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SPACE
TECHNOLOGY

Celebrating Astro-Electronics' 25th Anniversary

RCA Engineer

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• To disseminate to RCA engineers technical information of professional value • To publish in an appropriate manner important technical developments at RCA, and the role of the engineer • To serve as a medium of interchange of technical information between various groups at RCA • To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions • To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field • To provide a convenient means by which the RCA engineer may review his professional work before associates and engineering management • To announce outstanding and unusual achievements of RCA engineers in a manner most likely to enhance their prestige and professional status.

RCA Astro-Electronics leads twenty-five years of excellence

In 1957, a man-made star entered our firmament. Its name was Sputnik and it ushered in a new era of technology.

U.S. industry moved rapidly to the new challenge; none moved faster than RCA. Just five months after Sputnik, Dr. Elmer Engstrom, then Corporate Vice-President of the David Sarnoff Research Center, established RCA Astro-Electronics as a separate division to pioneer the development and production of satellites, space vehicles, and associated ground equipment.

Twenty-five years later, RCA Astro-Electronics is still pursuing that charter, more robust than ever. Since our first TIROS launch on April 1, 1960, Astro's engineers have successfully competed in all major areas of spacecraft application: communication, meteorology, navigation, and science. RCA Astro engineers—supported by Government Systems Division, the David Sarnoff Research Center, and other RCA divisions—have accomplished an impressive array of technological innovations and advances.

From a heritage as the sole supplier of military and civilian low-earth-orbit meteorological satellites, we have, in the still-young decade of the eighties, achieved the position as the preeminent domestic communications-satellite contractor.

During the past quarter century, Astro has built and successfully launched 78 satellites and presently has 36 under contract in various stages of design or fabrication.

This issue of the *RCA Engineer* is a tribute to twenty-five years of engineering excellence, and a statement of firm resolve to set the stage for an equally successful second quarter century.

Charles A. Schmidt

Charles A. Schmidt
Division Vice-President
and General Manager
RCA Astro-Electronics

RCA Engineer

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overviews

satellite communications

direct-broadcast satellite (DBS)

satellite launching

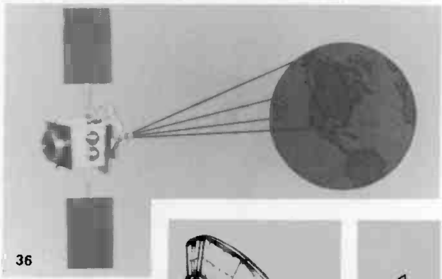
new missions

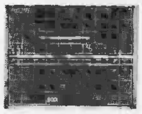
departments

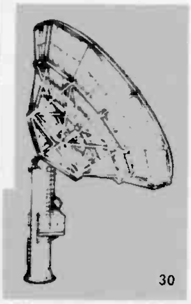
in this issue ...
space technology

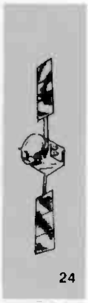
- **First quarter century:** *"Astro-Electronics has acquired a record of satellite orbital performance that is unmatched by anyone, anywhere."*
- **Roundtable:** *"For this session, to discuss various space technologies, we have gathered together the managers who are responsible for bringing the technology to bear on our products."*

- **Weaver:** *"This paper presents basic operational principles: what a communications satellite is and how it works."*
- **Cashman:** *"Distributed processing and man-machine interface enhancements are two trends that will influence satellite-control-center design over the coming decade."*
- **Balcewicz:** *"The trend since Satcom I has been to design a limited amount of reconfigurability into the spacecraft's antenna system."*
- **Gounder/Talley/Ino:** *"These designs offer precise dimensional tolerances and environmental stabilities that translate into superior rf performance."*
- **Acampora/Bunting/Petri:** *"Fine-structure processing of video signals does indeed provide signals with less noise."*

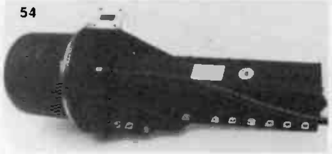




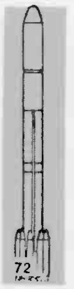


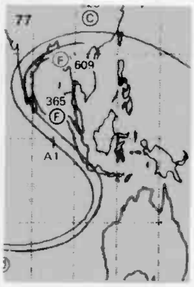


- **Buntschuh:** *". . . the main point is that with all design changes included, the DBS spacecraft is, in fact, a modified Satcom spacecraft—"*
- **Klensch/Knight/Staras:** *"First, the good news. In the past several years, significant progress has been made toward the development of an appropriate technology."*

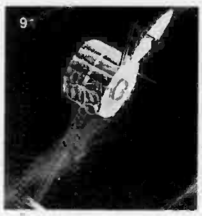


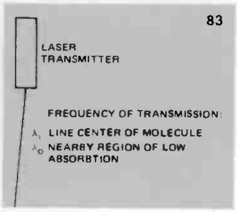
- **Simpson:** *"MTP's planners, experienced in hundreds of other missile and satellite launches, found many unique aspects of the Space Shuttle operation to consider."*
- **Muller:** *"The primary launch vehicles available for communications satellites are the Delta, the Ariane, and the Space Transportation System (STS), more popularly known as the Shuttle."*
- **Schwarze:** *"Actually, a myriad of activities, occurring simultaneously and integrated into a master schedule, result in a successful launch and on-station operational satellite."*





- **Rosenberg/Hogan:** *"Active laser sensors have the potential for measuring both these parameters with the accuracy and vertical resolution required for global weather forecasting."*
- **Maehl:** *"[Asteroids] may provide unique samples of the primordial material from which the solar system evolved, uncomplicated by the geological evolution that has taken place on the inner planets."*





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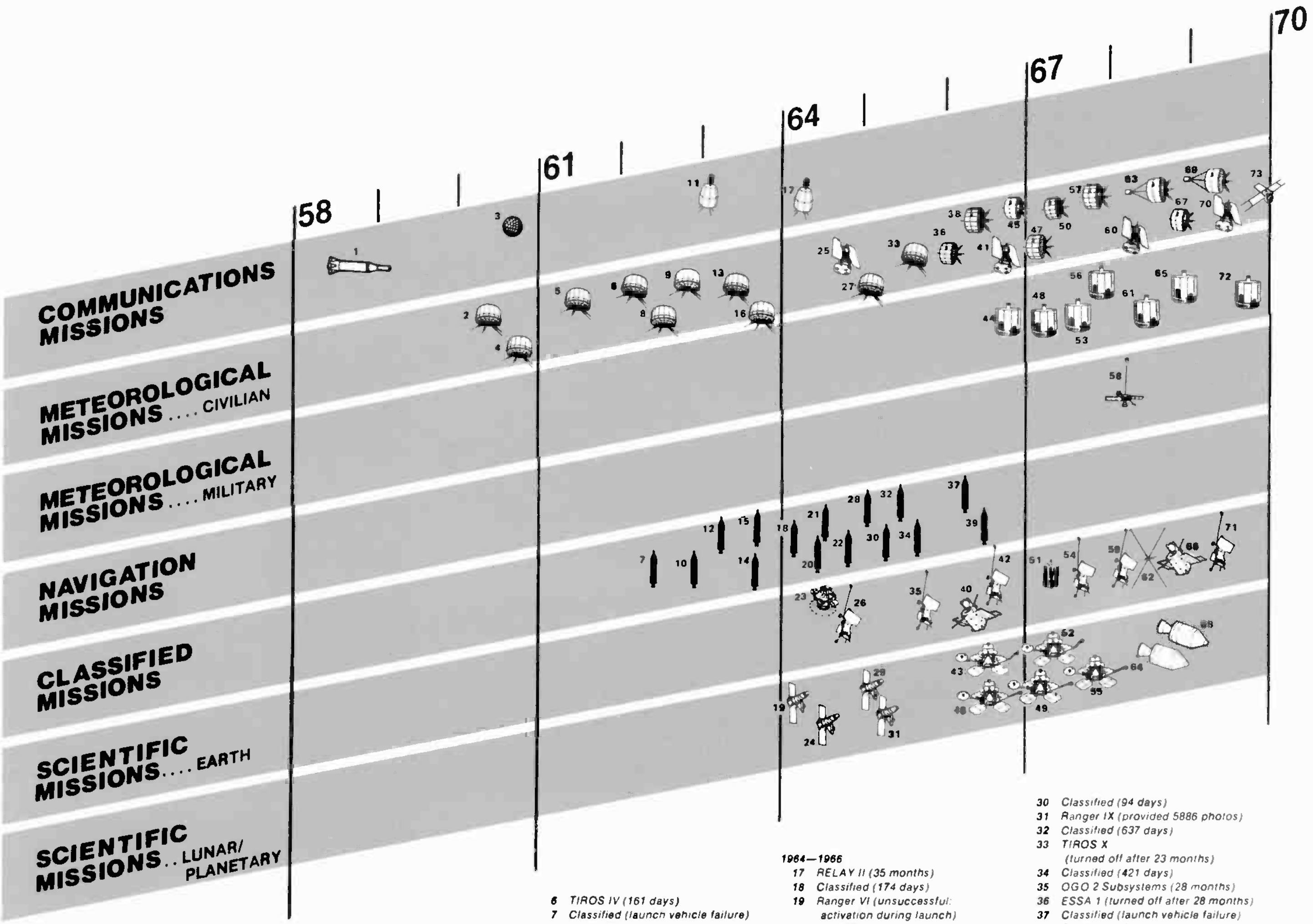
in future issues...

technology transfer/energy,
anniversary issue

RCA Astro-Electronics Staff

Astro-Electronics' first quarter century

RCA Astro-Electronics has completed its first quarter century of space activities with a stellar record of outstanding space achievements.



1958—1960
- **1** *SCORE (13 days)*
- **2** *TIROS I (89 days)*
- **3** *Echo 1 Subsystems (7 years, 9 months)*
- **4** *TIROS II (376 days)*

1961—1963
- **5** *TIROS III (230 days)*
- **6** *TIROS IV (161 days)*
- **7** *Classified (launch vehicle failure)*
- **8** *TIROS V (321 days)*
- **9** *TIROS VI (389 days)*
- **10** *Classified (217 days)*
- **11** *RELAY I (26 months)*
- **12** *Classified (87 days)*
- **13** *TIROS VII (turned off after 59 months)*
- **14** *Classified (launch vehicle failure)*
- **15** *Classified (launch vehicle failure)*
- **16** *TIROS VIII (turned off after 42 months)*

1964—1966
- **17** *RELAY II (35 months)*
- **18** *Classified (174 days)*
- **19** *Ranger VI (unsuccessful: activation during launch)*
- **20** *Classified (433 days)*
- **21** *Classified (607 days)*
- **22** *Classified (469 days)*
- **23** *SERT (1 hours)*
- **24** *Ranger VII (provided 4316 photos)*
- **25** *Nimbus 1 Subsystems (28 days)*
- **26** *OGO 1 Subsystems*
- **27** *TIROS IX (turned off after 40 months)*
- **28** *Classified (launch vehicle failure)*
- **29** *Ranger VIII (provided 7160 photos)*
- **30** *Classified (94 days)*
- **31** *Ranger IX (provided 5886 photos)*
- **32** *Classified (637 days)*
- **33** *TIROS X (turned off after 23 months)*
- **34** *Classified (421 days)*
- **35** *OGO 2 Subsystems (28 months)*
- **36** *ESSA 1 (turned off after 28 months)*
- **37** *Classified (launch vehicle failure)*
- **38** *ESSA 2 APT (turned off after 55 months)*
- **39** *Classified (553 days)*
- **40** *OAO 1 Subsystems (power supply failure)*
- **41** *Nimbus II Subsystems (turned off after 32 months)*
- **42** *OGO 3 Subsystems*
- **43** *Lunar Orbiter I Subsystems (10-month mission)*
- **44** *DMSP (788 days)*

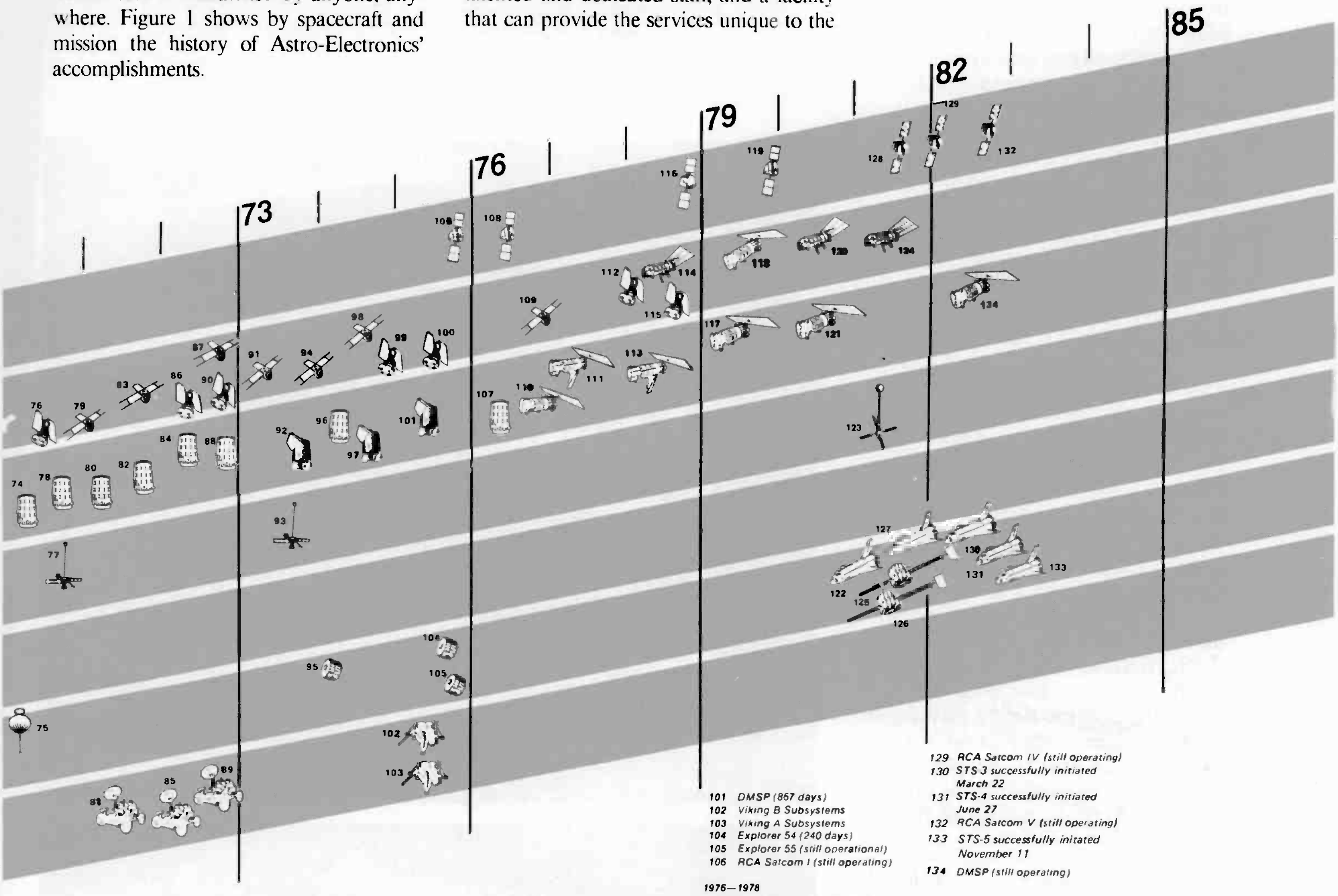
Fig. 1. *Now in our third decade of space.*

As the years have passed, Astro-Electronics has compiled space-performance records that have established its preeminence in space technology. In the past 25 years, 78 spacecraft were launched successfully, and all but one (Satcom C suffered an apogee-motor failure) met and exceeded the mission requirements. Astro-Electronics has acquired a record of satellite orbital performance that is unmatched by anyone, anywhere. Figure 1 shows by spacecraft and mission the history of Astro-Electronics' accomplishments.

Additionally, Astro-Electronics has provided space systems for many space programs. Again, the orbital performance of this equipment has been outstanding. A total of 46 subsystems were launched, of which 41 were successfully orbited and met or exceeded the mission objectives. Astro's stellar space performance, as summarized in Table I, is the product of a talented and dedicated staff, and a facility that can provide the services unique to the requirements of building and testing spacecraft systems. Here's how RCA Astro began.

The beginning

A Special Systems Development (SSD) Department was formed in 1957 of per-



45 ESSA 3 AVCS (turned off after 24 months)
46 Lunar Orbiter II Subsystems (11 months)

1967—1969
47 ESSA 4 APT (turned off after 15 months)
48 DMSP (100 days)
49 Lunar Orbiter III Subsystems (9 months)
50 ESSA 5 AVCS (turned off after 34 months)
51 ATS 2 Subsystems (Elliptical orbit prevented test)
52 Lunar Orbiter IV Subsystems (80 days)
53 DMSP (1012 days)
54 OGO 4 Subsystems (5 years)
55 Lunar Orbiter V Subsystems (6 months)
56 DMSP (167 days)
57 ESSA 6 APT (turned off after 25 months)
58 NAVSAT 18 (86 months)
59 OGO 5 Subsystems
60 Nimbus B Subsystems (launch vehicle failure)
61 DMSP (617 days)
62 Explorer 38 Subsystems
63 ESSA 7 AVCS (turned off after 19 months)
64 Apollo 7 Subsystems
65 DMSP (711 days)
66 OAO 2 Subsystems
67 ESSA 8 APT (2644 days)
68 Apollo 8 Subsystems
69 ESSA 9 AVCS (turned off after 4 years, 9 months)
70 Nimbus III Subsystems (turned off after 32 months)
71 OGO 6 Subsystems (18 days)
72 DMSP (720 days)

1970—1972
73 ITOS 1 (turned off after 16 months)
74 DMSP (78 days)
75 Stratoscope II, Flight 7 Subsystems
76 Nimbus IV Subsystems (Deactivated)
77 NAVSAT 19 (still operating)
78 DMSP (81 days)
79 NOAA 1 (turned off after 8 months)
80 DMSP (770 days)
81 Apollo 15 Subsystems
82 DMSP (350 days)
83 ITOS B (launch vehicle failure)
84 DMSP (700 days)
85 Apollo 16 Subsystems
86 Landsat 1 Subsystems (turned off after 5½ years)
87 NOAA 2 (turned off after 27 months)
88 DMSP (732 days)
89 Apollo 17 Subsystems
90 Numbus V Subsystems (still operating)

1973—1975
91 ITOS E (launcn vehicle failure)
92 DMSP (1210 days)
93 NAVSAT 20 (still operating)
94 NOAA 3 (1038 days)
95 Explorer 51 (4 days short of 5 years)
96 DMSP (900 days)
97 DMSP (100 days)
98 NOAA 4 (turned off after 4 years)
99 Landsat 2 Subsystems
100 Nimbus VI Subsystems (still operating)
101 DMSP (867 days)
102 Viking B Subsystems
103 Viking A Subsystems
104 Explorer 54 (240 days)
105 Explorer 55 (still operational)
106 RCA Satcom I (still operating)

1976—1978
107 DMSP (launch vehicle failure)
108 RCA Satcom II (still operating)
109 NOAA 5
110 DMSP (1100 days)
111 DMSP (still operating)
112 Landsat 3 Subsystems (still operating)
113 DMSP (581 days)
114 TIROS-N (868 days)
115 Nimbus VII Subsystems (still operating)
116 Anik B (still operating)

1979—1981
117 DMSP (still operating)
118 NOAA-6 (still operating)
119 RCA Satcom C (transfer orbit failure)
120 NOAA-B (launch vehicle failure)
121 DMSP (launch vehicle failure)
122 First Shuttle Launch STS-1 (successful)
123 NOVA-1 (still operating)
124 NOAA-7 (still operating)
125 DE-1 (still operating)
126 DE-2 (still operating)
127 STS-2 (successful)
128 RCA Satcom III (still operating)
129 RCA Satcom IV (still operating)
130 STS 3 successfully initiated March 22
131 STS-4 successfully initiated June 27
132 RCA Satcom V (still operating)
133 STS-5 successfully initated November 11
134 DMSP (still operating)

Astro launch

As we were going to press, RCA Astro-Electronics announced yet another satellite launch—the NOAA-E.

sonnel from Camden's Advanced Technology Laboratory and Princeton's RCA Laboratories. The SSD group, consisting of approximately 60 people, became involved in two studies. The first study, ACSIMATIC, was a program for handling and processing data and communications for the U.S. Army Intelligence Department. The second study, called JANUS, was for a space reconnaissance system for the Army Ballistic Missile Division at Huntsville, Alabama. In early 1958, the Department of Defense declared that space reconnaissance was not in the Army's charter. The JANUS project was reprogrammed as a meteorological observation satellite, then named "Juno-Met," then "Cloud-Cover," and finally "TIROS" (Television Infrared Observation Satellite). The project was assigned to the Army Signal Corps at Fort Monmouth, New Jersey. When NASA was established in 1959, the TIROS Project was transferred to the NASA Goddard Space Flight Center at Bethesda, Maryland.

In March 1958, the Astro-Electronics Products Division was formed and chartered with the responsibility for the development of spacecraft, space systems, and associated ground equipment. The Astro-Electronics facility was established at its present location at Locust Corners, shown in Fig. 2. The SSD personnel were transferred to Astro-Electronics, additional transfers were made from other RCA divisions, and new personnel were hired, increasing the staff to 260 by the end of 1958.

On December 18, 1958, less than nine months after Astro-Electronics was established, the SCORE satellite carrying the RCA communications payload in a compartment of an Atlas booster was successfully orbited, beaming back to earth the recorded Christmas message of President

Table I. *RCA Astro-Electronics' major firsts.*

First Communications Spacecraft	SCORE, 1958
First Meteorological Spacecraft	TIROS I, 1960
First Navigation Operating System	Transit, 1967
First 24-Channel C-Band Communications Satellite	Satcom I, 1975
First Hybrid Communications Satellite	ANIK B, 1978
First All Solid State Commercial Communications Satellite	Satcom V, 1982
First Direct Broadcast Satellite	STC DBS, scheduled for launch in 1986

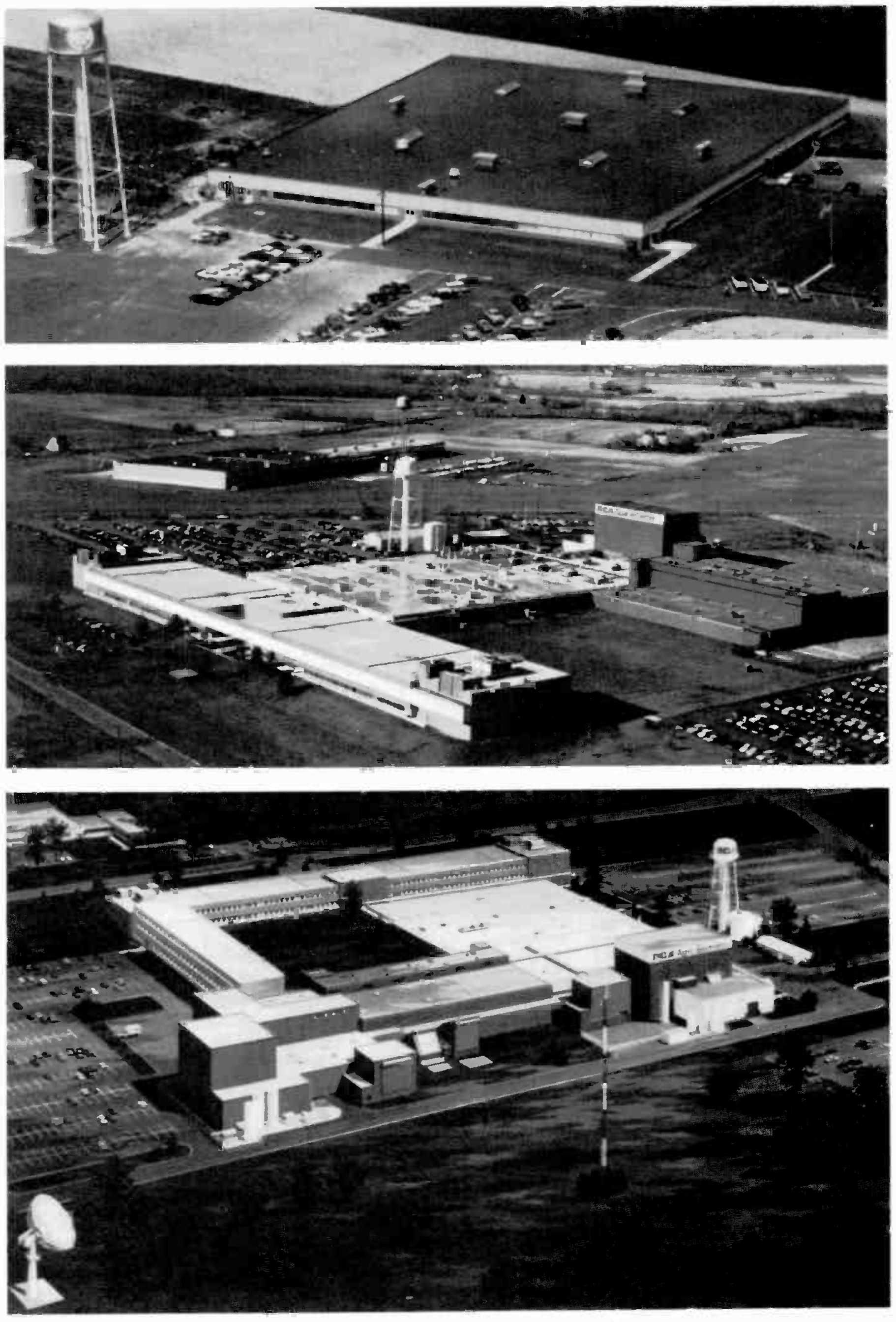


Fig. 2. *The original Astro-Electronics facility (from top)—Past, present, and future.*

Abstract: *Astro-Electronics, established in March 1958, contributed a communications payload to the SCORE satellite launched less than nine months later. Eisenhower's Christmas message, beamed back to earth by SCORE, demonstrated satellite-communications potential for the first time. Since that remarkable feat twenty-five years ago, RCA Astro-Electronics has developed satellites, technologies, and facilities unrivalled in the business. This article briefly notes the landmarks reached in the sixties, the seventies, and the eighties.*

Final manuscript received February 1, 1983.
Reprint RE-28-2-1

Dwight D. Eisenhower. SCORE demonstrated for the first time the potential for a satellite to relay communications from space.

One of the most important events in Astro-Electronics' brief history was the successful launch and orbital operation of the TIROS I meteorological satellite. Launched on April 1, 1960, the TIROS I was not only the world's first weather satellite, but was one of the most sophisticated spacecraft during that time. The 260-pound, 42-inch diameter, 22-inch high spacecraft (one of the largest and heaviest at that time) was configured with two 1/2-inch vidicon TV cameras. One was a wide-angle TV camera capable of imaging 4 million square miles with a single exposure, while the second camera was a narrow-angle high-resolution TV camera capable of 0.1-mile resolution from its 400-mile altitude. Video recorders stored and played back remotely observed scenes. The spin rate was controlled by five pairs of spin-up rockets; nutation of the spin axis was minimized by active mechanical dampers. TIROS II, launched in November 1960, was the first satellite equipped with scanning infrared sensors. A magnetic torquing coil was installed to control the motion of the spin axis. This novel Astro-Electronics innovation has been used on most of our satellites. Magnetic torquing has been used to stabilize the spin axis, control the satellite spin rate, null the residual magnetic field, control the roll and yaw axis, and precess the spin axis.

The sixties

In the early sixties Astro-Electronics expanded rapidly. The resounding success of the early TIROS satellites resulted in the acquisition of additional programs. The TIROS program expanded further with the initiation of the TIROS Operational Satellite ESSA. Astro acquired new programs such as the Echo passive-comunications satellite beacon, the active-communications satellite Relay, the SERT ballistic-trajectory space platform for testing ion engines in space, the Ranger 6 TV-camera payload for JPL's Ranger, the Nimbus subsystems (including the AVCS and APT (Automatic Picture Taking) TV cameras, the high-data-rate recorders, the multiplexer, power supply and solar arrays), and equipment for a number of classified programs.

Astro-Electronics expanded its staff and added the environmental center, buildings 402 and 403, and the engineering buildings 411 through 415 in 1961-1962. The new 20-foot by 24-foot diameter thermal-vacuum chamber was a sharp contrast to the old 4-foot diameter chamber in which the early TIROS spacecraft, barely clearing the inner walls of the chamber by 1-inch, were tested. A 25,000-pound-force random-vibration shaker was also added.

By the mid-sixties Astro-Electronics' reputation for developing reliable and cost-effective high-technology spacecraft systems and subsystems became well known. This laid the groundwork for the acquisition of additional programs: the Defense Meteorological Satellite Program (DMSP) for the Department of Defense, the production contract for 15 navigation satellites (NAVSAT) for the U.S. Navy, five Lunar Orbiter power system and solar arrays, equipment for the OGO (Orbiting Geophysical Observatory) and the OAO (Orbiting Astronomical Observatory), and the Apollo ground-controlled TV camera system and antenna. Work on the third-generation Improved TIROS Operational Satellite (ITOS), a three-axis-stabilized satellite, was set in motion.

The seventies

As NASA's Apollo program matured in the early seventies, NASA's expenditures declined sharply. However, Astro, with a solid base consisting of three important operational programs (TIROS/NOAA, DMSP, and NAVSAT), maintained a constant sales level and an adequate backlog of work. A fourth operational program, the commercial RCA Satcom, was initiated in addition to the Landsat RBV (return-beam vidicon) cameras, receiver, power system and solar arrays; the Viking command and communications subsystem for the Mars Lander; and the Atmosphere Explorer C, D, and E scientific spacecraft. The fourth-generation TIROS-N/NOAA-A-G and the DMSP Block 5D programs began.

Astro-Electronics' expansion continued in the early seventies with the addition of the high-bay integration building, one of the country's more modern clean-room facilities. A newly acquired quad-shaker facility could be used to test spacecraft weighing up to 10,000 pounds. This facility was suitable for vibrational testing of the TIROS-N and the DMSP spacecraft, which were ten times heavier and ten times larger than the earlier configurations. Also, an antenna-test-range facility was installed for testing the communications systems.

During the seventies, our spacecraft evolved into more complex and sophisticated configurations. The space-proven technology made Astro preeminent in spacecraft stabilization encompassing spin-controlled satellites and three-axis controlled, momentum-bias, and zero-momentum systems. Autonomous spacecraft were developed for DMSP and TIROS-N, and lightweight structures were made for Satcom. Active and passive thermal control subsystems were designed for many programs, and the use of GFEC (graphite-fiber epoxy composites) for structures, antennas, and communications elements were among the many innovations.

The post-Apollo period was highly competitive. Astro-Electronics' position in this arena was strengthened with its broad spectrum of programs that included meteorological, navigation, communications, and scientific satellites. This spectrum of offerings was made possible by the enhanced skill of Astro's personnel and the capabilities of its manufacturing, test, and integration facilities. Astro's reputation for designing and building reliable hardware, on schedule and cost effectively, continued to grow in the space industry.

In the second half of the seventies, Astro-Electronics acquired the Canadian Anik-B Telesat communications satellite program, the Space Shuttle CCTV camera subsystems, the Dynamics Explorer A and B scientific satellite, the NOVA navigation satellite, and additional follow-on contracts such as the Advanced TIROS-N (ATN), the DMSP Block 5D-2, and additional RCA Satcom spacecraft.

The eighties

In the early eighties, Astro-Electronics' technical and managerial skills were demonstrated in its lead position in the DMSP Block 6 and the NOSS competitive studies. A contract was received from NEC of Japan for system studies and hardware elements in the MOS-1 (Maritime Observation Satellite). Our competitive capability was demonstrated by the acquisition of two domestic communications programs: the GSTAR Program for GTE and the Spacenet Program for Southern Pacific Communications Corp., followed by the high-power direct-broadcast communications spacecraft program for Satellite Television Corporation (STC). In October 1980, Astro launched Satcom V, the first all solid-state communication satellite.

Astro is constructing a thermal vacuum chamber that will meet the demand for larger shuttle-compatible spacecraft. This

(Continued on page 10)

Recollections: Some of the pioneers

Table II. *Original Astro-Electronics staff in 1958.*

Albert T. Aronson
Thomas P. Baird
George A. Beck
Paul J. Bizzaro
Lewis E. Boodley
William E. Borgelt
Daniel D. Brodhead
Daniel J. Cannella
Joseph A. Casarella
Patsy J. Cimerola
Marvin S. Cohen
Glenn Corrington
William G. DeWindt
Harold B. Dougherty
Charles H. Gierman
Edwin Goldberg
Michael C. Greschak
Herbert M. Gurk
John Haluszka
William J. Haneman
Marvin H. Harper
Donald J. Hoch
Robert W. Hoedemaker
Eileen D. Huzzy
Jay L. Johnson
John E. Keigler
Samuel Kutik
Warren P. Manger
William E. Martin
Donald B. Martz
Norman G. Matthews
Walter Maxwell
George Newcamp
Joseph Paoletti
Frank Pinelli
John Procaccino
William E. Samuel
Frank Scearce
Robert Schmicker
Abraham Schnapf
John Schroth
Albert A. Seifert
John A. Seltzer
Joseph R. Staniszewski
Warren W. Wagner
Edwin R. Walthall
Paul R. Waseleski
Peter H. Werenfels

Fig. 3. *Astro-Electronics' softball team.*

On this anniversary, 36 of the original pioneers are still at Astro-Electronics (Table II lists this group). Some of the early days at Astro-Electronics are recalled by some of these people.

Ed Walthall, Fixed Service Satellite Technical Director

As a member of the original SSD team, I remember being housed in temporary wooden quarters at RCA Laboratories, where we were developing some of the first space systems. Today, a quarter century later, I am privileged to work on some of the most advanced space programs, and because of Astro's present growth, am again housed in temporary quarters.

John Schroth, Manager, Manufacturing Fabrication

I remember transferring from the security of the RCA Laboratories to the new, unknown RCA space venture that would become Astro. The experience of setting up Astro's machine shop has been a highlight of my life. It is this shop that has produced so many of the precision, complex parts that have contributed to Astro's success.

Joe Paoletti, Manager, Financial Operations

When I joined Astro at its inception, my small staff and I performed all accounting procedures and record-keeping manually. One of my earliest fond recollections concerns our softball team, shown in Fig. 3.

Don Martz, Manager, Maintenance and Services

I also transferred from RCA Laboratories with my personal toolbox being the only maintenance tools available when I joined Astro. I remember ordering new tools from the Sears catalog. One of the greatest thrills in my life is still remembering those first pictures from TIROS I.

Jack Keigler, Manager, Communications Satellite Systems

One of my first assignments at the newly created Astro was to simulate a picture of cloud cover as might be seen from space by TIROS I, which had not yet been launched. Toward this end, I suggested that we assemble a mosaic of photos taken from high-flying aircraft. A Navy reconnaissance squadron of four jets, from Jacksonville, Fla., was placed at my disposal. These jets flew up and down the Florida peninsula four times in parallel lines, twenty miles apart at an altitude of 50,000 feet to obtain enough photos to approximate a single early TIROS photo like the one shown in Fig. 4.

Joe Staniszewski, Navy Navigation Satellite System Program Manager

One of the projects I worked on in my early days at Astro was a project to photograph the moon's surface in a fly-by mission. We adapted a TIROS ½-inch TV camera for this purpose. Later, this project developed into the Ranger program. The Ranger spacecraft photographed the lunar surface prior to its impact on the moon. The immense satisfaction of receiving these pictures is unimaginable. Figure 5 shows Ranger. A typical Ranger TV picture is an improvement of 1000 to 1 over the best taken from earthbound telescopes. ”

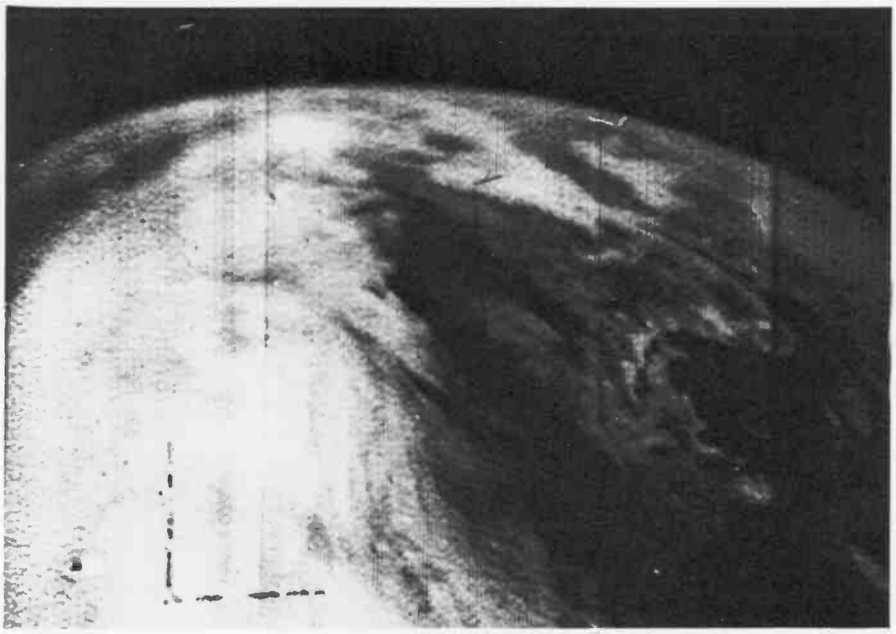


Fig. 4. *First TV picture of the Earth, taken from TIROS I.*

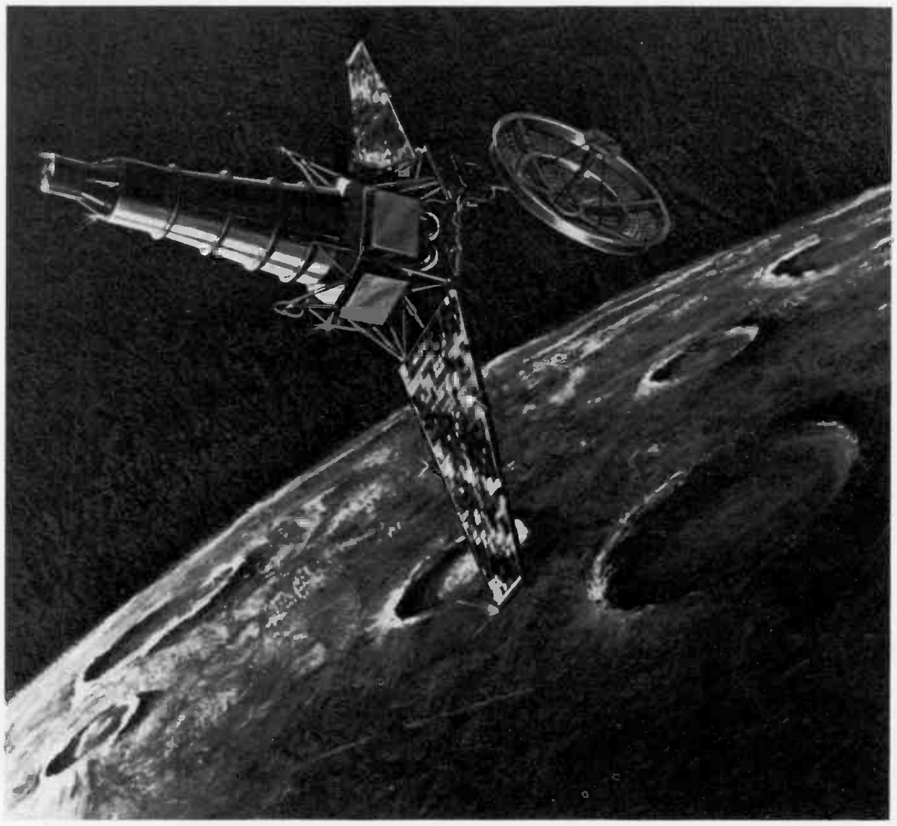


Fig. 5. *Artist's rendition of Ranger taking pictures of the lunar surface.*

Table III. *Astro-Electronics' 25 years of growth.*

Item	*1958*	*1983*
Facilities	78,000 sq. ft.	479,000 sq. ft.
Personnel	260	1,521
Sales	$4,700,000	$225,000,000
Contract backlog	$4,000,000	$700,000,000
Satellites successfully launched	0	78
Subsystems launched	1	47
Ongoing programs	SCORE TIROS ACSIMATIC	TIROS DMSP NAVSAT Satcom Spacenet GSTAR DBS for STC CCTV MOS American Satellite Corp. SOOS NOVA

Table IV. *RCA space systems' orbital operational life as of March 1, 1983.*

SPACECRAFT SYSTEMS - 15	*Launch Date*	*Orbital Life (months)**	*Mission Type*
Operational Systems			
NASA/NOAA			
NOAA-7	06-23-81	20.4	Environmental
NOAA-6	06-27-79	44.3	Environmental
USAF/DMSP			
5D-DMSP-21	05-01-78	58.0	Meteorological
5D-DMSP-22	12-20-82	2.5	Meteorological
U.S. Navy			
NOVA-1	05-15-81	21.5	Navigation
NAVSAT-20	10-29-73	112.3	Navigation
NAVSAT-19	08-27-70	150.4	Navigation
RCA Commercial Communications			
RCA Satcom V	10-27-82	4.2	Communications
RCA Satcom IV	01-15-82	13.5	Communications
RCA Satcom IIIR	11-12-81	15.5	Communications
Telesat Anik-B	12-15-78	50.5	Communications
RCA Satcom II	03-26-76	83.3	Communications
RCA Satcom I	12-12-75	86.5	Communications
Earth-Orbiting Scientific Satellites			
Dynamics Explorer-A	08-03-81	19.0	Earth's magnetosphere
MAJOR SUBSYSTEMS - 6			
Planetary			
Viking Lander-1	08-20-75	91.0	Mars - Science
Technology Satellites			
Nimbus-7	10-24-78	52.2	Weather technology
Nimbus-6	06-12-75	92.5	Weather technology
Nimbus-5	12-11-72	122.5	Weather technology
Landsat-3	03-05-78	62.0	Earth resources
Landsat-2	01-22-75	97.5	Earth resources

* Still in operation.

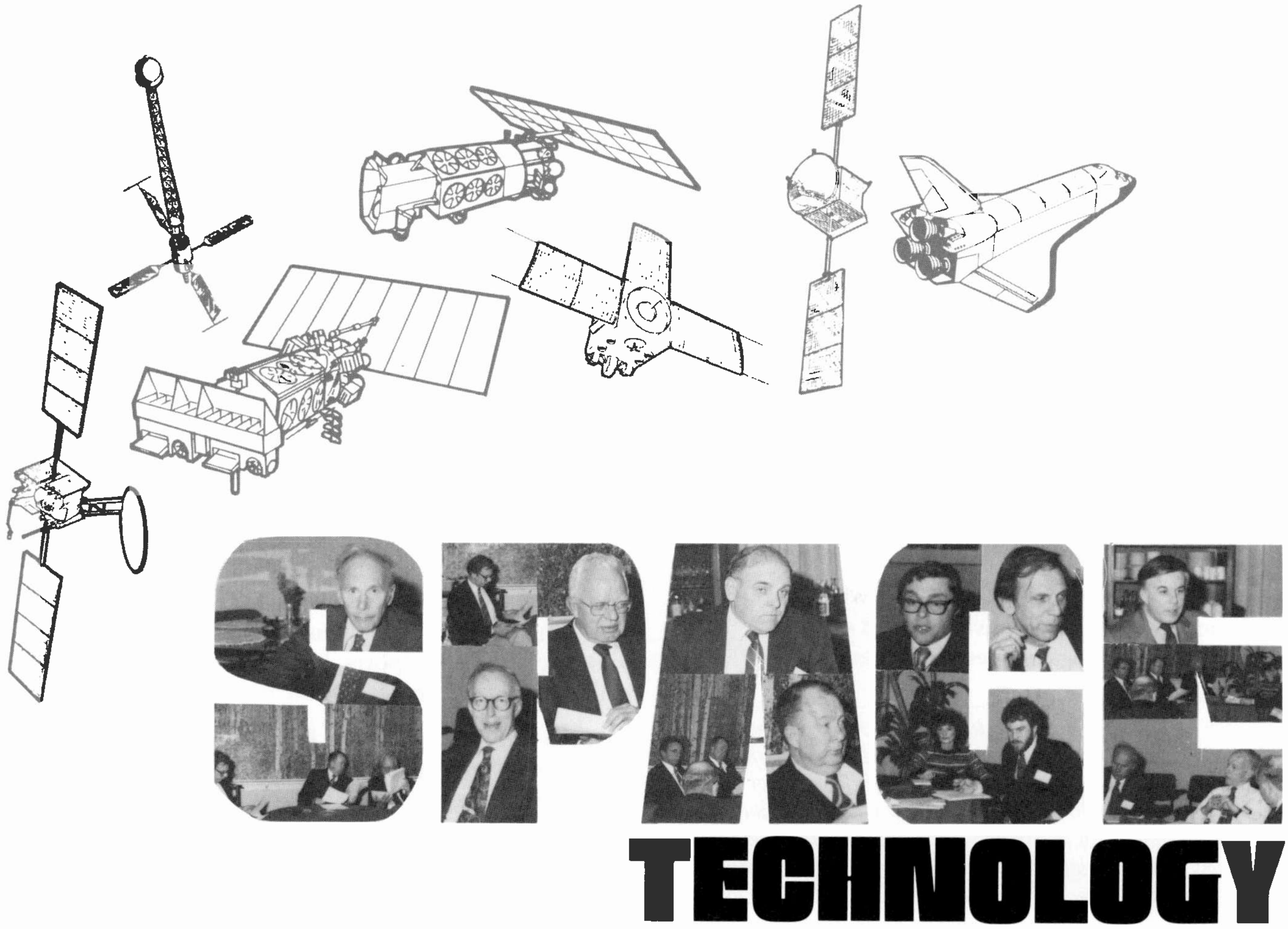
(Cont. from p. 7)

facility is the largest clean-pumped vacuum chamber in the country. Twenty-five years after being established as the center for RCA's space activities, Astro-Electronics is in a business and facility growth to meet the challenge for the next decade. Building 500 and temporary modular offices are in place, and a new high-bay building with the larger thermal-vacuum chamber, and an improved antenna test range will be in place as we complete our first quarter century. Table III illustrates Astro's growth in facilities, sales, and so on, in the past 25 years. Astro is prepared to start the next quarter century of space activities with the biggest backlog of work in its history and a spectrum of programs that clearly identifies Astro as a leader.

Astro's 25-year record of performance in the space industry is unequaled in terms of number of satellites and space systems in orbit, the number of successful missions, the diversity of the spacecraft, payloads and technology, and the cost-effectiveness in the production of Astro's spacecraft and systems' operation. Our present status in the satellite industry portends a shining future for Astro. As of this writing we have a backlog of 36 spacecraft. Continuing commitment to technical excellence and corporate investment has established Astro's place in the forefront of the satellite industry and will propel us on as we lead the industry into the next quarter century. Ours is a great heritage with an even greater future.

Astro-Electronics Space Technology Roundtable:

An Engineering Management Review and Forecast



Participants *(seated, left to right) Brian Stewart, Bob Miller, Hal Curtis; (standing, left to right) Roy Ohanian, Jack Keigler, Emil Dusio.*

The 25th anniversary of RCA Astro-Electronics coincides with record satellite business bookings. Thanks in large part to the outstanding technology developed at Astro and in supporting activities, the present engineering developments are many, and the future holds exciting prospects.

What are those technological ingredients for success? Our staff wanted answers, so with the help of Astro's Chief Engineer Bob Miller, and Editorial Representative Carol Klarmann, we took our questions directly to the Astro-Electronics engineering managers and asked them to focus on recent technological developments and to prognosticate the future growth of Astro's engineering capability.

On January 21, 1983, Hans Jenny, Tom King, Editorial Representative Carol Klarmann, and Mike Sweeny from the *RCA Engineer* staff sat down with members of Astro's engineering management to discuss the issues. During the lively interchange, reproduced here, the following participants touched on virtually every aspect of Astro-Electronics' technological spectrum of activities:

Abstract: *A wide-ranging roundtable discussion with members of Astro-Electronics' engineering-management team explores recent and projected space technologies. Bob Miller, Chief Engineer at Astro, opened the discussion with a statement of the roots of Astro's technology in communications and weather-satellite applications. The discussion that ensued held to recent developments in these basic areas. Spacecraft mechanical systems and materials, sensors, DBS, communications payloads, engineering synergism between RCA locations and divisions, cost benefits, Space Shuttle prospects, and computer-aided engineering are just some of the topics discussed.*

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Reprint RE-28-2-2

Bob Miller, who opened the discussion with a brief statement, is Astro-Electronics' Chief Engineer. He took that position last spring after working as Manager, Satellite Programs. Since joining RCA Astro-Electronics in 1964, Bob has managed a wide variety of space programs, including the NIMBUS, the Atmosphere Explorer, RCA Satcom, Anik-B, and TIROS spacecraft programs.

Roy Ohanian is Administrator, Independent Research and Development (IR&D). He oversees discretionary funds that RCA uses to "do homework" on future technology developments. These programs are not contract work, but they apply to all business areas.

Hal Curtis is Manager, Preliminary Design. His group is basically responsible for the conceptual design of the next-generation spacecraft at Astro—whether it's meteorological spacecraft, or communications spacecraft.

Brian Stewart is Manager, Spacecraft Systems. Spacecraft systems encompasses the mechanical disciplines of spacecraft technology: propulsion, power, thermal effects, structure, and guidance and control. His department takes the preliminary designs, which Dr. Curtis' group establishes at the beginning of a contract, and produces detailed designs and drawings necessary for the production of the mechanical equipment.

Jack Keigler's section of the engineering department is Communications Satellite Systems, responsible for the design and development of the communications-payload portion of the satellites—that is, the design of the antennas, receivers, transmitters, and interconnecting components. The group also technically supports, in these design areas, ongoing NASA and DoD satellite programs.

Emilio Dusio is Manager, Electronic Systems. Electronic Systems is responsible for the design and development of the nonradiofrequency portion of satellites, the supporting Aerospace Ground Equipment (AGE), and software for on-board AGE computers.

Jim Blankenship and *Ron Maehl* could not attend the roundtable because of previous commitments, but Jim has offered a sidebar (page 22) for this article, and Ron has contributed a full-length article (page 91) to this issue describing their respective areas.

Miller: RCA Astro-Electronics, since its inception in 1958, has been a leader in technology in the industry. Indeed, the success of Astro over the years can be attributed to the effective use of technology in this field. This use of available technology has enabled RCA Astro to accomplish many firsts in the space industry.

It started with applications of the technology RCA had in the field of infrared, television, and communications—in the TIROS satellite, and in the first application of communications equipment aboard the Atlas to provide the playback of President Eisenhower's statement during the Christmas season, 1958. That event marked the first satellite communications, and of course the early TIROS weather satellite was a first application of television to observation of weather from space. That application has continued over the 25 years. We have seen the recent advancement of domestic communications, wherein a large portion of our present-day business is in the domestic communications satellites—the fixed-service satellite field.

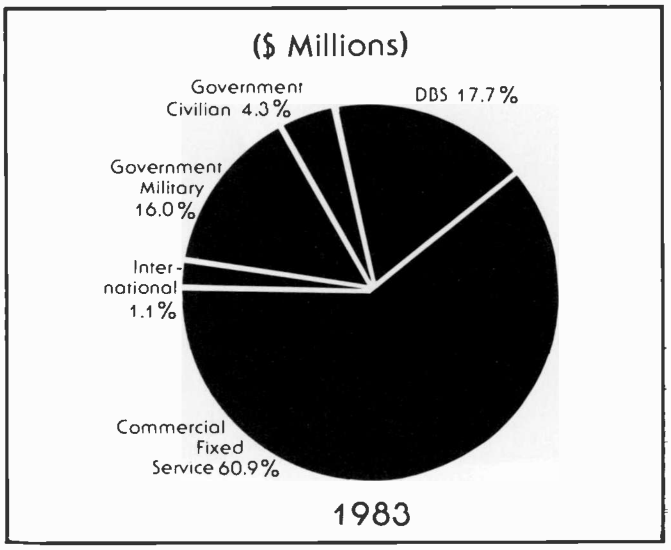
For this session, to discuss various space technologies, we have gathered together the managers who are responsible for bringing the technology to bear on our products.

RCA Engineer: *It's difficult to choose, but could you each describe one major engineering success in your area, achieved recently?*

Keigler: We like to think that our most shining example recently is the payload on the latest Satcom, Satcom V, launched in October, which is now in service for Alascom to provide communications service to Alaska. The unique feature of that spacecraft design is the use of all-solid-state transponders. It is the first time a communications satellite has used a solid-state amplifier to replace a traveling-wave tube for the transmitter power stage. Also on that spacecraft is a completely new antenna design referred to as a shaped-beam, high-efficiency antenna. This antenna is a marked improvement over that employed on the original Satcom series, which was first launched in 1975. Both of these components were developed within Astro.

Stewart: Of many innovations in the past years, I would pick out the development and application of something we call the electrothermal hydrazine thrusters (EHTs). These thrusters, an extension of the technology of previously developed propulsion engines, have allowed us to substantially increase performance on the order of 30 percent over what we achieved previously. This development, done in conjunction with our subcontractor, Rocket Research Corp. of Seattle, was begun essentially from scratch and has been completed, within about 9 months, for use on our Satcom G satellite. The success and speed of that development has astounded both ourselves and our customers.

“Right now we are preparing software enhancements to do on-board power management to make the spacecraft even more autonomous.”



Astro's business has changed from 100-percent government-related work at the outset, to predominantly commercial-communications-work today.

Keigler: I'd add that, in Brian's area, there are so many good things, it's hard to single out the best. For example, you wouldn't have the success of communications satellites without the use of the lightweight structural materials in our antennas. These composites have the strength-to-weight properties required *and* the proper dielectric properties for use in our antenna systems.

Curtis: My group doesn't deal with individual engineering developments, but certainly our biggest success in recent months has been the system design of the direct-broadcast satellite (DBS) for Satellite Television Corporation (STC), which was a winning proposal in intensive competition, and probably the start of a new industry. Again it wasn't something we did alone, it depended heavily on the Independent Research and Development (IR&D) work done in the communications group and on help from Brian's spacecraft-systems group.

Miller: I think that's an important point. In the areas that Jack (Keigler) has discussed with Brian (Stewart) and Hal (Curtis),

Bob Miller, Chief Engineer
"A fair amount of our cost in the production of equipment and satellites is the validation of the design, before it is committed to space. Astro has extensive environmental test facilities . . . RCA is adding to these facilities to accommodate the larger spacecraft that the Shuttle makes possible."

the seed money that comes through IR&D prepares our technology base and puts us in a winning position for competitions such as the direct-broadcast satellite for STC.

Ohanian: One important development with regard to IR&D is that, over the past few years, the various divisions or units at RCA have increasingly learned to work together to pool their technical talents in such a way that a winning end product can be made. It is particularly true of the close relationship between Astro and the Laboratories—and also the Advanced Technology Laboratories in Camden. Probably the best testimony I can think of for it is that, as little as three years ago, when we used to have joint IR&D project reviews, we could get most of those reviews done by mid-morning; we didn't have a lot to say. This year we have about 17 programs to discuss, and now it takes the better part of a day to have all the companion project people present their results on a regular basis. That shows a rather large expansion in the common areas in which we're all working.

We've also come a long way in radiation analysis. There were times when we did not have the tools, methods, or testing techniques to understand radiation degradation of devices in space. As a result we often had to apply rather conservative rules on shielding devices against the space environment. We are now able to calculate these effects in many cases down to very low percentages of error, say 5 or 10 percent, whereas in previous years we were glad to be within an order of magnitude. This enables us to save a lot of weight on a spacecraft, because in previous years we had to arbitrarily put perhaps 30 mils of lead on a device to protect it. Now we can calculate whether we need 5 mils of aluminum or 10 mils of aluminum. If you multiply that old requirement by the number of devices on a spacecraft, then you're talking about a considerable number of added pounds, which we now save.

RCA Engineer: *Roy, where has this improvement had a great impact?*

Ohanian: Well, I think particularly on the communications satellites that's had a great impact, because what's the ratio? How many extra thousand dollars per pound of fuel, what's the basic payoff for every extra pound of fuel?

"We use CAD for the layout of the electronics components and have a well-integrated system for design through test and manufacturing."

Stewart: I think it's dramatic, Roy, in terms of the user benefits. What is a typical communications satellite worth in terms of income or revenue per pound? I think someone said that was on the order of a million dollars per pound.

Ohanian: So the fact that we can just take off five to ten pounds, depending on the spacecraft design, is important. Or, alternatively, we can use more advanced devices without worrying so much about radiation effects.

RCA Engineer: *Emil, what's an important achievement in your area?*

Dusio: We are especially proud of the flawless launch and operation of the second-generation software for the recent DMSP F6 spacecraft program. That software does everything, from lift-off to operation in space. We eliminated many operational problems that we saw during the first five years of operation. Right now we are preparing software enhancements to do on-board power management to make the spacecraft even more autonomous.

RCA Engineer: *Roy, you referred earlier to the synergism among RCA business units. Could you outline a number of those successes?*

Ohanian: Yes. Let's first talk about a universal concern among all spacecraft designers, that is, the drive toward improved LSI circuitry. In the commercial world, this has led to higher-scale integration at ever-increasing densities. In the spacecraft business, we share this desire as much as anyone else, because improved LSI technology can save a great deal of weight and power—two of the most precious commodities we have to spend on any space mission.

However, we also have a requirement above and beyond that of the "normal" world, namely, that space systems must be tolerant of space radiation. RCA has been able to muster the forces of several of its divisions to achieve a string of successes in radiation-hardened device technology. There is no question that the cooperation among the Solid State Division (SSD), the Solid State Technology Center (SSTC), the Government Systems Division's Advanced Technology Laboratories (ATL), the David Sarnoff Research Center (DSRC), and Astro-Electronics has led to several key space systems available today, including our most recent achievement: a radiation-hardened, second-generation, all CMOS/SOS spaceborne computer.

Dusio: This was an all-RCA achievement. It required custom LSI chips produced by SSD/SSTC, circuit designs optimized for radiation-hardening by ATL, techniques for processing radiation-hardened chips developed at DSRC, and high-density circuit-packaging techniques developed at GSD's Missile and Surface Radar unit in Moorestown—all in accordance with the needs, systems analysis, and system designs determined at Astro.

I might add that the RCA CDP 1802 was the first microprocessor to achieve space qualification as part of a similar cooperation among RCA divisions.

> ***"Lidar sensors will represent a major breakthrough in . . . environmental sensing."***

Ohanian: ATL also has expertise in automation and pattern recognition, or "vision," systems that we are hoping to implement here at Astro in some automated manufacturing procedures. Similarly, we are incorporating, as they become available, concepts for distributed spaceborne data-processing architecture and computer-aided engineering as they are being developed at ATL. For our advanced imagers and laser-based remote sensor development, we are getting support from both ATL and DSRC.

But perhaps the best example of synergism is the DSRC-Astro effort on the C-band solid-state power amplifier (SSPA) that Jack alluded to earlier, and he can give you that history.

> ***"In fact, as we proceeded in the development of the SSPA, its performance advantages equaled or outweighed its reliability advantages."***

Keigler: Work began in 1975, when we became convinced that we could build a solid-state power amplifier with competitive gain, power output, and weight compared to the traveling-wave tube amplifier (TWTA). For space applications requiring high reliability and high efficiency, GaAs FETs (gallium arsenide field-effect transistors) were the technical breakthrough that resulted in devices with requisite power capability and efficiency for amplifiers to compete with the weight and power demands of the traveling-wave tubes.

It's interesting that, in the mid-1970s, the impetus was to replace the reliability risk of a thermionic cathode with a solid-state device. In fact, as we proceeded in the development of the SSPA, its performance advantages equaled or outweighed its reliability advantages. Namely, it is a more linear amplifier, therefore there is less intermodulation between multiple signals going through the amplifier. And, at the same bandwidth, the traffic capacity of an SSPA is considerably greater than that for its corresponding TWTA. From the point of view of the user, the traffic capacity per channel is markedly increased. In addition, the SSPA is more reliable.

RCA Engineer: *How does Americom fit into this picture of synergism?*

Keigler: Americom is capitalizing on this technology. They have developed modulation schemes—modems—that can exploit this linearity advantage so that they will now be increasing traffic capacity. When we started with the first Satcom, in 1975, the nominal maximum capacity of that 36-MHz-wide amplifier was about 900 one-way voice circuits per transponder channel. With the advent of the linear amplification that the SSPA provides, and with the introduction of single-sideband techniques to reduce the required bandwidth per voice circuit, Americom is planning on over 5,000 one-way voice circuits per transponder channel—and there are 24 channels, so you multiply that out and you have over 120,000 one-way voice circuits per spacecraft.

The other feature that the Satcom satellite introduced was a frequency-reuse technology of having orthogonally polarized signals, so that within the same rf bandwidth you can have two independent transmissions. In the case that we developed for

Jack Keigler, Manager, Communications Satellite Systems
"We don't have the number of buyers or applications for military-communications satellites that we have for commercial satellites, so our major thrust will continue to be in the commercial area."

Americom, there were vertically and horizontally polarized signals, so that the bandwidth has a 2:1 multiplication by that technique, and then the capacity per channel on each polarization is multiplied by this ratio of about 5,000 to 900, as just mentioned.

RCA Engineer: *Jack, can we move from commercial communications satellites to military communications satellites? What are Astro's plans for military communication satellites?*

Keigler: Military satellites, unlike commercial ones, come in rather widely spaced programs. The next announced military communications-satellite program is referred to as Milstar. The contract was recently awarded to Lockheed, with Astro being a contender for the payload computer. We don't have the number of buyers or applications for military-communications satellites that we have for commercial satellites, so our major thrust will continue to be in the commercial area.

Miller: Many aerospace companies have a part in large military programs. Perhaps Emil (Dusio) would like to comment on the particular segment (of the Milstar program) that we are addressing, which uses the technical expertise of not only Astro but ATL, SSTC, and SSD.

Dusio: We supported TRW in their pursuit of the Milstar bus contract. Our program had two components—a communications package, which is the payload; and a bus. TRW and Lockheed were competing for the bus.* We are supporting them with data processing, which is an extension of the on-board computer work that we developed for our DMSP program and are using on TIROS. At RCA, we have a three-part effort underway. We are using a GPU bit-slice processor to implement a 1750A architecture microprocessor.Together with the Solid State Division, SSTC is developing gate universal arrays (GUAs). We will perhaps be doing some software work with ATL in support of JOVIAL J73, the designated language for that program.

RCA Engineer: *What new technology comes out of government contract work at Astro that can be translated into commercial business?*

Dusio: Radiation-hardening technologies extend into the commercial market. Efforts to meet military requirements translate into less weight and longer available lives for the electronic components on a communications satellite. As we achieve lighter weight and longer life, we can fly more fuel and maintain a longer life in orbit—a commercial advantage. Other enhancements include leadless-chip-carrier packaging of radiation-hardened components mounted on ceramic substrates. These have the potential to reduce the weight of the housekeeping electronics to half its present value. In addition, stationkeeping maneuvers are developed from satellite-to-ground-station ranging measurements and triangulation. Enhancements to the ground-control station software systems will completely automate the stationkeeping maneuver planning and execution.

Keigler: A new NASA program going through the initial stages of procurement, the Advanced Communications Technology Satellite (ACTS), specifically addresses the development of technology for the next-higher frequency band. Satellite communications are, perforce, restrained to agreed-upon communications bands based on frequency assignments. The majority of commercial development to date has been called C-band communications, which uses the portion of the rf spectrum around 6 GHz for the earth-to-space link, and a 4-GHz downlink. Recently a number of carriers have expanded into Ku-band (14/12 GHz). Both of these are limited to 500 MHz of bandwidth.

"A lot of truly basic scientific research is being done and needs to be done in the area of sensor design. The clearer the picture from space, the far more efficient the data-gathering system is going to be."

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* Since this interview, Lockheed has been awarded the Milstar contract. Astro is now responding to Lockheed's request-for-proposal to provide the on-board computers.

"Astro has been building these so-called integrated satellites for a number of years on the TIROS and DMSP programs. That technology will carry over directly into the Shuttle era."

The next designated band, which is seen as the resource that the industry will add on when the first two bands—C-and Ku-band—have reached their capacity for the number of orbital slots they will support, is the so-called Ka-band with 30-GHz uplink and 20-GHz downlink, and usable bandwidth of 2.5 GHz. That's five times the bandwidth of the other two bands. The NASA ACTS program will demonstrate both the state of development of the hardware components to work at that frequency (which places new demands on amplifier noise figures and efficiency), as well as show the complex dynamic ground network needed to use the capabilities of that system in a very complex satellite-switched time-division multiple-access (TDMA) network of a lot of users accessing the satellite with very precisely controlled time slots and antenna-gain positions. The NASA ACTS program is expected to enter its first contract about a year from now, with the first launch scheduled for 1987 or 1988.

RCA Engineer: *What would you say are the problems inherent in going to the higher frequencies?*

Keigler: Well, there are several areas that require new developments: For the antenna system, a multiple-beam antenna must have high isolation between spot beams so there can be reuse of the spectrum spatially; in the transponder, both amplifiers at the output and receivers at the input must have the requisite performance at higher frequencies. Very exotic signal processing is to be done on board. The baseband processor, for example, is a high-speed digital processor that demodulates and reformats and remodulates this data stream with data rates on the order of 250 Mbps.

RCA Engineer: *Talking about government programs, what effect does the Shuttle have on satellite design? What do you foresee?*

Curtis: Satellites have been limited by expendable launch vehicles like Delta in two ways: First, the fairing—the heat shield between the spacecraft and the outside—limits the diameter of the spacecraft. Second, as the Delta program has evolved, and as the communications-satellite programs have evolved, Delta has limited the amount of weight that can be put into orbit. Now, in the Shuttle, the limiting diameter becomes 15 feet rather than the 7 feet of the Delta heat shield. The weight that can be placed in orbit remains limited by available perigee rocket motors, but jumps to a maximum of 13,400 pounds for Boeing's proposed TOS stage, in contrast to 2,750 pounds for the McDonnell Douglas Delta PAM-D stage. Therefore, spacecraft can become larger, and antennas can become larger. The first instance of this evolution is the DBS program. The DBS antenna is the first antenna that will exceed the size of the Delta fairing. The first satellites to exceed the Delta weight limit are satellites that we have recently proposed for both fixed service and DBS.

First, some background. The weight that can be put in orbit, even after Shuttle launch, is limited by the throw-weight capability of the next stage. This, too, has been limited by developments that have been transitions from the expendable launch vehicle. The next generation of those boosters will allow much greater weight into transfer orbit and into geosynchronous orbit. Americom's 16-channel, 40 watts per channel, K-band satellite now planned for launch in 1986, will use a larger perigee stage after Shuttle launch.

Stewart: Another point is that the Shuttle can lift these larger payloads, but only into very low-altitude orbits, unlike the expendable launch vehicles. Thus, the upper-stage propulsion capability must be provided on the satellite itself. There, Astro has a clear advantage: Astro has been building these so-called integrated satellites for a number of years on the TIROS and DMSP programs. That technology will carry over directly into the Shuttle era.

"Spacecraft such as the Dynamics Explorer, the Atmosphere Explorer and TIROS all have the ability to do useful missions to deep space."

RCA Engineer: *What exactly is an integrated satellite in this case?*

Stewart: Fundamentally, the satellite contains the capability of getting itself into orbit. It contains propulsion stages and a method of guidance and, in that sense, is a rocket itself.

On our DMSP program, for example, the satellite is the brains of the launch vehicle. It controls the guidance of the rocket from lift-off. All the trajectory programming and control is derived from the satellite.

Hal Curtis, Manager, Preliminary Design
"Certainly our biggest success in recent months has been the system design of the direct-broadcast satellite (DBS) for Satellite Television Corporation (STC), which was a winning proposal in intensive competition, and probably the start of a new industry."

Miller: The fact that the Shuttle takes you out of the atmosphere and into space, does this leave you design flexibility you didn't have before when we had to operate the satellite from the ground up?

Stewart: The satellite will still be exposed to the same environment, whether it's launched from Shuttle or from an expendable vehicle, but on the Shuttle it certainly does have the advantage that the crew is there with it and, for special missions that might require human intervention before committing the satellite to its final mission operation, you can gain an extra flexibility. For example, a satellite could be thoroughly checked out before being released from the Shuttle. Or it could be manually released if there were any problems with the separation from the launch vehicle. It is possible, but unlikely, that there could be failures under the extreme mechanical-stress environments encountered during launch.

RCA Engineer: *What are the different propulsion requirements?*

Stewart: Although the distance traveled by Shuttle isn't very far, the velocity you need to get there is a significant part of the total velocity required. Once you are in orbit, provided you have the ability to steer your satellite or your propulsion stage, you can use very low thrusts. On the other hand, to lift off from the ground, you need enough thrust to overcome the weight of the launch vehicle, and that restricts you to the very large engines that are on standard launch vehicles.

Ohanian: Not only that, but during low thrust, you could spread out the solar arrays and other deployables.

Miller: When we launch from the ground, we can't view stars or have other navigation references, so we have to resort to very expensive inertial measurement platforms and gyroscopes. The Shuttle's position in space is known quite precisely when the spacecraft and Shuttle are separated. Also, being out of the atmosphere and out of the heat shield offers the system designer other navigational techniques that may prove more cost effective.

RCA Engineer: *Let's focus for a moment on issues surrounding DBS. How are Astro engineers uniquely qualified to handle DBS?*

Keigler: In contrast to the current fixed-service satellites, DBS requires a higher effective isotropically radiated power (EIRP); namely, the product of the transmitter output power and the antenna gain must be greater. Because there is a specific geographical area to be covered, the antenna gain is limited. If the gain were increased, the beam would be smaller, and that would not be suitable for direct-broadcast service, which is planned to broadcast to approximately one U.S. time-zone area. So coverage area sets a limit on antenna gain.

Therefore, to get the required EIRP, which translates directly into the received signal strength to the ground, you must have higher transmitter power. The numbers that illustrate this are: For fixed-service satellites the output transmitter power is on the order of 5 to 20 watts, whereas that of a direct-broadcast satellite is something over 200 watts per channel. This also means fewer channels on the satellite, because not as many 200-watt channels can be supported as 20-watt channels.

And, in terms of demands on the satellite, we have to handle the concentrated thermal loads that these high-power tubes present, and we also have to assure that those high-power tubes and their high-voltage supplies have the reliability and life to make the investment economical.

Miller: In the case of DBS, there is the synergistic effect of the many operations of RCA. Government Systems Division has what is called a "focus" program in which the efforts of several

> ***"It's a part of our business for people to do what we call a 'sanity check' to verify that the numerical results correspond to the physical world."***

IR&D programs are directed to achieve a specific goal—in this case, the direct-broadcast satellite. The Microwave Technology Center at the DSRC, the Communications Satellite Systems group at Astro, and the high-voltage, high-power electrical power conditioner design group at GCS, Camden, all worked on IR&D programs that led to the transponder design. RCA's background and experience in high-power tubes, specifically in the area of cathodes and slow-wave structures, led to the selection of the appropriate traveling-wave tube. Brian Stewart's group at Astro did work on the attitude control, structure, power, and thermal subsystems. Astro's IR&D program included work on the composite materials and antennas. All of these technology developments came together to provide the winning configuration of the satellite that will be the most cost effective for our customer.

Stewart: The applications of new materials is certainly a significant factor in new satellite design. As we heard earlier, weight is a premium, particularly in commercial satellites. Years ago, typically 12 to 14 percent of the weight of a satellite was dedicated to structure. Today it's more like 4 or 5 percent. This is mostly a result of work in the area of composites. They are of significant benefit in this field, not only because of their low weight but because of their low coefficients of thermal expansion, which has given us the thermal structural stability that is so important to precision pointing in many applications.

RCA Engineer: *You've mentioned composites and you've mentioned the resources available. This preoccupation with structure leads directly into the question of computer-aided design and computer-aided manufacturing (CAD/CAM). What kinds of influence will CAD/CAM have on satellite design in the future?*

Stewart: That does lead directly to the question of CAD/CAM. Together with having the materials to achieve lightweight design, structural optimization is also a key factor in reducing weight. The advent of sophisticated tools and analysis coupled into CAD is a tool that we call computer-aided engineering. It is the new wave in our business and allows more precision and optimization in the design of our primary structures and all critical appendages that comprise a satellite. For example, the antenna reflectors used on our commercial satellites have been developed by these methods. They are designed from composite material, and the designs have undergone extensive optimization by use of these tools.

RCA Engineer: *What are some other applications of CAD/CAM?*

Dusio: We use CAD for the design and drafting of electronic circuit boards and have an integrated system from design through production to test. One benefit of this system is that we can perform many design iterations and then produce a consistent set of documentation for production and test of the design.

Curtis: One use we see for CAD is in the very early conceptual design stage of a spacecraft, particularly one that has many optical sensors with fields of view, and many other appendages. This ability, very early in the design process, to make a simple spacecraft structure in three dimensions, to model that sensor in three dimensions, to place it anywhere on the spacecraft, and to make the appendages move to assure that the sensors do not have obstructions, can save time by about a factor of ten.

Keigler: In the microwave area, we are using CAD tools in two areas that we didn't have as recently as three years ago. We have an in-house HP1000 facility to do antenna modelling. Our antenna designs with their shaped-beam performance require that the contour of the beam match the coverage area. We have about 50 interdependent variables to iterate to optimize an antenna design. This is feasible only with computer modelling.

Likewise, during the design of active microwave circuits—the microstrip circuits—we are tied into the VAX computer system at the Microwave Technology Center where there are computer models of active circuit performance to optimize the impedance matching and circuit tuning to get the maximum gain and efficiency of the rf circuits. This could never be accomplished by any kind of laboratory iteration.

"Years ago, typically 12 to 14 percent of the weight of the satellite was dedicated to structure. Today it's more like 4 to 5 percent."

Stewart: I'd like to make one more point on this. The virtue these systems have in our business is in the way they can couple the many disciplines that we have to avoid redundancy in our work. CAD is far more than just being able to make drawings on a scope. From those drawings we can develop finite-element models (FEMs). From those FEMs we can in turn do our mechanical analysis. Thermal analysis can be developed from those same FEMs as well as radiation analysis. We finally can produce the tapes by which the hardware is made in CAM. This end-to-end capability that reduces redundancy in engineering will be the ultimate benefit to us.

Brian Stewart, Manager, Spacecraft Systems
"These thrusters, an extension of the technology of previously developed propulsion engines, have allowed us to substantially increase performance on the order of 30 percent over what we achieved previously."

RCA Engineer: *In the manufacturing area, can you talk about your plans to use robotics?*

Ohanian: Our primary use of robotics is for automated coverglass placement on the solar cells. I believe that is now planned for production for DBS.

Miller: We have the first-generation IBM robot. The first application of that robot will be in a very repetitive operation, the application of cover glass to solar cells in the manufacturing of our solar arrays. That's just the first application of robotics. Later, robotics will be applied to other manufacturing operations. There is a subtle difference between robotics and CAM. We have been using numerically controlled machining for years —a step short of robotics. We have also used numerical control in assembly of other units, such as our welded-wire circuit boards. Computer control also extends to computer-aided testing of the solid-state power amplifiers and digital boxes.

Ohanian: Most people are used to robots producing many thousands of objects (cars on an assembly line, for example). But we don't produce thousands of satellites. We produce a few high-precision products. The question is, how do you convert robot technology so that it's cost effective in that domain of manufacturing where you're making relatively few items? You have to take advantage of the programmability of the robot to, in a quick but precise way, change as the different products are made. That is the key issue: Where is the trade-off between how much effort is needed in reprogramming the robot versus the few relatively precise items that will be made with it? That also may be true of other aspects of CAM. Is there unnecessary effort to develop software and the programs to produce the one or two pictures that you're going to produce? It may not be worthwhile.

RCA Engineer: *Also, are you removing your engineers farther and farther from their product?*

Ohanian: I don't know if that's true. I think, for all the "removal" you get, you also give the engineer a lot more feedback than before. As Hal was pointing out, the average engineer in previous days would be lucky to come up with one or two designs a month where he had the layout of all his instruments, and maybe he could see if two instruments were, say, interfering with one another. No question, he was right up on the drafting board seeing his work embodied right in front of him. He's now "removed" because his work is behind his CRT screen or on a disk file somewhere. In the meantime, though, he gets much more feedback. He knows sooner what he is producing and he can vary it much faster.

Keigler: The pitfall is that there is the risk that the people accept the output of some computer program without double-checking the physical world that it's describing. It's a part of our business for people to do what we call a "sanity check" to verify that the numerical results correspond to the physical world.

RCA Engineer: *What facilities do you have to do those things, to test out assumptions?*

Miller: That extends not only from the electrical performance tests of the equipment that we build, but to the overall design as well. A fair amount of our cost in the production of equipment and satellites is the validation of the design, before it is committed to space. Astro has extensive environmental test facilities where we subject not only these spacecraft, but the component "boxes" that go into the spacecraft, to environments such as vibration, thermal stress, and thermal vacuum. We should mention that RCA is adding to these facilities to accommodate the larger spacecraft that the Shuttle makes possible.

We are currently installing a large, 46-foot thermal vacuum chamber. A new K-band antenna range, to provide far-field testing of the longer focal length antennas that Jack's group is build-

> ***"The first application of (our) robot will be in . . . the application of cover glass to solar cells in the manufacturing of our solar arrays. That's just the first application of robotics."***

"(The engineer) is now 'removed' because his work is behind his CRT screen or on a disk file somewhere. In the meantime, though, he gets much more feedback."

ing, is also part of this facility. So, to verify that a design is good, we do subject it to a full range of performance and environmental tests.

As part of the argument, CAD allows more precise calculation of stresses, loads, resonant frequencies. But that has to be balanced by an increased knowledge of the materials we use. We design more efficient structures, having a smaller percentage of the total weight. But that also calls for a better knowledge of the materials. Before, the design margins were such that we could be off a little in the properties of the materials. Well, as we shave the margins of safety to increase the efficiency of the structures, it demands that we know the properties of the materials so we don't exceed the allowable limits. That can't be done by a computer program.

RCA Engineer: *What advances is Astro making to improve their meteorological satellites?*

Ohanian: As Bob mentioned before, meteorological satellites are a very large part of Astro's heritage. A lot of truly basic scientific research is being done and needs to be done in the area of sensor design. The clearer the picture you have from space, the more efficient the data gathering system is going to be. This has implications in weather prediction, earth resources, and strategic surveillance. Clearly, there is a great demand for accurate sensing information.

For RCA's part, there are a couple of programs worth mentioning. A key issue is: If we could achieve a staring planar sensor composed of a mosaic of small infrared sensors that could stay fixed on the earth, possibly from geosynchronous altitude, that sensor would have tremendous advantages over some of the sensors used now, which are spin-scan type sensors. In the spin-scan system, a limited number of sensors are spinning around to create a picture a little at a time. Relatively few pictures result because it takes several cycles before enough picture elements are taken. A staring sensor would also have reliability advantages. The key issue, though, is that the infrared response of the types of materials used in the staring sensors—platinum silicide and palladium silicide, Schottky-barrier infrared charge-coupled-devices (IRCCDs)—needs some development. They don't respond with as large a signal as we would like in certain key regions of the infrared spectrum. A considerable amount of physics research is needed to enhance that response.

That's a passive sensor, just sitting there "watching" the information come in. The next great leap in sensing will be active sensing. We already have a fair effort in this area on laser-based sensors, in which case we aim a laser toward the atmosphere and wait for the scattered signal, or report, to return. From that signal, because you're actively probing the environment, you can get much more information on what's in the atmosphere, where it's going, and at a much higher data rate. That brings about a number of basic research questions, not the least of which is: How do you support these high-powered lasers in space and make them "live" for a long period of time? When Jim Blankenship makes his contribution (see page 22), he may elaborate on these points.

Possibly the IRCCD sensors we have now could be used as particular channels on a future instrument. But we cannot now propose using those devices for the entire instrument. As for the laser work, we do have an experimental laser lab at Astro to do some probes of the sky. But we're a long way from a space-qualified spaceborne laser. A lot of work needs to be done throughout the industry in that field. The first step would be to use it on a Shuttle experiment and see what the response would be from space. It is not likely that such an experiment would occur for another three years.

Curtis: But I see it on a "free-flier," too. The next advance in environmental sensing will undoubtedly be ocean-surface sensing by the use of passive microwave imaging with a fairly large antenna that scans and simply resolves a beamwidth as it scans. This is basically a device that will measure the temperature of the ocean surface. Another oceanographic sensor will be a scatterometer, which is a multi-narrowbeam radar, the return from which is proportional to the very small wavelets on the surface and these, in turn, depend critically on wind speed, so that it becomes a wind-measuring device. The third instrument to be carried will be a very accurate radar altimeter that will be used to measure the geopotential surface of the ocean, and therefore to measure large-scale currents in the ocean. Such programs are actively under consideration by the Navy.

"RCA has all the necessary disciplines to successfully provide the direct-broadcast satellite."

Ohanian: The use of this information would be primarily ocean-current prediction or weather prediction?

Emil Dusio, Manager, Electronic Systems
"We are especially proud of the flawless launch and operation of the second-generation software for the recent DMSP F6 spacecraft program. That software does everything, from lift-off to operation in space."

Curtis: Tactically, for the Navy, it's "What am I surrounded by, in terms of temperature, winds, and ocean state?" Another advance in environmental satellites, for tactical use, is the reduction on-board of the basic data, its conversion into meteorological parameters, and its transmission in real time to users.

RCA Engineer: *What about the large space platform and space stations. Are they in RCA's future?*

Curtis: They're in the present, in the form of a small subcontract that we have from one of the eight companies that are studying the needs for a space station. NASA has an active program now in the study phase, for a space station—probably in a low-inclination low-altitude orbit—and the present eight contracts are an attempt to make an economic justification of, and to devise an architecture for, the space station. Our future in the space station would be to provide avionics subsystems for the space station.

RCA Engineer: *What possibilities do you see in the future for non-earth-orbiting spacecraft? How's Astro going to get involved?*

Curtis: In two cases in the last year we've had contracts from the Jet Propulsion Laboratory. One is a study of the feasibility of the use of our low-altitude satellites in Mars and Lunar Geophysical Orbiter missions. The other is a similar study for an Asteroid Rendezvous mission, which again is to look at the geophysical properties of the asteroid (see article by R. Maehl, page 91). Both of these are attempts by NASA to foster the application of inexpensive spacecraft buses—normally used for earth sensing—to deep-space sensing.

Sensor technologies

The next advancement in environmental sensing will be in the remote sensing of oceans. Astro is presently working with both NOAA/NASA and the DoD on the development of such space systems. These spacecraft will carry radar altimeters to measure the slope of the ocean for determination of current, and infrared and color scanners to measure the temperature and identify areas of pollution or chlorophyll concentration. This information is vital to the fishing industry.

Another design challenge in the system is the radar scatterometer. This is a six-antenna radar that can detect the corpuscular waves due to wind stress on the ocean surface. The return scatter from these waves provides an indirect measure of the surface wind speed. The most significant sensor is a large-aperture (3- to 6-meter-diameter) passive microwave imager. This device will scan the ocean and measure such parameters as sea temperature in clear or cloudy areas. This is used to define current boundaries. Also, the device will provide a measure of the sea state and ice boundaries.

The real design challenge is to place both the active and passive radar devices on the same spacecraft without rf interference. The scanning motion of the large antenna, approximately 60 rpm, is a significant design challenge considering that the spacecraft attitude variation must remain less than 0.1° with better than 0.997 probability on all axes.

Next-generation weather satellites will probably carry three basic instrument packages: a visual and

RCA Engineer: *Could you expand on that point?*

Curtis: Yes. Spacecraft such as the Dynamics Explorer, Atmosphere Explorer, and TIROS all have the ability to do useful missions in deep space. So the question becomes: How do I modify the spacecraft bus for this purpose? The modifications in communications, for instance, are significant. Secondly, the spacecraft can by no means create the same amount of power in infrared imager; a microwave sounder for operations through clouds (both instruments similar to those carried today); and a laser-based system for detailed sounding of the atmospheric temperature, moisture, and probably constituents such as ozone. The same laser-based system will also provide direct measurements of winds in clear air.

The technical basis of atmospheric sounding will be a differential absorption lidar technique, commonly referred to as DIAL. Basically, a tunable laser is operated at two very close frequencies: one at which the atmosphere's absorption occurs, and one only affected by atmospheric scatter. The return signals can then be processed to remove all nonabsorption atmospheric effects, resulting only in a signal that is directly proportional to the absorption properties of a certain gas. The proper selection of wavelengths can produce concentration-versus-height measurements or temperature-versus-height measurements.

Wind measurements are accomplished by measuring the Doppler shift in the backscatter of a laser beam due to the motion of aerosols. Two measurements at different angles resolve those vectors necessary to define the atmospheric motion fields.

RCA Astro, the Advanced Technology Labs, and RCA Labs have active IR&D programs to develop key elements of the lidar sensors of the future. They will represent a major breakthrough in state-of-the-art environmental sensing.

—Jim Blankenship
Director,
Advanced Programs

Roy Ohanian, Administrator, Independent Research and Development
"One important development with regard to IR&D is that over the past few years the various divisions or units of RCA have increasingly learned to work together to pool their technical talents in such a way that a winning end product can be made."

deep space, a long way from the sun. But, with modifications, these inexpensive spacecraft can be used for the deep-space missions.

RCA Engineer: *Could someone sum up? What questions or issues do scientists and engineers hope to resolve with future satellites?*

Ohanian: Everyone in one way or another has essentially reduced allowable margins. We are becoming increasingly sophisticated. True, satellites are getting bigger and more powerful. But, at the same time, we are doing much more with each unit of weight and power that we have at our disposal. Everything is being pushed to tighter tolerances. And I'm not sure whether we're driving the technology because of the tighter tolerances, or whether the technology is making the reduction in design margins possible. We're pushing for the next dB of gain, trying to remove an extra few ounces of shielding, removing weight from the structure, trying to achieve an optimum configuration of sensors. This trend should continue for a number of years where, in order to gain efficiency, we just have to push the limits as hard as we can. If we don't, our competitors will.

Acknowledgment

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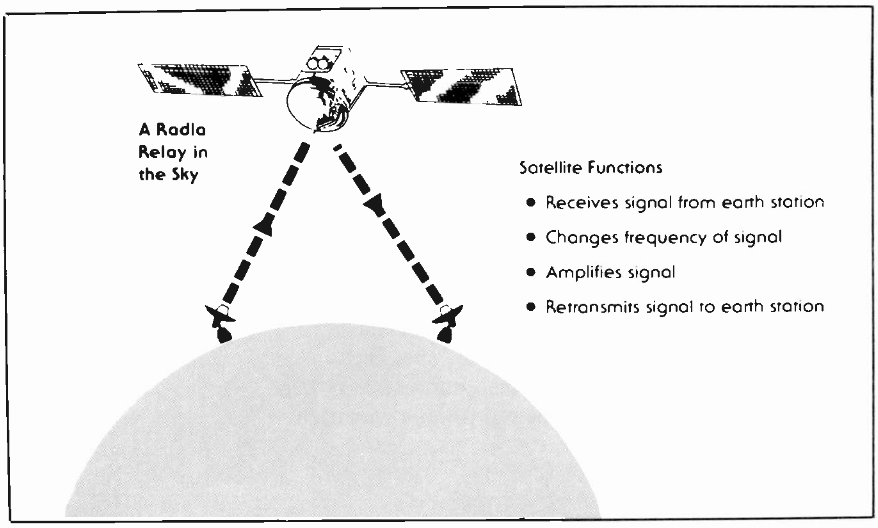
F.C. Weaver

Introduction to communications satellites

Illustrations accompany the fundamentals, and provide the foundations for understanding satellite communications.

The use of communications satellites to transmit voice, data, and television programming is revolutionizing business and home entertainment services. This paper presents basic operational principles: what a communications satellite is and how it works. Current issues such as reduced orbital spacing to relieve the shortage of orbital slots will also be covered. As with any new technology, the state-of-the-art is steadily advancing. The introduction of solid-state power amplifiers (SSPAs) to replace traveling-wave-tube amplifiers (TWTAs) will increase the traffic capacity and the reliability of communications satellites. Some of the benefits of SSPAs versus TWTAs are described. Direct Broadcast Satellites, the latest innovative application of microwave technology, will use high-power TWTAs to transmit television programming directly from the satellite to low-noise home receivers.

1 A communications satellite is simply a radio relay in the sky. It performs four primary functions: (1) it receives a signal from an earth station, (2) it changes the frequency of the signal, (3) it amplifies the signal, and (4) it retransmits that signal to another earth station. A satellite can provide for point-to-point and point-to-multipoint connections to earth stations within its coverage area.



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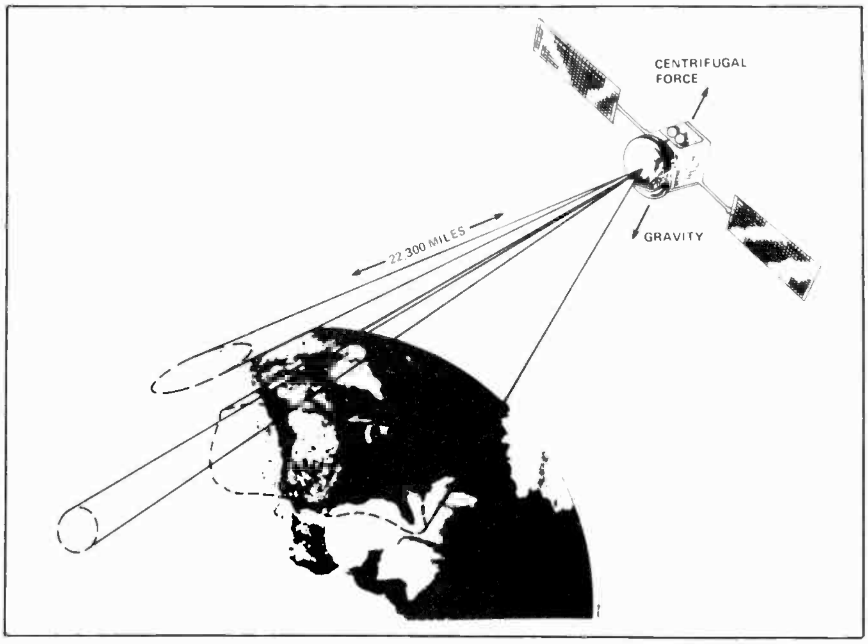
2 A communications satellite must operate at geosynchronous orbit where the spacecraft appears to be stationary when viewed from the ground. At a height of 22,300 miles above the earth's equator, the gravitational pull of the earth and the centrifugal forces acting on the satellite are in balance when it is revolving at the same angular velocity as the earth: one revolution per day. The spacecraft 's velocity is 6,879 miles per hour. In that orbit, the up-and-down propagation time for a signal would be approximately one-fourth of a second.



Fixed Satellite Service (FSS)

C-band 6/4 GHz	Uplink 5.925-6.425 GHz	Downlink 3.7-4.2 GHz
K-band 14/12 GHz	14.0-14.5 GHz	11.7-12.2 GHz

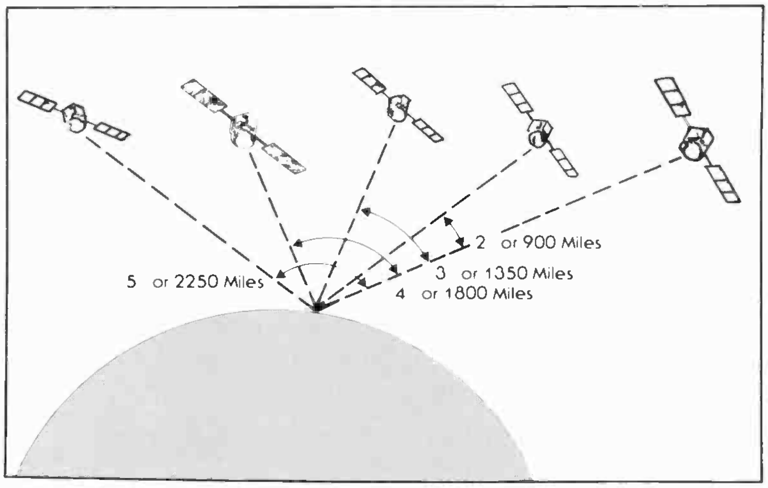
Broadcast Satellite Service (BSS)

K-band 17/12 GHz	Uplink 17.3-17.8 GHz*	Downlink 12.2-12.7 GHz*

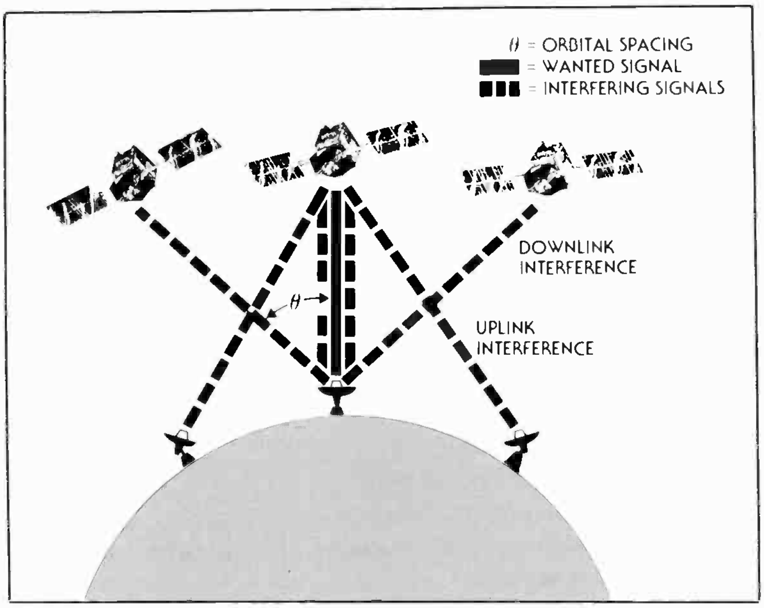
*TBD at RARC-83

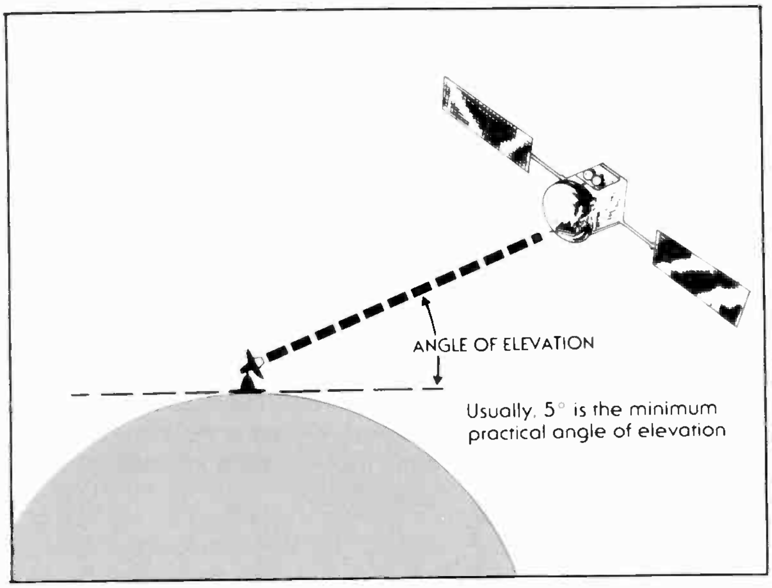
3 In North and South America, transmission to and from the satellite occurs at specified frequencies established by the International Telecommunications Union (ITU). This figure shows how frequencies are allocated for both the Fixed and the Broadcast Satellite Service (BSS). The BSS frequencies will be assigned at the Regional Administrative Radio Conference in June 1983.

4 Satellites operating at the same frequency must be spaced far enough apart to reduce interference. This figure illustrates current and proposed spacing requirements. At 22,300 miles, one degree of separation corresponds to 450 miles. For U.S. satellites, the Federal Communications Commission (FCC) requires 4° spacing at C-band and 3° at K-band. In a bilateral agreement with the Canadian Department of State and the FCC, Canadian satellites operate with 5° of separation at C-band.



5 It is proposed that 2° spacing may be required at both C- and K-band for satellites operating over the U.S. Such a move would create more orbital slots, but there is a potential for more interference. This figure identifies the sources of interference. There is uplink sidelobe interference from the earth station, and there is also downlink interference from adjacent spacecraft. The implication of a move to 2° spacing is that the earth-station antenna-sidelobe discrimination must be improved to reduce interference.





Usually, 5° is the minimum practical angle of elevation

6 Although 2° spacing may create more orbital slots, the finite arc that covers the U.S. is determined by the angle of elevation. As shown here, the angle of elevation is that angle subtended at the antenna between the satellite and the earth's horizon. To avoid barriers such as mountains or tall buildings and to reduce the amount of the signal's travel through the earth's atmosphere, 5° has been determined as the minimum practical angle of elevation.

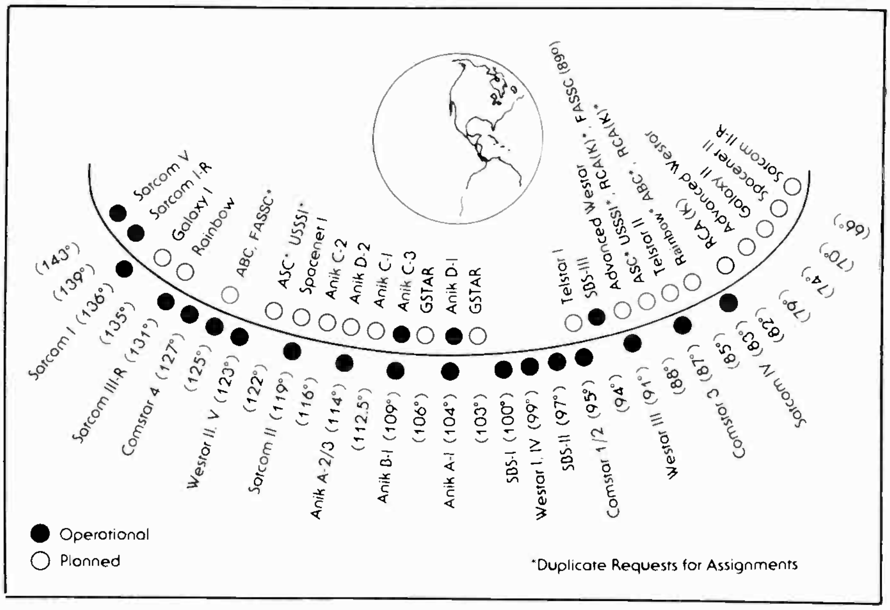
7 Assuming that we do have a 5° angle of elevation, the orbital arc that can cover the continental U.S. (CONUS) is between 54° and 143° west longitude. To cover all 50 states, a communications satellite would have to be positioned farther westward in that orbital arc, between 119° and 143° west longitude. To provide communications coverage to Canada, both C- and K-band satellites are located around 100° west longitude. At positions near 100° west longitude, satellites can cover Canada at some of the northern latitudes that lie far above the Arctic Circle.

United States (assuming minimum 5° elevation)
CONUS (lower 48 states): 54° - 143° West Longitude (WL)
All 50 states: 119° - 143° WL

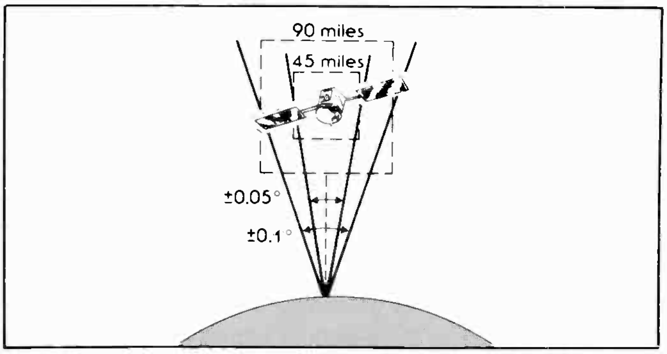
Canada
C-band: 104° - 114° WL (5° spacing required)
K-band: 105° - 116° WL (3° spacing required)

Available slots (from 54° - 143° WL)
22 at C-band with 4° spacing for U.S. and 5° spacing for Canada
30 at K-band with 3° spacing

8 Given the orbital arc that has been defined, how many slots are there? At C-band with the current 4° spacing requirement, there are approximately 22 slots available; at K-band with the current 3° spacing requirement, there are approximately 30 slots available. This figure illustrates how crowded the current orbital arc is. The shaded slots represent operational communications satellites. The unshaded slots represent communications satellites currently planned to provide service, or those still awaiting FCC approval. A proposed 2° spacing would create more orbital slots and relieve some of the congestion.



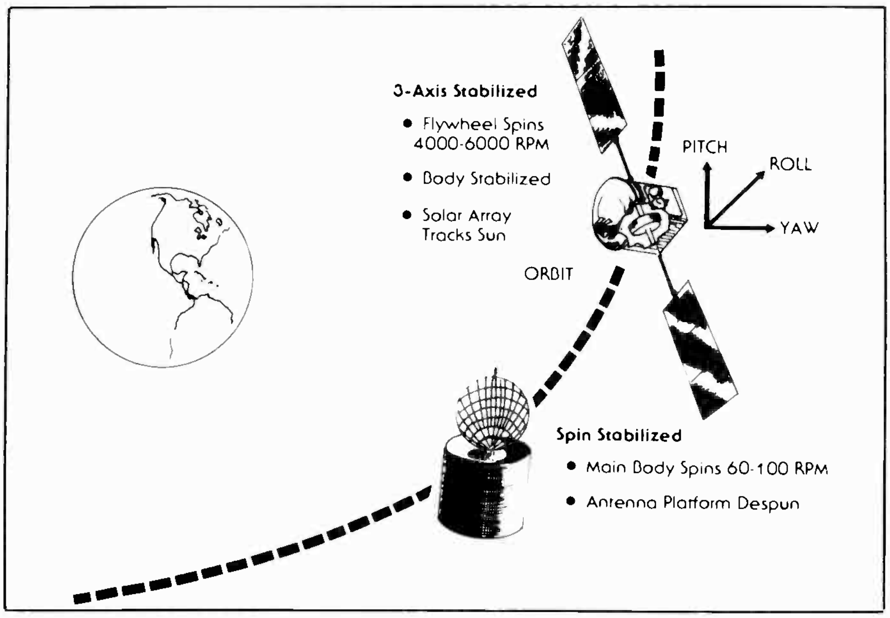
*Duplicate Requests for Assignments



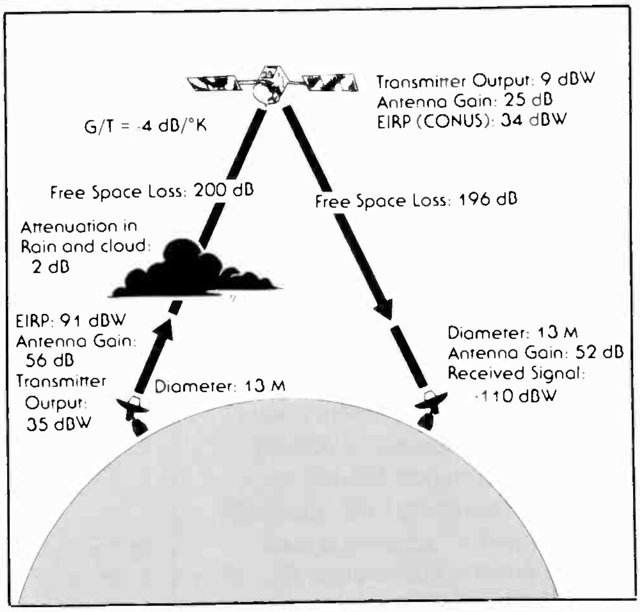
9 Stationkeeping, which is performed by a reaction-control subsystem on the spacecraft, is required to maintain position in orbit and to keep the downlink signal over the desired coverage area. C-band communications satellites are controlled to within ± 0.1 degree north-south and east-west. That restriction translates to a "box" that is approximately 90 miles on a side. For satellites operating at K-band, the requirement is 0.05 degree north-south and east-west, corresponding to a box that is only 45 miles on a side.

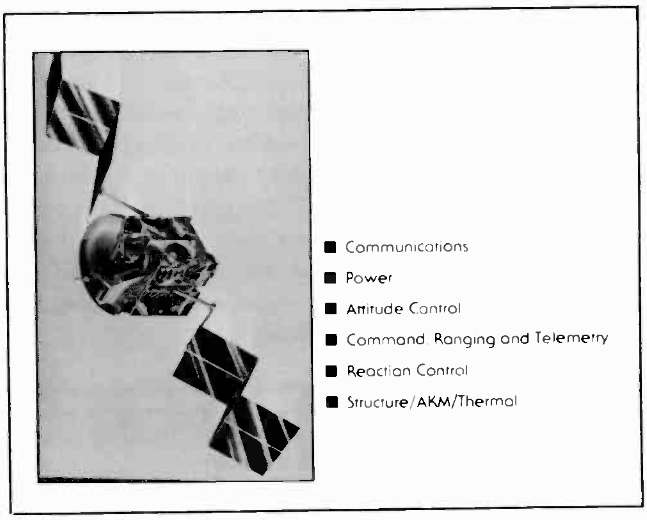
10 To maintain that spacecraft's orientation in orbit, the spacecraft is either spin stabilized or three-axis stabilized. With a spin-stabilized spacecraft, the main body spins at a rate between 60 and 100 revolutions per minute. The solar cells that provide the electrical power to all of the spacecraft subsystems are mounted on the main body of the spacecraft. So, at any given time, roughly one third of that surface area is exposed to the sun. Because the antenna must always face the earth, it is mounted on a de-spun platform.

A three-axis stabilized spacecraft operates differently. Instead of the main body spinning, a flywheel is mounted within the main body of the spacecraft. It spins between 4,000 and 6,000 revolutions per minute while the main body is positioned with respect to the three orthogonal axes that are shown in the diagram. Because the main body is not spinning, the solar cells are mounted on panels that track the sun as the spacecraft moves around in its orbit.



11 With the communications satellite properly positioned in orbit, we can have effective communications service 24 hours a day, via a typical C-band transmission link. The uplink signal is transmitted at 6 GHz from a large earth station that uses a reflector of approximately 13 meters in diameter. The effective isotropic radiated power (EIRP) of this signal is approximately 91 dBW. The signal is attenuated by rain and clouds, and it also loses strength as it travels the 22,300 miles to the spacecraft. The weak signal is received at the spacecraft, it is amplified, the frequency is downconverted from 6 GHz to 4 GHz, and then retransmitted to earth with a downlink EIRP of about 34 dBW. K-band transmission links work much the same way; however, rain can more severely attenuate the signal. Therefore, to compensate for the loss by rain and clouds, more uplink power must be provided from the earth station and more downlink power from the spacecraft.





12 Several subsystems work together to make the satellite transmission link possible. The most important is the communications subsystem, or payload, consisting of the antenna and the transponders. In the Advanced RCA Satcom, the communications payload weighs approximately 287 pounds—about 25 percent of the spacecraft's on-orbit weight.

Two other subsystems of primary importance on the spacecraft are the power and the reaction-control subsystems. The power subsystem consists of the solar arrays and batteries, which supply electrical power to the spacecraft during eclipse periods. The power subsystem provides power to every other system aboard the satellite. The reaction-control subsystem maintains the satellite—which is perturbed by the effects of the sun and moon and the elliptical shape of the earth's gravitational field—at its orbital station. It contains spherical tanks that hold the hydrazine propellant.

The attitude-control subsystem orients the satellite's antenna to a designated boresight angle. The command, ranging, and telemetry subsystem receives ground commands and transmits the spacecraft's status back to the ground. The apogee kick motor sends the spacecraft into a circular, geosynchronous orbit. The thermal subsystem maintains the spacecraft to within safe operating-temperature limits.

Frank Weaver, Manager, Communications Satellite Marketing, is responsible for marketing domestic communications satellite programming. Previously, as Manager, Marketing Administration, he was responsible for News and Information, advertising, and business analysis. He joined RCA Astro in 1977 as marketing representative. He received a BSEE from Howard University and a MBA from the University of North Carolina.
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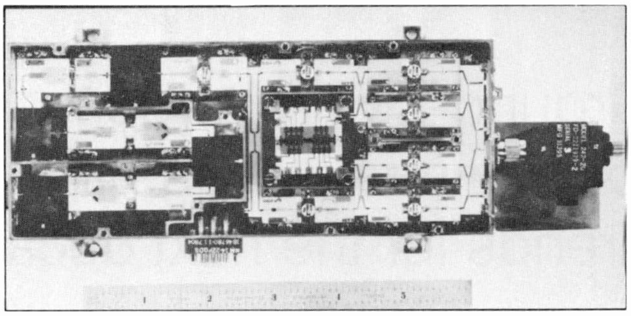
13 Astro-Electronics has made many technological advances in satellite design, and we are still working on some that will increase the payload performance, reliability, and lifetime in orbit. A specific example of this technological enhancement is RCA Satcom V (shown in **12**), the world's first all-solid-state communications satellite, which was successfully launched on October 27, 1982. All 24 transponder channels are powered by 8.5-watt solid-state power amplifiers (SSPAs) developed jointly by RCA Astro-Electronics and the Microwave Technology Center of the RCA Laboratories. In addition to the increased reliability and longer life of the SSPA compared to traveling-wave-tube amplifiers (TWTAs) used on other communications satellites, the SSPAs of Satcom V provide greater traffic capacity per transponder channel due to their higher linearity and lower AM-to-PM distortion. Initial tests demonstrated the capability of two high-quality TV signals per transponder channel, operating without any input drive backoff as would be required for TWTAs. Thus, with these SSPAs, such a two-for-one TV service is possible, even to the many small, receive-only terminals.

The GaAs FET device was designed for C-band service with a dc-to-rf efficiency of approximately 33 percent and an operating gain of 60 dB. The amplifier, which covers an instantaneous bandwidth of 160 MHz selectable within the 3.7- to 4.2-GHz band, operates with a nominal input potential of 8.7 volts and weighs less than 13 ounces, approximately half the weight of the TWT it replaces, and measures 7" × 3" × 0.75".* This significant weight differential may be used in the spacecraft's solar-power supply to offset the slightly lower dc-to-rf power efficiency of the SSPA compared to the efficiency of the two-collector TWT (typically 33 percent versus 38 percent).



- 8 5 WATT
- GaAs FET
- LOW VOTALGE (10V
- INCREASED CAPACITY WITH IMPROVED LINEARITY
- LOWER COST IN HOUSE PRODUCTION

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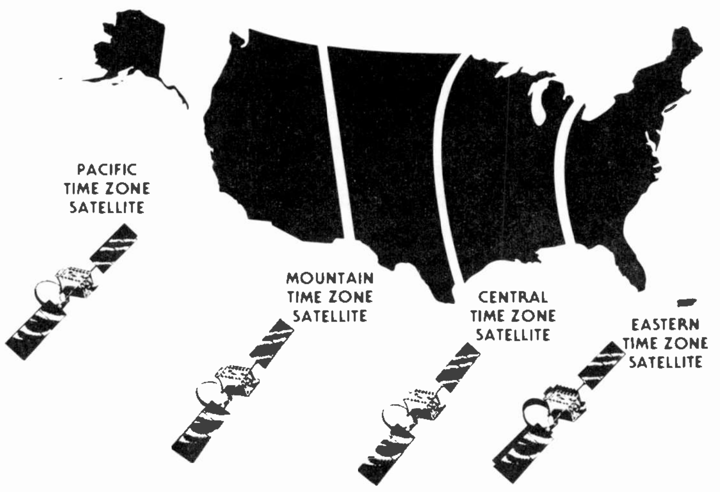
* H.J. Wolkstein and J.N. LaPrade, "Solid State Power Amplifiers Replacing TWTs in C-Band Satellites," *RCA Engineer*, Vol. 27, No. 5, p. 7 (Sept./Oct. 1982).



14 High-power microwave devices are also being used to provide the new Direct Broadcast Satellite (DBS) Service. In October 1982, RCA Astro-Electronics was awarded a contract by Satellite Television Corporation, a subsidiary of Comsat, to provide DBS equipment for Phase I of STC's new venture. It was the first DBS contract awarded for a U.S. system.

Direct broadcast spacecraft operate with 200-watt TWTAs, a power 10 to 40 times that of conventional C- or K-band satellites. By concentrating this power in an area approximating one U.S. time zone, it is possible to receive television programming directly from the satellite to the home with an antenna less than one meter in diameter. The primary audience for DBS would be those viewers who do not have cable and have limited program offerings.

From this discussion, it can be seen that communications satellites are simply microwave relay stations in space with many applications ranging from fixed to broadcast satellite services. In the fixed service, satellites have enhanced the growth of cable television and business communications. Satellites will play a major role in the broadcast service by creating another distribution network for the delivery of programming to individual households at any location.

W.F. Cashman

Ground-control processing for communications satellites—Trends for the next decade

The satellite is only part of the space-communications picture. On the ground, in the control centers, the man-machine interface is being improved, as computer technology allows status data to be presented more clearly and acted upon more swiftly. Also, new computer system architectures will provide greater reliability and growth capability.

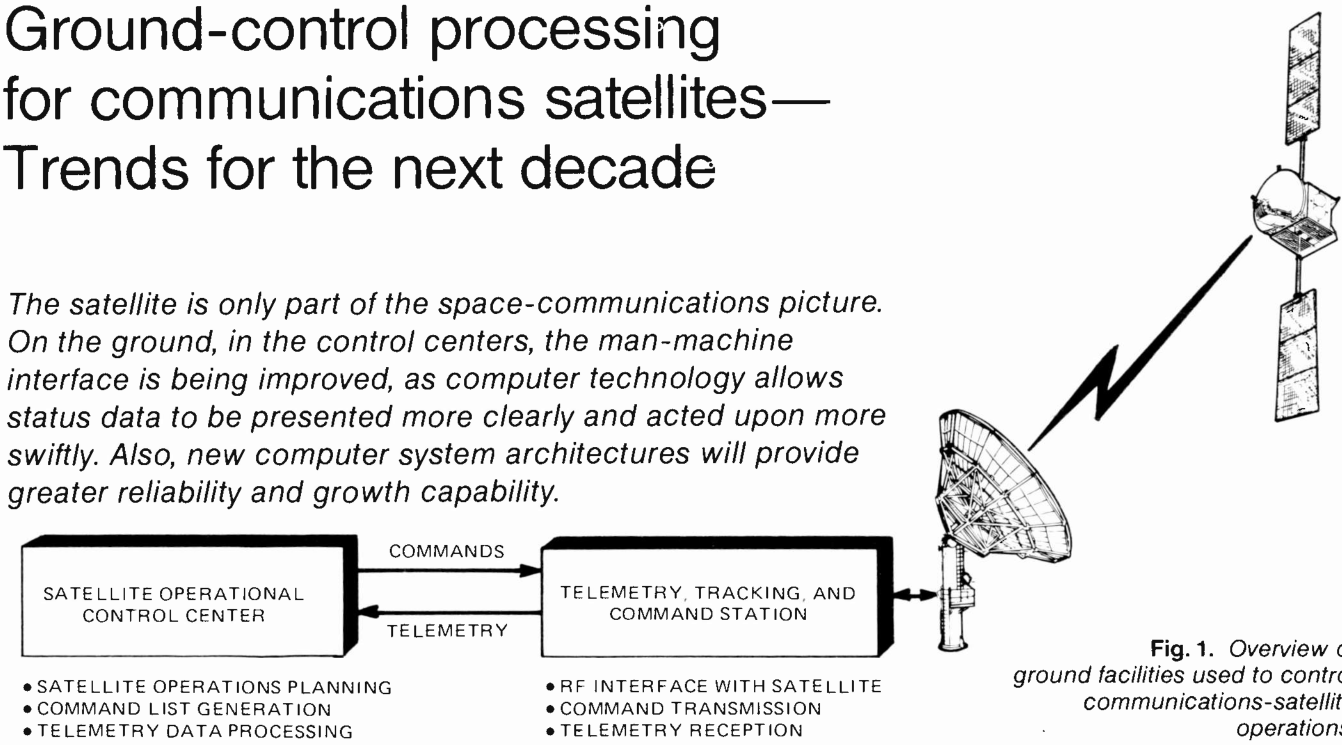


Fig. 1. *Overview of ground facilities used to control communications-satellite operations.*

Commercial communications satellites are placed in geostationary orbits about 22,300 miles (35,800 km) above the earth's equator. From these points in space, the satellites relay signals between ground-based communications stations. Operation of the satellites is planned and executed by ground-operations personnel, who use telemetered data to monitor satellite status and generate any needed commands to control satellite functions.

Abstract: *Contemporary ground systems for real-time control of communications-satellite operation use centralized processing architectures and provide operator interaction via keyboards and alphanumeric video display terminals. One challenge of the next decade will be to exploit emerging technologies related to processing architectures and man-machine interfaces, thereby improving system performance. Future ground systems will likely employ distributed-processing architectures to facilitate system expansion and the implementation of redundancy. In addition, operator displays will employ color and graphics to promote information comprehension, and non-keyboard data-entry devices will be available for operator input.*

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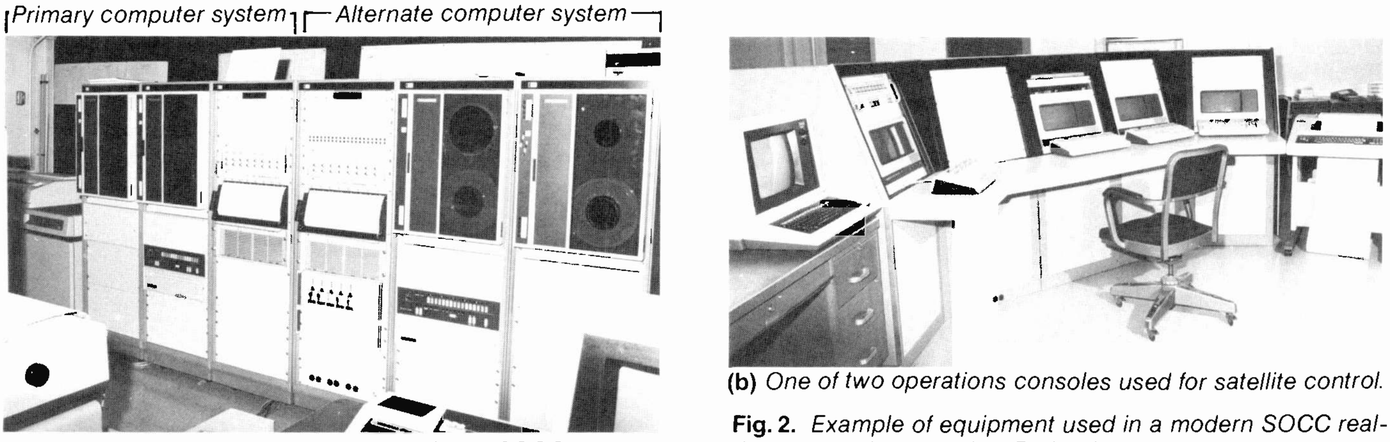
Ground-control activities for a communications satellite are normally divided between a Satellite Operational Control Center (SOCC) and a Telemetry, Tracking, and Command (TT&C) Station. The SOCC has responsibility for planning satellite operations and generating command lists to implement these plans. Also, satellite-telemetry data are processed at the SOCC to monitor the health and configuration of the satellite. The TT&C Station provides the rf interface with the satellite and is used to transmit satellite commands and receive satellite-status telemetry. Although the SOCC and the TT&C Station may be collocated, many systems employ separately located facilities and tie them together with data- and voice-communications links. Figure 1 presents an overview of ground facilities used to monitor and control a communications satellite.

Present-day communications-satellite control systems rely on digital computers to assist operations personnel by formatting satellite commands, and by displaying and checking satellite-telemetry data. The majority of the real-time data processing performed to support satellite operations takes place in the SOCC. Typically, the SOCC real-time computing system uses a centralized processing architecture in which a single high-performance minicomputer performs all needed processing, and a redundant backup minicomputer is available to recover rapidly from a failure of the primary computer. The system's man-machine interface is implemented using black-and-white, alphanumeric video display terminals for output displays and keyboards for operator input.

During this coming decade, it seems likely that the processing architecture and man-machine interface will evolve to take advantage of benefits offered by new hardware options and increasingly sophisticated software designs. In particular, distributed processing will be used to allow easy growth of satellite-control systems to accommodate additional satellites and to partition the processing hardware into small units that will allow redundancy to be



(a) *This redundant computer system performs SOCC ground-control processing.*

(b) *One of two operations consoles used for satellite control.*

Fig. 2. *Example of equipment used in a modern SOCC real-time computing complex. Redundant computer systems provide necessary system availability.*

achieved at a small incremental cost. For the man-machine interface, greater use will be made of displays offering both graphics and color capabilities. Although keyboards will be retained for operator input, they will be augmented by "touch panels," and other means, as appropriate, to facilitate the task at hand.

The next step in SOCC computer-system architecture

Ground-processing requirements

At the SOCC, the communications satellite's operational configuration is established, satellite orientation and orbital position is maintained, and the status of satellite subsystems is monitored. Satellite control is exercised by operators who use SOCC computers to prepare command lists that are relayed to the satellite via a TT&C Station. SOCC computers are also used to control the operation of turnaround-ranging equipment located at the TT&C Station. These ranging data are returned to the SOCC where they are processed to determine satellite orbital position. Finally, SOCC computers are used to accept satellite-status telemetry data from a TT&C Station, process the telemetry for display to the operator, and perform limit-checking to detect anomalous conditions.

To perform the required functions, SOCC processing must occur in real-time. Many satellite-commanding activities are time critical; satellite telemetry must be processed quickly so that up-to-date status information can be displayed for operator review. The computing capability needed to support real-time processing can be substantial, particularly for an SOCC handling multiple satellites simultaneously. It is also worth noting that commercial communications satellites generate substantial revenues amounting to $35-million to $40-million per year, per satellite. For this reason, the entire ground-control system must be designed to achieve high availability so that equipment failures do not jeopardize revenue flow. Thus, two important requirements for SOCC computing systems are real-time operation and high availability.

Today: Centralized processing

Present-day control centers tend to perform all satellite-control processing in a single minicomputer system—even in those cases where multiple satellites are being controlled. This concentration of all command-generation and telemetry-processing tasks in a single computer is termed centralized processing. A multi-tasking operating system provides the means by which the various ground-control tasks share the CPU and peripheral resources. The use of a single computer in this application has been made possible by significant advances in computer speed and memory capacity over the past ten years. This use of a single computer system to handle multiple satellites is less costly than dedicating one computer system to each satellite.

Although a single minicomputer system can provide sufficient capability for real-time command and telemetry processing, such a system does not meet the requirement for high availability. The needed availability can be achieved through the use of additional redundant equipment that can be brought on-line if the primary equipment fails. A common means of configuring the redundancy is to duplicate the primary system in the redundant system, that is, to use high-level redundancy.[1] This redundancy approach has the advantage of minimizing the amount and complexity of switching required to "cut in" the redundant system. As long as any needed data bases are accessible to the redundant system (say, via two-ported access to a shared disk drive), the only required switching is to move the TT&C communications links from the failed system to the redundant backup. With the "cutover" accomplished, satellite-control processing can resume in the redundant system, and the primary system can be repaired.

Figure 2 shows an SOCC computing complex that uses Hewlett-Packard 1000/F minicomputer systems and centralized processing. High-level redundancy is provided by having duplicate computer systems. Figure 3 contains a simplified block diagram of the computing complex.

With the current state of the art, centralized processing offers several benefits. Ground-control system designers have gained considerable experience during the past decade in working with centralized processing architectures. Hardware to support single-CPU systems is available from a number of vendors, and techniques for optimizing the hardware configuration to maximize system throughput are reasonably well understood. Programming of a single-CPU system is relatively straightforward. Because special programming skills are not required, most programmers can design and implement the required software.

On the other hand, centralized processing has a number of significant disadvantages. Because all tasks are executed in the same computer system and thus contend for the same resources, it is important to limit peak resource usage to less than 80 percent. This constraint will ensure that required real-time performance will not be degraded under peak loading conditions; however, the analysis needed to demonstrate design compliance with the constraint under all conditions may be quite involved. Accommodation of growth is another area of difficulty associated with centralized pro-

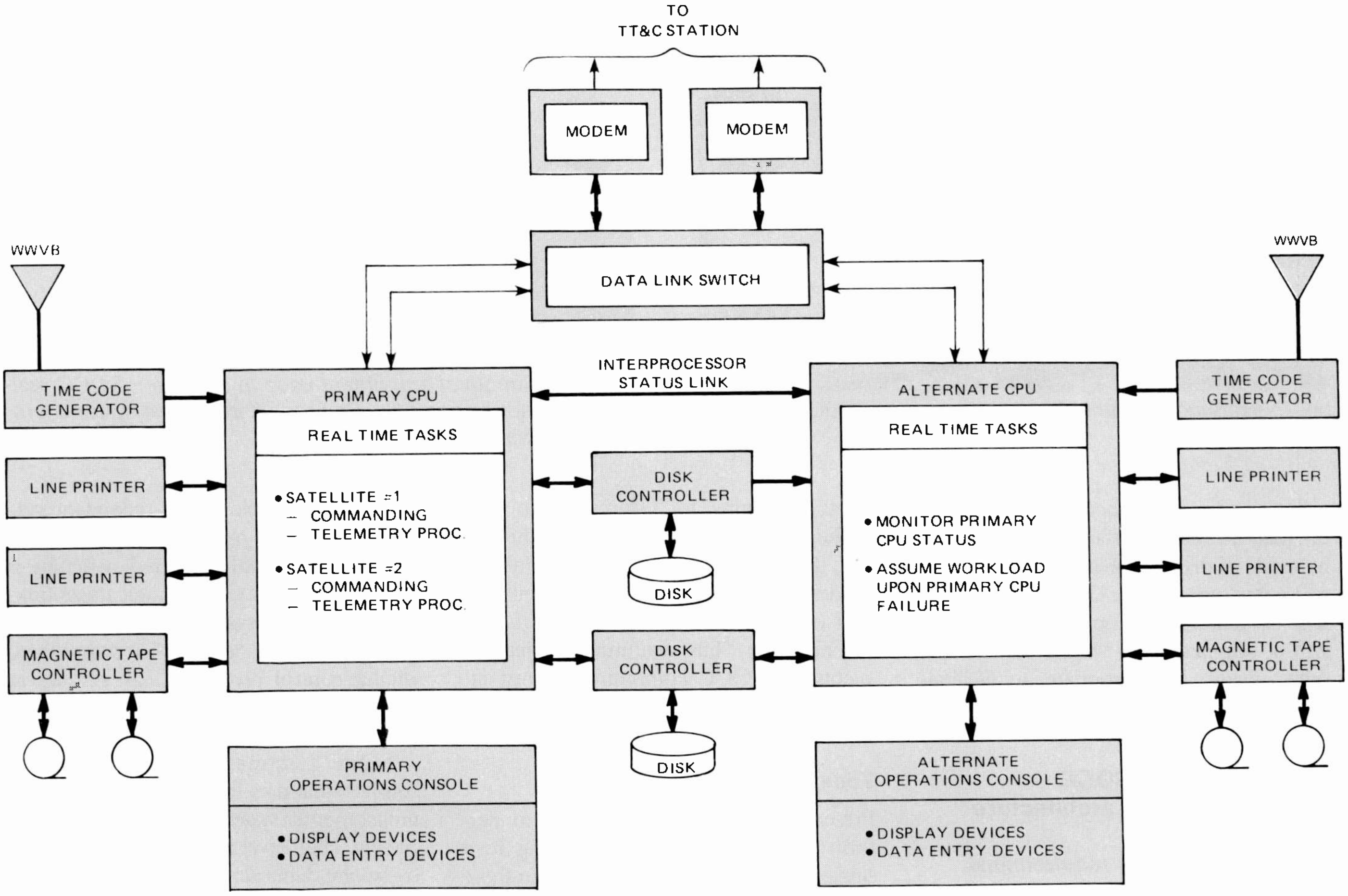


Fig. 3. *An SOCC real-time computing system in which processing for all applications tasks is centralized in a single CPU. A redundant, alternate CPU assumes satellite-control tasks should the primary CPU fail.*

cessing. A ground-control system designed to handle only an initial number of satellites may require expensive hardware and software upgrading to handle additional satellites, whereas a system designed to handle the total number of planned satellites might be greatly overdesigned for the initial satellite complement. Neither of these situations is financially attractive. Finally, redundancy in centralized processing systems generally is implemented by duplicating the primary system. This use of high-level redundancy simplifies cutover procedures and eliminates reliability problems associated with complex equipment-switching networks, but the cost of having duplicate systems is high.

The future: Distributed processing

A distributed-processing system employs a collection of CPUs and peripherals to provide the computing power needed by an application.[2] The CPUs may be cooperating closely (that is, tightly coupled) or operating nearly independently (that is, loosely coupled) depending on the requirements of the application. Distributed-processing software is modular and partitioned to reflect the organization of the computer hardware. The result of this hardware and software combination is a multiprocessing environment for task execution.

Figure 4 presents one of several possible distributed-processing configurations[3] designed to handle a satellite-control application similar to that considered in Fig. 3. As can be seen by examining Fig. 4, control processing for each satellite is performed in a separate CPU, with the active CPUs sharing access to the TT&C communications links and the computer-system peripherals. Data are routed through the distributed-processing system in the form of fixed-length message packets over the redundant intercommunications bus. Use of a packet structure permits efficient movement of bus traffic, selective message routing, and close control of message integrity. Peripheral devices are attached to the bus by the use of interface (I/F) processors that support the bus protocol.

To circumvent the failure of a CPU, a spare CPU already connected to the intercommunications bus is loaded with the appropriate software package. Duplication and sharing of peripheral subsystems allow sufficient backup capability to accommodate peripheral-device failures. Growth of the ground-control system to handle additional satellites can be accomplished by adding CPUs to the bus and loading them with copies of the common software package used for command and telemetry processing.

Distributed-processing configurations have the potential to provide a cost-effective design for future satellite ground-control applications—particularly in those applications requiring growth capability and high availability. However, several challenges must be overcome before the potential can be realized.

First, hardware supporting distributed, real-time processing systems is not readily available from a large number of vendors; in some cases, the available hardware is not flexible enough to be used in the satellite-control application. Next, standard systems software (specifically, operating systems and on-line diagnostics) is generally

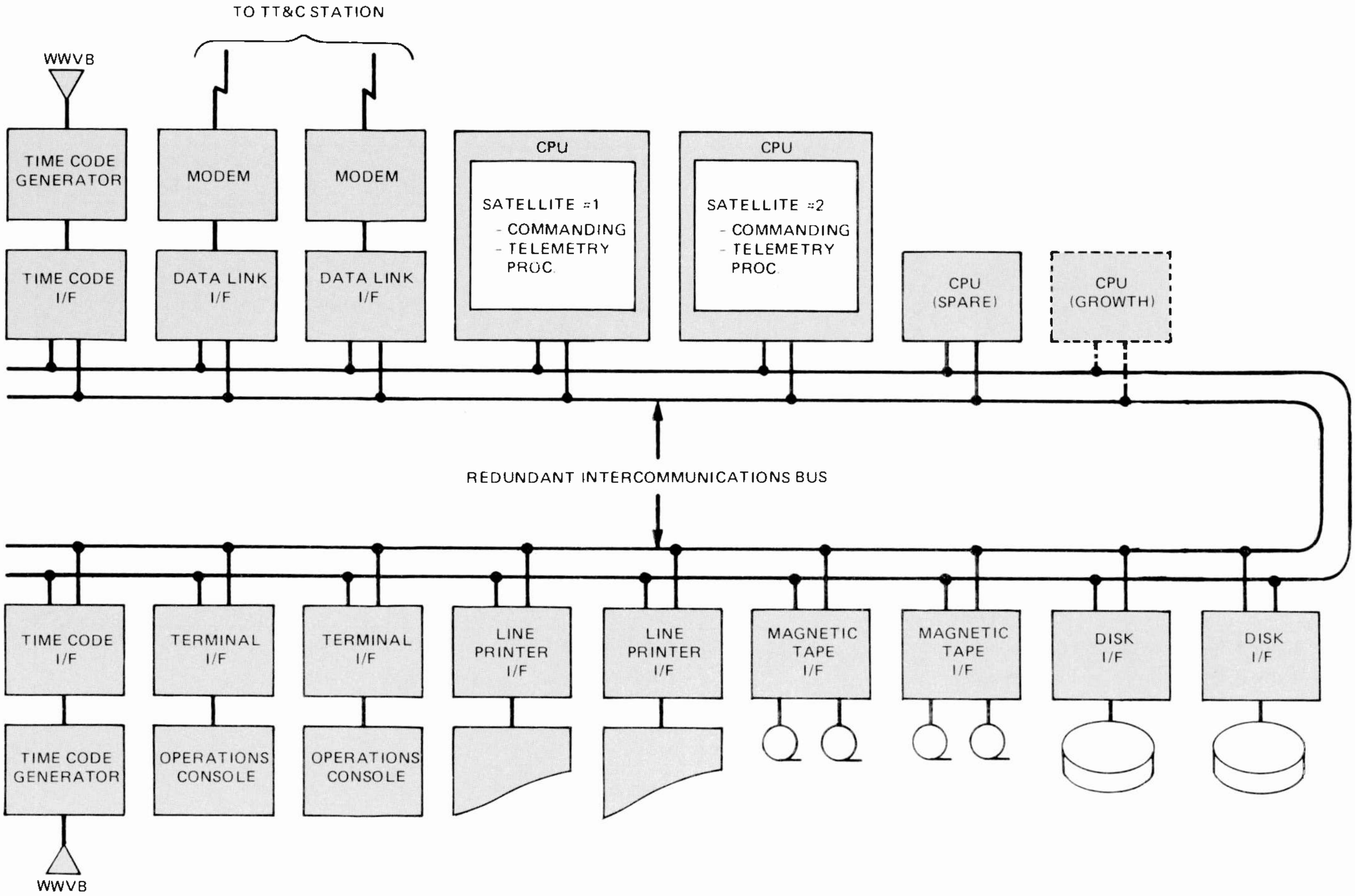


Fig. 4. *A future SOCC real-time computing system using distributed processing for satellite-control tasks. Redundancy provisions and accommodation of growth are facilitated by the modular architecture of hardware and software.*

not capable of performing cutover of redundant CPUs and rerouting of message packets (to bypass failed hardware units) as part of the normal multiprocessing environment.

Finally, although distributed processing tends to limit the workload of a given CPU and to make the processing requirements less variable, distributed processing does place a heavy burden on the communications medium—in our example, the redundant intercommunications bus. Better techniques need to be developed for making efficient use of bus capability and for analyzing average and worst-case bus traffic to eliminate the possibility of real-time performance degradation.

Evolution of the man-machine interface

Operator interface requirements

In a satellite-control application, the operator is responsible for monitoring satellite status, generating command lists to establish satellite configuration, and controlling all ground-based equipment used to support satellite operation. To perform these tasks, the man-machine interface located at the operations console must provide both a display capability for status data and a means for operator entry of commands. As a minimum, the console must permit rapid, up-to-date display of satellite or ground-equipment status, and it is preferable to have the data converted to natural (engineering) units rather than shown as raw telemetry values. On the operator entry side, the input device(s) must permit an operator to select all operational modes of the satellite and ground equipment, and here it is preferable to structure the interaction to speed operator-input tasks and minimize operator errors. The following paragraphs discuss the present approach to implementing the man-machine interface for communications-satellite control and the future evolution of this interface.

Today's man-machine interface

In a typical ground-control system, alphanumeric black-and-white CRT terminals serve as the workhorses for display of status data. These CRTs provide adequate capability to present so-called "pages" of satellite- or ground-equipment status in a tabular format. Raw status data are usually converted to engineering units before display to facilitate operator comprehension, but, when appropriate, raw data can also be displayed. Most systems will perform comparison of selected status points against operator-specified limits, and, if a point falls outside the limits, the operator is notified. This notification may take the form of a message on the display device, but may also be communicated by flashing a displayed value or using a "reverse-video" format. Figure 5 shows a sample page used to display the status of a satellite subsystem.

In some operator consoles, CRT-display terminals—having enhanced capabilities such as color, graphics, or both—are being used to supplement the alphanumeric black-and-white CRTs. The reason for employing enhanced display devices is that such devices give a designer additional options in presenting information to an operator.[4] This

Reaction control subsystem

REA status

Thruster	Enabled	Armed	C.B. Temp. (° C)	Thruster	Enabled	Armed	C.B. Temp. (° C)
1	Yes	Yes	200	7	No	No	15
2	Yes	Yes	200	8	No	No	15
3	Yes	Yes	200	9	No	No	15
4	Yes	Yes	200	10	No	No	15
5	No	No	15	11	No	No	15
6	No	No	15	12	No	No	15

EHT status

Thruster	Enabled	C.B. Temp. (° C)	A.H. Curr. (amps)	Thruster	Enabled	C.B. Temp. (° C)	A.H. Curr. (amps)
13	Yes	600	16	15	Yes	600	16
14	No	15	0	16	No	15	0

RCS status

Tank 1 Temp.	10° Celsius	Latch Valve 1	Open
Tank 2 Temp.	10° Celsius	Latch Valve 2	Closed
Tank 3 Temp.	10° Celsius	Latch Valve 3	Open
Tank 4 Temp.	10° Celsius		
Odd-System Press.	250 psi	Even-System Press.	250 psi

Fig. 5. *Sample telemetry page showing status of a satellite subsystem. Such pages use capabilities found in conventional alphanumeric, black-and-white CRT terminals. This page is shown typeset for greater readability.*

additional flexibility permits display of information in a way that promotes operator comprehension and speeds operator response to contingencies. Costs for these enhanced capability displays have declined over the past decade, and the number of vendors making reliable, commercial-grade devices has increased. Thus, greater use is being made of these displays in the design of new satellite-control centers and in upgrades of existing centers. The limiting factor in realizing the potential of enhanced-capability displays is the current lack of a methodology (or guidelines) to help in designing display formats.[5]

Turning to the issue of operator entry in today's systems, we find that a keyboard is used exclusively as the input device in almost all systems. Keyboards offer considerable flexibility in generating command strings and supplying any needed data values. An operator is assisted in his input tasks by selection menus (or prompts) displayed on a CRT. To select one of the items in a menu, an operator uses the keyboard to type in the digit or letter associated with the item (or moves a cursor to the item) and then depresses an "enter" key. These menus structure the input dialogue so that only valid options are available for operator selection at each stage of the input process. Moreover, any data supplied as part of the dialogue, whether supplied directly or by mnemonic reference, are checked for conformance to the set of values that may legally occupy the designated data fields. This use of menus and data validation eliminates many potential operator-input errors.

Man-machine interface trends

Looking to the future, one is certain to see heavy, possibly total use of color-graphics terminals for status displays. These devices will allow use of color diagrams, plots, and bar charts to indicate satellite or ground-system status. They will also allow use of black-and-white tables of data where such displays are deemed to be the best choice. Equal in importance to the advances in display devices will be the increased software analysis of data prior to display.

As noted earlier, today's systems can limit check data values and alert the operator to out-of-limit conditions. However, a single problem may lead to numerous fault indications, and the operator is forced to deduce the cause. Future systems will aid the operator by analyzing the fault data to determine the likely cause of the problem, displaying the problem cause, and suggesting options for problem correction. When multiple problems occur simultaneously, the problems will be given priorities, with the most critical problem displayed first for operator action. Figure 6 presents a sample color-graphics display screen that might be used to show the status of a satellite subsystem.

For operator-entry tasks, future systems will employ various alternative input devices. One promising alternative device for menu-selection tasks is a "touch panel" that fits over the screen of a CRT display. With this device installed, an operator makes menu selections by touching designated areas of the display screen. Thus, operator concentration is not disturbed by constant shifting of attention from the screen to the keyboard and back again. The keyboard will be used only where data entry is required by a task.

The envisioned evolution of the man-machine interface will produce a number of operational benefits. Communications-satellite operations are characterized by long

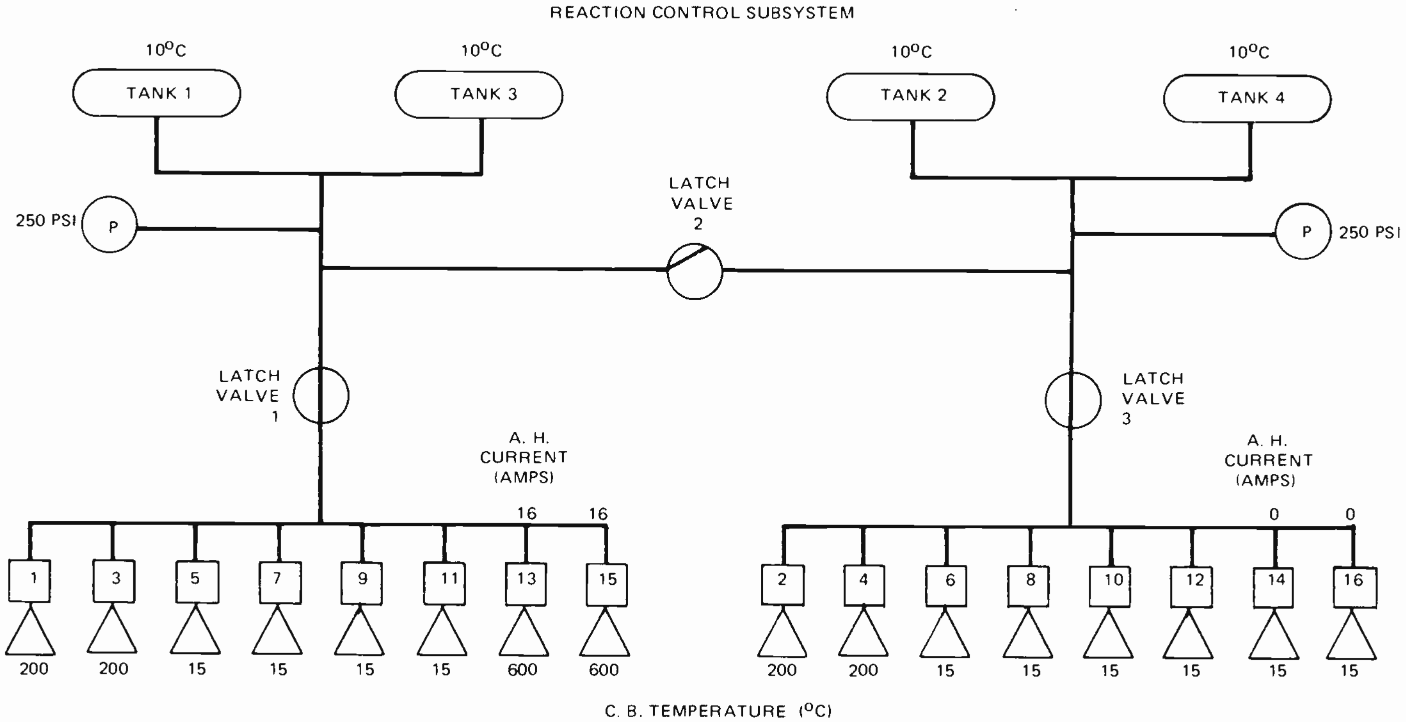


Fig. 6. *Sample color-graphics display showing status of a satellite subsystem. Colors are used to denote enable/arm status of thrusters and propellant flow path. Out-of-limit telemetry values are highlighted using appropriate colors.*

periods of low-level, routine control and monitoring of on-station satellites, with occasional peak periods occurring at the times of satellite orbital-correction maneuvers. The future man-machine interface will promote operator control and monitoring of planned satellite activities. More importantly, the future interface will produce more rapid recognition by the operator of contingency conditions and will hasten his response to them. In addition, the improved man-machine interface will increase the predictability and consistency of operator performance and reduce the skill level required to operate a satellite.

To achieve these benefits, some challenges must be addressed before the future man-machine interface can become a reality. Because much of the hardware technology needed to support this interface already exists, the hardware challenge is to further reduce costs and increase reliability. The software challenges are to develop tools that simplify the generation and modification of color-graphics screen images used for status data display, and to construct routines, possibly based on fault trees, that analyze status data and relate fault indications to probable cause. Finally, perhaps the most difficult challenge will be to develop a methodology to guide designers in producing color-graphics screen images that optimize transference of status information to an operator.[6, 7]

Conclusions

Distributed processing and man-machine interface enhancements are two trends that will influence satellite-control-center design over the coming decade. Benefits of these trends include greater ground-control system availability at lower cost and more effective operator control of the satellite. However, these benefits will be realized only after certain challenges concerning hardware, software, and design methodology have been conquered.

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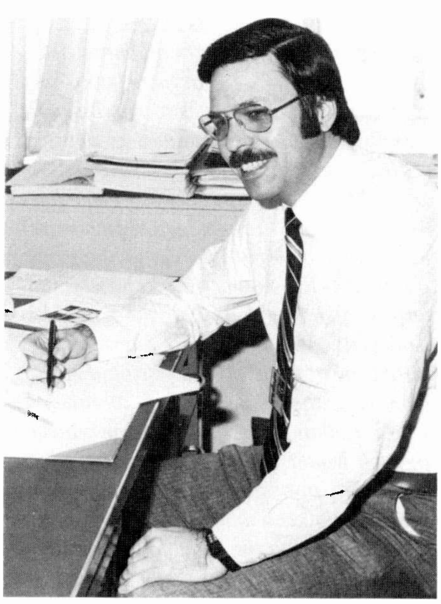

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J.F. Balcewicz

In-orbit reconfigurable communications-satellite antennas

In-orbit reconfigurable antennas can change with the demand, and with the times, thereby optimizing communications-satellite performance.

Abstract: *Shaped-beam antennas are used on present-day geosynchronous-orbit communications satellites to maximize the effective isotropically radiated power (EIRP) reaching the desired coverage areas. When a communications satellite must meet its coverage requirements over a wide range of orbital positions, the performance of its single, fixed-antenna pattern is often less than that which could be achieved with an antenna pattern optimized for a single orbital position. A communications satellite with an antenna whose radiation pattern could be adjusted in-orbit would clearly offer an attractive capability. In-orbit reconfigurability is also desirable to accommodate changing traffic demands during the satellite's 10-year lifetime. This paper describes several current examples of RCA-designed communications satellites that include modest in-orbit reconfigurability (namely Satcom G, Spacenet, and GSTAR), and gives details of a proposed design for a reconfigurable communications-satellite antenna with commandable beam shapes matched to a wide range of orbit positions and service areas.*

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There is a fundamental relationship between the angular coverage provided by a directive antenna and its gain. Antenna gain is expressed in dBi (or decibels above the gain of an isotropic radiator). The isotropic radiator may be thought of as an omni-directional antenna that radiates uniformly in all directions. Antenna gain is therefore a measure of the degree to which the radiation from the antenna is concentrated in a specific desired direction. The relationship is given by:

$$\text{Gain (dBi)} = 10 \log_{10} (K/\theta_1\theta_2) \quad (1)$$

The constant, K, in equation (1) is usually about 27,000 for practical antennas, and θ_1 and θ_2 are the dimensions of the antenna's angular coverage pattern expressed in degrees. As an example, an antenna designed to generate a 7° × 3° elliptical radiation pattern (which is approximately the size of the 48 contiguous United States as seen from geosynchronous altitude), would be expected to have a gain at beam center of 31.1 dBi from equation (1). The gain at the edge of the 7° × 3° beam would be nominally 3 dB lower.

One communications-spacecraft parameter of great importance is effective isotropically radiated power (EIRP), which specifies how powerful the spacecraft's transmissions are. EIRP in dBW (decibels above a 1-watt reference), may be calculated from equation (2):

$$\text{EIRP (dBW)} = \text{Power (dBW)} + \text{Gain (dBi)} \quad (2)$$

As seen from equation (2), EIRP is the sum of the power (in dBW) that is fed into an antenna and the gain of that antenna in dBi. For the 7° × 3° antenna discussed previously, a 5-W (or $10 \log_{10} 5 = 7.0$ dBW) input-power level results in a transmitted EIRP of:

$$\text{EIRP (dBW)} = 7.0 \text{ dBW} + 31.1 \text{ dBi} = 38.1 \text{ dBW} \quad (3)$$

at beam center and 35.1 dBW around the edge of the 7° × 3° pattern. Note that 35.1 dBW represents a power level of 3.24 kW. This demonstrates the ability of the antenna to concentrate the 5-W rf power generated on the spacecraft into the desired coverage area, thereby acting as a much more highly powered transmitter.

For most communications-spacecraft applications, the greater the EIRP that can be generated (subject to spacecraft weight and power constraints and sometimes regulatory constraints as well) the better. One way to increase EIRP without increasing the power fed to the antenna is to reduce the antenna coverage area to a minimum and thus increase the antenna's gain. This is why shaped-beam antennas[1] have come to be used in modern communications-satellite systems. A shaped-beam antenna produces a radiation pattern that exactly matches the desired coverage area. This minimizes the angular extent of the coverage region, maximizes the antenna gain, and prevents radiation of spacecraft power into unwanted regions.

The problem

Unfortunately, there is a drawback to this situation. Because a shaped-beam antenna-radiation pattern is so well matched to the shape of a specific geographic region as

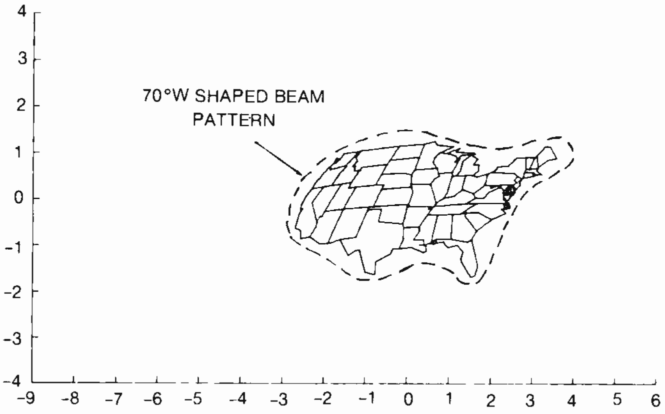


Fig. 1a. *Shaped-beam coverage of CONUS from a satellite at 70° W. The antenna-radiation pattern conforms closely to the shape of CONUS as viewed from geosynchronous altitude.*

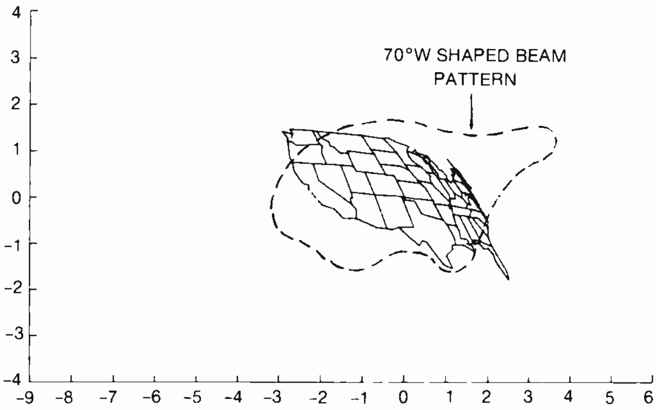


Fig. 1b. *Use of the 70° W shaped-beam pattern at 140° W. The shape of CONUS changes drastically from 70° W to 140° W. Coverage of northwest and southeast CONUS is poor, and transmit power is wasted off the California and mid-Atlantic coasts.*

seen from geosynchronous altitude, even small changes in coverage-region shape will result in less than optimum performance.

Such changes in coverage-region shape can result from either the addition or deletion of certain regions from the nominal satellite service area or from a relocation of the satellites from one geosynchronous station (longitude) to another. An example of the former might be a desire to add coverage of Alaska and Hawaii to a communications satellite with continental United States (CONUS)-only coverage, after only a fraction of the satellite's 10-year life has expired. Satellite relocation must be considered because specific orbital slots are not assigned to a spacecraft until long after the design phase is complete and because the Federal Communications Commission is always considering ways of using the "geosynchronous arc" more efficiently, including relocating satellites already in orbit. Figure 1 shows the shape of CONUS as seen from geosynchronous orbit locations of 70°W longitude and 140°W longitude. It is seen that a shaped-beam antenna pattern providing good coverage from 70°W would provide extremely poor coverage from 140°W.

An added dimension to this problem is the spare satellite(s). Consider the case of a communications carrier who wishes to have two satellites in orbit: one at 70°W and one at 140°W. To maximize the performance of each, the spacecraft designer must design two different shaped-beam antenna patterns, one for each orbital location. To protect himself against a catastrophic spacecraft failure, the carrier also orders a spare satellite. His problem is in deciding which antenna design should be put on the spare spacecraft. Not knowing, *a priori*, which spacecraft will fail, he may have both antenna systems built and wait for a spacecraft failure before mounting the antenna on the spacecraft. Unfortunately, the time involved in mounting the antenna, completing spacecraft testing and obtaining a launch date may be 9 months or longer. Providing a spare spacecraft antenna that is a compromise between the 70°W and 140°W antenna design is also unattractive because it would provide less performance than the carrier's customers were receiving. Having two spare spacecraft, one for each orbit location, is a possible but costly alternative.

The solution

The solution under current study at Astro lies in designing a communications-satellite antenna system that is reconfigurable in orbit. Such a system would generate a number of shaped-beam antenna patterns that could be selected via the command link once the spacecraft was placed in orbit.

Satcom

The original Satcom series includes the spacecraft shown in Table I. These spacecraft have no in-orbit reconfiguration capability. Any attempt to match the antenna's radiation pattern to the desired coverage regions had to be made prior to launch. For this reason, the nominal antenna footprint shown in Fig. 2 was slightly modified for several groups of channels on the Satcom I and Satcom II spacecraft. These modifications included a shift of one six-channel beam on Satcom I west, a six-channel beam on Satcom II southeast, and another six-channel beam on Satcom II northwest to improve coverage of Alaska. Had Satcom II failed early in its life, the Satcom I spacecraft would not have been able to effectively back up those six Alaskan channels.

Table I. *First-generation Satcom spacecraft.*

Spacecraft	*Launch date*	*Orbital location*
I	December 1975	135°W
II	March 1976	119°W
IIIR	November 1981	131°W
IV	January 1982	83°W

The Satcom IV spacecraft was designated to serve CONUS from an easterly longitude. Because of the radical change in the shape of the coverage region between the westerly orbit locations (119°W, 131°W, and 135°W) and 83°W, the elliptical antenna pattern, canted at an angle of 20.5° to the equatorial plane, was not suitable for Satcom IV. Consequently, the entire Satcom IV antenna system was rotated through 16° to provide an elliptical footprint whose major axis was nearly horizontal (aligned with the east-west direction of CONUS).

Satcom V, launched in October 1982 and stationed at 143°W longitude, is the first of the advanced Satcom spacecraft.[2] It also contains no in-orbit antenna pattern reconfigurability. However, the Satcom V antenna system provides shaped-beam coverage of all 50 United States for the 12 vertically polarized channels and Alaska-only coverage for the 12 horizontally polarized channels. Satcom G, scheduled for an April 1983 launch, must provide a backup

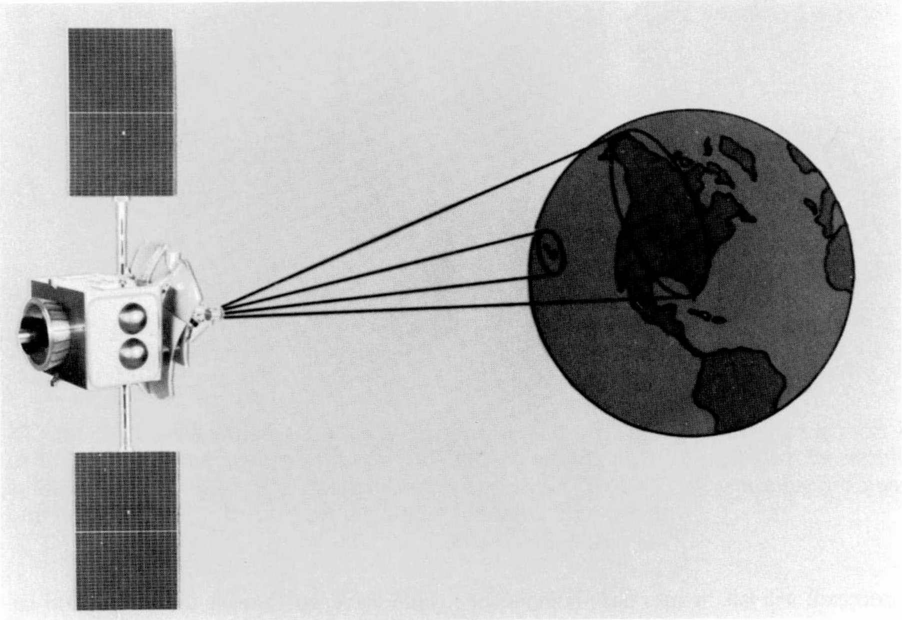


Fig. 2. *Satcom I, II, and IIIR antenna-pattern footprint from westerly orbit longitudes. The 8.4° × 3.2° elliptical radiation pattern is tilted 20.5° with respect to the equatorial plane to cover CONUS/Alaska.*

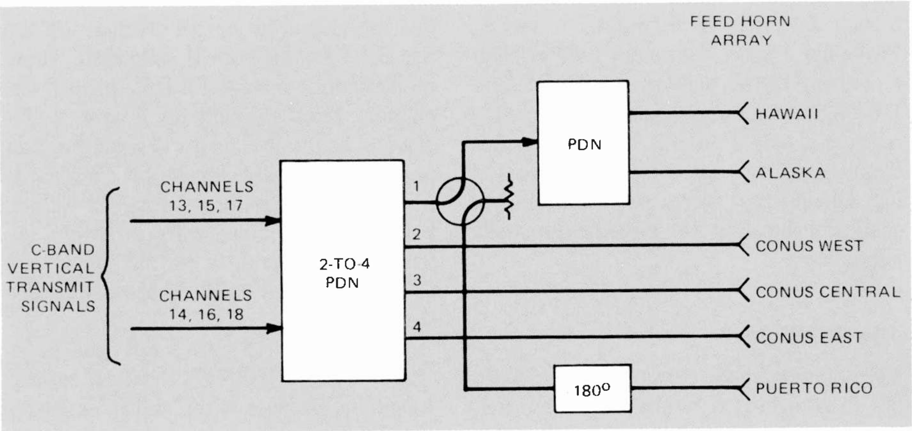


Fig. 3. *Spacenet antenna block diagram. The switch directs a fraction of the transmit power to the Hawaii and Alaska feed horns for western coverage or to the Puerto Rico horn for eastern coverage.*

capability for the 12 Alaskan channels. It will accomplish this by use of an in-orbit reconfigurable antenna. The design of this antenna is such that the 12 horizontal channel signals may be sent to one of two antenna-power-dividing networks (PDN). One of the networks divides the transmit power among the three horns that cover Alaska. The other PDN divides the power among the seven horns that cover CONUS, Alaska, and Hawaii. Selection between the two PDNs is made via coaxial transfer switches that are remotely controlled from the ground.

Spacenet

Astro is currently constructing four Spacenet communications spacecraft for the Southern Pacific Satellite Company. The first launch will be in 1984. It is anticipated that one of the spacecraft will be located at 70°W longitude and must provide C-band coverage of CONUS and Puerto Rico while another spacecraft will be located at 119°W longitude and must cover CONUS, Alaska, and Hawaii. Furthermore, the second satellite must serve as a launch backup for the first, and it must be possible to relocate a spacecraft from a westerly station to an easterly station (or vice versa) any time after launch. A reconfigurable C-band antenna shown in Fig. 3 was designed for this mission.

For the switch in the position shown, the power leaving Port 1 of the 2-to-4 PDN is sent to the Hawaii and Alaska transmit feed horns, and the Puerto Rico horn is terminated. This provides western coverage. For the alternate switch position, the Port-1 power is sent to the Puerto Rico feed horn, and an eastern coverage pattern results. The 180° phase shift is needed to provide a monotonic phase pro-

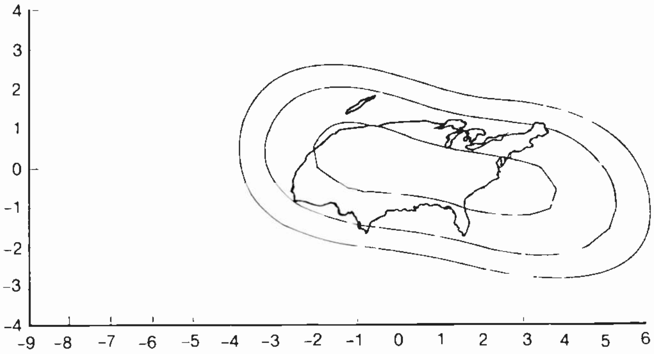


Fig. 4a. *Typical Spacenet EIRP pattern: Eastern satellite configuration (70° W). Transmit power is divided among the CONUS west, CONUS central, CONUS east, and Puerto Rico horns.*

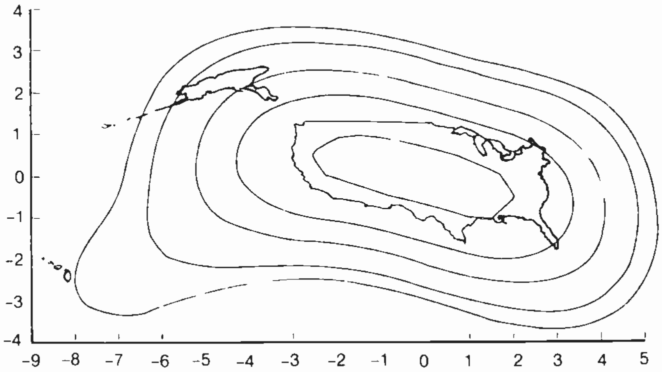


Fig. 4b. *Typical Spacenet EIRP pattern: Western satellite configuration (119° W). Transmit power is divided among CONUS east, CONUS central, CONUS west, Alaska, and Hawaii horns.*

gression over the feed array. This is necessary for the individual component beams to add constructively and not exhibit a deep hole within the coverage region. Typical EIRP patterns are shown in Fig. 4 for the eastern and western antenna configurations.

GSTAR

Astro is also constructing four Ku-band spacecraft for the GTE Satellite Company. They will be launched beginning in 1984. These spacecraft have been designed to operate over a relatively narrow range of orbital longitudes (94°W to 106°W). With regard to reconfigurability, fourteen of the sixteen transponder channels aboard each GSTAR spacecraft must be individually switchable among a CONUS radiation pattern, an eastern spot-beam pattern, and a western spot-beam pattern. This is accomplished by the combination of output multiplexer and antenna equipment shown in Fig. 5. There is a variable power divider (VPD) for each of the fourteen channels that can be individually set. When the VPD sends all of its incoming power to the seven eastern feed horns via the east multiplexer and east PDN, an eastern spot beam is formed. Similarly, the western spot beam is formed when the VPD sends 80 percent of its incoming power to the six western feed horns and 20 percent to the eastern feed horns. An east/west split of 55 percent/45 percent generates a CONUS beam. The phase of each channel's signal paths through the east and west multiplexers must be equalized to ensure that east and west spot beams constructively combine to create the CONUS beam.

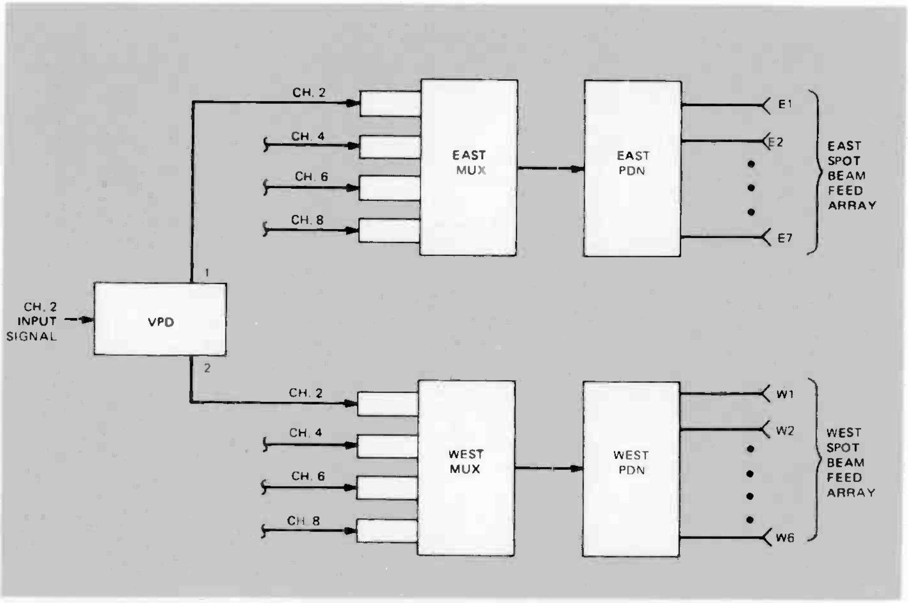


Fig. 5. *GSTAR output multiplexer/antenna block diagram. Fourteen of the sixteen channels contain a variable-power divider (VPD) that is controllable from the ground and is used to form an east or west spot beam or an all-CONUS beam.*

Reconfigurable antenna system

An Independent Research and Development (IR&D) program was conducted in 1982 to develop and analyze a conceptual reconfigurable antenna system that could provide the range of antenna-radiation patterns necessary to act as a spare for the Satcom series of spacecraft. Consequently, the antenna system was required to generate good shaped-beam antenna patterns from 66°W, 83°W, 119°W, 129°W, and 139°W including spot-beam coverage of Alaska (as in Satcom V). A block diagram of the antenna system that was developed is shown in Fig. 6. It consists of 15 VPDs, 2 fixed-power dividers, and an array of 13 feed horns. The horns are labelled to indicate the region of the coverage area that

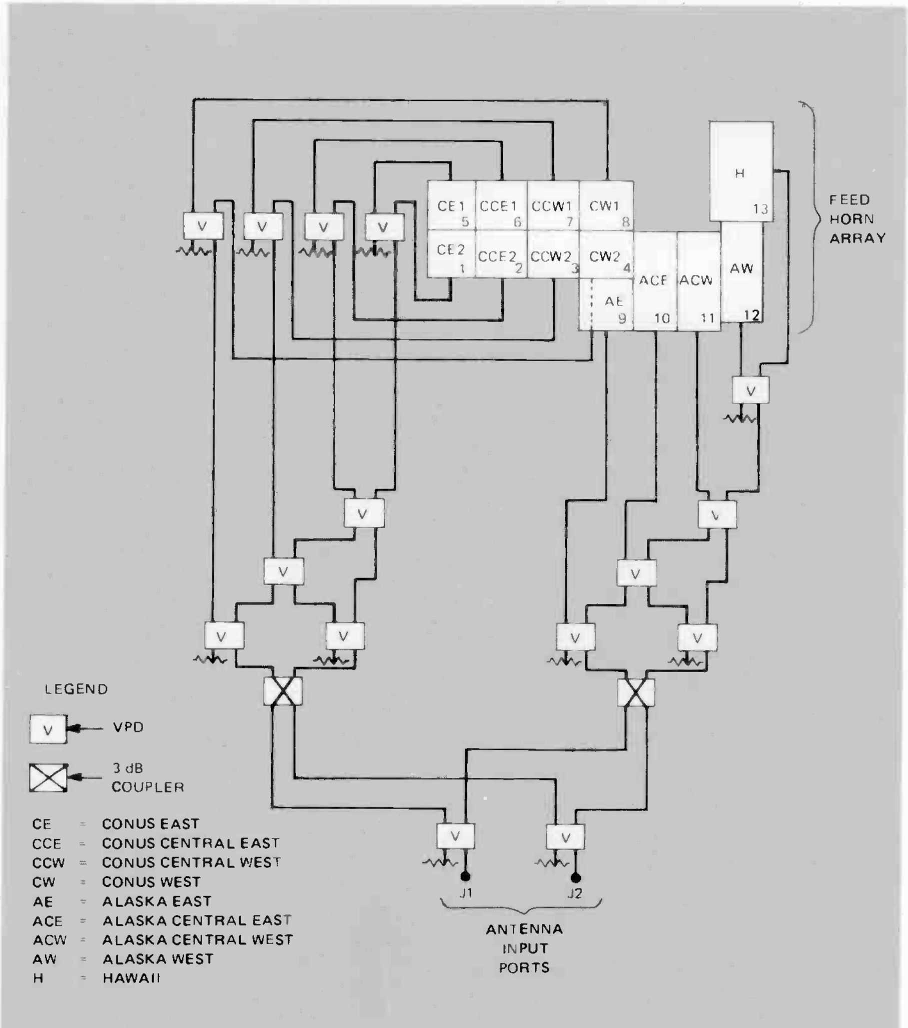
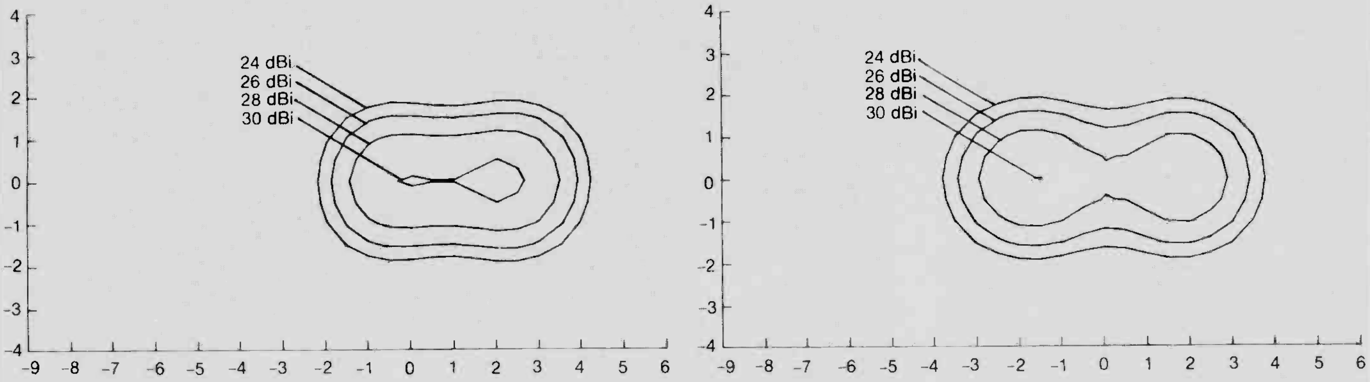
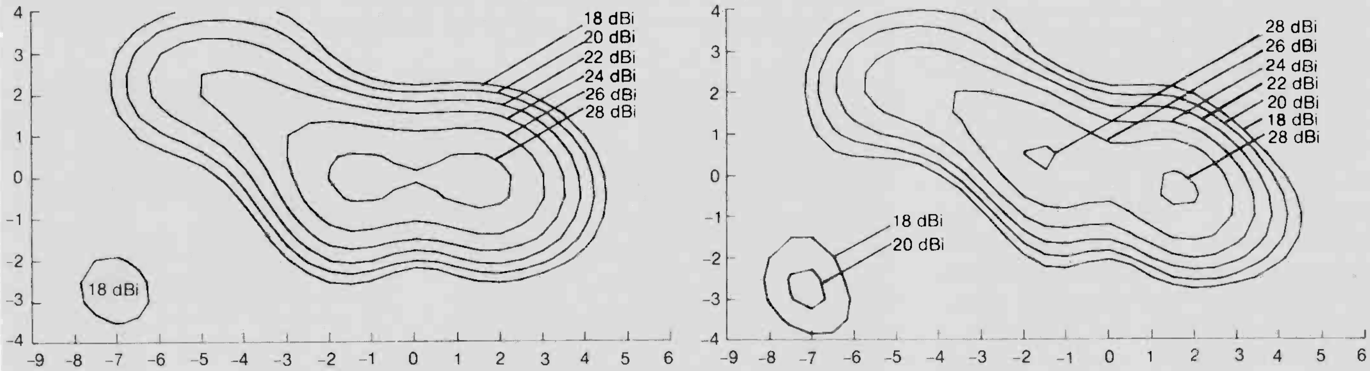


Fig. 6. *Reconfigurable-antenna-system block diagram. The 15 VPDs enable a wide range of transmit-power distributions to be achieved under ground control.*



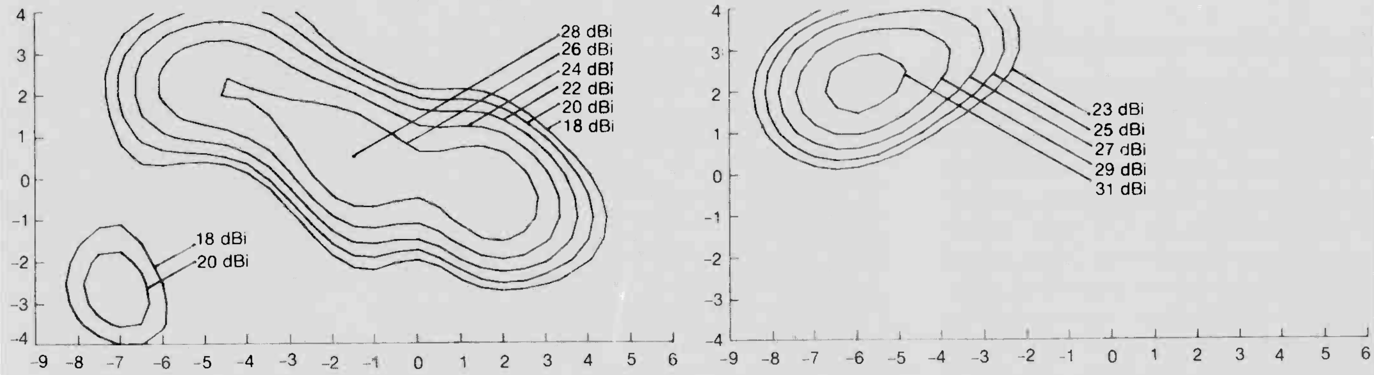
A. 66°W (CONUS)

B. 83°W (CONUS)



C. 119°W (CONUS/ALASKA/HAWAII)

D. 129°W (CONUS/ALASKA/HAWAII)



E. 139°W (CONUS/ALASKA/HAWAII)

F. 139°W (ALASKA ONLY)

Fig. 7. *Transmit-antenna gain pattern for the reconfigurable antenna system. This sample of possible antenna patterns shows how the shaped-beam coverages can be changed as a function of orbital longitude and specified service area.*

their component beams illuminate. The CONUS horns (horns 1 through 8) are arranged in a "southern" row (horns 5 through 8) and a "northern" row (horns 1 through 4). By properly selecting the division ratio in each VPD, the input power can be split among those feed horns needed to produce a shaped-beam pattern over the desired coverage region. Figure 7 shows several examples of the patterns that may be generated, and Table II defines the percent of input power that is present in each feed horn to produce each pattern.

The added flexibility of this reconfigurable antenna system does not come without penalty. These penalties are additional weight and rf losses as compared to an antenna system optimized for a single-longitude mission.

Conclusions

There is a need in future communications-satellite missions to be able to alter the communication antenna's radiation pattern in orbit to respond to changes in orbital location or the specified service areas, and to provide a general-purpose spare satellite that can back up the other satellites. The trend since Satcom I has been to design a limited amount of reconfigurability into the spacecraft's antenna system. The most reconfigurable of the designs described above will be implemented only if the weight and loss penalties can be reduced to manageable levels.

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Table II. *Feed-horn power-division percentages.*

Feed horn		***Percent of input power for:***					
Number	*Name*	*66° W*	*83° W*	*119° W*	*129° W*	*139° W (Conus/ Alaska/ Hawaii)*	*139° W (Alaska only)*
1	CE2	16.6	8.0	6.3	—	—	—
2	CCE2	16.8	16.0	12.6	13.1	12.1	—
3	CCW2	16.6	17.5	13.7	13.1	12.1	—
4	CW2	—	8.5	6.7	13.1	12.1	—
5	CE1	16.6	8.0	6.3	13.1	12.1	—
6	CCE1	16.8	16.0	12.6	13.1	12.1	—
7	CCW1	16.6	17.5	13.7	13.1	12.1	—
8	CW1	—	8.5	6.7	—	—	—
9	AE	—	—	5.5	5.5	5.4	28.8
10	ACE	—	—	5.6	5.6	8.0	28.8
11	ACW	—	—	5.5	5.5	8.0	28.8
12	AW	—	—	—	—	—	13.6
13	H	—	—	4.8	4.8	6.0	—

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R.N. Gounder | E. Talley | S. Ino

Thermally stable, precision antenna reflectors for satellite communications

Lightweight, sturdy composite materials provide satellite reflectors with the dimensional stability under operational environments required for effective performance.

The communications satellites built by RCA Astro-Electronics are shown in Fig. 1. The antenna reflectors used on these satellites fall into three categories: Frequency-reuse, dual-shell reflectors; dual-polarized, single-shell reflectors; and solid, single-shell reflectors. These reflectors may be either fixed to the spacecraft or deployable from a stowed configuration.

Communications antenna reflectors

Fixed, frequency-reuse, dual-shell reflectors

The fixed, frequency-reuse, dual-shell reflector (Fig. 2) is exemplified by the Satcom partially overlapping, dual-shell, C-band reflectors; the Advanced Satcom, fully overlapping, dual-shell, C-band reflectors; the GSTAR fully overlapping, dual-shell, K-band reflectors; and the Spacenet fully overlapping, dual-shell C-band reflectors.

In general, these communications-antenna reflectors consist of two parabolic sandwich shells, one in front of the other. These shells are attached to each other with precisely contoured sandwich ribs, resulting in a "super-sandwich" assembly. The two shells are orthogonally polarized. This arrangement allows for compact and efficient packing of two reflectors within the launch vehicle's volume envelope. The apertures of the reflecting shells range from 30 to 86 inches in diameter, and their focal lengths are generally in the range of 25 to 85 inches. The two shells are usually

Abstract: *This paper discusses advanced-composites applications to communications-antenna reflectors used on RCA-built satellites. Various types of reflector systems and their specific materials and structural requirements are reviewed. The mechanical design, analysis and test results for the different types of advanced-composite reflectors are presented. The specific problems associated with deployable, frequency-reuse, gridded Kevlar reflectors and large, deployable, high-frequency graphite reflectors are discussed. Novel design concepts for the control of thermal distortions in deployable, composite reflectors are presented.*

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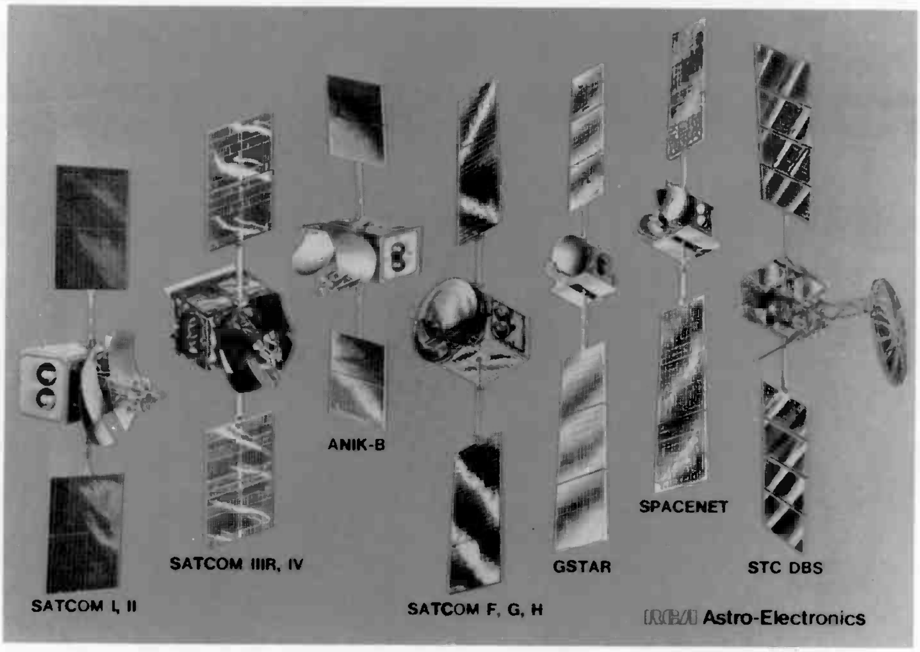


Fig. 1. *RCA-built communications satellites. RCA Astro-Electronics is building communications satellites for C-band and K-band communications as well as Direct-Broadcast Satellite (DBS) systems.*

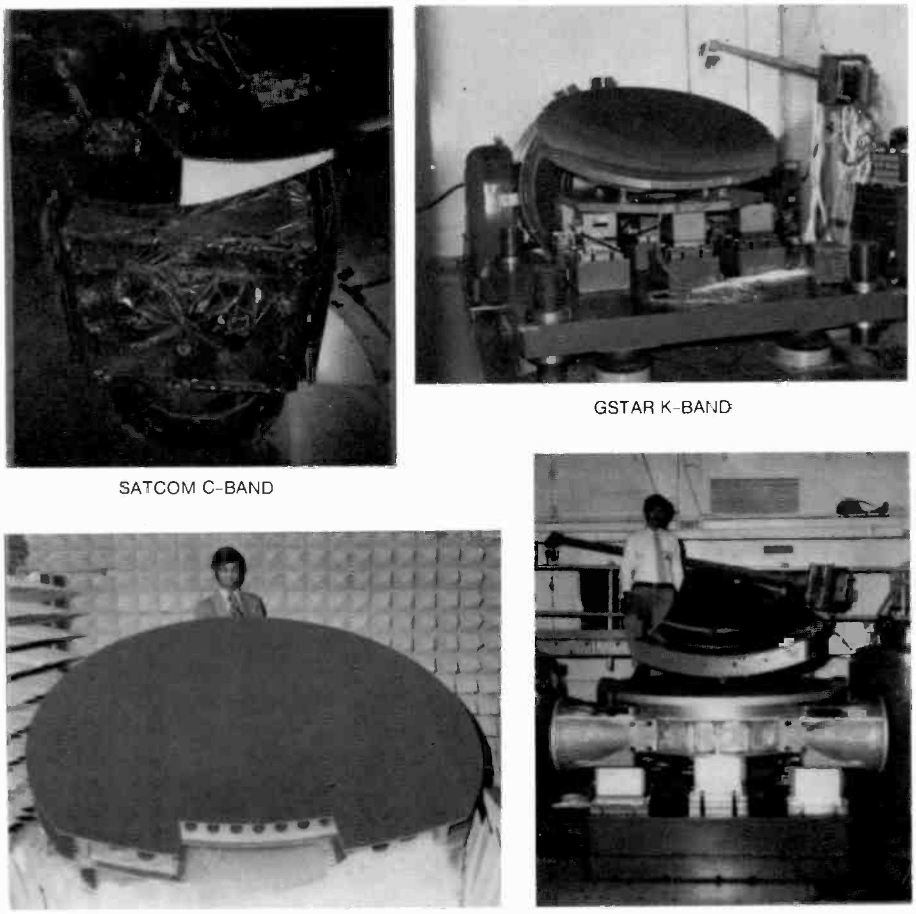
offset for sufficient separation of their focal points, to allow for positioning of their respective feed-horn assemblies.

The individual reflectors are sandwich-shell structures with reflecting surfaces that have parabolic contours satisfying the following relationship:

$$U^2 + V^2 = 4fW$$

where f = focal length. The vertex of the paraboloid is located at $U = V = W = 0$. The sandwich shell is fabricated from Kevlar 49 fabric/epoxy and consists of a honeycomb core, top and bottom face sheets, and edge closures. The honeycomb core and edge closures are fabricated from single-ply Kevlar 49 fabric/epoxy. The top and bottom face sheets are of two-ply construction with the rf reflecting grids bonded to the parabolic surface. The rf reflecting grids consist of thin copper elements of specified dimensions and spacings. Upon projection to the focal plane, the copper elements are parallel to the appropriate polarization axis of the reflector.

The two reflectors are bonded to each other by means of a Kevlar 49 fabric/epoxy honeycomb-core sandwich construction similar to that of the reflector shells. The rib subassembly provides maximum stiffness and thermal stability while requiring a minimum amount of material between the two reflectors. Astro-Electronics engineers achieve minimum insertion loss for the bottom vertical reflector by selecting proprietary materials with low-loss rf characteristics and by optimally orienting the skins, core, and rib assembly. In addition to reinforcing the shells, the rib assembly provides load paths from the shell to the support points. The dual-shell reflector assembly is supported by fixed legs configured to minimize the effects of thermal distortion of the reflectors. The legs are made of graphite/epoxy composites. Titanium mounting brackets are bonded to the bottom of the legs.



SATCOM C-BAND

GSTAR K-BAND

ADVANCED SATCOM C-BAND

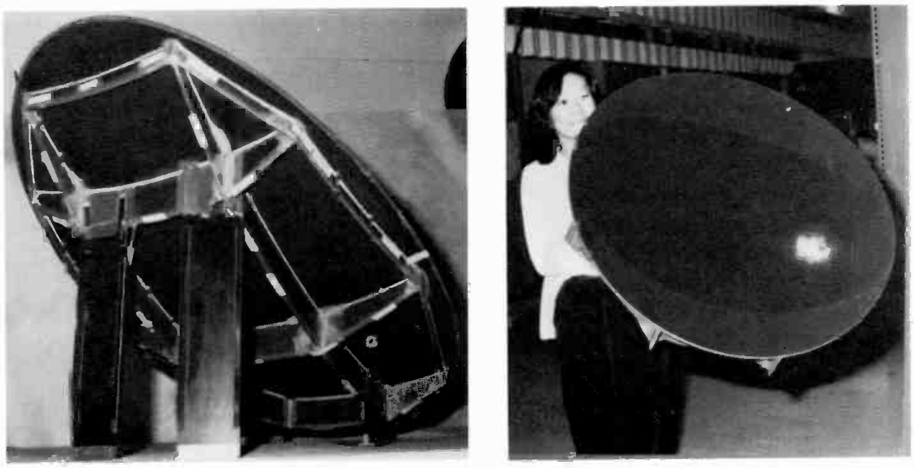
SPACENET C-BAND

Fig. 2. *Fixed, frequency-reuse, dual-shell reflectors. Overlapping dual-shell reflector designs offer compact packing within the limited launch-vehicle volume. The super-sandwich design results in high structural stiffness and dimensional stability.*

Fixed, dual-polarized, single-shell reflectors

Anik-B and Spacenet K-band reflectors (Fig. 3) are two examples of fixed, dual-polarized, single-shell reflectors. Dual polarization on a single shell is achieved by bonding two types of polarization grids on different areas of the reflecting surface. One polarization is reserved for the transmit beam and the other for the receive beam. The Spacenet K-band reflector, for example, has a 36-inch by 31-inch elliptical aperture with the entire aperture area suitably polarized to reflect the horizontally polarized transmit beam, whereas only the middle 36-inch by 20-inch aperture area "sees" the vertically polarized receive beam. Such dual-polarized, single-shell reflectors are used when a single feed assembly is employed in both receive and transmit modes.

This type of reflector also consists of Kevlar 49/epoxy honeycomb-core sand-



ANIK-B K-BAND

SPACENET K-BAND

Fig. 3. *Fixed, dual-polarized, single-shell reflectors. Provision of dual polarization on a single reflecting surface allows the use of a single-feed assembly for both receive and transmit modes.*

Fig. 4. *Solid single-shell reflectors offer extreme dimensional stabilities (less than 0.003-inch rms distortions) under mission thermal environments.*

wich shells, Kevlar 49/epoxy sandwich ribs, and graphite/epoxy fixed-support legs. The reflecting grids are bonded to the top surface of the sandwich shell.

Solid single-shell reflectors

The solid single-shell reflector concept is exemplified by the 36-inch diameter aperture, Independent Research and Development (IR&D) reflector shown in Fig. 4. The conventional design of these reflectors consists of a graphite/epoxy skin, an aluminum honeycomb core, and a sandwich-shell structure. A modified design may employ a hybrid of graphite/epoxy and Kevlar/epoxy for the skin material and Kevlar/epoxy honeycomb for the core material. The concept shown in Fig. 4 represents a minimum weight, maximum environmental stability, single-shell, solid reflector design. This type of reflector consists of a quasi-isotropic lay-up, graphite/epoxy skin supported at the edge only by means of graphite/epoxy stiffener rings. The reflecting surface may be coated with a thin layer of vapor-deposited aluminum (VDA) to enhance rf reflectivity.

Deployable reflectors

Fixed reflectors offer design simplicity and enhanced mechanical performance. However, if a large number of reflectors have to be provided on a spacecraft, or the operational dimensions of the reflector exceed the available launch-fairing cross sections, deployment of the reflectors becomes necessary. In this case, the reflectors are stowed in orientations such that they stay within the launch vehicle's fairing envelope. After launch, the reflectors are deployed to their operational orientations.

Any of the three categories of reflectors, described earlier, may be deployed. Figure 5 shows a deployable, frequency-reuse, dual-shell reflector and a solid deployable, single-shell reflector. The former is a developmental IR&D hardware and the latter represents the reflector design for a 17/12-GHz direct-broadcast system.

Performance of antenna reflectors

The operational rf performance of an antenna reflector is usually achieved by meeting several mechanical specifications. These include dimensional tolerances; dimensional stability under operational thermal, radiation, zero-gravity, and aging environments; and load-carrying capability under a launch environment. Actual requirements depend on the specific mission. In all of the reflector systems developed thus far, RCA designs have exceeded the specification requirements.

Fabrication tolerances

With the aid of the subcontractor, Composite Optics, Inc., of San Diego, California, RCA has established unique reflector-fabrication techniques that have resulted in

(Continued on page 47)

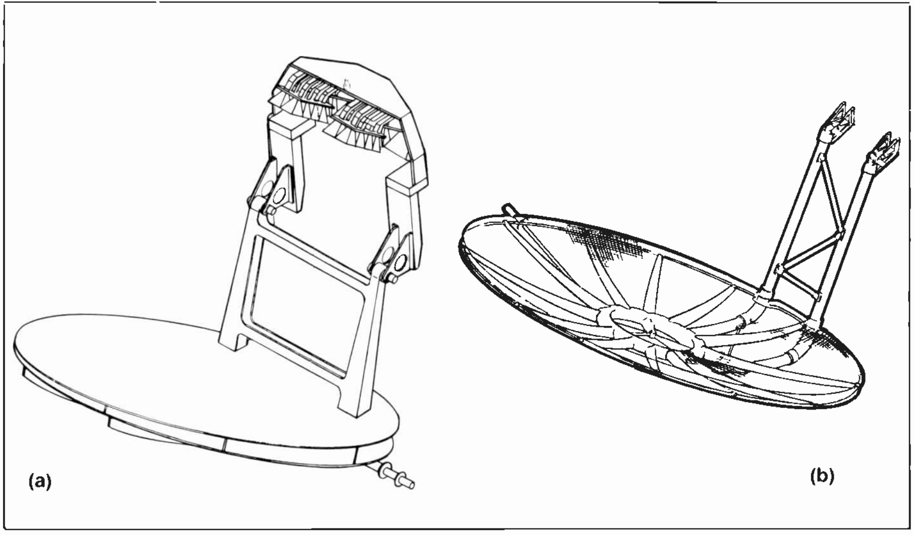
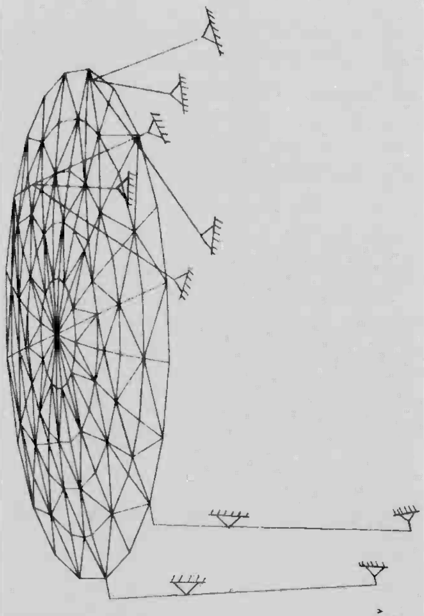
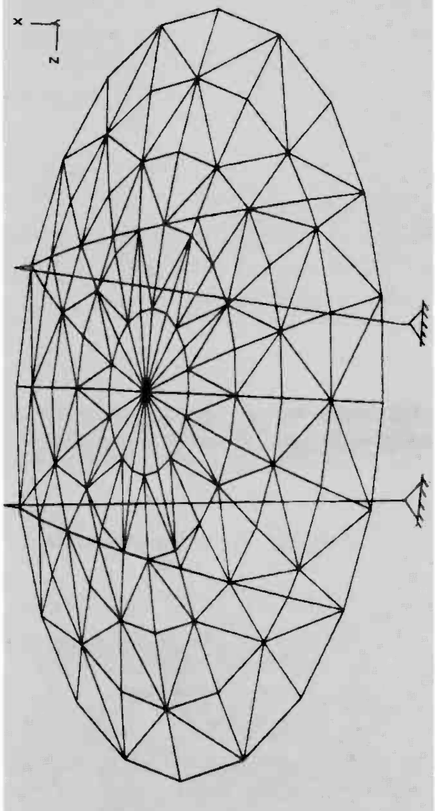


Fig. 5. *Deployable antenna reflectors. Deployable reflector designs allow for a large number or large area reflectors on a single spacecraft. Both the single-shell and the dual-shell reflectors may be deployed:* **(a)** *is a solid, single-shell, 17/12-GHz reflector.* **(b)** *is an IR&D frequency-reverse, dual-shell reflector.*



(a) *FEM of stowed reflector.*



(b) *FEM of deployed reflector.*

Fig. 6. *Finite-element model (FEM) of deployable, frequency-reuse, dual-shell reflector. FEMs are used to predict reflector natural frequencies, stress margins and distortions under mission environments.*

Table I. *Overall dimensions of RCA-developed antenna reflectors.*

Spacecraft system	*Type of reflector assembly*	*Aperture shape and size*
Advanced Satcom	Frequency reuse, dual-shell C-band	Truncated circle 84" major axis 64" minor axis
GSTAR	Frequency reuse, dual-shell K-band	Circular 60" diameter
Spacenet	Frequency reuse, dual-shell C-band	Double-truncated circle 66" major axis 48" minor axis
Spacenet	Dual-polarized, single-shell K-band	Elliptical 36" major axis 31" minor axis

Authors (left to right) Gounder, Ino, and Talley.

Raj Gounder, Manager, Advanced Structures, RCA Astro-Electronics, is responsible for the development of advanced lightweight structures for RCA-built satellite systems. He managed the mechanical design of the antenna subsystem for the Advanced Satcom, the mechanical design of the antenna reflectors for the GSTAR and Spacenet programs, and the mechanical design of the advanced-composite cradle structure for the SOOS program. Also, he has managed a number of advanced-structures technology programs including advanced-composite lightweight solar-array development, advanced-composite spacecraft center-core structure, and composite-materials and processing-technology programs. Dr. Gounder received his Ph.D. in Materials Science and Engineering from Northwestern University in 1972.

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Sari Ino, received her B.S. degree in Mechanical Engineering from Columbia University in 1980. Since she joined RCA Astro-Electronics in 1980, Ms. Ino has been working in the field of composites, designing and testing reflectors for communications satellites.

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(Cont. from p. 45)

extremely precise dimensional tolerances. The tolerances, as-built, are far better than the specification requirements in each and every hardware developed by RCA.

Dimensional stability under space thermal environments

The dimensional stabilities of RCA-developed antenna reflectors, under operational temperature distributions and materials-aging conditions, have been established by a combination of materials testing and finite-element analysis. These predicted performances have been well-proven by the operational performances of the communications spacecraft shown in Fig. 1. In addition, the predicted performances are currently being further verified by direct photogrammetric measurement techniques on some of RCA's latest reflectors.

Figure 6 shows the finite-element model employed for the thermal distortion analysis of the IR&D, deployable, frequency-reuse, dual-shell reflector assembly shown in Fig. 5. The predicted performances of these reflectors are far superior to the specification requirements. Recently, RCA has developed several unique mechanical and thermal design concepts for antenna reflectors that show further improvements in the environmental stabilities of these hardware.

Lightweight, advanced-composite reflector structures

The communications-antenna reflectors described above are made from Kevlar 49/epoxy and/or graphite/epoxy composites. Judicious application of such advanced materials has resulted in minimum-weight designs for the antenna reflectors. The overall dimensions and the total assembly weights of the RCA-developed reflectors are summarized in Table I.

Conclusions

RCA Astro-Electronics has established innovative mechanical designs for communications-antenna reflectors as proven by a variety of reflector hardware for a number of communications-satellite missions. These designs offer precise dimensional tolerances and environmental stabilities that translate into superior rf performance. Such excellent reflector performance has been achieved with minimum-weight structures because of the judicious application of advanced-composite materials.

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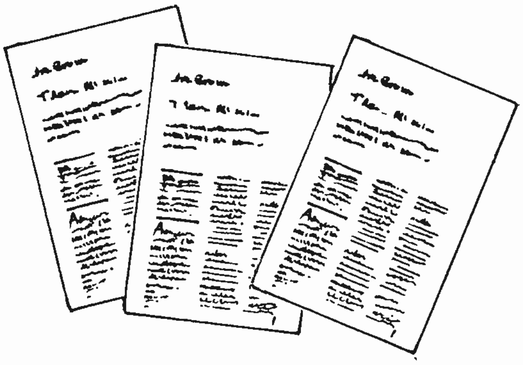

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A.A. Acampora | R.M. Bunting | R.J. Petri

Noise-reduction in video signals by a digital fine-structure process

A crisp video picture depends on a signal without noise and interference. Direct broadcast operations are particularly susceptible, but new digital techniques will "muffle" the noise.

The spectrum of both monochrome- and color-video signals has a structured aspect in the frequency domain. This structuring manifests itself as spectral "clumps, or pickets" of energy with spacings related to the horizontal rate of the video signal. The well-known example of Fig. 1 illustrates how the luminance component (Y) and chrominance component (C), each with picket spacings of 15.734 kHz, are interlaced in the National Television Standards Committee (NTSC) format. The resulting spacing of this composite signal is thus 7.867 kHz in the frequency regions where both Y and C coexist.

This fine-structure aspect of video signals lends itself to some interesting processing applications, the most popular of which is comb-filter separation of luminance and chrominance. The objective of the work presented here is to improve the signal-to-noise ratio (SNR) by processing a noisy received composite video signal with a method resembling comb filtering.

Abstract: *As the technology of satellite-video transmission moves toward closer-spaced satellites that operate at higher frequencies into smaller earth stations for direct-broadcast applications, the noise and interference introduced into these signals increases. Increased noise and interference also occur in the conventional satellite systems when video signals are frequency multiplexed to improve bandwidth use. The objective of the digital techniques presented in this paper is to process a noisy received composite video signal in a way that reduces the noise and thereby improves the signal-to-noise ratio.*

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Basic theory

A recursive filter is used at the receiver to provide periodic attenuation in the spectral regions between pickets. In this way, noise added to the signal before it reaches the receiver can be de-emphasized in frequency regions where there is little signal energy. However, the interpicket regions are not entirely devoid of some important signal energy. In the NTSC-color case, this energy is associated with changes in luminance and chrominance within the scene in the vertical direction. Hence, the application of de-emphasis alone would suppress the noise, but would also create objectionable artifacts in the video picture, especially at these vertical boundaries.

For this reason, a corresponding complementary process is used at the transmit-

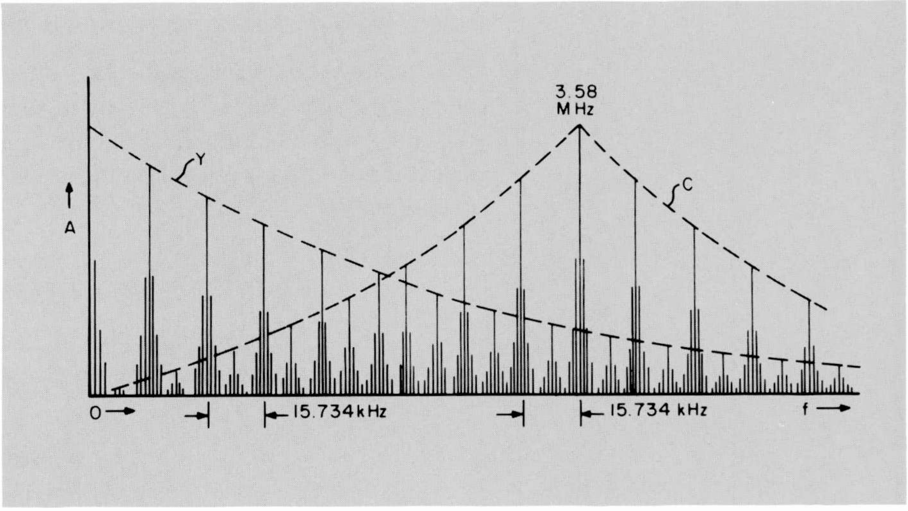


Fig. 1. *TV energy spectrum. Notice how the spectral pickets of the modulated 3.58-MHz color carrier fall between those of the luminance signal. The width of both Y and C pickets is determined by the degree of scene change in the picture's vertical direction.*

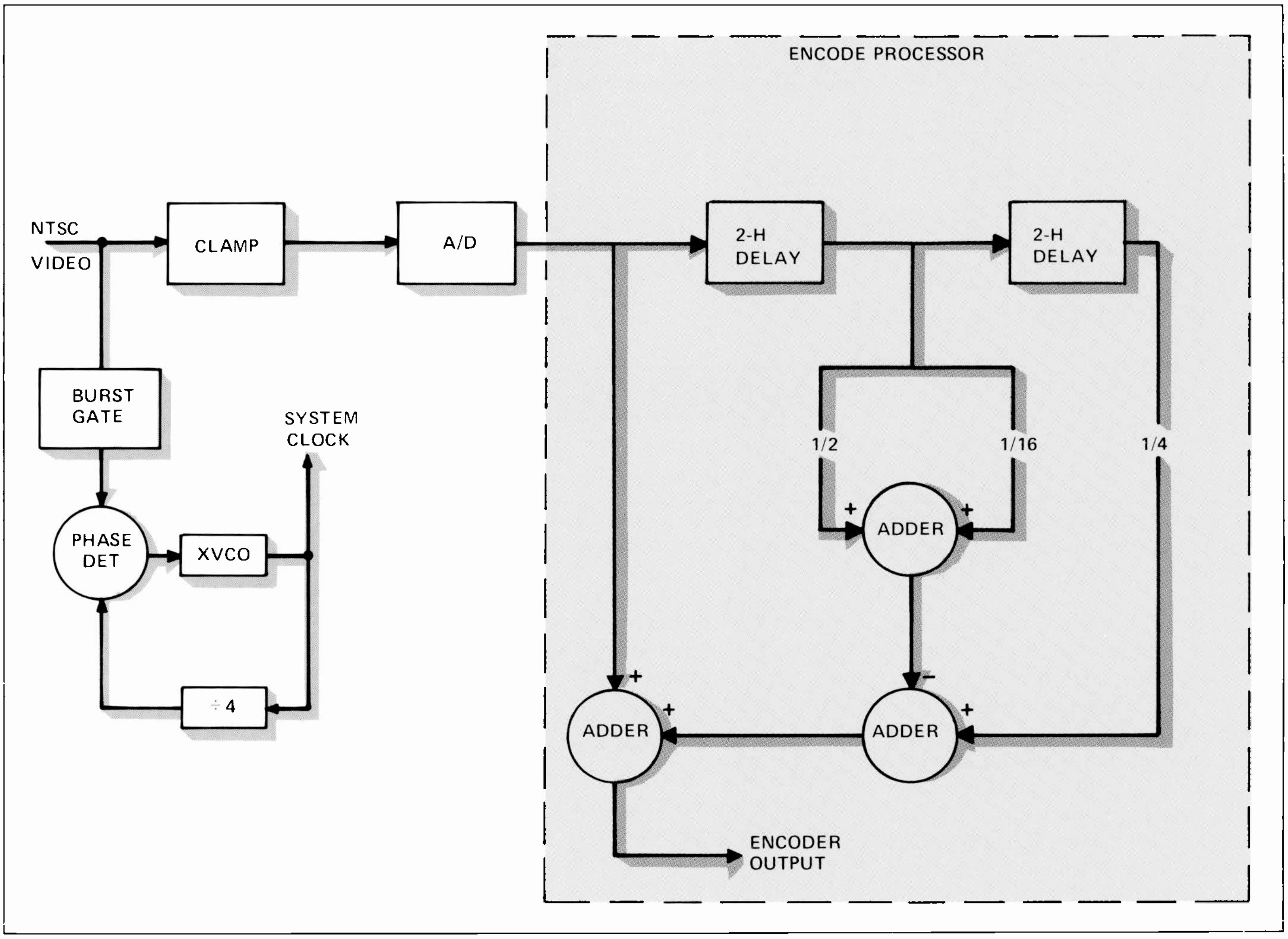


Fig. 2. *NTSC encoder system with pre-emphasis processor. The delay-line structure creates a 3-tap finite-impulse-response (FIR) filter for the pickets of spectral energy.*

ter. The process is also recursive and acts to pre-emphasize the interpicket region. This predistortion is entirely accounted for in the end-to-end system since the pre-emphasizer (encoder) and the de-emphasizer (decoder) are designed to have a flat back-to-back frequency response. In more rigorous terms, the Z-plane poles and zeroes of the encoder are the same zeroes and poles of the decoder, respectively.

Encoder system implementation

The encoder block diagram is shown in Fig. 2. Since the process is digital, a synchronous system clock must be developed. A crystal voltage-controlled oscillator (XVCO), operating at four times the nominal color-subcarrier frequency, is used to provide this clock. To ensure synchronism, the XVCO output is divided by four and phase locked to the color subcarrier (3.58 MHz) of the incoming video. This subcarrier is obtained by gating the burst. The phase comparator develops an error signal to maintain lock. Because of the relationships in NTSC video between the frequencies of the horizontal-line rate and of the color subcarrier, exactly 910 clock pulses are formed for each horizontal line in the video signal. Therefore, horizontal-line-time delays can be accurately determined by counting clock pulses.

The input video is clamped prior to the analog-to-digital conversion (A/D). The A/D derives 8-bit parallel digital samples of the input video, which appear at the system clock rate.

Encoder processor

These digitized video levels are now passed to the encoder processor. There is a cascade of two digital delay lines, each of which is two horizontal lines long. This system forms a 3-tap digital filter. A process board "weights" the taps, appropriately adjusts the signs, and accumulates the sum to obtain the filter output. The transversal filter thus formed is a finite-impulse-response (FIR) design. Notice that the tap weights have denominators that are powers of two. This fact allows simple weighting without the use of digital multipliers. The technique used in place of multiplication is to "bit shift and add."

The details of the tap-output accumulation of the process are shown in Fig. 2. The ¼ weight applied to the end tap is simply a shift to the right of the data byte by two bit positions. The 9/16 weighting of the center tap is formed by adding 1/2 to 1/16 of the data byte as shown, each portion of which is obtained by a "right shift" of one bit position and a "right shift" of four bit positions, respectively. The middle tap (with inverted sign) and the end tap are summed in a full adder, and further accumulated with the input tap to form the output. The output is converted back to analog form by a digital-to-analog (D/A) converter.

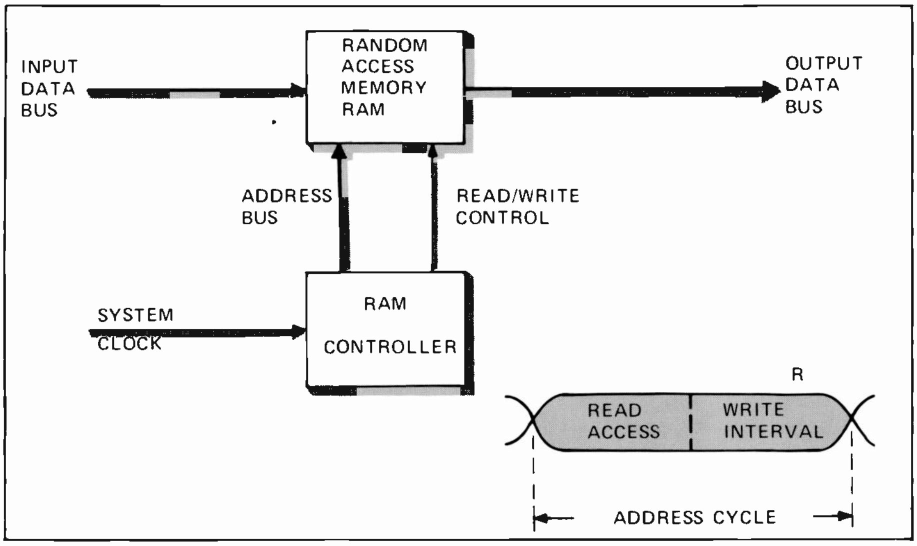


Fig. 3. *Digital delay uses random access memory. Use of a read-modified-write during an address cycle, makes it possible to delay all bytes by the address recycling time.*

Since two TV lines of delay must be achieved between successive taps, each delay element is required to store 2 × 910, or 1820, bytes. Straightforward digital shift registers would do, except for the long lengths involved. It is easier to configure the delay as a random-access-memory (RAM) structure, shown in Fig. 3. The system clock is used in a RAM controller to step an address generator, and also steer the read/write cycle of the RAM. A read-modified write is employed where the contents of memory are addressed and read out; in the latter part of the same address cycle, the new data is written in. This newly written data is not accessed for reading until the clock undergoes 1820 cycles. Thus, the output data is delayed by two TV lines relative to the input data.

Decoder system implementation

The major difference between the encoder and decoder is that the latter processor is an infinite-impulse-response (IIR) digital filter, where the weighted tap outputs are recirculated back to the digital-delay-line input. The block diagram of Fig. 4 illustrates this difference. The digitized video from the A/D enters a full adder, where it is joined with the sum of the weighted taps.

Again, a 3-tap filter is formed from a cascade of two 2-H delay lines. The center tap is weighted and summed with the end tap. The end tap now has the sign inversion. The resulting signal is added to the input signal. This aggregate signal is the input to the delay lines as well as the decoder output. As before, the weights are formed by bit shifting-and-adding techniques. The process output is returned to analog form by means of a D/A converter.

Frequency responses

The frequency response of the encoding system is shown in Fig. 5. The frequency regions between pickets are pre-emphasized by a gain factor K. The significance of K will be presented shortly.

Since the center and end tap weights of the IIR filter in the decoder have signs opposite to those of the FIR filter in the encoder, the decoder frequency response is the reciprocal of the encoder response (see Fig. 5).

The previous responses show that, for larger K, there will be large attenuations in the noisy interpicket regions at the decoder. The result is better SNR improvement. Correspondingly, the interpicket regions would be highly emphasized at the encoder. The result is large overshoots in the transmitted signal at times when the picture (scene) has significant changes in the vertical direction. This would be tolerable in transmission systems that are not peak-power limited. But since this peak-power limitation does exist in microwave or satellite FM systems, the overshoots cause overdeviations, which drive the FM carrier out of the available radio bandwidth, and result in severe distortions (tearing) on vertical edges.

There is then a compromise K based on just-noticeable tearing (JNT). For the case at hand, this K is 16/11. In more appropriate terms, the expected SNR improvement is 2.2 dB.

Test results for NTSC video

The fine-structure processor was subjected to noise tests to determine the value of the process. To determine if indeed the back-

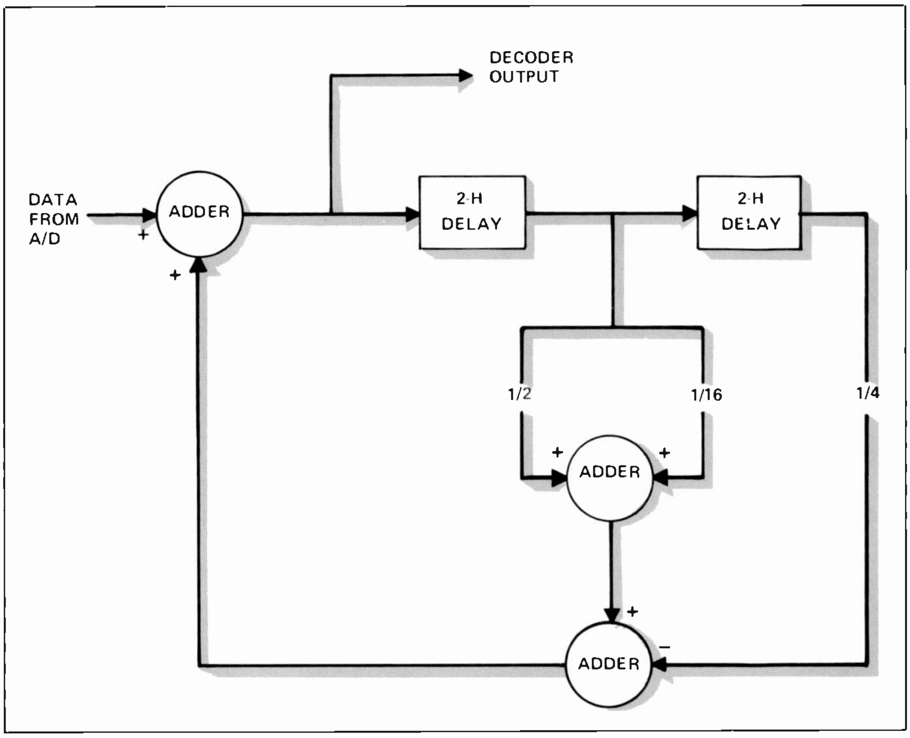


Fig. 4. *NTSC decoder with de-emphasis processor. Since the delay-line taps are fed back to the input, an infinite-impulse-response (IIR) filter is created.*

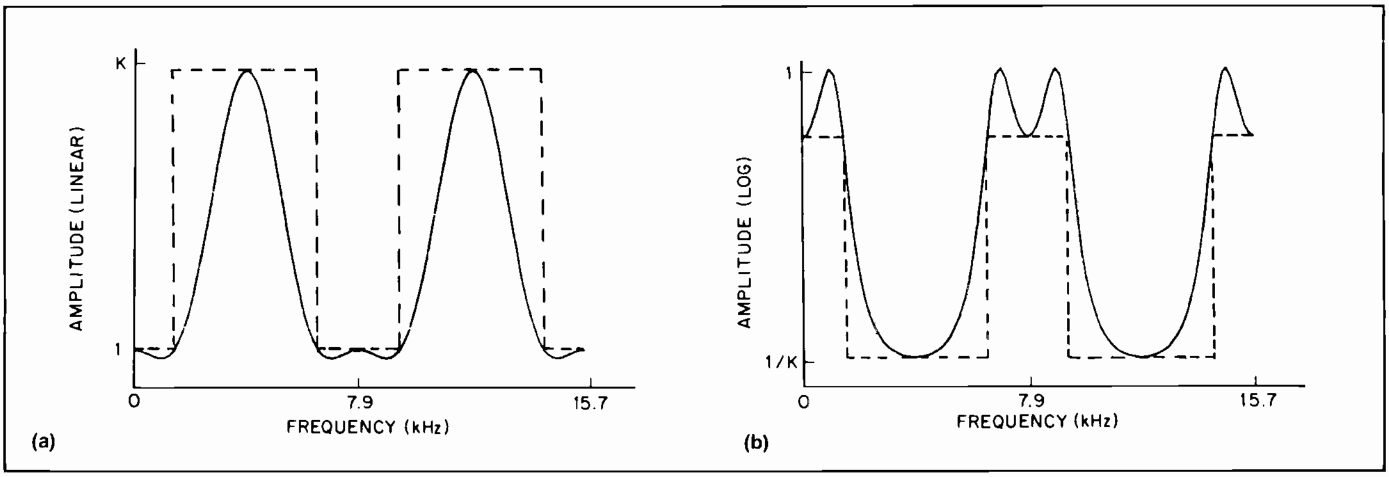


Fig. 5. *Frequency responses.* **(a)** *At the encoder, the spectral regions between Y and C pickets are boosted by a gain factor* K. **(b)** *At the decoder, the interpicket regions are now cut back by a factor of* K *to create an overall unity gain response.*

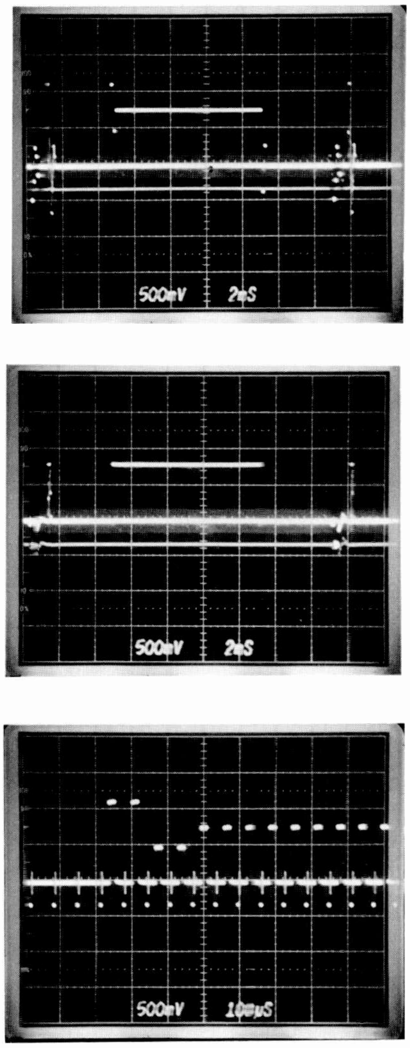
to-back coder/decoder (CODEC) system has flat response, a video test signal called the "window" is used. This waveform, shown in Fig. 6, is valuable in the tests since it has a vertical transition from black level to white level, and then returns to black level. These transitions cause signal energy to spread into the regions between pickets, such that these edges themselves become accentuated by the encoder, as shown in Fig. 6. The magnified view of the leading edge of the window shows that the transient lasts for four TV lines and comprises a pair of two TV-line intervals. However, after passing through the matched decoder, the signal is restored to the normal waveform, as shown in the figure.

When noise is inserted between the encoder and decoder, interesting results are obtained. Although objective measurements verify the theoretical SNR improvement of slightly more than 2 dB, the recursive action of the decoder tends to correlate the added noise. The linear addition of the noise at the tap outputs gives rise to a resulting interference, which has less noise-power density, but is more structured in the scene's vertical direction.

This phenomenon can be seen in the TV-monitor screens shown in Fig. 7. The normally grainy noise is transformed into vertically correlated noise, for which the eye has greater acuity. Therefore, on a subjective basis, only half of the objective improvement is realized.

The determination of *K* revisited

For the simple 3-tap filters presented so far, there is only moderate control over the shape of the filter response. It is pri-



(a) WINDOW SIGNAL AT ENCODER OUTPUT

(b) WINDOW SIGNAL AT DECODER OUTPUT

(c) EXPANDED VIEW OF ENCODER OUTPUT

Fig. 6. *System waveforms.* **(a)** *At the encoder output, the leading and trailing edges of the window signal are perturbed by the action of the encoder.* **(b)** *At the decoder output, the window signal is restored because of the back-to-back unity gain.* **(c)** *An expanded view. The leading edge of the window is perturbed over two line pairs corresponding to the two 2-H delay lines.*

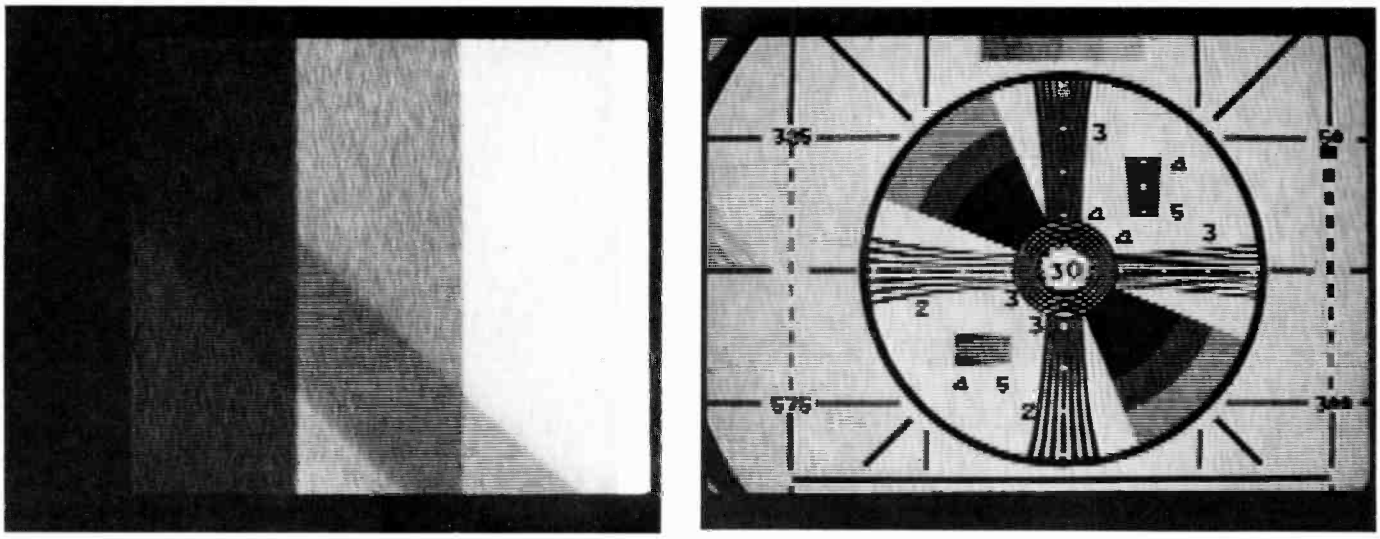
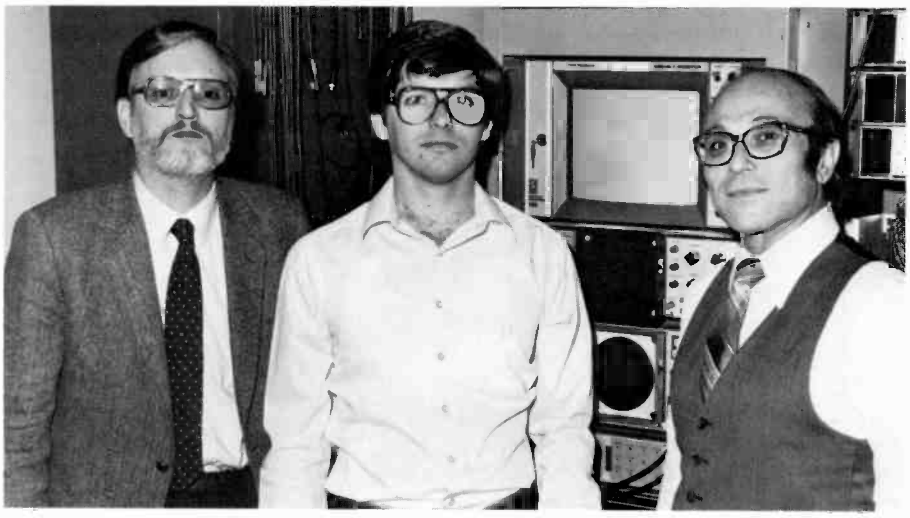


Fig. 7. *Screen photographs. Both staircase and monoscope waveforms show the effects of noise correlation in the vertical direction.*

marily the peak-to-valley separation that provides the noise-suppression factor. The peak-to-valley ratio is directly dependent on the processor gain K. A more important discovery is that the degree of spatial correlation is also proportional to K. Hence, the determination of processor noise improvement is not a function of peak-power considerations only; the noise correlation is a more decisive factor.

The only possibility of providing any further noise improvement, while not appreciably increasing K, is to create filtering that has improved shape factors. Sharper-skirted filters with wider reject-band frequency intervals are obtained by digital filters with progressively more weighted taps. These shapes can approach the dotted responses shown in Fig. 5.

Within the constraints of the present hardware, a 5-tap filter can be obtained by splitting each of the 2-H digital delay elements (see Figs. 2 and 4) in half. This forms a 5-tap filter with 1-H delay separa-



Authors (left to right) Petri, Bunting, and Acampora.

Al Acampora joined RCA in 1959, at the Advanced Communications Laboratories in New York. His work involved all phases of military and commercial communications. In 1970, he joined RCA Global Communications, as Staff Engineer and, in 1973, he was awarded the David Sarnoff Outstanding Achievement Award for his work in narrowband video transmission. Since joining RCA Laboratories, Princeton, New Jersey, as a Member of the Technical Staff in 1978, Al has continued his work in communications systems. His initial programs involved video processing for teleconferencing applications. He has been involved in digital implementation of video-processing systems, especially for existing and next-generation satellite transmission, and he has contributed to the development of digital television receivers. In 1982, he was promoted to Senior Member of the Technical Staff.
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Richard Bunting joined RCA Laboratories in 1977 and was involved in the evaluation of companders for satellite communications. He helped in the testing of A/D and D/A converters for the Digital Audio Project. More recently he has been involved in analog and digital video-signal-processing systems. Mr. Bunting was promoted to Technical Associate in 1982.
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Robert Petri, upon discharge from the U.S. Army in 1967, where he taught for two years at the Signal Corps Communications and Electronics School, at Ft. Monmouth, N.J., joined RCA Astro-Electronics Division. Among other activities, Robert worked on slow-scan weather-satellite video-camera systems. After two years, Robert transferred to the David Sarnoff Research Center where his first challenge was to explore various digital compression techniques on black-and-white images using a flying-spot scanner. Following this, he assisted in the development of a digital time-division-multiplex communication system. Presently he is involved with state-of-the-art digital video-processing techniques.
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tions. Such a filter, however, has a periodicity that cannot support the presence of the interleaved chrominance pickets; testing can be accomplished only on monochrome video signals. Nonetheless, valuable information can be obtained and subsequently scaled to include the color-signal case.

Monochrome system tests

The CODEC processes designed for the more complex filters in the monochrome case are shown in Fig. 8. Because of the shape-factor improvement, a noise reduction of about 5 dB is expected. For the same amount of signal overdeviation at vertical transitions, the system should provide about 3-dB further improvement over the previous NTSC CODEC's performance.

Tests with noise show the improvement to be objectively realized. However, subjective tests show that the correlation factor cuts substantially into the visible improvement—again about half the measured result is apparent.

Discussion

Fine-structure processing of video signals does indeed provide signals with less noise. However, the reduced noise-power density is manifest in a noise spectrum that has stronger low-frequency content than that of the original noise. This is due to the correlative properties of the process. Visual perception, the ultimate critic in all display systems, has more acuity to low-frequency disturbances. Thus, the correlation phenomenon eradicates some of the objective improvement.

It appears that this subjective loss is less in cases where the amount of additive noise at the decoder is decreased. This is perhaps due to a nonlinear perception of visual disturbance as a function of the strength of the perturbation.

The systemic problem is that the process operates in the spatial (that is, the dimensional axis) domain of the video scene. As such, the correlation inherent in the fine-structure process yields visual artifacts in this domain. There is continuing work at the Laboratories to develop systems that will reduce the spatial artifacts and, therefore, lessen the amount of "backoff" in subjective versus objective improvement.

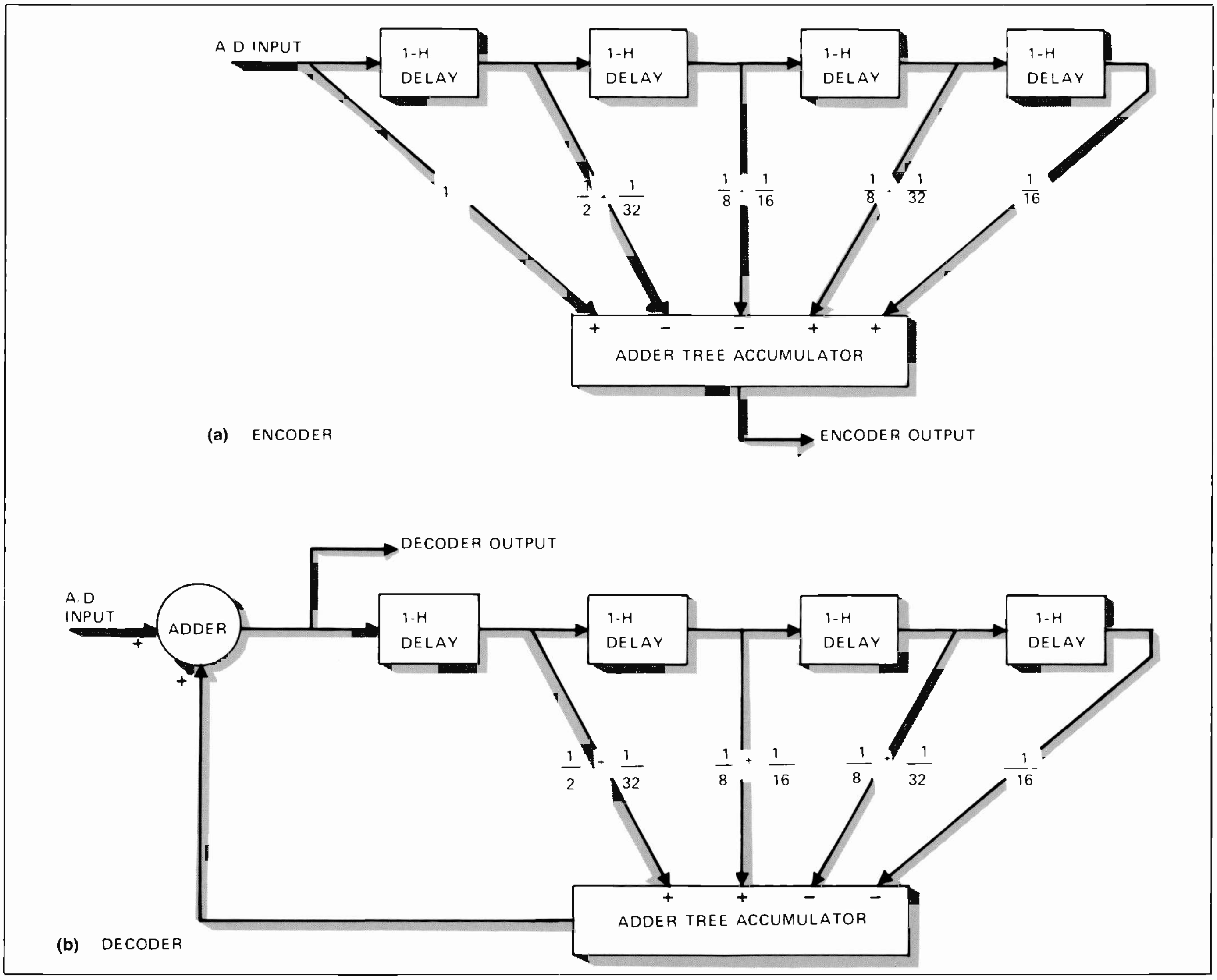

Fig. 8. *Process for the monochrome case.* **(a)** *At the encoder, by splitting up the delay lines into four 1-H sections, a monochrome FIR is obtained.* **(b)** *At the decoder, with sign reversals in the adder tree, and feedback to the input, the corresponding IIR filter is obtained.*

R.F. Buntschuh

Direct-broadcast satellite considerations

The solutions to the direct-broadcast satellite technical challenges are clearly available.

Abstract: *The newest entity in the communications-satellite field is the direct-broadcast satellite (DBS), capable of broadcasting TV signals of nearly studio quality to home-satellite terminals costing as little as $300. This new application for commercial satellites brings with it many technical challenges and some interesting solutions.*

The effective isotropic radiated power (EIRP) requirements for a DBS spacecraft are reviewed, and means of implementation discussed. The two principal means are (1) increased rf power generation through use of high-power TWTAs, and (2) use of antenna concepts that maximize the efficiency of an antenna by providing a more nearly uniform illumination over the coverage area than by conventional techniques employing elliptical shaped beams.

Available technology has been used via a series of modifications to a Satcom bus to accomplish the transformation into a high-power direct broadcast satellite.

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The direct-broadcast satellite* (DBS) will provide TV signals directly to the home from geostationary orbit. To allow for practical and inexpensive home terminals for users, the signal level from the spacecraft must be many times larger than that from a fixed-service satellite (FSS) whose earth terminals, being limited in number and not constrained in size due to installation requirements, can be configured with reflectors having diameters in excess of 3 meters. Typical radiated power from a DBS satellite is characterized by effective isotropically radiated power (EIRP) ranging from 55 to 58 dBW for continental U.S. (CONUS) services and up to 63 dBW for European DBS systems. This is to be compared to the fixed-service satellite's 34 to 40 dBW EIRP. The 15- to 20-dB increase in radiated power makes the DBS spacecraft unique in the family of geostationary communications spacecraft.

There are several ways of increasing EIRP. One is to use traveling-wave-tube amplifiers (TWTAs) designed for high efficiency as well as high power. Another less obvious way of increasing EIRP is to tailor the antenna beam shape to a smaller than CONUS coverage area—typically a time zone—and to use an antenna that has a high-gain rolloff with angle, thereby concentrating the radiated power in the desired coverage zone and reducing the wasted power outside the coverage zone.

These technologies were used in the RCA Astro-Electronics design that was successfully proposed to the Satellite Television Corporation (STC) in response to their request for proposal for a direct-broadcast satellite. This program is the first domestic DBS satellite program that has gone to the contract stage in the United States. The STC spacecraft supports three channels of direct-broadcast transmissions on a spacecraft in the Delta weight class of 650-kg mission orbit weight. The same technologies are applicable to satellite designs for up to six channels of transmission capability.

High-power TWTAs

Approximately 10- to 12-dB enhancement of EIRP over FSS designs is accommodated through the use of TWTAs providing approximately 220 watts at the beginning, and 200 watts at the end, of satellite life at the DBS operating frequency of 12.5 GHz. These TWTAs are available from Thomson-CSF and AEG-Telefunken, who developed them for the TV-SAT and TDF programs of Germany and France, respectively.

The three-channel STC spacecraft will generate 660 watts at beginning, and 600 watts at the end, of satellite life. This compares to the 144 watts of rf power generated by the initial 24-channel Satcom spacecraft and the 340 watts generated by the GSTAR spacecraft. Because these spacecraft are both of the Delta class, it is obvious that there must be some other change in a DBS spacecraft design to allow this much generated rf energy to be provided. That significant difference is that the DBS spacecraft does not supply transponder operation during spacecraft eclipse, thereby negating the requirement for a large battery. For a single channel's operation during eclipse, approximately 20 ampere hours of battery capacity would be required, excluding depth-of-discharge considerations. This is roughly equivalent to the total battery capacity used on the early Satcom spacecraft. Even though battery technology has improved since the early Satcom, the battery weight required for

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* DBS service discussed in this paper is defined by a 12.2-to 12.7-GHz downlink this is "true" DBS as defined by the ITU. However, "low-power" DBS, making use of 11.7 to 12.7 GHz, is offered through fixed-service spacecraft.

round-the-clock operation of the DBS payload would be prohibitive for the Delta-class spacecraft.

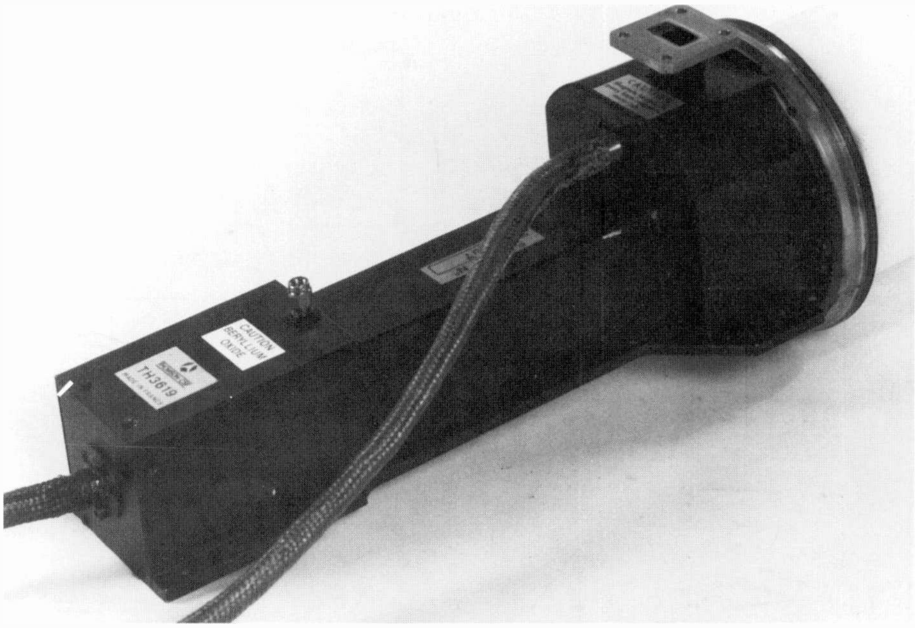


Fig. 1. *A 220-watt TWT manufactured by Thomson CSF employing a radiating collector design. The collector is coated with alumina to stabilize the emissivity of the surface over life.*

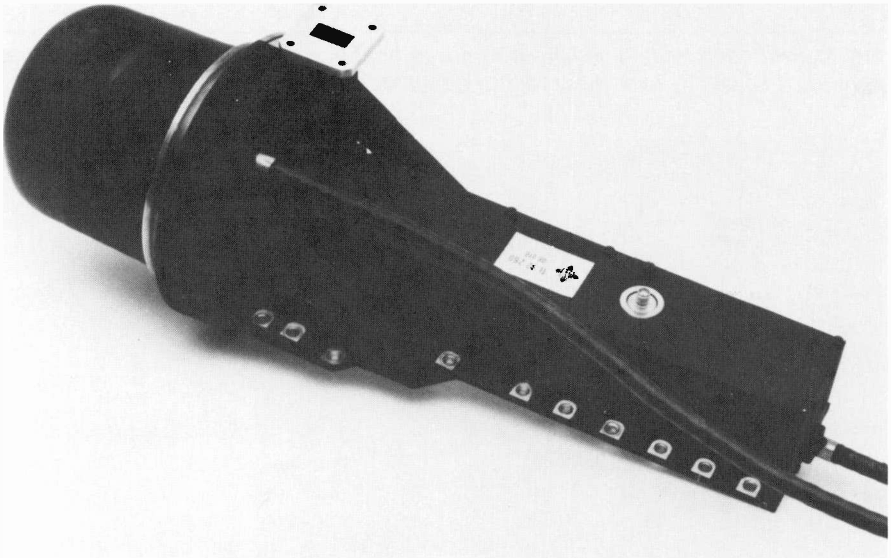


Fig. 2. *The 220-watt TWT manufactured by AEG-Telefunken uses a radiating collector design differing in detail and implementation from the Thomson design. This collector is coated with a highly emissive coating.*

The lack of transponder operation during spacecraft eclipse is of small concern from an operations standpoint in that the spacecraft can be located an hour to the west of the coverage zone, thereby causing any outage to occur past local midnight, viewers' time. This is a small price to pay for the very important weight saving achieved.

The lack of transponder operation during eclipse, however, does cause the spacecraft designer some additional concerns. The first of these concerns is that the demonstrated lifetime of the in-orbit TWTAs on the Satcom spacecraft has been better than on other satellite programs, and that a possible and probable explanation is that the Satcom payload is never cycled off and on. Fears associated with this situation prompted a qualification program for the TWTAs. The program includes the accelerated life testing of the tubes in a simulated space environment that includes simulation of the thermal profile during seven years of eclipses and thus subjects the tubes to the thermal transients they will encounter.

The second major spacecraft-systems issue caused by the non-operation of the transponder during spacecraft eclipse is that the lack of thermal dissipation during the eclipse will cause the payload temperature levels to plummet. The high-power payload for the STC spacecraft will dissipate approximately 800 watts during operation, as compared to the Satcom dissipation of only 300 watts during operation. Once the radiator sizes have been determined by the energy-dissipation requirements to maintain the payload at safe temperature levels, then the amount of make-up heat energy required to limit the cold temperature at the end of an eclipse must be determined, and the battery must then be sized to supply this make-up heat during an eclipse.

The TWT design employed has a forgiving aspect to it in that the majority of the heat dissipation in the TWT is in the collector and that heat is radiated directly to space. Figures 1 and 2, photographs of the two tubes under consideration, show the radiating collectors. The collector is seen to be nearly cylindrical and is meant to be mounted on the spacecraft so as to be exposed to the environment of deep space. Of the 267 watts of heat dissipated from each tube, 130 watts is dissipated by this collector directly to space. Therefore, the conducted thermal dissipation from the TWTAs of the DBS payload, that which must be handled by the spacecraft, is reduced from the 800 watts previously stated to 410 watts, or less than twice the thermal dissipation of the Satcom spacecraft. Strictly from the standpoint of dissipation, the solution is within reach.

The remaining major thermal problem is caused by the nature of the dissipation in the DBS payload. It behaves almost like a point source. A total of three TWTAs operate at any time, for a total of 410 watts of conducted dissipation. The total dissipation occurs at six points on the payload panels. Heat spreading from these hot spots must be accomplished, or the local temperatures will rise above the survival temperature of the components. Figure 3 reveals the application of heat pipes embedded into the payload panels to accomplish this heat spreading. The same spreading could be accomplished without heat pipes

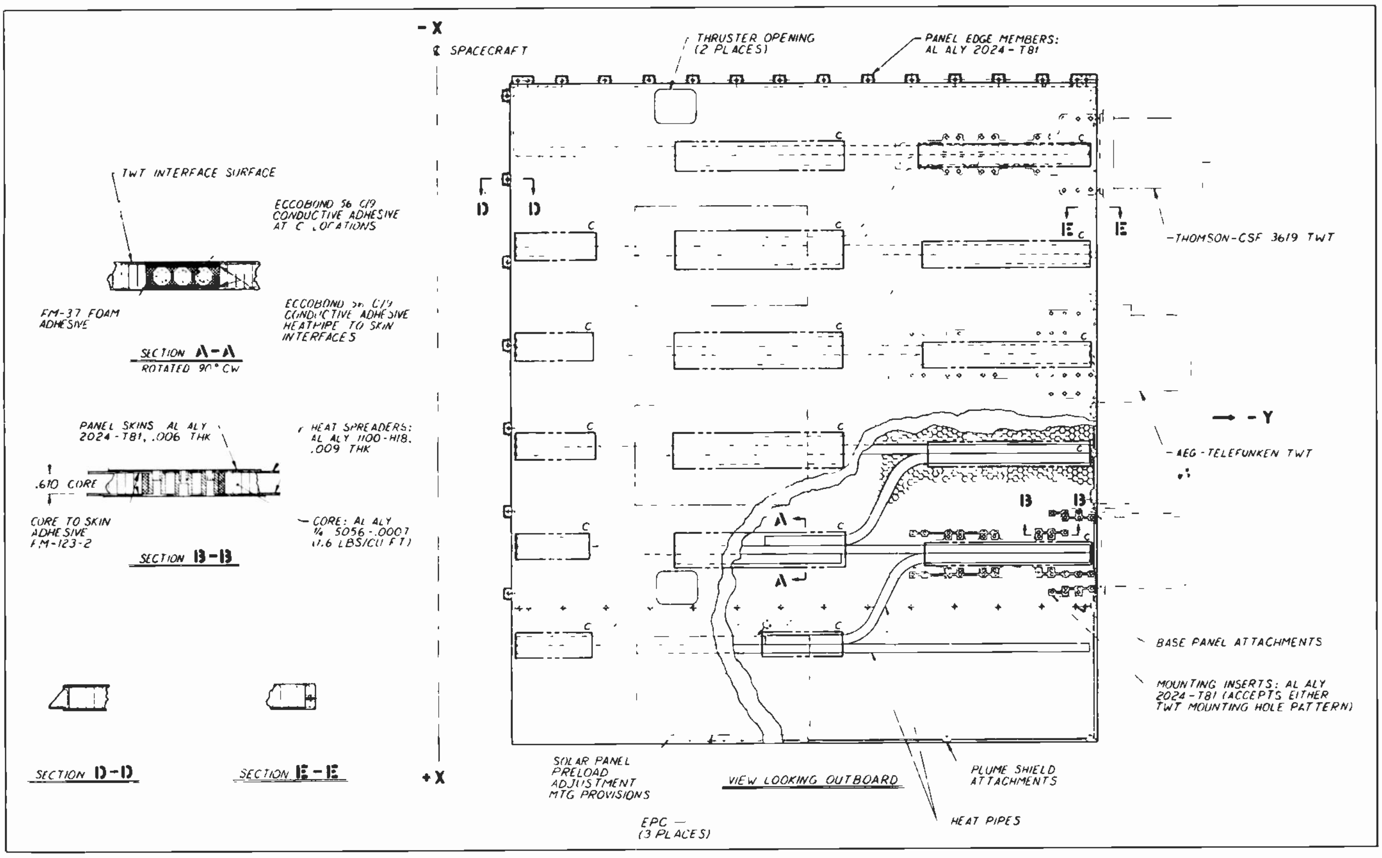


Fig. 3. *Proposed heat-pipe layout removes heat from TWT and EPC hot spots and spreads if efficiently over the radiator panel area.*

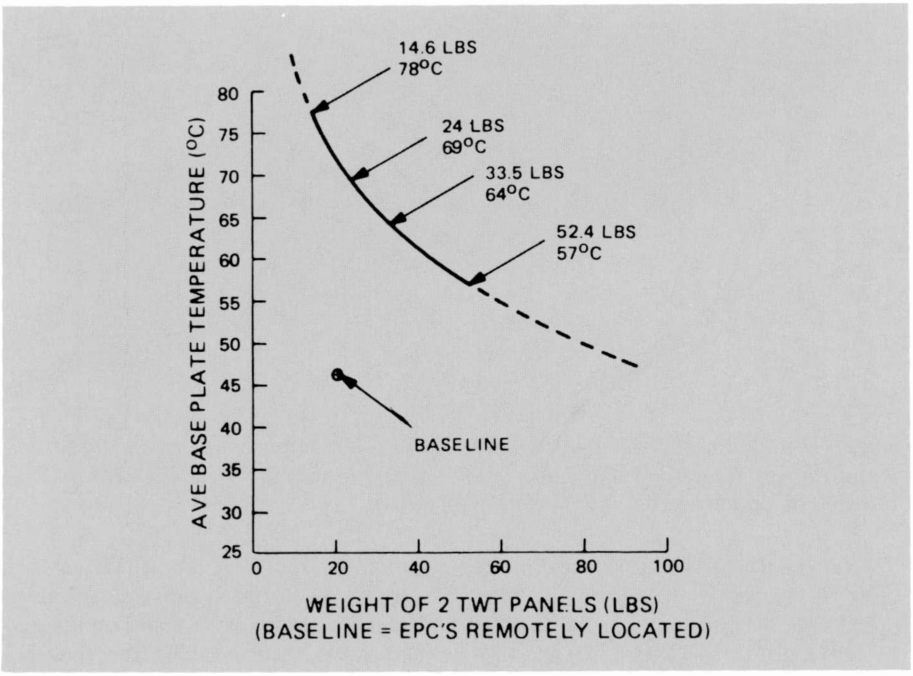


Fig. 4. *Comparison of radiator panel weight versus average TWT baseplate temperature for the conventional aluminum heat spreader and the radiator panel with embedded heat pipes.*

at the expense of weight taken up in thicker skins as in the Satcom spacecraft. Figure 4 is the result of the weight trade-off between heat pipes and aluminum heat spreaders, and clearly shows that the heat pipe is the winner of the trade-off.

The next logical question is: Can we use a variable conductance heat pipe to allow control of the radiation of heat during eclipse and thus reduce the weight of the batteries required for thermal control during eclipse? For the STC spacecraft, the answer is "no," because the transfer-orbit battery requirements are also a driving factor in the sizing of the battery. That is not to say that the answer to the question will not be reversed when the six-channel DBS spacecraft is examined in detail.

These discussions have highlighted the problems in thermal design of the DBS spacecraft. Implicit in the discussions is the importance played by the dc-to-rf conversion efficiency obtained by the TWT as well as the dc-to-dc conversion efficiency obtained by the TWT EPC (electronic power conditioner). The conversion efficiency of load bus power to rf obtained for the STC design is more than 40 percent, and must remain there to allow three channels on a Delta-class spacecraft.

Antenna and coverage considerations

The second method of attaining a high EIRP is to match the antenna pattern of the spacecraft precisely to the desired coverage area, and to size the coverage area to include that group of people interested in viewing programs with a given schedule. STC equated viewing groups to time zones and has thus specified the use of antenna patterns that cover roughly one time zone per beam. The single time zone per beam provides approximately a 6-dB increase in radiated power as compared to a CONUS coverage pattern.

The next consideration is that of antenna type. Choices available are restricted to reflector-optic designs with two principal alternatives. The older technology is to use a shaped-aperture reflector to provide a beam of approximately the proper shape. Beams of this type have a cross section of the $(\sin x)/x$ shape, and it is common practice to place the edges of coverage at the 3-dB performance contour of the resultant beam shape. The spacecraft designer, in attempting to satisfy system-performance requirements, finds that the energy transmitted outside the coverage area is wasted and must be minimized to provide acceptable performance. He also finds that energy expended within the coverage area that exceeds the specified requirements detracts from the performance at the peripheral points, which are the points at which he is graded. Therefore, he seeks the use of antenna technology that allows the most precise matching of performance to the requirements, within available hardware.

To attain a better match of beam shape and coverage area and to provide a more constant antenna gain across the coverage area, the reflector can be oversized, and the outputs of many adjacent horns can be combined to provide a zone of nearly constant illumination. It is difficult to estimate the percent increase in efficiency attained by this technology; however, a quick comparison of the gain attained through the use of the shaped beam and of that attained by an elliptical beam covering the same coverage area (time zone) reveals an enhancement of 2 dB. The shaped-beam antenna has seen much use in space and, to a limited extent, is found in the antenna design of the early Satcom spacecraft. When the payoff to the customer of small changes in antenna performance provides significant changes in downlink performance (to the extent of saving millions of dollars in user terminals expense), then the attention to design detail required for the precise shaped-beam antenna becomes paramount.

An added advantage of the shaped-beam antenna is that the pattern can take on the form of increased EIRP to those areas with largest rain attenuation, such as the Gulf Coast of the United States. This feature has been incorporated into the antenna designed for the STC spacecraft.

The use of the oversized antenna, while providing the antenna gain necessary to accomplish the mission, is not without its problems. The aperture required for the DBS antenna design is 2.2 meters in diameter. This reflector size is much larger than those previously used on RCA spacecraft. Figure 5 shows the STC DBS configuration, which uses a deployed reflector with the feed-network body mounted, in contrast to the normal Satcom fixed reflector and tower-mounted feed system. A fixed reflector could have been employed; however, the focal-length restrictions would have made an impractical antenna system. The result would also be marginal from the point of view of mechanical mass properties. With the deployed-reflector configuration, the calculated inertia ratio for the STC configuration is greater than 1.1, better by far than the normal Satcom ratio of 1.04.

Summary

The three-channel direct-broadcast satellite, as configured by RCA Astro for STC, has accomplished the goal of supporting three fully redundant 200-watt channels in a Delta-weight-class spacecraft. To accomplish this task, several applications of new technologies were employed. Noteworthy are the use of TWTs with direct-to-space radiating collectors, heat pipes for thermal energy distribution, and a deployed antenna reflector to allow the use of large-aperture and long-focal-length antennas.

There are many more less substantive changes from the RCA Satcom series of spacecraft to the DBS spacecraft configuration; however, the main point is that with all design changes included, the DBS spacecraft is, in fact, a modified Satcom spacecraft—changes have been made to the details to adapt the basic design to still another mission.

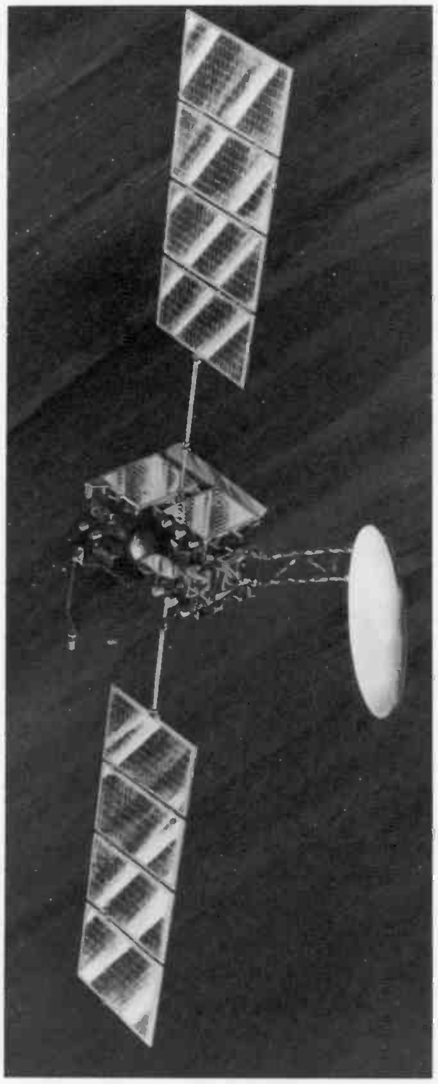
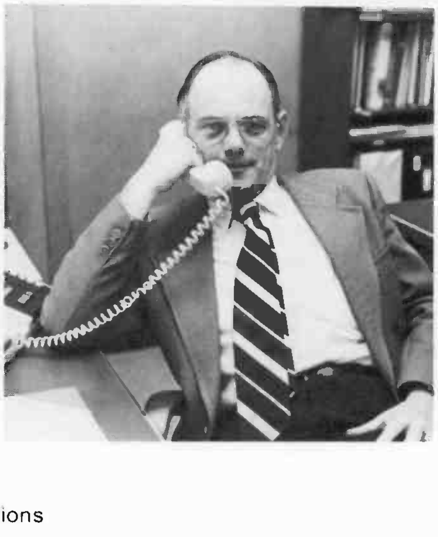


Fig. 5. *Prominent on this view are the TWT collectors protruding from the north and south payload panels and the long focal length, deployed reflector.*



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Critical system parameters in the DBS service

There may be a heavenly picture in your future now that DBS is in the countdown phase for its first launch. The aggressive advocates for this new service feel that what this country needs is a good two-foot dish on every garage.

Satellite distribution of television programs—both pay and advertiser supported—is proliferating rapidly. Cable operators were the first major customers for such a delivery service; more recently, master-antenna TV operators (those who supply TV programs to smaller self-contained units—for example, apartment houses, hospitals, condominium complexes, and so on) have started to appear and, shortly, direct-to-the-home delivery by DBS (Direct Broadcast Satellite) is expected to begin. An excellent overview of DBS was presented by John F. Clark in his paper in the *RCA Engineer*, July/August 1982. Our paper discusses, somewhat more quantitatively, several of the key system parameters that are planned for this new service.

Abstract: *The FCC has recently authorized several companies to proceed with their plans to construct satellites that will provide a TV service direct to the home. Although this may imply to some that all technical, and perhaps even financial, problems have been resolved, actually that is not the case. Some of the system parameters have indeed been agreed upon, for example, polarization (circular), channel spacing (26 MHz), and nominal home-antenna size (0.75 m). Others, however, have still not been definitively determined. Among these are the roll-off of the antenna sidelobe pattern and the subjective effect of interference from neighboring satellites. These play a vital role in determining satellite spacing in orbit and, therefore, the total number of channels available. Finally, much more consideration must be given to what is probably the most important parameter of all; namely, the design of a low-cost home terminal.*

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System parameters already set

Two major features of the DBS system make it different from current communication satellite systems. First, rainstorms can significantly degrade the signals in the frequency band for DBS (12/14 GHz). Second, to make the home receiving system relatively inexpensive, the satellite-radiated power will be 10 to 14 dB higher than any in use today. The first of the above characteristics manifests itself in attenuation and depolarization of the transmitted signal. As it turns out, signal attenuation is the more serious effect in many parts of the U.S. (not, of course, in the desert regions of the Southwest) and can result in poor reception for 5 or 10 minutes at a time on, perhaps, 50 different occasions during the year. Luckily, more than half of these occasions are likely to occur on summer afternoons, which may not be a particularly important viewing period. But only experience will show how the public will react to this situation.

The second of the DBS system characteristics (that is, high-power satellites) implies that one DBS satellite will be able to carry only three to six channels because of weight and power considerations. But since approximately 36 TV channels will be able to fit in the allocated frequency band, one orbital position will have to ultimately accommodate 8-to-10 co-located satellites, a situation that may be a problem all by itself. Furthermore, the high signal requirement at the home receiver terminal will mean that all the co-located DBS satellites will use directive antennas that will provide coverage to approximately one time zone only. Therefore, to cover all of the U.S., it is expected that four orbital positions will be used and, as mentioned above, each position will contain up to 10 satellites.

Channelization

Tentatively (the final decision is due in 1983), 500 MHz of bandwidth has been allocated to the DBS service—from 12.2 to 12.7 GHz for the satellite-to-earth link and 500 MHz more (from 17.3 to 17.8 GHz) for the earth-to-satellite link. Initially, at least, the modulation will be FM. Since the FM improvement (and, therefore, the signal-to-noise ratio) increases with increasing rf bandwidth, the first decision required was a trade-off between the total number of channels that could be accommodated in the allocated bandwidth and the signal quality achievable in any one channel.

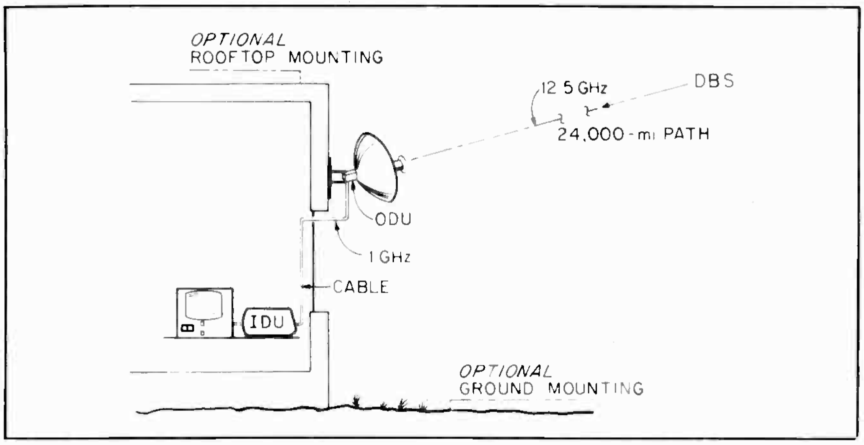
After much discussion in an industry-government advisory committee to the FCC, a reasonable compromise was reached. Channels (called transponders) of 26-MHz bandwidth would be arranged according to the frequency plan shown in Fig. 1. The dashed lines indicate qualitatively the spectrum of the signals within each of the transponders. In effect, there would be a total of 36 transponders allocated to the U.S.—18 of them would be on one polarization and 18 additional transponders, frequency offset by half of a transponder bandwidth, would be on the orthogonal polarization. The home-terminal antenna will have fairly good (but not perfect) rejection of the unwanted cross-polarized signals that fall in the same band. The frequency-offset plan sketched in Fig. 1 increases the rejection of the unwanted signal.

Specifically, if a viewer wishes to watch channel 3, which is on one polarization, there is a possibility that interference from channels 2 and 4 may be objectionable. Without frequency offset, the energy from channel 4 (which would be co-channel with channel 3) would be depressed approximately 25 dB by the home-terminal antenna. But because the spectrum of a TV signal is highly concentrated around the center of the band, the frequency-offset plan permits substantially less than one-half the energy of channels 2 and 4 to fall within the most important portion of the spectrum in channel 3. This feature permits additional rejection of the cross-polarized signal and will be discussed more quantitatively below.

Polarization

Basically, there are two possible choices for the pair of orthogonal polarizations shown in the frequency plan of Fig. 1. Either one polarization is vertical and the other horizontal, or one polarization is right-hand circular and the other is left-hand circular. It turns out that a pair of linear polarizations (vertical and horizontal) suffers less degradation in heavy rain than does a pair of circular polarizations. But circular polarization is slightly easier to install at the home receiver than linear polarization, because one does not have to align the home-antenna polarization with that of the down-coming radiation. Subjective tests carried out by one of the authors indicated that, because of the frequency-offset plan sketched in Fig. 1, even the highest degradation expected in the use of circular polarization is likely to be acceptable to the vast majority of viewers. In other words, rain will attenuate the signal to unusable levels before it degrades the polarization purity to objectionable levels. For these reasons, the FCC Advisory Committee on DBS (mentioned earlier) recommended implementation of circular polarization.

DBS home-receiver installation



A 12.5-GHz FM signal from a Direct Broadcast Satellite (DBS) falls on a small "dish" antenna on the home. An outdoor unit (ODU) mounted on the back of the antenna amplifies and downconverts the signal to a frequency of approximately 1 GHz. The 1-GHz signal is then delivered by a low-loss cable to an indoor unit (IDU) that processes the FM signal and reformats it to an AM signal that can be accepted by the home TV set for viewing. Downconversion in the ODU is necessary to reduce the line losses from the ODU to the IDU.

System parameters to be determined

Carrier-to-interference ratio

One aspect of this item has already been discussed in connection with the decision on polarization. The evidence (described below) appeared sufficient to assure that circular polarization would perform satisfactorily in rain. But there is another important system consideration that requires better information than is currently available; namely, how far apart in the geosynchronous orbit can one place DBS satellite clusters? If one places them too close together there may be unacceptable interference at the home terminal. On the other hand, if one places them too far apart, there may not be enough room to accommodate all of the channels needed for all the time zones of the U.S., Canada, Mexico, and the Caribbean countries. While this type of problem also exists in present satellite communication systems, DBS imposes a special requirement for very low cost receiver antennas. These antennas must be quite small (2- to 3-ft diameter). By definition, they will have much wider beams and, possibly, higher sidelobe levels than the antennas in current use. Therefore, the question of co-channel interference from adjacent satellites deserves special consideration.

Signal quality. Three major factors influence the quality of a TV signal; namely,

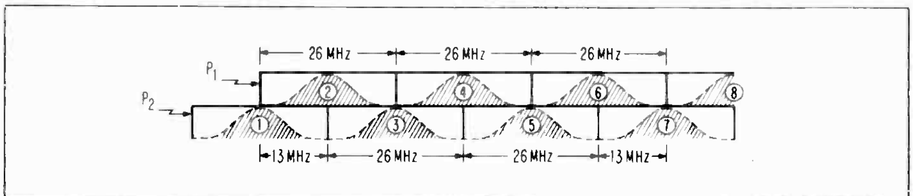


Fig. 1. *Probable frequency channelization for the U.S. DBS service.* P_1 *represents one polarization and* P_2 *represents the orthogonal polarization. These polarizations will be circular according to present plans.*

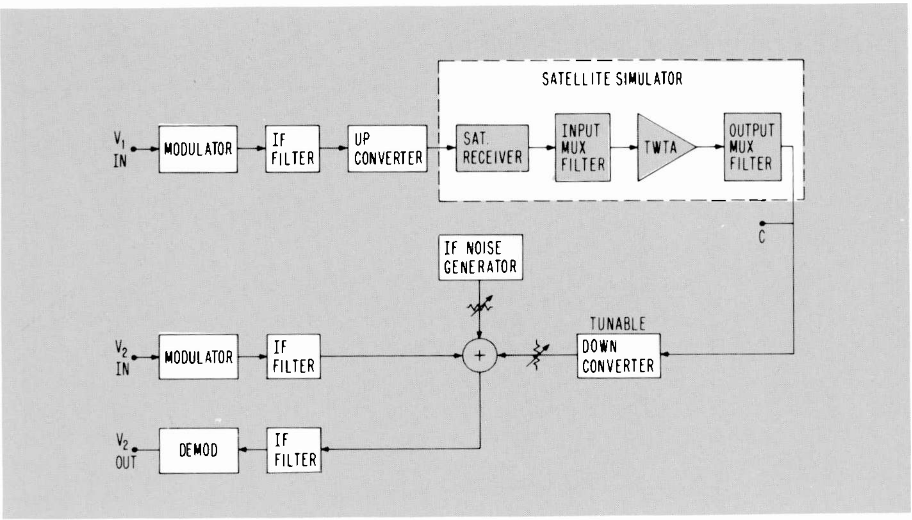


Fig. 2. *Test setup for measuring "just-observable interference" as a function of carrier-to-interference ratio (C/I), frequency offset, and carrier-to-noise ratio (C/N). V_2 represents the desired signal; V_1 represents the interfering signal. The frequency band occupied by the interfering signal can be varied by the tunable downconverter, while its amplitude can be varied by an attenuator (symbolized by the variable resistance). Carrier-to-noise (C/N) can also be adjusted by an attenuator.*

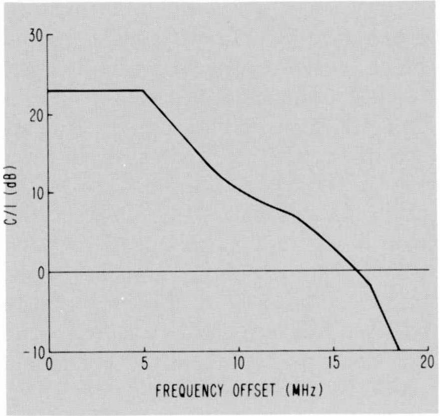


Fig. 3. *Subjectively measured results of "just-observable interference" as a function of carrier-to-interference (C/I) and frequency offset.*

thermal noise, distortion, and interference. Thermal noise and distortion depend primarily on the home-terminal designer, but interference is a system consideration and requires agreed-upon standards. Subjective tests conducted 20 and more years ago in connection with current TV broadcasting determined that a S/N of 43 dB results in a good picture, a S/N of 48 dB yields a very good picture, while a S/N of 52 dB or more provides an excellent picture. But there is a dearth of good subjective data on interference. Therefore, to get a handle on this question, a limited series of tests were undertaken at RCA Laboratories.

Currently, a more complete set of tests are in progress together with tests undertaken by other participants in the FCC Advisory Committee on DBS. To better appreciate the complexity of these tests, consider that the interference could be caused by a single carrier or a number of different carriers having similar or different modulating waveforms. For example, the desired signal might be a standard NTSC waveform FM modulating a carrier with a peak deviation (Δf) of 7 MHz, say, while the interference could be due to (1) an HDTV (high-definition TV) signal FM-modulating its carrier, (2) a time-compressed signal, (3) another NTSC signal, or (4) a combination of these signals. It is also possible that the interfering signal is not co-channel but is offset in carrier frequency. Clearly, an interferer whose center frequency is offset from that of the desired signal will introduce less energy in the band of the desired signal (see Fig. 1). In the limit, when all of the spectral components of an interfering signal lie out-of-band from those of the desired signal, no interference is perceived. For the frequency-offset case, then, the receiver-filter characteristics play an important role in interference reduction.

Tentative results from measurements. Laboratory experiments—to determine the effects of interference for the co-channel case, and also as a function of carrier offset—have been performed. The block diagram shown in Fig. 2 illustrates the implementation to carry out those tests. Referring to Fig. 2, the "satellite-simulator" box is electrically equivalent to a transponder. Since only one simulator was available, it was used in the path of the interfering signal (marked V_1). The "desired" signal (V_2) feeds the summing point directly at IF (70 MHz), as does the 70-MHz wideband noise generator. As shown, the receive path also connects to the summing point and produces an output signal (V_0). Level controls on both the "noise" and the "interference" paths can be independently adjusted to provide any value of C/I from roughly +50 to −50 dB and any value of C/N from less than 0 dB to +38 dB.

The curve shown in Fig. 3 is the result of two expert viewers observing the effects of a single interfering signal on a desired signal. Both signals were NTSC-FM operating at a peak deviation (Δf) of 7.1 MHz. The bandwidth of all three IF filters (one for each modulator and one for the demodulator, as shown in Fig. 2) was 25 MHz in this experiment. The curve gives the value of C/I (carrier-to-interference ratio in dB) that the two observers agreed represents just-observable interference. The C/I values are plotted as a function of carrier offset. At a carrier offset of about 16 MHz, the C/I for just-perceptible interference is 0 dB. But more important, at a frequency offset of 13 MHz (see the channelization plan in Fig. 1), the required C/I is about 8 dB. This implies that the cross-polarization rejection should be at least 11 dB per interferer. Even 15 dB is easily achievable with circular polarization under rain-degraded conditions. This fact played an important role in recommending circular polarization, a topic discussed earlier.

Attention is directed to the required C/I at zero offset (that is, co-channel interference). Our results indicate that a C/I of 23 dB is sufficient, but another investigator (Ed Miller and his group at NASA Lewis Research Center) has measured co-channel C/I requirements around 30 dB. Some explanations of this discrepancy will be given shortly, but it is very important to get agreement on this topic because orbital spacing—and, therefore, the total number of channels for the U.S., Canada, and Mexico—depends on it. It should be explicitly noted that the C/I values discussed here should represent the interfering power, I, of all the interferers taken together. Single-entry interference should, therefore, be about 4 dB lower, that is, the C/I for a single interferer should be at least 27 dB based on RCA tests, but around 34 dB based on NASA Lewis tests.

The design of the experiments. The signals used for these experiments were off-air programming (cable news network) for the desired signal (V_2) and color bars for the interfering signal (V_1). Just-perceptible interference values depend on the video

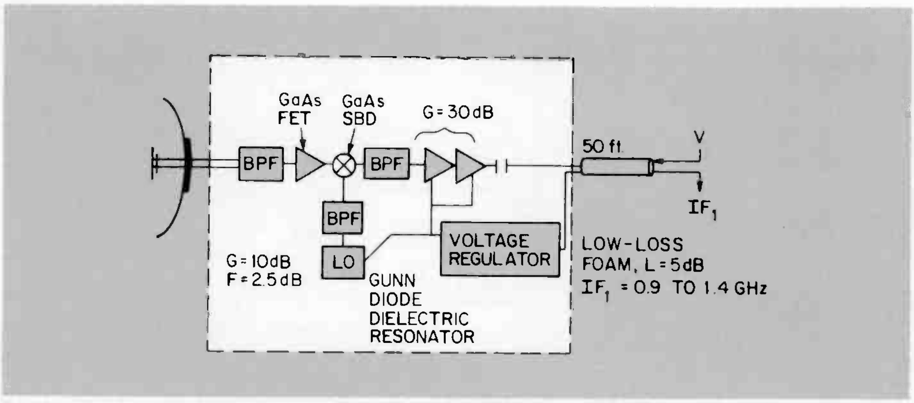


Fig. 4. *Block diagram of an outdoor unit (ODU) for a DBS home receiver. A 12.5-GHz FM signal from the DBS satellite is picked up by the antenna on the left and is amplified, downconverted to approximately 1 GHz, and fed through a 50-ft low-loss cable to the indoor unit (IDU) in the home. The line marked V at the right represents the power from the home to the ODU mounted on the back of the antenna. Specific symbols are: G, gain of the amplifiers; F, noise figure; BPF, bandpass filter; FET, field-effect transistor; LO, local oscillator; and SBD, Schottky-barrier diode.*

material used in each channel as well as on the relative timing between the two signals. For the results shown in Fig. 3, the two signals were not locked together so that the visual effect has the interfering signal slowly moving horizontally and even slower vertically. If one observes the interference effects for long enough, both horizontal and vertical sync times will be centered in the picture. This black "cross" condition is one of the most stringent tests (usually, indicating high-visibility interference in the desired picture).

Other combinations of signals could also be used to determine the just-observable C/I ratio. Still-picture (slides) or electronically generated video test signals (color bars, for example) could be used exclusively. When two motion pictures are used, the results suggest that a lower C/I is acceptable because the motion tends to obscure effects of interference (the beat pattern is continually changing, making the effects less perceptible).

This sensitivity of just-observable C/I on the nature of the video signals makes it important not to use, as a system criterion for C/I, the results obtained from either the most lenient or the most stringent set of video signals.

Current subjective experiments use a number (four to six) of agreed-upon slides as the desired signal, and a motion (off-air) video signal as the interference. This combination should produce results that will be more-or-less typical of actual operating systems.

Some preliminary results on multiple interferers suggest that more total interference power is allowable for the same criterion of just-perceptible interference than when only one interferer is present. If further tests prove this correct, the reason could be due to the more uniformly distributed interference power (low correlation between signals). More detailed experiments are planned in this area by both the U. S. and Canada.

The home terminal

General considerations. To be acceptable for the general consumer market, the DBS home terminal must meet several criteria. First of all, the cost must be very low—$500 retail is a maximum. Manufacturing costs would therefore have to be $200 or less. Second, the terminal must be easily transported and easily installed. Next, the terminal must be designed for long life (7 to 10 years). Finally, the terminal should be no more difficult to use than an ordinary TV set and outdoor antenna. The first two criteria, plus the esthetic requirement that the antenna not be too intrusive (demanded by the community), force the design toward a "dish" antenna with a diameter in the 2- to 3-ft range. A detailed stringent examination of all the factors indicates that the antenna and the outdoor unit (ODU) are the key cost and performance items of the home terminal.

A block diagram of the ODU, which will be mounted on the back of the home antenna, is shown in Fig. 4. A key component in the ODU is the low-noise GaAs field-effect transistor (FET) amplifier. It is currently expected that a cost-effective noise temperature will be in the range of 225 to 290 Kelvin. This figure corresponds to noise figures of 2.5 to 3 dB. In addition, there will be an indoor unit (IDU) containing a multichannel FM demodulator with individual channel tuning, a channel-number display system, video and stereo-audio baseband processing with baseband outputs, an AM modulator for use with TV sets not having video and audio inputs, and the power supply for both the IDU and the ODU (which are interconnected by low-loss coaxial cable). A block diagram is shown in Fig. 5.

Figure of merit. A parameter that has become standard in describing the performance of an earth station is the quantity G/T, where G is the gain of the antenna and is strongly dependent on its size, while T is the system's noise temperature in Kelvin (K). This is just another way of expressing the noise figure of the receiver. Table 1 below provides current estimates of cost as a function of the performance capability of the DBS home terminal. These estimates represent a substantial improvement over those used only three years ago (1980). From the table, it can be seen how fast cost and weight increase with increasing antenna size. Link budget calculations indicate that a home terminal G/T of 10 to 12 dB/K should be quite satisfactory for almost all locations in the U.S. There is, therefore, reason to hope that a 0.6-m (2-ft) antenna may prove satisfactory. Just three years ago, conventional wisdom held that a minimum antenna size of 0.9 m (3 ft) would be required.

Antenna pattern. In addition to getting a highly efficient antenna (that is, high gain on-axis for a given diameter), it is important to keep sidelobes suppressed so as to minimize interference from co-channel transponders at adjacent orbital positions. These two requirements (high gain and good sidelobe suppression) are usually incompatible requirements. However, recent work at RCA Laboratories appears to have led to the right formula for accomplishing both.

Figure 6 shows a measured pattern (solid curve) for a 2-ft antenna having 74-percent efficiency and good sidelobe suppression. For comparison, the desired goal for sidelobes specified in the Final Report of the Conference Preparatory Meeting for the 1983 Regional Administrative Radio Conference (RARC '83) is shown by the dotted curve. We see that the RCA Labs design falls below the specified mask almost everywhere.

The important region of interest is in the angular range of 15 to 20 degrees. From geographic considerations, the suitable orbital arc for a DBS service to cover North America is of the order of 90 degrees in differential longitude. If 15 degrees orbi-

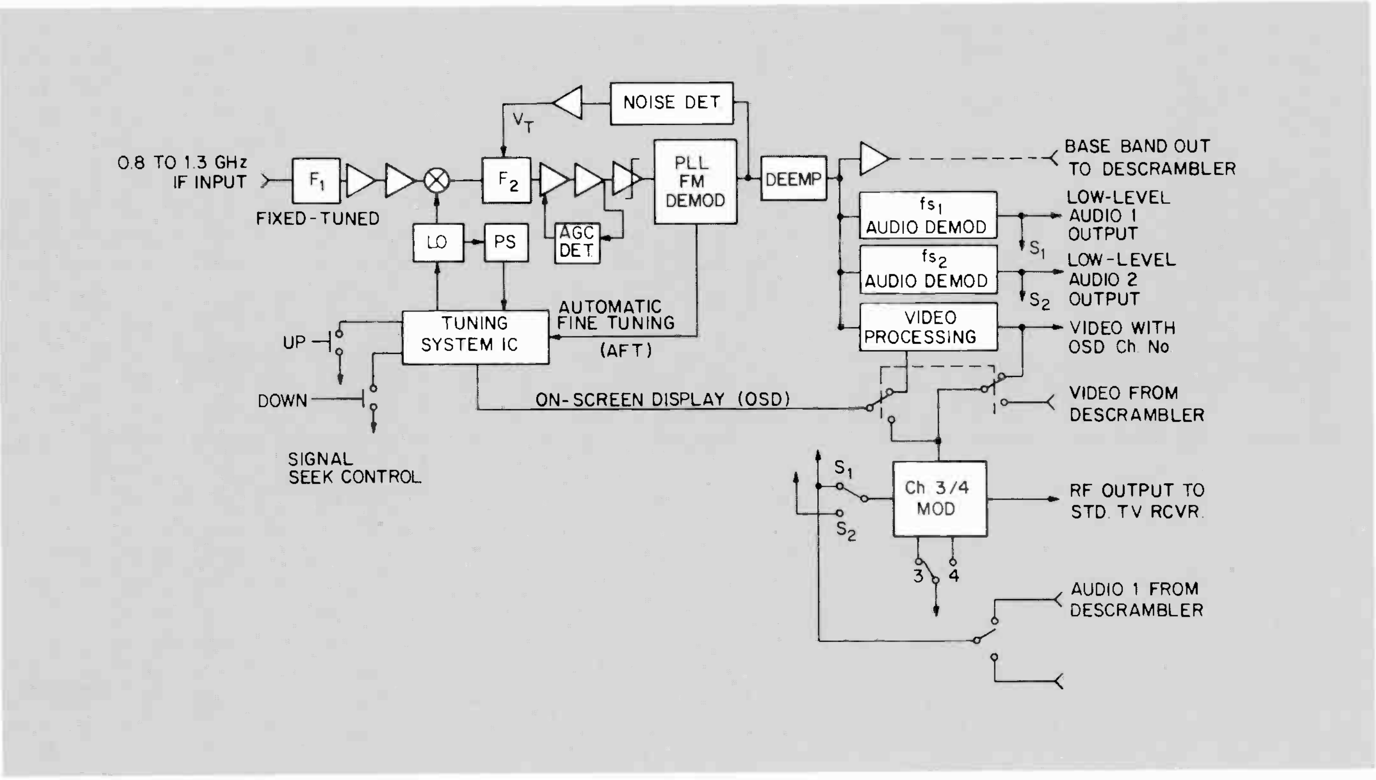


Fig. 5. *Block diagram of the indoor unit (IDU) for a DBS home receiver. The 1-GHz FM signal from the ODU is processed in this unit and put into a format that can be accepted by the TV set in the home. The symbols in this diagram are: AGC, automatic gain control; DEMOD, demodulator; DEEMP, deemphasis network; DET, detector; IC, integrated circuit; LO, local oscillator; MOD, modulator; PLL, phase-locked; and PS, prescaler.*

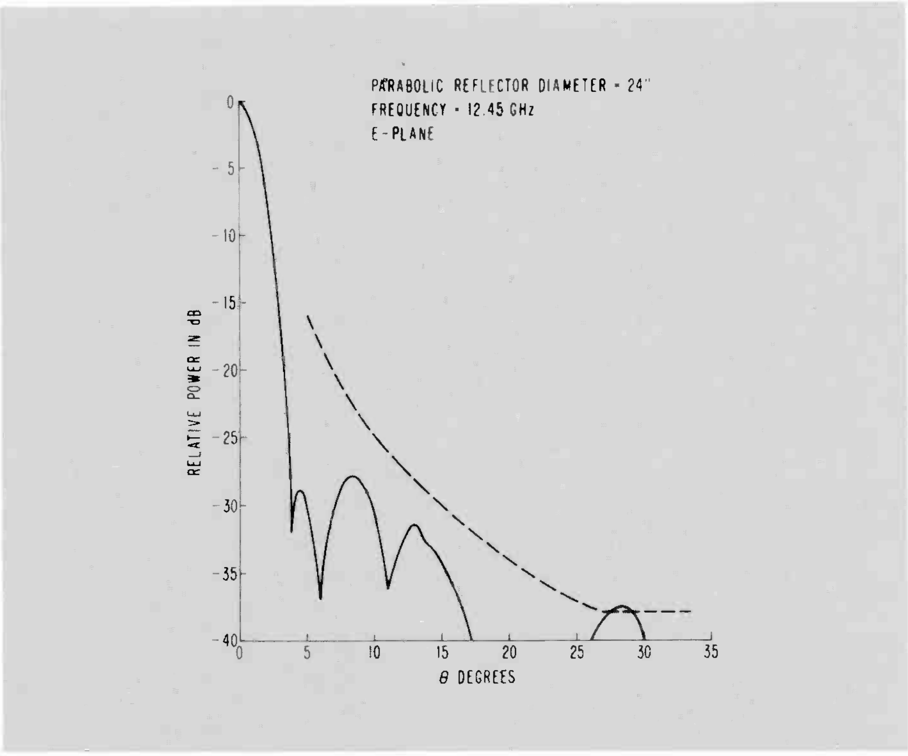


Fig. 6. *This figure shows a measured pattern of a 2-ft DBS "dish" antenna developed at RCA Laboratories (solid curve) that easily meets a desired goal for antenna sidelobe levels (dashed curve) specified by an FCC Advisory Committee.*

tal spacing can be achieved, then seven orbital positions can be used. On the other hand, if 20 degrees orbital spacing is required, only five orbital positions can be used. The difference (seven versus five) is very significant.

Where do we stand today?

First, the good news. In the past several years, significant progress has been made toward the development of an appropriate technology. The noise temperature of the receiver's front end has been reduced by about 3 dB at no increase in cost, and antennas with reduced sidelobes and higher gain have been demonstrated also at no increase in cost. In 1977, the Europeans, for example, felt that a cost-effective G/T for the home terminal would be about 6 dB/K and that this would require a 3-ft "dish." Today, a G/T of 11 dB/K with a 2-ft "dish" seems reasonable (see Table I.).

Two technical problems of some consequence remain. One requires agreement by the technical community on a C/I standard so that satellite orbital spacing can be specified. The other relates to an acceptable standard for scrambling of the

Table I. *Cost as a function of home-terminal performance (50 K has been added to receiver noise to allow for sky noise, earth scattering, and line loss).*

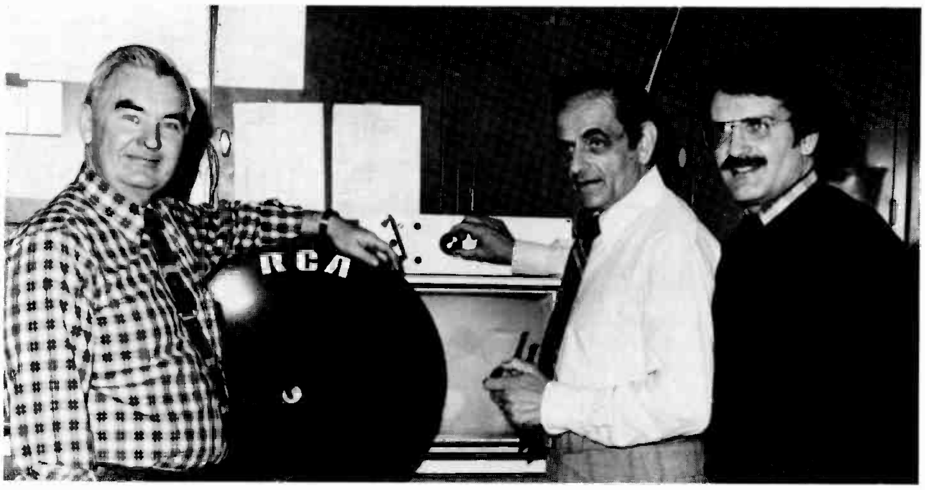
				Front-end characteristics		
				3	2.5	NF (dB)
Antenna characteristics				290	225	T (K)
Diameter (m)	*Gain (dB)*	*Wt. (lb)*	*$*	7.00	11.00	$
0.6	36.4	14	17	11.1	12	G/T (dB/K)
1.0	41.1	38	46	15.8	16.7	
1.22	42.5	57	68	17.2	18.1	
1.6	45.4	97	116	20.1	21	

TV signal. Since several of the DBS applicants plan to provide a "pay TV" service, those signals must be scrambled with descramblers made available only to those who pay for the service. There are two conflicting requirements imposed on the scrambling/descrambling schemes. First, the scrambling code must be sufficiently complex so that it should not be easily defeatable by a cheap descrambler made by a garage-shop "manufacturer." Second, the descrambler should be inexpensive since every subscriber must have one. A detailed discussion of this aspect of DBS is worthy of a paper by itself and will not be discussed further here.

The bad news is concentrated in the financial and business end of this service. DBS satellites are very expensive. In addition, where will the distinctive programming come from? The leading business entity in this field, Satellite Television Corp. (STC) estimates an investment of almost $700 million in the first four years. Other estimates exceed a billion dollars—and this to provide only three TV channels! Furthermore, competition for the consumer's entertainment dollar from other sources such as CATV, STV, LPTV, video-disk and so on can be very intense. Perhaps the most hopeful sign is that close to 20-million households are never likely to be connected to cable systems because they live in sparsely populated communities. Significant penetration of that market may make DBS a viable business.

Should DBS gain a foothold in the home-entertainment business, the prospect for higher-quality TV could improve significantly. For example, time-compression and high-definition TV (HDTV), currently under development in various laboratories, could provide enhanced picture quality to new TV receiver product lines.

While the future—as always—is unknown, the prospects are challenging.



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Harold Staras has had over 30 years of professional experience in research and development in areas relating to radio-wave propagation, antennas, and telecommunications. He played an instrumental role in developing troposcatter in the 1950s, was a group head directing technical development in vehicular electronics and mobile radio in the 1960s and early 1970s, and has participated in the analysis and planning of satellite communication systems ever since. Dr. Staras is a Fellow at RCA Laboratories, currently engaged in satellite communications studies in support of RCA's communications satellite programs. Recent studies in this area include DBS and satellite video-conferencing.
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J. Simpson

RCA's Missile Test Project supports Space Shuttle operations

Missile Test Project, part of RCA Service Company, helped get the Shuttle off the ground.

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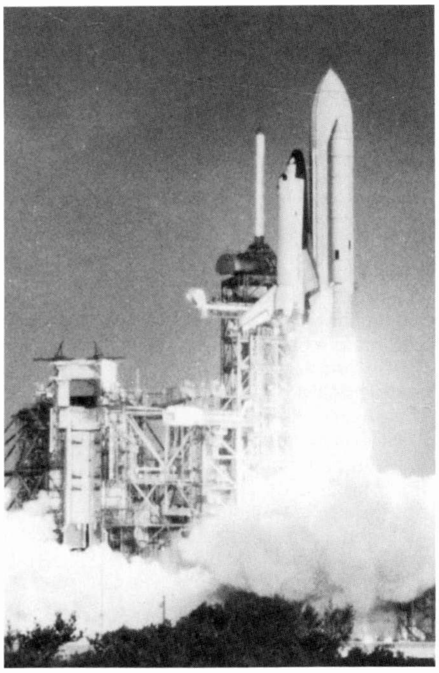

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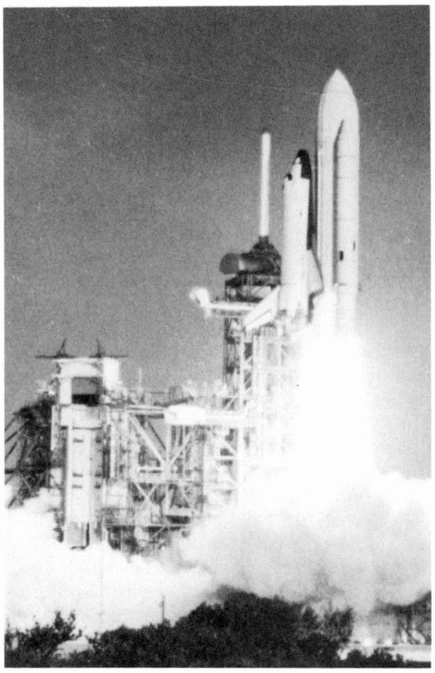

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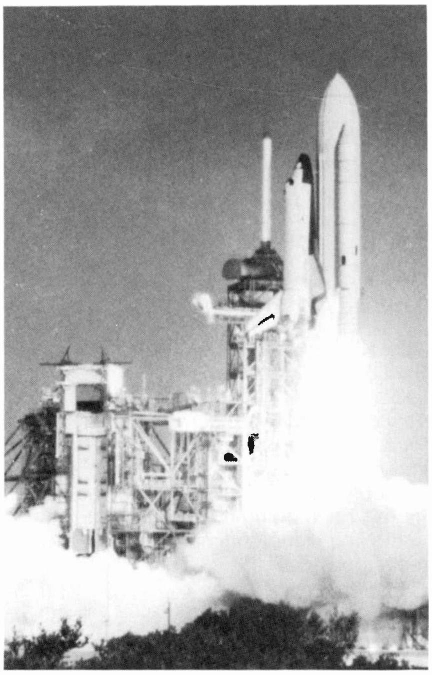
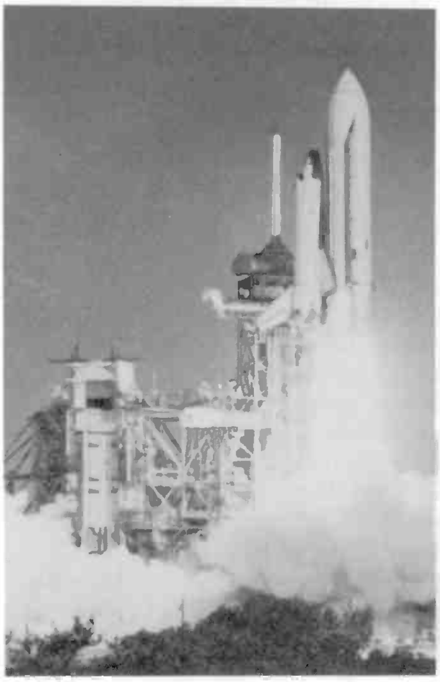


1 . . . We have ignition and a lift-off!"



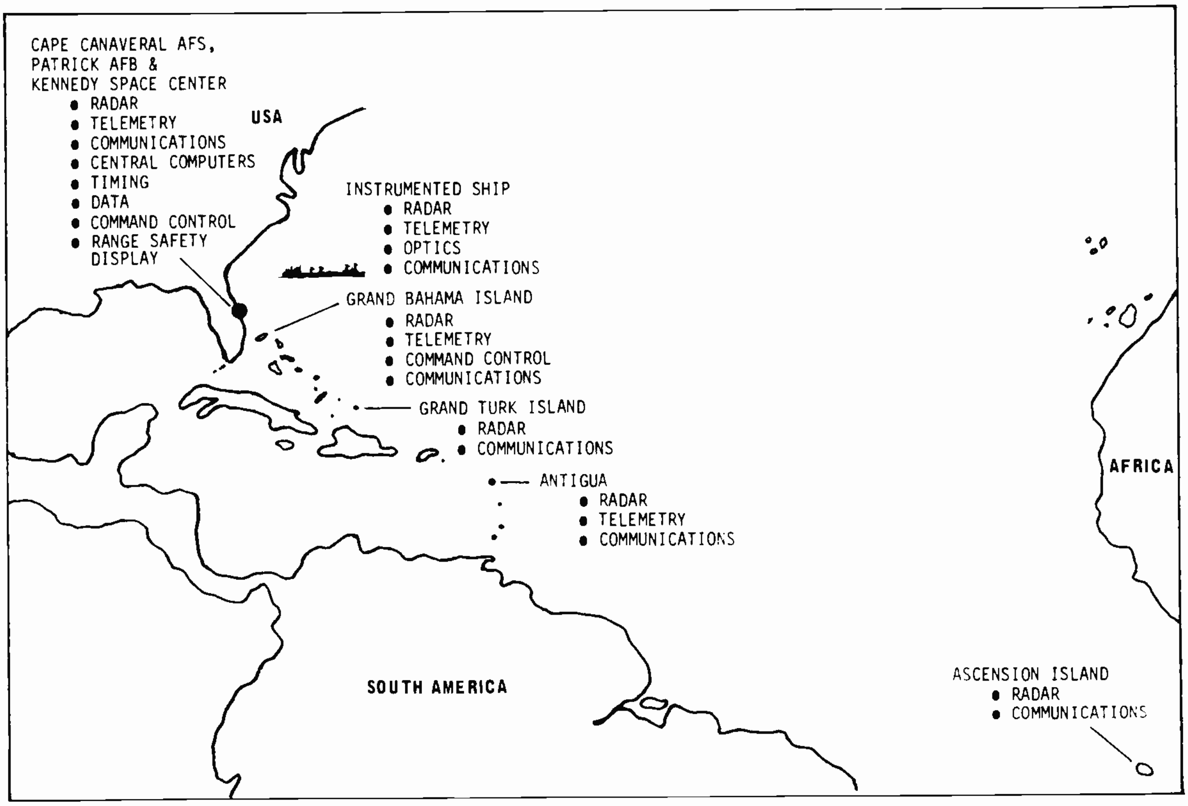


Fig. 1. *The USAF Eastern Test Range extends from Cape Canaveral, Florida, to Ascension Island in the South Atlantic ocean. MTP operates tracking, communications and data systems at each range location in support of Space Shuttle and other operations.*

Another Space Shuttle is boosted into orbit. This exciting final segment of the countdown, shown by the TV networks and weekly news magazines, is usually the limit of the average American's involvement in the launch of a space vehicle. Moreover, as the launches become more routine, less coverage is allowed to interrupt regular network programs. The launch of a communications, weather, scientific or other unmanned satellite goes almost unnoticed today, and yet the services provided by the technology inherent in these satellites continues to have a great impact on the quality of American life.

As the thoughtful TV viewer might surmise, the excitement of the last few seconds before ignition, and the thundering roar of an ascending rocket engine, are just the tip of the iceberg. A tremendous amount of effort is expended in the preparation before, during, and after the launch and flight of a Space Shuttle and many other satellites. RCA's Missile Test Project (MTP) people at the Eastern Space and Missile Center's Eastern Test Range (ETR) contribute greatly to this effort, and share in the satisfaction and pride in a successful operation (Fig. 1).

Abstract: *RCA's Service Company's Missile Test Project, which has been supporting NASA and DOD launches since 1953, contributed greatly to the planning for the unique aspects of the Shuttle launch. Modifications to the Eastern Test Range enabled complete tracking and range-safety control of the launch vehicle. Four major phases of the Shuttle launch support are described, and numerous sidebars present different issues of the multidisciplinary effort.*

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MTP plans for the Shuttle

Actually, MTP's involvement in many complex launch operations can be measured in terms of "T-minus weeks"—and in the case of a completely new launch vehicle, sometimes months. This was certainly the case with the Space Shuttle. That operation presented many challenging problems, and not only for NASA's spacecraft design engineers. MTP programmers and engineers were responsible for modifying ETR tracking, computer, command-control, and display systems to be compatible with a whole new set of flight possibilities.

RCA planners and system analysts were busy devising the best possible methods for the modified tracking systems to acquire and maintain track of an object that, because of weight considerations, was not to carry a radar beacon.

MTP controllers were also given the new responsibility of planning for, and controlling the operation of, not just Eastern Test Range trackers, but the worldwide network of Department of Defense (DOD) tracking resources. MTP operators, technicians, and data-processing people needed operating instructions, training, experience and skill to meet the stringent requirements imposed by NASA, Air Force Range Safety, and the overriding consideration of the lives of the Shuttle astronauts.

MTP's planners, experienced in hundreds of other missile and satellite launches, found many unique aspects of the Space Shuttle operation to consider. For example, they had to account for the unknown effects of multipath reflections from the boosters, external tank, aircraft-shaped spacecraft and the service tower at

Fig. 2. *The Range Safety Display System provides Air Force Range Safety Officers with accurate electronic displays of Space Shuttle and other launch-vehicle flight conditions, plus the ability to remotely control transmitters that can send destruct signals if necessary. MTP provides maintenance and software services.*

the time of, and shortly after lift-off. In addition, the antenna patterns of airborne transmitters would be frequently changed, as selected by NASA controllers to favor NASA ground receiving stations. And limitations were imposed on Range radars to only "skin track" (non-assisted echo-track) the Space Shuttle vehicle, because of the absence of a C-band radar beacon. Moreover, a booster exhaust flame could, in flight, reach an effective length of almost a mile, and could possibly act as a better reflector of radar signals than the desired target itself, the Orbiter spacecraft.

Once launched, the jettisoned solid rocket boosters would need to be tracked to ocean impact, and simultaneously, the spacecraft would be tracked on its way into orbit. A "return to launch site" situation could occur in the case of an aborted mission, and the spacecraft would have to be tracked and its position displayed until landing, for Range Safety considerations. The system that would be used by Range Safety Officers to destroy the Shuttle boosters and fuel tank if abnormal or unsafe flight conditions existed, was designed to use a sophisticated and secure coding sequence with a fail-safe verification method dissimilar to other airborne destruct systems (Fig. 2).

In addition, two small T-38 "chase" planes, piloted by astronauts, were to fly racetrack patterns in the launch area, transmit TV pictures to a ground station, and be available to assist the Space Shuttle astronauts in the event of a "return to launch site" abort. These aircraft had to be continuously tracked so they could be vectored to the correct altitude and position at the time of lift-off. The TV signals originated by the aircraft had to be received on the ground and distributed to NASA for use by NASA and the TV networks. The tracking operations of radars—normally involved in Army, Navy and Air Force Range operations at widely dispersed locations—had to be conducted in a single, effective, and data-compatible network.

All of these situations required either the development of new software, new or modified hardware, and many new operating procedures. As early as 1978, MTP people, in coordination with Pan American World Services (prime contractor for the Eastern Test Range) under the direction of the U.S. Air Force, began the long task of modifying the Range for Space Shuttle support.

MTP missile and space support

For the past 30 years, the RCA Service Company's Missile Test Project (MTP) has provided primary technical support services to the Eastern Test Range (ETR), which stretches from Cape Canaveral to the Indian Ocean. MTP technicians and engineers operate and maintain the data-acquisition, data-processing, range-safety, communications, and other support systems used on the Range. At present, there are 13 precision tracking and signature radars, 14 telemetry systems, and 127 computers and microprocessors on the mainland and on down-range stations and ships.

Engineering, drafting, and technical shops modify existing systems and integrate new or modified systems into the Range instrumentation complex. Over 1,000 engineering tasks and 20,000 repair and calibrations services are handled each year.

Data processing maintains approximately 200 active production programs for its large computers. Some of MTP's major space-support accomplishments are:

- First C-band radar track of a space satellite (AN/FPS-16 XN-1 radar track of Sputnik 2 on December 21, 1957).
- Major support and operational techniques for a worldwide multi-radar network for Project Mercury, the first U.S. manned space program.
- Development of beacon-pattern "wobbulation" technique to minimize acquisition and angle-tracking problems caused by phase-front disturbances. Used by NASA for the Mercury and Gemini launches.
- Development and refinement of search and acquisition techniques to aid pencil-beam tracking radars in obtaining track on satellites at extended ranges and with large azimuth uncertainties.
- Development and routine application of computer programs to fit single- and multi-revolution satellite track data and to determine radar random and systematic errors.
- Establishment of around-the-clock high-accuracy space-object tracking capability for North American Air Defense Command (NORAD). Incorporation of automated techniques has increased capacity up to 3,500 tracks per month per radar.
- Development of computer-directed (on-axis) tracking techniques to significantly improve radar accuracy and precision.
- C-band radar track of Apollo spacecraft out to 64,000 nautical miles (approximately one-third of the way to the moon).

—*Larry Mertens,* Manager
Technical Analysis

Chase/TV aircraft support

Problem: When the requirement to support the Chase/TV aircraft was received, all the mainland C-band radars were committed to provide real-time trajectory and impact-prediction data for the Range Safety group during the Shuttle launch. Necessary hardware to vector the aircraft and to designate the C-band TV-receiving antenna were not available.

Solution: An FPQ-13 radar (0.13) located at Patrick Air Force Base was available; however, this radar did not have auto beacon/skin and powered flight-track capability. The necessary hardware and software changes were implemented.

The old XY-plotting boards were replaced with a new computer-driven CRT vector-control display system (VCDS). An extensive programming effort was required to provide map displays for aircraft racetrack patterns and intercept points, for orbiter return to launch site and planned landing at Kennedy Spacecraft Center, and for assorted alphanumerical readouts.

The Eastern Test Range Telemetry Site on Merritt Island (Tel-4) was tasked to receive the C-band TV signal from the aircraft and transmit the video over land lines to the NASA TV facility. Since the C-band antenna does not have auto-track capability, the following designate plan was implemented:

- Designate data was derived from another Tel-4 antenna that can track aircraft L-band beacon.
- A MK-51 optical tracker was installed to overcome tracker-antenna elevation limitations when an aircraft flies directly over Tel-4.
- Slip rings were installed on the L-band tracker to eliminate antenna-cable wrapping problems.
- Designate data was also derived from the Radar 0.13 tracking the aircraft C-band beacon.

All systems have satisfactorily supported the Shuttle program through the STS-5 launch. However, the computer-software programming effort continues as new requirements are received from NASA.

—Larry Mertens

Fig. 3. *MTP operates the Master Control Console of the Cape Canaveral AFS Central Computer Complex, the focal point for real-time operational data processing.*

Modifying the Range

For example, two radars that normally operate in the C-band range (5400 to 5900 MHz) were modified to allow alternate operation at S-band telemetry frequencies (2200 to 2300 MHz). By using the Orbiter telemetry downlink as a signal source, this modification enhanced the radars' ability to discern and discriminate between different targets at the time of booster separation.

Another modification having a similar purpose, and made to two additional radars, was dubbed "Lead/Lag Edge Track." This change gave the radars the ability to maintain track of the lead or lag edge of the radar echo signal, rather than the centroid portion of the pulse. The "Lag Edge" mode could be used at the time the large solid rocket boosters separate from the still-accelerating spacecraft, to diminish the possibility of having the radar erroneously track the descending boosters. The "Lead Edge" mode of track would be used if separation was to occur when the spacecraft combination was returning to the launch site, following a mission abort. Both of these modifications were made to the radar hardware, and some software changes were required.

Many other modifications involved Range Safety Command Control systems, dynamic CRT displays for Range Safety use, and the processing of track data from all over the world through MTP-operated computers, for routing to the Goddard and Johnson Space Centers (Fig. 3). Over 50 different computer programs either had to be developed or modified by RCA analysts and programmers, all subject to rigid certification procedures before use.

As each new element was added, or modified, many individual tests verified correct equipment operation, followed by major simulated launch scenarios, to ensure that each segment contributed properly to the overall system operation. As might be expected, there were several "back to the drawing board" cases before the successful combination of software, hardware, and operator action was achieved. During this time, the Range was also busy with other non-Shuttle-related work. RCA's MTP organization participated in the support of almost a hundred other launches such as Titan, Pershing, Atlas-Centaur, Trident, Poseidon, and several Delta launches including one carrying an RCA Satcom satellite.

As the Shuttle launch date approached, many tests validated the several interfaces between NASA launch facilities, the Orbiter, and the Range systems such as the "Hold Fire" switches and

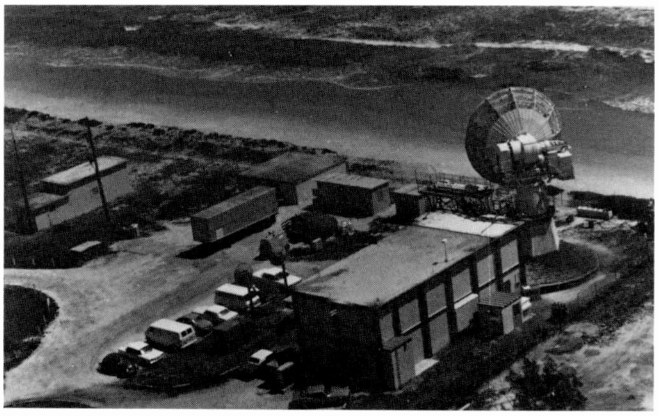

Fig. 4. *This FPQ14 C-band tracking radar at Patrick AFB, Florida, was built by RCA, and is operated by MTP. It provides important tracking data during Space Shuttle launch and orbital phases.*

Radar performance monitoring on shuttle flights

MTP System Controllers direct operations at the Central Computer Complex, and supervise the data interface with display systems and worldwide tracking sensors.

Missile Test Project analysts monitor the performance and accuracy of the 32 radars comprising the Department of Defense (DOD) C-band radar network during support of all Space Shuttle missions from launch to landing. The approach is basically a worldwide extension of the near-real-time Radar Accuracy Monitoring Program (RAMP), which was instituted at the Eastern Test Range as early as 1969. During the orbital flight phase, the Shuttle Orbiter is tracked by typically 25 or more C-band radars (FPS-16 and MIPIR types) of the DOD and NASA Test Ranges, to provide data input to the High-Speed Trajectory Determination Processor at the Johnson Space Center, Houston. All data are routed through the Central Computer Complex (CCC) at the Eastern Test Range, and the data of radars to be checked—regularly once per day—are copied.

The data of typically up to 12 radars per solution are processed at the CCC (see figure) in near-real-time in the orbit-determination and error-modeling software (TEAM/TRACE programs) that solves for radar systematic errors (for example, biases, refraction, data timing, survey, dynamic lags). Plots of residuals with respect to tracking coordinates and other parameters are provided to assist the analysts in recognizing and interpreting anomalies in the radars' performance. With these aids, radar analysts, well familiar with the characteristics of the different radar types, are able to spot a variety of operational/technical problems and their sources, which are not necessarily recognized by the operating crews. Data timing, discontinuities, encoder-bit errors, range-tracker find/verify logic, marginal receiver sensitivities, unusually large biases, refraction over- and under-correction, and surveys are typical of the problems routinely identified. The analysis results are usually available within a few hours after the radars' tracks, and are relayed via the Shuttle Support Group to the Test Ranges for corrective actions.

This monitoring program has repeatedly demonstrated with each Shuttle mission its effectiveness in assuring NASA of radar accuracy within the acceptable tolerances of 0.25 mils in angles and 100 ft in range. In the Shuttle support effort, the program's sensitivity to radar errors is typically better than 0.05 mils in angles and 15 ft in range.

—*Larry Mertens*

circuits, the visual countdown indicators, and the scores of audio-communications circuits between key controllers. Many of these tests included participation by Air Force Range Safety Officers, who used the launch simulations to check out all of the command control/destruct, computer and display systems operated by MTP people, and to verify compatibility with Shuttle airborne equipment. These officers also simulated various disastrous flight situations or abnormal conditions, as training exercises for the real thing.

In April 1981, NASA declared its readiness to launch Columbia (STS-1), the first Space Shuttle, in the Orbital Flight Test phase. The Eastern Test Range, Air Force Range Safety, Pan Am and RCA confirmed the readiness of not only ETR resources, but also those of the DOD worldwide tracking network.

Space Shuttle Columbia was orbited on April 17, 1981, and a new era in space technology began. Many MTP people remembered earlier successes.

Since 1953, RCA MTP has been the major subcontractor to the Eastern Test Range, and has operated radar- and telemetry-tracking systems, and communications and data-processing equipment during all manned space flights including the Mercury, Gemini, Apollo, and Skylab programs.

To provide launch area or orbital track data, RCA specialists are stationed at Patrick Air Force Base, Cape Canaveral Air Force Station (AFS), Kennedy Space Center, and "down-range" islands as far away as Ascension in the Atlantic Ocean (Figs. 4, 5, 6, and 7). An Air Force tracking ship manned by RCA MTP technicians and engineers is also located in the Atlantic Ocean.

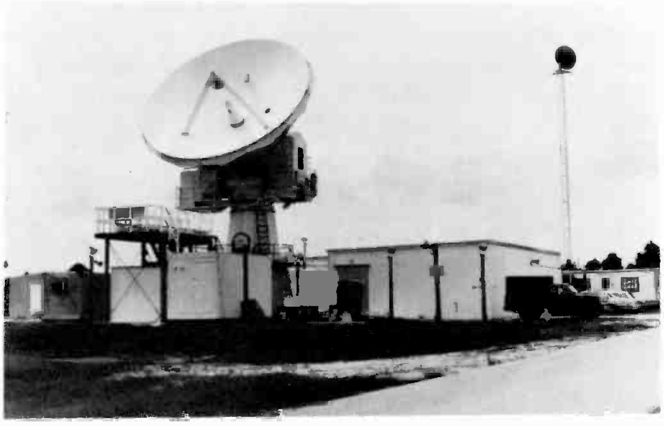

Fig. 5. *This RCA TPQ14 radar has a 30-foot-diameter antenna, and is located at the Kennedy Space Center, Florida. Operated by MTP, it provides early launch-tracking and impact-prediction data for Range Safety Display.*

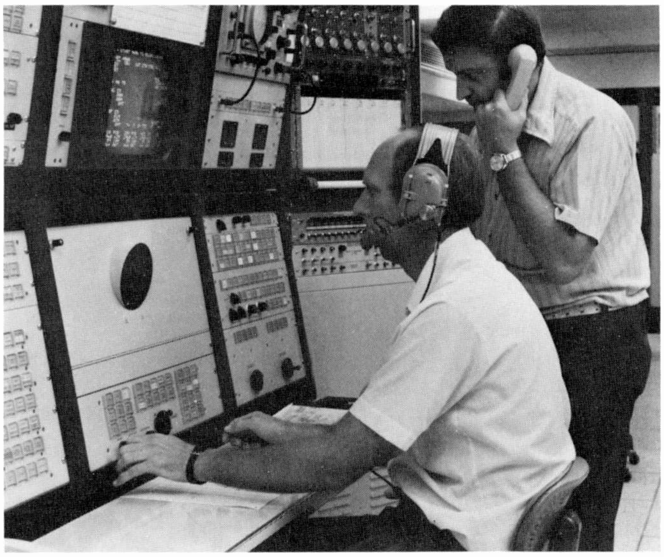

Fig. 6. *MTP radar operators use skill, experience and sophisticated software to provide smooth and accurate tracking data.*

The support effort

During Columbia's STS-1, and in later flights, RCA MTP operations people provided support in four major phases.

Launch phase

Seven different land-based radars tracked the Orbiter from the launch pad, to the separation of the solid rocket boosters, and the acceleration of the Orbiter into its orbit. Tracking systems on-board ship in the Atlantic Ocean tracked the jettisoned solid rocket boosters during their parachuted descent into the ocean (Fig. 8). A Range Safety Display System includes redundant CRTs and television presentations for use by the Air Force Range Safety Officers in determining whether the Shuttle flight is nominal and within safe boundaries, or abnormal requiring an "abort" or "return to landing site" decision. Timing signal generators, distribution equipment, and visual countdown systems were supported in NASA launch and operational control areas.

Computers received and processed tracking data for "real-time" display of position, velocity, impact or orbital prediction for the Air Force Range Safety Officers' display. Computers reformatted individual tracking-system data into a multiplexed stream for transmission to NASA control centers at Goddard and Johnson Space Flight Centers. A Command Control system could terminate the mission during the launch phase, at the direction of the Air Force Range Safety Officer. Voice and data communications systems and switches allowed key mission controllers to have current and accurate information during all phases of the flight.

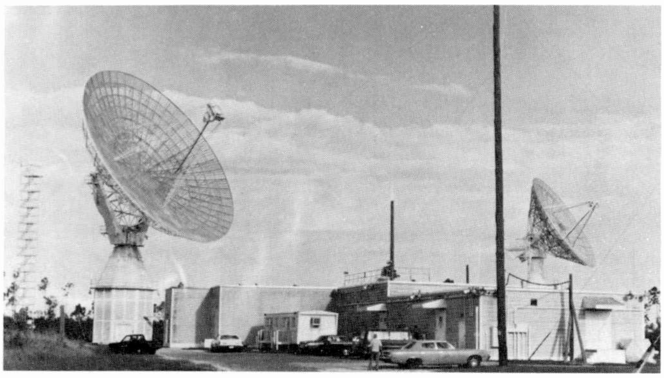

Fig. 7. *These 85- and 33-feet-diameter telemetry-tracking antennas are located at Grand Bahama Island on the Eastern Test Range. They acquire internal missile, satellite and Space Shuttle performance data for mission controllers and USAF Range Safety Officers.*

Orbital phase

RCA MTP operates six tracking radars located in Florida,and in the Grand Bahama, Grand Turk, Antigua, and Ascension Islands during the orbital phase. The acquired track data is transmitted to the Johnson Space Flight Center at Houston and is used in calculating orbital conditions.

Landing phase

During landings at Kennedy Space Center (KSC), MTP-operated radars track the Shuttle Orbiter during its traverse across Florida to its final glide path and landing on the 15,000-foot long Shuttle Landing Facility. Two chase aircraft accompany the Orbiter on its final approach, one carrying color-television equipment. MTP-operated telemetry antennas track these aircraft, and receive and distribute the color-television signals for NASA and the TV networks.

"Lead range" support

NASA, although operating a network of its own tracking stations, relies on DOD facilities around the world to provide almost continuous data coverage of the Space Shuttle orbital flights. These facilities consist mainly of tracking systems associated with U.S. Air Force, Army and Navy Missile Ranges. In 1978, the Government decided that the Eastern Test Range would be the "lead" range for all of DOD-provided Space Shuttle support. This "lead"-range responsibility entails the preparation of operating procedures and directives for the use of DOD tracking systems around the world during checkout tests, simulation and actual Space Shuttle operations. It also requires the coordination and control of DOD facilities during operations providing a single focal point of contact between NASA and DOD. The Lead Range Control Center is located at Cape Ca-

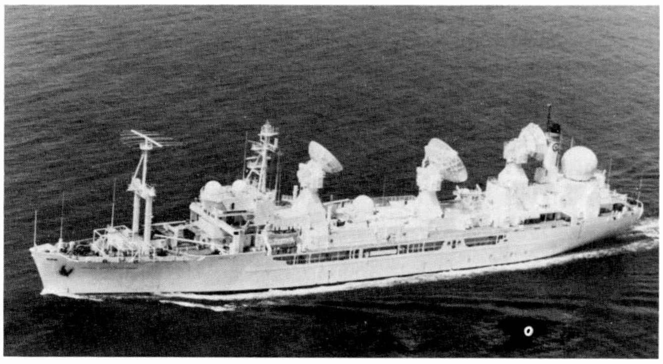

Fig. 8. *MTP people on board Range Instrumentation Ships use radar, telemetry and photographic systems to track missile and space-vehicle components, such as Space Shuttle solid rocket boosters, which impact in the ocean.*

naveral AFS, Florida. RCA MTP specialists are members of this special Lead Range Shuttle Support Group, and exercise operational control over other DOD systems.

All of the track data acquired by these worldwide systems is ultimately used by NASA's Johnson Space Center computers to maintain a display, and to predict the Orbiter's position. It became apparent that some form of analysis was necessary to ensure the quality and compatibility of DOD-derived data. MTP's Technical Analysis organization was chosen to be the data watchdog for DOD sensors. MTP's analysts perform daily evaluations of Shuttle orbital track data so that any operational or metric problems may be detected and corrected.

Conclusion

The Space Shuttle flight testing phase is now over, but launch of the "Columbia" or "Challenger" can not yet be considered "routine"—although that certainly is the goal of NASA and Air Force planners. Frequent flights, short turnaround times, and many different payloads are likely to become normal Space Shuttle situations.

At present, ETR and MTP's first interface with each Shuttle occurs at T-minus 55 days, with a test to be certain that command-control transmitting and coding equipment on the ground is compatible with the corresponding receiving equipment in the spacecraft. Other tests between the Range and Orbiter are scheduled at T-minus 50 and 45 days, continuing on to the actual day of launch.

If Shuttle launches are to occur every three to four weeks as planned, then many challenges remain for the Eastern Test Range and for the people of MTP in meeting compressed periods of readiness testing, and ensuring the continued success of the Space Shuttle support. As before, it will require programming, engineering, and operating skill and innovation. RCA's Missile Test Project will be ready.

Jack Simpson was born in England, served in the Royal Air Force, and joined RCA Service Company Consumer Services in New York in 1948. He transferred to the Missile Test Project in 1958 and has held various operational management positions in that organization. He currently is Manager, Test Operations Support, responsible for the operation, maintenance, planning and control of Range Instrumentation systems operated by RCA during launch countdown and tracking operations at the USAF Eastern Test Range.

Contact him at:
Test Operations Support
Missile Test Project
RCA Service Company
Patrick AFB, Florida
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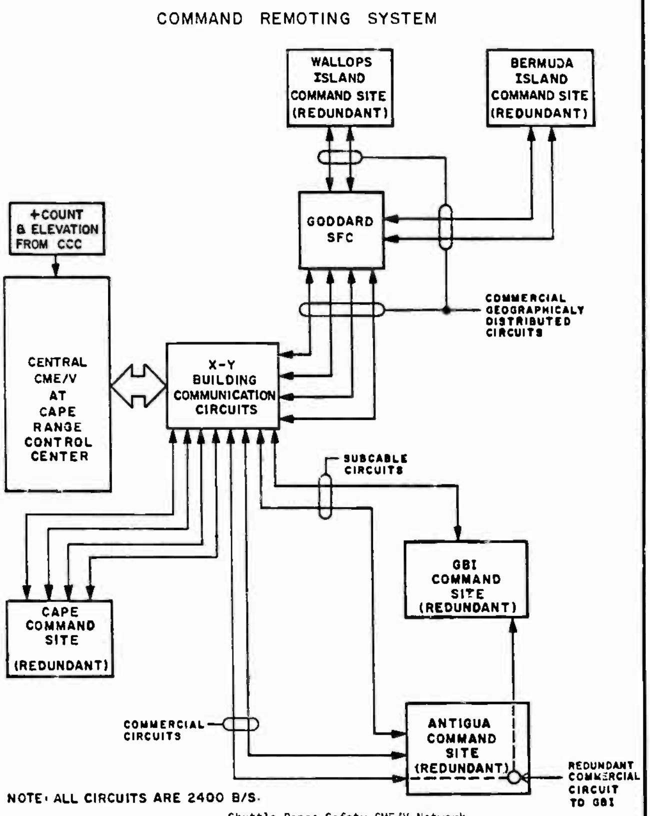
Command Remoting System

The Command Remoting System is mandatory instrumentation for all Shuttle launches. This system allows the Range Safety Officers to remotely control the Command Control Transmitting System at the Cape, on Grand Bahama and Wallops Island, and on Bermuda. Should a malfunction require such action, the Range Safety Officers are able to terminate the Shuttle flight.

The Command Remoting System is an LSI-11 based, redundant, computer-communications/control network. Some of its features are automatic carrier control and plus-count adaptive-destruct delay. Error detection and automatic switching of the redundant terminals, combined with fail-safe techniques, provide maximum reliability in this critical system.

RCA MTP was assigned a major role in the hardware and firmware design of this system. The system was fabricated, installed and is maintained by MTP personnel.

—Larry Mertens



Shuttle Range Safety CME/V Network

K.H. Muller

Launch vehicles for commercial communications satellites

As more launch systems become available, spacecraft designers must become more flexible to accommodate them. Here's a roundup of current launch systems.

Commercial communications satellites operate in geosynchronous orbit, approximately 22,300 miles (19,323 nautical miles, or nmi) above the earth's equator. To "place" a satellite into the correct orbit, various propulsion systems are required. The primary launch vehicles available for communications satellites are the Delta, the Ariane, and the Space Transportation System (STS) more popularly known as the Shuttle. Delta and Ariane place the spacecraft in a geosynchronous transfer orbit that has a perigee (low point) at about 100 to 200 nmi above the earth and an apogee (high point) at geosynchronous altitude. The STS places a spacecraft into a low-altitude (about 160-nmi) circular orbit. An additional propulsion system, a perigee stage, is needed to impart the required additional velocity to the spacecraft to place it into geosynchronous transfer orbit. RCA provides the spacecraft with an Apogee Kick Motor (AKM) that then takes the spacecraft from transfer orbit into a circular geosynchronous orbit (Fig. 1).

The early RCA Satcoms were launched by the Delta launch vehicle, and therefore, the spacecraft was specifically designed and tested to be compatible with Delta. However, current communications-satellite programs, such as GSTAR, Spacenet, Satellite Television Corporation's direct-broad-

Abstract: *The author discusses the capability of the Ariane family of launch vehicles, the Delta family, and the Space Transportation System (STS) known as the Space Shuttle. The challenges and advantages of designing for all vehicles is described. The facilities available at the Ariane launch site in French Guiana, as opposed to those at the Kennedy Space Center, are discussed. Comparisons of spacecraft design requirements are given in the tables.*

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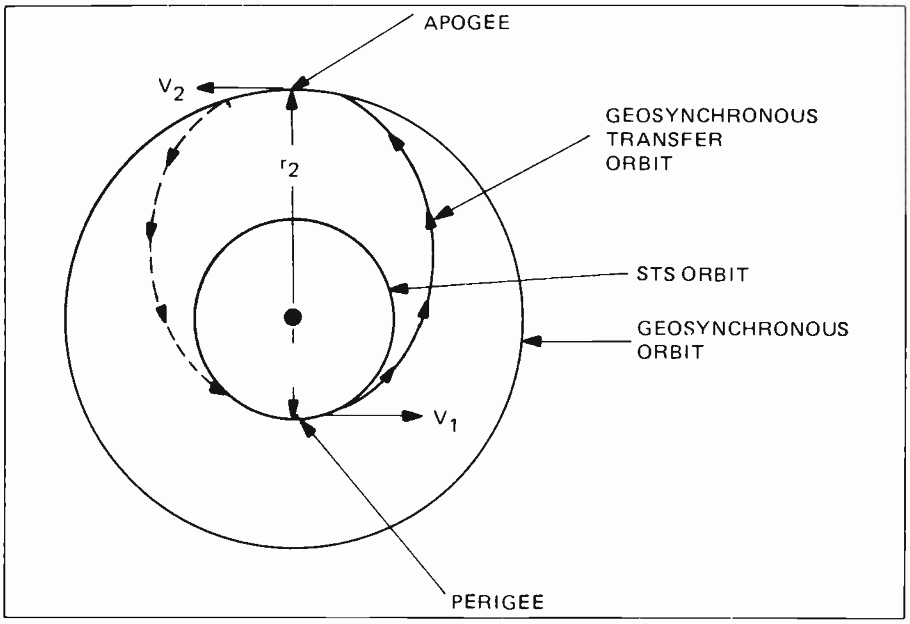

Fig. 1. *The various orbit relationships are shown for an idealized communications-satellite mission. The PKM, or perigee stage, imparts the* V_1 *velocity increment while the AKM, or apogee kick motor, imparts the* V_2 *velocity increment.*

cast satellite, and advanced Satcom, require compatibility with at least two and sometimes all three of the primary launch vehicles. Because these launch vehicles have different structural, thermal, electrical, safety, rf, and contamination requirements, the spacecraft design must envelop all the demands, but is constrained by the most critical requirement. Launch-vehicle interface requirements have been compiled into the Library of Space Transportation at Astro. In addition to the primary launch vehicles—Delta, Ariane, and STS—the Titan, Atlas, and Japanese H-1 launch vehicles could be chosen to launch RCA's spacecraft.

The launch vehicle is chosen by the customer. The customer generally prefers to maintain several launch options to guard against a delay in his operational program. For example, GSTAR is to be compatible with the Delta, the Ariane, the STS with the perigee-assist module (PAM-D) stage, and the STS with the PAM-D II perigee stage. The major technical factor in the choice of the launch vehicle is its "throw-weight capability." Table I gives the approximate geosynchronous-transfer-orbit capability of various launch systems. An allowance has been made for the different launch sites.

There are also numerous business considerations when selecting the launch vehicles, such as the following: price, launch date availability, cash flow, added revenue from greater throw-weight capability, relaunch policy, and (if considering foreign launch vehicles) the political risk. A comparison of the cost of launch systems is given in Table II.

Delta

The workhorse launch vehicle for RCA's satellites has been the Delta launch vehicle. The Delta launch vehicle was derived from the Thor Ballistic Missile, and, as Fig. 2 shows, it has had a long history of space missions. Its development has resulted in significant payload improvements. Currently, two versions of the Delta are in use, the Delta 3910 and the Delta 3920. The difference between these two vehicles is in the second stage, as can be seen in Fig. 3. Either vehicle can be fitted with a PAM or TE 364-4 third, or perigee stage. Although the Delta is scheduled for launches through 1986, many of its payloads have been shifted to the Shuttle. It is programmed to be phased out by 1986. Even if NASA phases out of the Delta launch business, Delta may become the

Table I. *Comparative launch weight capability.*

Launch system	*Weight (lbs) Transfer orbit*	*Weight (lbs) Geosynchronous orbit**
Delta 3920	2800	1460
STS PAM-D	2765	1455
1/2 Ariane 3 (low)	2513	1468**
1/2 Ariane 3 (high)	2634	1535**
STS PAM-DII	3960	2080
STS PAM-A	4400	2315
1/2 Ariane 4†	4150	2420

* Assumes optimum AKM.
** Due to location of launch site.
† Under development, available 1986.

Table II. *Comparative launch costs.*

Launch system	*Cost (millions of dollars)*
Delta 3910/PAM	36.0
Delta 3920/PAM	41.0
Delta 3924	37.8
STS/PAM	17.5*
Ariane	31.0

* NASA has increased STS launch costs. Current projections for 1986 would place this value at $28.5M.

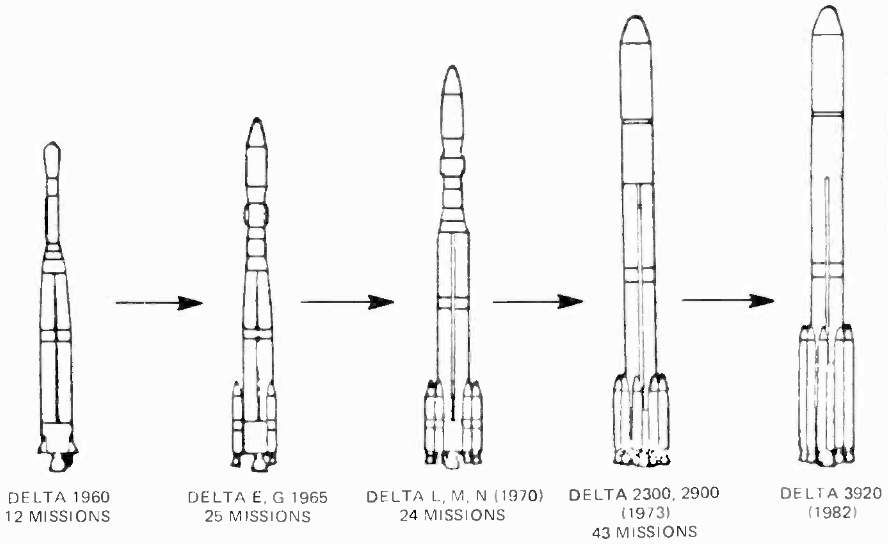

Fig. 2. *The growth history of the Delta launch vehicle is shown. The Delta has been the primary communications-satellite launch vehicle for over 20 years.*

basis for a commercial launcher competitive with Ariane.

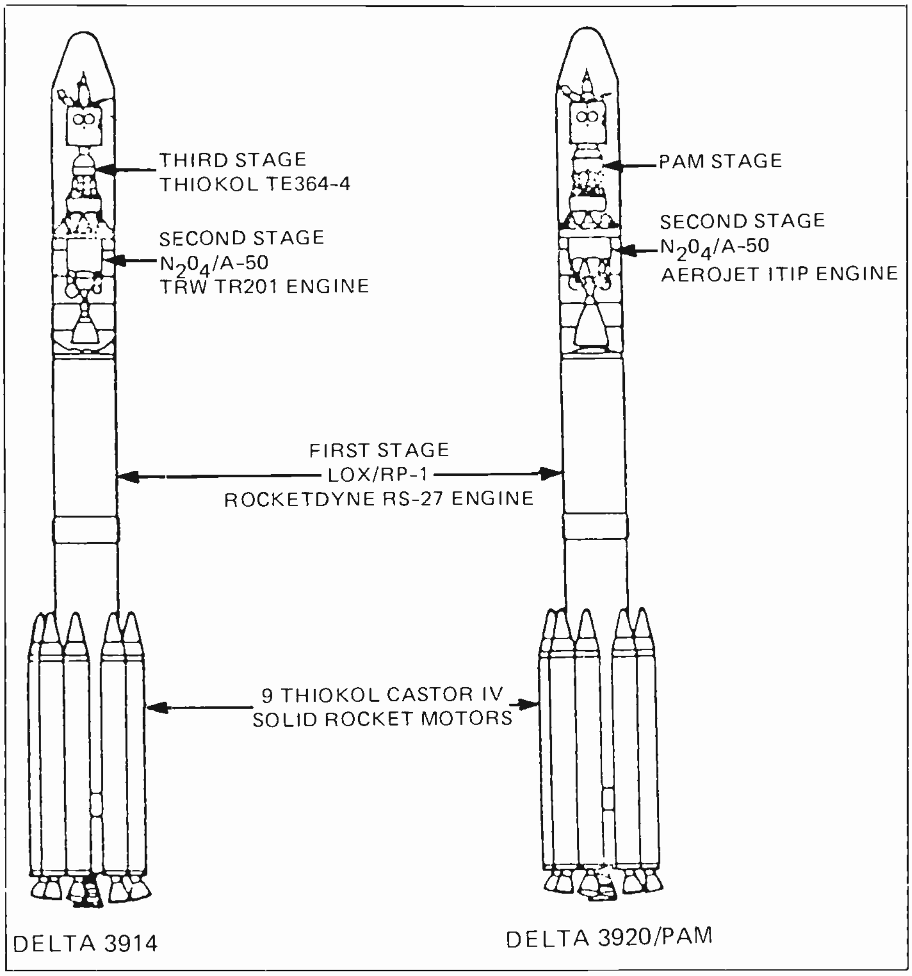

Fig. 3. *The Delta is shown with different second and third stages. The third stage is interchangeable between Deltas.*

Table III. *Space Shuttle system.*

Overall length	184.2 ft (56.1 m)
Height	76.6 ft (23.3 m)
Payload weight	
• *Due East*	65,000 lb (29,483 kg)
• *104°*	32,000 lb (14,575 kg)
Orbiter	
Length	122.2 ft (37.2 m)
Wingspan	78.1 ft (23.8 m)
Payload bay	15 ft diameter by 60 ft long
Main engines (3)	
• *Vacuum thrust (each)*	470,000 lb (2090.7 kN)
OMS engines (2)	
• *Vacuum thrust (each)*	6000 lb (26.7 kN)
RCS	
• *38 engines*	
Vacuum thrust (each)	870 lb (3869.9 N)
• *6 Vernier engines*	25 lb (111.2 N)
Weight (inert)	162,000 lb (73,482 kg)

Shuttle

The new launch vehicle of the 1980s is the Space Transportation System (STS). The STS injects its payloads into a circular orbit at an altitude of 160 nmi. A perigee stage and an apogee stage must be provided.

Although the throw-weight capability of the Shuttle is 65,000 pounds into the 160-nmi orbit, the communications-satellite weight is limited by the available perigee stages. STS 5 launched two communications satellites by the use of the PAM-D, which can place a 2765-pound spacecraft in geosynchronous transfer orbit. Other perigee stages and their geosynchronous-transfer-orbit capabilities are as follows: PAM-D II, 3960 pounds; PAM-A, 4400 pounds; and IUS (inertial upper stage), 10,000 pounds.

Because the perigee stage represents a significant portion of the launch costs, has a great effect on throw-weight capability, and significantly affects spacecraft design, RCA Astro is studying the feasibility of developing a modular liquid-perigee stage. The liquid-perigee stage would allow "optimizing" a spacecraft design for the Shuttle, while significantly reducing launch costs.

Table III gives the characteristics of the STS system, and Fig. 4 gives some of its payload capabilities. The Shuttle has some significant capabilities compared to expendable launch vehicles. The spacecraft can be checked out in orbit, before it is separated from the Shuttle. A failed component could be returned for refurbishment. Once deployed, repair, replacement of components, or recovery of a communications spacecraft is not economically feasible now because the Shuttle's orbit is much lower than that of the satellite. In the future, many of the Shuttle's unique capabilities will permit larger antennas, fuel replenishment, and larger spacecraft.

Because of the manned nature of the Shuttle, its safety requirements are much more stringent than those of expendable launch vehicles (ELVs). Thus, spacecraft design for STS compatibility is more of a challenge than that for an ELV. Triple-redundant inhibits for pyrotechnic signals, use of nonflammable materials, and use of fracture mechanics for structural design are just some of the restrictions that must be followed on the Shuttle. RCA Astro's first Shuttle launch is planned to be the GSTAR-3 spacecraft in July 1985.

Ariane

Ariane is a European launch vehicle marketed by a commercial European company, Arianespace. Ariane has had five flights, three of which were completely successful. Our Spacenet and GSTAR customers have chosen Ariane 3 as the launch vehicle for their first two spacecraft. These are scheduled for launch in 1984.

Ariane is undergoing a development program, similar to that of the Delta, to increase its throw-weight capability (Fig. 5). Ariane 3 will be used for future commercial-satellite launches, sending two payloads into orbit with its unique SYLDA arrangement (Fig. 6). The Ariane 3 can boost a single payload, weighing 2634 pounds, into geosynchronous orbit. Although this is less than the 2765-pound throw-weight capability of the STS/PAM-D, the favorable location (5.5°N latitude versus 28.5°N latitude) of the Guiana Space Center (CSG) versus that of Kennedy Space Center (KSC) results in a geosynchronous-orbit launch capability of 1535 pounds versus 1455 pounds, respectively. Arianespace is developing a larger booster called Ariane 4. This booster will be available in several versions with either 0, 2, or 4 solid or liq-

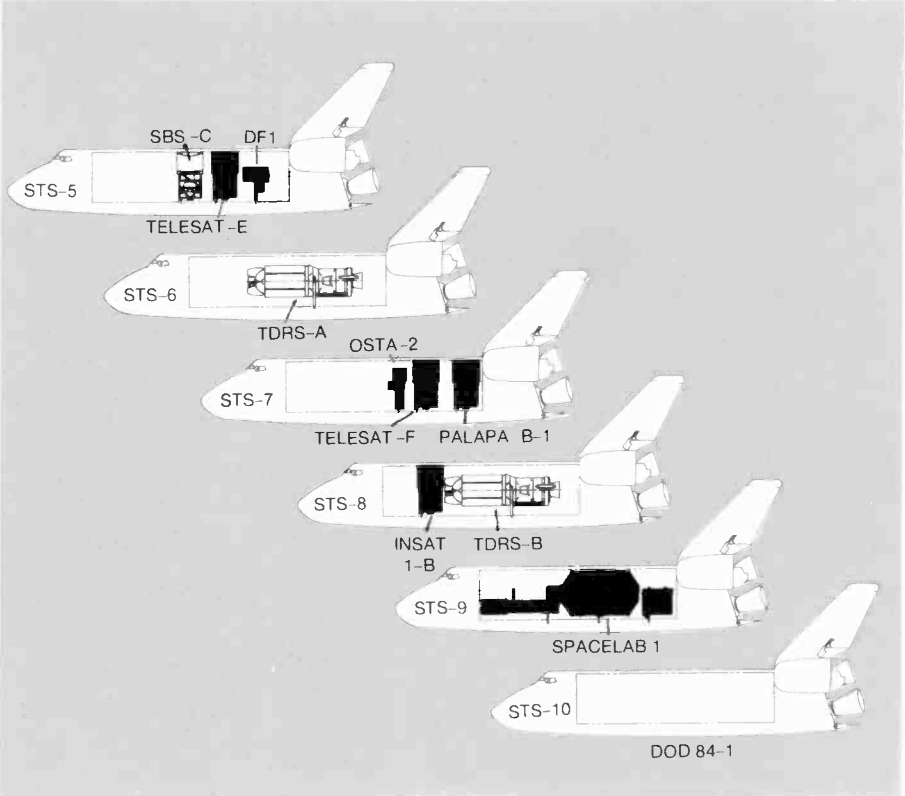

Fig. 4. *A large variety of spacecraft can be launched by the Shuttle. A representative STS payload capability is shown.*

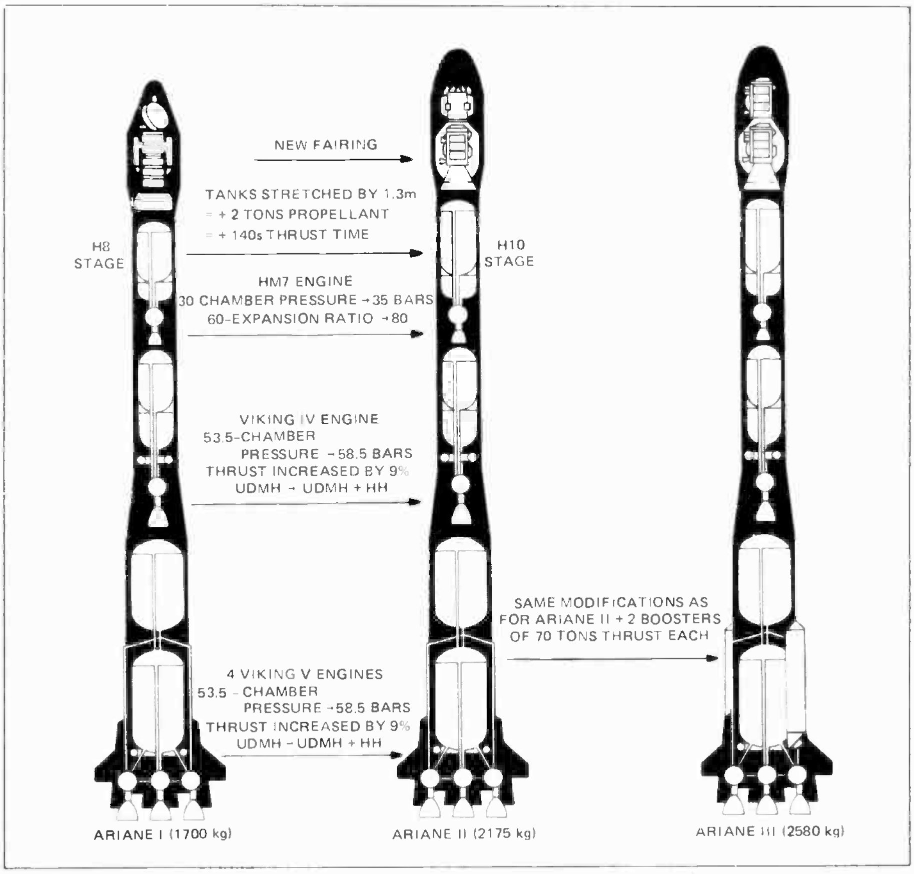

Fig. 5. *The differences between Ariane 1, 2, and 3 are shown. Ariane 3 will fly first in early 1984 and then will become a commercial spacecraft launcher.*

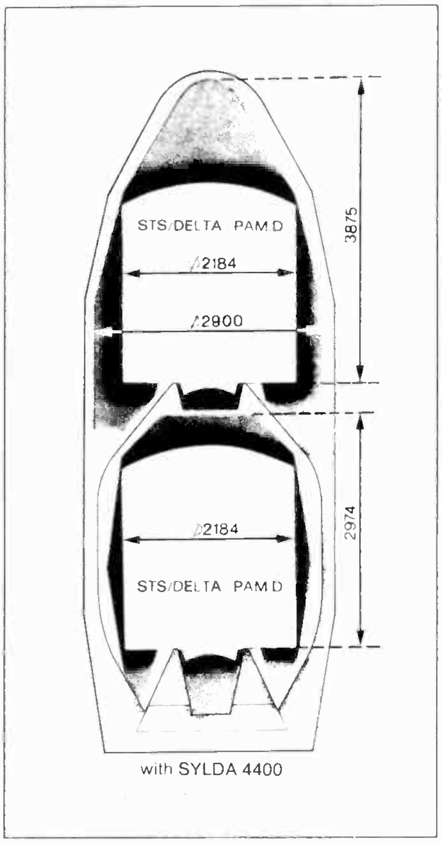

Fig. 6. *This shows the dual-payload capability of the Ariane 3. The dimensions are in millimeters.*

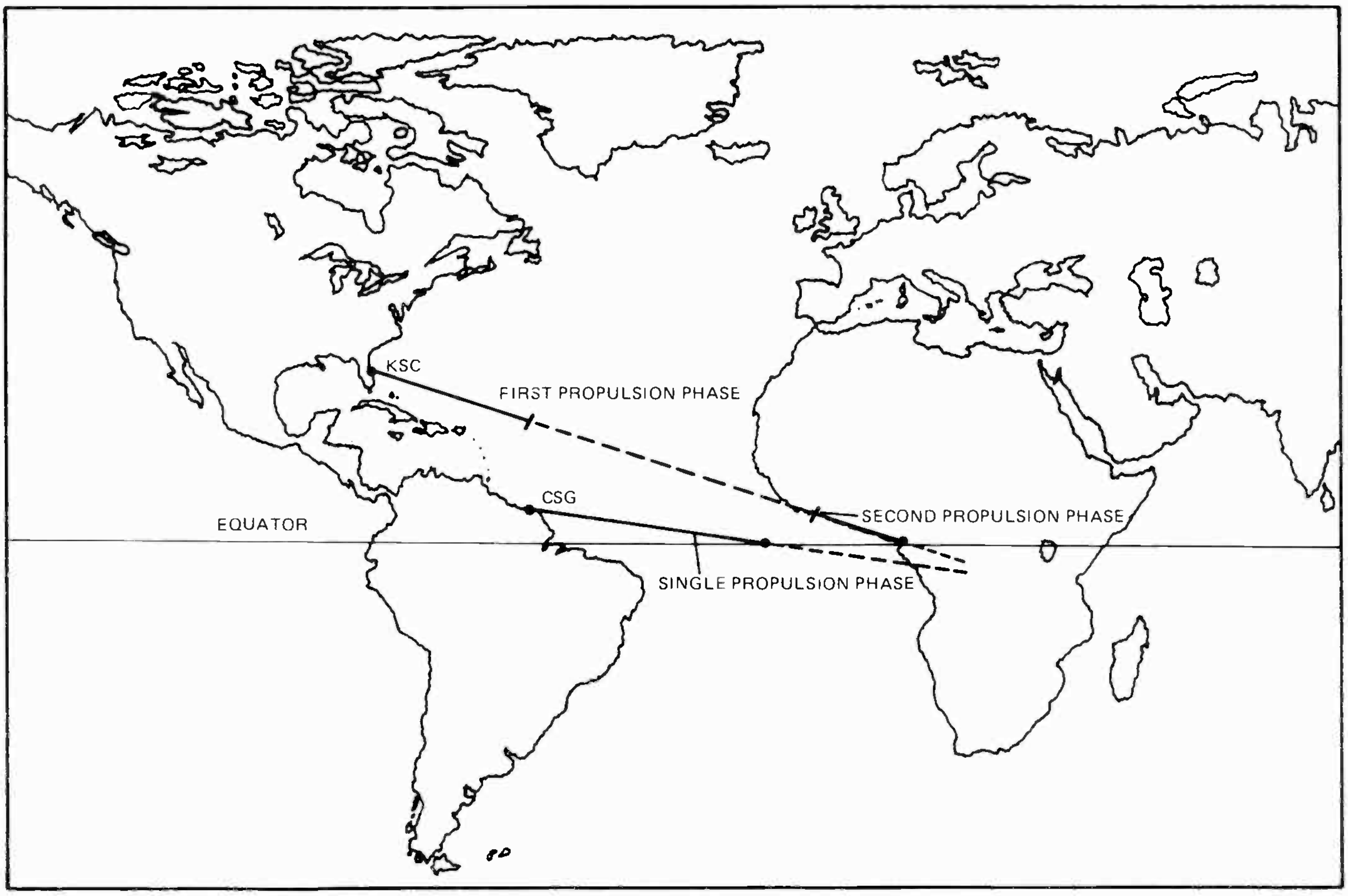

Fig. 7. *The launch trajectories for communication satellites from KSC and CSG are shown. CSG is favorably located for low-inclination or equatorial orbits.*

uid boosters. It should provide formidable competition to the STS and any commercial launch vehicle developed from 1986 on.

Launch site

A discussion of the launch vehicles would not be complete without brief mention of the launch sites (Fig. 7). Delta and STS are launched from KSC in Florida. The area is well developed and well known, and launch-site spacecraft integration and checkout activities present no unique problems. Ariane is launched from the CSG in French Guiana on the coast of South America. The launch-site facilities, such as a spacecraft preparation and checkout building, control centers, and a launch tower, are new, large, and well equipped. However, CSG is isolated, surrounded by jungle and water, and is not the most desirable place to visit or work. For those who do not speak French, language will be a problem. While KSC has Disney World as a tourist attraction, CSG has Devil's Island.

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J.J. Schwarze

Satellite launching—A combined effort

Here's a step-by-step guide to the activities that precede a satellite launch, with Americom coordinating the efforts of many private and government enterprises.

Abstract: *The launch into orbit about the earth and the ultimate positioning of the satellite at its assigned orbital location, ready for service as a communications repeater, happens rather quickly. But it is the culmination of more than two years of both spacecraft and launch-vehicle preparation, including design reviews, component assembly and test, and system integration and test. Launch activities begin in earnest approximately six weeks before the launch date, with participation not only by a variety of major and secondary subcontractors, but also by many units within Americom. Before launch, a special communications network must be established, ground facilities at control-and-tracking stations must be checked out and calibrated, and personnel and equipment readiness must be verified by rehearsal of all events scheduled from launch to satellite-earth acquisition and locking. The excitement of the launch period builds to a crescendo at the lift-off of the launch vehicle, slowly wanes during the following day or two, and builds up again to the firing of the apogee kick motor (AKM), the deployment of solar arrays, and the achievement of attitude control with the antenna pointed to earth. Subsequent activities, during drift orbit to the assigned longitudinal station and check-out of all spacecraft systems, is relatively routine.*

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To the general public, launching a spacecraft into orbit, though a spectacular sight at lift-off, may seem a fairly simple accomplishment. You take a spacecraft, mount it on top of a large rocket, shoot it into space, steer it to the proper location, and voilà: an operational satellite.

Actually, a myriad of activities, occurring simultaneously and integrated into a master schedule, result in a successful launch and on-station operational satellite. I will attempt, in a few pages, to provide an overview of all major events and disciplines involved both within Americom and by contractors. A typical time phasing of these events is presented in Fig. 1.

Launch vehicle

All Satcom launches to date have used the Delta 3900-series launch vehicles. The 3900 series resulted from a RCA/McDonnell Douglas jointly funded development program to achieve a greater payload (spacecraft) lift-off weight capability than available from the existing 2900-series vehicles. The manufacturing/test cycle for a Delta launch vehicle is nominally 24 months.

Approximately 10 to 12 weeks before the launch, the vehicle is received at the launch site (Air Force Eastern Test Range, Cape Canaveral, Florida) in sections—first stage, second stage, third stage, and nine solid motor strap-ons. It takes McDonnell Douglas personnel approximately four and a half weeks to do some initial equipment installations, to test, to erect the first stage on the launch pad, to install and align the nine solid strap-ons, and to mate the second stage. The next four and a half weeks are devoted to first- and second-stage integration and test, first-stage fueling, and third-stage mating with the spacecraft.

As the final week begins, the third stage and spacecraft are mated to the second stage, followed by additional tests and inspections, second-stage fueling and countdown-sequence rehearsal. It should be noted that all activities involving hazardous operations such as fueling, explosive installations and arming, are performed under the watchful eye of both NASA and Air Force range-safety personnel.

Three days before launch, a final launch readiness review (called the T-minus 3 review) is held. The review is conducted by a NASA review team consisting of specialists in various disciplines such as hydraulics, structures, electronics, and so on. Attendees at the review meeting include NASA, Air Force, McDonnell Douglas, Aerojet, Thiokol, Americom and Astro-Electronics personnel. McDonnell Douglas and their rocket engine subcontractors report on the status of all systems and review all first-flight items, significant test discrepancies, and resolution.

A member of Americom's Program Management Organization (PMO), the Manager, Launch Vehicles, arrives at the launch site approximately five weeks before the launch date. The PMO manager monitors the launch vehicle integration and test progress, and provides coordination between various disciplines of NASA, McDonnell Douglas, Astro-Electronics, Americom, and various service agencies. This coordination includes establishing schedules for integrated spacecraft and launch-vehicle activities, and arranging for the facilities, equipment, and support personnel required for spacecraft activities.

On launch day, final preparations and inspections are com-

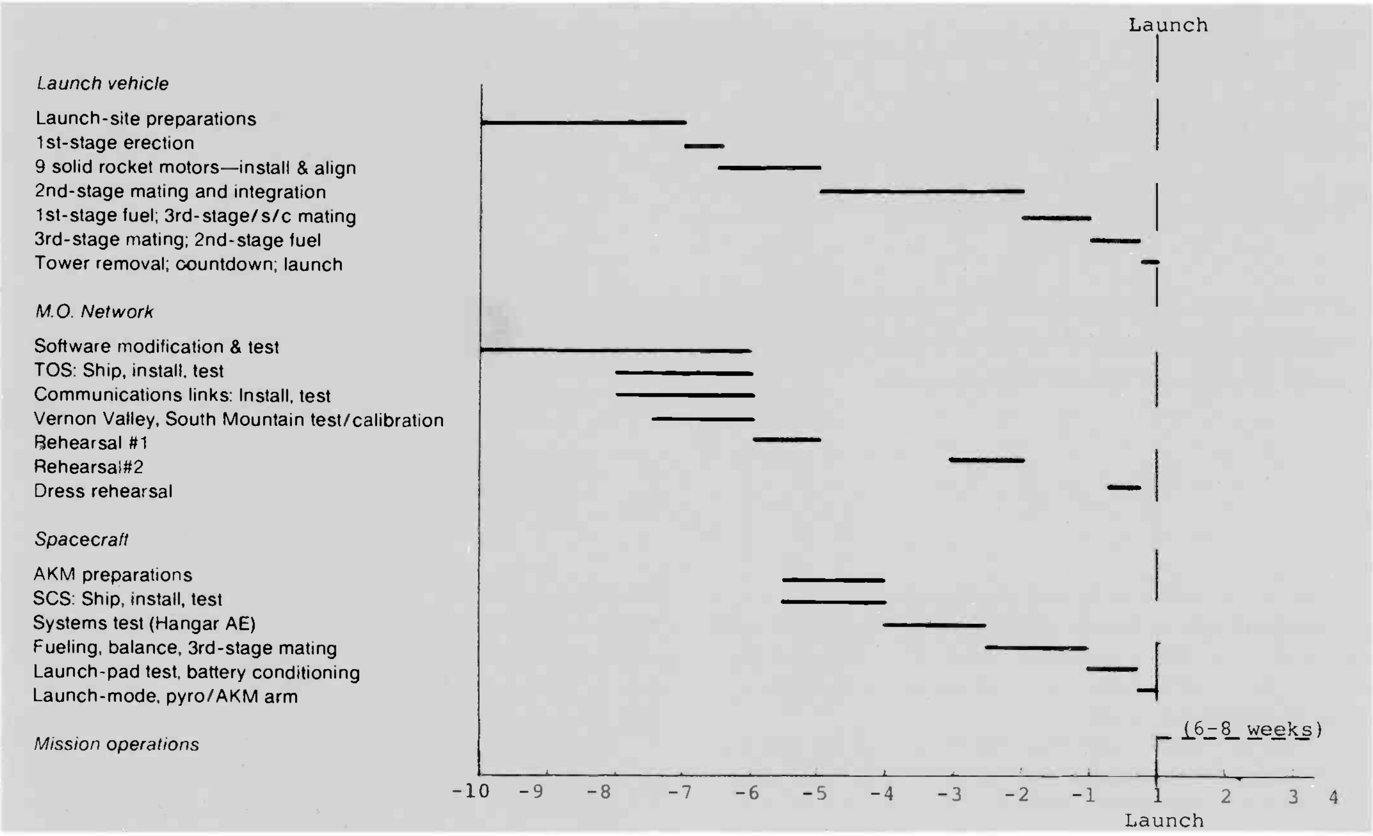

Fig. 1. *Launch activities schedule. Close coordination of activities on the launch vehicle, the spacecraft and the ground mission operations network is required to achieve a scheduled launch.*

pleted and the service tower is rolled back from the launch vehicle five or six hours before launch. The Air Force uses periodically deployed weather balloons to closely monitor wind conditions and to assure that wind shears will not adversely affect the booster trajectory. Excessively high winds or electrical storms in the immediate area could cause a postponement of the launch.

Three hours before launch, members of the launch team assume their stations in the blockhouse at the launch pad, and in the Mission Director's Center and Data Evaluation Center at Hangar AE (approximately 2.5 miles from the pad), to begin the final countdown.* During the countdown, launch vehicle and spacecraft parameters (pressures, temperatures, and so on) are monitored continuously and contact is maintained with the government-tracking network (in Florida, Lesser Antilles Islands, the South Atlantic, and the Indian Ocean) and the RCA manned sites (in Italy, Australia, New Jersey, and California) to verify system readiness. After lift-off, these stations will report on the vehicle trajectory and the significant events depicted in Table I.

At the time of spacecraft separation, the launch vehicle has completed its task of placing the spacecraft into an elliptical orbit (transfer orbit) about the earth having a low altitude (perigee) of approximately 90 miles and a high altitude (apogee) of approximately 22,300 miles. The transfer-orbit parameters (apogee, perigee, inclination, and so on) are documented in a standard Satellite Orbital Parameters Message (SOPM) and transmitted to Vernon Valley Satellite Operations Control Center and the Intelsat headquarters in Washington D.C. to establish initial antenna azimuth and elevation at the Intelsat and Americom tracking sites.

Table I. *Significant events: Lift-off to spacecraft separation.*

Event	*Time after lift-off* (minutes and seconds)*
Solid motor burnout (six motors ignited for lift-off)	0 : 57
Solid motor ignition (three remaining solids)	1 : 02
Solid motor separation (first six solids)	1 : 10
Solid motor burnout and separation (last three solids)	2 : 02
Main engine cutoff (MECO)	3 : 44
First-stage separation	3 : 52
Second-stage ignition	3 : 57
Fairing separation	4 : 14
Second-stage cutoff	10 : 02
Second-stage restart	20 : 21
Second-stage cutoff	21 : 36
Second-stage separation	22 : 38
Third-stage ignition	23 : 20
Third-stage burnout	24 : 03
Payload (spacecraft) separation	25 : 26

* Times are typical and vary somewhat for specific launches.

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* Americom's launch-team representative is usually the Vice-President of Technical Operations, designated "RCA Mission Director." He generally is supported in the Mission Directors Center by Americom and Astro personnel including Americom's Space Systems Director, Americom's Launch Vehicles Manager, Astro's Satcom Program Manager, and other engineering managers from both organizations.

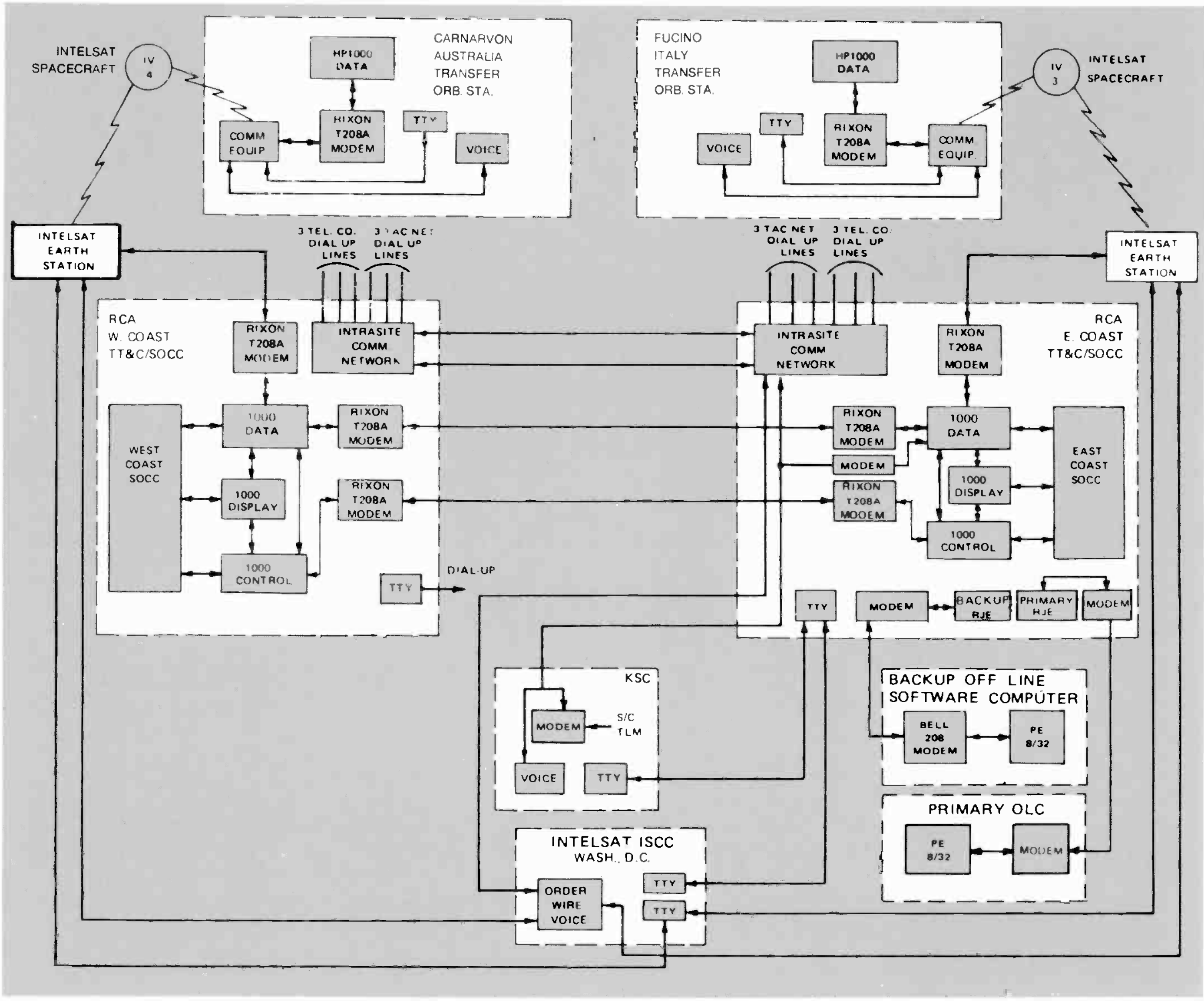


Fig. 2. *RCA Satcom telecommunications interfaces. Prior to launch spacecraft telemetry is transmitted in real time to the Vernon Valley SOCC via land lines. Telemetry during Transfer Orbit is transmitted via Intelsat satellites from Australia and Italy to the east and west coast SOCC.*

Mission operations network

The mission-operations network encompasses all the terrestrial facilities and personnel controlling the satellite in the elliptical transfer orbit provided by the launch vehicle, circularizing its orbit at geosynchronous altitude (22,300 mi.), and locating it at the assigned longitudinal orbit position in operational attitude, that is, antenna boresight on earth and solar array facing the sun.

Equipment in the mission-operations network is widely scattered:

Transfer Orbit Station (TOS)	Fucino, Italy
Transfer Orbit Station (TOS)	Carnarvon, Australia
Satellite Operations Control Center (SOCC)	Vernon Valley, N.J.
Back-up SOCC and Tracking Station	South Mountain, Calif.
Primary Mission Computer	Princeton, N.J.
Back-up Mission Computer	Santa Monica, Calif.
Spacecraft Checkout Station (SCS)	Cape Canaveral, Fla.
Intelsat Communications Center	Washington, D.C.

Communications

Voice and data communications links between these sites must be in place and operational six weeks before launch. The Americom Mission Operations group determines the requirements for each link and with this information the Wirelines group is responsible for ordering the end-to-end installations and verifying proper adjustments and quality tests. Figure 2 is a detailed view of data circuits only. Note that intersite links are redundant.

Transfer Orbit Stations (TOS)

The TOS equipment contains a computer and transmit-and-receive equipment. Americom Mission Operations personnel update

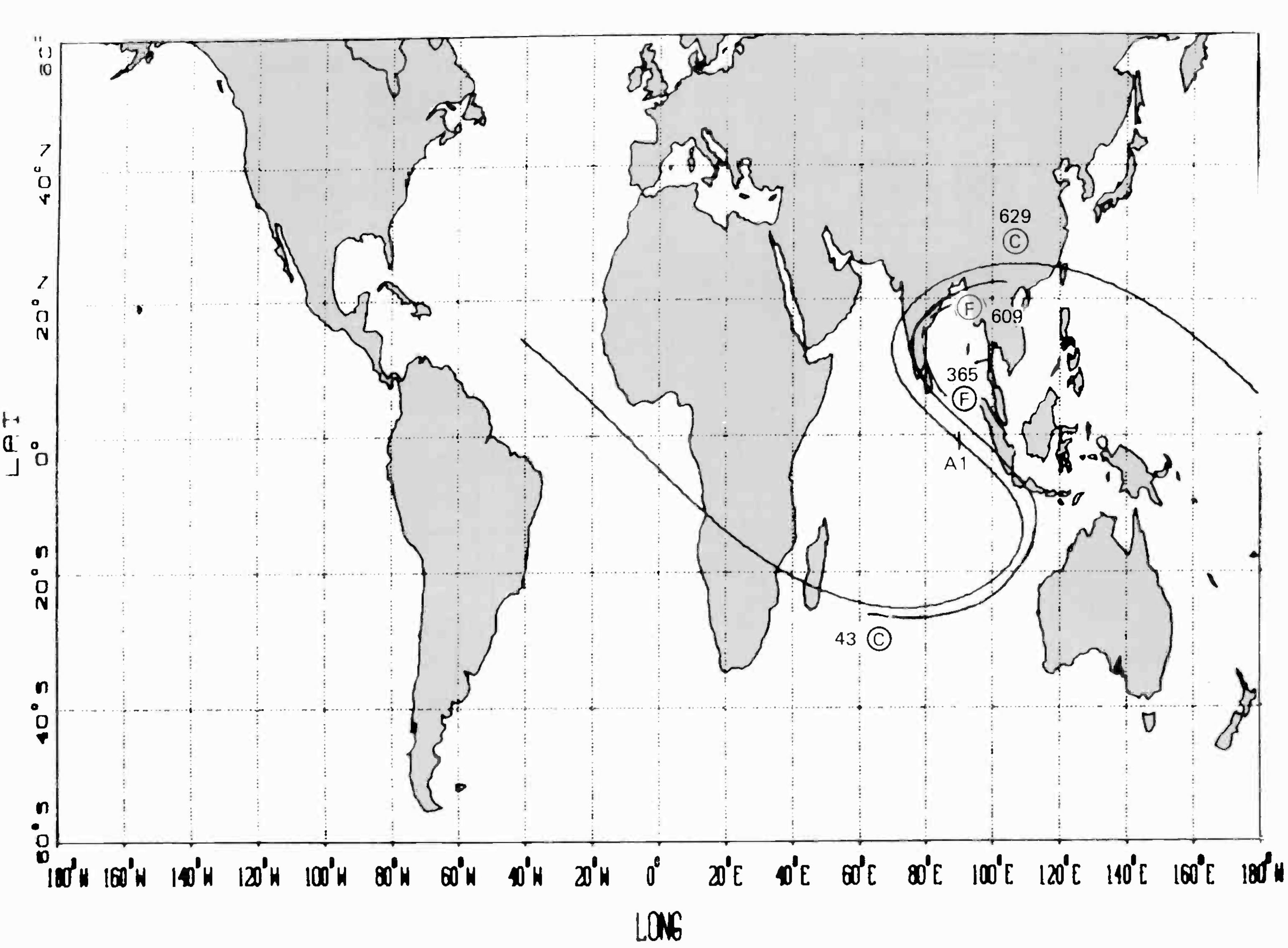


Fig. 3. *RCA Satcom F nominal transfer-orbit ground trace. This chart shows the path traversed by the satellite for the first orbit and a half, and the contact times (in minutes after lift-off) for the Transfer Orbit stations at Carnarvon, Australia, Fucino, Italy; Vernon Valley, New Jersey; and South Mountain, California.*

LEGEND

VERNON VALLEY (VV) IN CONTACT
SOUTH MOUNTAIN (SM) IN CONTACT
CARNARVON (C) IN CONTACT
FUCINO (F) IN CONTACT

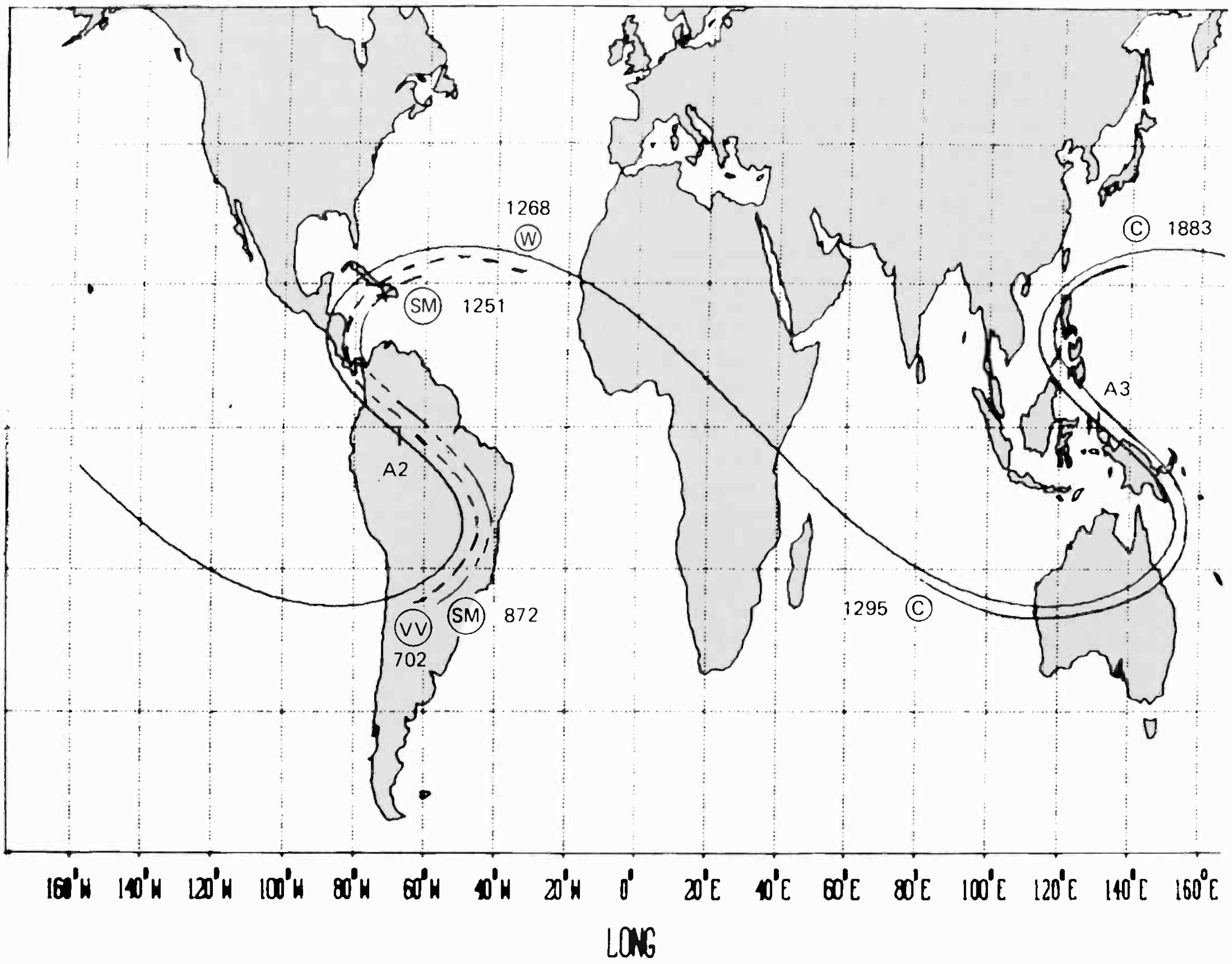
the computer software for compatibility with the spacecraft being launched, calibrate and test the stations, and deliver them to RCA Astro-Electronics. Astro packs and ships the stations to Fucino and Carnarvon and integrates them with the leased Intelsat tracking antennas. Each station is manned by Astro personnel familiar with both hardware and software. The TOS provide Vernon Valley SOCC with orbit parameters and satellite telemetry acquired during that portion of the transfer orbit that each station "views" the satellite. Figure 3 shows typical "viewing" times for the TOS sites (as well as Vernon Valley and South Mountain) during the first one and a half orbits.

Mission computer

More commonly referred to as the off-line computer, this is the principal tool used by Astro mission analysts to determine precise orbit parameters and satellite attitude, and to plan transfer orbit maneuvers such as spin-rate trim, satellite precessions, and Apogee Kick Motor (AKM) firing. Before each launch, the mission-computer software must be modified for compatibility with the spacecraft being launched and the planned launch vehicle trajectory. After modification, validation testing is performed on the primary computer located at Americom headquarters in Princeton and the back-up computer located at the subcontractor facility in Santa Monica, California. During the rehearsals and the launch period, subcontractor hardware and software personnel are standing by both computers to perform immediate maintenance if required. Americom analysts are stationed at Vernon Valley to assist the Astro mission analysts in executing the programs from remote terminals.

Satellite Operations Control Center (SOCC)

The Vernon Valley and South Mountain earth stations are the control sites for all Satcom operational satellites. Tracking, telemetry and command equipment at the two sites are essentially



identical. Although the equipment is in continuous use except for periodic preventive maintenance, a detailed validation test is performed by Spacecraft Operations and Mission Operations personnel six or seven weeks before launch. During the validation, the frequencies, signal levels and path losses are calibrated. Prior to station validation, modifications to the "real-time" operational software required for the new satellite are incorporated and tested by software personnel from Mission Operations.

Rehearsals

Approximately six weeks before launch, with equipment at all sites checked out and intersite voice/data lines in place and operational, the first of three launch rehearsals is held. The rehearsal is conducted with personnel at their assigned stations at Vernon Valley, South Mountain, Carnarvon, Fucino, Cape Canaveral, Princeton, and Santa Monica. The rehearsal serves three purposes: (1) a functional test of the entire integrated system, (2) a "dry run" of procedures, and (3) a familiarization of all personnel with the detailed tasks to be performed during, and subsequent to, launch.

This rehearsal, which takes approximately one week, is supervised by the Astro Mission Director and is basically a dry run of all events that are to take place between lift-off and station acquisition. All irregularities or anomalies are recorded, and the next two weeks are devoted to determining the cause of problems (equipment, software, procedure, operator error) and making required fixes.

A second rehearsal is held approximately three weeks before launch and, again, all problems are documented for correction at the conclusion of the rehearsal.

The first two rehearsals are conducted during twelve-hour work days, and the sequence of events rehearsed is at the discretion of the Astro Mission Director. The third and final "dress rehearsal" is started four days before launch. It runs twenty-four hours a day, following the mission time line precisely as scheduled for the actual events that are to occur from lift-off to AKM firing. During the dress rehearsal all Americom, Astro and subcontractor-support personnel participate on their assigned shifts (two twelve-hour shifts). The dress rehearsal is usually concluded twelve to twenty-four hours before launch.

Spacecraft

At the conclusion of a 24- to 30-month design, build, and test period, the spacecraft is placed in a protective, environmentally controlled container, and shipped via air-bearing truck to Hangar AE at the Cape Canaveral launch site. (The nominal time of arrival at the site is 4 weeks before launch). The spacecraft is unpacked, inspected, and readied for test by Astro personnel, monitored by Americom Quality Assurance personnel. The test equipment (Spacecraft Checkout Station or SCS) arrives at the launch site about one week before the spacecraft and is set up and calibrated. Subsystem performance tests are conducted by the Astro test team and monitored by Americom Spacecraft Engineering and Quality Assurance. Spacecraft telemetry data is transmitted to Vernon Valley SOCC during this period as an additional check of the telemetry-processing system.

Upon completion of the electrical subsystem testing and a pressure test of the Reaction Control System (RCS), the spacecraft is again placed in the shipping container and transported to the Delta spin-test facility. Here, the spacecraft is weighed, and hydrazine propellant is loaded, and the RCS system is pressurized to 30 psi. The AKM, which arrives at the launch site one to two weeks ahead of the spacecraft for checkout and preparation, is then mounted in the center cylinder of the spacecraft. The assembly is then placed on a spin-balance machine, rotated at approximately 60 rpm, and appropriate weights added to the spacecraft to achieve a dynamic balance. The spacecraft is then mated to the third-stage motor and the entire assembly is transported to the launch pad and mated atop the second stage of the launch vehicle. Functional tests are conducted from the SCS in Hangar AE via an rf link to the pad, and the battery conditioning and AKM safe and arm equipment located in the blockhouse is checked out. The RCS system is then topped off to a final pressure of 350 psi. Approximately three days before the launch the fairing is installed, leaving limited access to the spacecraft via conveniently located access holes. Approximately seven hours before the start of the terminal countdown, harness connections are made to place the AKM safe and arm, and the spacecraft pyrotechnic circuits, on internal battery power. The access holes are then sealed and the spacecraft system is placed in launch configuration. Spacecraft telemetry is continuously monitored at Hangar AE and also transmitted to Vernon Valley. SCS personnel periodically report spacecraft status during the terminal countdown to the RCA team in the Mission Directors Center. This team usually consists of Americom's V.P. Technical Operations, Space Systems Director, Launch Vehicles Program Manager, Astro's Satcom Program Manager, and several support personnel from both organizations. Five or six minutes after lift-off, telemetry contact is lost.

Mission operations

Once the launch vehicle has placed the spacecraft in orbit about the earth, it is now considered a satellite. The first contact from the satellite is made by the Carnarvon TOS approximately two hours after lift-off. Telemetry data is relayed to the SOCC for review by the Astro analysts. The Carnarvon controller commands the satellite into the Transfer Orbit mode, that is, momentum wheels off, horizon and sun sensor on.Tracking and attitude data are compiled and transferred to the mission computer for orbit and attitude determination. From this information, antenna-pointing angles and contact times for the four tracking sites are updated. This process is repeated with data obtained from each of the sites.

After the satellite reaches the first apogee, the controllers at the SOCC initiate a 90° reorientation of the satellite (momentum vector to negative orbit normal) to improve communications and sensor geometry. The satellite is again reoriented near the third apogee to the proper AKM firing attitude. During ensuing orbits, ranging and attitude data are processed and spin-rate and attitude adjustments are made as required. At the selected apogee (typically the seventh for Satcom satellites), the AKM is fired and the satellite's orbit is circularized at geostationary altitude. The satellite spin rate is reduced to 10 rpm and is reoriented with the momentum vector at positive orbit normal. From this attitude the "dual-spin turn" is initiated by turning on the momentum wheels at high speed and the satellite precesses to an attitude with the communications antenna facing earth. After a final despin operation, the solar arrays are deployed and oriented facing the sun. The earth sensor is then activated and the attitude-control system "locks on" to the earth.

The time from lift-off to earth acquisition is usually three to four days. During this time, the Americom Spacecraft Operations personnel continue to monitor and control the operational Satcom satellites (four operational satellites at the time of Satcom V launch in October 1982) while assisting the Astro Mission Operations team in commanding and telemetry processing of the newly launched satellite.

Once in geostationary orbit, the satellite is considered in the "drift orbit" phase, that is, it will drift from the longitudinal position achieved at AKM-fire at an inherent drift rate and direction determined by its actual altitude above or below the precise geosynchronous altitude. From that point, the drift rate and direction may be adjusted by firing appropriate thrusters. After four to six weeks of testing to verify performance of all subsystems (including redundancies), the satellite is ready for operation as a communications repeater.

Joe Schwarze is Director, Space Systems, in Americom's Technical Operations Department at Princeton. His section is responsible for procurement, launch and operation of satellites in Americom's Satcom system. Since joining RCA in February 1974, he has been involved in spacecraft design approval, manufacture, test, launch, and in-orbit operation of Satcoms I through V, which are now operational. He is currently working on Satcom IR and IIR to be launched in April and August 1983, and on the definition and procurement initiation of the next generation of Satcom satellites, which will operate at Ku band. He received the B.E.E. degree from Brooklyn Polytechnic Institute in 1964.

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Passive and active sounding from satellites for atmospheric temperatures and constitutents

Whether a sensor passively detects atmospheric properties or a laser actively probes them, the theory and operation of these "remote sensors" are becoming a hot topic. Temperature and water vapor are taken here as examples that can apply to other atmospheric properties.

The quality of weather forecasts depends on the quality of the meteorological data from which the predictions are made. Satellites provide ideal platforms from which to collect this information because of their large areas of coverage, and because of their frequent or even continual observations. Sensors on such satellites must determine the atmospheric properties—from a remote location—by detecting and measuring electromagnetic radiation that has interacted with the atmosphere. Such remote sensors are classified as either active or passive, depending on whether they produce the electromagnetic radiation themselves (active), or merely detect that which occurs naturally (passive).

All current spaceborne meteorological instruments are passive sensors. Such sensors are playing an increasingly important role in the forecast system. However, they are rapidly approaching their theoretical limits of performance in terms of accuracy and, most significantly, their ability to resolve the vertical structure of the atmosphere. Active sensors based on lasers can overcome these limitations, and will represent the next advance in spaceborne remote-sensing technology.

This article discusses the techniques by which active and passive instruments determine two important meteorological parameters: the vertical structures of temperature and humidity. First, the physical basis of passive temperature and moisture sounding is developed. Then, some specific algorithms that are used to estimate these profiles are presented. Once the abilities of passive sensing techniques are explained, the theory of active laser-based sounding is discussed. Finally, Astro's role in the development of this new generation of remote sensors is highlighted.

Abstract: *The passive sounders aboard the DMSP and NOAA satellites provide information about atmospheric temperature profiles, moisture content, and ozone burden. The physical principles of these sounders, the data-retrieval techniques, and the measurement limitations will be discussed. An analysis of the capability of the DMSP sounder to provide water-vapor profiles, performed recently at RCA Astro-Electronics, will be presented. Active laser sensors, known as lidar systems, (LIght Detection And Ranging), can potentially overcome the deficiencies of passive sounders, most importantly by an improved capability for resolving vertical atmospheric structure. The physical principles of lidar sensors, as well as Astro's role in the development of these systems, will be described.*

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Passive sounders

A passive sounder measures the net upwelling radiation being emitted and reflected by the earth and the atmosphere in specific spectral bands called channels. The measuring device can be a Fourier-transform interferometer, a grating or prism spectrometer, or a radiometer that consists of a detector or detectors with a rotating filter wheel.

The theoretical basis of retrieving atmospheric temperature and constituent profiles from passive-sounding data is embedded in the radiative transfer equation (RTE) that relates the radiance R_i, which is the measured radiation in channel i, to the state of the atmosphere and the earth.

The measured radiance in channel i, R_i in the atmosphere, can be written formally as the sum of various measurable terms. These contributions include energy emitted by the earth, the upwelling atmospheric emission, the downward atmospheric emission reflected by the earth, the sun radiation reflected by the earth and scattered by the atmosphere, and the deep-space 4-Kelvin radiation reflected by the earth. Each of these terms depends to some extent on the state of the atmosphere, that is, the vertical temperature and species profiles and the aerosol distribution. Clearly, to extract atmospheric information from observed radiances in a number of channels is an enormous task, unless we carefully choose the spectral bands of the channels to minimize the contribution of most of the terms in the equation. In this paper, we shall limit our discussion to temperature and humidity sounders in which the main contribution to the radiance is from the radiation emitted by the earth and by the atmosphere.

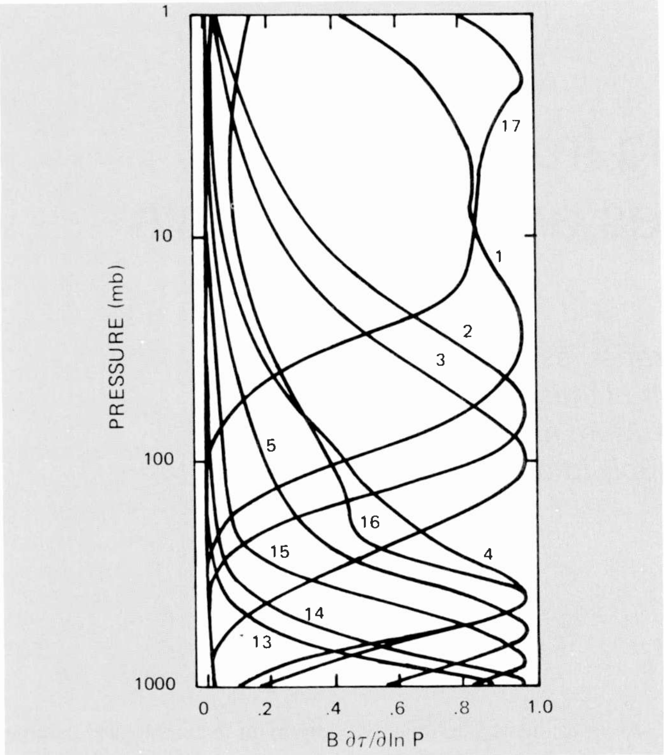

Fig. 1. *HIRS weighting functions for the primary sounding channels. The weighting functions show the contribution from each level to the measured radiation (adapted from W.L. Smith, H.M. Woolf, C.M Hayden, D.Q. Wark, and L.M. McMillan, "The TIROS-N Operational Vertical Sounder,"* Bull. Am. Meteor. Soc., *Vol. 10, pp. 1177-1187, October 1979).*

The radiative transfer equation

In the spectral region from 30 to 10μm, assuming local thermodynamic equilibrium, to a very good approximation, the radiative transfer equation can be written as,

$$R_i = B[T_g,\nu_i]\ \tau(P_s) + \int_{\log P_s}^{\log P_{sat}} B[T(P),\nu_i]\ \frac{\partial\tau_i(P)}{\partial \log P}\ d\log P \quad (1)$$

where ϵ_i is the emissivity of the earth surface, $B[T,\nu_i]$ is the Planck function, ν_i is the center frequency of channel i, T_g is the temperature of the ground, $T(P)$ is the temperature at pressure level P, P_s and P_{sat} are the pressures at the surface and at the satellite altitude, respectively, and $\tau(P)$ is the frequency-averaged transmission from the top of the atmosphere to pressure P.

The transmission function $\tau(P)$ is a key factor in selecting the spectral bands of the different channels. In general, $\tau(P)$ is a function of the molecular species and the temperature. However, for channels with a wide spectral band (greater than 10 cm^{-1}), the function $\tau(P)$ has only a slight dependence on the temperature. The atmospheric temperature information is contained mainly in the Planck function in Equation (1), while the information on the distribution of molecular species is contained only in the transmission function.

Although the contribution to the measured radiance is from the entire atmosphere, limited information about the vertical structure of the atmosphere can be obtained by measuring radiances at different channels. However, the channels must be chosen in such a way that the main contribution to the radiances of the different channels comes from different atmospheric layers. The contribution at any level is determined by the integrand in Equation (1). This function is known as the weighting function and, in general, peaks at different values of P for each channel.

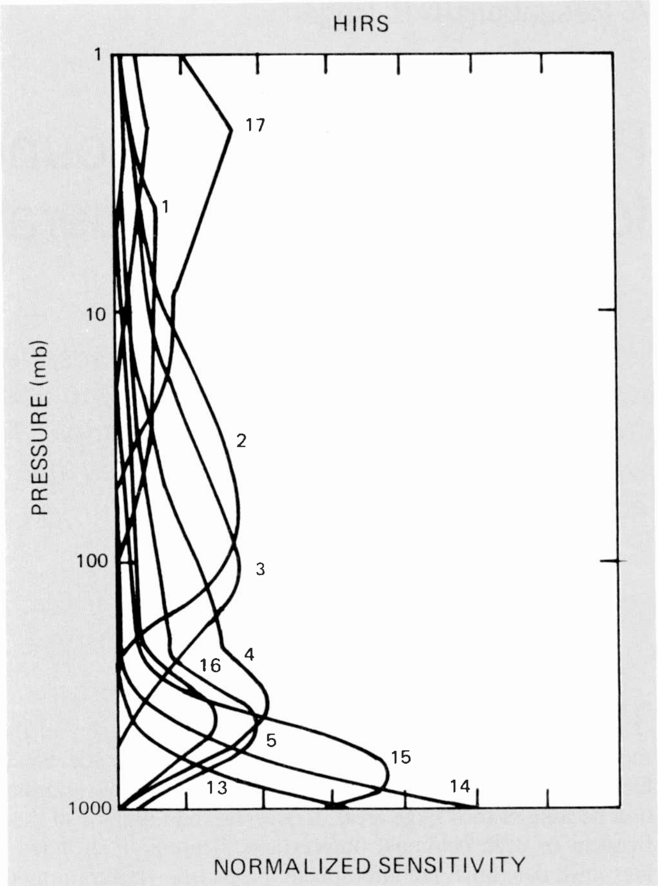

Fig. 2. *HIRS normalized temperature sensitivity functions. These sensitivity functions indicate the relative change in radiance due to a change in atmospheric temperature at each level (adapted from J. Susskind, A. Rosenberg, and L.D. Kaplan, "Advanced Meteorological Temperature Sounder (AMTS) Simulations," Fourth National Aeronautics and Space Administration Weather and Climate Conference, printed in program* Review, *pp. 191-197, Goddard Space Flight Center, Greenbelt, Maryland, January 1979).*

Temperature sounding

For temperature sounding, sensors must "probe" the atmosphere in spectral bandpasses in which the main absorber is a molecular species with a constant mixing ratio. A natural candidate is carbon dioxide, which has a constant mixing ratio of about 330 ppm. As an example, the high-resolution infrared sounder (HIRS) aboard NOAA satellites, part of the TIROS-N vertical operational sounder (TVOS), contains 20 channels, 10 of which are in CO_2 bands.

To evaluate the capabilities of the sounder to retrieve vertical temperature profiles, examine the properties of the different channels in relation to the observed radiance as given by Eq. (1). In particular, we analyze the following parameters.

- The weighting function $B[T(P),\nu_i]\ \partial\tau(P)/\partial \log P$ versus log P, which indicates the contribution to the observed radiance of the different atmospheric layers.

Table I. *Characteristics of the SSH/2 Sounder.*

Channel number	*Wavelength (μm)*	*Wavenumber (cm^{-1})*	*Halfwidth (cm^{-1})*	*Principal absorbing species*
1	13.4	747	12.5	CO_2
2	13.7	731	12.5	CO_2
3	14.1	708	12.5	CO_2
4	14.4	695	12.5	CO_2
5	14.8	676	12.5	CO_2
6	15.0	688.5	3.0	CO_2
7	12.5	797	12.5	H_2O
8	18.7	535	15.0	H_2O
9	20.1	497	17.0	H_2O
10	24.5	408	14.0	H_2O
11	22.7	441	20.0	H_2O
12	23.9	420	22.0	H_2O
13	25.2	397	12.5	H_2O
14	28.3	353	14.0	H_2O

- The function $\partial R_i/\partial T$ versus log P, which gives the sensitivity of the radiance to changes in temperature at different layers.
- The effects of other gases with nonuniform mixing ratios on the observed radiances.

Figures 1 and 2 give the normalized weighting function and sensitivity functions for the CO_2 channels of the HIRS instruments. Both functions peak at different pressure layers for the various channels. For example, most of the contribution to the radiance of channel 1 is from the stratosphere, while most of the contribution to channel 8 is from the lower troposphere. These two channels are also sensitive to changes in temperature in this region. However, channels 3 and 4 exhibit broadly overlapping weighting and sensitivity functions. Consequently, the information contained in these channels is to some extent redundant and provides only the average temperature over a large atmospheric layer. It is the widths of the weighting function and of the sensitivity functions that limit the vertical resolution of a passive sounder. The width of the weighting functions of the HIRS channels is partially a result of the broad spectral band of the channel. However, the width of the weighting functions of a passive sounder has a theoretical limit that is about 50 to 75 percent of the scale height of the parameter to be measured. For temperature sounding, this limit is about 4 to 6 km, which gives the theoretical vertical resolution of a passive sounder.

Some of the channels of HIRS are contaminated by H_2O and N_2O. To use these channels for temperature retrievals, we must know the distribution of these two molecules.

Humidity sounders

For moisture sounding, we select a spectral region with water-vapor absorption bands. The HIRS instrument, for example, contains three water-vapor channels in the 7-μm region. The Special Sensor H2 (SSH/2) aboard the DMSP satellite contains eight water-vapor channels in the 20-30 μm pure-rotational band of water. Table I gives a list of these channels and their spectral characteristics. To evaluate the capability of these channels to retrieve water-vapor profiles, we must analyze the shape of the integrand in Equation (1) and the sensitivity of the different channels to changes in the amount of water vapor and to changes in temperature. These analyses have recently been performed at Astro.

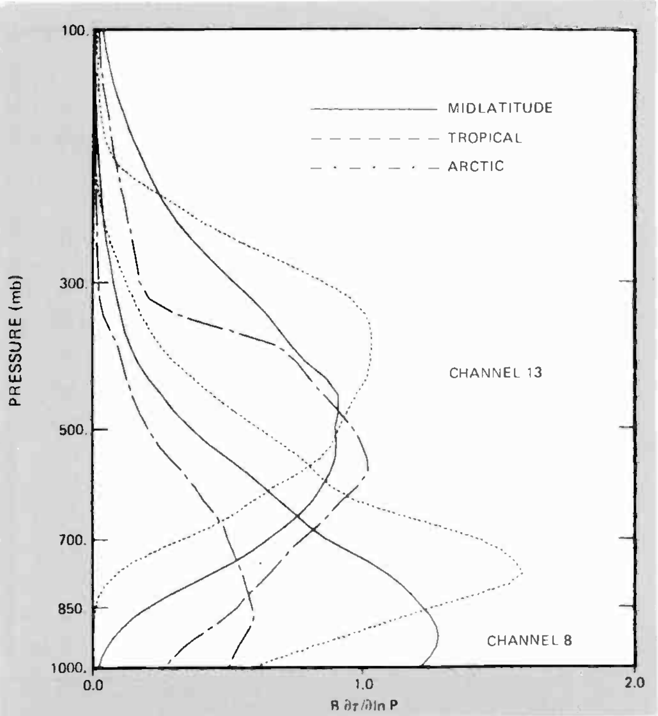

Fig. 3. *SSH/2 weighting functions for channels 8 and 13 for three model atmospheres. Note the shift towards lower pressures for the peak in each weighting function, for model atmospheres with large amounts of water vapor (tropical), relative to drier models (arctic).*

The weighting function $\beta[T(P),\nu_i]d\tau(P)/d\ln p$ is used for the different channels. For temperature-sounding channels, these functions depend only slightly on the atmospheric profiles. However, for water-vapor sounding channels, these functions depend strongly on the atmospheric profile as is illustrated in Fig. 3, which shows the weighting functions characteristic of three climatological regions.

In water-vapor sounding channels, unlike temperature-sounding channels, the relative contribution to the radiance from different atmospheric layers depends strongly on the parameter to be retrieved, that is, the water-vapor content. Therefore, it is difficult to match, or map, the sounding channels to the different atmospheric layers without some prior knowledge of the atmospheric water-vapor profile. As in the case of the HIRS temperature-sounding channels, the weighting functions are very wide and some of them overlap.

The sensitivity of the measured radiance to changes in water vapor and temperature is shown in Fig. 4. Figure 4 clearly indicates that none of the channels is sensitive to changes in water vapor near the surface. Even channels 7 and 8—considered to be surface-sounding channels since most of their contribution to the radiance is from the lower atmospheric layers—are not sensitive to water-vapor changes in this region. This differs from the temperature-sounding channels, where the sensitivity functions are very similar in shape to the weighting functions. This lack of sensitivity to changes of water vapor near the surface is not unique to the SSH/2. In general, any passive sounder operating in a spectral region for which the emissivity is close to unity is insensitive to changes in the concentration of atmospheric con-

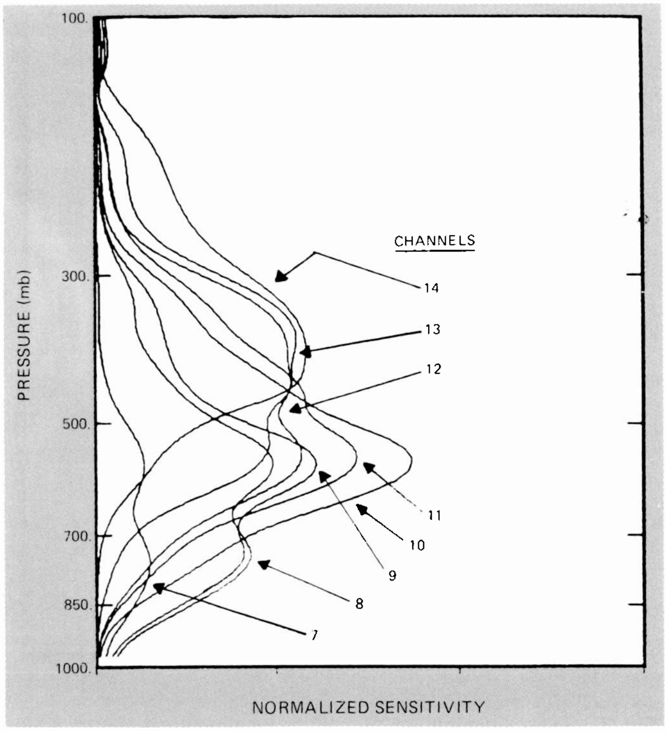

Fig. 4. *SSH/2 normalized water-vapor sensitivity functions. None of the channels respond to water-vapor changes near the surface (about 1000 mb).*

stituents near the surface of the earth. The reason is that when a change occurs in the amount of a trace constituent near the surface, each of the terms in Equation (1) changes by almost the same magnitude, but with opposite sign. Consequently, the net change in the measured radiance is very small.

Because most of the atmospheric moisture is near the surface, a passive sounder's ability to retrieve the total content of water vapor in the atmosphere is very limited. The lack of sensitivity of the channels means that the sounder must rely on indirect means to determine lower-tropospheric water-vapor profiles. In the region between 400 and 700 millibars (about 3 to 7 kilometers above the surface), the sensitivity is higher, and the moisture profile in this region can be retrieved by nonlinear methods for solving the radiative transfer equation.

Retrieval techniques

Two basic approaches are used to retrieve atmospheric information from observed radiances. In one class of methods, referred to as statistical methods, the physics of the atmosphere via the RTE does not enter directly into the solution. One merely correlates the state of the atmosphere, that is, temperature or/and humidity profiles, to the observed radiances. The correlations are obtained from a set of in situ ground-truth measurements of the atmosphere and a set of observed radiances that are collocated in time and space with these measurements. In the other approach, known as physical retrieval methods, Equation (1), or some approximation to it, is solved simultaneously for all the observed radiances.

Temperature retrievals

The discussion will now turn to the specific problem of determining temperature profiles. The simplest approach is to assume a linear relationship between the radiance measurements and the temperature at a fixed number of levels throughout the atmosphere. This relationship can be represented as,

$$\Delta T = C\,\Delta R \qquad (2)$$

where ΔT is a column vector of temperature deviations from some mean value of each level, ΔR is a column vector of radiance deviations from some mean value for each channel, and C is a matrix that maps the measurements onto the retrieved profiles. One approach to deriving a solution matrix C is to discretize the integral in Equation (1), and write it as a sum. Then, the resulting equation is linearized around some standard value. We may now write,

$$\Delta R = D\,\Delta T \qquad (3)$$

This approximation assumes that the levels are thin, the dependence of the weighting functions on temperature is small, and the true profile is close to the standard profile. These assumptions are generally reasonable ones for channels used in the sounding of temperature.

One way to derive C is to find the least-squares solution of the matrix Equation (3). Almost invariably the solution from this procedure "blows up"; a matrix inversion is attempted on a singular matrix, or one that is so nearly singular (for the purposes of the computer you are working on) that a "divide by zero" results. This is the mathematical consequence of trying to determine a solution from a small number of redundant observations, without incorporating additional information. The techniques used to include the additional information required for solution are referred to as Constrained Linear Inversions. A typical case occurs when one has available a "first-guess" profile that is believed to be reasonably close to the true profile. The constraint then requires that the retrieved profile not deviate too much from the "first-guess" profile. Another often-used constraint minimizes the first derivative of the retrieved profile (and thereby eliminates highly oscillatory solutions). Often, constraints with less easily identifiable, but nevertheless real, physical consequences are used.

The inversion techniques just discussed are physically based inversions, because recourse is made to the radiative transfer equation (1) in the solution. Another approach to determining the matrix C in Equation (2) is to rely on statistics. A set of in situ measurements (most likely made with balloon-borne instruments) is correlated with simultaneous measurements made by a satellite. Again, the most straightforward approach—a least-squares solution—meets with disaster. That this technique should befall the same fate as the linear, physically based retrievals may at first seem surprising, but on further thought we realize that it should have been expected. The recourse to statistics does not eliminate the physical reasons the solution "blew up," but rather embeds the physics in the correlation matrices. Techniques similar to those used in constrained linear inversion are also applicable here, but the physical consequences are not as readily apparent.

Statistical inversion techniques are computationally efficient, and essentially self-calibrating. However, one major drawback concerns the statistics—are they truly representative? Good solutions require that the observations used in deriving the matrix C should come from nearly the same climate as that to which the matrix is applied for a retrieval. Otherwise, for example, a C matrix derived from profiles taken over Siberia will do extremely poorly when used to estimate the temperature over the Indian Ocean. This creates a dilemma: Accurate profiles are most needed in those areas where the statistics are the poorest (over the oceans and unpopulated regions). Thus, even though a statistical technique is currently being used operationally by the National Weather Service to process profiles obtained from the TIROS satellites, further progress in retrieval accuracy must resort to retrievals based on physical principles.

So far, this section has been concerned with linear techniques. Statistical methods can be extended to nonlinear prediction, but with little or no benefit. Such is not the case for the physical retrieval techniques.

Because Equation (1) is too complicated to enable one to write down an analytical solution, it must be solved iteratively; hence, the name nonlinear iterative retrieval techniques. An initial profile (actually a vector consisting of the temperature at each vertical level in the coordinate system) must be obtained. Call this profile T_0. Since, for temperature sounding, we are dealing with absorbing gases of constant mixing ratio (CO_2 for the HIRS instrument), the radiance for each channel can be estimated by applying Equation (1). Let the resulting estimated radiance be a vector R_0. Now the iterative solution may be expressed as some function G of the previous guess, the corresponding estimated radiances, and the measured radiances.

The function G is the relaxation formula. This procedure is continued until some criteria for stopping are met. The criteria must consider several cases:

- The solution has converged to within the noise level of the instrument;
- The procedure is diverging; and
- The solution has stopped converging, but is not within the noise level.

The first case indicates success of the technique; the remaining two cases show various degrees of failure. Convergence, however, does not guarantee that the retrieved profile is accurate. The non-uniqueness of solutions to (1) is evident here also.

Nonlinear iterative methods tend to exhibit a high degree of dependence on the first guess. In other words, the final solution is very similar to the first-guess profile. This is the price that must be paid to obtain any solution at all—remember the tendency of the linear solutions to "blow up." Also, as might be expected, the procedures usually require more computer time than linear techniques.

Water-vapor retrievals

Much of what was said concerning temperature-profile retrievals can also be applied to water-vapor-profile retrievals. However, a number of differences make the task even more difficult. First, information desired is contained in the transmission term, not in the Planck function as was the case for temperature channels. The dependence of this term on water-vapor concentration is extremely complicated. A more serious problem relates to the sensitivity—actually a lack thereof—of the moisture channels. As was mentioned previously, any infrared water-vapor sounder will have very limited sensitivity to water-vapor changes near the surface. This is unfortunate, because most of the water vapor is found near the surface.

Because of these complications, one is tempted to try a statistical solution. If such a solution is attempted using only the radiances from the water-vapor channels, the results are rather poor. Adding the CO_2 sounding channels to the linear statistical prediction matrix—Equation (3)—improves the accuracy markedly. Reasonable results are obtained even for levels near the surface. This improvement results primarily because of statistical correlations between water vapor and temperature: On average, the higher the temperature, the more moisture is contained in the air.

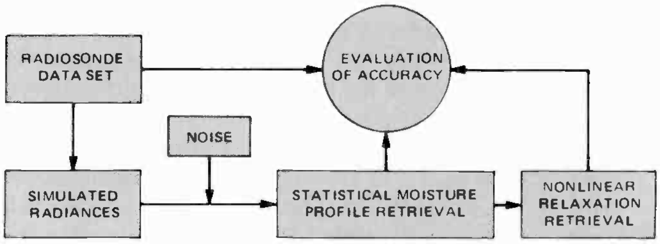

Fig. 5. *Simulation procedure for evaluation of water-vapor retrieval accuracy. The true water-vapor profiles were compared to those computed from the calculated radiances (including simulated measurement noise) by the retrieval algorithms.*

Linear physical methods are not suited to moisture retrievals because of the extreme variation of water-vapor densities. Such variations are not consistent with the assumptions required to linearize the problem.

At Astro we have been developing a technique to retrieve moisture profiles. The technique combines a statistical with a nonlinear iterative relaxation method. The method was developed specifically for the SSH/2 infrared sounder on the DMSP series of satellites, but it has applications to any constituent profile retrieval in the infrared or microwave region.

Our approach consists of obtaining a statistical profile estimate. This estimate is used as a first guess to a nonlinear iterative relaxation technique. This relaxation method is constrained to modify the first-guess profile only in regions where the water-vapor channel radiances have a high sensitivity to water-vapor changes. We accept the fact that, due to the lack of direct information on surface water vapor, a statistical prediction is the best we can do there. At other levels, the statistically derived profiles are reasonably accurate, but could be improved further.

As a necessary prerequisite to this study, an algorithm that permits the rapid computation of the atmospheric transmission in each of the channels of the SSH/2 was developed. This "Rapid Algorithm" was necessary because the more exact calculation of transmittance, which resorts to detailed calculations for each spectral line, takes many minutes of computer time for each channel.

The statistical first-guess procedure is very similar to the technique developed by Smith and Woolf and used by the National Weather Service for obtaining temperature profiles. Since the SSH/2 is not yet operational, simulation procedures were used to test the method's accuracy. Figure 5 gives an outline.

The statistical first-guess gave profiles with accuracies of about 30 to 35 percent throughout most of the troposphere. Two relaxation algorithms were developed at Astro. Both algorithms behaved similarly and were able to improve the results in the middle troposphere—approximately 2 to 7 km above the earth's surface—by about another 10 percent.

Near the surface and at upper levels, neither procedure was able to improve on the profiles obtained by the statistical method. This is exactly what was expected from the sensitivity analysis that was discussed in the section on humidity sounders.

Active sounders

The current limitations of passive temperature and humidity sounders is twofold. First, the signal-to-noise ratio is poor. This degrades the accuracy of the retrieved parameters. Most importantly, the weighting functions of the channels are broad, which results in a poor vertical resolution. Although the weighting functions can be narrowed to some extent, by a careful selection of narrow spectral band channels, or by using interferometric techniques, there is a theoretical limit to the width of the functions. This is a property of the atmosphere, not of the instrument. Furthermore, for moisture retrievals, passive sounders (with the possible exception of microwave sounders over oceans) do not have sensitivity near the surface. Active remote sensing is not constrained by the same limitations, and hence the possibility exists of improving on the performance of current sensors by the use of active systems. Our discussion will be limited to active sensors based on laser sources and lidar systems. As the name suggests, lidars (for LIght Detection and Ranging) are essentially radars operating in the visible or infrared region.

The lidar equation

A lidar system contains a pulsed laser source(s), a telescope, and an electronic gating detection system that can measure, as a function of time, the laser radiation reflected by the atmospheric aerosols and molecules . A schematic diagram of a lidar system is shown in Fig. 6. Lidar's ability to measure the scattered radiation for a well-defined atmospheric layer allows enhanced vertical resolution sensing capability. The theoretical vertical resolution is half of the pulse width. For a 20-ns pulse, the theoretical vertical resolution is 3 m. But time averaging, which is necessary to decrease the noise, degrades the vertical resolution. In general, 1-to 2-km vertical resolution is sufficient for remote sensing from space platforms.

The lidar equation, the theoretical basis for active remote sensing, can be written as follows

$$P_r(\nu',R) = P_t(\nu)\left[\beta_a(\nu,R) + \sum_i \rho_i(R)\sigma_i(\nu',R)\right](A/R^2)$$

$$\tau(\nu,R)\tau(\nu',R)\,\Delta R \bullet G$$

where $P_r(\nu',R)$ and $P_t(\nu,R)$ are the received and transmitted power at frequencies ν' and ν, respectively, R is the distance from the lidar to the atmospheric layer to be probed, $\beta_a(\nu,R)$ is the back-scattering coefficient of the atmospheric aerosols, ρ_i is the density and σ_i is the scattering cross section of the molecular species i, A is area of the telescope, $\tau(\nu,R)$ and $\tau(\nu',R)$ are the atmospheric transmittance at frequencies ν' and ν, and G is a system calibration factor. While $P_r(\nu',R)$ is the measured quantity of the lidar system, the atmospheric information is contained in the terms $\beta(\nu,R),\rho_i(R),\sigma_i(\nu'),\tau(\nu,R)$ and $\tau(\nu',R)$. Several methods were proposed in the literature to extract atmospheric parameters from these terms. For example, by measuring the return signal at the Raman-shifted frequency $\nu'=\nu-\nu_m$ where ν_m is a vibrational transition of water, or a rotational transition of nitrogen or oxygen, it is possible to get information about moisture content from $\rho_i(R)$ or temperature profiles from the Raman scattering cross section $\sigma_i(\nu',R)$. This method is probably not applicable for remote sensing from space because the Raman cross section is very small. Another technique for temperature and humidity measurement, which is more promising for space application, is known as the DIAL (DIfferential Absorption Lidar). In this method the return signal is detected at the same frequency as the transmitted signal, $\nu' = \nu$.

The DIAL technique

The basic principle of DIAL consists of measuring the absorption at a single frequency due to a single spectral line. The absorption due to a single line depends primarily on three fac-

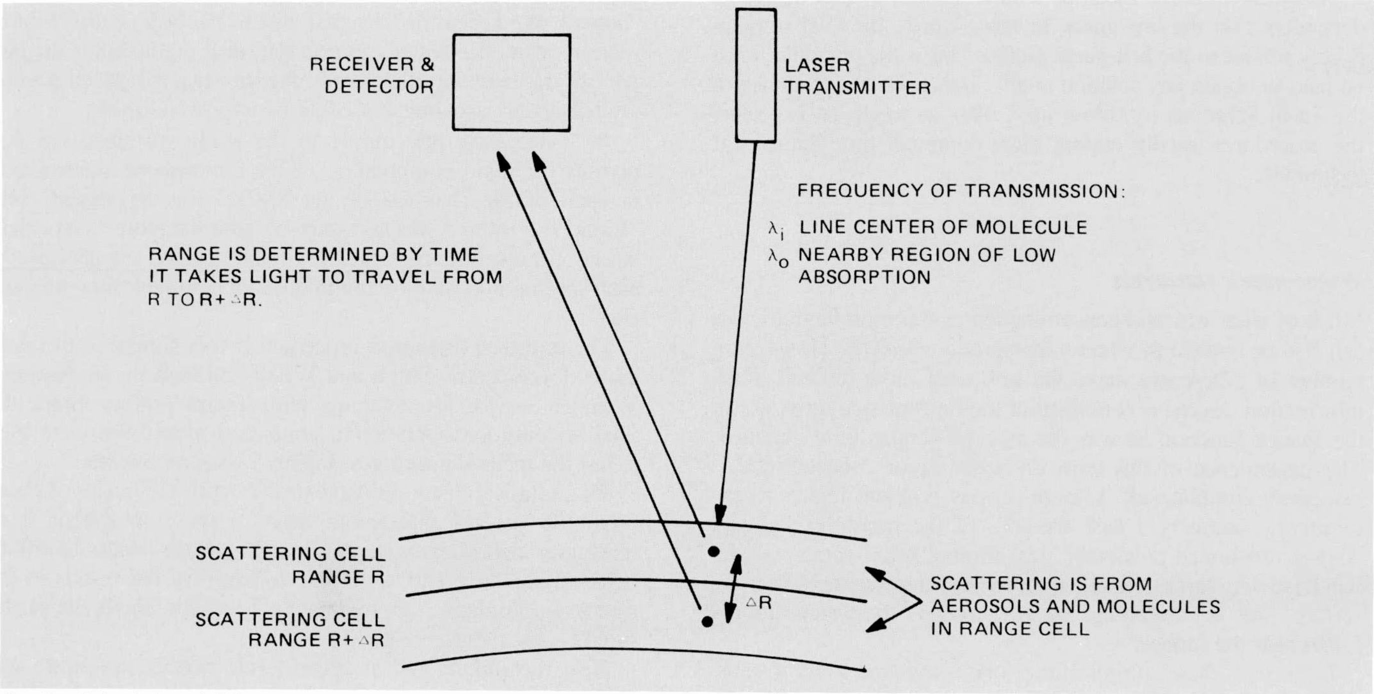

Fig. 6. *Principle of lidar measurements. The laser transmitter and receiver are at the same location. Time gating of the detector allows precise determination of range.*

tors: the concentration of absorber in the path, its temperature, and the total pressure. For the case of absorption at a line center, where the primary spectral broadening mechanism is due to molecular collisions (pressure broadening), the dependence on pressure is dropped. The strategy of the DIAL technique can now be seen:

- By selecting a spectral line where the dependence on temperature is small, the concentration of the absorbing gas can be determined.
- Temperature can be measured by selecting an absorbing gas with a constant concentration and a high sensitivity to temperature.

To determine the absorption due to a single spectral line, the effects of all other lines and gases as well as the dependence of the return signal on the total scattering, must be eliminated. This is accomplished by transmitting laser pulses at two frequencies. The first frequency corresponds to the center of an absorption line. The second is in a nearby spectral region of only background absorption. Because the variation in absorption of a line near its center is very large, one is able to select his second frequency so that the effects of other lines and gases are approximately constant at the two frequencies. The ratio of the detected power at these two frequencies, known as the on-line and off-line pulses, then yields the transmission due to the single line alone. Further, by gating the detector in time one can determine the absorption at any range from the laser.

Figure 7 illustrates the principle of these measurement strategies. The normalized absorption for three selected lines in the 720-nm region is shown. The line on the left has a positive dependence of absorption on temperature, while the one in the center has a negative dependence. It can be seen that the effect of temperature extends throughout the line, but that it is strongest at the center. The residual absorption shown in the line wings is due to the sum of the wing absorption due to all of the lines in the band. The last line shown on the left is selected so that its temperature dependence is near zero. Such a line would be selected for the determination of absorber concentration.

A third strategy, investigated in depth at Astro, consists of determining both the temperature and absorber amounts. Use of two on-line off-line pairs permits the simultaneous measurement of both these parameters. Actually, only three frequencies are needed since the same off-line frequency can be used for the calibration of both on-line signals. This three-frequency DIAL technique was analyzed for the measurement of temperature and humidity, using two water-vapor lines in the 720-nm absorption band. Errors were estimated for DIAL systems operating from the ground, the air, and the Space Shuttle. For passive measurements the physics of the absorption process was the factor limiting the accuracy and vertical resolution of the measurements. For DIAL measurements the limiting factors are characteristics of the instrument itself: chiefly, laser power and receiver size.

Because of the potential for improving remote-sensing capabilities, Astro is taking an active role in the development of DIAL systems, in addition to theoretical investigations of the type just discussed. We are also proceeding with experimental confirmation of our theoretical predictions, and with developing the technology needed to place such systems in the hostile environment of space.

The three-frequency DIAL concept was checked in a series of experimental measurements at the Goddard Space Flight Center in a cooperative program of NASA, the University of Maryland and Astro. The experiment confirmed the ability of water-vapor lines in the 720-nm region to provide information on temperature and humidity.

Current DIAL systems in this spectral region use tunable dye lasers. Such dye lasers are not well suited for space applications. Their overall efficiency is quite low, less then 0.1 percent. The liquid dye is the most serious problem, because of its volatility and the requirement that it flow at a high rate to ensure continued laser operation. An additional complication is the requirement for another laser source to pump the dye, usually a

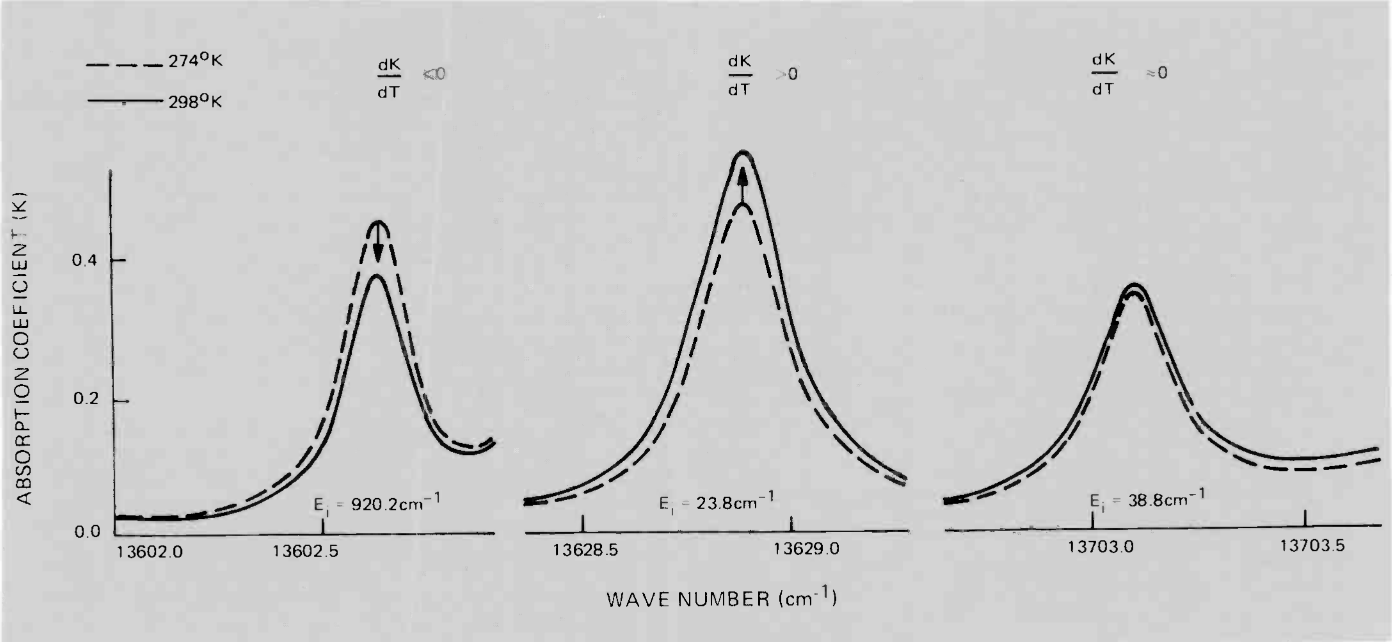

Fig. 7. *Temperature variation of absorption for three water-vapor lines. Low values of ground-state energy,* E_l, *result in an increase in absorption with temperature; high values result in a decrease.*

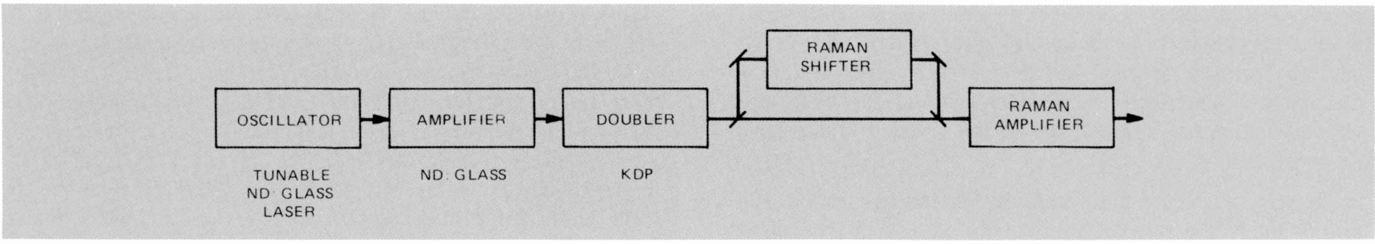

Fig. 8. *Tunable DIAL laser transmitter schematic. The oscillator-amplifier configuration is needed to optimize output energy. The doubler is a crystal with a nonlinear polarizability that converts a pulse of frequency ν to a pulse of frequencies ν and 2ν.*

doubled neodymium-based solid-state laser.

For these reasons, Astro has concentrated on the development of an alternative laser system that can transmit in the 720- to 760-nm region. The laser system is diagrammed in Fig. 8. It is based on a neodymium-doped glass laser that transmits a tunable pulse with a wavelength near 1060 nm. A KDP crystal doubles the frequency to about 530 nm. A cell filled with a Raman active gas at high pressure shifts the laser pulse to a longer wavelength. Hydrogen can be used to obtain pulses in the 720-nm water-vapor band. Such a system can produce pulses at higher energy and with better efficiency than is possible with a dye laser. In addition, the lack of flowing liquids makes the system much more suitable for space applications.

Our efforts at Astro are concentrated on obtaining extremely narrowband pulses from the neodymium:glass laser, and optimizing the efficiency of conversion by the Raman cell. A related effort being undertaken by the RCA David Sarnoff Research Center is the development of diode arrays for pumping the neodymium:glass laser. Currently these lasers are pumped by gas-filled flashlamps. Lifetimes of these flashlamps is limited (typically about a million shots), and the spectral distribution of the energy limits efficiency of neodymium:glass lasers to about 1 percent. The increase of both lifetime and efficiency by a factor of ten or more with the incorporation of diode pumping is believed possible.

Conclusion

Current passive spaceborne sounders provide useful information on temperature profiles, although not within the accuracy and vertical resolution desired by weather forecasters. The quality of humidity data from these sounders is even lower. Improvements in the accuracy of these measurements is being hampered by theoretical limitations on the performance of passive sensors. Active laser sensors have the potential for measuring both these parameters with the accuracy and vertical resolution required for global weather forecasting. RCA is taking an active role in developing this new generation of atmospheric sensors, which will represent the next advance in spaceborne remote sensing.

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R.C. Maehl

The TIROS-based asteroid rendezvous mission

Within our solar system, asteroids will be the most scientifically useful targets for exploration. Inexpensive modifications of current technology will be the key to getting the project off the ground.

Very few missions have been more intriguing and enlightening than those to deep space. First, there were the preliminary lunar missions, precursors to the Apollo program, followed by preliminary fly-by probes to Mars, Venus, and Mercury. Predicated on the technology and scientific return from these missions, we expanded our study of the inner planets to include a Mars landing and sample analysis, sophisticated multi-spacecraft missions to Venus, and then, fly-by missions to the outer planets—Jupiter and Saturn.

Outer-planet fly-bys, first done by Pioneers 10 and 11, and subsequently by the more sophisticated Voyager 1 and 2 spacecraft, provided spectacular data that has greatly expanded our understanding of these giants of the solar system. More importantly, when taken together with the body of knowledge gained from the more detailed data available from the inner planets, the outer-planet fly-bys provided us with a far more sophisticated view not only of our solar system but also of our earth as a planet. These data provided us with significant clues to the evolution and, perhaps, the future of our own planet's atmosphere and topology. For example, scientists can relate such seemingly varied topics as plate tectonics (continental drift), evolution of the atmosphere, and development of life on the earth by way of a complex series of hypotheses, still very preliminary, which involve data gained from these planetary missions.

The first look at Uranus, and possibly Neptune, will be provided by Voyager late in this decade, extending still further man's presence in the solar system. In addition, the Galileo orbiter/probe mission, also late in this decade, will provide our first in-depth study of Jupiter. For the first time, a probe will sample the atmosphere of this, our solar-system's largest planet. In the same time frame, the Venus Mapper will make detailed maps of the surface of Venus. A synthetic aperture radar system aboard the spacecraft will, for the first time, sufficiently resolve surface details of the cloud-shrouded planet to allow an in-depth geological comparison with our planet.

Given the current state of our exploration of the solar system, the next set of targets are quite readily chosen. They are the minor bodies—asteroids and comets.

Abstract: *Because asteroids provide a unique sample of material that may hold significant clues to the way the solar system was formed and has evolved, they are prime candidates for exploration. Very little is known about asteroids other than that they do exhibit diverse properties and are found in a wide range of orbits, primarily situated between Mars and Jupiter (the main belt) but with a significant number having perihelion (that is, the point in the orbit at which they are closest to the sun) near and even inside the earth's orbit.*

To fully understand the asteroids and their implications to solar-system physics, an orderly study of several different types, via spacecraft in asteroid orbits, is required. A logical first step in this progression is the study of one or more earth-approaching asteroids. This approach will allow cost-effective first missions by the use of earth-orbiter spacecraft technology for limited missions that will, aside from their own scientific merit, set the stage for multiple-asteroid-rendezvous missions with main-belt asteroids.

This paper discusses the rationale behind such missions, the scientific objectives (particularly how the study of earth-approaching asteroids will enhance and complement the study of main-belt asteroids, meteorites and comets) and the requisite spacecraft technology.

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Asteroid exploration

Asteroids and comets are extremely important to our understanding of the evolution of the solar system. They may provide unique samples of the primordial material from which the solar system evolved, uncomplicated by the geological evolution that has taken place on the inner planets.

Asteroids, aside from being key to our understanding of the solar system, may also be important for other reasons. Because asteroids are suitable for manned missions, they could be tapped for their mineral wealth, whether it be exotic materials that may be in short supply on earth or, more likely, common materials for use in large-scale space structures.

This last option is potentially feasible because many asteroids are in orbits that could provide material (either processed or for processing) to geosynchronous orbit with far less energy required than would be necessary to bring the same mass from earth. This possibility leads to speculation that, for example, aluminum-smelting operations on a manned asteroid base or an asteroid mine, could provide raw material to a manufacturing facility in earth orbit. A manned asteroid base could also provide for a variety of other space research and manufacturing operations. There is almost no end to speculation as to potential uses of an asteroid.

Currently, the simple fact remains that, before any of these possibilities can even be seriously considered, we must significantly understand the physical and chemical properties of asteroids, and this is precisely what would be done with a preliminary scientific spacecraft mission to such a body. As of today, the only data available are from ground-based observation. These data allow us to make some crude classification (by spectral type), allow us to calculate spin rate, and, with some assumptions, allow us to estimate the size distribution of the asteroids. But these observations are inadequate for anything more than the selection of a target for precursor missions, required as preliminaries to exploitation of the asteroids. Further, because asteroids exhibit such diverse properties, multiple rendezvous missions to many different types of asteroids will be necessary.

Several scientific working groups have addressed the question of what sample of asteroids would provide an adequate, general understanding of their nature. In general, recommendations include several sizes of asteroids and a wide range of orbital parameters (between 1 and 5 astronomical units) including one group, the near-earth asteroids. These could be studied, at low cost, using modified earth-orbiter spacecraft technology (the RCA TIROS spacecraft) and existing launch vehicles.

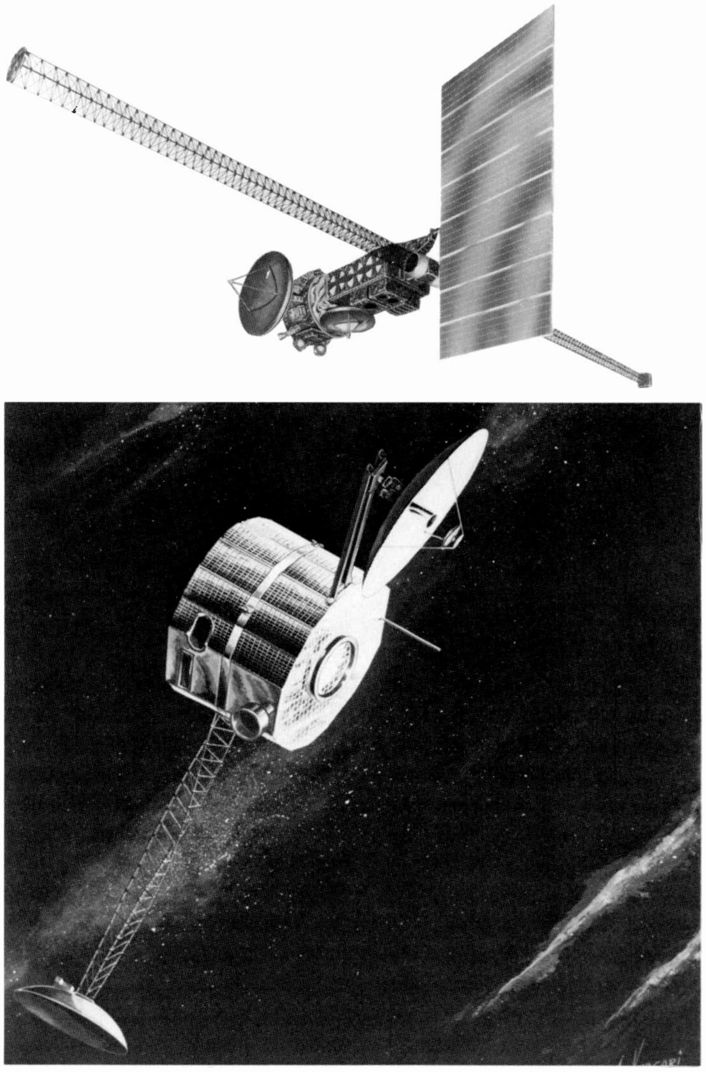


Fig. 1. *Two spacecraft options, one based on Dynamics Explorer (above) and one based on TIROS (top), could be applied to deep-space missions.*

Low-cost planetary spacecraft options

The concept of low-cost planetary spacecraft has been evolving at RCA since 1980. In 1981 and 1982, NASA funded studies to RCA and others through both the Jet Propulsion Laboratory and Ames Research Center for low-cost Mars missions. Two of these concepts are shown in Fig. 1. The concept of using a modified TIROS spacecraft for an asteroid-rendezvous mission was first developed under an RCA Independent Research and Development (IR&D) project, and later development was funded by the Jet Propulsion Laboratory through a systems-study contract. Initial work done at RCA established the limits of applicability of earth-orbiter spacecraft to deep-space missions. The established boundaries extend from Venus to the asteroid belt: Any closer to the sun than Venus (for example, Mercury) and the thermal constraints are so significant that systems designed for earth application are totally inadequate (Fig. 2). Going away from the sun, Mars is an ideal candidate for the application of earth-orbiter technology; in fact, the environment the spacecraft would see in orbit around Mars is surprisingly close to that of earth. Going out farther, some designs may be applied to main-belt asteroid missions. The major limitation would be the power that could be derived from the solar array. However, at Jupiter and beyond, it can be clearly demonstrated that earth-orbiter technology does not apply. At these distances, radiothermal generators must replace solar arrays as the source of power, and the extremely cold temperatures preclude use of earth-orbiter thermal design. In addition, the environment near Jupiter and the planets

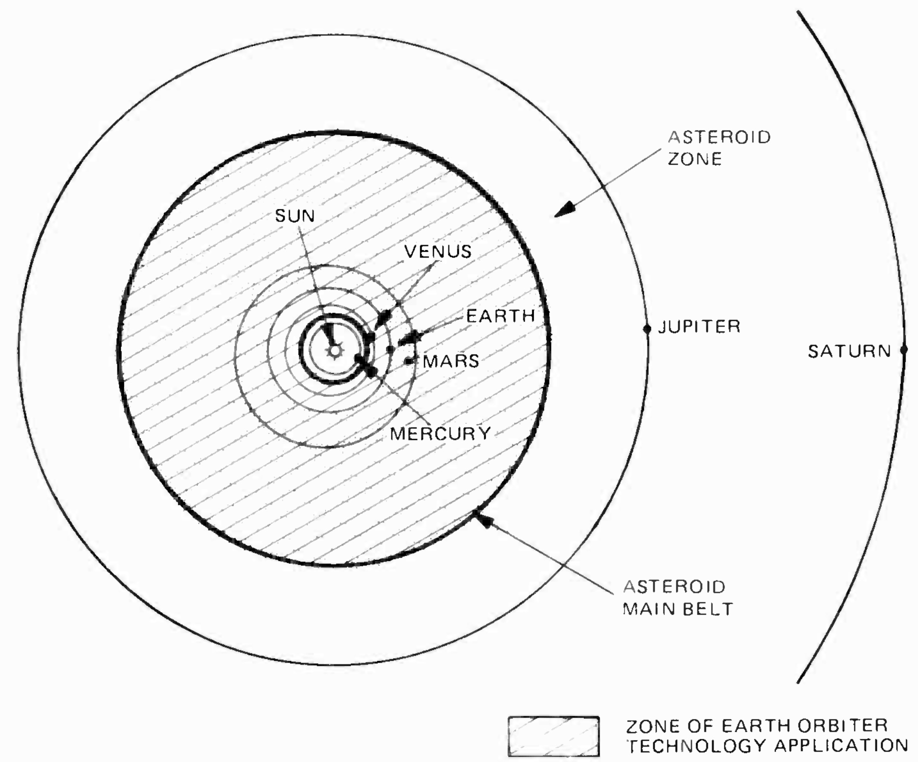


Fig. 2. *The range of "acceptable" environments for the application of earth-orbiting spacecraft to deep-space missions. Beyond these limits thermal and/or power problems necessitate major systems redesign.*

beyond is characterized by intense radiation hazards that exceed nominal design limits of most spacecraft.

With the range of applicability of earth technology established, clearly a wide range of missions of scientific interest can be accomplished cost effectively, with no scientific compromise, by application of earth-orbiter technology. Near-earth asteroid-rendezvous missions are one of the most exciting prospects. To fully appreciate the rather astonishing conclusion that TIROS (a spacecraft designed to make meteorological observations from a low-earth circular polar orbit), can fully support a mission as exotic as an asteroid rendezvous, it becomes necessary to understand in more detail the rationale (and therefore the instrument complement) behind the asteroid mission. To do this, let us momentarily digress to answer some questions about what exactly we hope to learn in the first mission.

Near-earth asteroids

The first obvious questions are: Where do the asteroids come from? Are they remnants of an exploded planet or perhaps a planet that never quite formed? Did they evolve in their present form because of the influence of Jupiter? Why are they mostly concentrated between Mars and Jupiter?

We know that most asteroids fall in a region called the "main belt" (between Mars and Jupiter). However, we also know that asteroids are not constrained to lie in the main belt. Hundreds or perhaps thousands of asteroids penetrate deep into the inner solar system, extending into, and even across, the orbit of earth. This set of asteroids, earth-approaching and earth-crossing, are taken together as "near-earth" asteroids. To fully understand the nature of asteroids and their implication to the development and evolution of the solar system, it is important to study both main-belt and near-earth asteroids and to understand their relationship. Because we need to study both types, and because near-earth asteroids are by far more easily accessible than main-belt asteroids, it is logical to select them as the target for the first spacecraft mission.

Given this selection, the questions the first mission should address are readily defined. Specifically, where do the near-earth asteroids come from? Are they merely asteroids from the inner edge of the main belt whose orbits were perturbed, perhaps by a close approach to Mars, that sent them on orbits into the inner solar system? Are they extinct nuclei of short-period comets, or are they in any way related to comets? Perhaps they have nothing to do with main-belt asteroids or comets. If so, where do they come from?

The next question is: What is the relationship of earth-approaching asteroids to meteorites and their classification? Meteorites fall into a highly structured classification scheme, and an understanding of the relationship between the asteroids and this classification scheme is potentially of great value. This knowledge would help us to understand asteroids, and would also provide a better understanding of the geologic and/or cosmogenic context in which the vast amount of meteorite data that exists should be placed. This can also be said of the lunar data provided by Apollo. In addition to these major questions, there are many other second-order questions related to the space environment that the study of asteroids could answer.

First mission objectives

To allow us to address these questions, the first asteroid mission will be required to (1) determine chemical and mineralogical composition, (2) observe surface morphology, (3) determine bulk density and density distribution, and (4) determine magnetic properties. Definition of a baseline instrument complement that could be used to address these objectives was completed at the Jet Propulsion Laboratory and supplied to RCA. Instruments included were a gamma-ray spectrometer, an x-ray spectrometer, a multi-spectral infrared mapper, an altimeter, an optical (CCD) imager, and a magnetometer.

Table I shows a comparison between the existing TIROS instrumentation and the asteroid-mission instrumentation. This comparison clearly shows that the spacecraft requirements to support both sets of instruments are similar. Imagers and sounders that TIROS normally carries are nadir-

Table I. *Comparison of actual TIROS-N and proposed TIROS-N/Anteros primary sensors.*

Parameter	*Asteroid Imager*	*TIROS Radiometer*	*Anteros Spectrometer*	*TIROS IR Sounder*
Mass (kg)	28.0	30.4	18.0	33.1
Power (W)	25	30	16	22
Dimensions (cm)	30 × 24 ×88	51 × 30 × 65	66 × 47 × 81	51 × 30 × 65
Data rate (kbps)	806.4	660.0	11.5	2.88

pointing devices that must be held steady and properly pointed. The same is true of the imager, infrared mapper, altimeter, and spectrometers on the asteroid mission. One significant difference is that total weight and mounting area requirements are significantly less than those of TIROS, allowing for simplification of the basic spacecraft. In addition, the power, thermal, command and control, and data systems of TIROS can be applied to this mission with little or no modification. The communications system, of course, requires extensive modification because, as is the case in any deep-space mission, the distances from the earth to the spacecraft are exceedingly large. This necessitates a large high-gain antenna. The attitude-control system also needs some modification due to the required use of a star reference for navigation guidance. Tracking, command, and data acquisition will be carried out via the Deep Space Network.

STS launch vehicle

One of the key elements of this mission is the ability to use an existing launch vehicle, thereby avoiding the programmatic and cost problems that arise when launch-vehicle development is required in parallel with spacecraft development. Accordingly, it was decided at the outset of the study that the selected target asteroid must fall in a category accessible by existing vehicles. The launch system chosen was the Space Transportation System (STS) with the two-stage Inertial Upper Stage (IUS). Development of all portions of this system is complete, and the STS/IUS combination will fly, for the first time, early in 1983 as the launch vehicle for the first Tracking and Data Relay Satellite (TDRS).

Mission scenario

If we take the known performance of the STS/IUS combination, the mass of the spacecraft, and the orbit of the target asteroid, we can determine whether we can provide the energy to make the mission feasible. In essence, we calculate if it is possible to achieve the same orbit about the sun as that of the target asteroid. In general, to rendezvous with the asteroid, a five-phase mission is involved.

First, the STS lifts off and goes to a standard STS parking orbit with an acceptable inclination as determined by the orbit of the target asteroid. Second, the IUS/spacecraft combination is separated from the STS, and, after achieving proper inertial reference and a safe separation distance from the STS, the IUS fires and injects the spacecraft into the proper heliocentric transfer orbit. Remnants of the IUS and separation adapter are then jettisoned, the array is partially deployed, the cruise-phase configuration is assumed, and the second phase of the mission begins. This phase of the mission will last between 3 and 12 months (depending on the target) and involves a cruise coast around the sun as shown in Fig. 3, which is the specific case of the asteroid Eros.

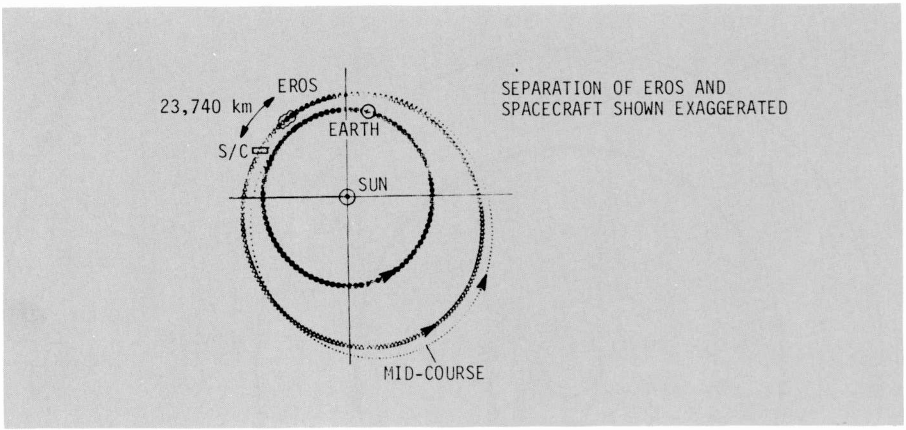


Fig. 3. *The trajectory to be flown by the asteroid-rendezvous spacecraft for the mission to the asteroid EROS. Several launch windows are available for this mission.*

During this mission phase, the spacecraft and instruments are essentially dormant; periodic checkouts, health monitoring, and an occasional midcourse correction are the only planned activities. While in this phase, detailed tracking of the spacecraft and the asteroid are ongoing, and midcourse maneuvers are derived from this detailed tracking data. The target window for the spacecraft is an imaginary circle, centered on the asteroid, with a radius of about 6000 km.

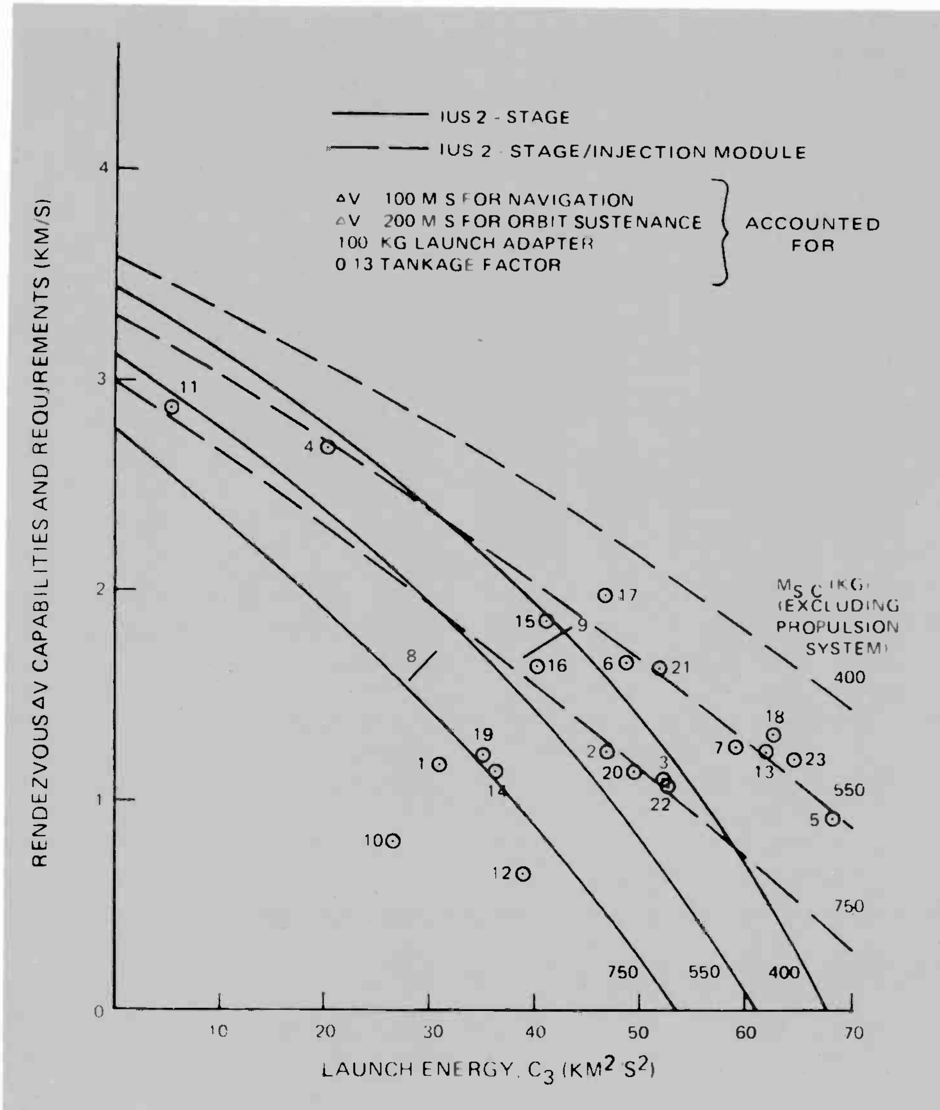
As the spacecraft approaches the asteroid, the third phase of the mission begins. This is the crucial phase in which the on-board propulsion system (a large hydrazine system in the current system design concept) is used for a major velocity adjustment (on the order of 1 to 2 km/s) that takes the spacecraft from the transfer orbit to the asteroid orbit. At this point, the spacecraft is flying along with the asteroid, in the same orbit, but far enough away to be unaffected by its gravitational pull. At this point, the asteroid will appear, to the spacecraft, as the brightest object in the sky, somewhat like a full moon appears on earth, and therefore, will be detected easily by the on-board instruments. All instruments will be brought on line, checked out, and will begin operation. Images that start coming back from the asteroid will provide not only scientific data but also a critical navigational tool for the fourth phase, the approach to the asteroid.

During this phase, the spacecraft is given a small push, by its propulsion system, in the direction of the asteroid. Over a period of several days, it slowly approaches the asteroid, imaging the target as it goes. On-board sensors carefully monitor any perturbations to its trajectory as it enters the asteroid's gravitational sphere of influence.

When the sphere of influence of the asteroid is reached, the fifth mission phase begins. At this point, several mission options are available. These include (1) sequential drift arcs, that is, repeated hyperbolic passes past the asteroid from long distances; (2) interrupted free fall, that is, stopping the spacecraft, letting it fall towards the asteroid, and then interrupting the free fall before impact; (3) stationkeeping, that is, holding a fixed orbital position over the asteroid; and (4) orbiting.

The reason so many options are available and, for the most part energetically feasible, is that asteroids are small, and their gravitational attraction is very weak. For example, on a typical asteroid a few kilometers in diameter, the escape velocity is so low that a man running across the surface would fly off into space and escape the asteroid's gravitational pull. Another consequence of this weak gravitational attraction is that altitudes and velocities for our orbiting spacecraft are on the order of 10 km and less than 1 m/s, respectively, far different from what we are accustomed to dealing with.

Calculations have been done on the consequences of these various options, and the current mission scenario involves three of the four. Stationkeeping has been eliminated because, even given the weak gravitational attraction of the asteroid, fuel re-



#	NAME DESIGNATION	LAUNCH DATE
1	3673 1980 PA	10/30/88
2	2061 ANZA	10/07/88
3	3643 1972 RB	08/25/88
4	3684 1980 YS	02/12/89
5	887 ALINDA	01/04/90
6	1627 IVAR	07/24/90
7	3688 1979 QB	09/15/90
8	1943 ANTEROS	05/27/87 06/06/87
9	1943 ANTEROS	05/13-22/90
10	1982 DB	01/09/89
11	1982 DB	02/05/88
12	3636 1980 AA	01/14/88
13	3669 1979 VA	09/25/88
14	3687 1981 CW	01/14/89
15	3650 1977 VA	10/16/89
16	433 EROS	01/25/89
17	2368 BELTROVATA	08/04/89
18	3641 6344 P-L	11/18/89
19	1943 ANTEROS	05/22/90
20	3636 1980 AA	01/14/90
21	3673 1980 AA	10/19/90
22	1627 IVAR	08/01/90
23	2061 ANZA	09/29/90

Fig. 4. *This plot shows launch energy* (C_3) *plotted against total velocity increment* (ΔV) *achievable for the current design. Any asteroid that falls under this curve is a viable target.*

quirements are excessive at the low altitudes we would like to achieve.

In the current baseline, near the end of phase four, we would target the spacecraft and adjust its velocity so the first pass near the asteroid would result in an unbound hyperbolic trajectory (the sequential drift arc). We would then stop the spacecraft, reverse its direction, and fly a series of such maneuvers at an ever-decreasing, closest-approach distance. After this series of maneuvers, we would have a fairly detailed map of the surface and would be able to safely define an optimum orbit into which we would then insert the spacecraft. From this orbit, detailed magnetic-field and altimetry observations would be done, surface maps would be improved, and the x-ray and gamma-ray survey would be done.

After accomplishing detailed orbital coverage, we would "stop" the spacecraft and do a series of interrupted free-fall maneuvers to image the asteroid as closely as possible. The entire duration of the fifth mission phase would be between 3 and 12 months. At the end of the mission, we would most likely attempt as soft a landing (in reality a quasi-controlled crash) on the asteroid as possible. For this first mission, such a maneuver would not be mission critical and should, at most, be construed as an engineering test for the next-generation mission.

Up to now we have considered target asteroids only in a generic sense. It is possible to quantize the constraints due to spacecraft size, IUS performance, and orbit-injection-velocity change requirements and relate this to the accessibility of specific asteroids. In Fig. 4, C_3 is plotted (in essence, the launch energy achievable from the IUS) against the total velocity change requirements, post injection. Several asteroids are plotted on this graph at the point where the C_3 and ΔV would allow an entry to their orbit (and a launch window for rendezvous). The line of the graph shows what is achievable, using an all-hydrazine propulsion system, for a 500-kg dry spacecraft—roughly the TIROS/asteroid spacecraft mass. Any asteroid that falls below this line is, therefore, a viable target.

One important consequence of viewing the problem this way is that it allows the project to begin even before the target is selected. So long as the ultimate target asteroid falls below this line, it is a feasible mission option. The working baselines for the study were the asteroids Anteros and Eros, both shown on the cross plot. New asteroids are being discovered periodically, and the list is expanding. The asteroid that is currently the easiest to get to, 1982 DB, was only recently discovered (and was a relatively near miss in its most recent pass by the earth).

Conclusion

In summary, the TIROS/asteroid spacecraft mission has significance in two very important respects. First, as the maiden mission to a minor body, it will provide our first look at a very important class of bodies in the solar system and will therefore provide the opportunity for basic discoveries in much the same way Voyager provided information about the outer planets. This mission will also serve as a precursor, providing critical data required to plan more extensive asteroid missions, perhaps leading to manned missions followed by manned bases to exploit the resources of the asteroids. Second, of equal importance, this mission could be the first of a series of low-cost, deep-space missions that would permit us, consistent with the NASA budget for planetary programs, to significantly expand the number of missions flown. This expansion will allow us to increase our knowledge of the solar system via optimum use of the Shuttle's capability.

Other missions currently being considered for this series include several Mars missions that include climatology, geochemistry, and aeronomy, and a lunar polar orbiter that would survey the polar region of the moon and ascertain whether the moon can be a source of raw materials to be used for manufacturing in space. In fact, the same TIROS spacecraft described here is also a candidate for several of these missions, opening the possibility of a spacecraft series that would further enhance the cost-effective exploration of the solar system and our understanding of the implications for our own planet.

Ronald Maehl, Manager, Market Development—NASA, is responsible for marketing non-military government satellite programs. He joined RCA Astro in 1979 as Manager, Science Accommodations. He was responsible for science payload accommodations and the integration of the Dynamics Explorer spacecraft. Later, he was appointed Manager, Science Programs, and was responsible for the development of scientific satellite programs. Dr. Maehl received a B.S. in Physics from the University of Missouri at Rolla and an M.A. and Ph.D., also in Physics, from Washington University.

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—*N. Goldsmith and H. Kressel*

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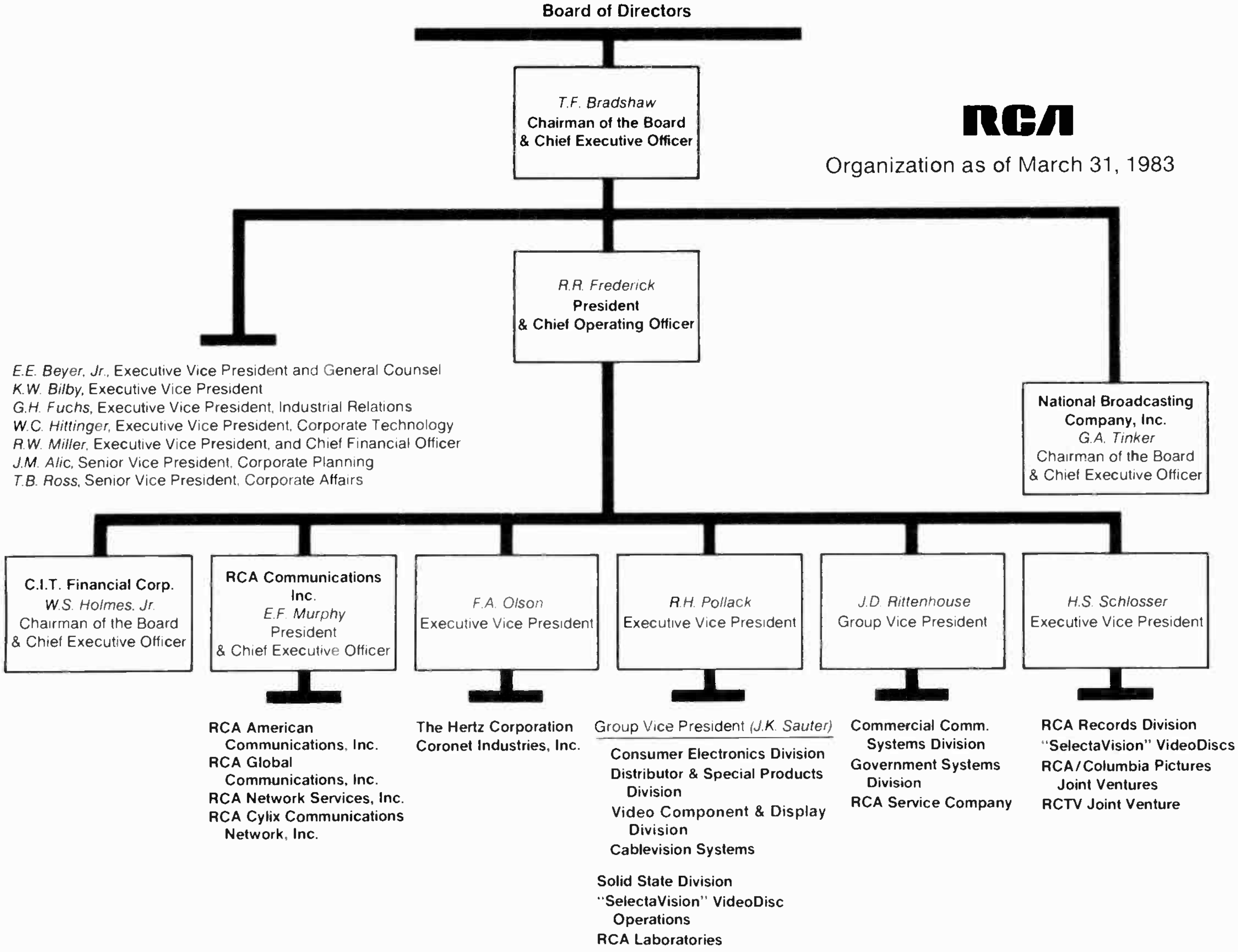

RCA

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T.B. Ross, Senior Vice President, Corporate Affairs

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& Chief Executive Officer

C.I.T. Financial Corp.
W.S. Holmes, Jr.
Chairman of the Board
& Chief Executive Officer

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RCA Network Services, Inc.
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Coronet Industries, Inc.

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Distributor & Special Products Division
Video Component & Display Division
Cablevision Systems

Solid State Division
"SelectaVision" VideoDisc Operations
RCA Laboratories

J.D. Rittenhouse
Group Vice President

Commercial Comm. Systems Division
Government Systems Division
RCA Service Company

H.S. Schlosser
Executive Vice President

RCA Records Division
"SelectaVision" VideoDiscs
RCA/Columbia Pictures Joint Ventures
RCTV Joint Venture

Senior Management Realignment

A realignment of RCA's senior management, aimed at placing greater emphasis on long-range corporate planning and development of new technologies, was announced on February 8 by **Thornton F. Bradshaw,** Chairman and Chief Executive Officer.

Executive Vice-President **William C. Hittinger** has been named to head a new group, Corporate Technology, and **James M. Alic,** formerly a Group Vice-President, has been named to the new position of Senior Vice-President, Corporate Planning. Both Mr. Hittinger and Mr. Alic report to Mr. Bradshaw.

Mr. Hittinger continues to be responsible for Patent Operations, Licensing, and Staff Engineering, and adds a new activity, Technical Evaluation and Planning, headed by **Dr. James Vollmer,** Senior Vice-President. Mr. Hittinger also serves as the senior technical advisor to the Chairman of the Board and the President and will represent RCA on technology matters with government agencies, trade associations, and academic institutions.

Dr. Vollmer, in addition to his responsibilities for technical evaluation and planning at the corporate level, will assist and advise the Corporate Planning activity on technical matters as requested. He will also have responsibility for maintaining an effective relationship with appropriate federal government agencies in developing business opportunities for the Corporation.

Mr. Alic assumes responsibility for developing and administering the Corporate strategic planning program and providing functional direction for such programs in RCA's major operating units.

A new organizational structure is now in place under **Robert R. Frederick,** President and Chief Operating Officer. The following executives now will report to him.

—**Roy Pollack,** Executive Vice-President, who now assumes responsibility for the RCA Laboratories in addition to his current responsibilities for the Consumer Electronics Division, Video Component and Display Division, Distributor and Special Products Division, Cablevision Systems, Solid State Division, and "SelectaVision" VideoDisc Operations.

—**John D. Rittenhouse,** who is now a Group Vice-President, assumes responsibility for the Government Systems Division, Commercial Communications Systems Division and the RCA Service Company. Mr. Rittenhouse had been Division Vice-President and General Manager of the Picture Tube Division, now the Video Component and Display Division.

—**Eugene F. Murphy,** who continues as President and Chief Executive Officer, RCA Communications, Inc. This organization includes RCA American Communications, Inc., RCA Global Communications, Inc., RCA Network Services, Inc., and RCA Cylix Communications Network, Inc.

—**Frank A. Olson,** who continues as Executive Vice-President with responsibility for the The Hertz Corporation and Coronet Industries.

—**Walter S. Holmes, Jr.,** Chairman and Chief Executive Officer of C.I.T. Financial Corporation.

—**Herbert S. Schlosser,** who continues as Executive Vice-President in charge of RCA Records, VideoDiscs, and certain RCA joint ventures.

—**Grant A. Tinker,** Chairman and Chief Executive Officer of the National Broadcasting Company, Inc., continues to report to Mr. Bradshaw.

Mr. Bradshaw said the realignment was made to strengthen the company's ability to seize on the most promising electronic business opportunities in the future.

Quinn Heads Video Component & Display Division (formerly Picture Tube Division)

Charles A. Quinn has been appointed Division Vice-President and General Manager, Video Component and Display Division. He will report to **Jack Sauter,** Group Vice-President. Mr. Quinn had been Division Vice-President, Operations, Consumer Electronics Division. There, he had been responsible for the engineering, production planning, purchasing, manufacturing and product assurance functions of the division.

The division, with principal facilities in Lancaster and Scranton, Pa., Marion, Ind., Circleville, Ohio, and Puerto Rico, supplies picture tubes to RCA and other color television receiver manufacturers. The division entered the color data display tube business last year.

Mr. Quinn joined RCA in 1965 as an Administrator of the Corporate Staff Purchasing function in Camden, N.J., and moved to the Communications Systems Division the following year. He joined the Consumer Electronics Division in 1974 as Director of Purchasing.

Quinn is a native of Philadelphia. He earned a bachelor's degree in electrical engineering from Villanova University and an MBA in economics and finance from Duquesne University.

Tietjen is President of RCA Americom

The election of **Dr. James J. Tietjen** as President and Chief Operating Officer of RCA American Communications, Inc. was announced by **Eugene Murphy,** Group Vice-President of RCA Corporation.

Dr. Tietjen has served as Staff Vice-President at RCA Laboratories since 1977 and has 20 years of service with RCA. He suc-

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Clemens Named Staff Vice-President

Appointment of **Dr. Jon K. Clemens** as Staff Vice-President, Consumer Electronics Research, was announced by **Dr. William M. Webster,** Vice-President, RCA Laboratories, in Princeton, N.J. In his new position, Dr. Clemens is responsible for RCA Laboratories research on digital products, television, and VideoDisc systems.

Since joining RCA Laboratories in 1965, Dr. Clemens has played a leading role in the development of the RCA "SelectaVision" VideoDisc system. In 1976 he was appointed Head, Signal Systems Research, with the primary responsibility for developing the VideoDisc signal system for both the mastering of records and the player design. In 1981 he was appointed Director, VideoDisc Systems Research Laboratory.

In 1980 Dr. Clemens was a co-recipient of the Rhein-Prize—presented by the Eduard Rhein Foundation of West Germany—for his contributions to the VideoDisc system. Dr. Clemens is a co-recipient of the IEEE Vladimir K. Zworykin Award for outstanding contributions to the development of an electronic disc system for recorded television programs. The award will be presented to him in June of this year. Dr. Clemens has received two RCA Laboratories Outstanding Achievement Awards as well as a special VideoDisc award in 1973. In 1981 he was a recipient of the David Sarnoff Award for Outstanding Technical Achievement for his work on the CED VideoDisc system.

Dr. Clemens received a B.A. degree in Physics from Goshen College in 1960. MIT awarded him B.S. and M.S. degrees in 1963 and a Ph.D. degree in 1965, all in Electrical Engineering.

ceeds **Andrew F. Inglis,** who will retire from RCA on June 1 after 30 years of service, and who has served as President of RCA Americom since January 1977.

During the iterim period, Mr. Inglis will serve as Vice-Chairman of RCA Americom. Both Dr. Tietjen and Mr. Inglis will report to Mr. Murphy, who is also Chairman and Chief Executive Officer of RCA Americom. Following June 1, Mr. Inglis will continue to serve the company as a consultant in matters primarily relating to long-range planning for its communications services.

In announcing the appointment, Mr. Murphy said, "Dr. Tietjen will bring to RCA Americom an outstanding background of management capability and technological achievement, including direction of the research and development effort that culminated in the development of the RCA VideoDisc. These skills will enable the company to maintain its leadership in providing domestic satellite-communications services to businesses, the media, and government agencies."

A native of New York City, Dr. Tietjen received his B.S. degree, *cum laude*, in Chemistry from Iona College in 1956. He was awarded his M.S. and Ph.D. degrees in Physical Chemistry in 1958 and 1963 from The Pennsylvania State University.

The author of more than 30 published articles primarily relating to materials and components research, he has received RCA's highest technical honor, the David Sarnoff Award for Outstanding Technical Achievement, in 1967 and 1970. He was also awarded RCA Laboratories Outstanding Acheivement Awards in 1965 and 1969.

Staff announcements

Roy H. Pollack, Executive Vice-President, announces that **Jay J. Brandinger,** Division Vice-President and General Manager, "SelectaVision" VideoDisc Operations, and **David Arganbright,** Staff Vice-President, Business Management and Control, VideoDisc Project, will report to the Executive Vice-President. **Mark L. Frankel** is appointed Staff Vice-President, Planning.

Automated Systems

Thomas E. Fitzpatrick, Director, Vehicle Test Systems reports to **A.T. Hospodor,** Division Vice-President and General Manager. **Richard E. Hanson,** Manager, Vehicle Test Systems Development and **John F. Martin,** Manager, Program Operations, report to **Thomas E. Fitzpatrick. John S.J. Harrison,** Manager, Avionic Test Systems Engineering; **Richard P. Percoski,** Manager, Automatic Test Systems Engineering, report to **D.M. Priestley,** Chief Engineer. **Chris A. Wargo,** Manager, Program Operations, reports to **Eugene M. Stockton,** Director C^{3}I Systems.

Consumer Electronics

Leonard J. Schneider, Division Vice-President, Manufacturing, announces that the Board of Directors of RCA Taiwan Limited elected **Kenneth S. Williams** as President and General Manager. Mr. Williams reports administratively to the Board of Directors, RCA Taiwan Limited, and he reports functionally to the Division Vice-President, Manufacturing.

Edmund W. Riedweg, Plant Manager, Bloomington Plant, announces the Bloomington Plant organization as follows: **Robert R. Beasley,** Manager, Plant Engineering; **Terry J. Burns,** Manager, Television Manufacturing—Plants I & II; **John H. Cook,** Manager, Industrial Relations; **Forrest W. Eads,** Manager, Manufacturing Analysis; **Gerald A. Gradek,** Manager, Television Manufacturing—Plant III; **James J. Legault,** Manager, Quality Control; **Philip G. McCabe,** Manager, Manufacturing Engineering; **Bruce W. Phillips,** Manager, Financial Operations; and **Russell M. Smith,** Manager, Materials.

J.B. Thomas, Manager, Manufacturing Engineering, announces the appointment of **Keith A. Searcy** as Manager, Process Engineering. Mr. Searcy will report to the Manager, Manufacturing Engineering.

Laboratories

William M. Webster, Vice-President, RCA Laboratories, announces the organization of the RCA Laboratories as follows: **Jon K. Clemens,** Staff Vice-President, Consumer Electronics Research; **Henry Kressel,** Staff Vice-President, Solid State Research; **Kerns H. Powers,** Staff VicePresident, Communications Research; **Richard E. Quinn,** Staff Vice-President, Administration; **Alfred H. Teger,** Staff Vice-President; **William M. Webster,** Acting, Materials and Manufacturing Systems Research; **Brown F. Williams,** Staff Vice-President, Display and Energy Systems Research; and **Dominick A. Zurlo,** Staff Vice-President, Industrial Relations.

Jon K. Clemens, Staff Vice-President, Consumer Electronics Research, announces the organization of Consumer Electronics Research as follows: **David D. Holmes,** Director, Television Research Laboratory; **Arthur Kaiman,** Director, Digital Products Research Laboratory; and **John A. van Raalte,** Director, VideoDisc Systems Research Laboratory.

Bernard J. Lechner, Director, Video Systems Research Laboratory, announces the organization of the Video Systems Research Laboratory as follows: **Emilie M. Lengel,** Head, Systems Technology Research; **Allen H. Simon,** Fellow, Technical Staff; **Frank J. Marlowe,** Head, Digital Video Research; **Charles B. Oakley,** Head, Satellite Transmission Technology Research; **Leonard Schiff,** Head, Communication Analysis Research; **Harold Staras,** Fellow, Technical Staff; **Paul Schnitzler,** Head, Broadcast Systems Research; and **Robert E. Flory,** Fellow, Technical Staff.

RCA Cylix Communications Network, Inc.

Ralph R. Johnson, President and Chief Executive Officer, RCA Cylix Communications Network, Inc., announces the organization of the President and Chief Executive Officer as follows: **R. Ronald Burgess,** Director, Personnel; **Byron M. Eagle,** Vice-President, Finance and Administration; **Floyd H. Jean,** Vice-President, Engineering and Development; **Ralph R. Johnson,** Acting, Operations; and **Ronald L. Young,** Vice-President, Marketing.

Solid State Division

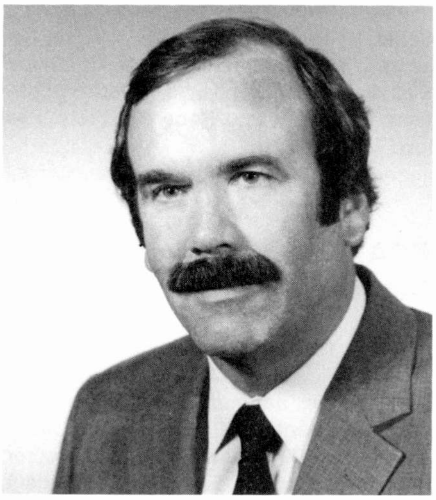
Jon A. Shroyer, Division Vice-President, Integrated Circuits, announces the appointment of **Otto H. Schade, Jr.** as Principal Member of the Technical Staff. Mr. Schade will report to **George J. Waas,** Manager, Design Engineering-Bipolar & MOS Logic.

Larry J. French, Division Vice-President, Solid State Technology Center, announces the appointment of **Christopher B. Davis** as Principal Member of the Technical Staff. Mr. Davis will continue to report to **Larry M. Rosenberg,** Manager, Design Automation.

Carlton L. Rintz, Director, Tube Operations, announces the appointment of **William S. Lynch** as Manager, Materials, Planning and Operations Support. Mr. Lynch will report to the Director, Tube Operations.

William S. Lynch, Manager, Materials, Planning and Operations Support—Tube Operations, announces the organization of Materials, Planning and Operations Support—Tube Operations as follows: **John H. Hipp,** Manager, Purchasing; **Arthur A. May,** Manager, Warehouse and Distribution; **Robert J. Rutherford,** Manager, Systems and Facilities; **Joseph D. Schmitt,** Manager, Production Planning—Power Tube; and **William M. Sloyer,** Manager, Production Planning—Conversion Tube.

Williams elected IEEE Fellow



Dr. Brown F. Williams, Staff Vice-President, Display and Energy Systems Research, has been elected a Fellow of the Institute of Electrical and Electronics Engineers (IEEE). Fellow is the highest membership grade attainable in the IEEE, conferred upon "persons of outstanding and extraordinary qualifications in their particular fields." Dr. Williams was honored "for technical contributions and innovative leadership in research and development of electron devices." He is one of 130 Fellows elected in 1982 from among the IEEE's world-wide membership of 234,000.

Burlington Sigma Xi club meeting

The RCA Burlington club of Sigma Xi held a meeting at the Automated Systems facility on November 17, 1982. The meeting, conducted by Club President **Lionel Arlan,** included a report on the Society Annual Delegates Meeting and induction of fourteen new associate members.

Guest speaker, **Dr. Fred Sterzer,** Director of the Microwave Technology Center at the David Sarnoff Research Center, spoke on "Localized Hyperthermia Treatment." This fascinating lecture described how localized hyperthermia treatment (sustained heating of tissues to temperatures of about 42 to 43.5°C) is one of the number of unconventional methods of treating cancer that are receiving increased attention from oncologists. Dr. Sterzer reviewed the effects of hyperthermia on malignent cells and tissues, and described techniques and apparatus developed at RCA Laboratories for clinical application.

Monshaw elected IEEE Fellow

V.R. Monshaw was elected a Fellow of the Institute of Electrical and Electronic Engineers effective January 1, 1983, with the following citation:

> "For contributions to the reliability engineering of space electronic systems"

Mr. Monshaw is Manager of Product Assurance at RCA Astro-Electronics.

Vollmer to head Rutgers business advisory council

Dr. James Vollmer, Senior Vice-President of RCA Corporation, has been named Chairman of the new Executive Advisory Council to the business studies faculty at Rutgers University's Camden campus. The 10-member council was formed by Rutgers to advise faculty members on curriculum, to study how faculty members and students can help business, and to keep the faculty informed of business trends, according to Dr. Peter Weissenberg, Associate Dean for Business Studies at Rutgers—Camden.

Dr. Vollmer has a doctor's degree in physics from Temple Unversity, where he later taught for five years. He also was graduated from the Harvard Business School's Advanced Management Program. He joined RCA in 1959.

Balzer is committee chairman

Dan Balzer, Manager, Propulsion & Space Transportation, Astro-Electronics, was elected by the AIAA Technical Committee on Liquid Propulsion (TC-LP) to serve as the Committee Chairman effective May 1, 1983. The term of office is two years. The general scope of the AIAA TC-LP is to foster the development of technology for all aspects of reaction propulsion employing liquid or gaseous propellants. The committee is composed of representatives from government agencies, universities, virtually every major aerospace company in the U.S. and foreign-country members from England, France, Federal Republic of Germany, and Japan.

Bartolini named 1983-84 Sigma Xi National Lecturer

Robert A. Bartolini, Solid State Devices Laboratory, is one of 30 scientists to be named a Sigma Xi National Lecturer for 1983-84. Each year the scientific research society assembles a College of National Lecturers so that its chapters and clubs can have the opportunity to hear nationally known scientists discuss particularly lively areas of current research. Dr. Bartolini will lecture to various Sigma Xi groups on "Laser Recording of Mass Memory Data: The Potential Solution to the Information Explosion."

Lannon on ASQL committee

R. Lannon of Quality Engineering, RCA Astro-Electronics was a committee member responsible for developing exhibitor participation at the 26th Annual Symposium for the Phila. Section of ASQC (American Society for Quality Control) held Nov. 18, 1982, Cherry Hill Inn, Cherry Hill, N.J.

Sommer wins Gaede-Langmuir Award

Dr. Alfred H. Sommer from Thermo Electron Corporation has been selected as the 1982 winner of the Gaede-Langmuir Award:

> "For inventions and development of photocathodes and secondary emitters used in a variety of applications such as vacuum tubes, high energy physics, medicine and biology, astronomy, night vision and television."

Alfred H. Sommer was born and educated in Germany. He received the Dr. Phil. degree in Physical Chemistry from Berlin University in 1934. Throughout his career at RCA Laboratories (1953-1974), his main interest has been development and study of new photoemissive and secondary electron emitting materials and their applications in photomultipliers, image tubes and TV camera tubes.

Woll to receive engineering award

Dr. Harry J. Woll, Staff Vice-President and Chief Engineer, RCA Electronic Products, Systems and Services, received the 1982 Yarnall Award from the University of Pennsylvania's Engineering Alumni Society.

RCA man elected to IEEE Board

The IEEE Assembly has elected new Vice-Presidents for Regional and Educational Activities, and other officers. **Merrill Buckley, Jr.,** Missile and Surface Radar, Former Region 2 Director, replaces Hans Cherney on the Executive Committee and the Board of Directors, as Vice-President for Regional Activities.

Enstrom is VP of The Electrochemical Society

Dr. Ronald E. Enstrom has been elected a Vice-President of The Electrochemical Society. The Society is headquartered in Pennington, New Jersey and facilitates communication among about 6000 scientists in a number of materials-related research areas both in the United States and abroad. He has served on a number of committees within the Society, and most recently has been chairman of the Electronics Division, which focusses on the growth, processing, technology and science of semiconducting materials for electronic device applications.

Dr. Enstrom is with the Display Processing and Manufacturing Research Laboratory at the RCA David Sarnoff Research Center in Princeton, New Jersey. He is the author or co-author of more than 60 papers, has been awarded 5 patents, and was awarded the David Sarnoff Award for Outstanding Technical Achievement, which is the RCA Corporation's highest scientific award. For the academic year 1973-74, he was at the Swiss Federal Institute of Technology in Zurich, Switzerland.

NBC engineers in professional societies

NBC's engineers are involved currently in several professional societies. For example, **Robert J. Butler** is on the Electronic Industries Association (EIA) committee on Satellite Equipment and Systems. **Donald J. Musson** is on the IEEE Broadcast Group Audio Measurements Subcommittee, and he is IEEE Administrative President of the Broadcast Technology Society. **Burnett Sams** is on the Society of Motion Picture and Television Engineers (SMPTE) Working Group for Standardization of Digital Control of Television Equipment. **David Rabinowitz** is on the SMPTE Working Group on Digital Video Standards and on the SMPTE Sub-Group on Digital Studio Implementation. The important voluntary standards-setting activities of industry, to which these men contribute, help to determine the shape of future broadcast technologies.

Isom wins AES bronze medal

Warren Rex Isom, who joined RCA in 1944 and retired in 1975 after 10 years as Chief Engineer for RCA Records, received the Audio Engineering Society Bronze Medal at the 72nd Convention. He was cited for "distinguished and creative services to the Society over many years and his particular contributions to special publications." Mr. Isom spent his professional career on the frontier of engineering, particularly at the interface of electronics and mechanics.

Upadhyayula chairs IEEE chapter

Dr. L. Chainulu Upadhyayula is currently the Chairman of the Electron Devices/Microwave Theory and Techniques Chapter of the IEEE Princeton section. He is also elected to the Committee on Digital Microwave Theory and Techniques Society. Upadhyayula is a Member of Technical Staff, RCA Laboratories.

Technical excellence

Harrison wins Americom's first technical excellence award

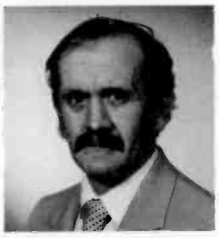
RCA American Communications, Inc., has announced that the first recipient in its Technical Excellence Award program is **Irving W. Harrison,** a group leader for space systems mission operations.

Mr. Harrison was cited by the company's Awards Committee for work that resulted in a redesign of the tracking, telemetry and control computer software systems that maintain RCA Americom's Satcom communications satellites while in orbit 22,300 miles above the equator.

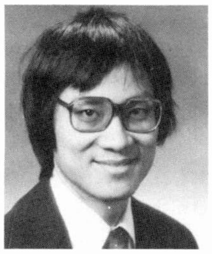
John Christopher, Vice-President, Technical Operations, cited Mr. Harrison's "outstanding display of knowledge, implementation skill and dedication on this project," which helped RCA Americom to fulfill its contractual commitments to Alascom, Inc., and to meet interface obligations with spacecraft software and hardware conirctors.

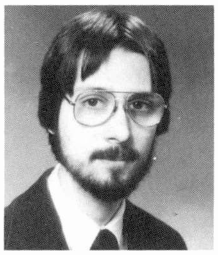
Mr. Harrison has been associated with RCA Americom since 1975, when he served as a ground systems analyst at the company's main earth station in Vernon Valley, N.J. He later moved to headquarters as a senior systems analyst in Technical Operations until assuming his present position in 1979.

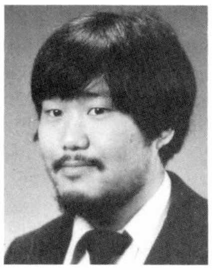
The Technical Excellence Award program is an RCA corporate-wide activity that originated 15 years ago for the purpose of serving the professional needs and interests of the company's engineering community. It was established this year at RCA Americom to promote engineering excellence and the development of activities leading to enhanced professionalism and productivity.


Harrison

MSR's special technical excellence awards


Cheng


Griffin


Katsumata

Bernie Matulis, Chief Engineer at Missile and Surface Radar, announced three special Chief Engineer's Technical Excellence Awards to be presented to **Raymond Cheng, Brian Griffin,** and **Kun Katsumata,** all engineers at the Advanced Technology Laboratories. A brief summary of their accomplishments follows.

For their significant accomplishments on the Military Computer Family Program in defining the original CPU hardware and microcode architecture for the AN/UYK-41 super minicomputer and AN/UYK-49 microcomputer. Their efforts consisted of partitioning the design for VLSI technology insertion, developing detailed hardware specifications for each functional element, generating more than 2,000 lines of microcode, establishing simulation models, and, finally, verifying both the hardware architecture and microcode via functional simulation.

In addition, they played a key role in the debugging and testing of the advanced development modules, handling the prime responsibility for microcode integration, and supporting the acceptance test and system software integration.


Automated Systems team award. *From left to right: R. Caron, D. Nowak, R. Thomson, A. Hospodor, Division Vice-President and General Manager, R. Cowley, A. Fortin, Jr., M. Lospinuso, K. St. Pierre, L. Armstrong, D. Chin, D. Lee, F. Shirak.*

The STE/M1 Validation/Verification team, directed by **A.H. Fortin, Jr.,** received a commendation for outstanding team performance in validating and verifying Simplified Test Equipment for the Abrams M1 tank. The team members worked for many months in Center Line, Michigan, at the General Dynamics Land Systems Division tank manufacturing facility. Their dedicated efforts resulted in expeditious completion of validation and verification of STE/M1 and permitted the RCA production contract to proceed without delay. The Engineering Team award honors the following team members for outstanding effort on this important project:

L.R. Armstrong,
Engineering Scientist

R.W. Caron,
Member Technical Staff

D. Chin,
Member Technical Staff

D.K. Lee,
Member Technical Staff

M.D. Lospinuso,
Senior Member Technical Staff

D. Nowak,
Senior Member Technical Staff

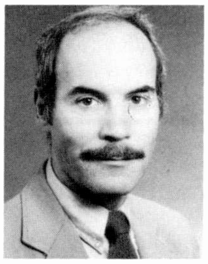
K.J. St. Pierre,
Member Technical Staff

R.J. Thomson,
Data Processor, Engineering

The Engineering Team Award program was instituted in late 1982 by the Automated Systems Engineering Department, to give credit and recognition to deserving teams for successful completion of important projects or a key phase of a project.

Paterson wins MSR's annual technical excellence award

Bill Paterson won Missile and Surface Radar's Technical Excellence Award for 1982.


Paterson

For outstanding contributions to the architecture design of the Military Computer Family and for system engineering leadership on the program. He personally developed a detailed, transaction-based simulation model of the minicomputer in GPSS (General Purpose System Simulator). With a baseline model thus established, he made extensive use of BMEWS and AEGIS software program application statistics as a basis for key trade-offs in memory subsystem design. These trade-offs were slanted toward real-time Command and Control processing environments and involved decisions in cache utilization, cache page size and update strategies, and system bus structure. The superiority of the architecture has been verified in extensive AD model demonstrations.

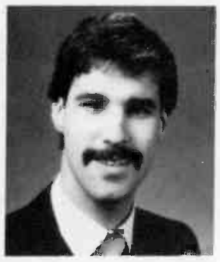
As chief system engineer for the program, he has been responsible for the overall MCF system design, including traceability of the functional design from concept to the Advanced Development models, and thence to the projected final design that will include insertion of VLSI technology. As RCA's representative on the Army's Nebula Tiger Team, Mr. Paterson has also played a key role in the finalization of the MCF Instruction Set Architecture.

MSR third-quarter 1982 awards


Blum


Houck


Hui


Cooper


Hughes


Landry


Mason


Monastra


Scott

At Missile and Surface Radar, the review of Technical Excellence Award nominations for the third quarter 1982 has yielded nine winners.

C. Blum—for important acomplishments in two distinct areas of the EDM-4 antenna development program. His design of state-of-the-art rectangular coaxial power dividers exceeded design requirements, and his involvement in software development for testing phase shifters and drivers has also proved completely successful. These achievements are particularly noteworthy, coming in his first year as a graduate engineer.

A.S. Cooper—for his initiative, dedication, and tenacity in the implementation of a Hybrid Circuit Design System—an extraordinary performance, well beyond that expected from one of his experience and position. His efforts, which included development of more than 40 program modules, have resulted in an effective system for the design and checkout of hybrid circuits on ceramic substrates.

R.L. Houck—for extraordinary performance under difficult circumstances in restoring operational status to a NIDIR radar located in a remote foreign location. With no recourse to MSR for information or assistance, Mr. Houck exhibited his expertise by resolving problems in a wide range of areas, including azimuth encoders, pulse amplifiers, magnetic tape controls, and elevation bandwidth circuitry.

G.A. Hughes—for his successful structural design and development of fabrication and assembly techniques for the EDM-4 antenna structure. His approaches to alignment of the high-precision, ultra-lightweight deep beam assemblies to the integrated horn/front plate assembly provided a structure with significantly lower weight than that of the SPY-1A.

K.P. Hui—for outstanding performance in the development of Military Computer Family CPU subsystems and integration of Nebula microcode in the hardware. His technical direction and personal design contributions were key elements of the successful design and implementation that produced more than 2100 unique integrated circuits in seven months.

N.R. Landry—for contributions to the EDM-4 antenna array development, especially in the computer-aided design of the precise power divider T-junctions used in the beamformer networks. Augmenting this work was a set of computer-aided test programs for evaluation and analysis of the complex beamformer network circuits. He earlier provided a computer program for evaluation of the phase shifters.

R.J. Mason—for his design combining the capabilities of the precision 3D Applicon system and the Gerber photo-plotter to produce artwork, photomasks, inspection templates, and drawings for large (2×4 feet) microwave etched circuits. Also produced were tapes for numerically controlled machining of associated ground planes. The resulting circuits are laminated by a vendor, under Mr. Mason's direction, to provide column beamformers for the EDM-4 antenna array.

E.J. Monastra—for his contributions to the design and test of the MCF advanced development CPU, including integration and testing of Nebula microcode. In addition to assuming personal responsibility for detailed design of 970 of the 2100 unique integrated circuits, Mr. Monastra initiated a number of logic design techniques that made it possible to meet the highly compressed integration and testing schedules.

M.J. Scott—for extraordinary performance under difficult circumstances in restoring operational status to a NIDIR radar located in a remote foreign location. With no recourse to MSR for information or assistance, Mr. Scott successfully resolved a wide variety of electrical and mechanical problems in the local oscillator assembly, transmitter tuner control, microwave pressure and dehydration systems, and boresight tower signals.

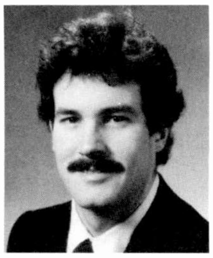
The award winners were honored at a special function, and each received a commemorative desk plaque and a current text or reference book.

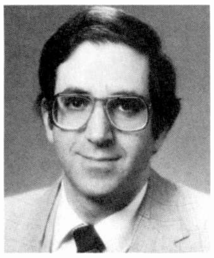
MSR fourth-quarter 1982 awards

At Missile and Surface Radar, the review of Technical Excellence Award nominations for the fourth quarter 1982 has yielded seven winners.

D.W. Copeland, Jr.—for significant contributions to AEGIS Combat System training through incorporation of the ownship motion simulation capability of the hull sonar as an integral part of the overall AEGIS Combat System Training System (ACTS). As a result of his efforts, the utility of the antisubmarine warfare trainers has been extended so that the entire AEGIS Combat System can apply simulated navigation data for dockside training.

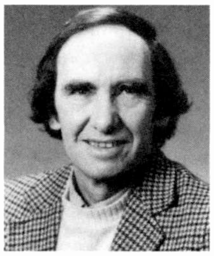
M.R. Ducoff—for demonstrating outstanding technical expertise over a broad range of radar system engineering skills in modeling, simulating, and evaluating the probable and predicted performance capabilities of an advanced Soviet air defense threat radar system. The thoroughness and depth of detail that characterized Mr. Ducoff's analysis was so compelling that the Govern-


Copeland


Ducoff


Henderson


McBride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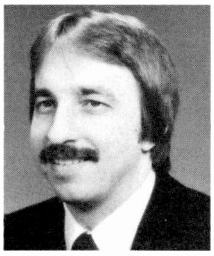
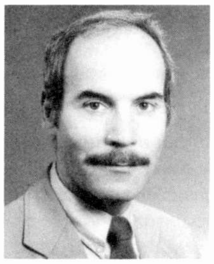

Seymour


Paterson

ment is updating its Threat Assessment Report to incorporate the results of his efforts.

D.W. Henderson—for designing and developing a Military Computer Family (MCF) Test Case Generator for evaluating all variations of operation codes used in the Nebula Instruction Set Architectures. The resultant ISA tests, and a Demonstration Test Plan he created, were highly successful in verifying the capabilities of the MCF computers in customer demonstrations. Further, his innovative techniques are readily adaptable to testing other developmental computer equipment.

E.J. McBride—for his technical performance and leadership during the design and development of the Military Computer Family Advanced Development input-output subsystem. Mr. McBride personally designed the hardware for the majority of this large and complex subsystem, which consisted of more than 800 integrated circuit chips. In addition, he provided technical direction in the development of over 4500 lines of complex microcode. Finally he undertook responsibility for development and testing of five serial and six parallel I/O Mupac boards.

R.D. McCamy—for designing, documenting, and coding the Military Computer Family Run Time Monitor, a basic multitasking operating system for demonstrating MCF hardware. Building a program of this size (2,200 lines of code) and complexity for a new, untested machine, in a new language, made his achievement outstanding. In addition, Mr. McCamy continued his responsibilities as Chief Programmer for the MCF Software Support Group throughout the period of development.

W.J. Paterson—for outstanding contributions to the architecture design of the Military Computer Family and for system engineering leadership on the project. Mr. Paterson personally developed a detailed, transaction-based simulation model of the MCF minicomputer, using GPSS, a general purpose system simulator. His innovative modeling approach and important tradeoff decisions resulted in a final architecture that was successfully built and demonstrated in Advanced Development models.

G.L. Seymour—for his special achievements in defining and implementing functional requirements for four minicomputer-based test stations critical to the Military Computer Family Advanced Development (AD) program. Under a tight deadline, Mr. Seymour defined the functional requirements and then built, tested, and integrated the equipment and software for these test stations. This achievement and his prior I/O contributions were key to the success of the MCF AD Program.

GCS PONTIAC team wins award

The Government Communications Systems PONTIAC Design Team has been selected for a Technical Excellence Award for the successful design of a Special Arithmetic Unit (SAU). The team members honored are:

Joseph Branch, Jr.
Joseph Dombrowski
Patrick Lonski
Marilyn MacRae
Vincent Masciandaro
C. Alan Michel
Merwyn Russell
David Sapp
Willie Singley

The SAU design was based on existing RCA equipment that needed enhanced performance, and greatly improved reliability and maintainability. The SAU is an important component of systems in the field, and is complex and sophisticated. The PONTIAC Design Team achieved a highly reliable design as well as diagnostic software for fault isolation and easy repair. The entire hardware and software design was accomplished on a crash schedule to meet the customer's need. To achieve the design schedule of nine months, the PONTIAC team used the customer's secure computer-aided design facility at a remote location (during odd hours) to generate complete documentation for multiwire board fabrication. The whole team participated in the design automation effort to achieve fault-free input of design information in a strange CAD format, and detailed checking of the output. The customer was very appreciative of the PONTIAC team performance and recognized it the best way: a sole-source award for production of 70 SAUs.


PONTIAC Design Team award. *Seated (left to right): Dave Sapp, Pat Lonski, Marilyn MacRae, Joe Dombrowski, and Willie Singley, award winners. Standing (left to right): Don Parker, Director, Digital Communications and Recording Systems; Merwyn Russell, Alan Michel, Vince Masciandaro, award winners; Bob Schollenberger, Unit Manager; Don Kaplan, Unit Manager; Joe Branch, award winner; and Jim Fayer, Chief Engineer.*

GCS technical excellence award

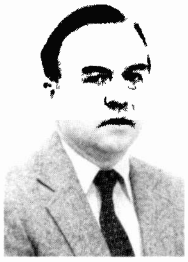
MPT-85 Design Team award. *Left to right: Jim Fayer, Chief Engineer; Dick Araskewitz, Bob Nichols and Dean Johnson, team award winners; and Don Parker, Director, COMSEC programs.*

The Government Communications Systems Technical Excellence Committee has made a team award to **Dick Araskewitz, Dean Johnson,** and **Bob Nichols** of Digital Communications Engineering for their outstanding work in the design and development of the MPT-85 Multipurpose Tester. The objective of this project was to develop a product that could be used for FALCON and other COMSEC applications to function as a system test vehicle, a burn-in exerciser and monitor, and a first-article exerciser and tester. The unit had to be low cost and easy to use.

The final hardware design was a well-conceived assembly of wire-wrap platters and a printed-circuit board of line terminations. Solid-state crosspoints were also used throughout to eliminate any cabling changes or discrete switches. Software for this project was written in BASIC by this same team. Several software versions were written to accommodate the first four types of burn-in tests, three types of system test, several first-article tests, and self tests.

The MPT-85 was a major factor in reducing production cost estimates, and as a result RCA won the FALCON "B" Program. The customer is very impressed with this product, and is suggesting that it be used for several other applications.

Consumer Electronics gives annual TEC awards



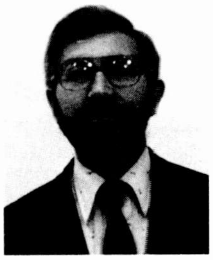
Tults

Teskey

Testin

Herskowitz

McCorkle



Moore

Recipients of the Consumer Electronics 1982 Annual TEC Awards were chosen by the TEC from among the Quarterly TEC award nominees throughout the year. The RCA Consumer Electronics Engineering Community congratulates these six recipients on their outstanding accomplishment.

Juri Tults—for the innovative development of synthesizer logic for the CATV version of the FS-I IC and for the FS-II IC.

John Teskey and **William Testin**—for outstanding effort in implementing FS 1.5 despite an extremely short development cycle. As a result, the benefits and cost advantages of the unified remote were realized a year earlier than expected.

Martin Herskowitz, David McCorkle, and **George Moore**—for the development of an automatic system that measures and aligns center purity, center convergence, Z-axis edge purity, and yoke rotation while providing enough mechanical integrity to allow yoke-clamp tightening without disturbing alignment.

Fourth-quarter awards at Consumer Electronics

Van Breemen

Left to right: Toler, Stephens, and Gobush.

Fourth-quarter TEC awards were recently given to the following twelve people. Based on managers' recommendations, the recipients' work was researched by the Technical Excellence Committee. The nominating managers were then interviewed, and selections for awards were made.

Bertram VanBreemen—for his development of the mathematical theory that led to a novel projection TV screen concept which not only provides a dramatic improvement in light output, but also increases viewing angle in both the horizontal and vertical directions.

Red Toler, Terry Stephens, Raymond Gobush—a team award for innovative design of an automated system for packaging and delivering plastic cabinets from the end of the finishing line directly into trucks while producing real-time production and shipping inventories using a laser/bar code scanning system.

Darrel Billings—for his proposal and successful development of a chassis load/unload shuttle mechanism for ATE systems. The shuttle mechanism significantly increases ATE throughput, allowing a reduction in the number of ATE systems per production line.

Billings

William Testin and **John Teskey**—a team award for outstanding effort in implementing FS 1.5, despite an extremely short development cycle. As a result, the benefits and cost advantages of the unified remote were realized a year earlier than expected.

Testin (left) and Teskey.

Jack Chaney, Tom Yost, Dave Brown, Russ Fling, and **Bob O'Brien**—a team award for exceptional motivation and dedication in the development of the integrated circuit characterization system.

Mountaintop technical excellence award

The Mountaintop Technical Excellence Award is designed to recognize and reward members of the technical community who have consistently exhibited qualities of initiative, leadership, technical competence, attitude and follow-up. The Technical Excellence Committee announced that the recipients of the award for January, 1983, are **Gloria Vodzak** and **Joe Melluzzo.** The recipients of the February, 1983, award are **Wayne Ordille** and **Ernie Scaran.**

Vodzak

Melluzzo

Ordille

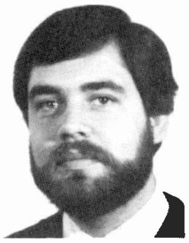
Scaran

Left to right: Chaney, Yost, Brown, Fling, and O'Brien.

Eleven at Consumer Electronics get third-quarter TEC awards

Sampson

Speer



Wilson

Hermeling

Third-quarter TEC awards were recently given to the following eleven people at Consumer Electronics.

Todd Sampson—for the design and implementation of a low-cost pattern generator for testing digital ICs and microprocessors.

Walter Speer—for the development of a novel rotary detent tuning mechanism that can be side mounted to the TV cabinet, allowing smaller overall cabinet size.

Danny Wilson—for exceptional effort in the successful completion of an improved program to automate a group of four, 250-ton injection-molding presses.

Gil Hermeling—for the development and calibration of the 2-meter TEM cell and his state-of-the-art contribution to the measurement of electromagnetic interference in TV products via its use.

Mark Harger, John Teskey, Charles Brombaugh, Harold Blatter, Joseph Amaral, and **Gregory Tamer**—a team award for the development of a higher-performance, cost-reduced infrared remote control system.

Harger, Blatter, Teskey, Amaral, Brombaugh, and Tamer.

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