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Earth Station Technology

The Smarts Behind the Dish

by Robert A. Nelson

The earth station is the link between the terrestrial data sources and the remote satellite resource. Its most familiar component is the earth station antenna, which can be tens of meters in diameter or a small portable dish. In addition, there are numerous, less obvious devices in the chain of devices that transmit or receive the signal. This article will briefly summarize some of the most important aspects of earth station operation.

TRANSMITTER CHAIN

Information to be transmitted is delivered to the earth station via coaxial cable, fiber, terrestrial microwave, or satellite. The devices in the transmitter chain typically consist of the multiplexer, the modulator, the upconvertor, a high power amplifier, and the antenna. The multiplexer combines the individual channels onto a single data stream. The information can be encrypted and encoded with a forward error correction code. The modulator modulates the baseband signal containing the desired information onto an intermediate frequency (IF) carrier, usually at 70 MHz. The upconverter changes the carrier to the radio frequency (RF) signals used to transmit the signal, such as C-band (6 GHz) or Ku-band (14 GHz). The high power amplifier (HPA) amplifies the modulated RF signals from the output of the upconvertors to the required power at the input terminals of the antenna. Finally, the antenna transmits the amplified RF signal to the satellite.

A common form of modulation used in digital satellite communication is M-ary phase shift keying. In this technique, the carrier can assume one of *M* phase states, each of which represents a symbol. In binary phase shift keying (BPSK), there are two phase states, 0° and 180°, representing a binary one or zero. In quaternary phase shift keying (QPSK), there are four phase states that represent the four symbols 11, 01, 00, and 10. A QPSK modulator is equivalent to two BPSK modulators out of phase by 90°. It can be shown that both BPSK and QPSK modulation require the same power per bit for the same bit error rate (BER), but QPSK modulation requires only half the bandwidth. Moreover, all other forms of digital modulation require more power. Thus QPSK is by far the most prevalent form of modulation used in satellite communication and is the industry standard.

Analog frequency modulation (FM) is still commonly used for the transmission of television signals. This has been a convenient mode due to the widespread use of standard equipment. However, there is a slow but deliberate transition to digital technology for television.

The HPA can be either a klystron, a traveling wave tube (TWT), or a solid state power amplifier (SSPA). The bandwidth of a klystron is fairly narrow and is the same as the bandwidth of a transponder, or about 40 MHz at 6 GHz and 80 MHz at 14 GHz. A C-band klystron can have a typical power of 3.3 kW. Although it has a narrow bandwidth, a klystron has relatively high efficiency (about 40 percent) and is generally economical to operate.

A TWT is a broadband device with a bandwidth of about 500 MHz, or about the full bandwidth of a 24 transponder satellite comprising 12 transponders at each polarization. The TWT is more flexible, since it can put the same carrier into all 12 transponders. However, since it is a nonlinear device, it must be backed off to operate in the linear region when multiple carriers are present. A 350 watt Ku-band TWT with 6 dB of backoff has an output power of about 90 watts. The loss can be partially reduced using equalizing devices called linearizers. Helix TWTAs are available at Ku-band with a power of 700 W and at C-band with a power of about 3 kW. Still higher power, at around 10 kW, can be attained with coupled-cavity TWTs.

An SSPA is very efficient and thus does not produce much heat. A typical SSPA power is 2 or 3 watts, but can be as high as 80 or 100 watts.

At Ku-band the HPA must be located near the antenna to minimize losses, but at C-band it can be farther away, such as in the control building, since the loss per unit length of the waveguide diminishes with frequency. For a typical elliptical waveguide, the loss per 30 meters (100 feet) is about 5 dB at Ku-band, compared to about 1 dB at C-band.

RECEIVER CHAIN

The devices in the receiver chain reverse this process. The antenna receives the modulated RF signals from the satellite. The power level at the output terminals of the antenna is about a picowatt. This extremely low power level is comparable to the sound level from a barely audible mosquito. A low noise amplifier (LNA) amplifies the received RF signals. The downconverter changes the received RF signals to IF signals for the demodulators. The information is extracted from the received IF signal by the demodulator and is decoded and decrypted. The demultiplex equipment then distributes the baseband information to the customers through the router and switch after a check of key parameters and rebalancing. Data rates are usually in some standard format, such as a 1.544 Mbps T1 channel or a 45 Mbps DS3 channel, consisting of 28 T1's.

The LNA is mounted on the antenna itself to minimize waveguide loss. This is the first active component and its performance is the primary factor in determining the capability of the receiver. The LNA must have a high gain but contribute very little noise. During the 1980s it was difficult to produce a Ku-band LNA with a noise temperature of 160 K. Today, using field effect transistors, it is possible to reduce this value to around 75 K. Because of the manner in which the noise temperatures combine in a series of devices to produce the overall system temperature, it is essential to place the LNA, with a high gain and low noise temperature, at the head of the receiver chain.

Instead of an LNA, a low noise block downconverter (LNB) may be used. An LNA only amplifies the signal, while an LNB both amplifies the signal and downconverts the frequency to L-band, again to minimize losses. Systems at C-band use both LNA and LNB designs, but Ku-band systems employ LNBs almost exclusively.

ANTENNA

Since electromagnetic energy propagates in the form of waves, the spreading of the energy as it leaves the antenna is described by the theory of diffraction. The larger the antenna reflector is in comparison with the wavelength, the less spreading there is. The physics of radio waves is identical to the physics of visible light and thus the spreading of radio frequency waves from an antenna reflector is analogous to the transmission of light through an aperture. In fact, a reflector antenna is often referred to as an aperture antenna.

Monochromatic light, such as from a laser, will produce a series of concentric Airy rings when passed through a small circular hole and projected on a screen. The central bright spot is like the main lobe of an antenna pattern. The surrounding dark and bright rings are analogous to the nulls and side lobes of the antenna pattern.

The antenna reflector is usually a paraboloid of revolution. The configuration of the antenna is called a direct feed if the feed horn or low noise amplifier (LNA) is located at the prime focus. Large antennas usually have a subreflector, of either the convex hyperbolic Cassegrain type or the concave ellipsoidal Gregorian type. The subreflector permits the LNA to look into cold space and away from the warm ground, so as to significantly reduce the antenna noise temperture. In an offset antenna, the feed is located to one side. The advantage of the offset design is that it eliminates blockage effects from subreflectors.

Many antennas have tracking capability that permit them to follow a satellite in a geosynchronous, but inclined, orbit. Inclined orbit operation is now a common part of the business plan of satellite operators to extend the useful life of a satellite. The tracking mechanism may be programmed with an ephemeris that determines the look angle as a function of time of day, or it may have an automatic servo loop with a memory that maximizes the received power.

The gain of the antenna is the measure of its ability to concentrate the radio frequency electromagnetic energy in a specified direction, in comparison to a hypothetical isotropic antenna that radiates its energy equally in all directions. It is determined by the size of the physical aperture, the frequency of the radiation, and the efficiency.

The gain is proportional to the square of the antenna diameter and to the square of the frequency. For example, an Andrew 4.6 meter earth station antenna with a Gregorian feed when operated at C-band has a transmit gain of 48.2 dB at 6.175 GHz and a receive gain of 44.4 dB at 4.0 GHz. The same antenna can be used at Ku-band with a transmit gain of 55.1 dB at 14.25 GHz and a receive gain of 53.8 dB at 11.95 GHz.

Factors that affect the efficiency include the geometrical shape of the aperture, the method of illumination (so-called taper), the amount of spillover of energy past the edge of the antenna, surface roughness, blockage, and phase coherence.

Another fundamental parameter is the half power beamwidth. This is the angle between the half power points of the main lobe of the antenna pattern. The half power beamwidth varies in inverse proportion to the frequency and the antenna diameter. For example, the Andrew 4.6 meter antenna at C-band has a transmit half power beamwidth of 0.63° and a receive half power beamwidth of 0.92°, while at Ku-band these values are 0.28° and 0.34°, respectively. On the other hand, a huge 64 m deep space tracking antenna at X-band (8.4 GHz) may have a half power beamwidth of only 0.04°.

Two key parameters are the equivalent isotropic radiated power (EIRP) and the antenna figure of merit. The EIRP is associated with a transmit antenna and is the product of the power P to the input terminals of the antenna and the antenna transmit gain G_t. The figure of merit is associated with a receive antenna. It is the ratio of the antenna receive gain G_r and the system temperature T, which is a measure of the noise power accepted by the antenna and must be as low as possible.

EARTH STATION STANDARDS

Earth stations are characterized by the antenna size, the type of service, the frequency band, the EIRP, and the G/T.

Transmit antennas must conform to international and domestic regulations. The sidelobes must fall within a specified envelope in order to mitigate interference with neighboring satellites and terrestrial systems. The standard international specification for the sidelobe gain of new antennas with diameter to wavelength ratio greater than 100 and operating with a geostationary satellite is given by $G = 29 - 25 \log \theta$ dB, where θ is the off-axis angle. The earth station antenna side lobe pattern is the primary characteristic that determines the minimum spacing between satellites along the geostationary arc.

In addition, the EIRP in a given bandwidth must be within specified values at various bands and the antenna must meet certain radiation hazard constraints. The document governing satellite communications in the United States is Part 25 of the Rules of the Federal Communications Commission (FCC).

Satellite operators also establish standards for their individual systems. For example, INTELSAT has established technical parameters that must be met for acceptance within a particular application.

EARTH STATION FACILITIES

A good example of a commercial earth station facility is the Washington International Teleport, located in Alexandria, Virginia just inside the Washington Capital Beltway. This facility is a hub for voice, data, video, internet, and other services to customers ranging from major television broadcasters to telemedicine and distance learning providers.

Another example is the Hughes Spring Creek earth station, located in southeast Brooklyn, which is the primary TT&C facility for the Hughes C-band and dual payload Galaxy satellites. It also provides backup for the Hughes Ku-band spacecraft. Spring Creek provides uplink access for C-band customers in the New York City area. One of the antennas is used by Hughes Network Systems for a shared VSAT (very small aperture terminal) hub, which supports customers who operate private data networks.

INDUSTRY TRENDS

The legacy of analog video is big transmitters using big antennas. The current trend is to shift the burden of closing the satellite link from the earth station to the satellite, thereby permitting smaller and smaller earth station antennas. Whereas satellites launched during the 1980s were simple repeater ``bent pipe'' satellites, with a typical primary power of 1 to 2 kW, today's generation satellites have extensive onboard processing and a total power of 10 to 15 kW or more.

In addition, there is an emphasis on broadband applications at high frequencies, including Ka-band (30/20 GHz) and the new V-band (50/40 GHz). As noted by Teledesic president Russell Daggatt at the *Satellite 98* Conference, the paradigm for broadband applications used to be video on demand. Today it is internet access via satellite.

There is also changing emphasis on types of services. In the past, satellites have almost entirely provided voice, video, and data connectivity for international and domestic common carriers and operators of television and data networks. Now there is an emphasis on consumer services to meet a global demand for information and a convergence of telephone, data, and video applications.

CONCLUSION

The technology of earth stations has been reviewed and a few illustrative systems have been described. In coming years the number of large earth station facilities that we are accustomed to seeing will continue to grow. However, in addition, there will be an exponential growth of small earth terminals for consumer services. Like a web, the major nodes will be filled in by a dense network of smaller nodes of varies types and sizes.

Dr. Robert A. Nelson, P.E., is president of Satellite Enginering Research Corporation, a satellite engineering consulting firm in Bethesda, MD.