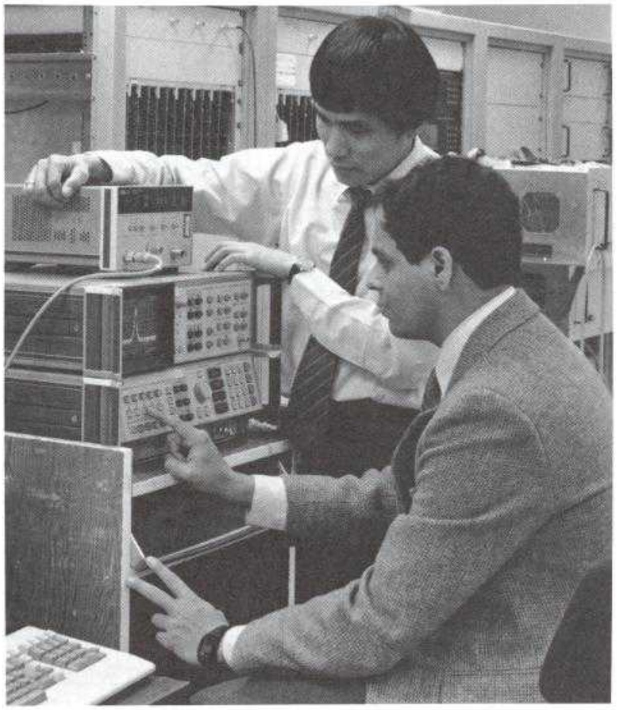


Figure 3. STARCOM software development enhances operation of low-cost remote stations

OTHER

NASA–TDAS Laser Intersatellite Link

A study of optical intersatellite links in a future NASA data relay system, "TDAS Laser Intersatellite Communications," was completed under a contract from Ball Aerospace Systems Division with funding from NASA/Goddard Space Flight Center. The purpose of this study was to design optical communications transceiver (OCT) terminals for forward and return links between two geosynchronous (GEO) satellites spaced by 160° and between a low-earth-orbit (LEO) satellite and either of the GEO satellites. The terminal designs were based on 1992 technology and included optical transmitters and receivers, the RF/optical interfaces that prepare forward and return data for transmission over the appropriate RF or optical links, and identification of system monitoring and control requirements, command sequences, and self-testing requirements. In addition, a schedule was established for the hardware development of the various terminal designs, including identification of the technologies considered critical to their timely development.

Direct-detection optical communications subsystems were selected for the TDAS forward and return optical links. For the high-data-rate return links (2 Gbit/s between the two GEO satellites and 1 Gbit/s between the LEO and GEO satellites), this selection was based upon power budget calculations performed for direct- and heterodyne-detection optical systems. In the direct-detection system, incoherent power combining of several GaAlAs diode lasers allowed the use of moderately sized antenna diameters (30 cm on the GEO satellites, 18 cm on the LEO satellite). On the other hand, the heterodyne-detection system needed a lower transmitter power, but still required coherent power combining of several diode lasers to use these same antenna diameters. This entailed a more complicated implementation and substantially increased complexity for the heterodyne system, which was already rather complex due to the frequency stability requirements in the transmitter and the frequency tracking requirements and spatial alignment problems in the receiver. A direct-detection system was preferable for the forward optical links because it would simplify the optical transceiver designs and avoid the use of both direct-detection and heterodyne-detection links in the TDAS.

SYSTEM DEVELOPMENT DIVISION

The System Development Division (SDD) is responsible for system design and development activities in support of the several COMSAT lines of business, INTELSAT, and other COMSAT clients. SDD activities encompass the development of computer-based systems, including the design and implementation of software and the selection, acquisition, installation, and integration of hardware. Other SDD projects involve the development of digital hardware and microprocessor firmware for prototype equipment produced by COMSAT Laboratories, and the development of analysis and simulation techniques and computer software for evaluation and optimization of satellite communications systems and subsystems. At the forefront of the SDD 1986 effort was the exploration of new computer hardware and software technologies and their application to distributed processing systems, as well as systems analysis and simulation. The division also established the standards, methodologies, and tools needed to develop highly reliable, easily maintained software products.

COMSAT JURISDICTIONAL R&D

System Availability Model

During 1986, a system availability model (SAM) was developed which uses the availability factors for system components, mean-time-between-failures (MTBF), and mean-time-to-repair (MTTR) to compute overall system availability. These analyses may be performed for communications networks, earth stations, computer systems, or any specified equipment configuration that has known MTBF and MTTR factors associated with its components. Data are input to the SAM via an interactive interface, and a component data base is accessed by the program. Both IBM PC and IBM mainframe versions of the SAM have been developed (Figure 1).

Interactive Intermodulation Analysis

An interactive graphical interface was developed for the COMSAT Intermodulation Analyzer (CIA). This new version of the program, ICIA, enables the user to interactively adjust the frequency or power of carriers within a transponder while viewing a graphical representation of the frequency plan on the screen (Figure 2). The program analysis can be invoked at any time to determine the RF intermodulation products that result from the specified frequency plan. The user can then iteratively adjust the carrier frequencies or powers and invoke the analysis until the desired performance is achieved. This program is available on the IBM mainframe or an IBM PC.

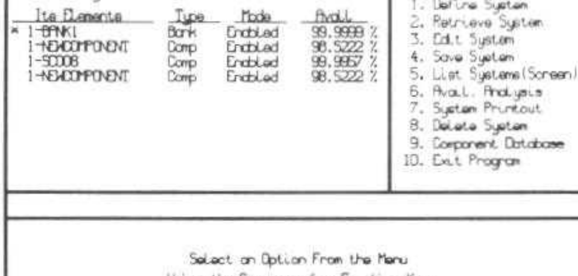


Figure 1. *System availability model operator screen*

Systems Analysis Tools

Four systems analysis tools were developed by the SDD during 1986 for use by the Space Communications Division: interactive transmission analysis, antenna coverage software, on-station plotting program, and quality-of-service analysis software.

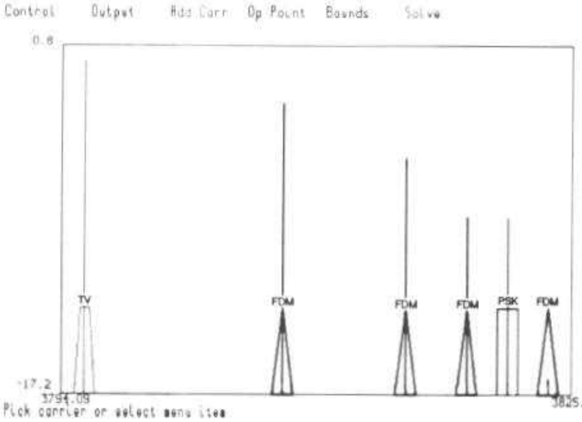


Figure 2. *Interactive COMSAT intermodulation analyzer (ICIA) output*

Interactive Transmission Analysis

An interactive version of the Satellite Transmission Analysis Program (ISTRIP) was developed jointly with the Communications Techniques Division in 1985 and 1986. ISTRIP enables the user to interactively arrange carriers within a frequency-reuse, multiple-transponder frequency plan. This program is described in detail in the Communications Techniques Division's section of this report.

Antenna Coverage Software

A completely new version of the Antenna Coverage Program (ACP) was released in 1986. This program generates satellite antenna beam patterns on a world map for several beam types, including elliptical, circular, shaped, tabular, and user-defined (Figure 3). The new ACP will also generate contours of constant elevation angle, great circle paths, visibility contours, and other satellite-related data, and can account for satellite antenna pointing errors and path losses (Figure 4). The program is installed on the COMSAT IBM mainframe, and an IBM PC version has been developed.

On-Station Plotting Program

The Satellite On-Station Plan Plotting Program (SOSP), begun in 1985, was completed in 1986. SOSP is a menu-driven interactive program that views and plots space segment data associated with satellites in a multiple-satellite system. Users enter deployment information (including orbital slot assignments and launch dates) for individual satellites. Several charts may then be generated. The "population" chart depicts the number of satellites in orbit space over a specified time period; the "bubble" chart displays the location of each satellite at a given point in time; and the "line" chart displays the role and location of each satellite, from its launch date through its retirement.

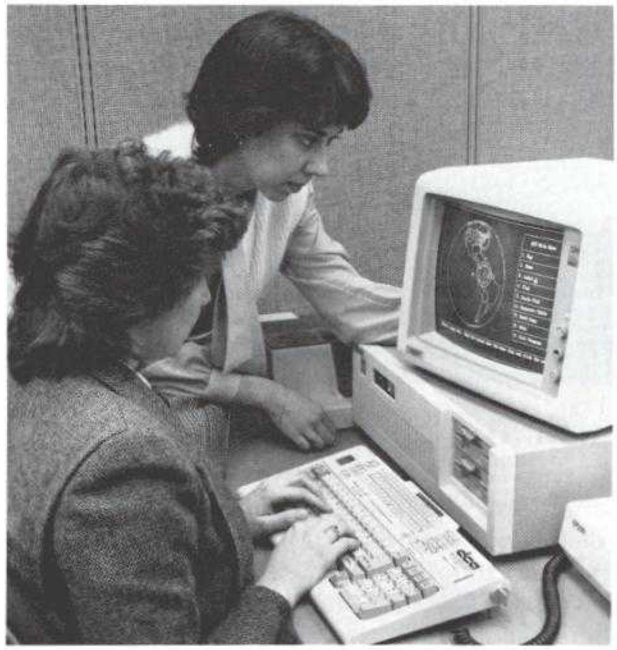


Figure 3. *Evaluating antenna gain patterns using the Antenna Coverage Program (ACP)*

Quality-of-Service Analysis Software

Several new analysis capabilities were added to the Network Analysis Program (NAP) to support CCITT quality-of-service studies. The program analyzes the performance of a specified packet-switched network in terms of traffic throughput, message delays, average queue sizes, and network loading. Routing decisions can also be made. The user defines the network as a number of processing nodes connected by communications links. Traffic is assumed to be transmitted across the links in finite-length packets, which are controlled by a specified link-level protocol. Each node may contain one or more traffic sources which generate messages at a specified rate to various destination nodes. These messages are packetized using the

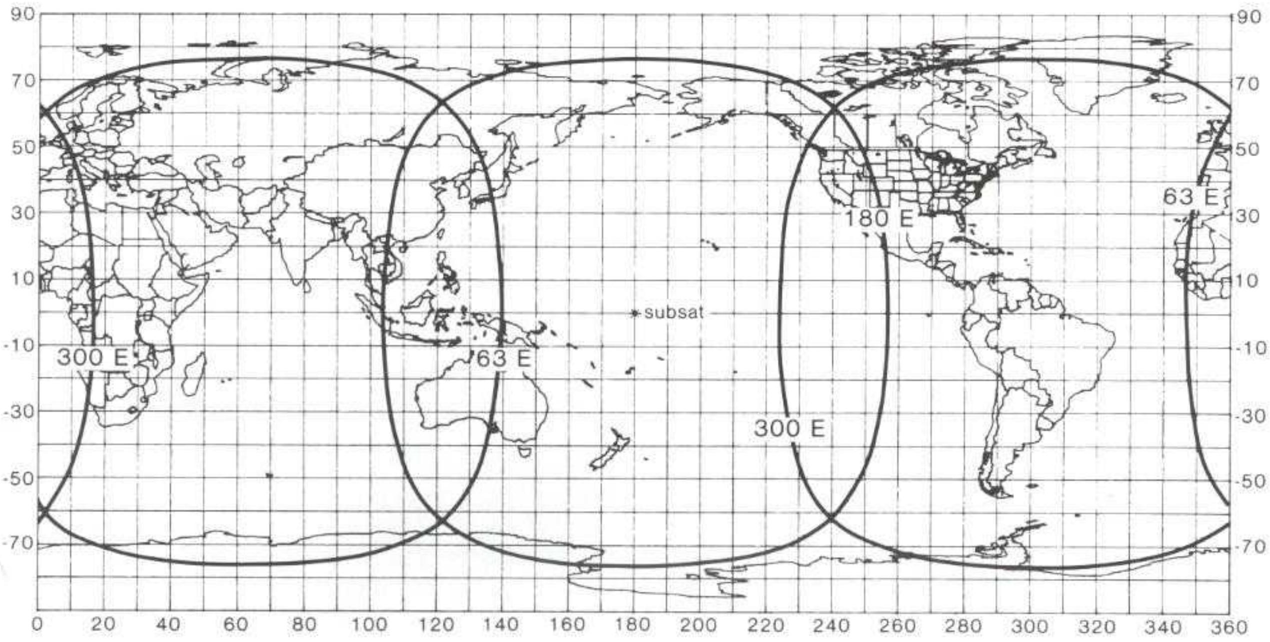


Figure 4. *Antenna Coverage Program output*

protocol specified for the node. Various processes may be defined at each node, and traffic may be directed to specified processes. The program produces tabular displays of selected network parameters and analysis results.

Standard-C Terrestrial Services

On behalf of COMSAT Maritime Services, the SDD has completed a study of the terrestrial services to be offered to shipboard users of the new INMARSAT Standard-C terminals. Initially, these services will include interconnects to the public Telex network, and provision for dial-up connection to an "electronic mailbox" at each CES.

This study also provided the groundwork for a distributed processing system to support Standard-C services, which will be installed in 1987.

COMSAT SUPPORT

Western Union and MCI M&C System Enhancements

The Western Union and MCI monitor and control (M&C) subsystems are time-division multiple-access (TDMA) networks which are based on the COMSAT Technology Products DST-1000 equipment. The M&C subsystem consists of hardware and software in a central M&C computer colocated at the primary reference terminal, and M&C equipment at each local TDMA site. At these sites a programmable controller is connected to switchable and nonswitchable discrete points to monitor and control RF equipment for that station. The programmable controller transmits the states of the points back to the central M&C computer when polled through the common signaling channel. At the central M&C, an operator can request displays of the current equipment status of any local terminal, and may control the discrete points through the central computer. In the event of a failure in the reference station or common signaling channel, the central M&C computer can communicate with the local traffic terminal via automatic direct distance dialing. This feature provides the centralized operator with continuous control of the network.

During 1986, the SDD provided COMSAT TeleSystems with an M&C subsystem for a DST-1000 TDMA system purchased by MCI Communications. The MCI M&C subsystem is a modified version of the existing Western Union M&C provided in 1985. During 1986, analyses determined the hardware and software modifications required to convert the Western Union M&C to the MCI M&C; hardware was installed and the required software modifications were made. Where required, operator screens and functions were converted to be MCI-specific.

Throughout the year, the SDD provided COMSAT TeleSystems with engineering support for both the Western Union and MCI systems. This support ranged from providing software modifications and enhancements for the M&C systems to answering questions for COMSAT TeleSystems personnel and customers. The SDD enhanced the M&C systems by allowing an operator to add, change, and delete direct dial phone numbers from a data base at the central M&C. In case of a primary communications failure, the M&C system automatically uses these phone numbers to dial up and restore communications to the failed terminal.

DFS Monitoring and Control Enhancements

The advent of powerful microprocessors and microcomputers has made advanced, complex, highly reliable, and cost-effective satellite system architectures feasible (Figure 5). The Deutsches Fernmeld Satelliten (DFS) system is one such state-of-the-art TDMA system, delivered by COMSAT TeleSystems to the Deutsche Bundespost (German Postal and Telecommunications Service). The DFS system is a digitized, 60-Mbit/s TDMA satellite communications system capable of supporting voice, heavy route trunking, distributed video, data, and facsimile. The magnitude of the project was considerable, and despite challenging deadlines the project was completed on schedule in September 1986. The SDD was actively involved, providing software support in many areas.

DFS Phase 1, which was completed in 1985, consisted of the hardware for the traffic terminals, the reference terminals, and the network control system. Phases 2 and 3, which were initiated in 1986, made DFS into a fully variable, demand-assigned TDMA network.

In the demand-assigned mode, TDMA frame space is continuously reallocated for efficient utilization of transponder bandwidth. In addition to dynamic frame reconfiguration, SDD designed, implemented, and tested software for demand-assigned allocation of calls, fully redundant equipment configuration, operator interface, and the generation of route lists, numbering plans, and traffic reports.

Figure 5. *SDD software engineers examine a DFS hardware diagram*

Frame Reconfiguration

Frame reconfiguration is the automatic optimization of the space segment for flexible and economic use of the available transponder bandwidth. When a call arrives, the call setup information is placed in a packet that is routed to the appropriate destination. A call is then established by allocating it a certain portion of the TDMA frame. Capacity is either shared in the demand-assigned portion or dynamically allocated, depending on the traffic patterns in the network. Accurate traffic statistics are maintained by continuous network monitoring.

Call Processing

Each traffic terminal in the DFS system has software that supports demand-assigned multiple access (DAMA). This software allows the setup and clearing of calls, and permits the reallocation of frame space. DAMA also plays a role in setting up reservation calls. Frame space for reservations is preallocated for a given period of time. Each traffic terminal has the ability to transmit on only one frequency, but can receive on any of four frequencies.

The most common types of calls are single-channel voice and data calls. Space for such calls can usually be allocated by DAMA using information maintained locally within the terminal. In contrast, the frame space for reservation calls is determined in advance by software in the network control processor (NCP), and such information is periodically downloaded.

Redundancy

Redundancy employs automatic switchovers to maintain the availability of the system in the event of component failure. In the DFS system, redundancy is addressed at the board and chassis levels in the traffic terminals, and at the station level in the reference terminals and network control processors. SDD contributions were in the areas of traffic terminal and NCP redundancy.

Traffic terminal redundancy is accomplished by sending messages from the on-line side to the standby side whenever a call is set up or cleared. DAMA also participates in auditing activities which ensure continued integrity of the call data base.

NCP redundancy was complicated by the need to combine large, existing, interdependent, memory-based data bases; by the large body of preexisting, nonredundant software; by the time constraints for final delivery; and by a number of hardware constraints.

Operator Interface

The NCP operator interface provides an easy, menu-driven man/machine interface for the TDMA network operator. The interface supports status requests for monitoring various components of the system, and triggers alarms to alert the operator to malfunctions in the system.

The design for the NCP operator interface originated in the SDD, and SDD personnel were responsible for the development phase of the subsystem. Using nearly 100 screens, the interface performs five major functions: status monitoring and diagnostics, configuration management, network performance monitoring, alarm monitoring, and miscellaneous.

Route List and Numbering Plan

The route list and numbering plan subsystem in the NCP maintains the data base of current route and trunk usage and the numbering plan of the 100 traffic terminals, and serves as an interface between the central control facility and the traffic terminals. Operators in the central control facility can use the data base to allocate trunk space according to customer requests, and to redistribute new numbering plans as needed. This subsystem is designed as a multiple command server and provides central control facility operators with a user-friendly environment and with the ability to interact with more than one traffic terminal simultaneously.

DST-1100 Diagnostic System

The DST-1100 diagnostic subsystem allows an operator to exercise various test functions throughout the TDMA system in order to isolate faults to the level of field-replaceable units. Tests may be initiated from the NCP for remote testing of any terminal within the TDMA network, or locally at an individual terminal.

A portion of the diagnostic subsystem is present on every microprocessor in the TDMA equipment, with a manager residing in the redundancy monitoring unit of each terminal. The manager receives requests from the operator interface, coordinates the testing within the terminal, gathers the test results, and sends the results to the operator interface for display. The diagnostic subsystem offers a full range of tests, including onboard, interface, and loopback tests. Diagnostic chains of complete sequences of coordinates tests were provided.

The system was designed with the knowledge that it would continue to evolve. New revisions are supported by automating the software-building procedure using utilities written for the host operating system. The system also takes advantage of being data-driven. The majority of control information is kept in a master table, which is used to generate unique control tables for each processor in the TDMA system.

STARCOM

Designed and manufactured by COMSAT Technology Products, Inc., STARCOM is a private satellite network that can supplement or replace common-carrier networks for business communications. STARCOM uses very small aperture terminal (VSAT) transmission hardware and the COMSAT Satellite Multiprocessor Operating System

(COSMOS) to provide clean, high-speed digital circuits and software-driven reconfiguration for flexibility and optimization of network configuration. Business advantages provided by STARCOM include rapid installation, network security, and relatively low communications costs. A STARCOM private network consists of a central facility (known as the hub) and interface units (known as on-premises terminals, OPTs) at each remote location (Figure 6).

Software Development

The Network Technology Division at COMSAT Laboratories designed COSMOS to provide efficient use of satellites, reliable high-speed data communications, and greater flexibility in configuration. SDD personnel were responsible for the development of a VAX VMS version of COSMOS, called COSMAX, which allows VAX VMS systems such as the Micro VAX to perform as network administrator and data base manager. The data base management system provides an authoritative repository, on disk, for network configuration data and traffic data. During system initialization, switchover, and OPT activation, the network queries the data base in order to load appropriate information. The data base screens display statistical data so that operators can predict and tune network operations.

SDD developers have been involved with much of the management interface. The operator enters network data base updates, and a copy is sent via the data base server to the appropriate network process, which in turn updates the RAM images of the data base in the various hub processors. A confirmation message is returned to the data base server, which permanently commits the update to the data base management system. This ensures that the data content is parallel between the real-time RAM data base in the NCC and the disk-based NCDS data base.

Other STARCOM tasks to which SDD personnel were assigned included configuration management and the development of data protocol executives. An Ethernet device driver was modified to make it more useful in the STARCOM environment.

Shared Network Support

During 1986, the SDD provided the STARCOM engineering support for the management information system (MIS) of the shared network. The MIS provides billing, accounting, and performance data for the STARCOM system. The SDD investigated several architectures needed to provide these functions, which define in detail the hardware and software required for the MIS. A major effort was involved in determining all of the communications interfaces between the MIS and the STARCOM system. All inputs and outputs between both systems were determined, and a formal interface document was delivered.

Figure 6. *SDD computer scientists integrate elements of the STARCOM hub.*

INTELSAT

Transmission Impairments Analysis Software

The SDD, in concert with the Communications Techniques Division, supported the INTELSAT engineering and operations staff by maintaining and enhancing the INTELSAT Satellite Transmission Impairments Program (STRIP). STRIP was installed on the INTELSAT IBM MVS system in 1986 and a significant number of output capabilities were added to the program, including detailed transponder and margin summaries. STRIP computes impairments resulting from co-channel interference, adjacent channel interference, thermal noise, and intermodulation for carriers of various types (digital, FM, TV, SCPC) in a multiple transponder, frequency reuse, and frequency plan. COMSAT also provides INTELSAT with fast-reaction support for software modification.

Burst Scheduling Software

The SDD continued to maintain the INTELSAT burst time plan (BTP) software system, which generates burst schedules used by earth stations within a network in the INTELSAT TDMA system. After a network schedule has been determined, other programs within the system make control and equipment assignments for the individual stations. The schedule and other assignment information are then formatted into operator-readable master time plans (MTPs) and machine-readable condensed time plans (CTPs). The MTPs are sent to the participating INTELSAT signatories for review. After approval is received, the CTPs are transmitted from the INTELSAT Operations Center TDMA Facility (IOCTF) in Washington, D.C., to the individual reference and traffic stations. The CTPs are loaded into the terminals and become operational when the synchronous BTP change is made for the network. During 1986, in addition to minor enhancements, the format of the MTPs was significantly revised and the programs that generate the MTPs were modified accordingly.

Operations Center Software Support

Under Contract INTEL-510, the SDD has completed a series of tasks aimed at improving various aspects of IOCTF operations. These tasks included the preparation of functional requirements documents for an improved method of distributing satellite position data to the TDMA reference terminals, and for a method of logging and redisplaying TDMA reference and monitoring terminal data at the IOCTF.

Also under this contract, the IOCTF software was modified to permit the distribution of test CTPs to TDMA traffic terminals. The SDD also provided installation and testing support following relocation of the IOCTF to the new INTELSAT headquarters.

CORPORATE SUPPORT

Distributed Processing Networking Software

The SDD designed and implemented the networking software for the GEOSTAR central data processing facility, which consists of a number of Hewlett Packard HP-9000s connected by a segmented local area network (LAN). The GEOSTAR Networking Software package is implemented in Pascal and C for processors using the UNIX operating system. The software performs the following functions:

- handles the routing of messages through a fixed itinerary of application processes,
- reroutes messages to backup nodes and processes in the event of link processor failure,
- supports multiple message priorities and the packing of messages into LAN packets to minimize CPU overhead,
- supports the reassignment of application processes to network nodes, and
- provides centralized monitoring of the network status and performance, and dynamic updating of network tables to reflect changes in the network configuration or processing functions.

Network Analysis Program

The GEOSTAR data processing facility is a typical example of a distributed processing network. The SDD developed a network analysis program for GEOSTAR that can be used by a network designer to predict the performance of a system composed of processing nodes connected by communications links (either point-to-point or shared by a number of nodes). Network performance, as measured by throughput and end-to-end delay, can be determined by a number of factors including the following:

- message itineraries and routing decisions,
- the CPU processing rate of the nodes and the capacities of individual links,
- protocol parameters, including maximum block size and max-out count, and
- link performance parameters, including propagation delay and bit error rates.

The program will be included as an integral part of the GEOSTAR data processing system operator interface, providing operators with immediate feedback on the effects of changes in traffic loads, or the consequences of reconfiguring the network in response to these loads or to failure of network components.

Core System Firmware

During 1986, the SDD designed, developed, and delivered firmware for the GEOSTAR core baseband processing unit. This work was performed in support of COMSAT Technical Services for its contract with GEOSTAR.

The core baseband processing unit provides monitoring and control functions for the GEOSTAR remote units, and supervises message processing and transmission. Inputs consist of decoded data from the receiver unit and user input data from an external keyboard. Outputs are in the form of display data sent to a user screen at the remote unit, and messages sent to the transmitter unit for transmission to GEOSTAR Central. The baseband processor performs all of the functions that enable the core subsystem to pass messages back and forth from the keyboard/display unit to GEOSTAR Central.

The firmware, which is composed of independent input and output processes, is implemented on an INTEL 8085 processor in the core baseband processor. The output process also provides monitoring and control.

In 1984 the National Aeronautics and Space Administration (NASA), a preeminent force in satellite communications technology, undertook a new research and development program: the Advanced Communications Technology Satellite (ACTS) Program. The program goals are the development of basic technologies to ensure the availability of adequate and affordable satellite communications beyond the year 1990, and the continued availability of U.S. satellite communications resources by effectively utilizing the limited resources of the geostationary orbital arc.

ACTS system development was continued in 1986. RCA ASTRO-Electronics is the prime contractor for the program and has responsibility for the spacecraft bus; the on-board multibeam communications package (MCP) is being furnished by TRW; and the on-board baseband processor is being supplied by Motorola. The ACTS spaceborne configuration includes a laser-based communications experiment, known as LASERCOM, under development at MIT's Lincoln Laboratory.

The NASA ground station (NGS) and the master control station (MCS) are the responsibility of COMSAT Laboratories.

THE TECHNOLOGY NEEDS OF TOMORROW

A fundamental goal of the ACTS program is to ensure continued U.S. leadership in vital areas of satellite communications technology. A second goal is to develop communications techniques and equipment to exploit the spectrum-rich, but largely unused, K_a-band. A third is to investigate and verify system techniques for more effective use of all frequency spectrum resources allocated to satellite communications. The ACTS program proposes to meet all these objectives.

The following component technologies comprise the baseline ACTS system:

Spot-Beam Technology. Concentrating radio frequency (RF) energy into spot beams significantly enhances the ability to reuse an allocated frequency band, because RF energy is placed only where it is needed, and not spread over an entire continent. Further, the higher levels of concentrated power associated with spot beams permit deployment of lower-cost terminal equipment. The use of fixed and hopping spot beams is an important extension of this technology.

On-Board Switching Technology. This approach permits the interconnection of up-link and down-link spot beams, thereby meeting subscribers' connectivity requirements and matching an established time-division multiple-access (TDMA) timing plan.

On-Board Baseband and Remodulation Processing. Because it isolates up-link errors from down-link errors, remodulation is more effective than the use of analog repeaters in isolating up-link errors, and allows mixed-rate up-links and down-links to accommodate networks of both large and small terminals. The resultant intermediate baseband signal can then be processed and bundled by destination in much the same way as with a terrestrial tandem switch.

Demand-Assigned TDMA Networking and Control. The MCS uses TDMA/demand-assigned algorithms for the coupling and control of ground segment and satellite resources. This approach provides cost-effective matching of the subscribers' transmission and connectivity requirements to the ACTS system performance envelope, as well as optimal allocation of satellite resources such as power and spectrum to the remaining users.

The ACTS experimental system verifies each of these critical technologies and tests their combined effectiveness in a communications satellite system, while providing an in-orbit test bed that permits significant testing by the experimenter community.

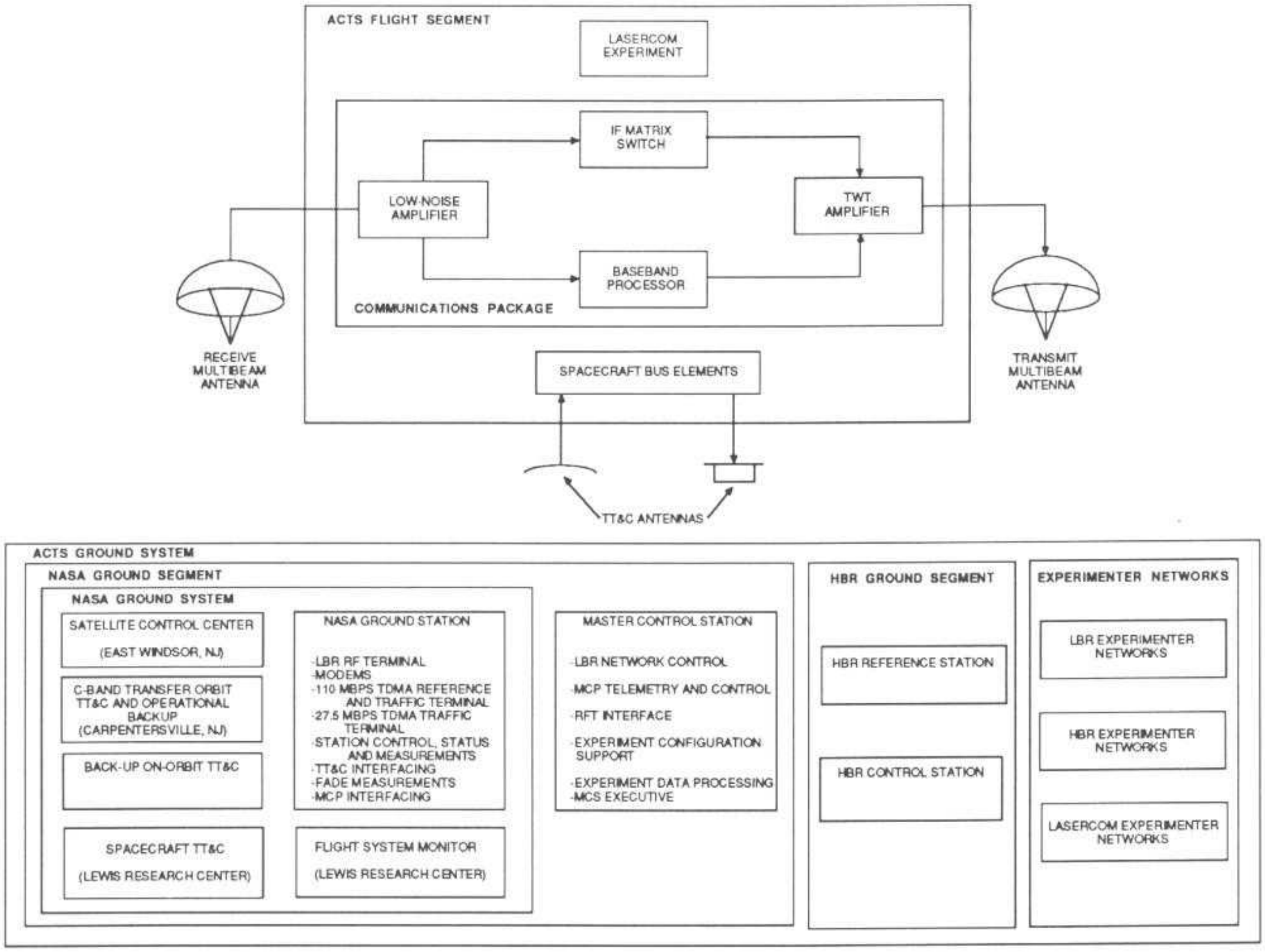


Figure 1. *The current ACTS system configuration features both fixed and scanning spot-beam coverage*

THE ACTS SYSTEM

The ACTS system configuration, consisting of a flight segment and a ground segment, is shown in Figure 1. The ACTS spacecraft features two types of spot-beam coverage, with each beam covering an area approximately 150 miles wide. Sixteen fixed spot-beam regions are available, each focused on a major U.S. city, with two scan sectors (East and West) for high-speed, selectable pointing. This spot-beam pointing is programmed from the MCS so that scanning transmit and receive beams dwell on a sequence of regions; the length of the dwell is related to the amount of traffic being passed. During 1986, a steerable antenna was added to the ACTS to provide Alaska/Hawaii coverage.

The up-link and down-link signals are classified as high burst rate (HBR) or low burst rate (LBR), and are carried in three very wideband channels. The HBR signals, planned for 220-Msymbol/s burst rates, are routed through an on-board intermediate frequency (IF) matrix switch which interconnects the up-link and down-link spot-beam antennas. The LBR up-link signals, with burst rates of either 27.5 or 110 Msymbol/s, are routed through the baseband processor. After initial demodulation and rate-changing of the TDMA bursts, the signals are time-slot interchanged and remodulated for the down-link at a rate of 110 Msymbol/s. Forward error correction (FEC) and reduced modulation rates are applied adaptively to the transmission to permit operation during rain fades, with the decoding and encoding performed in the baseband processor.

The ACTS Ground Segment

The ACTS ground segment consists of the following five distinct elements:

The NASA Ground Station consists of a single RF terminal (RFT), which is primarily responsible for translating LBR communications signals between the K_a-band interface with the ACTS spacecraft and the digital interface of the TDMA terminals, and is driven by two LBR TDMA terminals: the 27.5-Msymbol/s traffic terminal, with its terrestrial interface equipment for accommodating terrestrial interconnection; and a combined reference terminal and traffic terminal operating at 110 Msymbol/s. The reference terminal is responsible for maintaining TDMA system synchronization and integrity, as well as serving as the control-message interface for the MCS. The NGS also includes RCA-provided telemetry, tracking, and command (TT&C) equipment that interfaces with the RFT subsystem. The NGS will be located at NASA's Lewis Research Center (LeRC) in Cleveland, Ohio.

The Master Control Station controls the LBR network and the on-board multibeam communications package, serves as the focal point for mission and experiment operations, and provides displays and reports that are required for orderly system operation.

The Telemetry, Tracking, and Command Facilities are related largely to spacecraft support operations such as stationkeeping. The RCA facilities in Carpentersville and East Windsor, New Jersey, will perform this function. RCA will also provide the TT&C elements to be located at the NGS.

The HBR Ground Segment will function similar to the LBR NGS and MCS, but will be directed toward communications through the IF switch matrix in the MCP. NASA is responsible for developing the HBR, which will be located in the vicinity of the NGS at LeRC.

The LASERCOM Ground Segment is primarily the responsibility of MIT's Lincoln Laboratory. NASA's Goddard Space Flight Center has proposed an auxiliary experiment to be operated via LASERCOM and will probably have operational responsibility for that experiment. The interfaces of these experiments with the ACTS ground segment are still to be determined.

In addition to the ACTS ground segment, an experimenters' network equipped for either or both the LBR and HBR operation will be incorporated into the ACTS system by means of the MCS.

The ACTS Program At COMSAT Laboratories

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

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, to produce system and subsystem schedule networks and detailed cost projections for each element of the program. This information is continually monitored and updated, distributed within COMSAT, and reported on a regular basis to the customer.

The ACTS PMO is responsible for ensuring that this cost and schedule control system satisfies the criteria established for use on this NASA contract.

During 1986, COMSAT's progress on the ACTS program was affected by diminished Government funding and the resulting diminished allocation to COMSAT Laboratories. Because of these funding constraints, as well as Shuttle availability problems, NASA extended the program approximately 1 year, with an expected launch date of November 1990. In response to this program redefinition, the ACTS PMO reexamined the program, including the required resources and associated schedule, to allow COMSAT to successfully meet the program's objectives.

At present, the equivalent of more than 15 percent of COMSAT Laboratories personnel are dedicated to the ACTS program's technical and administrative activities. During the next 3 years this overall level will increase, so that an average of 25 percent of the total manpower resources of COMSAT Laboratories will be engaged in this cost-plus-fixed-fee contract. These ACTS-funded activities will filter into almost every technical and support organization within the Laboratories. Through the experience gained on the ACTS program, each of these organizations is developing the new skills and disciplines required for any major development program.

COMSAT's ACTS team spent much of 1986 extending the system-level requirements and specifications into functional subsystems, developing the functional descriptions of those subsystems and interface specifications, and bringing the functional planning to increasingly lower and more complex levels in the developmental hierarchy. The end of the year saw increasing amounts of design-level work, component procurement, software coding, initial testing and debugging, and firmware/hardware partitioning.

The major program milestone of the year was the Preliminary Design Review (PDR) presented by COMSAT in April 1986. The objectives of the PDR were as follows:

- to evaluate the progress, technical adequacy, and risk resolution of the selected design approaches;
- to verify design compatibility with performance and engineering specification requirements;
- to assess the technical risk associated with the selected manufacturing plan;
- to ensure that development flows and schedules were logical and feasible; and
- to verify that design maturity is adequate to proceed with detailed design, leading to unit fabrication and testing.

The program and design approach were accepted with only minor changes.

ACTS PROGRAM TECHNICAL DEVELOPMENT

The technical development associated with NGS and MCS implementation can be divided into five specific management areas: systems engineering, RF terminal development, TDMA terminal development, MCS development, and performance assurance.

Systems Engineering

COMSAT's systems engineering role in the ACTS program is twofold. Primarily, systems engineering is responsible 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 RCA as prime contractor. Both roles draw heavily on the Laboratories' communications analysis resources. These responsibilities have led to significant engineering and analytical contributions, with the Communications Techniques Division being the primary contributor.

Technical issues resulting from the complexity of the ACTS system, and the correspondingly complex NGS/MCS, have required a number of analyses and two major modeling efforts. Activities in 1986 culminated with the delivery of the supporting documentation required for the NGS/MCS Preliminary Design Review. Technical issues raised at that review will lead to additional studies.

Software modeling of the ACTS communications channels is a significant part of the systems engineering effort, and supporting RCA at the systems level has been vital to the COMSAT NGS effort to establish earth station parameters and evaluate channel impairments. Modeling initially has been oriented toward parametric allocations. As hardware is developed, parametric measurements will be made and entered into the model. Total channel and ground segment communications performance will then be evaluated. These predictions will form the baseline for measurement of systems performance in a major test of the ground and space segments prior to launch and in-orbit operation.

A second software simulation effort under development involves modeling the network control processes within the LBR system. Included are demand assignment, adaptive FEC, and acquisition and synchronization. This model emphasizes the interface between the MCS/NGS and the baseband processor (BBP) on the spacecraft.

Investigations into the reliability of the control process, its robustness, the efficiencies of the TDMA system, and beam-hopping limitations have been major areas of study during the past year. Figure 2 shows one result of these studies, depicting the time variation of the control message channel probability of bit error and the use of forward error correction (FEC) coding. Plans for 1987 include the completion of the basic modeling effort, at which time activity will focus on evaluating systems operation.

Early in 1986, COMSAT provided baseline descriptions of the ACTS system for use by NASA in establishing information packages for experimenter terminal procurement and experiment scenarios. COMSAT Laboratories' expertise in advanced communications techniques makes it uniquely qualified to assist NASA in these tasks.

Systems engineering has also worked this year to enhance the definition and documentation of the

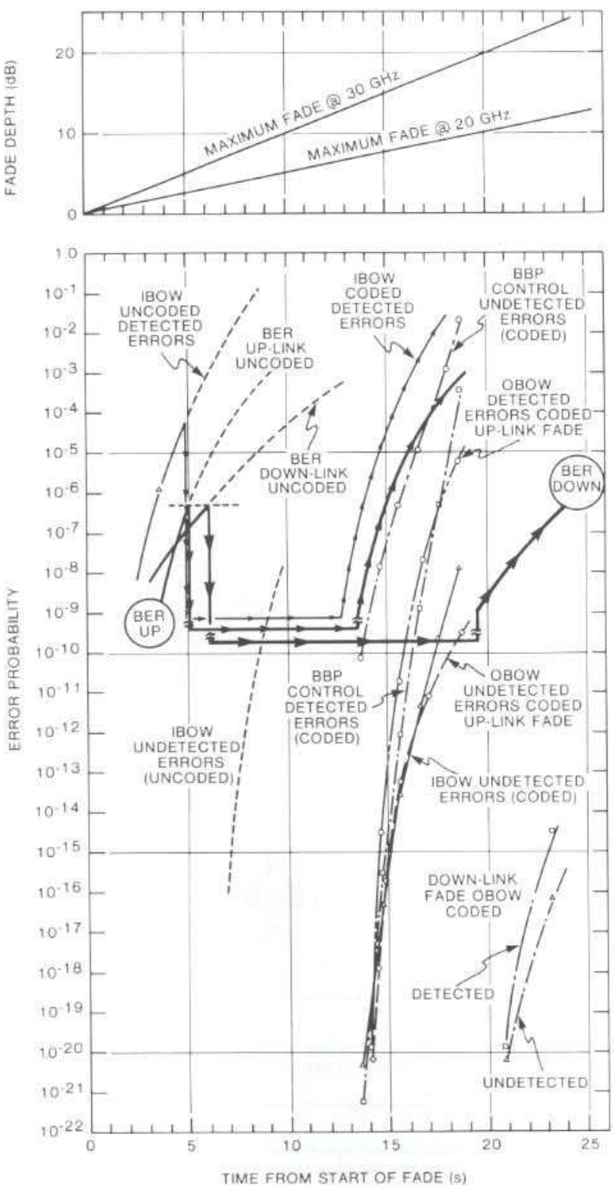


Figure 2. *Control message channel performance in maximum rain fade*

numerous interfaces between various equipment elements of the NGS/MCS. Such documentation is essential in a multicontractor environment.

Systems engineering continues to be concerned with the post-delivery operations and maintenance of the NGS and MCS. Figure 3 is a preliminary drawing of one possible configuration of the NGS/MCS facility. The MCS and TDMA equipment is on the ground floor of the building at LeRC, while the RFT equipment will be located in an elevated mezzanine, which is directly below the roof-mounted antenna. The consoles on the main floor serve as the operational focal point for data collection.

RF Terminal Development

RFT development is the responsibility of the Microwave Technology Division at COMSAT Laboratories, which brings its long history of microwave design expertise (including significant K_a-band experience) to this challenging program. Vital contributions also are made by the Applied Technologies Division.

Figure 4 is a block diagram of the RF and IF portions of the RFT. The antenna subsystem, pointed and controlled by the antenna control unit and the RFT supervisory network (RFTSN), tracks the spacecraft, receiving and transmitting 20- and 30-GHz signals, respectively. The transmit system accepts signals from the modulators at IF, up-converts them to the transmit frequencies and amplifies them to the transmit power level. The receive subsystem accepts 20-GHz down-linked LBR, telemetry, and beacon signals from the ACTS spacecraft, amplifying and down-converting them to 3-GHz and 70-MHz IF and then forwarding them to the demodulators. The loopback subsystem samples the to-be-transmitted signals at several points and couples them back (in appropriate RF or IF form) into the receive subsystem for diagnostic and maintenance reasons, if required. The modem subsystem contains the modulators and demodulators that translate between digital baseband signals and modulated IF signals.

Details of the RFTSN are shown in Figure 5. The RFT supervisor provides the interface to the system operator. Through keyboard and display screen terminals, the operator commands are managed and directed to the subsystems: rain fade measurement, RFT control and status, experiment measurement, and antenna control. The operator input terminals will be in various locations, including (for TT&C purposes) the RCA Satellite Control Center in New Jersey.

Appropriately, the RFT is capable of performing experimental measurements of various signal parameters under computer control, for use by the system experimenters. The instrumentation and design will employ existing technology developed by COMSAT Laboratories during its successful history of measuring spacecraft performance. The

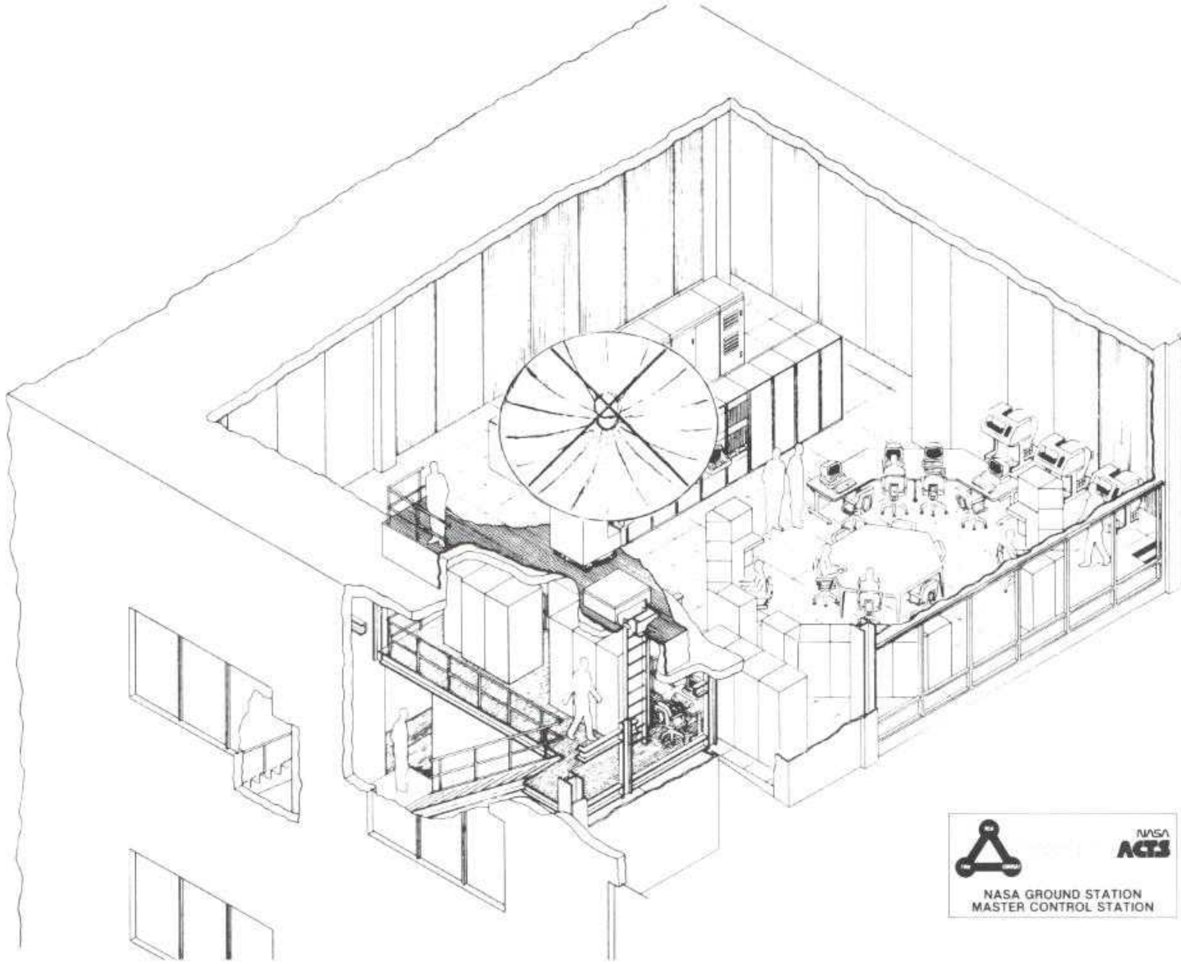


Figure 3. *A sample NGS/MCS facility configuration*

technology is currently being extended to accommodate the unusually high bit rates and the unconventional serial minimum-shift keying (SMSK) modulation format.

For the LBR, up-link transmission power in excess of 50 W at 30 GHz is required, and COMSAT has performed the modeling necessary to develop the specification for such a 30-GHz transmitter tube. A contract for three power amplifiers with that capability was negotiated and placed in late 1986 with Hughes Aircraft. This contract will be completed in April 1989 with the delivery of the traveling wave tube amplifiers (TWTAs).

The command transmitter (to control the spacecraft) and the earth station antenna will be procured under contracts to be placed in 1987 and 1988. In the case of the command transmitter, a different specification must be developed for a narrower band but a much higher power level.

The ACTS system's choice of SMSK modulation for the spacecraft-regenerated LBR links requires the availability of matching earth station modulators and demodulators. SMSK modulation has not been extensively used in very-high-speed transmission, and the technology has been developed for NASA under proof-of-concept contracts. Consequently, COMSAT has had to develop modem test equipment specifications and procedures to ensure adequate modem performance in orbiting spacecraft. A subcontract with Motorola for the LBR modems and associated special test equipment is now in place.

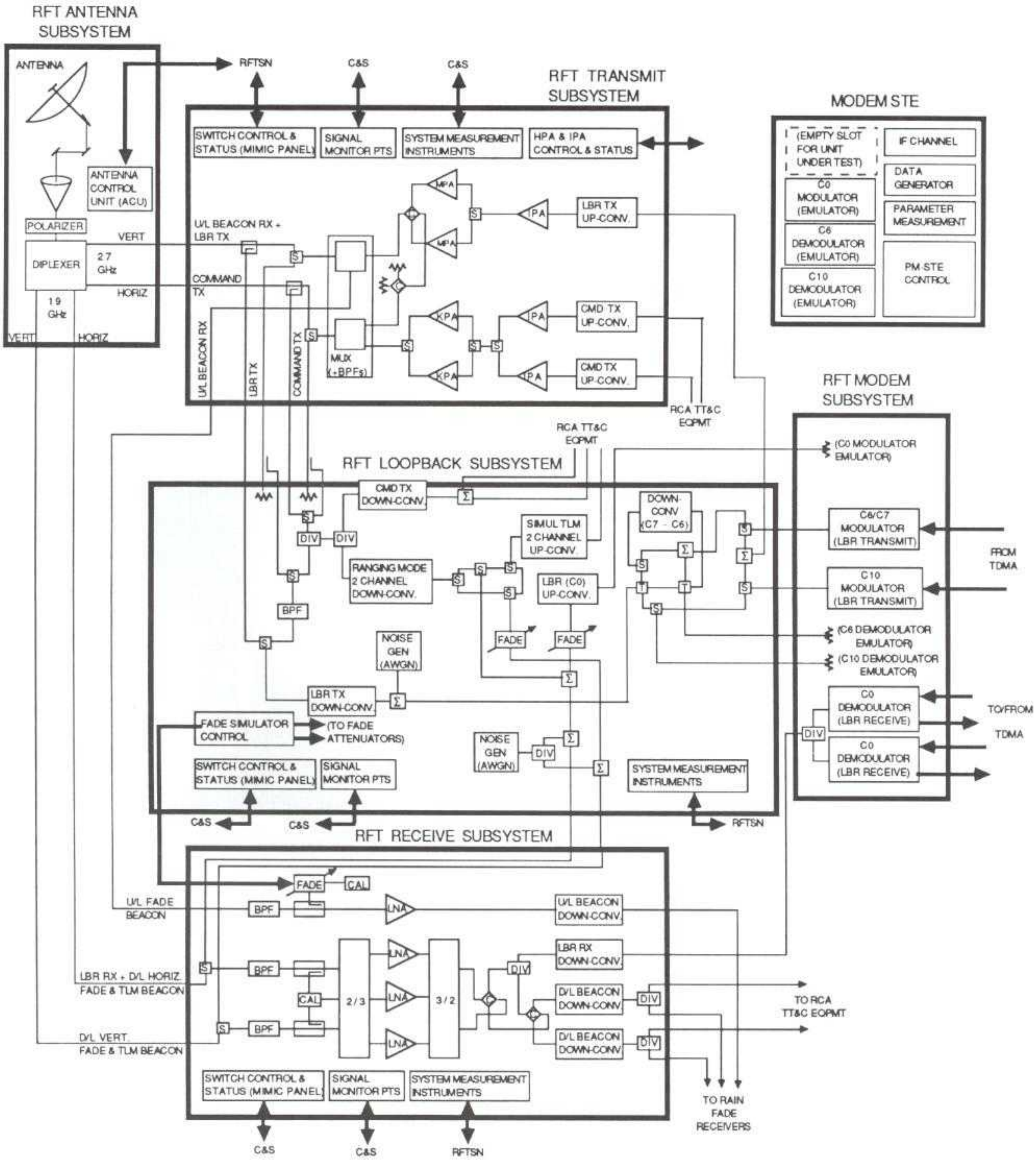


Figure 4. *RFT block diagram (RF and IF)*

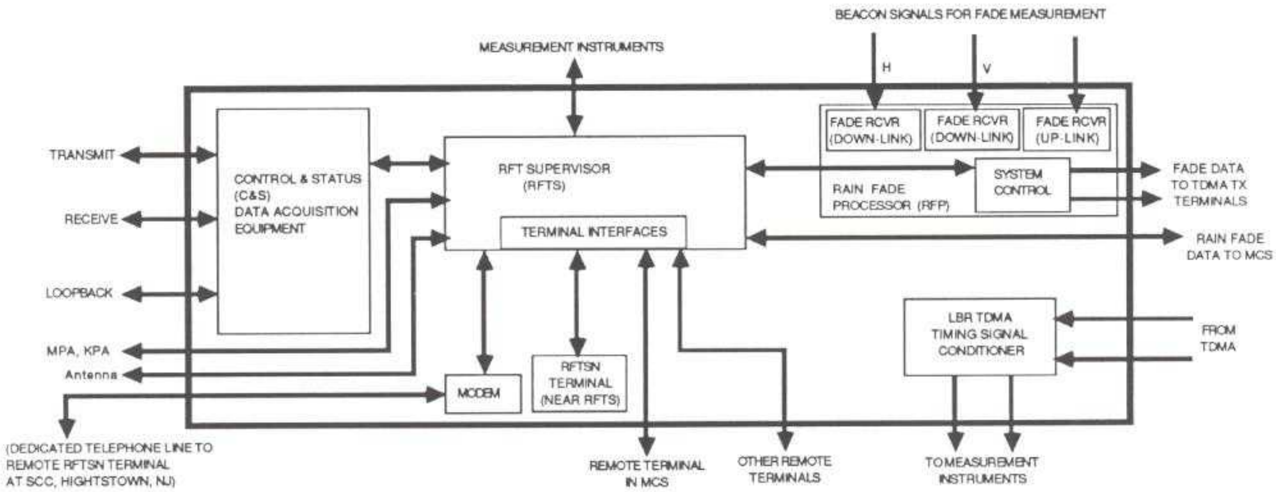


Figure 5. *RFT supervisory networks*

The frequency and power of the ACTS up-link transmitted signal will extend the previous limits of such satellite systems. The ability to transmit high-power and high-frequency signals through a single antenna that is also used for signal reception places stringent demands on the design and implementation of the frequency and polarization-separating components. In developing these, COMSAT Laboratories is drawing on its considerable experience in the design and fabrication of high-performance microwave filters, multiplexers, and antenna polarization diplexers. An example of the technological advances being realized in this program is shown in Figure 6, where a Chebychev filter prototype developed for the ACTS 30-GHz up-link frequency is shown next to a similar COMSAT filter presently used for C-band up-link frequencies.

TDMA Terminal Development

Two TDMA terminals are under development by COMSAT Laboratories as prt of the ACTS NGS: the 110-Msymbol/s TDMA reference and traffic terminal, and the 27.5-Msymbol/s TDMA traffic terminal. The Network Technology Division has responsibility for this development, which ranges from architectural concept, through design and production, and into acceptance testing. The division will also provide support durig system-level integration and on- and off-site testing.

At each level of the developmental hierarchy

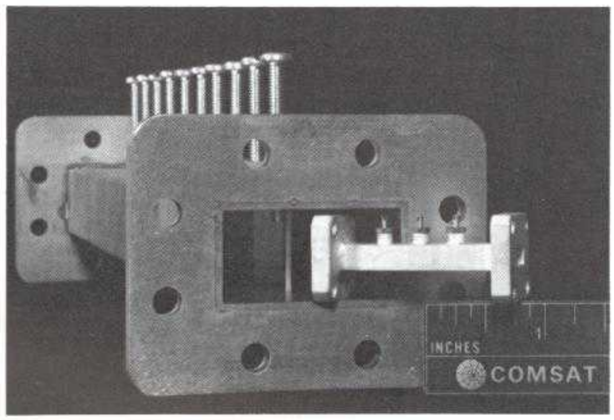


Figure 6. *Comparison of C-Band and K_a-Band filters*

functional descriptions were written to ensure that the basic requirements of the program were satisfied and that the performance envelope was well defined. Interface specifications were outlined to ensure that lower-level elements can interact in a definitive, nonambiguous manner. Partitioning of the function into hardware and software must be addressed, and plans for testing must also be defined.

Included in the ACTS ground segment Preliminary Design Review was the architecture of the generic TDMA terminal. This microprocessor-controlled architecture consists of the following nine principal functions (depicted with their interfaces in Figure 7):

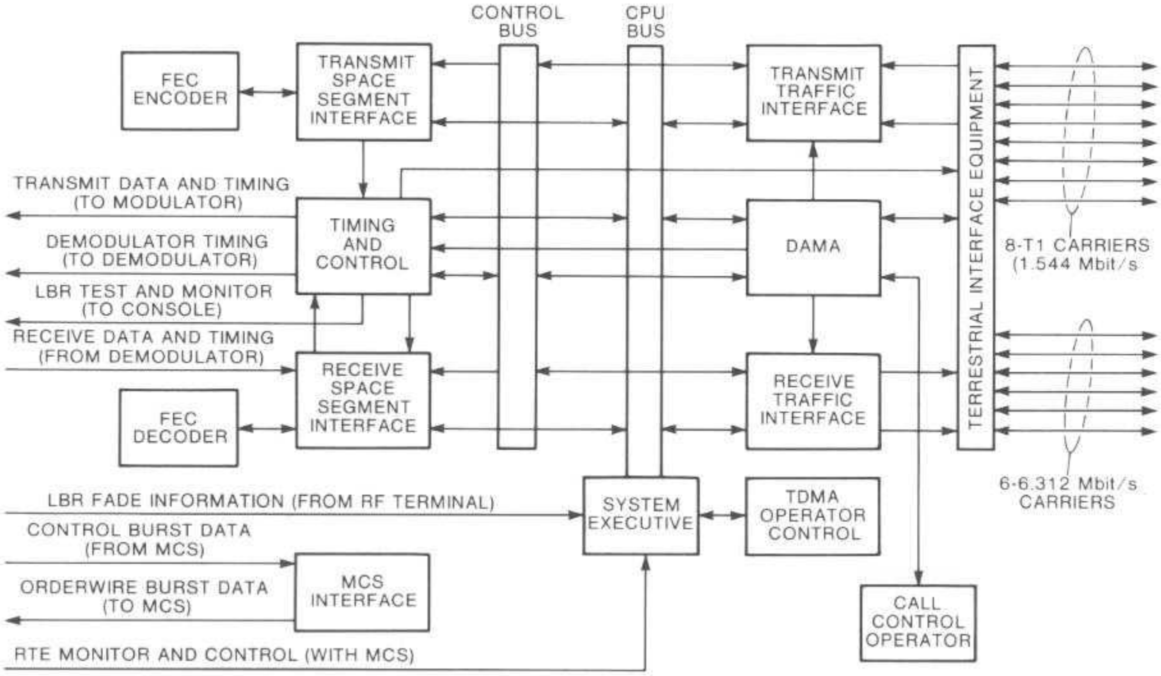


Figure 7. *Functional block diagram of a generic LBR/TDMA terminal*

- Terrestrial Interface Equipment
- Transmit Traffic Interface
- Transmit Space Segment Interface
- Receive Space Segment Interface
- Receive Traffic Interface
- Demand-Assigned Multiple Access
- System Executive
- Timing and Control
- MCS Interface

Design-level work partitions these functional blocks into three physical units: the transmit burst controller, the receive burst controller, and the terrestrial interface equipment.

One result of the replanning that concluded the year's effort was the development of a preliminary manufacturing plan, which anticipated the hardware necessary for the final configuration. The plan suggests that some 50 types of circuit boards must be developed, and that over 300 boards will be fabricated, assembled, and tested before being incorporated into the final TDMA rack assemblies. Approximately six high-speed microprocessors will be working simultaneously to maintain stable system performance during operations at a 110-Msymbol/s rate.

The FEC decoders will also be included in the TDMA racks. Since the FEC process provides a more rugged signal structure than the normal (uncoded) signal, FEC is used for critical control messages and for traffic during rain fade periods when the K_a-band is susceptible. This decoding requires equipment of significantly greater complexity and special-purpose implementation. The Communications Techniques Division at COMSAT Laboratories has extensive experience in decoding algorithms and was awarded an internal contract to deliver the engineering models and production units for the TDMA terminals. Figure 8 is a block diagram of the ($R = 1/2$, $k = 5$) decoder, which is based on the Viterbi soft-decision (2-bit) algorithm.

MCS Development

Figure 9 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 spacecraft payload, including the BBP. It also supports ACTS experiments by controlling system configuration parameters and managing recorded data.

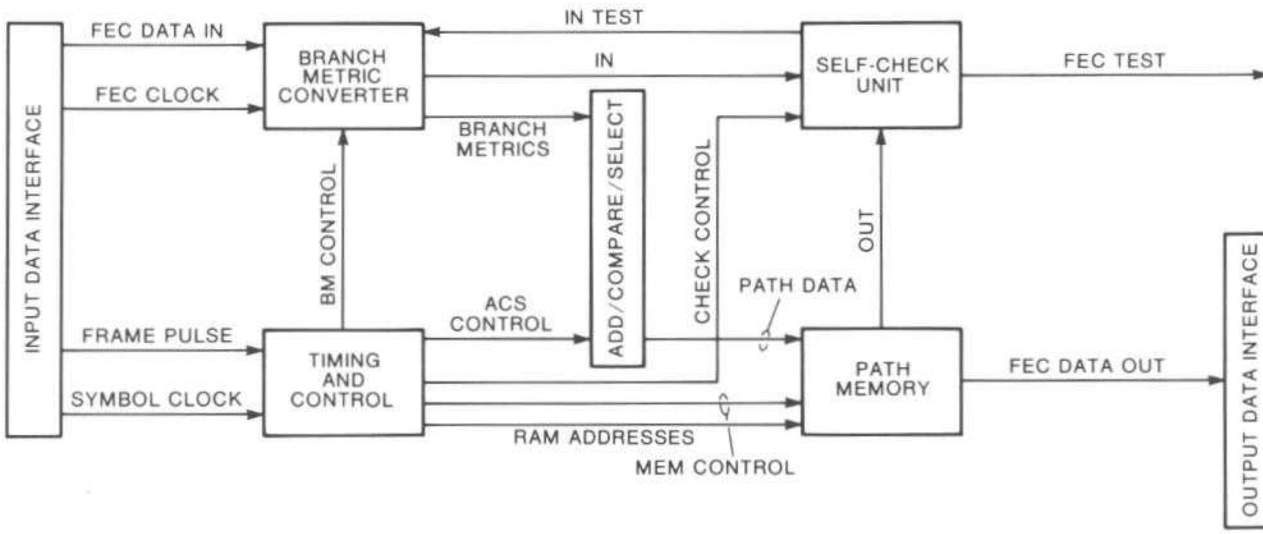


Figure 8. *FEC decoder functional block diagram*

The MCS is implemented entirely in software, hosted on a VAX 8600 super-minicomputer (Figure 10), and consists of the following eight distinct 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 on board the ACTS spacecraft (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 for configuring 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 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.

The DAMA functions performed by the MCS employ several algorithms, depending on the circuit

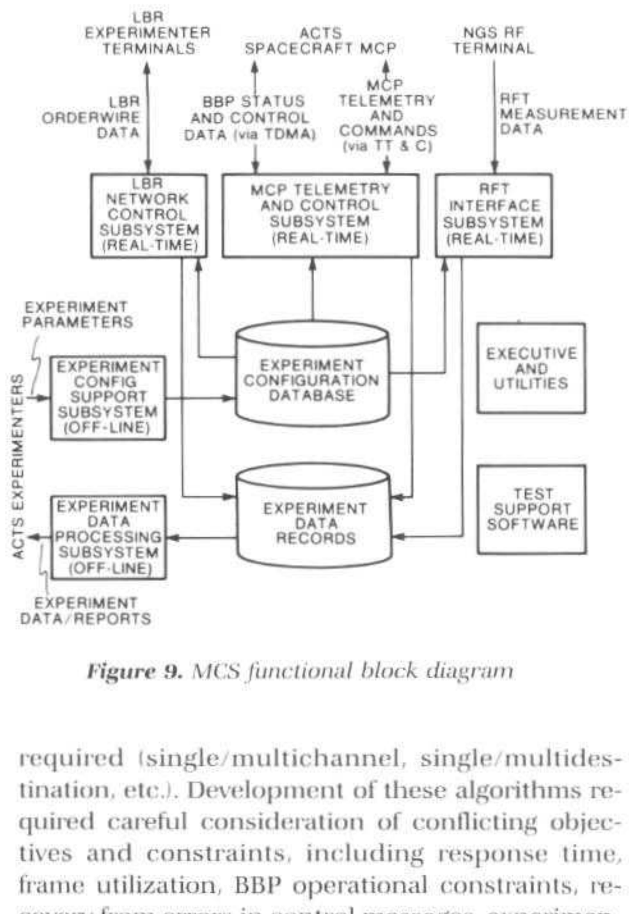


Figure 9. *MCS functional block diagram*

required (single/multichannel, single/multidestination, etc.). 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 3-5 seconds, and the complexities of

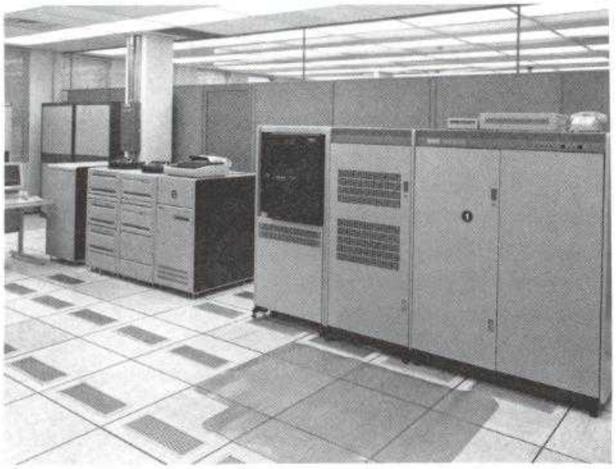


Figure 10. *The MCS VAX 8600 development installation*

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 fully demonstrate the flexibility and efficiency available in a TDMA network with an on-board baseband switch.

Associated with the DAMA functions is the BBP routing algorithm, which determines how a desired input-to-output connection is to be achieved. For any set of desired connections, there are thousands of possible routing path combinations. In order to maintain reliable and responsive network control, it is essential that the MCS find a routing path through the BBP quickly (on the order of milliseconds), and that the MCS program the BBP using the minimum number of control codes required for implementation. The routing algorithm developed at COMSAT employs a set of simple list-processing functions and a multi-list data structure that preallocates memory areas in the BBP for each type of circuit and beam-to-beam connectivity. The resulting algorithm will find a routing path through the BBP for any type of circuit, while minimizing the required search time and the number of BBP control codes transmitted.

By the end of 1986, approximately 30,000 lines of code, of an anticipated 130,000 lines for the entire system, had been produced. Nineteen of 68 programs were completed, and four programs were successfully integrated into the first subsystem "build." As currently defined, the MCS will be constructed by integrating 25 builds, each composed of two or more programs. This incremental development/integration allows early testing and demonstration of key features of the system and permits maximum use of parallel development activities, which in turn shorten the total project schedule.

The work on the MCS project is being performed by the Laboratories' System Development Division (SDD). SDD has brought to bear its well-established methodology, including software design, coding, testing, and documentation standards; an effective configuration management/software performance assurance system; and an ever-expanding set of sophisticated software development tools and reusable utility software.

Performance Assurance

For the past year, the performance assurance team has focused on the installation, implementation, and operational validation of the performance assurance program for ACTS. Activities included the publication of support documentation, operating procedures, and the ACTS program operating instructions. The fabrication processes and the workmanship manual also were issued and implemented.

The team operated through three key program control groups: the Configuration Control Board, the Software Review Board and the Material Review Board. Each group developed standard operating procedures, agenda, working criteria, and interrelationships. Formal engineering progress reviews were established which addressed both in-house manufacturing processes and out-of-house parts procurements. Hazard and safety analysis procedures were implemented to support parts procurement, and parts control and material management systems were improved.

Procedures for change management for both in-house and out-of-house activities were implemented by configuration control management. Drawing and hardware configuration control merged into one control system.

Software performance assurance personnel designed and implemented the configuration control data base for all related MCS software, supported by the utilities code management system (CMS) and the module management system (MMS). Currently, the CMS library contains 1,800 (of a projected 8,000) ASCII source and test files related to the LBR, test support (TST), and the MCP subsystems. The MMS data base stores the executables and binary files associated with the above subsystems.

In the manufacturing and fabrication area, the ACTS performance assurance team established a production control function to control and monitor the preparation of components. Detailed procedures were developed to manage ACTS RFT deliverables from design, procurement of parts and components, inventory control, kit assembly, and fabrication, through final test and check out.

Guideline documents for program safety, maintainability and electromagnetic compatibility/electromagnetic interference (EMC/EMI) also were developed and provided as part of the PDR. Inspection procedures became operational, and an updated program-authorized parts list and associated parts specifications were implemented.

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PATENTS

The following patents were issued to employees (and former employees) of COMSAT Laboratories in 1986.

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Inukai, T., "Onboard Clock Correction by Means of Drift Prediction," Patent No. 4,602,375, issued July 22, 1986.

Kreutel, R.W., Jr., "Scheme for Aberration Correction in Scanning or Multiple Beam Confocal Antenna System," Patent No. 4,595,929, issued February 16, 1986.

Lee, L.-N., and Redman, M., "Video Scrambling Technique for Multiplexed Analog Component Formats," Patent No. 4,620,224, issued October 28, 1986.

Shenoy, A., and Johnson, P., "Serial Implementation of Viterbi Decoders," Patent No. 4,583,078, issued April 15, 1986.

Stegens, R., and Hawisher, G., "Coplanar Waveguide Quadrature Hybrid," Patent No. 4,591,812, issued May 27, 1986.

Vaidyanathan, H., "Hydrogen Electrode for a Fuel Cell," Patent No. 4,585,711, issued April, 1986.

*Non-COMSAT Author

HONORS AND AWARDS

In 1986, COMSAT Laboratories personnel made significant contributions to the state of the art of satellite communications technology, and were recognized for their accomplishments both within the Corporation and throughout the industry.

This year the COMSAT Research Award, which recognizes individuals who have made outstanding technical contributions to the work of the Laboratories, was presented to **Dr. Albert E. Williams** and **Dr. René R. Bonetti** of the Microwave Technology Division (MTD). Dr. Williams and Dr. Bonetti were honored for investigating and developing the use of higher-order modes in the design of high-Q microwave cavity filters, thereby controlling spurious modes and realizing high-quality multiple filters at millimeter-wave frequencies.

In addition, Dr. Williams, Manager of the Microwave Networks Department of the MTD, has been elected to the position of Fellow by the Institute of Electrical and Electronics Engineers (IEEE). The Institute is the largest professional engineering society in the world and a Fellow is a singular professional distinction conferred by the Board of Directors upon persons of extraordinary qualifications and experience. Dr. Williams was recognized for his contributions to the theory and development of multimode microwave filters, which are now the standard used in the input and output multiplexers of satellite transponders. This lightweight, on-board hardware has made it possible to greatly increase the number of transponders per satellite, reducing the cost per transponder and significantly improving international and domestic satellite communications.

Dr. Bonetti, **Dr. Christoph E. Mahle,** Executive Director of the Microelectronics Division, and **Dr. Ramesh K. Gupta,** Associate Manager of the Microwave Systems Department, were this year named Senior Members of the IEEE. Dr. Gupta was also elected to the position of Secretary for the Washington, D.C./Northern Virginia Chapter of the Microwave Theory and Techniques Society.


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