ACTS Technology

Communication satellites provide a unique perspective with which to view the earth's surface. At the geostationary altitude of 22,240 miles above the equator, they appear motionless in the sky. Serving as giant relay towers, they interconnect users in vast areas of the world who are within their continental field of view.

Due to interference considerations, communication satellites must maintain a certain separation. Therefore, only a limited number of satellites can be placed in geostationary orbit to provide communications for a region such as the United States. In addition, only certain radio frequency bands, assigned by international agreement, are available for commercial communication satellite use. The extraordinary success of satellite communication in the late '70s and early '80s threatened to exhaust both the available frequencies and the geostationary satellite positions for many regions in the world. New technology was needed to provide for this projected increase in demand. In addition to finding ways to use the existing frequency bands more efficiently, operations in the next higher frequency band (the Ka-band) were deemed necessary.

NASA's ACTS program provided new technology for increased efficiency using all radio frequencies including Ka-band. Increasing the spectrum efficiency was achieved by developing high-gain, multiple spot beam antennas and onboard switching and processing that allowed for a great increase in the number of times the same frequency could be reused by a single satellite [24]. In addition, the high-gain spot beams provided the very desirable benefit of allowing for smaller aperture user terminals at higher data rates. NASA and the U.S. commercial satellite industry jointly defined the ACTS program. ACTS was not intended to be an operational system. It was designed to be a test bed for verifying those advanced technologies that were beyond the ability of any one satellite company to finance. In the early 1980s, the U.S. satellite carriers had great concerns about the reliability of ACTS' advanced, high-risk technology. Companies felt that a flight test was necessary to prove the technology was feasible before they would incorporate it into their commercial systems. The ACTS program was designed to allow U.S. industry the opportunity to meet the communication needs of the twenty-first century while remaining competitive in the international satellite communication marketplace. The motivation for the program and its merits are discussed in Chapters 1, 7, 8, and 9. This chapter describes the technological advances made by the ACTS program.

ACTS System Overview

ACTS is an in-orbit, advanced communication satellite test bed, bringing together industry, government, and academia in a wide range of technology, propagation, and user application investigations. NASA's Lewis Research Center (LeRC) awarded the ACTS contract in August of 1984 to an industry team consisting of:

- Lockheed Martin (then RCA), East Windsor, New Jersey – for system integration and the spacecraft bus
- TRW, Redondo Beach, California – for the spacecraft communication pay-load
- COMSAT Laboratories, Clarksburg, Maryland – for the network control and master ground facility
- Motorola, Chandler, Arizona – for the baseband processor
- EMS Technologies (formerly called Electromagnetic Sciences), Norcross,
- Georgia – for the spot beam forming networks

The contract was actually awarded to RCA Astroelectronics of East Windsor, New Jersey (which was subsequently acquired by General Electric (GE), then by Martin Marietta, and is currently part of Lockheed Martin). In 1988, as a result of a congressionally mandated program funding cap, Lockheed Martin (General Electric Astro Space at that time) assumed responsibility for completing the development of the communication payload. Subsequently, Lockheed Martin subcontracted with Composite Optics, Inc., in San Diego, California, for the manufacture of the antenna reflectors and part of the bus structure.

ACTS was launched into orbit by the space shuttle Discovery (STS-51) on September 12, 1993, and achieved geostationary orbit at 100 degrees west longitude on September 28, 1993. As of the printing of this book, ACTS is still operating, but the in-orbit stationkeeping fuel has been depleted. Operations continue with an inclined orbit, using an autonomous, onboard program that provides a bias in the roll axis to offset the inclination and maintain the spot beams properly located on the ground.

The ACTS system is made up of a spacecraft and ground segment [25-28]. The spacecraft consists of a multi-beam communication payload and the spacecraft bus. The key technological components of the communication pay-load are the multi-beam antenna (MBA) assembly, the base band processor (BBP), the microwave switch matrix (MSM), and Ka-band components. The spacecraft bus houses the communication payload and provides attitude control, electric power, thermal control, command reception, telemetry transmissions, and propulsion for stationkeeping.

A NASA ground station (NGS) and master control station (MCS), collocated at the Lewis Research Center (LeRC) in Cleveland, Ohio, transmit commands to the satellite, receive all spacecraft telemetry, perform ranging operations, and provide network control for all user communication. The NGS/MCS process and set up all traffic requests and assign traffic channels on a demand basis. A satellite operations center was located at Lockheed Martin Astro Space in East Windsor, New Jersey, and connected to the NGS/MCS via landlines.

In June of 1998, the Satellite Operations Center was transferred to the Lockheed Martin Communications and Power Center facility in Newtown, Pennsylvania. The Satellite Operations Center has the prime responsibility for generating spacecraft bus commands and for analyzing, processing, and displaying bus system telemetry data. Orbital maneuver planning and execution are also handled by the Satellite Operations Center. The Lockheed Martin C-band command, ranging, and telemetry station at Carpentersville, New Jersey, provided transfer orbit support during launch and originally served as an operations backup to the Satellite Operations Center. In 1998, however, the backup function was transferred to the GE American Communications station in Woodbine, Maryland.

The ACTS communication payload provides service at digital data rates from kilobits per second (Kbps) up to hundreds of megabits per second (Mbps) via its various communication modes of operation. The major types of services include:

- On-demand, integrated voice, video and data services using T1 (1.544 Mbps) links to 4-foot customer-premises terminals
- Very high-data-rate (622 Mbps) networks
- Broadband (T1) video and data for aircraft and ships
- Aeronautical voice and low rate data
- Low-rate terrestrial mobile voice, video, and data
- Interactive, multimedia services (1 Mbps outbound and 20 Mbps inbound) using 18-inch terminals.

Terminals operated by various private, governmental, and university organizations validated these services. In addition, more than ten receive-only propagation terminals were used for propagation studies and modeling. ACTS is a three-axis-stabilized spacecraft that weighed 3,250 pounds at the beginning of its in-orbit life. It measures 47.1 feet from tip to tip along the solar arrays, and 29.9 feet across the main receiving and transmitting antenna reflectors. The ACTS multi-beam antenna is comprised of separate Ka-band receive and transmit antennas, each with horizontal and vertical polarization subreflectors. Antenna feed horns produce narrow spot beams with a nominal 120-mile coverage diameter on the surface of the Earth. Fast (less than 1 microsecond [....sec]), beam-forming switch networks consisting of ferrite switches, power dividers and combiners, and conical multi-flare feed horns provide sequential hopping from one spot beam location to another. These hopping spot beams interconnect multiple users on a dynamic, traffic-demand basis. A separate 3.3-foot, mechanically-steered antenna, receiving uplink and radiating downlink signals, is used to extend the ACTS communication coverage to any location within the hemispherical field of view from ACTS' 100 degree west longitude position. Beacon signals at 20.2 GHz and 27.5 GHz are radiated from two small, separate antennas.

Communication Modes of Operation

The multi-beam antenna provides dynamic coverage with fixed and hopping spot beams. Each hopping spot beam can be programmed to sequentially cover a set of spots and dwell long enough to communicate with users in each spot. By assigning each user an access time, several users can transmit and receive at the same frequency on a time-shared basis. This time division, multiple access (TDMA) technique requires a switching system onboard the space-craft to interconnect the beams and route messages. The ACTS communication payload provides two types of onboard switching to interconnect the multiple spot beams and route signals to their appropriate destinations: 1) base band processing (BBP) and 2) microwave switch matrix (MSM).

The BBP is a high-speed digital processor on the satellite that provides on-demand, circuit switching for the efficient routing of traffic among small user terminals. In essence, the BBP is the first switchboard in the sky to perform the same functions done by terrestrial telecommunication switch centers. Because its network is completely interoperable with the terrestrial system, ACTS can be considered a single node in a combined satellite/terrestrial network. ACTS conducts both time and space switching on board the satellite. The BBP switches traffic between the various uplink and downlink beams, automatically accommodating on-demand circuit requests. In the BBP mode of operation, four simultaneous and independent hopping beams (two uplink and two downlink) provide flexible, demand access communication between small (4-foot diameter antenna) user terminals with a maximum throughput of 1.79 Mbps or 28 64-Kbps circuits. Each uplink spot beam receives multiple channels. A user terminal is assigned an uplink channel and transmits its information using Time Division Multiple Access (TDMA). At the spacecraft, the receive signals are demodulated, decoded as required, temporally stored in memory, routed on a 64-kilobit individual circuit basis, modulated, encoded if required, and transmitted in the proper downlink spot beam using a single TDMA channel. During the 1 millisecond TDMA frame time, the beams hop to many locations, dwelling long enough to pick up or deliver the required traffic.

The MSM is an intermediate frequency (IF) switch capable of routing high volume point-to-point traffic and point-to-multipoint traffic over 900 MHz bandwidth channels. Using satellite-switched TDMA, the microwave switch matrix dynamically interconnects three uplink and three downlink beams. The user terminals transmit TDMA bursts according to their destination. At the satellite, the 30 GHz bursts are down-converted to an intermediate frequency, routed to the proper downlink beam port, up-converted to 20 GHz, and transmitted on the downlink. The switch paths are changed during guard intervals between bursts. Fixing the beam interconnections in a static mode allows additional flexibility for a variety of continuous digital or analog communication. The MSM mode accommodates user terminals operating from low kilobits per second up to 622 megabits per second.

The ACTS system can be configured in the BBP mode, the MSM mode, or a mixed mode. In the mixed mode, both the base band processor and the microwave switch matrix are operated simultaneously with some restrictions. The system can be quickly reconfigured from one mode of operation to another in a matter of minutes, further adding to the system's flexibility. This flexibility, along with the large total information throughput capacity, allows a large variety of users to be accommodated concurrently.