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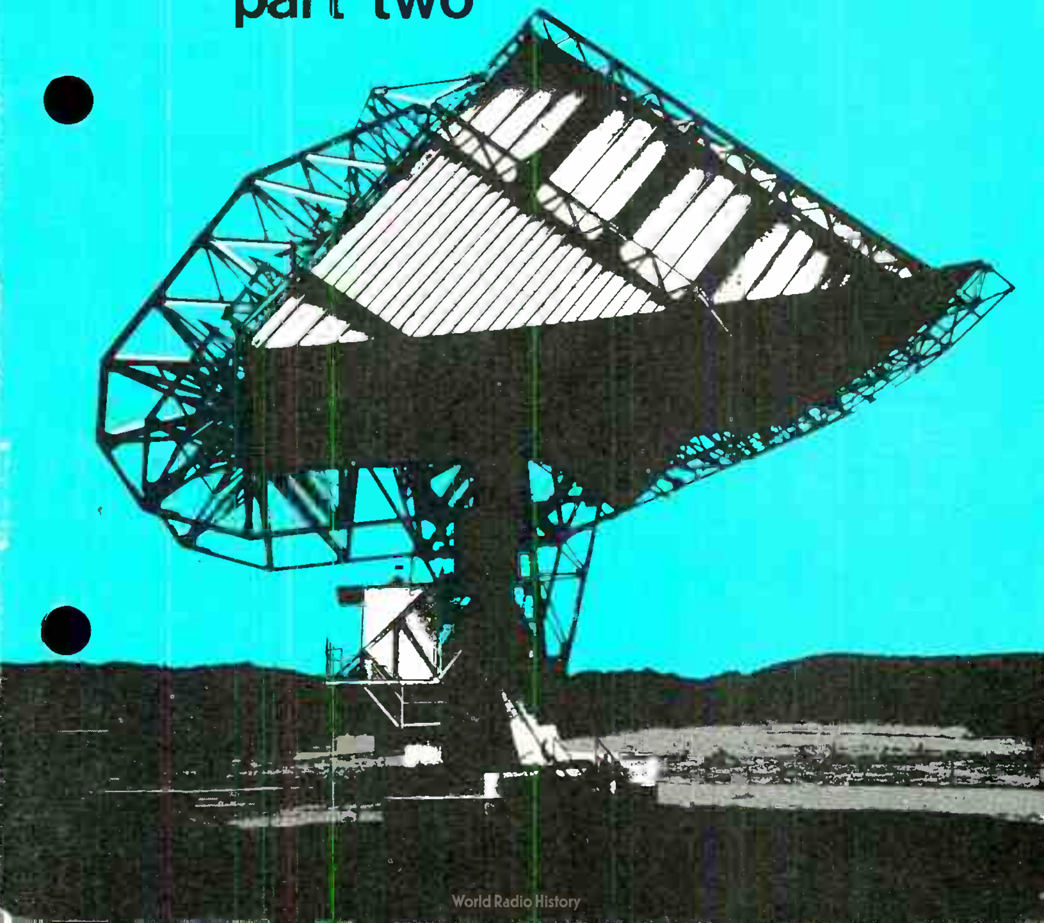
SATELLITE COMMUNICATIONS UPDATE
part two



Satellites are often referred to as the "Space Segment" of satellite communications systems. The January issue of the Demodulator summarized the history of communications satellites and briefly examined their future.

This issue of the Demodulator reviews the history of earth stations which are often referred to as the "Earth Segment" of satellite communications. After the earth station review, the article discusses the future of satellite communications as a whole, to conclude the "Satellite Communications Update".

The first earth stations for satellite communications were built in 1961-62. Stations were constructed at Andover, Maine; Goonhilly, United Kingdom and Pleumeur-Bodou, France – to participate in the Telstar and Relay experimental satellite programs.

These satellites were not geosynchronous. They had "low-altitude", highly elliptical orbits. These orbits were used because it was believed the long signal transit time, to and from a geosynchronous satellite, would be unacceptable for telephony.

Telstar 1, launched 10 July, 1962 had a perigee of 955 kilometers and an apogee of 6,328 kilometers. It circled the globe in 2 hours and 38 minutes. Telstar 2, launched 7 May, 1963 had an apogee of 10,508 kilometers and circled the globe in 3 hours and 45 minutes.

The apogees were positioned so that the line-of-sight, between the earth stations and satellites, was maintained as long as possible. Even so, these times were quite brief – often less than half an hour. Also the tracking requirements for the earth station antennas where quite stringent. Based on the results of the experiments, it was apparent that 8 to 12 low-orbital satellites would be required to provide minimal global coverage.

Earth Station Evolution

Returning to the discussion of the first generation earth stations, these were truly imposing structures. They used 3,000 watt transmitters to drive 85 to 110 foot in diameter antennas. As previously stated, the first antennas had to be steerable and able to track a satellite in orbit.

The horn antenna at Andover weighed 380 tons and was protected by a radome 18 stories high. The dome was made of fabric. Its shape was maintained by air pressure.

In addition to using the most advanced microwave technology of that time, the earth stations added a few advancements of their own including traveling wave masers for receiver front ends, high powered traveling wave tubes for the transmitters and liquid helium for cooling the electronics. Table 1 summarizes the original characteristics of the Andover and Goonhilly stations. The Pleumeur-Bodou station was similar to the one at Andover. These original stations have since been modified for commercial or government satellite service.

As shown in table 1, the original rf bandwidths were quite narrow, due to the limits of the receiver maser amplifiers. Initially, this was not a problem, since the satellites, including Intelsat 1, had similarly limited bandwidths.

		TRANSMITTER		RECEIVER		
STATION	ANTENNA	POWER	BANDWIDTH	FRONT END	BANDWIDTH	G/T
ANDOVER	PARABOLIC HORN	3 KW TWT	30 MHz	TRAVELING WAVE MASER	25 MHz	40 dB
GOONHILLY	FRONT FEED PARABOLIC	3 KW TWT	30 MHz	TRAVELING WAVE MASER	25 MHz	40 dB

Table 1. Original Characteristics, Two Earth Stations.

The G/T listed in the table is an important earth station parameter. It is discussed later.

The time delay question was resolved in 1966 after extensive field trials and user surveys involving the Intelsat I (Early Bird) geosynchronous satellite. Two additional earth stations were constructed for these tests; a massive station at Raisting, Germany and a smaller one at Fucino, Italy. The user surveys disclosed that customers did not consider time delay a significant problem.

Based on this evidence, the Intelsat Consortium decided that geosynchronous orbits should be adopted. This decision is a landmark in the history of satellite communications. Once the orbital geometry was established, the world could be considered as being divided into three zones, each of which could be served by one satellite. The zones are: the Atlantic-Ocean zone, Pacific-Ocean zone and Indian-Ocean zone. All of the world's important land areas are covered by these zones, as shown in Figure 1.

Second Generation Earth Stations

The second generation earth stations were built to accommodate the larger bandwidth of Intelsat II. Two U.S. stations were completed in November 1966; one at Brewster, Washington and one at Paumalu, Hawaii.

Among the technical advances included in these stations were masers with a 130 MHz bandwidth and Cassagrain antennas. The stations had a television capability and could establish telephone circuits with two distant earth stations.

Intelsat II was actually a stretched version of Intelsat I. Intelsat II's bandwidth allowed frequency division multiple access (FDMA) whereas Intelsat I could only be accessed by two ground stations at the same time. However, the 240 channels capacity was the same for both satellites. The FDMA operation was made possible by linear operation of the satellite traveling wave tube amplifiers. All earth stations transmitting to the satellite monitored and controlled their output power so that the satellites TWT continued to operate in its linear region.

The first of the Intelsat III satellite series was launched in 1968 and provided a distinct increase in bandwidth and channel capacity. These satellites have two transponders with a bandwidth nearly equal to the 500 MHz allotted for satellites in the 4 and 6 GHz bands.

Third Generation Earth Stations

Four, third-generation, U.S. earth stations were built during 1968, to work with Intelsat III. These stations are located at Etam, West Virginia; Jamesburg, California; Cayey, Puerto

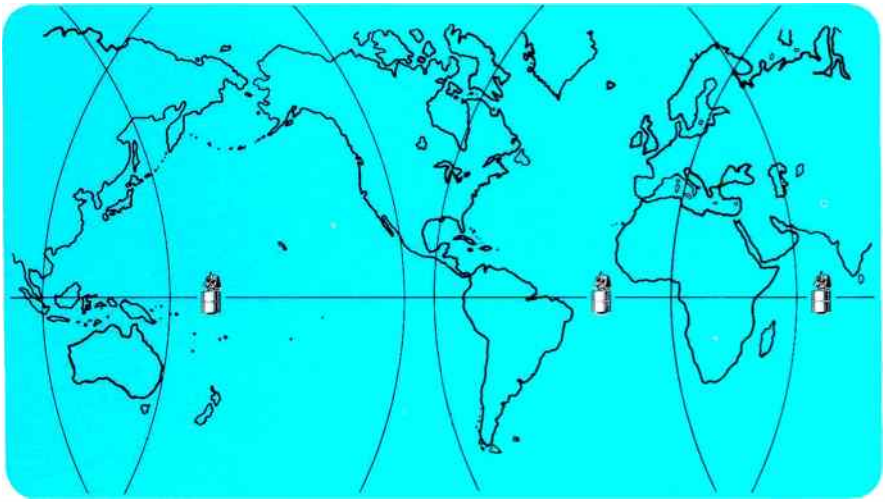


Figure 1. Global Satellite Communications Zones.

Rico and a second facility at Pamalu, Hawaii.

The receivers included newly designed parametric amplifiers with a 500 MHz bandwidth. The transmitters were equipped with 500 MHz bandwidth traveling wave tube amplifiers with over six kilowatts of output power. Antenna feed systems were necessarily made wideband. Antenna diameters were standardized at 97 feet to provide some compensation for the increased noise temperature resulting from the wideband parametric amplifiers and feed systems.

The Intelsat III satellite communications systems made truly global communications a reality. The new earth station designs were able to use the entire assigned bandwidth, so frequencies could be assigned without considering narrow band equipment. This made practical the use of FM/FDMA to provide multiple access to all earth stations in the network, using the same linear TWT operation as Intelsat II.

Although performance remained the constant criteria in early earth station design – substantial declines in cost occured with each successive generation. In the early days, operating costs were considered negligible in comparison to construction costs. However, this was no longer true by the time the third generation stations were completed. For this reason, fourth generation earth station design concentrated on reducing operating as well as constructions costs. Nevertheless, reliability and performance remained the pacing constraints, with emphasis on maintaining a high G/T ratio.

Fourth Generation Earth Stations

Typical fourth generation stations include the Bartlett Earth Station at Talkeetna, Alaska and a second facility at Andover, Maine. Both of these Comsat stations were constructed in 1970.

One notable feature of some third and most fourth generation earth stations is the wheel and track antenna mounting. The antenna structure is supported by and rotates on a peripheral circular track rather than a central, vertical axis. The track arrangement places the antenna's bearing points on the perimeter of a large concrete pedestal. Figure 2 is a photograph of an earth station showing the track arrangement.

This allows the pedestal's interior to be used as a control center and equipment room, thereby reducing the waveguide runs to the minimum practical length. For a small to medium sized station, almost all the equipment, including redundant items, is in the pedestal. Centrally locating the equipment and providing redundancy for critical units reduces the number of people required to maintain and operate the station. Table 2 summarizes the characteristics of the second through fourth generation earth stations.

Figure 2. Antenna with track and wheel assembly – Pamalu, Hawaii Earth Station.

Gain/Temperature Ratio

Referring back to Tables 1 and 2, the last column list the ratio of system gain to system noise temperature (G/T) as measured at the input to the receiver. This is the figure of merit for earth station receiving systems. Intelsat specifies a G/T ratio of 40.7 dB at a 5 degree elevation angle, for a class A earth station.

Antenna Gain

Since the gain used in the G/T ratio is the gain at the input to the receiver preamplifier, it is essentially equal to the antenna gain minus the transmission line losses. Antenna gain is usually measured at the first point where a transmission line may be connected so it may include some lossy elements but does not include the line.

The gain of an antenna is primarily dependent upon its physical size, as shown by the following formula for

GENERATION	STATION	ANTENNA	TRANSMITTER		RECEIVER		
			POWER	BANDWIDTH	FRONT END	BANDWIDTH	G/T
2	BREWSTER PAUMALU 1	CASSEGRAIN 85' DISH	10 KW	60 MHz	TRAVELING WAVE MASER	130 MHz	40.7 dB
3	ETAM JAMESBURG CAYEY PAUMALU 2	CASSEGRAIN 97' DISH	6.3 KW	500 MHz	COOLED PARAMETRIC AMPLIFIER	500 MHz	40.7 dB
4	ANDOVER 2	CASSEGRAIN 97' DISH	6.3 KW	500 MHz	COOLED PARAMETRIC AMPLIFIER	500 MHz	40.7 dB

Table 2. Second to Fourth Generation Earth Stations.

maximum gain of an aperture antenna. The aperture is the area of an antenna normal (perpendicular) to the direction of the incident energy (area of the mouth of a horn or area of a reflector for example).

$$Gu = \frac{4\pi A}{\lambda^2}$$

where: A is the area of the antenna normal to the direction of the incident energy.

λ is the wavelength of the incident energy.

The gain is relative to the gain of an of an isotropic antenna. This is a hypothetical device which radiates or receives equally well in all directions. It cannot be physically realized for electromagnetic waves.

Generally, maximum gain cannot be achieved. Antennas are not 100% efficient, so all the energy striking the aperture is not converted to power received at the antenna terminals. The formula for antenna efficiency (η) is:

$$\eta = \frac{Pr}{Ap}$$

where: Pr = received power
Ap = incident energy density

Antenna efficiency is normally expressed as a percentage.

The efficiency must be taken into account when calculating the gain of an actual antenna, so the gain formula becomes:

$$G = \eta Gu = \eta \frac{4\pi A}{\lambda^2}$$

The gain is normally expressed in decibels.

There are several factors which reduce antenna efficiency. Among these are some which increase sidelobe levels. These factors have a double effect on the G/T ratio. In addition to reducing the antenna gain, they increase the system noise temperature. Factors which increase the wide sidelobe and backlobe levels are particularly degrading.

Noise Temperature

All physical objects radiate energy. In the case of a thermal noise source, the radiated energy at radio frequencies is directly proportional to the absolute temperature of the source in degrees Kelvin (Planck's radiation law). For a thermal noise source, the physical temperature and noise temperature are equal.

The noise temperature concept is used to characterize the noise power from other types of noise sources. The physical temperature of these devices is not necessarily equal to their noise temperature.

Their noise temperature is the temperature at which a thermal noise source would have to be to radiate the same power. The noise temperature of a source may also be a function of frequency, if its noise power frequency spectrum is not flat.

The concept of noise temperature is not restricted to noise sources. The noise measured at the output terminals of an amplifier or antenna can be expressed in terms of an equivalent noise temperature. Expressed as temperatures, noise from the antenna and receiver can be added to arrive at the total system noise value.

Furthermore, gain and noise temperature are both relative power measurements, so the G/T ratio can be expressed as:

$$G/T = G\ (dB) - 10 \text{ Log } T\ (^\circ K)$$

where T is the antenna noise temperature in degrees Kelvin.

Antenna noise temperature includes radiations from objects on earth as

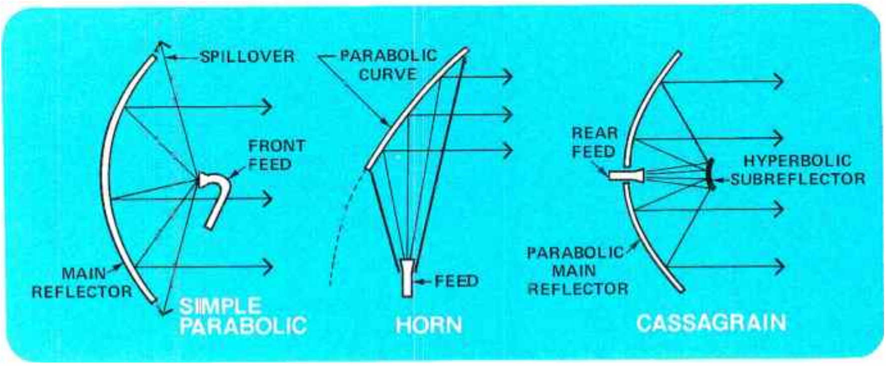


Figure 3. Three versions of the parabolic antenna, showing placement of rf feed and path of reflected energy. The Cassagrain is the most practical type for satellite communications.

well as radiations from objects in space. This is one reason why reducing the side and back lobes of an earth station antenna is important. When the antenna is receiving, these lobes represent sources of extraneous noise. When the antenna is transmitting, any energy in lobes other than the major lobe is wasted.

Antennas Types

From the foregoing discussion, there are three requirements for an earth station antenna, high gain (large aperture), low noise (high efficiency) and good steerability (pointing accuracy). This last requirement has been somewhat alleviated by satellite improvements but is still important.

There are several antennas which meet these requirements. Figure 3 shows three parabolic reflectors which are suitable.

The basic parabolic antenna is a highly directional device. However, the center feed at the focal point of the antenna cannot be precisely controlled to illuminate only the reflector. A certain amount of "spillover" occurs and adds undesirable back and side lobes. With the antenna reflector looking skyward, the feed is pointed back at the relatively noisy ground (approximately 290°K) so spillover adds to the antenna's noise temperature.

The horn reflector antenna was developed to reduce minor lobes. The antenna is basically a section of a parabola, with sides extended from the feed to the edges of the reflector. The horn is a highly efficient, low-noise antenna, but is large and costly.

The Cassagrain antenna is a practical compromise between the basic parabolic and horn antennas. Cassagrain antennas use two reflectors; a parabolic main reflector and a hyperbolic subreflector. The feed is at the rear of the main reflector so its looks at the sky (noise temperature approximately 30°K).

The antenna has low spillover, short transmission lines and good mechanical stability of the feed system. Careful engineering and precise construction are required to avoid placing elements in a position which could block radiation.

Tracking Telemetry and Command

Returning to the discussion of earth stations, there were more than 60 stations operating in 48 countries by 1972. Four specialized stations, Andover, Maine; Carnavon, Australia;

Fucino, Italy and Paumalu, Hawaii maintained a continuous check on satellite performance.

These stations track the satellite during and after launch and transmit commands when necessary to change its position. They monitor various satellite parameters such as temperature, spin rate and attitude as well as the EIRP (effective isotropic radiated power), carrier frequency, deviation and out-of-band noise of the communications electronics. The importance of EIRP is discussed later in this article.

Placing a satellite in synchronous orbit is a precise operation. First, the launch vehicle places the bird in a long elliptical orbit. The apogee of this orbit is about 22,300 miles from earth. To prepare for the next step, the orbit is accurately measured and the satellite's orientation is adjusted to precisely the right attitude.

When the satellite is at the farthest end of its ellipse and traveling at a right angle to the earth's radius, an apogee motor is fired to put the satellite in circular orbit. The time of the motor's ignition and the duration of its thrust are critically important to the success of this maneuver. Once the satellite is in circular orbit, its velocity is adjusted to synchronize with the earth's rotation and its attitude is adjusted to point the antenna in the right direction.

After the satellite is in synchronous orbit, it requires periodic adjustments of velocity and attitude to keep it "on station". This station keeping is accomplished by on-board jets which are fired in "squirts" by commands from an earth station, although for some satellites attitude is automatically controlled by on-board equipment. Any satellite communications system must have at least one earth station capable of performing monitoring and control functions. These functions are commonly referred to as TT & C (tracking, telemetry and command).

Intelsat IV is the current series of Intelsat satellites. The first Intelsat V launch is scheduled for 1980. The latest operational series, Intelsat IVA, employs orthogonally polarized antennas to transmit and receive signals simultaneously, in the same frequency band.

Intelsat approved the use of smaller, class B antennas for earth stations operating with Intelsat IV and IVA. These earth stations antennas may be as small as 11 meters in diameter. The class B stations represent a dramatic decrease in the size and cost of the earth stations.

Other innovations introduced by the Intelsat IV satellite communications systems include SPADE and experimental time division multiple access (TDMA). SPADE (Single channel per carrier, pulse code modulated, multiple access, demand assigned equipment) provides more efficient use of satellite bandwidth by assigning transponder capacity for use on a call by call basis. One of 12 transponders on an Atlantic Region Intelsat IV was assigned to SPADE, which uses a frequency division, multiple access technique. The technique divides the 36 MHz transponder bandwidth into 800 channels which are individually accessible. This is in contrast to the FDMA with permanent channel assignments used by Intelsat II and III.

A common channel, demand assigned, signaling and switching system (DASS) for earth stations was developed to complement the SPADE system. DASS is a TDMA system. Etam, West Virginia and Raistag, West Germany were the first earth stations equipped for SPADE operation.

The SPADE system provides demand assignments without central control. Pulse code modulation is used for channel encoding, and coherent, quad-

MESSAGE CHANNEL	
FREQUENCY DIVISION MULTIPLE ACCESS	
CHANNEL ENCODING	PCM
MODULATION	4-PHASE PSK
BIT RATE	64 Kb/s
BANDWIDTH PER CHANNEL	38 kHz
CHANNEL SPACING	45 kHz
FREQUENCY STABILITY	±2 kHz (AFC CONTROLLED)
BIT ERROR RATE AT THRESHOLD	10^{-4}
COMMON SIGNALING CHANNEL	
TIME DIVISION MULTIPLE ACCESS	
BIT RATE	128 Kb/s
MODULATION	2-PHASE PSK
FRAME-LENGTH	50 MS
BURST LENGTH	1 MS
NUMBER OF ACCESSES	50 (49 STATIONS + 1 REFERENCE)
BIT ERROR RATE	10^{-7}

Table 3. Spade System Characteristics.

rature, phase-shift keying is used to modulate each carrier.

Each rf carrier accommodates a single voice channel. The carriers have a bandwidth of 45 kHz. The transponder bandwidth is 36 MHz so it accommodates 800 carriers. Each carrier represents an access to the satellite.

Since each carrier corresponds to one voice channel, it is not transmitted unless voice is present on the channel. The transponder has sufficient power to support 800 channels which are on or off depending on talker activity.

The 800 channel capacity presupposes standard, class A earth stations with a G/T ratio of at least 40.7 dB/°K. Smaller stations, or a network of mixed earth stations, can operate in a SPADE system with reduced channel capacity. The important characteristics of SPADE are listed in table 3.

Intelsat IV's TDMA research and development was conducted in the Pacific basin area. TDMA is a technique for switching a satellite transponder between several earth stations. The switching rate is fast enough so that, for practical purposes, each earth station has full time access to the satellite.

Transmissions from an earth station are in bursts, with coded addresses to particular receiving stations. Each burst has a synchronized time slot to prevent interference. The satellite retransmits the signals in the synchronized sequence that they are received from the earth stations. A particular earth station receiver copies only those signals which are addressed to it.

Comparisons between DA/FDMA and DA/TDMA show that, when there are a large number of low traffic points to be interconnected, a single channel per carrier, FDMA system with PSK or FM modulation of each carrier is most efficient. When there are a smaller number of points but with medium to heavy traffic TDMA is most efficient. As the number of channels required for each link increases, the advantages of demand assigned channels decreases.

Quaternary phase shift keying (QPSK) in a burst mode is also used for TDMA. Since some form of phase shift keying modulation is used in many of the domestic systems described later and it will see increasing use in the future; its principles are discussed in the following paragraphs.

Binary phase shift keying (BPSK) is the simplest form of phase shift modulation. Each change in the baseband bit stream from 1 to 0 or 0 to 1 causes a 180 degree phase shift of the carrier being modulated.

In quaternary (four phase) modulation, the carrier is shifted 0°, 90°,

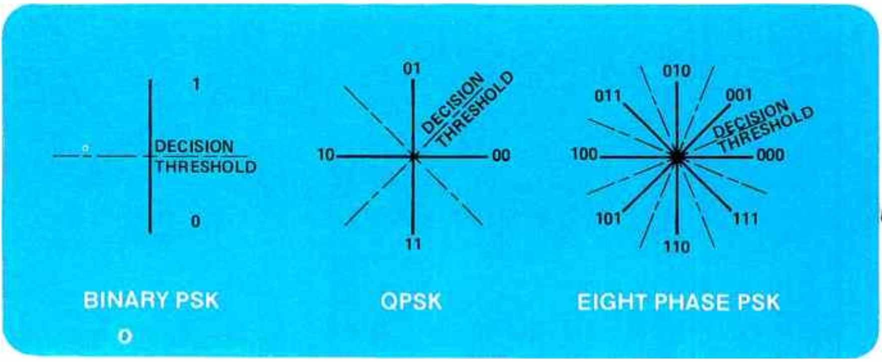


Figure 4. Relative phases and amplitude of PSK signals. The decision thresholds represent levels where the receiver must decide which signal has been received.

180° or 270°. Each shift represents two bits from the sequence to be transmitted. There are four possible combinations for a pair of binary digits; 00, 01, 10, 11. Each combination is assigned a phase value. The carrier is shifted in phase for each pair of bits (dibit) in the data or message sequence.

Eight-phase PSK uses tribits to modulate a carrier by shifting its phase to eight different values over a 360 degree range. Figure 4 diagrams the three PSK schemes just described.

Phase shift keying is suitable for TDMA systems because it can be easily accomplished with digital signals. PSK also makes efficient use of bandwidth and power and has a lower digital error rate than other modulation methods.

Digital error rate, for any modulation method, is dependent upon how hard it is for noise to make one signal look like another. The lowest error rate occurs when there are two signals diametrically opposite in phase as they are with BPSK.

However, the trend seems to be towards quaternary PSK for satellites because it saves on bandwidth and, with synchronous detection, provides an error rate equal to BPSK. In QPSK, two bits of information are carried in a pulse that would carry one bit of information in BPSK. But, for equal bit rates and received carrier power, QPSK signals are twice as long as and contain twice the energy of BPSK signals. The increased energy compensates exactly for the performance degradation resulting from using 90° instead of 180° signals.

Eight phase PSK is difficult to implement and has a higher error rate. Therefore, it is not used for satellite communications except in those rare cases where bandwidth considerations overide all other factors.

Frequency Reuse

Intelsat IVA doubles its use of the frequency spectrum by a technique called frequency reuse. The satellites use directional antennas with special feed assemblies to provide space discrimination, so the same frequencies can be used twice.

Intelsat V will have a reuse factor of four in the 6/4 GHz band because it will be equipped to transmit and receive simultaneously on orthogonal polarizations. The reuse factor drops back to two in the 14/11 GHz band because orthogonal polarizations are not used. Existing earth stations must be retrofitted with dual polarized antenna feeds to accommodate the frequency reuse techniques.

Polarization discrimination between adjacent channels has been used extensively in terrestrial microwave systems. However, its use for satellite communications presents some unique problems. Satellite communications will use overlapping channels, a condition which has been avoided on terrestrial systems. The overlapping condition requires almost perfect orthogonal polarizations to prevent interference.

Another problem unique to satellite communications is Faraday rotation. It results from the magnetic fields surrounding the earth. Polarized signals passing through the ionosphere are affected by these fields.

The effects vary slowly with the time of day. Rotation of the polarized beam is greatest during daylight hours and is minimal in the hours just before dawn.

The rotation also varies with frequency. The maximum daily polarization shift, for a 4 GHz signal, is about 4.6 degrees. Under the same conditions a 6 GHz signal shifts about 1.9 degrees.

Although these angular misalignments may seem small, the effects are quite large. The resulting interference is equal to 20 times the logarithm of the sine of the angle. If the orthogonal set's isolation is normally 40 dB, it will drop to 22 dB with a 4.6 degree misalignment.

These effects must be compensated. This is accomplished by constantly monitoring the Faraday rotation and inserting differential phase and differential attenuation compensating networks in the path. Some degradation in the G/T ratio results from this action but the trade-off is worthwhile, considering the increase in channel capacity.

At the end of 1978, the Intelsat network had 198 earth stations worldwide. Seven of these are in the United States. Plans call for 88 new stations to be added, worldwide.

Domestic Satellite Earth Stations

U.S. domestic satellites were authorized by the FCC in 1972. Westar 1, the first American domestic satellite was launched by Western Union in 1974 and followed by Westar 2 later in the same year.

Western Union now has five heavy route and three medium route earth stations in operation. They also lease excess channel capacity to other carriers. American Satellite Corporation leases transponders for its system which includes 19 earth stations, four for common carrier and the remainder for dedicated services to government and commercial customers. ASC plans to add seven more earth stations to its network

The entire capacity of the three Comstar satellites is used jointly by AT&T and GTE for long distance telephone transmission. AT&T has four earth stations and GTE has three. Comstar satellites reuse frequencies. Also, they transmit and receive simultaneously on orthogonal polarizations.

The first operational U.S. domestic satellite system was established by RCA, using the Canadian ANIK A2 satellite. RCA's own satellites, SATCOM 1 and 2 were launched in 1975 and 1976.

RCA provides message and television services to business and government. It has six common carrier earth stations and 18 dedicated to government users. RCA also leases satellite capacity to other users and transponders to Alaska Communications. Alascom has 20 heavy and medium route systems and about 100 small "bush stations" with 4.5 meter antennas serving small communities in rural Alaska.

The January issue of the Demodulator conservatively estimated that interstate telephone calls would reach a 9 billion annual rate by 1985. It is also estimated that, by that time, nearly 2,000 broadband satellite transponders will be in orbit. These transponders will provide the equivalent of approximately 1.5 million voice circuits.

However, all of these circuits will not be used for voice communications. Over the next decade, remarkable growth of satellite communications is also expected in two other areas; business communications and cable television (CATV).

Business Communications

Satellite Business Systems (SBS), a joint Comsat, IBM, Aetna Casually venture, is scheduled to begin operations in January 1981.

This system will have three satellites, two in geostationary orbit and one spare. It will be an all digital system providing integrated voice, data, facsimile and video services to locations that are widely dispersed geographically. It will be a TDMA system, with transmissions using QPSK in a burst mode. Transmission rate will be up to 6.3 megabits per second, in contrast to the present maximum of 1.5 megabits.

The SBS system will operate in the relatively unoccupied 12/14 GHz band, so SBS terminals can operate in cities without creating interference problems. Earth stations will be located on the customer's premises, perhaps on the roof or in the parking lot.

Xerox has applied to the FCC for an allocation in the 10-GHz band, to be used on a satellite-based business communications network. This system will operate in a similar fashion to the SBS system but is aimed at the small business user.

The Xerox network (XTEN) will use leased channels on RCA's Satcom or Western Union's Westar satellites. Its bit rate is 4.1 Mbls.

American Satellite Corporation recently announced it is converting its entire system to digital transmission. They will also use time division multiple access switching.

Video-conferencing by Satellite is another area of interest to business. The increasing costs of travel and the use of small roof-top satellite terminals have brought renewed interest in video-conferencing via satellite. Experiments in England and in Canada, have shown that participants, though initially enthusiastic, will not make frequent continuing use of the service if they are required to make complicated prior arrangements and travel to a central studio. However, recent experience in Canada and the U.S. (Project PRELUDE) indicates that on-premises facilities would probably receive much greater use.

Early experience with the videotelephone has shown that simply sending a small-format, reduced-resolution picture of the talker was of little value to most users, while recent tests by AT&T with a video conference system that provides studio-quality TV, graphics, facsimile, and good audio showed a much better level of acceptance.

Transmission of a high-quality color video for conferences, using existing satellites and today's earth station technology, generally requires the use of an entire satellite transponder in each direction. This amounts to 1/12 of the satellite's total capacity or an equivalent of 1,500 voice circuits. By accepting a slight compromise in quality, both directions can be carried in the same transponder, but for widespread usage, additional compression is necessary.

Bell Telephone Laboratories and GTE Laboratories are conducting video conferencing experiments using digital encoding and compression of the TV picture that can reduce the bandwidth by a factor of from 5 to 10 compared to currently used analog transmission techniques. Such reduction would have a significant effect in lowering the cost of transmission for a video conference. The only noticeable degradation is a slight "jumpiness" in pictures with large areas of rapid motion. This kind of motion is rarely seen in business-type video conferences.

CATV

The first CATV television programming via satellite was initiated September 1975. At that time, 9 meters was the minimum diameter antenna allowed by the FCC for receive only CATV earth stations. On December 15, 1976 the commission issued a ruling which effectively reduced the permissible diameter to 4.5 meters. The FCC has jurisdiction over receive only earth stations because their parameters effect orbital spacing, as described later under "Orbital Limits."

As a result of this ruling the cost of these earth stations was reduced 50% or more and CATV became a strong contributor to the current growth in satellite communications. Projections are that more than 3,000 earth stations will be serving over 5,000 CATV systems by the mid-1980's.

Broadcast Television

The broadcast networks are also using satellites for program distribution. The three major networks, ABC, CBS and NBC use satellite circuits to feed news and sporting events back to their network centers. Satellite channels are also used to transmit program material to regional distribution centers.

Public Broadcasting is well along with its satellite distribution system. When this system is completed, it will include seven transmit and receive stations; the main station near Washington, D.C. and six regional stations. In addition 142 receive only stations will serve the 162 public television stations. Many of these earth stations are already in operation, using leased WESTAR transponders.

Radio broadcasters are also using satellite links. So far their usage has been more on a coast to coast trunking basis than to individual stations. The news wire-services, AP and UPI are beginning to use satellite communications to send information to their subscriber newspapers.

Smaller diameter antennas are more feasible for domestic satellite earth stations than for global satellite earth stations. Domestic satellites cover smaller geographic areas, so they can use narrower beams and consequently higher gain antennas. For a given power input, higher gain antennas provide a greater effective isotropic radiated power (EIRP).

Spot beams have the highest gain antennas and consequently given the greatest increase in EIRP. Spot beams are best used for applications where there are a relatively few areas of heavy traffic which are widely separated geographically but are within the area covered by the satellite (the contiguous 48 states or the Scandinavian countries for example). Satellite distribution of CATV programs is adaptable to spot beam coverage.

The EIRP requirements for a satellite are dependent on several factors including:

- The earth station G/T.
- The type of modulation and baseband width which determines the bandwidth required for the earth station receiver.
- The required signal quality for FDMA systems or the permissible error rate for TDMA systems.

Effective isotropic radiated power is usually considered more of a critical factor in satellite than in earth station design. Earth stations generally have larger, higher-gain antennas and greater transmitter power. Their EIRP is high enough to assure that the received signal at the satellite is much higher than the receiver noise. For this reason EIRP may be considered a figure of merit for satellites whereas G/T ratio is the figure of merit for earth stations.

In the future, as satellites become more powerful with even higher EIRP, direct broadcasts from satellites to homes will be a distinct possibility. A one meter diameter, dish antenna should be more than adequate. A down converter would also be required to match the television receivers rf band. Produced in quantity, the antenna/converter combination could retail for under $300. Even farther out in the future, portable hand held transceivers may be capable of worldwide communications via very large satellites.

Satellite Limitations

The January issue of the Demodulator listed two limits on satellite communications; the frequency spectrum and the geosynchronous orbit. The concluding section of this article discusses each of these limits in turn.

Spectrum Limits

The eventual overcrowding of the frequency allocations has been a virtual certainty since the beginning of commercial satellite communications. The increasing demands for service have always outpaced technical developments designed to provide more efficient use of the spectrum.

In some heavy traffic areas, the 500 MHz bandwidth allocations in the 6 and 4 GHz bands are already overcrowded, even though satellites serving these areas use the frequency reuse technologies previously described. When similar situations are encountered in terrestrial radio communications, the classic solution is to go to higher frequencies with greater bandwidths. This same solution applies to satellites.

Intelsat V will use transponders in the 11/14 GHz as well as 6/4 GHz bands. However, it appears that U.S. domestic satellites will use the 11/14 GHz bands primarily for radio and television broadcasting, leaving the super high frequency bands for telecommunications traffic. These frequencies are attractive because they offer the possibility of large bandwidths. Bandwidths which accommodate upwards of 100,000 voice channels or equivalent signals could be achieved with a 30 GHz carrier.

Use of the super high bands would also largely eliminate the problem of interference between satellite and terrestrial systems. Earth stations can be located in areas where lower band frequency congestion prevents their installation at present.

The higher frequencies provide economies of scale in antennas and waveguide and consequently in their supporting structures. This fact makes rooftop locations more practical for higher frequency than for lower frequency earth stations.

Rain attenuation is a significant problem in the 11 GHz band and since it increases with frequency, it is possibly the most significant problem in the 30 GHz region under discussion. Rain attenuates a microwave signal in two ways; the water absorbs energy and the raindrops scatter it. The amount of attenuation is a function of the drop size, the temperature and the volume of water as well as the frequency. In other words, the bigger the drops and the higher the frequency, the greater the attenuation will be.

Note that the total annual rainfall is not the important factor. Concentrated rain is what causes trouble. This is the reason why GTE selected the

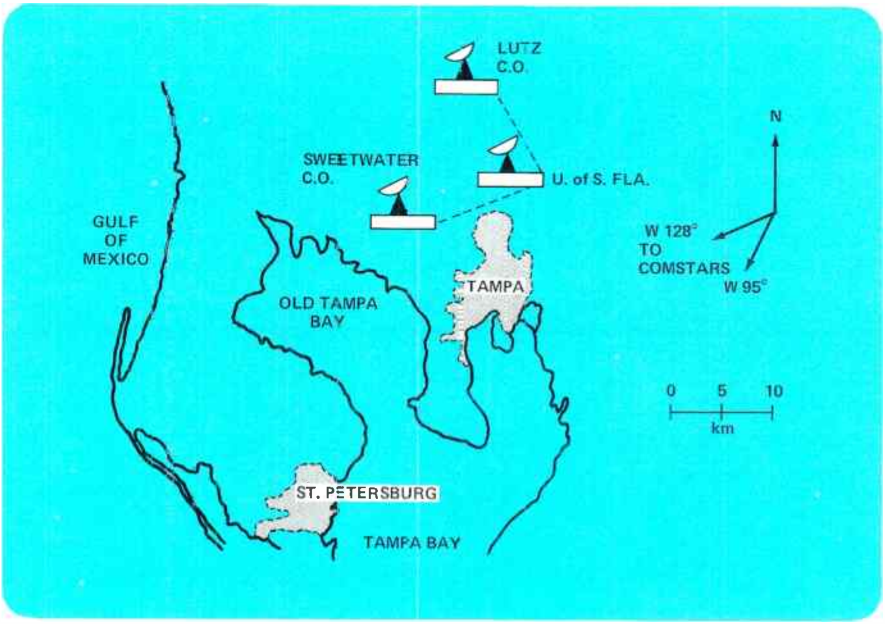


Figure 5. Florida triad for 19/29 GHz experiment.

area around Tampa Florida for propagation experiments at 19/29 GHz. The experiments are ongoing but preliminary findings were published by General Telephone and Electronics in a press release dated March 1, 1978, and in a GTE Laboratories Publication, "Profiles", Three, 1979.

The following paragraphs are extracted from these publications:

19/29 GHz Project

In these frequency bands, a major propagation experiment is underway in Florida to measure the rain-induced signal attenuation at three sites, using beacon signals from the COMSTAR satellites. This experiment is a cooperative effort of GTE Labs, GTE Satellite Corporation, General Telephone Company of Florida and the University of South Florida (USF).

The highest incidence of summer thunderstorm activity in the United States (89 thunderstorm days per year) occurs along the Gulf Coast, making the Tampa area ideal for experiments to measure the effects of heavy rain on satellite signals.

Figure 5 shows the location of the three stations at USF and General Telephone Company of Florida central offices at Sweetwater and Lutz. Each station in this "triad" has a small roof-mounted antenna (2.5 meters in diameter) and receiving equipment tied by data lines into the master control station at USF. The antennas are a special design developed by GTE Sylvania Electronic Systems Group.

Continuously recorded signals at both 19 GHz and 29 GHz, show the frequency dependence of rain-induced attenuation. Comparing signals at the three sites during passage of a storm measures the effectiveness of a receiving system that would select the best signal from a pair of stations to reduce rain outage. Definite preference for the Lutz-Sweetwater station pair has been observed in the first year's data.

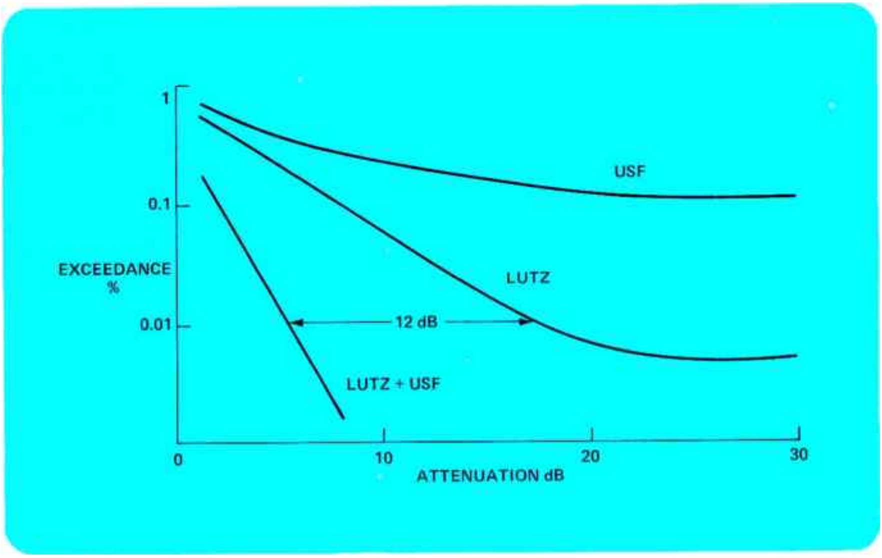


Figure 6. Diversity performance of Tampa triad June 1978 – 19 GHz.

Figure 6 shows typical curves of measured attenuation exceedance (percent of time the signal is below a given level) where the Lutz-USF pair achieved 12 dB performance improvement over the better of the two stations alone, at the indicated time percentage. By continually choosing the best signal from all three stations, an even greater improvement would be possible. Data of this type is essential for design of future satellite systems that are to achieve the high reliability needed for the telephone network. When reliability is not strictly specified, the curves allow the designer to make the best trade-off between cost, performance, and customer's objectives.

The ultimate goal is to discover the relation between signal fading and local rainfall statistics so that systems can be designed for any locale without resorting to the expensive and time-consuming process of beacon signal measurement for each new location.

Dr. Lee L. Davenport, Vice President and Chief Scientist of GTE, said that future domestic satellite systems will be able to utilize super-high frequencies despite the adverse effects of heavy rainstorms and other weather conditions upon the higher-frequency radio waves.

He told a news conference at the University of South Florida that a large number of additional communications channels will be necessary by the mid-1980s to meet the steadily increasing demand for communications services. Those channels will be available on the new satellite systems, and they will provide the high reliability required by the nation's long-distance telephone network, Dr. Davenport stated.

"We are now confident that rain interference with super-high frequency radio waves can be overcome by establishing satellite earth stations in pairs which are sufficiently separated and properly positioned for local storm patterns", Dr. Davenport said. "If such a site configuration is established the interference should rarely occur at both earth stations simultaneously."

The foregoing extracted paragraphs discuss an excellent example of an applied research and development program. The experimental results will provide practical solutions to a well defined problem. The results will have almost immediate application. Systems using 19/29 GHz frequencies will be operational in the next generation of communications satellites.

Millimeter Waves

At frequencies in the 50 GHz region and above, attenuation due to absorption by oxygen molecules becomes significant. Water molecular absorption is also significant at these frequencies and at "resonant" points in lower frequency bands. Rain and molecular attenuation of millimeter waves make their propogation in the earth's atmosphere impractical for common carrier use. However, satellites do not operate in the atmosphere.

Millimeter waves could be used to link satellites. Presently, two up and two down channels are required to connect two satellite systems in tandem. If a direct link existed between the two satellites, one up and one down channel would not be required and would be available for other traffic. A significant reduction in noise would also result as well as some reduction in the time delay. Frequencies in the 50 to 300 GHz range will probably be used to communicate between future satellites.

Orbital Limits

The number of satellites per unit of orbital arc is limited by the ability of the earth stations to keep the signals apart. Which is to say the number of satellites is limited by the beamwidths of both the satellite and earth station antennas.

Beamwidths are inversely proportional to antenna size, i.e. the smaller the antenna the wider the beam. So, from a strictly technical point of view, it seems that the necessity for avoiding orbital congestion and the trend towards smaller earth stations are in direct opposition.

However, technology is not the only consideration. Economics play a large part. Since there will be a far greater number of earth stations than satellites, the aggregate costs for earth stations will be much greater than for satellites. Therefore, reducing the cost of an earth station is more significant than reducing the cost of a satellite. For this reason, earth stations will continue to grow smaller and less expensive as satellites become larger, more powerful and provide sharper beam antennas.

A historic parallel exists in the broadcast industry where, as transmitters became better and broadcast stations more numerous and widespread, receivers became less complex and expensive. Today many broadcast receivers are throwaway items, cheaper to replace than repair.

This is not to say that earth stations will become throwaway items. However, some older stations will become obsolete and too expensive to operate and maintain. This situation already exists in some Electronic Data Processing Systems with older computer mainframes.

Remember that the discussion of satellite communications deals in aggregate costs. The cost per circuit has declined from the beginning and will continue to decline, for the foreseeable future.

Given the facts just presented, it appears that the solution to orbital crowding lies with the space platforms mentioned in the January issue. These platforms are also called Orbital Antenna Farms. This latter term will probably prevail since its acronym, OAF, is descriptive, humorous and easy to remember.

These antenna farms will be constructed in space. In contrast to existing satellites, these structures and the equipment they house will also be maintained and repaired in space. Although some disciplines may be stretched to the limit, the entire concept is within the state of the art of current technology.

Orbital antenna farms can solve the problem of orbital congestion. Although they are much larger than satellites, far fewer OAFS will be required.

However, the real success of this concept depends on the cooperation of a number of government and corporate entities that provide a wide variety of services, presently by using several individual satellites. The problems of money, property and prestige involved in several entities sharing a common facility are beyond the scope and competence of the Demodulator. However, it is apparent to the most casual observer that these problems do exist and that a great deal of patient effort will be required to solve them.

Laser Technology

Laser technology could go a long way toward solving both the frequency spectrum and orbital crowding problems. Lasers for space communications have been discussed since their introduction in 1960-61. An experimental laser communications system will be piggybacked aboard on experimental satellite to be launched by the space shuttle – possibly in 1980.

The following advantages make lasers highly desirable for space communications.

(1) The intensity of the beam which could allow satellites to be positioned beyond the geosynchronous orbit.

(2) The extremely low electromagnetic interference radiations which could allow laser bearing satellites to be placed in the geosynchronous orbit without interfering with existing satellites.

(3) The extremely narrow beamwidth of lasers, with antenna diameters measured in millemeters.

(4) The extremely high bit rates (bandwidth) that can be achieved.

The principal drawback on laser communications is the adverse atmospheric effects. At laser-beam wavelengths, these effects are more severe than they are at microwave wavelengths. However, these effects might be alleviated by locating diversity earth stations in regions with different weather patterns. Of course, atmospheric effects do not exist in space, so laser communications between satellites should be straight-forward and provide the same advantages as millimeter waves.

Satellite Versus Other Communications Systems

Any valid evaluation of a communications system's future must view that future in the light of other, competitive systems. This is the intent of the following paragraphs.

Before satellites, communications relied on a network composed of three terrestrial systems; microwave radio, land cable and submarine cable. Each of these systems has strengths and weaknesses, which define its best area of application. Each system was relatively secure in its own best area, with minimum competition from the other two.

This picture seemed to change radically with the advent of communications satellites in the mid-1960's. It appeared that the versatile satellites would successfully compete against all three existing systems and that these systems would be relegated to the secondary role of providing back-up and local distribution systems.

However, from the previous discussion, it is apparent that satellite communications systems have their own weaknesses, principally spectrum/bandwidth and orbital space limits. The spectrum congestion leads to increasingly troublesome RFI. Radio frequency interference is a problem common to both terrestrial and satellite microwave transmissions. It seems to increase exponentially with every new system and may well be the ultimate limiting factor on microwave communications.

For the reasons listed, satellites will not be able to satisfy the rapidly increasing demands for telecommunications services. To meet these demands over the next decade, all existing systems will be expanded and systems based on new technologies will be introduced.

Systems based on millimeter waveguide and fiber optic technologies are well past the development stage. These new systems will be discussed in future issues of the Demodulator.

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Correction

Our December 1978 announcement on new prices for GTE Lenkurt Demodulator loose leaf binders did not list the new international price.

The following prices went into effect April 1, 1979:

U.S., APO & FPO ADDRESSES	$ 2.50 ea.
ADDRESSES OUTSIDE OF U.S.	$ 4.00 ea.

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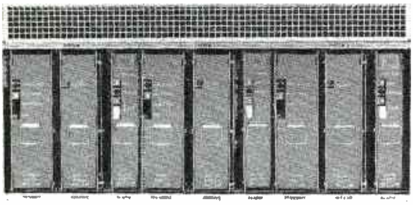
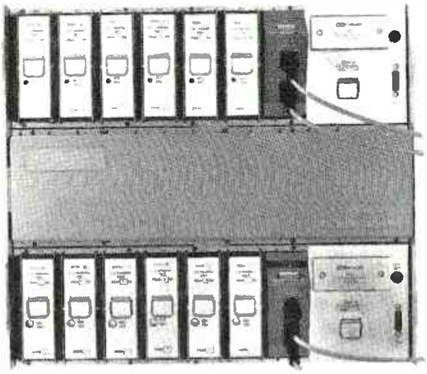
GTE Lenkurt's Optical Transmission Systems



FT3

- Provides optical transmission of DS3 signal at 44.736 Mb/s
- Standard DSX 3 electrical interface
- Up to 672 vf channels per fiber pair
- Losses as low as 3 dB per kilometer
- Plug-in design for easy future expansion



82B

- Immune to radio frequency interference, electromagnetic induction and impulse noise
- Negligible crosstalk
- Cost-effective, reliable LED and PIN diode technology
- Provides up to six voice frequency circuits per fiber optic pair

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