The FUTURES Channel®

MOVIE GUIDE

MOVIE NUMBER 5004

Communications Satellites

The Movie:

A system of satellites that orbit the Earth at various distances make it possible to communicate from anywhere, to anywhere. Featured: Kerry Joels, aerospace engineer. *(Movie length: 2:43)*

Background:

Communications satellites that remain always in the same position above the Earth were first proposed by science fiction writer Arthur C. Clarke, in an article for the British publication "Wireless World" in 1945. When he suggested it, Mr. Clarke said that the idea was probably 50 years ahead of its time, but in fact it took less than 20: the world's first geo-synchronous satellite was launched in 1963.

With a mass of anywhere from 500 kilograms to 2,000 kilograms, it takes a substantial amount of fuel—and money—to put a communications satellite into orbit. But once in position such a satellite can relay communications for millions of people, 24 hours a day. In fact, communications satellites for commercial and military purposes make so much sense that there are currently several hundred of them orbiting the Earth.

Curriculum Connections:

Measurement (weight, conversion) — 1

It can cost $15,000 per pound to put a satellite into geo-synchronous orbit. What is the cost for a satellite of mass 850 kilograms?

Measurement (rate) — 2

When a satellite is in the geo-synchronous orbit, it is 22,240 miles away from the surface of the earth. Given the speed of light is around 186,000 miles per second, compute the delay from the time a signal is sent up to the satellite to the time it is received by an antenna back on Earth.

Geometry (circles), Measurement (rate) — 3

Suppose that you put 80 satellites into low earth orbit at 800 kilometers above the surface of the Earth.

a) If the satellites are to be evenly spaced around the equator, how far apart must they be? (The Earth's radius is approximately 6,300 km).

b) If you were to make a call to a point 2,970 km away, how many satellites would it relay through? How far must the signal of your call travel between satellites and from the ground to the satellites and back? (Assume that the satellites are directly above the sending and receipt points of the call.)

c) How many seconds of delay are there between sending and receipt of signal in the situation described in (b)? (The signal travels at 300,000 km per second.)

Algebra (solving equations with exponents) 4

The relationship between a satellite's time duration of orbit (t) and its distance from the center of the Earth (d) is given by this equation:

$$t = kd^{3/2}$$

Use the fact that a satellite in geo-synchronous orbit, at 26,240 miles above the center of the Earth, has an orbital duration of 24 hours to find k. Then use that value of k to determine the distance from the center of the Earth for satellite orbits of these durations:

Duration of orbit	Distance
24 hours	26,240 miles
18 hours	
12 hours	
8 hours	
6 hours	
3 hours	
2 hours	

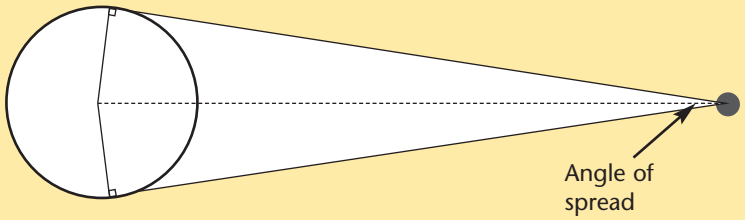
Trigonometry 5

Communications satellites receive signals from and transmit signals to Earth stations, which then send the signals to the receiving party. Suppose an Earth station is sending a signal, and the signal must be directed to within 5 miles of the position of the satellite. If the satellite is in orbit 22,240 miles above the surface of the earth, by how much of an angle can the signal diverge from a straight line to the satellite and still be picked up?

Trigonometry 6

This diagram shows the relationship between the "angle of spread" of the signal from a communications satellite and its distance from the Earth. (The angle of spread is the angle between two lines from the satellite that are tangent to the Earth. As shown in the diagram such tangent lines are perpendicular to radii that intersect them at their tangent points.)

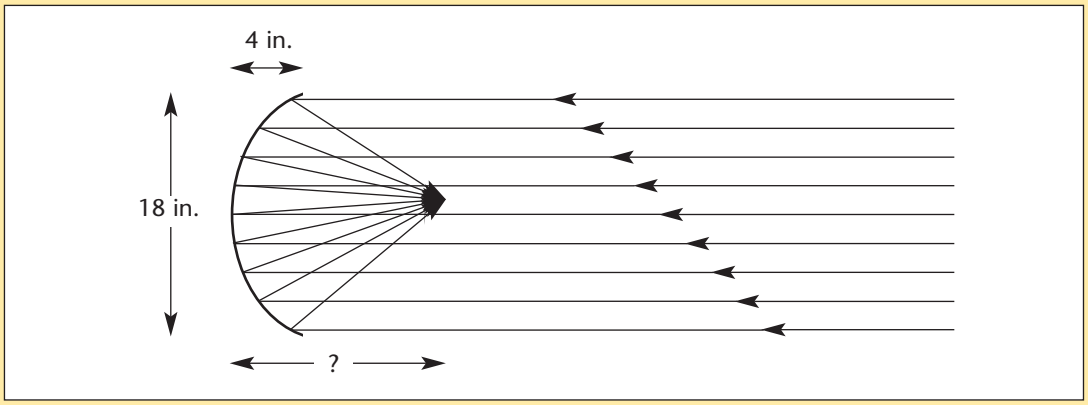
Use the fact that the satellite is 22,240 miles above the Earth, and the Earth's radius is 4,000 miles, to determine the angle of spread. (Hint: The dotted line has been drawn in to create two right triangles.)



Algebra (quadratic functions) 7

A satellite dish has a parabolic shape, which concentrates the incoming satellite signal to a point.

A typical TV satellite dish for a home has a diameter of 18". If the depth of the dish is 4", how far above the center of the dish is the focal point?



Algebra (solving equations with exponents) 8

The distance at which a satellite will be in geo-synchronous orbit around the Earth is determined by the two equations below.

a) $\frac{mv^2}{r} = \frac{GMm}{r^2}$

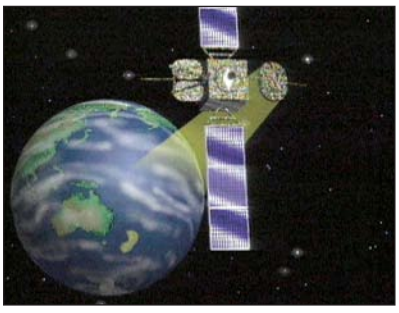
The force necessary to keep the satellite in orbit is equal to the force of the Earth's gravitational attraction at that distance.

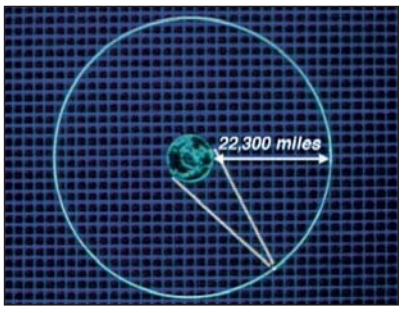
b) $v \neq \frac{2\neq r}{86400}$

The velocity of the satellite equals the circumference of is orbit divided by the number of seconds in 24 hours. This is the same as stating that the satellite orbits the Earth once every 24 hours.

v = velocity of satellite
r = radius of the orbit
G = gravitational constant = 6.67 x 10^{-11} m^3/kg-sec^2
M = mass of the Earth = 6.0 x 10^{24} kg
m = mass of the satellite

Solve these two equations simultaneously to find ***r***. Your answer will be in meters; convert that to miles.





Algebra (quadratic equations)

If the Space Shuttle were to make a maintenance trip out to a satellite in geo-synchronous orbit, the Shuttle would need to enter into an elliptical orbit around the earth. That orbit could be described by this equation:

$$y = b\sqrt{\left(1+\frac{x}{a}\right)\left(1-\frac{x}{a}\right)}$$

where ***a*** and ***b*** are numbers that determine the shape of the ellipse.

If all distances are measured in thousands of miles, then an actual orbit might be described by this equation:

$$y = 5\sqrt{\left(1+\frac{x}{13.5}\right)\left(1-\frac{x}{13.5}\right)}$$

1. Find the value of ***y*** for each value of ***x*** (to two decimal places):

x	-13	-12	-8	-6	-4	-2	0	2	4	6	8	12	13
y													

2. Plot the ordered pairs from the table above and sketch the curve that connects them.

3. In this orbit, the Earth would be at the position (-12.5,0), and the satellite would be at the position (13.5,0). Plot these points on your graph. How far is the Earth from the satellite?

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