SATELLITE COMMUNICATIONS

Information and Activities for students grades 7 - 12

Prepared by Dr. Regis Leonard for NASA's Lewis Research Center

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SATELLITES IN GENERAL

Part 1 of Section 1 (SATELLITE COMMUNICATIONS - A SHORT COURSE) of SATELLITE COMMUNICATIONS, prepared by Dr. Regis Leonard for NASA Lewis Research Center

What Keeps Objects in Orbit?

For 10,000 years (or 20,000 or 50,000 or since he was first able to lift his eyes upward) man has wondered about questions such as "What holds the sun up in the sky?", "Why doesn't the moon fall on us?", and "How do they (the sun and the moon) return from the far west back to the far east to rise again each day?" Most of the answers which men put forth in those 10,000 or 20,000 or 50,000 years we now classify as superstition, mythology, or pagan religion. It is only in the last 300 years that we have developed a scientific description of how those bodies travel. Our description of course is based on fundamental laws put forth by the English genius Sir Isaac Newton in the late 17th century.

> **Please note**, we say we have a "description" of how the sun and moon travel – not an "explanation." Even Sir Isaac, after publishing his theory of gravitation, made that distinction. Although his theory was an accurate description of how gravity works and was consistent with every bit of experimental evidence available at that time, he was careful to disavow any knowledge of why gravity worked that way.

The first of Newton's laws, which was a logical extension of earlier work by Johannes Kepler, proposed that every bit of matter in the universe attracts every other bit of matter with a force which is proportional to the product of their masses and inversely proportional to the square of the distance between the two bits. That is, larger masses attract more strongly and the attraction gets weaker as the bodies are moved farther apart.

> **OPTIONAL FOR THE MATHEMATICALLY INCLINED**
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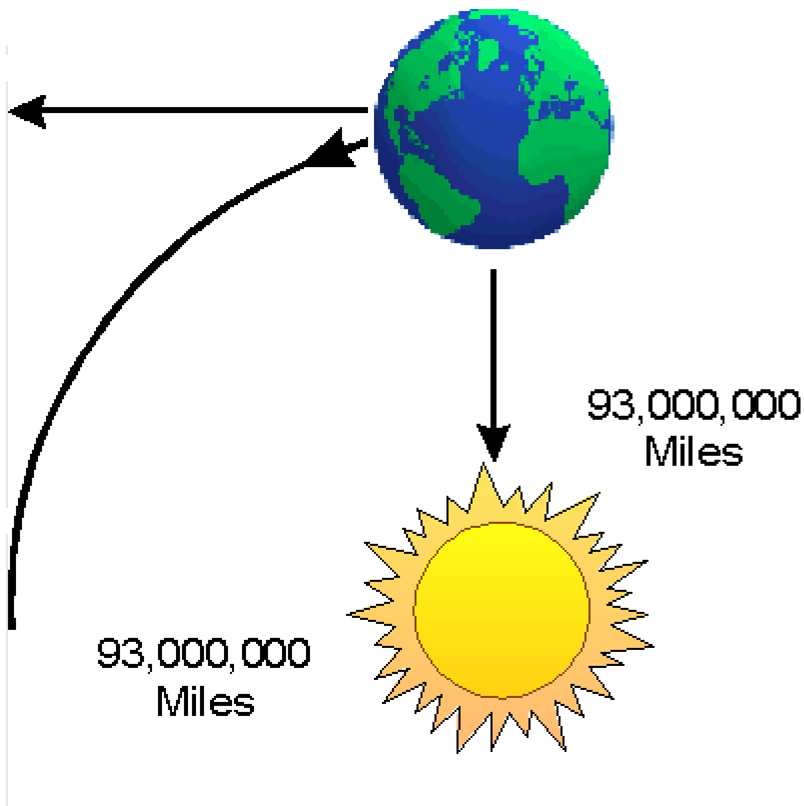
> Stated mathematically, Newton's law of gravity says that the magnitude of the attractive force (between the earth and the sun for example) is given by:
>
> $F = G(M_{earth}\, M_{sun}) / R^2$
>
> where:
>
> M_{earth} is the mass of the earth
> M_{sun} is the mass of the sun
> R is the distance between the sun and the earth, and
> .G is a constant which was measured by Cavendish in the late 18th century

Newton's law of gravity means that the sun pulls on the earth (and every other planet for that matter) and the earth pulls on the sun. Furthermore, since both are quite large (by our standards at least) the force must also be quite large. The question which every student asks (well, most students anyway) is, "If the sun and the planets are pulling on each other with such a large force, why don't the planets fall into the sun?" The answer is simply (are you ready for this?)

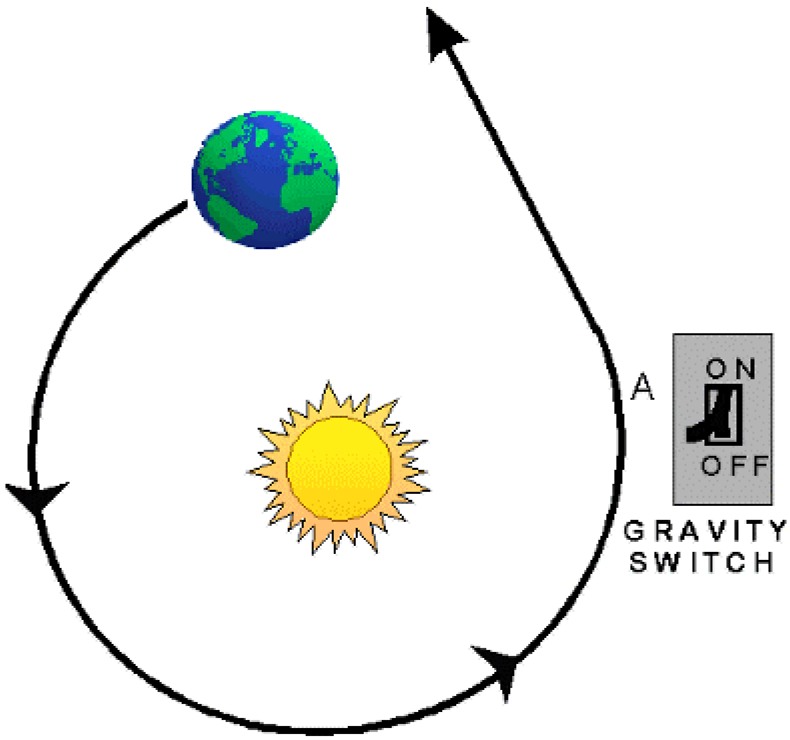
THEY ARE! The Earth, Mars, Venus, Jupiter and Saturn are continuously falling into the Sun. The Moon is continuously falling into the Earth.

Our salvation is that they are also moving "sideways" with a sufficiently large velocity that by the time the earth has fallen the 93,000,000 miles to the sun it has also moved "sideways" about 93,000,000 miles - far enough to miss the sun. By the time the moon has fallen the 240,000 miles to the earth, it has moved sideways about 240,000 miles - far enough to miss the earth. This process is repeated continuously as the earth (and all the other planets) make their apparently unending trips around the sun and the moon makes its trips around the earth. A planet, or any other body, which finds itself at any distance from the sun with no "sideways" velocity will quickly fall without missing the sun, will be drawn into the sun's interior and will be cooked to well-done. Only our sideways motion (physicists call it our "angular velocity") saves us. The same of course is true for the moon, which would fall to earth but for its angular velocity. This is illustrated in the drawing below.



The Earth Orbits the Sun With Angular Velocity

People sometimes (erroneously) speak of orbiting objects as having "escaped" the effects of gravity, since passengers experience an apparent weightlessness. Be assured, however, that the force of gravity is at work. Were it suddenly to be turned off, the object in question would instantly leave its circular orbit, take up a straight line trajectory, which, in the case of the earth, would leave it about 50 billion miles from the sun after just one century. Hence the gravitational force between the sun and the earth holds the earth in its orbit. This is shown in the drawing below, where the earth was happily orbiting the sun until it reached point A, where the force of gravity was suddenly turned off.



The Earth No Longer Orbits the Sun if Gravity is Switched Off

The apparent weightlessness experienced by the orbiting passenger is the same weightlessness which he would feel in a falling elevator or an amusement park ride. The earth orbiting the sun or the moon orbiting the earth might be compared to a rock on the end of a string which you swing in a circle around your head. The string holds the rock in place and is continuously pulling it toward your head. Because the rock is moving sideways however, it always misses your head. Were the string to be suddenly broken, the rock would be released from its orbit and fly off in a straight line, just as earth did in the drawing above.

One question which one might ask is " Does the time required to complete an orbit depend on the distance at which the object is orbiting?" In fact, Kepler answered this question several hundred years ago, using the data of an earlier astronomer, Tycho Brahe.

> Except for Kepler's analysis of his data, it is possible that Tycho Brahe would be best remembered today as a drinker and womanizer. However, without Brahe's unbelievably careful measurements of the planetary positions over many years, Kepler's revolutionary proposals would have been impossible.

After years of trial and error analysis (by hand - no computers, no calculators) , Kepler discovered that the quantity R3 / T2 was the same for every planet in our solar system. (R is the distance at which a planet orbits the sun, T is the time required for one complete trip around the sun.)Hence, an object which orbits at a larger distance will require longer to complete one orbit than one which is orbiting at a smaller distance. One can understand this at least qualitatively in terms of our "falling and missing" model. The planet which is at a larger distance requires longer to fall to where it would strike the sun. As a result, it takes a longer time to complete the □ trip around the sun which is necessary to make a circular orbit.

> OPTIONAL FOR THE MATHEMATICALLY INCLINED
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> Kepler's laws and the dependence of period on radius are simple consequences of Newton's second law of motion and Newton's law of gravitation. We know that the second law (which every physics student should recognize) says:
>
> $F = MA$

We also know that the F, or force, in this case is the force of gravity, given to us by Newton:

$F = G(M_{earth} M_{sun}) / R^2$

Finally, we know (or could show fairly easily) that the acceleration experienced by a body moving in a circle of radius R at constant speed (V) is given by

$A = V^2 / R$

Putting these two expressions into the F = MA equation, one obtains:

$G(M_{earth} M_{sun}) / R^2 = M_{earth}V^2 / R$

or just

$GM_{sun} / R^2 = V^2 / R$

But the velocity is simply the distance traveled in one orbit (2(pi)R) divided by the time required for one orbit (T). Inserting this quantity (2(pi)R / T) for V, we obtain:

$GM_{sun} / R^2 = (2(pi)R / T)^2 / R$

- or -

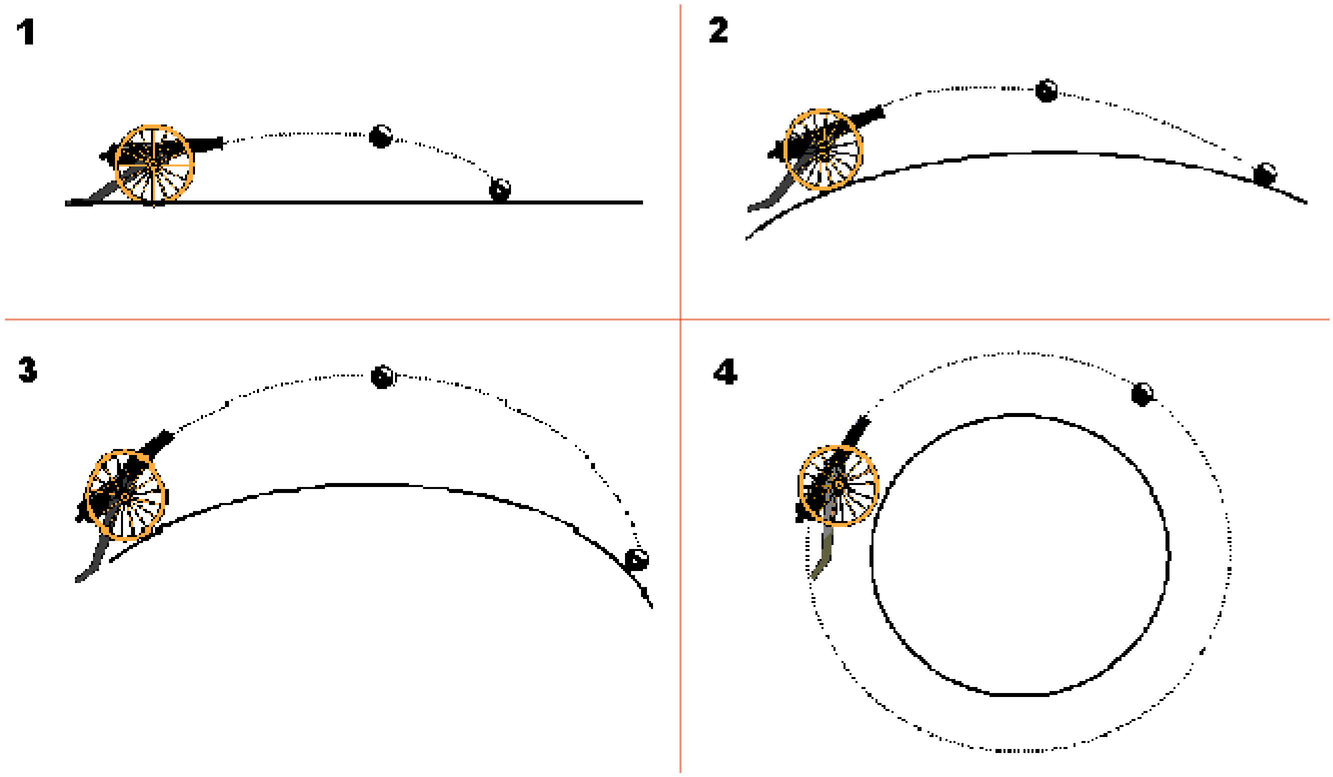
$T^2 = 4(pi)^2 R^3 / GM_{sun}$

Can We Imitate Nature? (Artificial Satellites)

Very soon after Newton's laws were published, people realized that in principle it should be possible to launch an artificial satellite which would orbit the earth just as the moon does. A simple calculation, however, using the equations which we developed above, will show that an artificial satellite, orbiting near the surface of the earth (R = 4000 miles) will have a period of approximately 90 minutes. This corresponds to a sideways velocity (needed in order to "miss" the earth as it falls), of approximately 17,000 miles/hour (that's about 5 miles/second) . To visualize the "missing the earth" feature, let's imagine a cannon firing a cannonball. (Below)

In the first frame of the cartoon, we see it firing fairly weakly. The cannonball describes a parabolic arc as we expect and lands perhaps a few hundred yards away. In the second frame, we bring up a little larger cannon, load a little more powder and shoot a little farther. The ball lands perhaps a few hundred miles away. We can see just a little of the earth's curvature, but it doesn't really affect anything. In the third frame, we use our super-shooter and the cannonball is shot hard enough that it travels several thousand miles. Clearly the curvature of the earth has had an effect. The ball travels much farther than it would have had the earth been flat. Finally, our mega-super-big cannon fires the cannonball at the unbelievable velocity of 5 miles/second or nearly 17,000 miles/hour. (Remember - the fastest race cars can make 250 miles/hour. The fastest jet planes can do a 2 or 3 thousand miles/hour.) The result of this prodigious shot is that the ball misses the earth as it falls. Nevertheless, the earth's gravitational pull causes it to continuously change direction and continuously fall. The result is a "cannonball" which is orbiting the earth. In the absence of gravity, however, the original throw (even the shortest, slow one) would have continued in a straight line, leaving the earth far behind.

For many years, such a velocity was unthinkable and the artificial satellite remained a dream. Eventually, however, the technology (rocket engines, guidance systems, etc.) caught up with the concept, largely as a result of weapons research started by the Germans during the second World War. Finally, in 1957, the first artificial satellite, called Sputnik, was launched by the Soviets. Consisting of little more than a spherical case with a radio transmitter, it caused quite a stir. Americans were fascinated listening to the "beep. beep, beep" of Sputnik appear and then fade out as it came overhead every 90 minutes. It was also quite frightening to think of the Soviets circling overhead inasmuch as they were our mortal enemies.



Launching an Artificial Satellite

> Let's think about what would have happened to a "bomb" which would have been dropped from an orbiting Soviet satellite (America's worst nightmare in 1957). Simply "dropping" the bomb would do nothing. The bomb had a sideways velocity of 17,000 miles/hour when it was part of the spacecraft. Simply separating it from the spacecraft will not cause it to drop to earth. It still has its sideways velocity and will continue to miss the earth as it falls. In order to make it hit the earth, we must get rid of its sideways velocity - a task almost as challenging as imparting that sideways velocity in the first place.

After Sputnik, it was only a few years before the U.S. launched its own satellite; the Soviets launched Yuri Gagarin, the first man to orbit the earth; and the U.S. launched John Glenn, the first American in orbit. All of these flights were at essentially the same altitude (a few hundred miles) and completed one trip around the earth approximately every 90 minutes.

People were well aware, however, that the period would be longer if they were able to reach higher altitudes. In particular Arthur Clarke pointed out in the mid-1940s that a satellite orbiting at an altitude of 22,300 miles would require exactly 24 hours to orbit the earth. Hence such an orbit is called "geosynchronous" or "geostationary." If in addition it were orbiting over the equator, it would appear, to an observer on the earth, to stand still in the sky. Raising a satellite to such an altitude, however, required still more rocket boost, so that the achievement of a geosynchronous orbit did not take place until 1963.

> You may have heard of Arthur Clarke. He is the same gentleman who wrote "2001: A Space Odyssey" and lends his name to "Arthur Clarke's Mysterious World" - the television series.

COMMUNICATIONS SATELLITES

Part 2 of Section 1 (SATELLITE COMMUNICATIONS - A SHORT COURSE) of SATELLITE COMMUNICATIONS, prepared by Dr. Regis Leonard for NASA Lewis Research Center

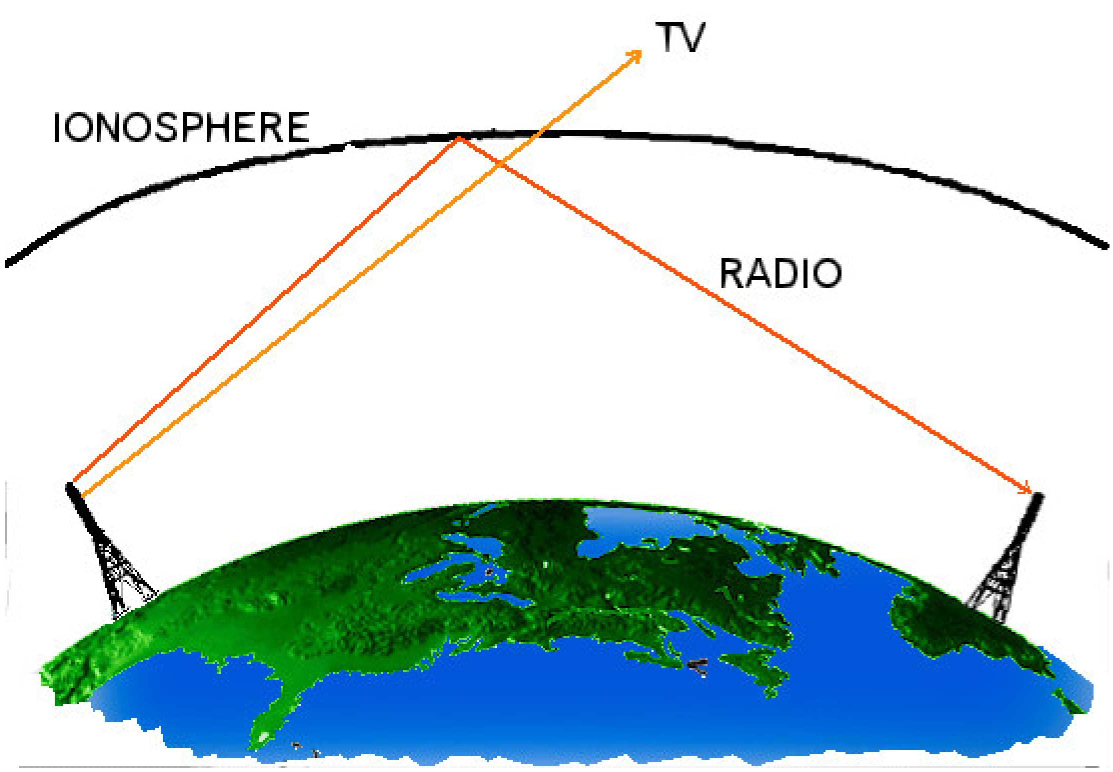
Why Satellites for Communications

By the end of World War II, the world had had a taste of "global communications." Edward R. Murrow's radio broadcasts from London had electrified American listeners. We had, of course, been able to do transatlantic telephone calls and telegraph via underwater cables for almost 50 years. At exactly this time, however, a new phenomenon was born. The first television programs were being broadcast, but the greater amount of information required to transmit television pictures required that they operate at much higher frequencies than radio stations. For example, the very first commercial radio station (KDKA in Pittsburgh) operated (and still does) at 1020 on the dial. This number stood for 1020 KiloHertz - the frequency at which the station transmitted. Frequency is simply the number of times that an electrical signal "wiggles" in 1 second. Frequency is measured in Hertz. One Hertz means that the signal wiggles 1 time/second. A frequency of 1020 kiloHertz means that the electrical signal from that station wiggles 1,020,000 times in one second.

> The expressions "kilo", "mega", and "giga" are used by scientists as a shorthand way of expressing very large numbers. The prefix "kilo" in front of a unit means 1000 of that unit. "Kilo is abbreviated as k. For example, a kilogram (Kg) is 1000 grams. In the same way, "mega" means 1 million. Mega is abbreviated as M. A megawatt (MW) is 1,000,000 watts. The prefix "giga" stands for 1 billion. It is abbreviated as G. Hence a gigabit (Gbit) of data is 1,000,000,000 bits of data.

Television signals, however required much higher frequencies because they were transmitting much more information - namely the picture. A typical television station (channel 7 for example) would operate at a frequency of 175 MHz. As a result, television signals would not propagate the way radio signals did.

Both radio and television frequency signals can propagate directly from transmitter to receiver. This is a very dependable signal, but it is more or less limited to line of sight communication. The mode of propagation employed for long distance (1000s of miles) radio communication was a signal which traveled by bouncing off the charged layers of the atmosphere (ionosphere) and returning to earth. The higher frequency television signals did not bounce off the ionosphere and as a result disappeared into space in a relatively short distance. This is shown in the diagram below.

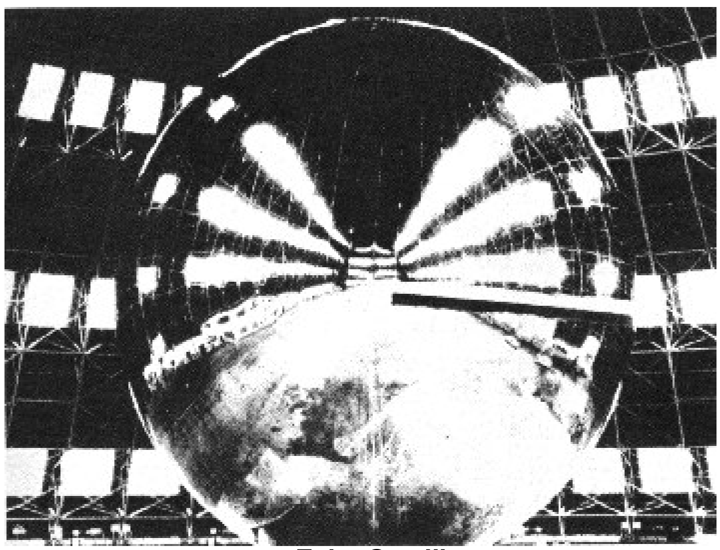


Radio Signals Reflect Off the Ionosphere; TV Signals Do Not

Consequently, television reception was a "line-of-sight" phenomenon, and television broadcasts were limited to a range of 20 or 30 miles or perhaps across the continent by coaxial cable. Transatlantic broadcasts were totally out the question. If you saw European news events on television, they were probably delayed at least 12 hours, and involved the use of the fastest airplane available to carry conventional motion pictures back to the U.S. In addition, of course, the appetite for transatlantic radio and telephone was increasing rapidly. Adding this increase to the demands of the new television medium, existing communications capabilities were simply not able to handle all of the requirements. By the late 1950s the newly developed artificial satellites seemed to offer the potential for satisfying many of these needs.

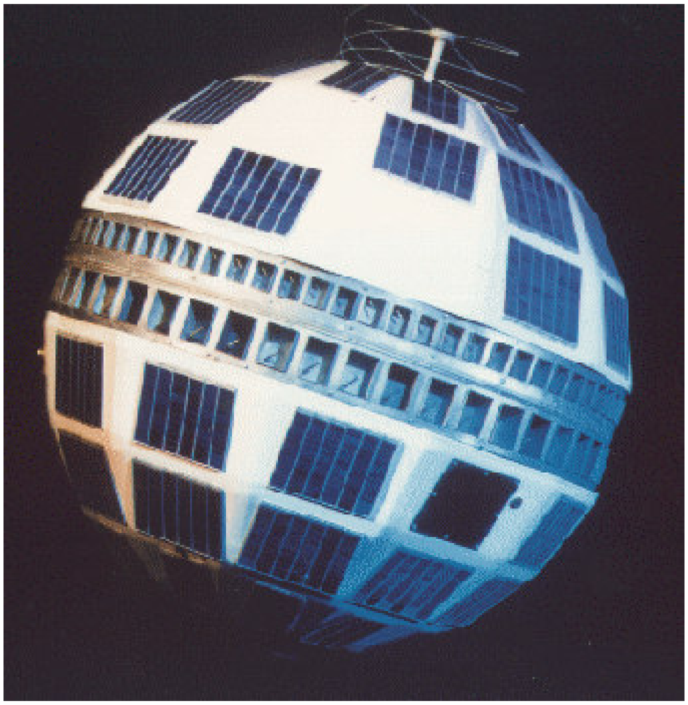
Low Earth-Orbiting Communications Satellites

In 1960, the simplest communications satellite ever conceived was launched. It was called Echo, because it consisted only of a large (100 feet in diameter) aluminized plastic balloon. Radio and TV signals transmitted to the satellite would be reflected back to earth and could be received by any station within view of the satellite.



Echo Satellite

Unfortunately, in its low earth orbit, the Echo satellite circled the earth every ninety minutes. This meant that although virtually everybody on earth would eventually see it, no one person, ever saw it for more than 10 minutes or so out of every 90 minute orbit. In 1958, the Score satellite had been put into orbit. It carried a tape recorder which would record messages as it passed over an originating station and then rebroadcast them as it passed over the destination. Once more, however, it appeared only briefly every 90 minutes - a serious impediment to real communications. In 1962, NASA launched the Telstar satellite for AT&T.

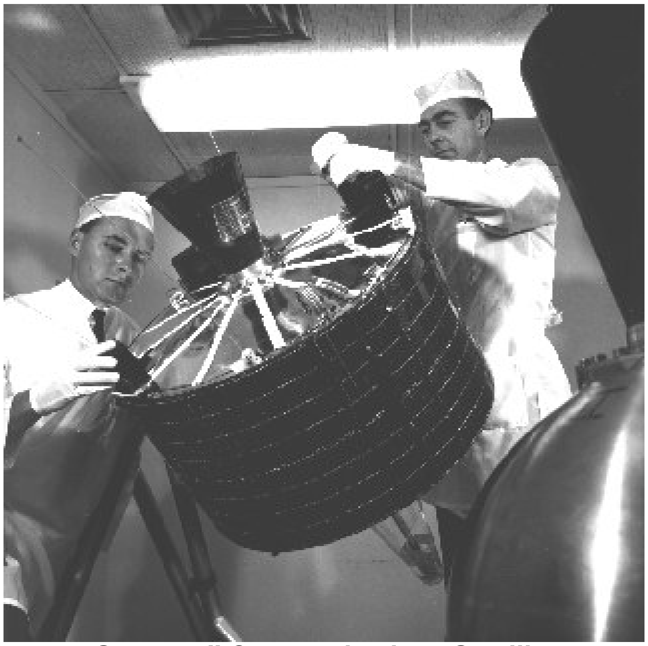


Telstar Communications Satellite

Telstar's orbit was such that it could "see" Europe" and the US simultaneously during one part of its orbit. During another part of its orbit it could see both Japan and the U.S. As a result, it provided real- time communications between the United States and those two areas - for a few minutes out of every hour.

Geosynchronous Communications Satellites

The solution to the problem of availability, of course, lay in the use of the geosynchronous orbit. In 1963, the necessary rocket booster power was available for the first time and the first geosynchronous satellite , Syncom 2, was launched by NASA. For those who could "see" it, the satellite was available 100% of the time, 24 hours a day. The satellite could view approximately 42% of the earth. For those outside of that viewing area, of course, the satellite was NEVER available.



Syncom II Communications Satellite

However, a system of three such satellites, with the ability to relay messages from one to the other could interconnect virtually all of the earth except the polar regions. The one disadvantage (for some purposes) of the geosynchronous orbit is that the time to transmit a signal from earth to the satellite and back is approximately □ of a second - the time required to travel 22,000 miles up and 22,000 miles back down at the speed of light. For telephone conversations, this delay can sometimes be annoying. For data transmission and most other uses it is not significant. In any event, once Syncom had demonstrated the technology necessary to launch a geosynchronous satellite, a virtual explosion of such satellites followed.

Today, there are approximately 150 communications satellites in orbit, with over 100 in geosynchronous orbit. One of the biggest sponsors of satellite development was Intelsat, an internationally-owned corporation which has launched 8 different series of satellites (4 or 5 of each series) over a period of more than 30 years. Spreading their satellites around the globe and making provision to relay from one satellite to another, they made it possible to transmit 1000s of phone calls between almost any two points on the earth. It was also possible for the first time, due to the large capacity of the satellites, to transmit live television pictures between virtually any two points on earth. By 1964 (if you could stay up late enough), you could for the first time watch the Olympic games live from Tokyo. A few years later of course you could watch the Vietnam war live on the evening news.

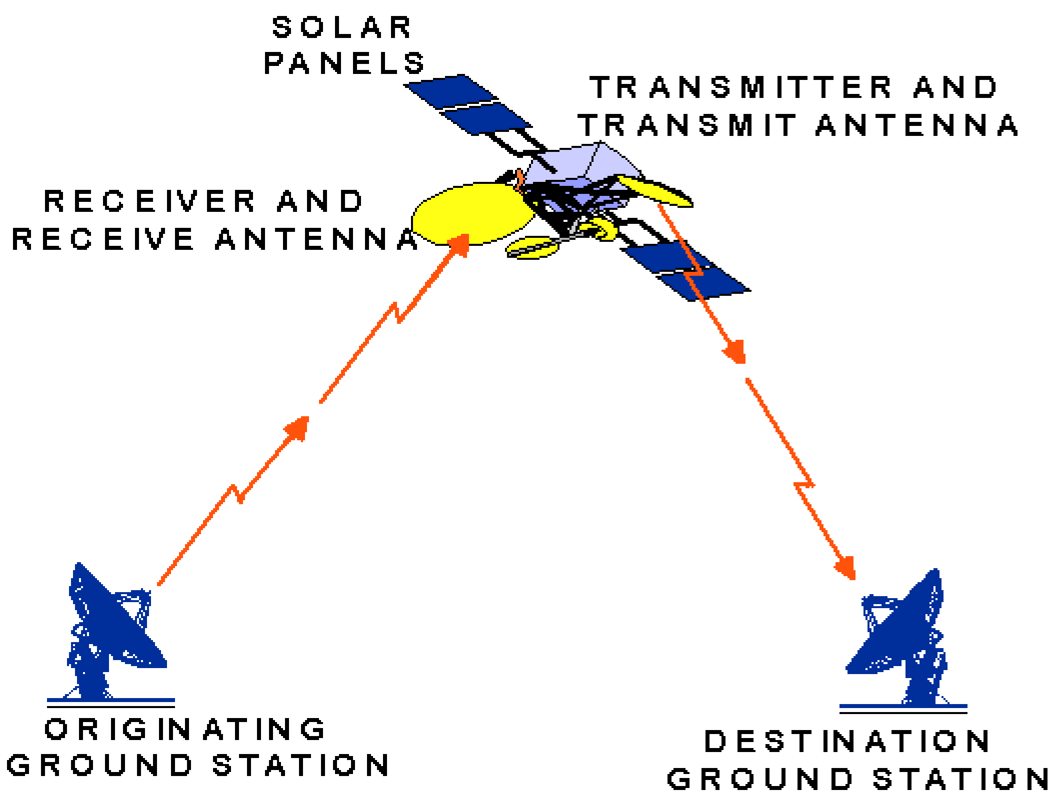
> A geosynchronous satellite must orbit at 22,300 miles altitude and it must be over the earth's equator. As a result, there are a limited number of "slots" for satellites. The allocation of these slots is carefully regulated by an international governing body. Needless to say, both processes are highly political inasmuch as (1) there are billions of dollars to be made, and (2) few things are more prestigious for a small, newly independent country than to be able to say, "We have our own satellite." To date (and for the foreseeable future) satellite communications is the biggest and virtually only money-making business in space.

COMPONENTS FOR COMMUNICATIONS SATELLITES

Part 3 of Section 1 (SATELLITE COMMUNICATIONS - A SHORT COURSE) of SATELLITE COMMUNICATIONS, prepared by Dr. Regis Leonard for NASA Lewis Research Center

Basic Communications Satellite Components

Every communications satellite in its simplest form (whether low earth or geosynchronous) involves the transmission of information from an originating ground station to the satellite (the uplink), followed by a retransmission of the information from the satellite back to the ground (the downlink). The downlink may either be to a select number of ground stations or it may be broadcast to everyone in a large area. Hence the satellite must have a receiver and a receive antenna, a transmitter and a transmit antenna, some method for connecting the uplink to the downlink for retransmission, and prime electrical power to run all of the electronics. The exact nature of these components will differ, depending on the orbit and the system architecture, but every communications satellite must have these basic components. This is illustrated in the drawing below.



Basic Components of a Communications Satellite Link

Transmitters

The amount of power which a satellite transmitter needs to send out depends a great deal on whether it is in low earth orbit or in geosynchronous orbit. This is a result of the fact that the geosynchronous satellite is at an altitude of 22,300 miles, while the low earth satellite is only a few hundred miles. The geosynchronous satellite is nearly 100 times as far away as the low earth satellite. We can show fairly easily that this means the higher satellite would need almost 10,000 times as much power as the low-orbiting one, if everything else were the same. (Fortunately, of course, we change some other things so that we don't need 10,000 times as much power.)

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In looking at the relative power requirements of satellites at different distances, it is useful to think of the total power (P_0) radiated as spreading out and striking the surface of a sphere which is centered on the transmitter and has a radius equal to the distance between the transmitter and receiver.

We know that the surface area of a sphere of radius R is given by

$A = 4(pi)R^2$

This means that if the power is emitted uniformly in all directions (isotropically) then the amount of power which strikes every square centimeter of the sphere is given by

$P = P_0 / 4(pi)R^2$

If our receiver has an area of Ar square centimeters, then it will detect an amount of power

$P_r = A_r P_0 / 4(pi)R^2$

If then R= 223 miles (it makes the arithmetic easier),

$P_r = A_r P_0 / 4(pi)(223 \text{ miles})^2$

On the other hand, if R = 22,300 miles,

$P_r = A_r P_0 / 4(pi)(22{,}300 \text{ miles})^2$

Which is 10,000 times smaller, so that in order to have the receiver detect the same amount of power, the transmitter power P_0 must be 10,000 times larger for the geosynchronous system.

For either geosynchronous or low earth satellites, the power put out by the satellite transmitter is really puny compared to that of a terrestrial radio station. Your favorite rock station probably boasts of having many kilowatts of power. By contrast, a 200 watt transmitter would be very strong for a satellite.

Antennas

One of the biggest differences between a low earth satellite and a geosynchronous satellite is in their antennas. As mentioned earlier, the geosynchronous satellite would require nearly 10,000 times more transmitter power, if all other components were the same. One of the most straightforward ways to make up the difference, however, is through antenna design. Virtually all antennas in use today radiate energy preferentially in some direction. An antenna used by a commercial terrestrial radio station, for example, is trying to reach people to the north, south, east, and west. However, the commercial station will use an antenna that radiates very little power straight up or straight down. Since they have very few listeners in those directions (except maybe for coal miners and passing airplanes) power sent out in those directions would be totally wasted.

The communications satellite carries this principle even further. All of its listeners are located in an even smaller area, and a properly designed antenna will concentrate most of the transmitter power within that area, wasting none in directions where there are no listeners. The easiest way to do this is simply to make the antenna larger. Doubling the diameter of a reflector antenna (a big "dish") will reduce the area of the beam spot to one fourth of what it would be with a smaller reflector. We describe this in terms of the gain of the antenna. Gain simply tells us how much more power will fall on 1 square centimeter (or square meter or square mile) with this antenna than would fall on that same square centimeter (or square meter or square mile) if the transmitter power were spread uniformly (isotropically) over all directions. The larger antenna described above would have four times the gain of the smaller one. This is one of the primary ways that the geosynchronous satellite makes up for the apparently larger transmitter power which it requires.

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Antenna gains, like many power specifications are usually quoted in decibels (dB). The ratio of two power levels in decibels is defined as:

$R = 10 \log_{10} (P_1/P_2)$

If the smaller of the two antenna mentioned above concentrated 100 times as much power on the receiver as would an antenna which radiated isotropically, then the gain of the smaller antenna would be

$10 \log_{10} (100) = 20$ dB

The larger antenna then concentrates 4 times as much power at the receiver as does the smaller one, which is 400 times as much as the one which radiates isotropically. Therefore its gain is

$10 \log_{10} (400)$ 26 dB

The power supplied by the larger is (400/100) = 4 times as great as the smaller, therefore its gain should be greater than the small one by

$10 \log_{10} (4)$ 6 dB - which it is.

Power levels are sometimes specified in dBW or dBm. These expressions indicate that the power level in question is being specified as a ratio to 1 watt or 1 milliwatt. For example, 13 dBW means that

$10 \log_{10}$ (the power level in watts) = 13

In other words, the given power level is really about 20 watts. Similarly, 13 dBm would correspond to 20 milliwatts of power.

One other big difference between the geosynchronous antenna and the low earth antenna is the difficulty of meeting the requirement that the satellite antennas always be "pointed" at the earth. For the geosynchronous satellite, of course, it is relatively easy. As seen from the earth station, the satellite never appears to move any significant distance. As seen from the satellite, the earth station never appears to move. We only need to maintain the orientation of the satellite. The low earth orbiting satellite, on the other hand, as seen from the ground is continuously moving. It zooms across our field of view in 5 or 10 minutes.

Likewise, the earth station, as seen from the satellite is a moving target. As a result, both the earth station and the satellite need some sort of tracking capability which will allow its antennas to follow the target during the time that it is visible. The only alternative is to make that antenna beam so wide that the intended receiver (or transmitter) is always within it. Of course, making the beam spot larger decreases the antenna gain as the available power is spread over a larger area , which in turn increases the amount of power which the transmitter must provide.

Power Generation

You might wonder why we don't actually use transmitters with thousands of watts of power, like your favorite radio station does. You might also have figured out the answer already. There simply isn't that much power available on the spacecraft. There is no line from the power company to the satellite. The satellite must generate all of its own power. For a communications satellite, that power usually is generated by large solar panels covered with solars cells - just like the ones in your solar-powered calculator. These convert sunlight into electricity. Since there is a practical limit to the how big a solar panel can be, there is also a practical limit to the amount of power which can generated. In addition, unfortunately, transmitters are not very good at converting input power to radiated power so that 1000 watts of power into the transmitter will probably result in only 100 or 150 watts of power being radiated. We say that transmitters are only 10 or 15% efficient. In practice the solar cells on the most "powerful" satellites generate only a few thousand watts of electrical power.

Satellites must also be prepared for those periods when the sun is not visible, usually because the earth is passing between the satellite and the sun. This requires that the satellite have batteries on board which can supply the required power for the necessary time and then recharge by the time of the next period of eclipse.

FUTURE COMMUNICATIONS SATELLITES

Part 4 of Section 1 (SATELLITE COMMUNICATIONS - A SHORT COURSE) of SATELLITE COMMUNICATIONS, prepared by Dr. Regis Leonard for NASA Lewis Research Center

The nature of future satellite communications systems will depend on the demands of the marketplace (direct home distribution of entertainment, data transfers between businesses, telephone traffic, cellular telephone traffic, etc.); the costs of manufacturing, launching, and operating various satellite configurations; and the costs and capabilities of competing systems - especially fiber optic cables, which can carry a huge number of telephone conversations or television channels. In any case, however, several approaches are now being tested or discussed by satellite system designers.

One approach, which is being tested experimentally, is the "switchboard in the sky" concept. NASA's Advanced Communications Technology Satellite (ACTS) consists of a relatively large geosynchronous satellite with many uplink beams and many downlink beams, each of which covers a rather small spot (several hundred miles across) on the earth. However, many of the beams are "steerable". That is to say, the beams can be moved to a different spot on the earth in a matter of milliseconds, so that one beam provides uplink or downlink service to a number of locations. Moving the beams in a regular scheduled manner allows the satellite to gather uplink traffic from a number of locations, store it on board, and then transmit it back to earth when a downlink beam comes to rest on the intended destination. The speed at which the traffic is routed and the agility with which the beams move make the momentary storage and routing virtually invisible to the user. The ACTS satellite is also unique in that it operates at frequencies of 30 GHz on the uplink and 20 GHz on the downlink. It is one of the first systems to demonstrate and test such high frequencies for satellite communications.

The ACTS concept involves a single, rather complicated, and expensive geosynchronous satellite. An alternative approach is to deploy a "constellation" of low earth orbiting satellites. By planning the orbits carefully, some number (perhaps as few as 20, perhaps as many as 250) of satellites could provide continuous contact with the entire earth, including the poles. By providing relay links between satellites, it would be possible to provide communications between any two points on earth, even though the user might only be able to see any one satellite for a few minutes every hour. Obviously, the success of such a system depends critically on the cost of manufacturing and launching the satellites. It will be necessary to mass produce communications satellites, so that they can turned out quickly and cheaply, the way VCRs are manufactured now. This seems a truly ambitious goal since until now the average communications satellite might require 6 months to 2 years to manufacture. Nevertheless, at the present time, several companies including Hughes Electronics, Motorola, and Teledesic, Inc., have indicated their intent to undertake such a system.

SUGGESTED CLASSROOM ACTIVITIES to accompany SATELLITE COMMUNICATIONS - A SHORT COURSE prepared by Dr. Regis Leonard for NASA Lewis Research Center

Part 1: Satellites in General
Demonstrate that a force is necessary to hold an object in its orbit:

- Attach a tennis ball (or other convenient object) to the end of a string. Swing it round your head in a circular "orbit". At some point, cut the string (that is "turn off the gravity") and observe what happens to the ball, that is, what direction does it go?.

Ask students to verify Kepler's law:

- Look up the average radius (R) of each planet's orbit and its period (T). Is the quantity R^3/T^2 the same for all of the planets?

Students can prepare reports on subjects such as:

- Sputnik
- Yuri Gagarin
- John Glenn
- The Mercury Astronauts

Conduct model rocket launches

- CAUTION: Be sure to observe proper safety precautions and be sure that there is adequate space for the launch, flight, and recovery. Almost any student (or pair of students) can build the commercially available model kits of "beginners' skill levels".

Part 2: Communications Satellites
To relate to students' experience:

- What is the frequency of your favorite radio station? AM or FM? KiloHertz or MegaHertz?

- Interview your parents (or, if necessary, your grandparents). What are their earliest memories of television?

- Interview or visit your local cable company. Can they explain the route that your MTV (or HBO or Learning Channel) takes in traveling from its origin to your house? Can you visit their ground station?

- How has satellite TV affected your life? What do you have that you didn't have otherwise? How has global TV affected our awareness of world events?

To Demonstrate the Geosynchronous Orbit:

- Have one student "portray" the earth; a second student the geosynchronous satellite. Have the "earth" stand in one place and rotate while the "satellite" revolves around the "earth", completing one revolution in exactly the time the "earth" completes one rotation. Ask the "earth" how the "satellite" looked during the rotation.

General Communications Activities:

- Ask class members to orally relay a message written on a piece of paper. Start at the back of the room. Ask the person at the front of the room to write the message (as he received it) on the blackboard. Compare it with the original written message.

- Have students devise their own non-verbal, non-written communication system and use it to convey a message from one side of the room to the other.

- Set up a point-to point telegraph system. A 6-volt power supply, a simple switch for a transmitter, and a 6-volt light bulb as a receiver are sufficient. Ask students to transmit a simple message of 6 or eight words, using the International Morse Code. Remind them that each "dot" and "dash" represents (approximately) one bit of transmitted data. Have them time their transmission and calculate a data rate in bits/second. Compare their efforts with the modern systems which can transmit 500,000,000 bits of information/second.

- Make a list of advancements in communications systems, beginning with person-to-person voice communications. Keep advancements and inventions in chronological order

- You are going to the park a block away. You are expecting an important phone call. How would you have someone from your home notify you when the call arrives? Consider solutions without electronics and with electronics.

Mathematical Activities:

- Communications satellites orbit at an altitude of 22,300 miles above the earth. How many meters is this?

- Light and radio waves travel at 300,000,000 meters/second. How long will it take a radio signal to travel from the earth to a satellite in geosynchronous orbit and back?

Possible student reports include:

- ECHO satellite
- SYNCOM satellite
- NASA's experimental satellites (ATS-1 to ATS-6, CTS and ACTS)
- INTELSAT satellites
- The INTELSAT organization and network
- Arthur Clarke
- Rockets in general - how do they work
- NASA Launch Vehicles (rockets) - specific rockets and what they were used for. (Redstone, Atlas, Agena, Titan, Saturn)
- Wernher von Braun

Part 3: Components for Communications Satellites
Collect pictures of satellites

Build models of satellites

- From household materials - either specific real satellites or students' own designs.

Posters

- Illustrating the basic components of satellites or the structure of a specific satellite.

Collect pictures of antennas

- Where does each come from? What is it used for?

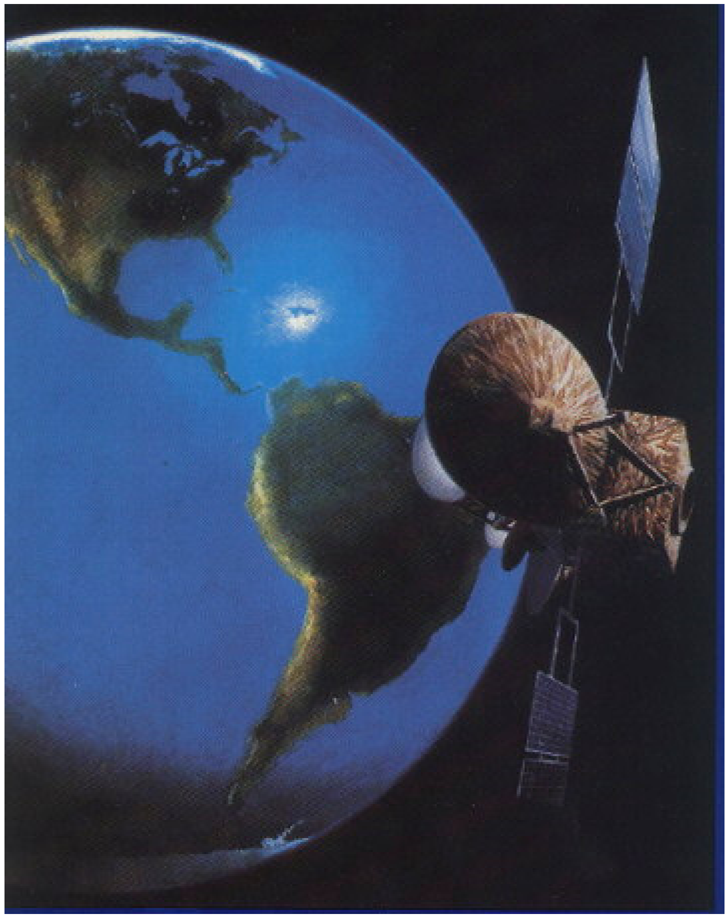
Demonstrate concept of electrically switched antenna beams

- Simulate antenna beams using a flashlight and a curved mirror. Moving the flashlight to a different location will cause the reflected beam to change direction. Using two flashlights, demonstrate how a different beam direction can be obtained simply by turning one beam on and the other off.

BACKGROUND MATERIALS FOR A VISIT TO NASA'S ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE (ACTS) FACILITY from SATELLITE COMMUNICATIONS, prepared by Dr. Regis Leonard for NASA Lewis Research Center

Part 1: General Description
FACTS:

The ACTS satellite was launched by means of the space shuttle Columbia on September 12, 1993. The satellite was intended as a test vehicle for new communications technology, and as such carries no commercial traffic. It is, however, available to any legitimate entity (government, corporation or university) who might wish to use its experimental capabilities. The cost of the ACTS program is approximately $500 million. This is largely because of the enormous amount of new technology which is being flown and demonstrated for the first time.



ACTS - An Experimental Communications Satellite

ORBIT:

ACTS was placed into a geosynchronous orbit (an altitude of 22,300 miles) at 100 degrees west longitude.

SPECIFICATIONS:

- Exclusive of its antennas and solar array, the satellite is a near cube with dimensions 80" x 84" x 75".
- Its solar array is 46.9' from tip to tip.
- The satellite weighs 3250 pounds.
- Its solar cells provide 1418 watts of electrical power.
- Its main antennas are 7.2 feet (uplink, receive) and 10.8 feet (downlink, transmit) in diameter.

Part 2: New Communications Technology
Higher Frequencies

The ACTS satellite receives information from ground stations at one of several frequencies near 30 GHz. Its downlink transmissions to the destination earth stations are at frequencies near 20 GHz. These frequencies are much higher than those currently used on satellite systems. Most commercial satellites presently in use operate with a 6 GHz uplink and a 4 GHz down link. By comparison, a typical AM radio station operates at 1000 KHZ (0.001 GHz) an FM radio station operates at 100 MHz (0.1 GHz). Channel 7 on your TV set is about 175 MHz. The higher frequencies used by ACTS have 4 significant effects:

- It demonstrates the feasibility of an entirely new resource. Just as you can only place a limited number of FM radio stations within the piece of the frequency spectrum allocated for that purpose, so you can only operate a certain number of "satellite stations" within any given frequency band. The lower frequencies which communications satellites have been using until now (4 - 6 GHz, known as the C-band and 11 - 14 GHz, known as the Kuband) are rapidly being filled up. Use of the 30 and 20 GHz bands will nearly double the amount of frequency space available for satellite communications.

- The higher frequency means that an antenna of a certain size will have greater gain than it would at a lower frequency. The satellite designer can use this fact to his advantage in two ways. First, a higher gain means a smaller spot will be illuminated by the beam when it strikes the earth. As a result, the power which the satellite radiates is concentrated in a smaller area. This will either improve the quality of communications or will allow the designer to actually reduce the power which the satellite emits.The smaller beam spot also means that the satellite can be more precise in selecting the destination for its transmissions. In fact, it can use two small beams, each aimed at a different destination, and, if they do not overlap, it can transmit to both destinations at the same frequency, at the same time without interference. The ACTS satellite has a total of 5 uplink and 5 downlink beams, each with a width of a little less than 0.5 degrees, which corresponds to a "footprint" on earth approximately 150 miles across. Most previous satellites had beams which covered at least half of the continental United States and frequently covered all of it or even the entire earth.

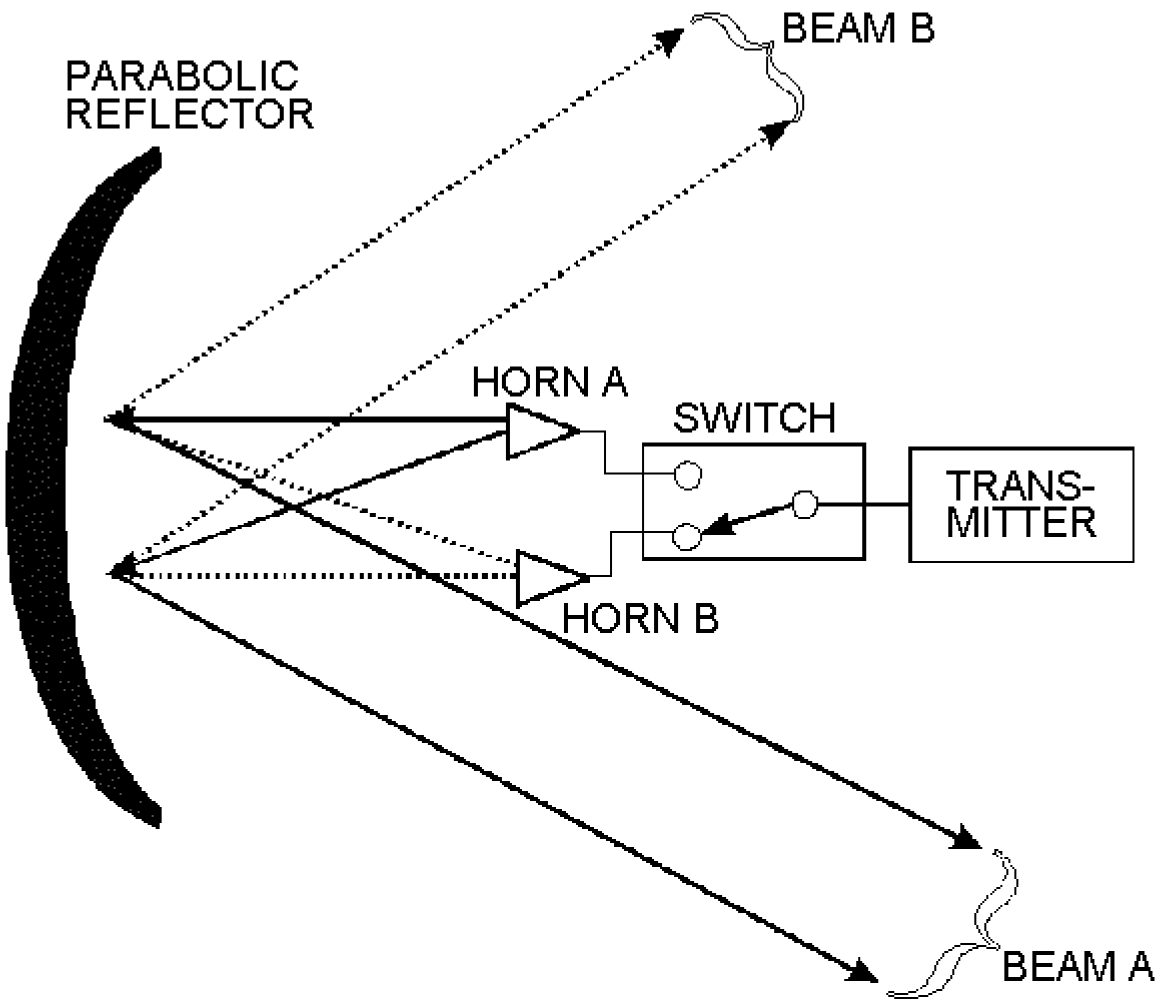
- A third effect of the higher frequencies at which ACTS receives and transmits is that it is capable of carrying much more information than would a similar satellite at lower frequency. Both the uplink and downlink frequency bands are approximately 2.5 GHz wide (from 27.5 to 30.0 GHz on the uplink; from 17.5 to 20.0 GHz on the downlink). This 2.5 GHz of bandwidth is enough for about 400 conventional television stations or 250,000 telephone calls, or 100,000 "high speed" data transfers (say from your "fast" 28K baud modem. As a demonstration version of a 30/20 GHz satellite, ACTS is not equipped to use the full data-carrying capability of the frequency band. However, it can handle a throughput of 1800 megabits/second, the equivalent of 450 television stations.

- Finally, ACTS' operating at these higher frequencies means that many of its components had never been built before and required extensive engineering research. The development of these components (transmitters, receivers, antennas and switching devices of the required performance) represented major advances in electronics technology. Their development and demonstration in space means that the satellite communications industry will have relatively inexpensive "off-the-shelf" components available when commercial use of these frequency bands becomes a reality.

Moveable Beams

Another unique feature of the ACTS satellite is that not only are its beams smaller than previous satellites, but some of them are moveable. The moveability is accomplished not by physically reorienting the antenna system to point in another direction, but by electrically switching the signal. To understand how this works, we need to look at the satellite's antenna in a little more detail. Attached to the transmitter is a small radiating element which launches the signal into space. For the frequencies used here, the radiating element consists of a "horn", which "feeds" a large reflector or "dish". The reflector is shaped like a parabola and acts just like an optical mirror, focusing the energy emitted by the feed horn located at "A" and sending it all off in the same direction, shown as the beam "A" in the figure below. Just as with an optical mirror, if the source of radiation (the feedhorn) is relocated to "B", the focused and reflected beam will go off in a different direction, shown as beam "B" in the figure.

The ACTS satellite has an array of feedhorns, each one corresponding to a different destination on the ground. Switches will route the transmitter signal to that horn which will reach the desired location. Because it is done by electrical switching rather than actually moving antenna parts, the beams can be rearranged in a matter of microseconds. If the beam moves through a series of preprogrammed locations, we say that the beam has "scanned" the entire area. A moveable or scanning beam on ACTS can visit 40 locations, covering a total of about 750,000 square miles, in 1/000 of a second. Two of ACTS' beams have this hopping capability. An operational satellite (that is, a money-maker, not an experiment) could use about 6 such "scanning" beams to provide service to the entire continental United States.



Beam Steering by Means of a Switch

Switching and Routing Capabilities

The ACTS satellite differs from all previous satellites in that switching devices on board the satellite (combined with ACTS' small spot beams) actually route messages, data, or TV programs to a particular destination, rather than "broadcasting" them across the entire country. As a result, it is sometimes referred to as a "switchboard in the sky". ACTS uses two different concepts in switching, depending on whether the message has arrived through one of the fixed beams or one of the scanning beams.

Let's look first at how the satellite provides connections between its fixed beams. Let's think about it first in "slow motion". Suppose the satellite has three fixed beams, one on Atlanta, one on Cleveland, and one on Tampa. The satellite operates by switching the connections among the three beams, so that each beam is connected to each other beam at a very specific time for a very precise length of time. Let's say that between 12:00 and 1:00 the satellite connects the Cleveland uplink beam to the Atlanta downlink beam. Then from 1:00 to 2:00, the satellite connects the Cleveland uplink to Tampa and from 2:00 to 3:00, it connects Cleveland to itself. At 3:00, it repeats the pattern, again connecting Cleveland to Atlanta for an hour. The Cleveland station then operates by recording all incoming messages on a set of three tape recorders - one for Atlanta-bound messages, one for Tampa-bound messages, and one for Cleveland-bound traffic. It would record Atlanta messages, for example, for three hours (say from12:00 to 3:00), after which, between 3:00 and 4:00, it would "burst" those 3 hours of Atlanta- bound messages up to the satellite. We might think of this as playing the tape recorder in the "fast forward" mode so that three hours of messages go out in one hour.

On the satellite, the messages are immediately sent down the Atlanta beam to a ground station which will record them and then play them out to the intended listener at normal speed (which will take it three hours). By the time it has played all of the message, another segment should be arriving from the Cleveland station. The listener at the end of the line in Atlanta will never suspect that his message has been recorded, transmitted at fast forward speed, and then played back at normal speed - except of course that the entire message has been delayed three hours. Since many messages are only a few minutes long, or request a reply occasionally, the real ACTS system must work at a much higher speed.

Connections between beams are provided every few milliseconds and will only last for a fraction of a millisecond, so that messages are delayed not by three hours but only by a few insignificant and practically undetectable milliseconds. This means, of course, that we can't really use tape recorders. They simply can't record, rewind, and fast forward in thousandths of a second. Instead, fast computer memories are used to store data until it is time to "burst" it to the satellite. The process now is really transparent to the end user.

The second mode of routing involves the use of the moveable or scanning beams. In this case, the ground station still needs to "tape record" the message which it wishes to send. It must now synchronize its fast-forward bursts of information with the arrival of the scanning beam at its location. The on board processor receives the message, stores it and retransmits it to the ground when the downlink beam is over the destination. Again, the receiving station will pass the message on to the intended recipient at a normal speed. He'll never suspect all of the skullduggery which has taken place. The moveable beam technique allows the satellite to provide flexibility in its service. If at any instant there are few or no transmissions from a particular beam spot, the satellite can reduce or even eliminate the time it spends on that particular spot, using the time for an area with more demand.

Part 3: ACTS Ground Station

The ACTS ground station at Lewis Research Center functions as the master control station, as well as being one of the "users". The computers which one can see in the control room provide the programming which determines where the hopping beams will travel, what interconnections will be made on the satellite, which ground stations will have access to the computer, exactly what times they can transmit and receive, and what data rates they can transmit. In addition, the facility here monitors the "health and welfare" of the satellite. These include things like whether the solar cells are providing the specified levels of power, whether the satellite is maintaining its position and orientation properly, and whether electronic systems in general are functioning properly.

On the roof of the building which houses the control room, there are two large dish antennas (4.5 meters and 5 meters in diameter.) One is for controlling the satellite and the user network. The other is for a user's terminal. Their orientation can be adjusted. However, it is a slow process and should be unnecessary so long as the satellite maintains its position properly. These antennas are shown in the photograph above.

Just below the roof is located the power equipment for the transmitter. It is located as close as possible to the antenna so as to lose as little power as possible in the cable which connects it to the antenna.

Part 4: Potential Applications of ACTS Technology and Concepts

The greatest advantages which an ACTS type of system offers are its flexibility, it accessibility, and its capacity. For remote areas and for users on the move (like ships, airplanes, and autos) it offers a communications link which is available when you need it without having to pay for a satellite channel for those times when you don't need it. This feature has already been demonstrated in several ACTS experiments. For example, voice, video, and data were transmitted from a seismic exploration vessel in the Gulf of Mexico to a ground station here. Similarly, communication between a NASA jet and the ground through the ACTS satellite has been demonstrated. Such experiments demonstrate the feasibility of things like "distance learning", in which a number of remote classrooms can be given access to otherwise unavailable teachers or resources.

In addition, the high data rates which are made possible by the higher frequencies mean that ACTS can be a useful link between a remote user and a modern supercomputer. Whereas conventional phone lines would severely limit the speed at which the user can obtain results or monitor progress , the ACTS high speed link, with gigabits of data/second allows the user to observe the supercomputer operation in near real time. This has been demonstrated in ACTS experiments in which engineers at Boeing in Seattle were able to watch the results of a computer simulation of a jet engine inlet, providing what they called a "virtual wind tunnel." Similarly, ACTS experiments have demonstrated the practicality of transmitting medical data, including high resolution X-rays or CAT scans via ACTS, thereby making possible diagnosis or consultation from otherwise inaccessible sources. Of course, high data rates are attractive to businesses which might transfer gigabits of data (things like your checking account balance) from one office to another every day. (Or maybe your grades from school to your home computer or TV set every day.)

Part 5: Questions to be Answered During a Visit to the ACTS Facility

1. What word, meaning "goes around the earth once a day", is used to describe the orbit of ACTS ?

2. At what altitude does ACTS orbit?

3. To an observer on the earth, how does ACTS appear to move?

4. What frequencies does the ACTS system use?

5. A larger antenna will result in a (1) larger or (2) smaller beam spot?

6. As frequency increases, the size antenna required to obtain a certain performance becomes (1) larger or (2) smaller?

7. An advantage of the higher ACTS frequency is that a larger bandwidth is available. What does this mean in terms of the amount of data which the satellite can transmit?

8. How wide are the ACTS beam spots?

9. How long does it take the ACTS hopping beams to "visit" all of their destinations?

10. Which of the following are not advantages of an ACTS type of communications system?
    - It can provide communications to remote areas.
    - It can provide communications to moving terminals (ships, planes, autos).

- It provides and charges for connection only as needed, and used - much like your telephone system.
- It is easy to repair.

11. Explain how the satellite's moveable beams are made to move.

12. What do we mean when we call ACTS a "switchboard in the sky"?

13. What did ACTS cost to build?

14. How much money is made each year from the satellite communications business?

15. Explain why a larger antenna allows the satellite to use a lower transmitter power.

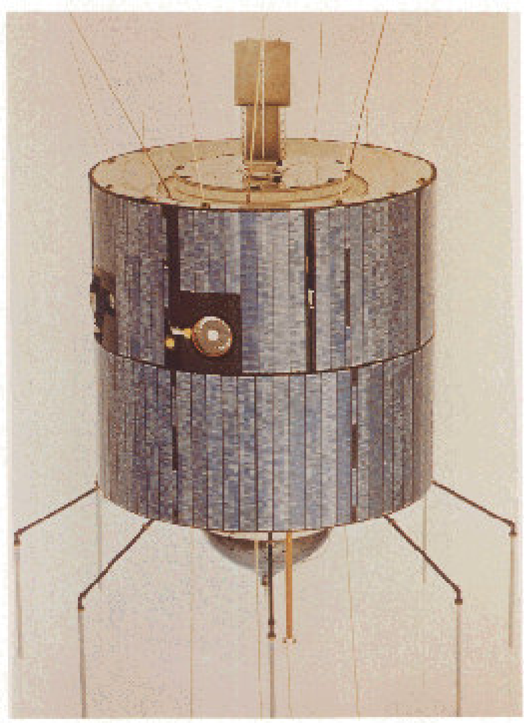
16. Name two applications where ACTS seems to offer advantages over conventional telephone.

17. How long does it take a message to travel from the earth to ACTS and back again?

BACKGROUND MATERIALS FOR A VISIT TO NASA'S APPLICATIONS TECHNOLOGY SATELLITE (ATS-3) FACILITY from SATELLITE COMMUNICATIONS, prepared by Dr. Regis Leonard for NASA Lewis Research Center

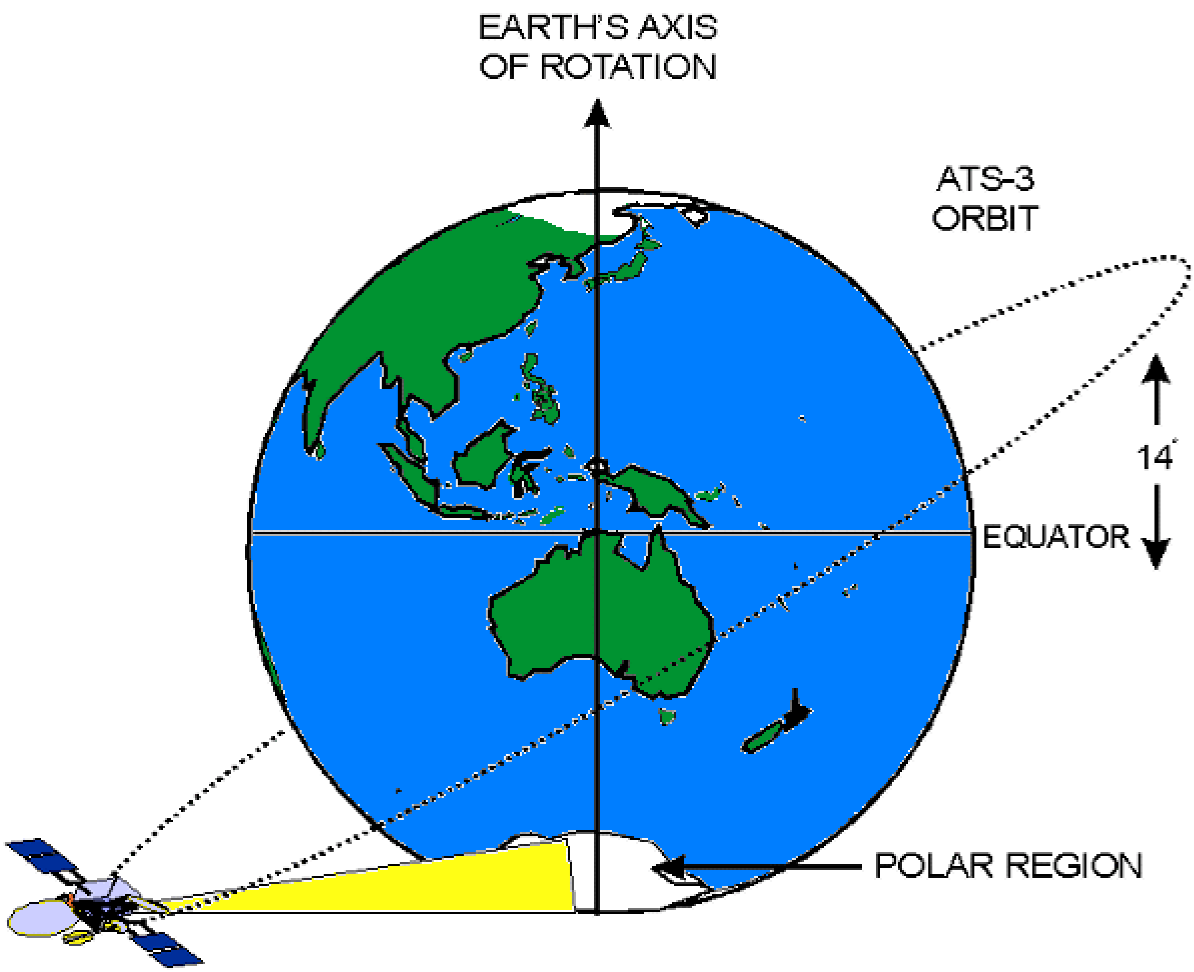
Part 1: General Description
FACTS:

The Applications Technology Satellite (ATS-3) was launched November 5, 1967. It was carried to orbit by means of an Atlas rocket, with an Agena second stage. The original experiments included a cloud camera which permitted the study of certain weather phenomena and C-band receivers and transmitters which were used for TV and data transfer experiments. The satellite was used to provide live TV coverage of the 1968 Mexico City Olympics. It obtained the first color pictures of the entire earth disk. Only a VHF (149 MHz up ; 135 MHz down) radio link is still operational. {below: The ATS-3 Geosynchronous Communications Satellite}



ORBIT:

ATS-3 was initially placed in a geosynchronous orbit at a longitude of 52.3 West. It has been moved to several other locations over its lifetime, but now resides at 105 west longitude. Because of the distribution of land masses on the earth, the satellite has no tendency to move from here and will maintain this location without a need for station-keeping fuel. (This is a good thing, because the station-keeping fuel was exhausted several years ago.) The orbit of the satellite is inclined about 14 degrees compared with the equator, as shown in the drawing below.



Orbit of the ATS-3 Satellite

This inclination means that as viewed from the earth, the satellite will appear to travel 14 degrees to the north and 14 degrees to the south each day. The inclination also means that for about 6 hours each day, the satellite can "see" the north or south pole.

SPECIFICATIONS:

- Original on-orbit weight: 798 pounds.
- Right circular cylinder: 58 inches in diameter; 54 inches long.
- Coverage: All of north and south America; much of Atlantic and Pacific Oceans, including Hawaii.

- Satellite Control station: Malabar, Florida.

- Satellite is "spin-stabilized". For satellites with directional antennas, that is, antennas which radiate preferentially in one direction, it is important that the antenna points in the proper direction, which requires that the spacecraft always point in the same direction. One way to keep the spacecraft always pointing in the same direction is to spin the entire spacecraft. In the case of ATS-3, the spacecraft is rotating at the rate of 95 revolutions per minute. The axis about which it rotates is pointed at the north star, so that it is parallel to the earth's axis of rotation. The spin of the spacecraft acts like a gyroscope. Unless some outside force gives it a push or pull the orientation of the spacecraft will not change. In space of course there are very few forces to disturb the spinning spacecraft. It is exactly like your bicycle wheel, which, as long as it's spinning, keeps the bicycle oriented properly, that is it does not allow it to fall over. If you come to a halt, however, and the wheels stop spinning, you lose the "spin stabilization" which they provided and …………FLOP!!

- Satellite transmitter power: 40 watts.

- Capacity: The spacecraft receiver and transmitter have 90 KHz of bandwidth. This is divided into 5 "channels" or stations, each of which can carry one voice conversation. It is possible to use two of the channels simultaneously, but the quality of the transmission will not be as good, since the two will be sharing the transmitter power available on the satellite.

GROUND TERMINAL:

The ATS-3 ground terminal at NASA's Lewis Research Center consists of two commercially available "VHF" radios (one for transmit and one for receive. You need two because transmit and receive are different frequencies.), an additional amplifier to obtain the power (about 100 watts) required for transmission to the satellite, and transmit and receive antennas, which are located on the roof of the building which houses the rest of the terminal.

Part 2: Present Users

- Any experimenter approved by NASA. Primarily experimenters are those looking for a communications system which will provide links from remote areas with a minimum investment in ground station equipment. At present an ATS-3 ground terminal can be assembled from commercially available parts for as little as $1000.00 (Fancier models could cost as much as $6000.00) .

- The ATS -3 system has been used to provide emergency communications during natural disasters. Some examples of these were the eruption of Mt. St. Helens in 1980, hurricanes Andrew and Iniki in 1992, and the Los Angeles earthquake in 1994.

- Because of its ability to provide coverage of the polar regions, the satellite is used fairly regularly for communication with the south pole and the Palmer Research station in Antarctica.

- An Emergency Response Communications Network, with stations across the continental U.S. and Hawaii utilizes the ATS-3 system.

Part 3: List of Questions to be Answered During a Visit to ATS-3

1. How old is the ATS-3 satellite?

2. How high is the ATS-3 satellite?

3. How long does it take the ATS-3 satellite to orbit the earth?

4. What is the shape of the ATS- 3 satellite?

5. The ATS-3 orbit is tilted 14 degrees from the plane of the equator. How would the satellite's motion look to us if it did not have this tilt?

6. How does the satellite's motion look to us with this 14 degree tilt?

7. Why is this satellite able to communicate with the polar regions when most of the communications satellites are unable to do so?

8. Why is ATS-3 spinning?

9. Where are ATS-3's solar cells?

10. Draw a sketch of the ATS-3 ground antennas.

11. If we talk to the satellite and then listen to our voice coming back, why is it delayed?

12. How much is the return signal delayed?

13. If the signal were a sound wave instead of a radio wave, how long would the trip from earth to satellite and back take?

14. Where are the solar cells on the ATS-3 satellite?

15. What frequencies does the ATS-3 satellite use?

16. What does mega- mean?

17. What does kilo- mean?

Part 4: Suggested ATS-3 Activities

Time Delay Measurement
Purpose:

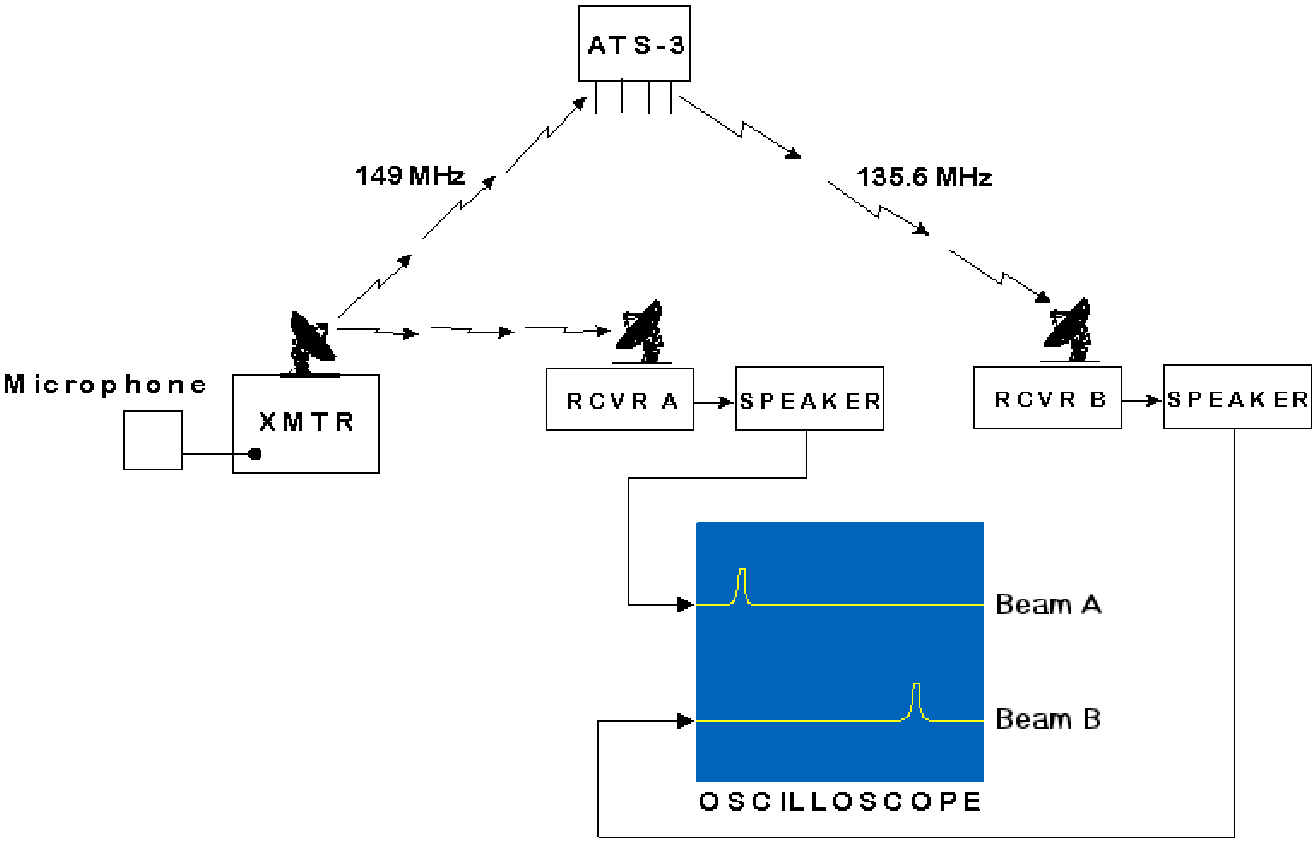
- To determine the time required for a radio signal to travel from our ground station to the ATS-3 satellite and back.

Apparatus:

- The ATS-3 ground terminal
  - One uplink transmitter at 149 MHz
  - One receiver (A) at 149 MHz
  - One downlink receiver (B) at 135.6 MHz

- A pair of speakers to provide an audible signal when an uplink transmission occurs (detected by receiver A) and when a downlink reception occurs (detected by receiver B).

- A dual-beam oscilloscope with one beam attached to each speaker.



Block Diagram of Delay Measurement

Procedure:

- Set up the oscilloscope to trigger its sweep when a pulse occurs on beam A.

- Create an uplink signal by tapping on the microphone or by simply 'keying" the microphone. Try to create the signal as the oscilloscope beam attached to receiver A is beginning its sweep.

- Observe the two oscilloscope beams. A pulse should appear on beam A and a second (delayed) pulse on beam B, which responds to receiver B.

- Locate the center of each pulse and calculate the time delay between them, based on the distance on the display and the horizontal time scale which has been selected.

Analysis:

- Given the time required for a radio signal to make the round trip from earth to a geosynchronous satellite and back (which you have just measured), calculate the satellite altitude, assuming that the speed of light (and radio waves) is 300,000,000 meters/second.

- Using the measured round trip time for a radio signal, calculate the speed of light, assuming that we know (Newton told us so) that a geosynchronous satellite must orbit at 22,300 miles above the earth.

Conversations with Antarctica

ATS-3 makes it possible for us to converse with researchers at Palmer Station, a research center located in Antarctica. The center has a staff of approximately 45 scientists and is dedicated primarily to marine studies: birds, plants, and microbiology, as well as long term environmental studies. Because the station is actually located just north of the Arctic circle (latitude = 64° 46' south) it is somewhat warmer than some of the other Antarctic installations. The temperature is also moderated somewhat by the fact that the station is located on an island (Anvers Island) and surrounded by water.

Activities Prior to Conversation:

- Find Palmer Station on the map: Its longitude is 64 04' west.

- Find information on the wildlife of the area:
  - Penguins (what kinds?)
  - Seals
  - Birds
  - Whales

- When are Antarctic seasons?

- What is Antarctic topology (mountains, volcanoes, etc.) like?

- How long do Antarctic seasons last?

- How long are the days and nights?

- What temperatures might one expect at this location?

- What temperatures would you expect at locations farther south?

- What is the coldest temperature ever recorded in Antarctica?

- What are some of the other research stations in Antarctica?

- How would one travel to Antarctica?