NASA Facts

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Switchboard in the Sky

The Advanced Communications Technology Satellite (ACTS)

On September 12, 1993, a new and soon-to-be award-winning on-ramp to the information superhighway was opened to heavy traffic: NASA launched one of the most revolutionary break-throughs in space communications history, the Advanced Communications Technology Satellite (ACTS).

ACTS is the first high-speed, all-digital communications satellite. It is the first to have sophisticated telephone-system-type switching onboard. It can carry data at standard fiber-optic data rates with the same transmission quality, added performance, and cost savings that a land-based network provides. It operates in the uncrowded Ka-band (18 to 30 gigahertz) portion of the radio spectrum. ACTS technology integrates well with ground telephone network systems, allowing for high-speed transmission over great distances to even the remotest locations.

For more than 6 years, ACTS was the testbed where Glenn researchers demonstrated the abilities and reliability of the system they designed and where U.S. companies and institutions tested their own uses of the NASA technologies.

The early intention was to solve another expected problem: crowding of the geosynchronous orbit where communications satellites fly. Satellites in geosynchronous orbit fly 22,300 miles above the equator at a speed that matches the rotation of the Earth. Satellites of the same frequency must be positioned, by international agreement, at least 4° apart to avoid interference between signals.

Commercial companies need greater communications capacity to support their many services, such as high-speed and high-security financial transactions for banks and wireless mobile networks for consumers. Countries the world over are clamoring for their own satellites, particularly those countries without the infrastructure for a reliable ground communications network.

Artist's concept of ACTS.

As early as the 1970's, Glenn researchers and their industry collaborators were aware that the demand for geosynchronous orbital slots would all too soon exceed capacity. They designed the technology, then launched ACTS to demonstrate that their new technology could meet the growing communications needs of a demanding public. Well before the end of the formal demonstration project in May 2000, the answer was a resounding yes.

SPACECRAFT DESCRIPTION

ACTS, which was built and operated by Lockheed Martin Corporation, was launched on September 12, 1993, as the primary payload of the Space Shuttle Discovery on its STS–51 mission. After separation from the Shuttle, a transfer orbit rocket propelled it into a geo-transfer orbit. After 7 days, ACTS moved into its geosynchronous operations orbit and stabilized into a nonspinning configuration. ACTS remained in this orbit at 100° west longitude throughout the life of its demonstration project. With its solar arrays and main communications antennas deployed, ACTS measures 47.1 feet from tip to tip of its solar arrays and 29.9 feet across from its main receiving and transmitting antenna. At the beginning of its on-orbit life, it weighed 3250 pounds.

ACTS has operated flawlessly, experiencing expected downtimes only during the spring and fall equinoxes when the spacecraft's solar panels are eclipsed. Experimental studies began 12 weeks after launch and continued through May 2000 when Glenn's experiments program came to an end.

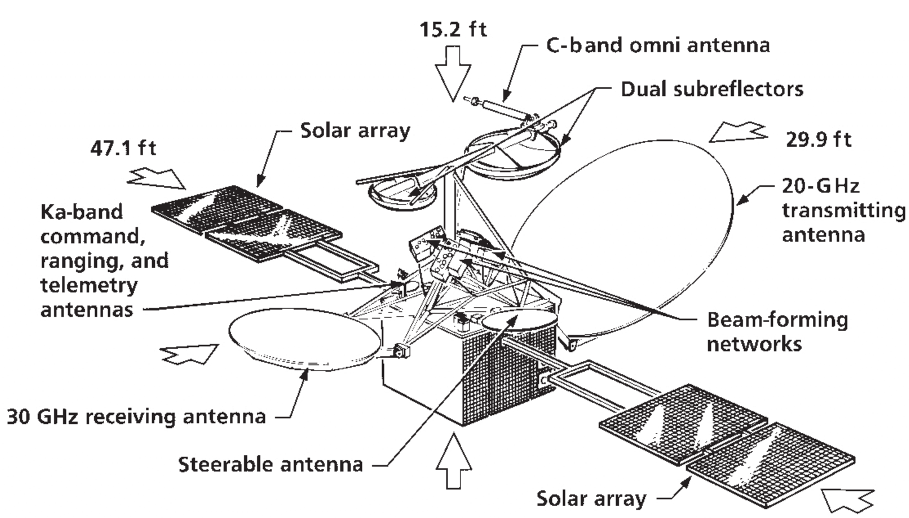
TECHNOLOGIES

The ACTS communications payload includes several technologies through which a full range of voice, video, and data communications services can be provided on-demand:

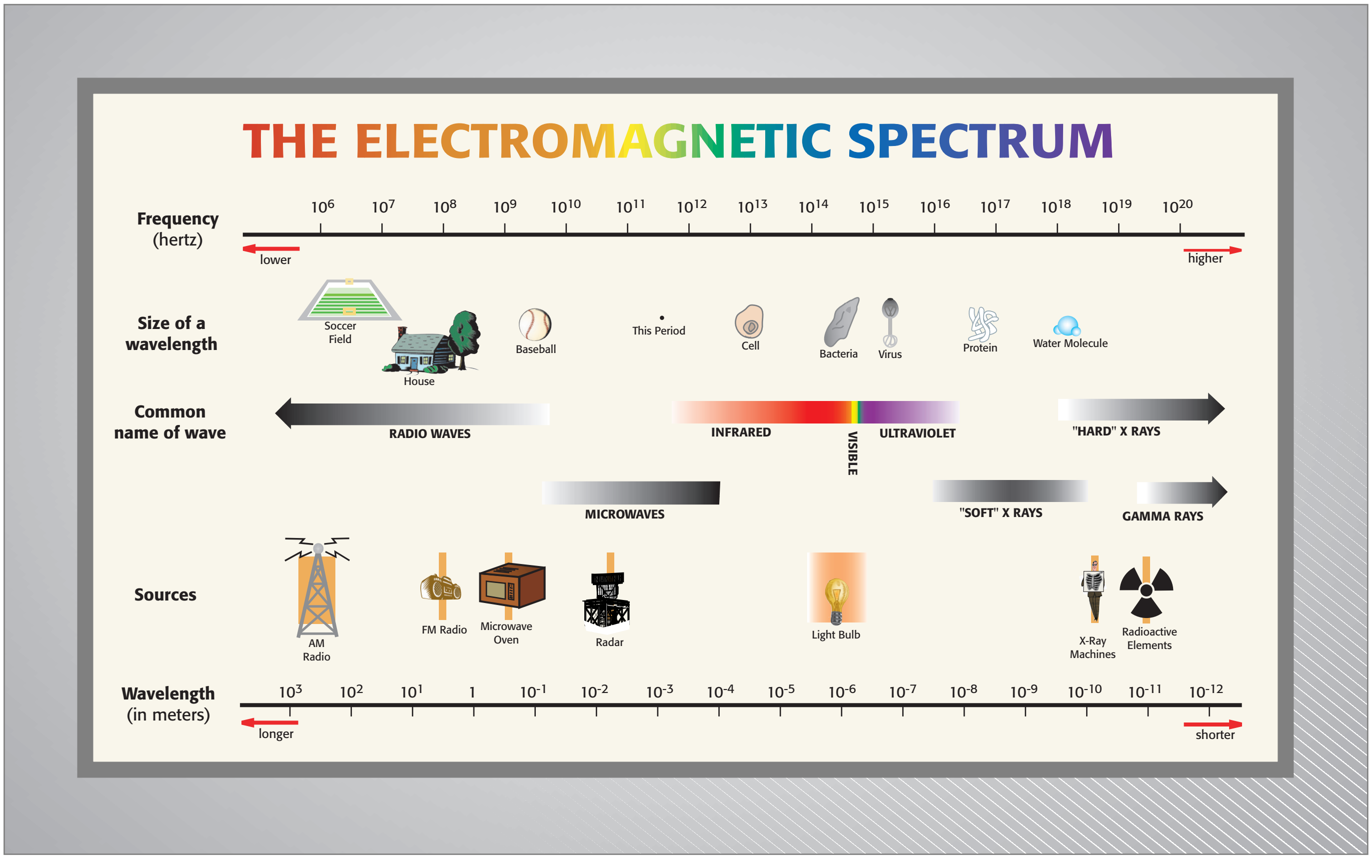
- Operation in the Ka-band radio spectrum where the 2.5 gigahertz of available spectrum is five times that available in lower frequency bands.
- Multiple, high-gain hopping-beam antennas that permit the use of smaller diameter Earth station antennas.
- Onboard baseband switching, which, like a telephony switching station, directly connects sending and receiving Earth stations. A further innovation in satellite communications is that ACTS makes the user-to-user connection in a single satellite hop.
- A microwave switch matrix that enables high-speed (billions of bits per second) and high-volume communications and data transfer.

Ka-Band Transmissions

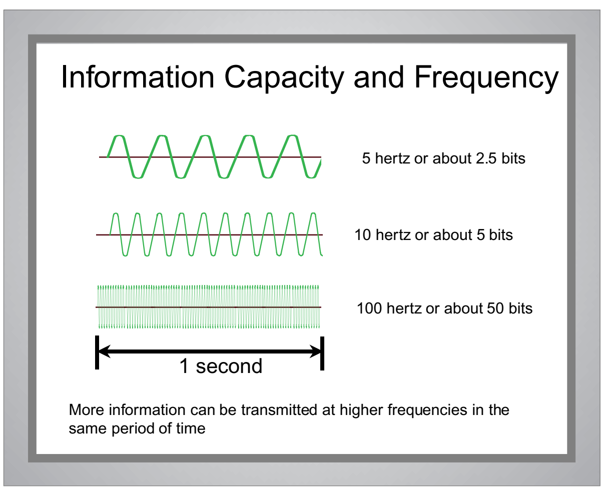
One way to increase the amount of information or data per unit of time transmitted by a satellite is to use a higher radiofrequency. Until ACTS, the higher frequency Ka-band was virtually unused—most communication satellites operate in the lower frequency C- and Ku-bands. The Ka-band has a greater bandwidth (in other words, it has a higher capacity for data transfer) and allows smaller spacecraft and ground stations. Ka-band frequency is capable of carrying simultaneously a multiple mix of



Major ACTS spacecraft components.



voice, high-speed data, and teleconferencing transmissions. The ACTS three transponders can process over a billion bits of data per second.

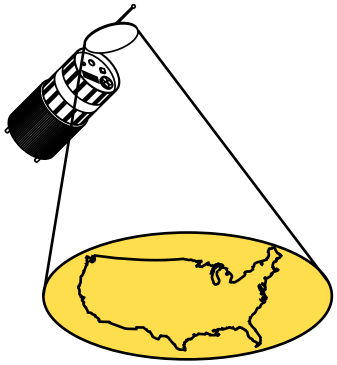


High frequency means short wavelengths, though. And the millimeter wavelength Ka-band signals are easily degraded by rain, a problem known as rain fade. Using detailed studies from 75 years of weather patterns, rain amounts, and their effects on lower frequency radio signals, Glenn scientists designed ACTS with higher signal strength, digital error correction codes, and the ability to slow the transmission rate to compensate for rain fade. The ACTS digital access approach to sharing the radio spectrum, known as time division multiple access or TDMA, is similar to that used in many cellular phones. In TDMA, each user is allocated a very large portion of the available bandwidth for a very short period of time.

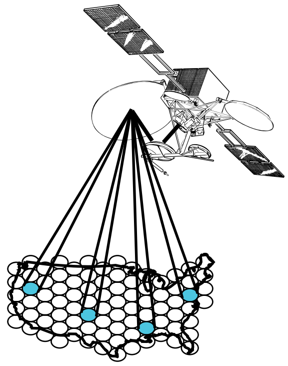
Multiple Hopping Beam Antennas

Until ACTS, communications satellites broadcast a single beam or “footprint” over a large part of the Earth. This is highly efficient for large-scale, one-way communication such as television broadcasts but not for on-demand two-way communications.

To accommodate real-time two-way communications for multiple users, ACTS uses 5 tightly focused spot beams directed to 51 sites. Each beam has a diameter on the Earth of 150 to 200 miles, and each can be “hopped” from one site to another in less than 1 microsecond. The small spot beams allow the same frequency to be used over and over because the spatial isolation between spots prevents interference between beams.



Conventional satellite single-beam broadcast.



ACTS spot beam and switching.

The tighter, more concentrated beams also permit smaller and less expensive Earth stations. They penetrate rain better and mitigate rain fade. ACTS, with its multiple hopping beams and other technologies, uses less power, provides three times the communications capacity, and can transmit data 20 times faster than conventional satellites of similar mass.

Onboard Digital Processing and Switching

In order to sort and route data transfer at high volumes and speeds, ACTS is equipped with a baseband processor and a microwave switch matrix. The baseband processor interconnects hopping spot beams. It receives data from one spot beam, stores the data as necessary, and forwards the message to the proper spot beam and address—all of this in microseconds.

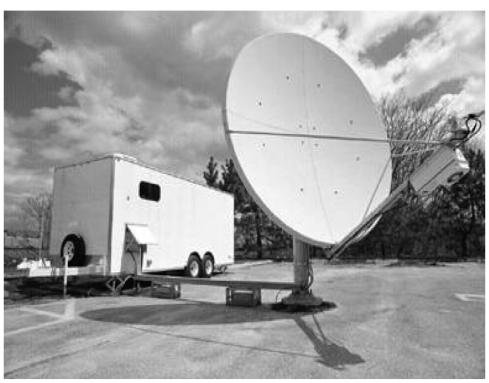
The microwave switch matrix interconnects fixed beams using three transponders, each with an available bandwidth of 900 megahertz (the total bandwidth of conventional C- and Ku-band satellites is 250 and 500 megahertz). The switch is capable of high-speed, high-volume transmission to terminals, operating at 622 million bits per second, and supported applications, such as linking to supercomputers via fiber-optic-satellite networks. The switch also proved well suited to transmitting data to and from mobile terminals with small, 14-inch antennas.

GROUND SEGMENT

Master Ground Station and Satellite Operations Center

The ground control segment includes the master ground station at Glenn, the satellite operations center in Newtown, Pennsylvania, and experimenters terminals at industry, university, and government locations across the United States.

The master ground station controls the spacecraft and the network, manages experiments, and records spacecraft and system data.



High data rate terminal

Very small aperture terminal

Ultrasmall aperture terminal

Experimenters terminals.

Traffic requests are processed and set up, and traffic channels are assigned on-demand. Command, ranging, and telemetry information is sent to and from ACTS via the master ground station.

The satellite operations center monitors spacecraft health and status. The center also handles orbital maneuvering and housekeeping functions. It is linked by terrestrial line to the master ground station at Glenn.

Experimenter Terminals

NASA Glenn researchers developed three special ground stations, or terminals, for certain types of user applications or experiments. In addition, some ACTS experimenters designed terminals suited to their particular needs. In all, 53 terminals were built and used by more than 100 experimenters to test ACTS abilities.

The high-data-rate terminals, equipped with an 11-foot antenna, handled high-volume, high-speed traffic to and from the ACTS transponders. The terminals connected seamlessly to terrestrial fiber-optic systems and supercomputers at rates up to 622 million bits per second. They could transport high-definition video at up to 520 million bits per second.

Very small aperture terminals were developed to work with the on-demand traffic to and from the baseband processor. Using a 4-foot antenna, these terminals can provide single hop data rates up to 1.8 million bits per second for voice, video, and data.

Ultrasmall aperture terminals are about the same size as today's 18-inch direct broadcast television terminals, but they can uplink data (send data to ACTS) as fast as 1.5 million bits per second and downlink (receive from ACTS) as fast as 45 million bits per second. The terminals are ideal for high-speed Internet service, electronic banking, and real-time videoconferencing.

Other experimenters designed mobile terminals small enough to be placed on ships, airplanes, and land vehicles. Still others used receive-only terminals for studying rain fade.

EXPERIMENTS PROGRAM

Since its launch, ACTS has successfully validated NASA's vision of future satellite communications and has demonstrated the ability of its technology to meet the needs of users applications. Experiments have been conducted in such diverse areas as computer networking, medicine, industry, education, defense, business, emergency response, mobile communications, and astronomy.

Telemedicine

ACTS helped physicians provide high-quality, low-cost health care to patients in remote areas. From their offices at the Mayo Clinic in Rochester, Minnesota, physicians diagnosed and evaluated patients at the Pine Ridge Indian Reservation in South Dakota. ACTS real-time voice, video, and data transfer allowed the physicians to see and speak to patients as well as receive diagnostic information from stethoscopes, ultrasound sonograms, and electrocardiograms. In one case, a child who had suffered for years from a misdiagnosed skin condition was cured after Mayo physicians diagnosed the condition as leprosy and prescribed appropriate treatment.

Early detection and diagnosis of breast cancer is another medical area benefited by ACTS. NASA Glenn, the Cleveland Clinic Foundation, and the University of Virginia conducted a clinical study in which mammograms were given to women in rural regions where there are few or no breast cancer specialists. In the first part of the study, mammogram images that were digitally compressed and transmitted were judged to be equal in quality and resolution to standard x-ray mammogram films. In the second phase, patients' mammograms were transmitted in real time to specialists for interpretation. Images taken in a local hospital can

Experimenter viewing digitally compressed images.

be interpreted elsewhere and reported back to the local physician immediately at very little additional cost.

Industry

The demand for new sources of fuel has caused offshore oil exploration to move into deeper ocean waters and to remote regions of the Earth, sending costs soaring. ACTS has played a vital role in helping U.S. oil companies demonstrate how high-speed satellite communications could make them more cost competitive. In effect, ACTS helped the petroleum industry remove time and distance obstacles from its operations.

Oil and gas companies use seismic information to chart the subsurface structure of the Earth. Done from sea vessels, the resulting data, sometimes amounting to billions of bytes, are recorded on magnetic tape and sent to analysts at distant facilities. Often, by the time the analysts realize that more data are needed, the collection ships have traveled miles from the site and must be sent back. The process of accurately charting an area can take months.

First ever shipboard trial was aboard the Geco Diamond exploration vessel.

ACTS transmitted these seismic data from offshore oil-drilling platforms to analysts in Washington, DC, in real time. Transferring data via ACTS not only saved months in research time at a savings of $200,000 per month, but also provided higher quality seismic data by giving scientists access to the data in enough time to redirect vessels to more promising areas of the ocean.

Education

The ACTS small terminals and higher data rates improved distance education experiences because the nearly instantaneous transmissions made for a more natural interaction among the participants. Georgetown University used ACTS to provide business education training to companies at universities in Bogota, Colombia, and Quito, Ecuador. By obtaining business knowledge via ACTS, local employees in these countries are better prepared to conduct business with U.S. companies. Also, the university was able to expand its educational services into international markets.

Participants in the electronic field trip to the Amazon rainforest.

ACTS took U.S. elementary and high school students on a virtual tour to the far reaches of the Amazon rainforest and to Antarctica for Passport to Knowledge electronic field trip programs. Through high-quality live audio and video links, students in their own classrooms helped perform science experiments and interacted with researchers at those exotic sites. Another electronic field trip, this one to NASA's Kuiper Airborne Observatory (a 1-meter infrared telescope flown above the clouds in a modified C–140 aircraft), is believed to be the first Internet transmission to and from a flying aircraft.

Defense

ACTS helped the U.S. Armed Forces gain experience with satellite-supported communications. ACTS was put to one of its toughest tests during the deployment of U.S. Armed Forces in Haiti. During the first month of the operation,

U.S. Armed Forces supported with satellite communications.

ACTS videoconferencing technology was the primary command and control system. ACTS provided the secure audio-video link allowing field commanders to talk to commanders in the United States including the Army Chief of Staff and even to then President Clinton. ACTS also functioned in the secondary role of connecting soldiers in Haiti to their families in the United States through live video contact between them.

The U.S. Navy used ACTS to improve communications with ships at sea. A link was established between the USS Princeton and the San Diego Naval Base using a tracking mobile antenna developed by the Jet Propulsion Laboratory, Pasadena, California. Unexpectedly, this capability was needed for a telemedicine application when the captain of a Greek merchant ship became ill and was taken aboard the Princeton. He was remotely diagnosed while still at sea and stabilized until he could be brought ashore for lifesaving surgery.

Other Applications

Some of the other significant demonstrations of ACTS technologies include

- Huntington Bank connected branch offices to the central computers to observe service performance during emergency communications restoration via satellite.
- The National Communications System demonstrated a Public Switch Network Restoral system using easily transportable and mobile terminals to restore phone service interrupted by a natural disaster.
- Cray supercomputers at the National Center for Atmospheric Research in Colorado and the Ohio Supercomputer Center in Ohio were connected for experiments that combined meteorological and marine forecasting.
- The Keck telescope at the Mauna Kea observatory on Hawaii, was linked to a CalTech data processing facility for experiments in remote facility control and data analysis.
- Supercomputers at Boeing and Glenn were connected to carry out computer-simulated wind tunnel tests.
- Eighteen organizations from U.S. computing and satellite industries, academia, and government agencies participated in an effort to overcome technical issues in networking high-speed satellite links with the terrestrial network over the Internet. Data from this effort has already been incorporated into improving commercial products and expanding the reaches of the Internet.

INTO TOMORROW

ACTS technology has shown the world new ways to use orbital space and radio spectrum resources. It offers alternatives in voice, data, and video communications networking to places where there is little or no ground infrastructure. It enables two-way, satellite communication at cable-modem speeds using antennas even smaller than today’s 18-inch dish.

With its overwhelming success, the ACTS project has set the stage for the continuing evolution of the information era into space by proving the reliability and fidelity of Ka-band transmissions. The Deep Space 1 technology demonstrator, a robot probe whose solar system tour included a rendezvous with a comet, used Ka-band to communicate data to and receive instructions from Earth. Since then, NASA has upgraded its tracking and data relay system for space communications to use Ka-band technologies.

So significant and valuable have been the ACTS contributions to the commercialization of space communications, that the ACTS project was inducted into the Space Technology Hall of

Space Technology Hall of Fame medal.

Fame in April 1997. Research and Development Magazine selected ACTS as one of the 100 most significant technologies of 1995 with its R&D 100 Award. In 2002, the Society of Satellite Professionals International recognized NASA for proving the viability of a number of first time satellite technologies using ACTS.

The ACTS satellite itself, though no longer used by NASA, is now an educational tool and testbed run by the Ohio Consortium for Advanced Communications Technology. Consortium members already have found many uses for it. Engineering schools use it to give students experience in satellite communications and spacecraft operations and control with an actual satellite. College education departments propose to evaluate distance teaching techniques using ACTS. Commercial consortium members will use ACTS to test, refine, and demonstrate new Ka-band equipment.

Given all these accomplishments and the promise, one wonders why we aren't using these new capabilities for our banking transactions or Internet downloads. Even as Glenn scientists were launching ACTS, improvements in terrestrial technologies, such as fiber-optic cables and cell phones, were introduced. The higher capacity of fiber and the cost competitiveness of cell phones made the ACTS new Ka-band technology less attractive to commercial developers. What is more, the many options consumers have in business, entertainment, and personal communications make it very hard to predict how or when these NASA technologies will be needed and find their way into our lives.

But when the need is truly there, we will have the technology to meet that need. ACTS has already been a benefit to us all.

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