DECEMBER, 1966
VOL. 15 NO. 12

the Lenkurt® Demodulator

LENKURT ELECTRIC . . . specialists in VOICE, VIDEO & DATA transmission

The first commercial use of man's ability to travel in space — not yet a decade old — has come in the field of communications. Soon, over 90 percent of the world's telephone facilities may be joined in a global network through communications satellites.

Long before communications-relaying space vehicles became a reality, scientists eyed the natural satellite of the earth—the moon. Early in 1946 Project Diana bounced the first radar signals off the moon. Twenty years later artificial satellites circle the globe, but the moon has not been forgotten. A ship-to-shore communications link using the moon as a reflector is expected to be operational sometime in 1967.

The first man-produced "beeps" directly from space were heard on October 4, 1957 from the Russian Sputnik I. The United States entered the space age on January 31, 1958 with Explorer I. Today, in addition to the spectacular manned exploration of space, commercial satellites stretch telephone circuits across the oceans, and telecasts from other continents are common.

American scientists placed the first communications satellite in orbit a year after Explorer I. Score—a short lived but highly successful "bird"—relayed messages up to 3000 miles and broadcast to the world a tape recorded Christmas greeting from President Eisenhower.

The 1960 flight of Echo I was witnessed around the world as the 100-foot balloon-like reflector satellite provided a "radio mirror" for powerful ground stations. Echo II went up in 1964 as experiments with passive reflectors continued.

An active repeater, Courier, extended the knowledge of space communications in 1960 with successful transmission of of high speed teletype, voice, and facsimile.

The commercial value of communications satellites was accentuated in 1962 with Telstar I, the joint project of NASA and AT&T. The first live telecasts between Europe and the United States added to the satellite's performance in transmitting high-quality voice, data, teleprint and other signals. Telstar II, and NASA's Relay I and II added more data.

By mid-1963, the first of three Syncom satellites was launched and communications milestones began to pile up. Syncom III brought the Tokyo Olympic games to the United States, and went on to demonstrate its value for all types of telecommunications. NASA has since concluded its planned tests, and both Syncom II and III are now working for the Defense Department, parked over the Pacific and Indian Oceans.

How High?

Most alternatives faced in the design of communications satellites are centered around the choice of orbits. Orbital mechanics govern precisely the height and period of a satellite. A satellite circles the earth in a period directly related to the satellite's altitude. (The mass of the satellite is negligible and can be ignored in most calculations.) A satellite 100 miles high circles the earth in about 87 minutes; at 1000 miles the period is 118 minutes. As the altitude increases, the orbital period becomes longer, until at an altitude of 22,300 miles a satellite orbits the earth in exactly the same time as one rotation of the earth—that is, every 24 hours. Placed in an easterly orbit over the equator, such a "synchronous" satellite appears stationary in the sky.

The first communications satellites—the Telstars and Relays—were in nonsynchronous orbits. The new breed, lead by Syncom and Early Bird, are synchronous and remain in precisely fixed positions. But depending on the application, each plan has advantages and disadvantages.

The lower the satellite, the shorter its period, and likewise the less time it will be in the simultaneous view of any two ground stations. For example, a 3000-mile-high satellite can be tracked for only 24 minutes by stations located 3000-miles apart—*if* the satellite passes directly over both stations.

Military Plan

A low-flying random orbit is especially appealing to the military, interested in the security of its communications system. The quasi- or nonsynchronous satellite does not require orbit-control commands from the ground, and therefore cannot be tampered with by an enemy. In the Initial Defense Communications Satellite Program (IDCSP), with up to 24 satellites placed in an 18,000-mile orbit, if a satellite fails for any reason another will soon move into view. The satellites drift around the earth at about 30° per day—any single satellite is in view for over four days at a time.

Commercial Advantage

Commercial systems planned through 1968 will be synchronous; the reasons are mostly economic. Fixed position synchronous satellites greatly simplify tracking, thus reducing the cost of ground stations. In developing a truly worldwide system, where each additional ground station may open communications to an entire region or country, the installation cost of these stations becomes increasingly important.

Tracking becomes a relatively simple function of the ground station of a synchronous system. As satellites are pushed by "solar wind" and pulled by gravity from the earth, moon, and sun, periodic adjustments in position are made by onboard thrusters. Between correction intervals typical 85-foot parabolic ground antennas track minor variations—measured in hundredths of a degree.

The synchronous satellite, at 22,300 miles above the earth, is visible to almost half of the globe at one time. Three satellites, spaced equally around the earth, would provide contact with any country served by an adequate ground station (Figure 1). An exception exists at the poles where signal strength is at a minimum. In practice, more than three satellites undoubtedly will be used to increase the number of circuits available in high density areas, and to ensure greater flexibility.

Long transmission delay time is the one serious disadvantage at synchronous altitudes. A one-way telephone path through such a satellite is about 50,000 miles—a delay of 265 milliseconds. Since delays of over 400 ms are unacceptable for voice communications, circuits probably will be limited to only one satellite hop in spanning the globe. The problem, however, does not concern the transmission of television or data.

The products of new technology are easily phased in with a synchronous system. Three or four satellites can replace an entire synchronous system, and older low-capacity units can be moved to areas where traffic is lighter.

The ability to relocate synchronous satellites is a needed feature should a failure occur. An extra satellite, parked in a low traffic area, could be moved in as a replacement in much less time than it would take to prepare and launch a new vehicle. Using onboard thrusters, a satellite can move about 10° per day — from a station over the Atlantic to the Pacific, for example, in about 15 days.

Intelsat

Global communications is being established through the International Telecommunications Satellite Consortium (Intelsat), made up of 54 participating countries. Congress has franchised the Communications Satellite Corporation (Comsat) to establish service for American common carriers, and to represent this country in dealings with Intelsat. Comsat is the major shareholder in Intelsat and serves as its manager.

Any country can join Intelsat, agreeing to share the financing of satellites and tracking equipment. Each country has the responsibility for its own ground stations, with at least 25 countries expected to have working stations by 1971.

The first commercial communications satellite, popularly known as Early Bird, began operation over the Atlantic in mid-1965. Two advanced Intelsat 2 satellites (Blue Birds) will establish the first service over the Pacific and add to the channel capacity over the Atlantic. The third generation Intelsat 3 satellites are scheduled for launch in early 1968 to further expand the worldwide system.

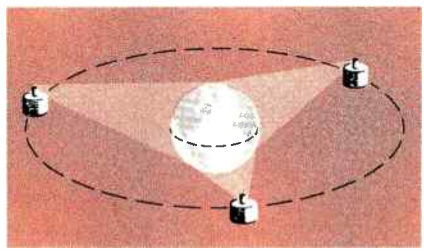

Figure 1. Three satellites in synchronous orbit could cover the entire earth.

Power Source

A sizeable tradeoff between rocket booster power and payload weight must be made in orbiting any object. Since the communications satellite must carry its own power source into space, energy for all electronics is necessarily limited. In turn, the less radiated power from the satellite's transmitter, the lower the signal-to-noise ratio and the fewer channels that can be relayed.

The solar cell remains the most practical power source in space, delivering about 6 watts per pound. Even at that, Intelsat 2 must make do with about 85 watts. Experts claim that up to 800 watts is possible using only skin-mounted solar cells, and deployable arrays might boost available power into the kilowatt area. But such arrays, like nuclear energy power for spacecraft, must remain in future plans.

Today's problem is doing the most effective job with the equipment available. With power output confined, attention has naturally turned to spacecraft antenna design—itself restricted by other physical considerations.

Satellites are prevented from tumbling uncontrollably through space by giving them a bullet-like spin of about 150 rpm. Spin stabilization eliminates some problems, but creates others, especially for antenna designers. With the satellite spinning, it is impossible to use a conventional directional antenna.

Present communications satellite antennas produce a toroidal or "doughnut shaped" pattern with about 9-dB gain (Figure 2). Better than a omnidirectional antenna, the method nevertheless "loses" considerable energy in the portion of the pattern not touching the earth.

Despun Antennas

Future spin-stabilized satellites will be equipped with devices for focusing this otherwise lost energy, increasing

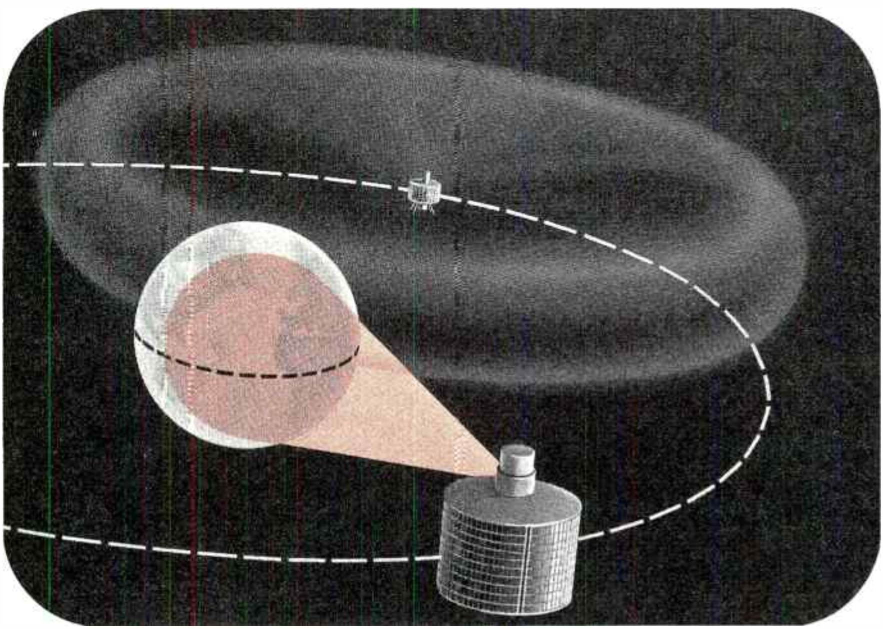

Figure 2. Toroidal pattern of first communications satellites (rear) loses much rf energy to space. Intelsat 3 will focus its communications beam toward earth, using new despun antennas, with up to 16 dB gain.

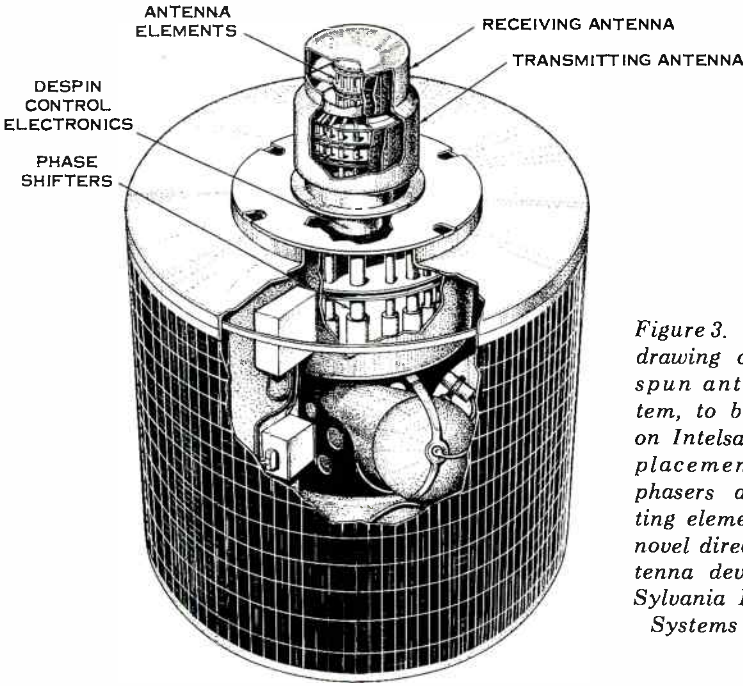

Figure 3. A cutaway drawing of the despun antenna system, to be initiated on Intelsat 3, shows placement of the phasers and radiating elements of the novel directional antenna developed by Sylvania Electronics Systems Division.

the gain considerably. Expected minimum gain will be 13 dB, with peak gain about 16 dB. The trick is to rotate the antenna in the opposite direction to the satellite, thereby keeping the "despun" beam pointed to earth.

Three types of despun antennas are possible: mechanical, electronically switched, and electronic. The mechanical method uses a directional antenna that is physically counter-rotated about the axis of the satellite. The greatest danger is mechanical failure. The electronically switched method systematically shifts rf power from antenna to antenna, keeping overlapping beams in the desired direction. The pure electronic approach—the one selected for the Intelsat 3 satellites—steers the beam by varying the phase of the signal as it feeds a series of radiating elements (Figure 3).

The electronically despun antenna has three major subsystems: an earth center reference system, control circuits, and the radiating assembly. Two redundant horizon sensors scan the earth as the satellite rotates. Control circuits regulate the action of phase shifters, which direct the rf energy to the radiating elements of the antenna. The result is a radio beam continually focused on the earth.

At synchronous altitudes, the earth's disk is just over 17° across. Allowing for satellite stabilization and antenna tracking errors, a beam approximately 19° x 19° would adequately cover most points on the globe. For specific purposes, the beam could be made more directional, thereby increasing the gain. For example, a satellite designed to relay traffic only from the United States to Europe might have a fan-shaped beam 19° x 10° (long to the east-west).

Minimum gain would be increased to 16 dB, with peak gain at 19 dB.

An alternative to spin stabilization is being tested, requiring no onboard thrusters or other control devices. Known as *gravity-gradient* stabilization, the method would maintain the same side of the satellite always facing the earth. A long object in space will tend to align itself vertically with the strongest source of gravity—in this case, the earth. Extendible arms could, in effect, make the satellite such a "long" object. Highly directional antennas could then be accurately pointed earthward.

Early Bird

Important advances are continually incorporated in new satellite designs. Our first communications satellite now seems small compared to vehicles being developed. Early Bird weighs 85 pounds, is 28 inches in diameter, has a solar power capacity of about 46 watts, and can relay 240 two-way voice channels, or two-way television. The communications system has two transponders (receiver-transmitters), one for each direction of traffic. The transmitter output comes from one 6-watt traveling wave tube; a second TWT is carried for redundancy. The bandwidth of the transponder is 25 MHz. Receiver frequencies are in the 6-GHz band, with transmission back to earth in the 4-GHz range. Telemetry and control signals to and from the satellite are at VHF frequencies in the 136 MHz range.

Intelsat 2

The latest addition to the global system, Intelsat 2, has five times the bandwidth (125 MHz) of the Early Bird, and three times the output power (18 watts). Increased power provides greater geographical coverage, while the wideband capability allows multiple access for the first time. Now a number of different ground stations can channel through the satellites at the same time. Capacity remains at 240 high-grade voice channels.

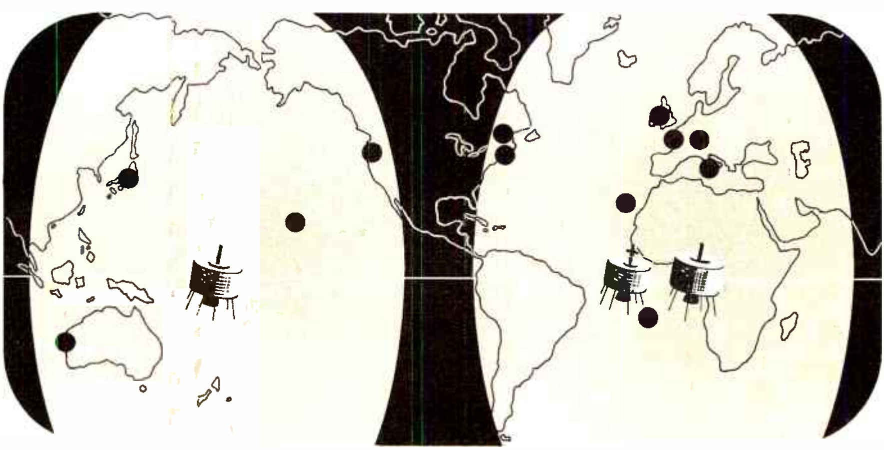

Figure 4. Ground stations on both sides of the Atlantic and Pacific will be connected through Early Bird and Intelsat 2 satellites.

So called "quasi-linear" transponders are a unique part of the multiple access design; transmitter output increases linearly with an increase in input power. There is no radiated power from the satellite until a signal is received from earth. If several signals are received simultaneously, transmitter power is divided among them proportionally according to the power of the received signal. The quasi-linear method reduces intermodulation products and crosstalk inherent in the Early Bird fixed-output transponder.

Four 6-watt TWT's are carried in the spacecraft. Three of them normally will work in parallel; the fourth is a spare. The Intelsat 2 satellite has an orbital weight of 165 pounds, is 56 inches in diameter, and produces 85 watts of power from solar cells. Communication and telemetry frequencies are virtually the same as in Early Bird.

Electronics

Within the Intelsat 2 transponder, the incoming 6-GHz signal passes through a low-noise tunnel diode rf amplifier to a directional coupler where command signals are extracted (see Figure 5). The communications signal is converted directly from 6 GHz to 4 GHz in a mixer section, then delivered to a driver TWT. The driver tube operates only on command, providing ground control selection of two redundant receivers. A beacon frequency (for tracking) is then added before the signal is supplied to the four output TWT's.

The satellite is capable of receiving a signal at any frequency between 6283

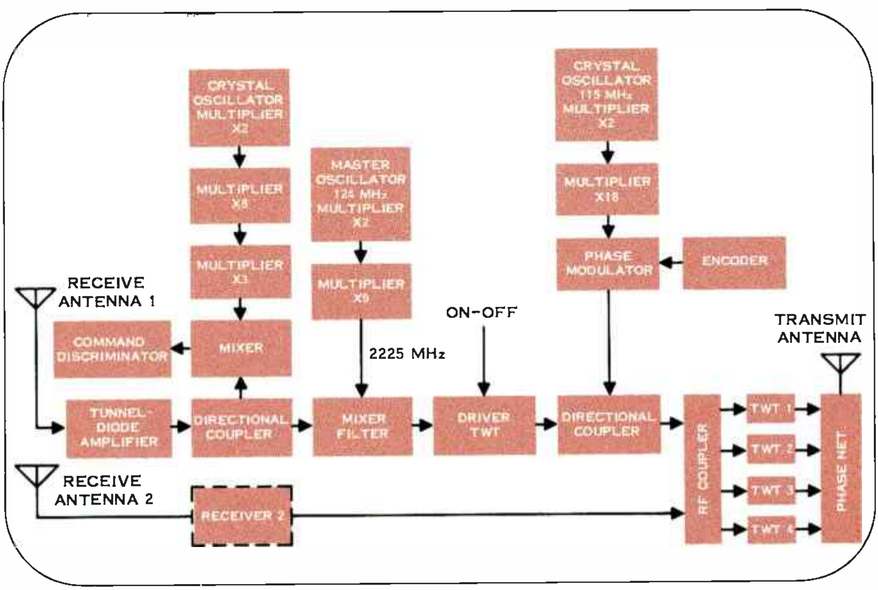

Figure 5. Communications system block diagram for Intelsat 2, built by Hughes Aircraft Co.

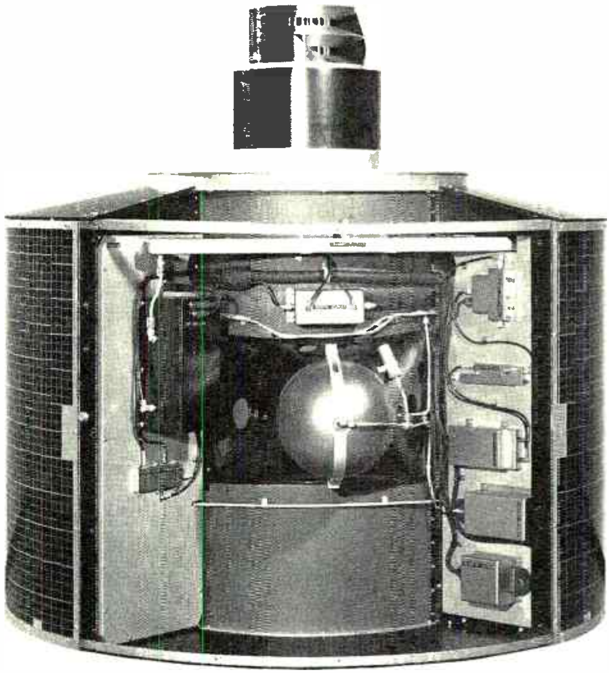

Figure 6. Seen inside Intelsat 3, to be launched in 1968, are many of the electronic and propulsion systems included in the third generation communications satellite being built by TRW Systems.

MHz and 6409 MHz. The incoming signal is translated at the mixer by 2225 MHz to the transmit band of 4058 MHz to 4184 MHz.

Telemetry and control signals are available on both VHF (136 MHz) and through the modulated beacon carried with the communications channels.

Together with adding satellite communications capability over the Pacific and increasing service in the Atlantic, Intelsat 2 will play a vital role in the Apollo space program. NASA will use a number of circuits for astronaut voice relay, spacecraft television, high-speed tracking data, and telemetry. Transmission path will be from the Apollo spacecraft to NASA surface stations (including special tracking ships at sea), and then via the communications satellites to mainland ground stations.

Intelsat 3

Even higher capability is being designed into the Intelsat 3 satellites, to be launched in 1968. Measuring 56 inches in diameter, weighing 250 pounds, and with solar power of 160 watts, the communications package will be able to handle at least 1200 two-way voice channels or four television channels (See Figure 6).

Each of the two transponders aboard Intelsat 3 will have a bandwidth of 225 MHz, with high-level 10-watt TWT output stages. Incorporating electronically despun antennas, the satellites will have an effective radiated power of about 22 dBw (decibels above one watt), compared to about 15 dBw for Early Bird. Like its predecessors, Intelsat 3 will use rf amplification, with translation from 6 GHz to 4 GHz.

Table A. Frequency allocations agreed on at the 1963 Geneva Extraordinary Administrative Radio Conference. Commercial bands, shared with terrestrial systems, are shaded; others are for special applications (including military).

Frequency Bands	Service	Frequency Bands	Service
1700-1710 MHz	Space Research (Telemetering & tracking) (shared)	5725-5850 MHz	Communication-Satellites (Earth-to-satellite) (shared)
1770-1790 MHz	Meteorological-Satellites (shared)	5850-5925 MHz	Communication-Satellites (Earth-to-satellite) (shared)
2290-2300 MHz	Space Research (Telemetering & tracking in deep space) (shared)	5925-6425 MHz	Communication-Satellites (Earth-to-satellite) (shared)
2690-2700 MHz	Radio Astronomy (exclusive)	7250-7300 MHz	Communication-Satellites (Satellite-to-Earth) (exclusive)
3400-4200 MHz	Communication-Satellites (Satellite-to-Earth) (shared)	7300-7750 MHz	Communication-Satellites (shared)
4400-4700 MHz	Communication-Satellites (Satellite-to-Earth) (shared)	7900-7975 MHz	Communication-Satellites (Earth-to satellite) (shared)
4990-5000 MHz	Radio Astronomy (shared in some areas)	7975-8025 MHz	Communication-Satellites (Earth-to-satellite) (exclusive)
5250-5255 MHz	Space Research (shared)	8025-8400 MHz	Communication-Satellites (Earth-to-satellite) (shared)
5670-5725 MHz	Space Research (Deep space) (shared)	8400-8500 MHz	Space Research (shared) (exclusive in some areas)

Life expectancy of synchronous satellites is about five years, governed by the onboard fuel supply for positioning thrusters. When the fuel is expended, the satellite will begin to drift slowly westward. Its communications capability, however, could continue for some years. The life of the electronics is primarily dependent on the source of electrical power—solar cells. These cells deteriorate with exposure to radiation, a common hazard in space, especially near the Van Allen radiation belts. Intelsat 3, for example, will begin its service with 161 watts of available power. After five years only about 105 watts can be expected from the solar cells. But this is still enough to support at least limited communications.

Modulation

The satellite microwave repeater has much more bandwidth than its terrestrial cousin. Bandwidth in satellites is needed not only to increase channel capacity, but to allow multiple access from many ground stations. Each ground station will use a discrete carrier frequency, with a number of multiplexed channels. Frequency division multiplex with frequency modulation (FDM/FM) is used in current systems, but other modulation techniques are possible. Time division multiplex (TDM) tests have been completed with the Early Bird satellite. Pulse code modulation (PCM) was used successfully to carry voice and data signals between two North American terminals.

Russian Satellites

Even though Intelsat countries have 90 percent of the international communications potential, considerable work is being done by nonmember countries—especially the Soviet Union. Russia has lofted several Molniya-class communications satellites in 12-hour elliptical orbits. Successful transmissions of many types of signals, including color television, have been carried out in joint experiments with the French. While the Russian satellites apparently lack channel capacity, they do boast high-powered transmitters and other "weighty" equipment. The Molniya has a command receiver, 40-watt transmitter, two reserve transmitters, and two steerable parabolic antennas. In addition, the satellite has orbital adjustment and three-axis attitude control capabilities. Apparently with room to spare, the Russians are also including meteorological equipment on board, returning cloud photos to weathermen.

Expanded Uses

Great potential in distant communications exists in many areas beyond the telephone and television industries. The Federal Aviation Agency is interested in establishing service for transoceanic flights, so often out of reach of HF and VHF radio. This could come by mid-1967. The same advantage would be available to ships on the high seas.

The possibility of broadcasting television directly to the home via satellite has received considerable attention recently. Though the practicality of such a system may be questioned for some years, technologically it is not difficult to imagine.

Satellites vs. Cables

Of immediate interest to international common carriers is the commercial value of satellites. Coaxial submarine cables—only ten years old themselves—remain as the backbone for communications across the oceans. More high-capacity cables will be installed in the next five, ten, or even more years. From the present 3500 voice channels, international service could jump to over 7000 in the next five years, and triple in 10 years. Much of this growth, especially between dense traffic areas, can be handled by high-capacity cable. Of course, satellites will absorb their share of the market.

Probably more important are the new markets satellites will create for international communications. Continent-to-continent television, for example, had to wait for satellites—cables lacked the necessary bandwidth. Satellites will likewise provide a logical medium for high-speed data transmission between commercial centers around the world.

We have obviously crossed the threshold toward complete global telecommunications.

(Editor's note: Additional information on specialized satellite subjects may be found in previous issues of the Demodulator. The May 1962 issue includes a more detailed examination of orbital mechanics in communications satellites. The August 1966 edition concerns echo suppression, a technique vital to communications through satellites. A discussion of ground stations is planned for the January 1967 issue.)

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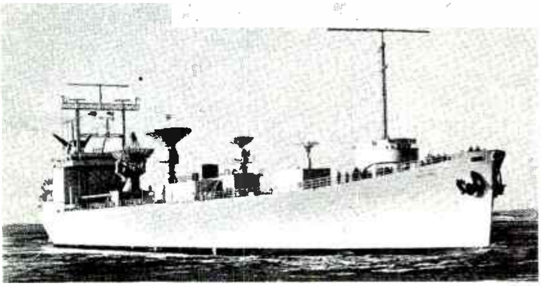
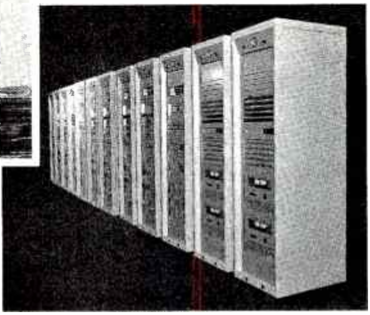


USNS VANGUARD

46A MULTIPLEX



Communications between the Apollo moonship and earth will be conveyed by Lenkurt 46A multiplex equipment aboard tracking ships stationed around the world.

Signals from the spacecraft will be received at ships like the USNS Vanguard, and relayed by communications satellite to the mainland. The 46A also is used at a number of satellite ground stations.

Suited for small 4-channel systems, or high-density routes of 600 channels or more, the 46A multiplex system has the unmatched ability to handle voice and data signals in *any* proportion. For information, write Lenkurt, Dept. B720.

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