HOW FAR AWAY ARE THE SATELLITES?

Concepts

- A signal is a wave
- Wave characteristics can be used to measure properties such as velocity, distance, and time
- Every measurement has units
- Units are interchangeable

Materials

- Paper and pencil
- Calculator

Required skills

- Basic understanding of dimensional analysis, errors and rates
- Knowledge of basic algebra

Background

Did you listen to the radio this morning? The news programs and music that you heard were the result of radio waves being broadcast out into the air above the area you live in. GPS satellites in space send information, in much the same way, through the use of radio signals to receivers on Earth's surface. So, how is it possible for these signals, detectable physical quantities, to transmit information and sound through the air and through space? The answer is waves. A waves is a disturbance that transports energy, not matter, through a system. There are many different types of waves. One, that we are particularly interested in, is called a mechanical wave. Mechanical waves involve disturbances of a mechanical medium such as air, water, earth, and space. The propagation of a mechanical wave is easily demonstrated by sound waves created when a person talks. When a person speaks, vibrations in their throat create disturbances in the air in the form of sound waves. The sound waves continue to make disturbances as they travel. These disturbances are picked up by hairs in your ears and amplified, or increased. The result is the sound that you and others hear when someone is talking.

The key to understanding mechanical waves is in understanding oscillatory motion, or simply, motion back and forth about a constant point. Picture a pendulum. Consider the point when the pendulum is hanging straight down and not moving as the constant point. When the pendulum is raised and released it moves back and forth across the original constant point. Waves act just like this. The most common graph of a wave shows it moving back (positive) and forth (negative) across a constant point (zero.) Waves are made up of repetitive patterns of back and forth movement. [link to picture of pendulum in constant state and in motion]

People use special terminology to describe waves, their properties and characteristics. Often you hear about amplitude, the maximum disturbance or distance from the constant point; wavelength, the distance over which a wave pattern repeats; period, the time for one complete wave cycle to be completed, and frequency , the number of wave cycles per unit of time that pass a given point. All of these terms represent wave characteristics which are essential when waves are used to calculate variables of motion such as distance, velocity, and time.

Before solving "motion" problems, there are four things you need to have: the equations for each property, values for at least two variables in the equation, the units for each variable and the appropriate conversion factors. Conversion factors are ratios that allow you to interchange between variables. For example, there are 100 cm in 1 m, or in ratio form, 100:1 cm:m. If you had a value in meters and wanted to know what it was in centimeters you could multiply your value by 100 and have your answer in centimeters. In this example, the words centimeters and meters represent units. Units tell others what you are describing and comparing. If you had a new puppy and someone asked you how old it was, you wouldn't say 6, you would say six weeks or six months. Weeks and months act as units for the value 6. All values have units. It is important to know what units go with every value you use because units can also tell you if you are on the right track to getting the answer to a problem. Take the following problem: you have 6 cassette tapes and you want to trade with your friend who has CD's. Assuming that 1 CD is worth two tapes, how many CD's can you get in the trade? You would set the equation up this way:

$$(6 \text{ tapes}) \times (1 \text{ CD} / (2 \text{ tapes})) = 3 \text{ CD's}$$

In this example you see the use of both conversion factors and units. First, the conversion factor is 1 CD for 2 tapes. Here, you divided tapes by tapes leaving you only with CD's. Second, the words "tapes" and "CD's" acted as units in this example. If you had not used these units you would have been trading 6 for 3, and no one would know what they were getting or giving away. Also, if you had multiplied tapes by tapes no units would have canceled and you would have gotten a ratio instead of an answer with only one unit. Hint: Always look at your units. If they cancel, you are on the right track; if they don't, double check your calculations until they do.

Helpful Formulas

- Frequency = 1/period
- Distance = velocity x time
- Velocity = wavelength x frequency
- Velocity of light waves in space (a vacuum) = 2.99×10^8 m/s
- Wavelength is the distance over which a wave pattern repeats
- Wavelength has the unit: meter
- Frequency has the unit: Hz
- Period has the unit: seconds
- Cycles have invisible units
- 1 MHz = 1×10^6 Hz
- 1 Hz = 1cycle/ s = 1/ s

Procedure

1a. Assume that a signal leaves a satellite in space at 08:55:36 a.m., arrives at an Earth-based receiver at 08:55:43 a.m. and travels at the speed of light at all times. What is the distance from the satellite to the receiver? (Answer should be in meters.)

1b. What is the answer to problem 1a in kilometers?

2. One satellite signal frequency is at 1575 MHz. Using the information given in problem 1a, How many cycles have been completed when the signal reaches the receiver?

3. From your answers and the information provided in the last two problems, find the wavelength of each cycle.

4. If it takes .00004 seconds for a signal, traveling at the speed of light, from your favorite radio station to get from Burbank to Downtown LA, determine the distance the signal has traveled, how many cycles have been completed, and the wavelength of each cycle. Hint: the radio station call number = radio signal frequency in MHz (FM).

Questions to Answer

- Do your distance estimates seem reasonable?
- How would you convert your answer from meters to miles?
- Is it possible to get the same answers if you start with different given variables?
- What could cause errors in your calculations?
- What could change the distance or the speed?
- How is space different than Earth?
- Do an antenna's surroundings effect what it receives?

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