The Lenkurt Demodulator

NEWS FROM LENKURT ELECTRIC

VOL. II, NO. 5 MAY, 1962

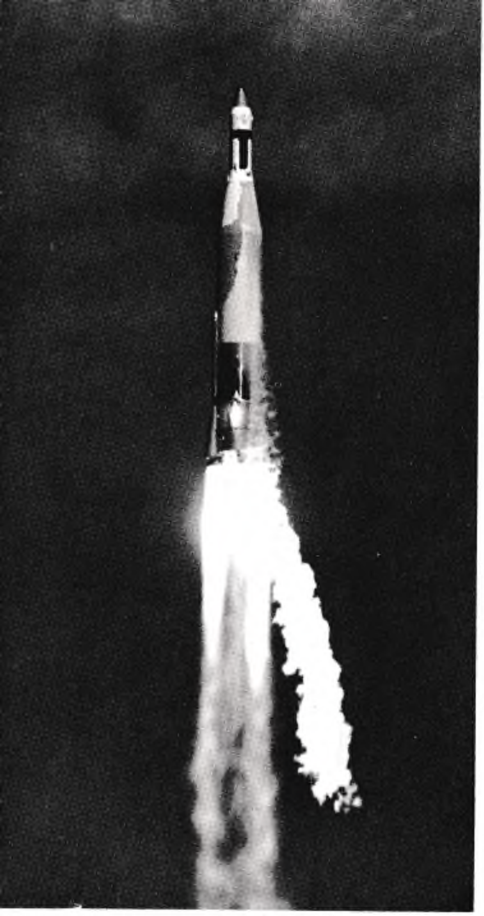
EARTH SATELLITE COMMUNICATIONS

A giant step forward in the art of telecommunication is now in the making. Unlike such advances in the past, this one results not so much from new discoveries in electronics or communications technique, but from man's rapidly increasing ability to overcome the raw forces of nature.

Artificial earth satellites are the most recent benefit from this growing power, and now enable man to place television "weather eyes," radio repeater stations—and even communications switching centers—high above the earth where they can serve very large areas. This article surveys some of the fundamentals of earth satellites and how they can be used for telecommunications.

In the year 1267, Roger Bacon suggested that distant communication by magnetic means might be possible. By 1746, the deed had been accomplished over two miles of wire. Shortly after Samuel F. B. Morse's successful demonstration of his code in 1844, telegraphic communication spread swiftly throughout the world. The subsequent invention of telephony and radio, then microwave and television, helped push our global civilization to new heights.

Despite the tremendous improvements made possible by new techniques, communication has never been really cheap. The physical plant required—the miles of wire or cable, the radio repeaters, the complex terminal equipment—all have placed a price on communication that has sharply limited it to areas where demand is sufficient to justify the cost. Thus, while an underseas cable able to carry a few dozen channels of voice and telegraph might be justifiable, nobody has been able to afford a cable that could carry a television transmission across the oceans. Similarly, where traffic is lighter, perhaps no cable at all is economically feasible. In such areas, the burden of communications has fallen on fairly dependable "high-frequency" radio communications. Even this is fairly expensive in terms of communications



LOCKHEED MISSILES AND SPACE CO.

Figure 1. Atlas rocket carrying Agena satellite roars into sky. Hundreds of tons of fuel are required to place even small objects in orbit. Once difficult to achieve, the control and reliability necessary for successful orbiting is now routine.

capacity, since only single channels are usually practicable; available bandwidth and the propagation characteristics may not permit more.

Communication satellites appear able to provide a very efficient solution to this problem. Circling the earth beyond its atmosphere, satellites can provide a direct link between many distant points below.

Why Satellites?

Actually, there is very little novel or revolutionary about satellite communications except the ability to place the required equipment in orbit. Certainly, the satellite-borne equipment must be specially designed to fit the needs of the application, but no new or novel basic principles are required.

Many technical factors favor satellites for communication. Microwave frequencies, with their tremendous bandwidth and information capacity, are the natural choice for this service. Signals between one and ten gigacycles (thousand megacycles) pass through the atmosphere with relatively little attenuation. Below this range, radio energy is scattered by the ionosphere, and atmospheric noise smothers the signal; at higher frequencies, atmospheric oxygen and water vapor rapidly absorb the transmission.

This microwave "window in the atmosphere" makes it possible to transmit television signals or hundreds of voice channels up to a satellite for relay to points thousands of miles away. This is in contrast to conventional methods which may require hundreds of repeaters to transmit the signal between two points. The satellite's biggest advantage is that it has a direct radio "view" of very large areas of the earth, and can provide a common link between all the distant points in sight. This single fact makes it feasible to establish truly global communications on a scale never before possible. In addition, the ability to span thousands of miles using only a single repeater promises communications of a quality not possible with conventional techniques.

How to Orbit

Artificial satellites are now possible because we have learned how to produce and control the huge amounts of energy that are necessary to place even small objects in orbit. All objects on or near the earth are drawn toward it by a relentless gravitational force that is proportional to their combined mass, but inversely proportional to the square of their distance from the earth's center of gravity. Thus, the farther away an object is from the earth, the less it "weighs," and the weaker the pull of gravity upon it.

In order for an artificial satellite to achieve orbit, it must be lifted above the atmosphere and started moving around the earth at the exact speed required to produce a centrifugal force just equal and opposite to gravitational force at that altitude. In effect, the satellite is falling freely toward the earth, but because of its tangential or sideward velocity (which would carry it away from the earth in the absence of gravity), it remains at the same altitude, as diagrammed in Figure 3. If the tangential velocity is greater than required to just balance the pull of gravity, the object tends to fly off into space. If the satellite is slowed down — by atmospheric drag, for instance—it is pulled back to earth by gravity.

Since the earth's gravitational attraction becomes weaker at greater altitudes, high-altitude satellites do not need to circle the earth as rapidly as low satellites to overcome gravity. Thus, the period required for each orbit becomes a function of the satellite's altitude. Actually, the period should vary with the mass of the satellite, since gravitational force is proportional to the product of the masses of the earth and the satellite. However, since the satellite's mass is so very tiny compared to that

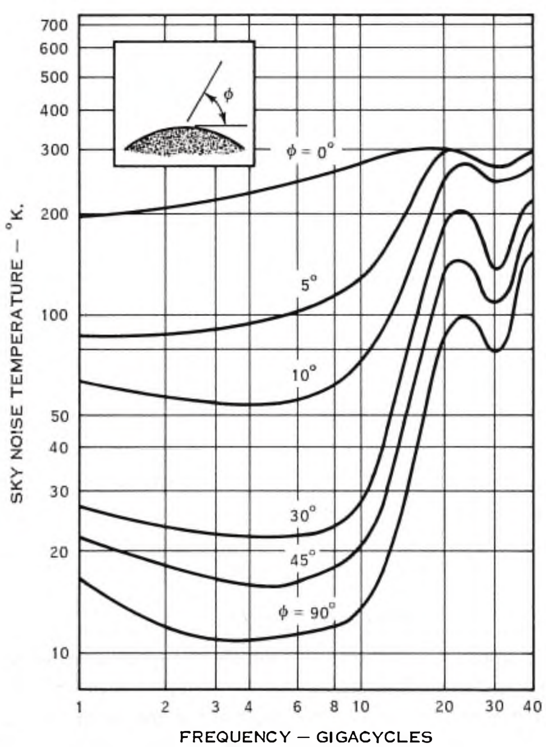


Figure 2. Atmospheric noise increases sharply above ten gigacycles (kmc), particularly when antenna angle with horizon is small. Increase in noise corresponds to attenuation by oxygen and water in atmosphere. Galactic noise from stars and interstellar gases increases rapidly at frequencies lower than one gigacycle.

of the earth, its effect is negligible. Only when the satellite approaches the size of the moon—which has a mass about 1% that of the earth—does its mass have a noticeable effect on orbital period.

The period of an artificial satellite in circular orbit can be easily calculated when altitude is known, by using the relationship

$$t^2 = \frac{a^3}{k}$$

where a is altitude or distance *from the earth's center of gravity* (not the surface), and k is a constant. For convenience, assume that the radius of the earth is 4000 miles. Then $k = 8.9 \times 10^6$, when altitude a is given in statute miles, and the period or time t is in minutes. Due to the rounding of actual values, the period determined in this way is only approximate, but is still accurate to within a few seconds of the true value.

We find that a satellite 100 miles above the surface circles the earth in about 87.5 minutes, while a satellite 600 miles up requires 104 minutes. At an altitude of a thousand miles, a satellite completes its orbit in 118 minutes. As the altitude becomes still greater, the orbital period becomes longer, until at an altitude of 22,270 miles, a satellite orbits the earth in exactly the same period of time as the earth's rotation—just under 24 hours. Such a satellite is called a *synchronous* satellite because its orbit is synchronized with the rotation of the earth. When a synchronous satellite travels eastward directly over the equator, it appears from the surface to be stationary in the sky (if it could be seen), and is sometimes referred to as a "stationary" satellite.

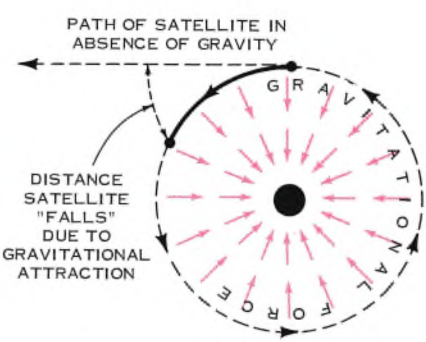


Figure 3. Tangential velocity of satellite keeps it clear of earth, although it is constantly "falling" freely. When velocity, direction and gravitational field just balance, satellite "falls" in circular orbit. Because of small errors of speed or direction, most orbits are eliptical rather than circular.

Passive versus Active Satellites

Any communication satellite system will require compromises between many design factors which tend to conflict with each other. Some of these factors are quality (a function of the signal-to-noise ratio), cost, reliability, and coverage. One basic decision is whether to use "active" or "passive" satellites.

A passive satellite is one used merely as a reflector of signals transmitted from the earth. An active satellite is one which carries radio equipment for receiving and re-transmitting the signal.

The passive satellite has the tremendous advantage of economy, simplicity, and reliability. With no functions to perform except "to be there," and with nothing to fail or get out of adjustment, the passive satellite may be able to last indefinitely. Such a communications satellite has already been tried successfully. *Echo I,* the first experimental passive communications satellite, was placed in a 1000-mile orbit in August, 1960. *Echo,* shown in Figure 5, is a metal-covered balloon 100 feet in diameter. Since its launch, *Echo* has been used to relay voice, music, and even television transmissions over great distances. Although it is still in orbit, it has now become wrinkled and distorted so that reflected signals now scintillate or "twinkle"—varying in strength by a factor of about ten to one.

The main disadvantage of passive satellites is the extremely large amounts of transmitter power required to obtain a useful signal at the receiver.

Disregarding antenna sizes and operating frequency, the transmitter power required to obtain an adequate signal is proportional to the fourth power of the distance to the satellite, and inversely proportional to the square of its diameter:

$$\frac{\textit{Transmitting power}}{\textit{Received power}} = \frac{\textit{altitude}^4}{\textit{diameter}^2}.$$

This indicates that if, for instance, 10,000 watts of transmitter power are required (as in the case of *Echo I*) to return a barely adequate, narrow-band signal from a 100-foot satellite orbiting 1000 miles above the earth, effective transmitter power would have to be increased to 810,000 watts if the satellite altitude were increased to 3000 miles. Alternatively, the same results would be obtained if the diameter of the satellite were increased to 900 feet. If the satellite were located 5000 miles above the surface, six million watts of transmitter power would be required or the satellite would have to be nearly 2½ miles in diameter.

Since the satellite itself is a passive reflector, it imposes no important restrictions on bandwidth, but increased bandwidth requires a proportionate increase in transmitter power, thus further restricting the type of transmission that could be handled economically.

Even if extremely large amounts of transmitter power should prove to be economical, a very difficult problem of

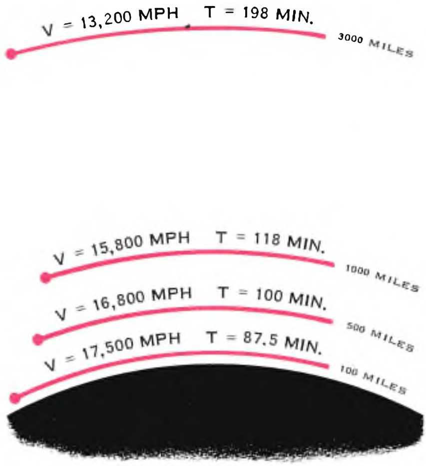


Figure 4. Gravitational force decreases with increased altitude, requiring lower velocity to maintain orbit. Some typical velocities and periods for earth satellites of different altitudes are shown. Although less velocity is required at high altitudes, much more energy must be expended in reaching it.

interference with other communications would very likely result. Even when extremely good antennas are used, antenna side lobes, and energy dispersed and reflected in the atmosphere could interfere with other services in the same frequency band over great distances.

If we seek to reduce power or increase bandwidth by *lowering* satellite altitude, we encounter other problems. Below about 250 miles, the life of the satellite will be shortened by drag from the outer fringes of the atmosphere. More important, however, the area that can be covered by a low-altitude satellite is greatly reduced. The low-altitude satellite crosses the sky very rapidly, making it difficult to locate and track, and leaving little time during which it can be shared or viewed by both terminals.

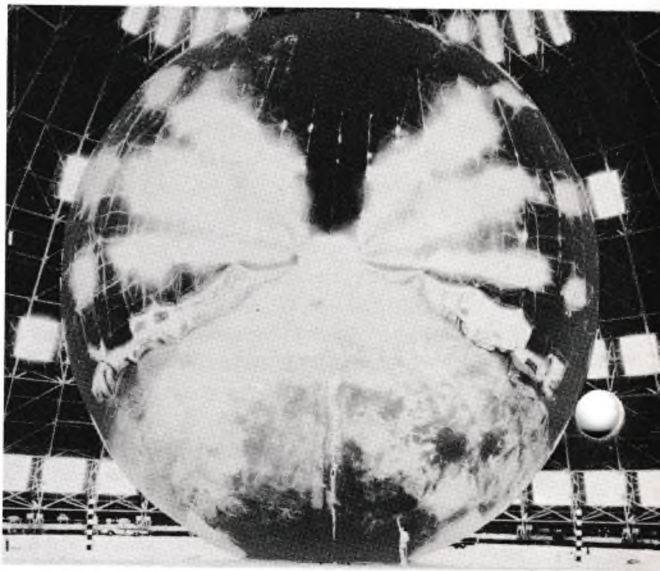
By contrast, the active communications satellite is freed of the altitude limitations of the passive satellite. It has many unique problems of its own, however, the most pressing being that of reliability. An active satellite consists of one or more radio transmitters and receivers, and a suitable source of power. This equipment must be rocketed into orbit and then operate properly for years without any possibility of receiving routine maintenance and occasional adjustment or repair.

The environment beyond the atmosphere is incredibly harsh. Floods of radiation and ultra-high energy particles from the sun erode the proper function of components, and sap the ability of silicon solar cells to continue providing vital electric power. Microscopic meteorites travelling many times the speed of a rifle bullet riddle the satellite, giving it a sort of cosmic sandblasting, occasionally hitting some vital element and putting the satellite permanently out of service.

However, the tremendous signal power advantage of an active satellite makes this approach worth a serious effort. A very small satellite transmitter returns a much greater signal to earth than would be reflected even from large, low passive satellites. It has been calculated that an output power of only two watts will suffice for transmitting broadband signals from a satellite closer than three thousand miles, even if the transmitting antenna radiates equally in all directions. Of course, this requires rather large receiving antennas at the ground stations. No matter how far out the satellite is located, however, the two-watt signal will still be sufficient if the transmitted energy is directed into a beam which just covers the disk of the earth. Thus, the farther the satellite is from earth, the narrower the transmitted beam must be. At the synchronous satellite altitude of 22,300 miles, antenna beamwidth should be about 17.5°.

The need for directive antennas introduces a new problem: that of keeping

Figure 5. First passive communications satellite, Echo I, during trial inflation before launch. Although 100 feet in diameter, Echo weighs only 130 pounds. Satellite is a balloon of strong Mylar plastic covered with thin film of aluminum. Launched into nearly perfect circular orbit on August 12, 1960, Echo still orbits. Pressure of sunlight has caused shape of orbit to change with time.



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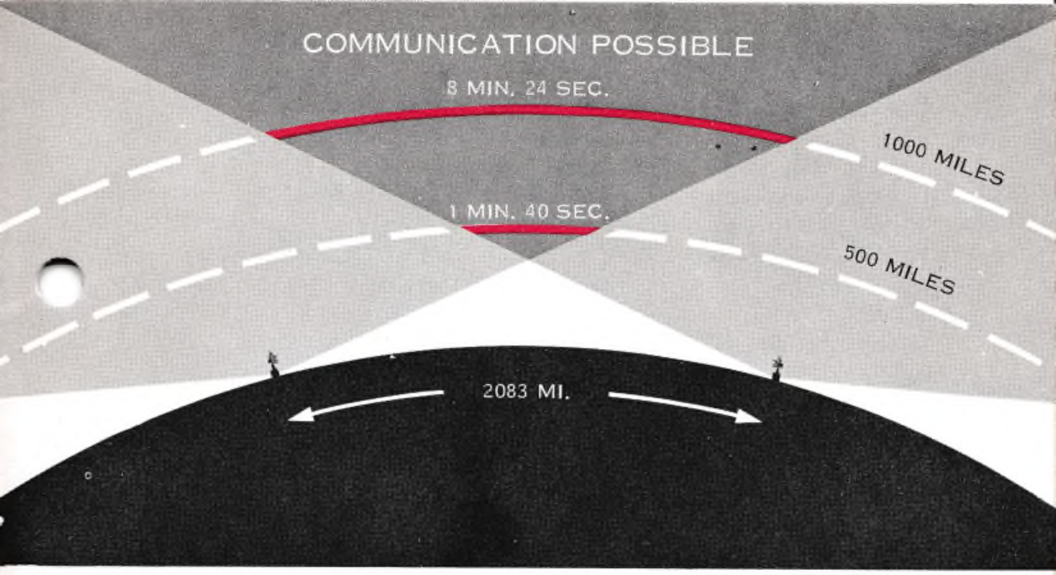

Figure 6. A major difficulty of low-altitude satellites is their rapid transit time and limited coverage. For communication, satellite must be within view of two stations simultaneously. Experimental low-level satellite soon to be launched will be placed in highly eliptical orbit designed to increase its time over northern hemisphere at expense of southern hemisphere.

the antenna pointed toward the earth. For a satellite in orbit there is no "up" or "down". Since gravity and centrifugal force exactly offset each other, the satellite is weightless, and gravity cannot practicably be used as a reference in aiming the antenna. Some satellites have been oriented by sighting the earth's horizon in several directions, then altering the attitude of the satellite by small jets of compressed gas, or by rotating small flywheels in the appropriate direction, thus moving the satellite in the opposite direction by reaction.

If some sort of stored propellant such as compressed gas or hydrogen peroxide is carried aloft with the satellite to keep it oriented, the useful life of the satellite will end shortly after the propellant is exhausted. A system using electrically-driven flywheels might last much longer. In this method, a flywheel (which might be the motor itself) is spun in the opposite direction to that desired of the satellite. Since nothing impedes the movement of the satellite, it would rotate until stopped by a brief reversal of the flywheel. However, this technique appears to be suitable only for overcoming small oscillatory or irregular forces acting on the satellite, and must be supplemented by some other method of attitude control when some constant force or torque acting on the satellite must be overcome.

Another possible orientation method which has been suggested is to use suitably placed coils aboard the satellite, which would be energized as required to work against the earth's magnetic field, in much the same fashion as an electric motor operates. The magnetic field is weak at high altitudes, and the resulting torque would be small. However, only a little force is required in the friction-free vacuum of space. Regardless of the method or combination of methods used for directing satellite antennas toward the earth, and keeping the panels of solar cells pointed toward the sun, it is imperative that they continue to work reliably—or the satellite dies.

High or Low?

Although communications satellites are still highly experimental, intense planning is going into the configuration of the future systems. One of the most important considerations is the orbital altitude of the satellites, for altitude has a profound effect on the cost and function of the system. Many space scientists believe that the ultimate system will use synchronous satellites located 22,300 miles above the equator. Because a signal relayed through a satellite requires about 0.3 second to travel from one terminal to the other, some have feared that the resulting 0.6-second delay before a reply could return would be too objectionable in two-party conversations. However, tests indicate that talkers adjust rapidly to this delay.

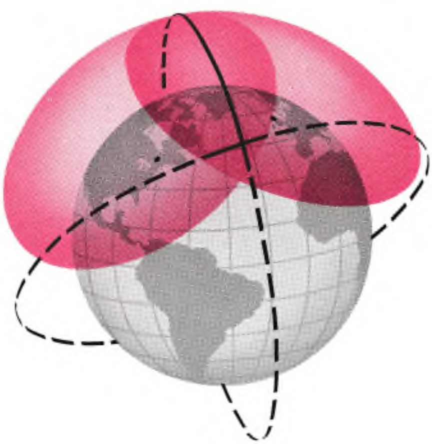

Figure 7. Time during which communication is possibe between stations will vary with location of orbit relative to stations. This will change with each pass. Tinted area shows coverage of each station and where they overlap. Communication between the two is possible only in overlap area.

All so-called two-wire talking circuits experience "echoes" due to unavoidable characteristics of the telephone equipment, but these echoes usually return to the speaker so fast that they are masked by some of the original sounds themselves. The long delay imposed by a high-altitude satellite relay allows the echo to be heard, however. The effect is extremely distracting and may even be intolerable to the talkers. It was once feared that this problem was so formidable that synchronous satellites would necessarily be limited to such one-way services as relaying television or business data. However, a new type of echo suppressor developed by the General Telephone Laboratories appears to have overcome this problem quite satisfactorily.

A more important consideration is the effect of satellite altitude on system *cost*. A synchronous satellite appears to hang nearly motionless in the sky. At somewhat lower altitudes, the satellite travels slowly across the sky, while at low altitudes, it races from horizon to horizon very swiftly. For instance, a satellite 250 miles high and passing directly overhead is in view less than 8½ minutes. At best, only about 6½ minutes of this would be suitable for communications, since signal quality is poor when the tracking antennas are within 10° of the horizon. Below 10°, noise from the earth and its atmosphere degrade and mask the signal. The problems of anticipating, locating, and tracking a satellite at this altitude are formidable and their solution very costly.

At greater altitudes, the problem becomes progressively easier; a thousand-

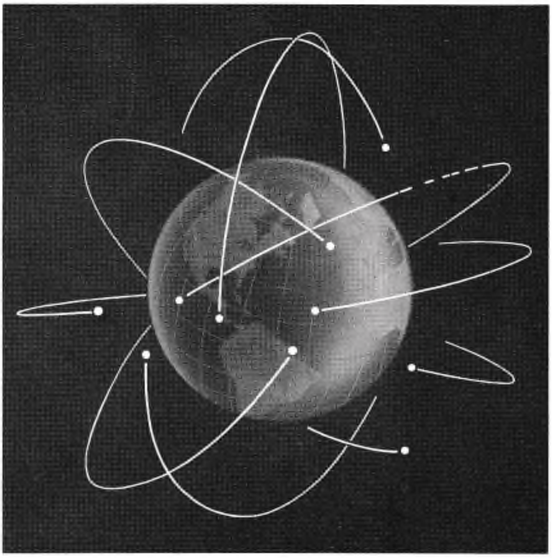

Figure 8. Fifty or more low- or medium-altitude satellites in random orbits will be required to assure continuous communication between any two stations. Number must be even larger to allow communication with other stations. Although numerous, these satellites can be relatively cheap. Terminal costs are high, due to finding and tracking difficulties.

mile satellite (which passes overhead) remains in view about 20 minutes.* However, only about half of this time is useful for communications, since the satellite must be tracked by *two* stations located far apart. Thus, in the simplest case, a 1000-mile satellite could be tracked simultaneously by two stations 1950 miles apart for only about ten minutes before it would be lost by one. A 3000-mile satellite could be tracked for 24 minutes by stations located 3100 miles apart, providing the satellite passes directly over both stations.

In a system using relatively low altitude satellites—that is, lower than synchronous altitude, many satellites will be required to assure that at least one will be in view of a pair of terminal stations most of the time. Multiple access to the satellite system—i.e., use of the system by several pairs of terminals in the same part of the world—is possible only by increasing the number of satellites visible at one time.

Each terminal will require at least two tracking antennas; while one tracks, the other searches for the succeeding satellite. A computer will be required to store information about the orbits of all the satellites, and to point the antennas at the proper point in space at the right instant. In such a system, the necessary ability to follow a satellite across the sky limits the size of the antenna and therefore its performance. However, large, expensive tracking facilities might be easily justified for linking points which share very heavy traffic. If the satellite orbits are low enough to avoid the need for aiming satellite antennas downward, the satellites themselves can be relatively cheap.

Synchronous Satellites

The synchronous satellite system has an entirely different set of conditions. The satellites themselves are relatively expensive, while the ground stations are

*The earth's rotation will increase these figures somewhat, depending on the direction travelled by the satellite, and its period. These examples disregard this factor.

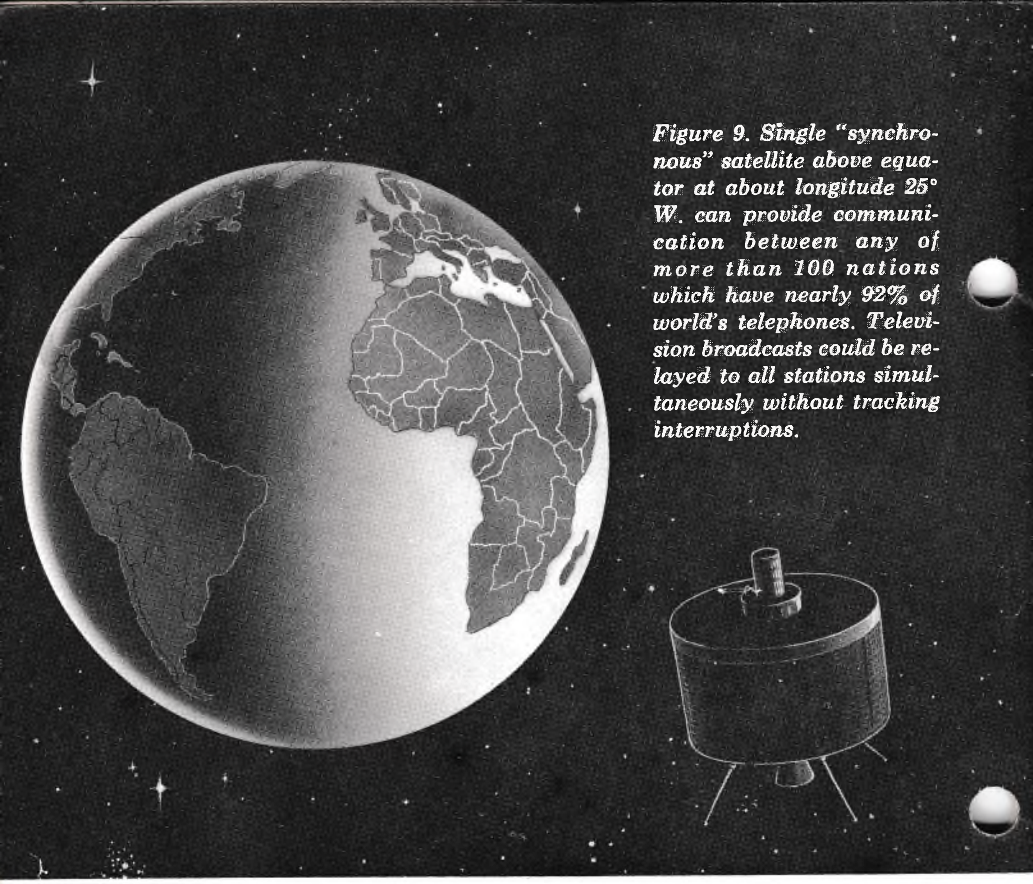

Figure 9. Single "synchronous" satellite above equator at about longitude 25° W. can provide communication between any of more than 100 nations which have nearly 92% of world's telephones. Television broadcasts could be relayed to all stations simultaneously without tracking interruptions.

cheap. The greatest expense is getting the satellites into orbit. In addition to the much more expensive rocket boosters needed to achieve the desired altitude, a very "sophisticated" procedure is required to alter and adjust the direction of the satellite in order to orbit it in the equatorial plane at the correct distance from the earth.

The synchronous satellite provides multiple access by many terminals. Coverage is so great that three satellites can cover the entire earth—excluding only the polar regions. Even a single satellite located over the equator at longitude 25° W will be able to provide service to more than 100 nations, as shown in Figure 9. This includes all of Central and South America, Africa, western Europe, and eastern Mexico and North America.

Simultaneous multiple access would require that each terminal maintain extremely high precision and stability of transmitting frequencies—on the order of 1 part in 10^{10}. (See DEMODULATOR, *January*, 1962 for a discussion of how this may be done.)

However, terminal requirements are still greatly simplified. Since the satellite always occupies the same region of the sky, there is no need for a second tracking antenna and a computer with which to "acquire" successive satellites. Although there are a number of forces which may "perturb" the orbit of a synchronous satellite, causing it to drift from its original position, these are quite small, and may permit large antennas to be constructed which have only a limited tracking capability, thus reducing their cost very greatly. Already several experimental antennas of this type have been built, and which are able to track objects in the sky by moving the "feed" or focal point of the antenna, rather than the large reflector itself. Other antennas have been designed which are able to track moving objects electronically by changing the phase relationships between elements of large antenna arrays.

Thus, the most expensive elements of a terminal station are eliminated in a synchronous system. Since economics largely determines the availability of communications to areas of light traffic, the synchronous satellite with its much lower terminal costs promises to extend wide-band transmission and communication to many areas of the world that otherwise could not support the more elaborate facilities required for low-altitude satellites. Of course, such a system will have to be compatible with existing world-wide communications networks.

Despite the desirability of synchronous satellites for certain types of service, many problems must still be solved before they can become more than an experiment. Although we have now achieved a fairly high degree of reliable capability in placing various objects in low orbits, this has not yet been achieved for synchronous altitudes. In addition to requiring much more powerful rockets than we now have available, these launching systems will have to be able to make major course deviations, and well-controlled fine adjustments of orbital speed in order to achieve the desired ultimate orbit. Even after achieving a perfect orbit, minor corrections will have to be made from time to time in order to minimize the tracking requirement at the terminals. This will require operational reliability of a sort still rare.

"Orbiter Dictum"

Accomplishment of a truly global communications system capable of exchanging television and other cultural information between the people of many lands will have profound benefits for all. We are now on the threshold of this achievement. Although there were many bitter disappointments in early attempts to place objects in orbit, this has now become quite routine. Similarly, early failures may be expected in the more advanced communications satellite experiments now impending. However, even if these failures occur, they will be stepping stones leading to eventual success. •

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The new echo suppressor eliminates the problems of speech clipping and speech chopping which are characteristic of conventional echo suppressors under certain conditions. Any number of 931A Echo Suppressors may be operated in tandem without degrading speech quality.

Operating principles and performance characteristics of the new echo suppressor are described in Form 931A-P4 (Issue 2), now available on request from Lenkurt or Lenkurt Field Offices.


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