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Where on Earth?

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GE Astro Space/SPL

An artist's impression of a GPS satellite.

Spacecraft move around the Earth in many different orbits, according to their purpose. In this article, we look at one use of satellites — navigation.

In a flat, rectangular field near Bognor Regis in Sussex, a tractor moves steadily up and down, spreading fertiliser. But this is no ordinary tractor. For a start, there is no driver. The vehicle is controlled by an onboard computer which uses satellite technology to determine its position in the field.

The computer has a detailed record of the crop yield from every square metre of this field last autumn; where the yield was poor, extra fertiliser is added to the soil.

The tractor's onboard computer relies on the **global positioning system** (GPS), a navigation system originally set up by the United States Department of Defense but now more widely available. If you go sailing, you may use a GPS receiver for navigating, an increasing number of mobile phones have GPS built in, and so do many cars.

THE GPS SATELLITES

The GPS 'constellation' is made up of 24 satellites. They occupy six orbits around the Earth, with four satellites spaced around each orbit (Figure 2).

- Orbit radius: 20 190 km — about three times the radius of the Earth.
- Orbital period: about 12 hours, so each satellite orbits the Earth twice a day.
- Orbital tilt: 55° relative to the plane of the equator.

The satellites are spaced out in this way so that, wherever you are on the Earth's surface, you will be in 'line-of-sight' of at least four satellites at any moment; in other words, your GPS receiver will be receiving at least four signals.

GPS SIGNALS

Each of the 24 satellites transmits a signal towards the Earth. This is a digital signal — it consists of a sequence of on–off pulses of different lengths (Figure 1). The signal encodes a range of information, including the identity of the satellite and the time. The receiver can decode this information to work out the user's position on the Earth.

Signals are transmitted at two different frequencies, L1 = 1575.42 MHz, and L2 = 1227.6 MHz.

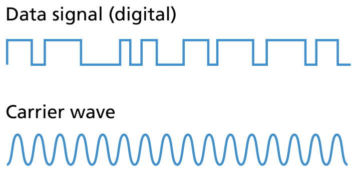

Figure 1 *The digital GPS signal transmits information at a slow rate — about 50 bits per second.*

These frequencies are in the microwave region of the electromagnetic spectrum, with a wavelength of 20 or 30 cm. The wavelength must be as short as this if a position is to be determined to within a metre or so.

Two frequencies are used because microwaves are slowed down as they pass through the ionosphere, a charged region high in the atmosphere, and this introduces an error into the measurements. Different frequencies are slowed down by different amounts, just as violet light is slowed down more than red light as it passes through glass; this is an example of **dispersion**. Expensive GPS systems can compare the two signals and correct for the error. Most civilian receivers use only the L1 frequency.

CALCULATING POSITION

If you have a GPS receiver, how can it use the four or more signals reaching it to work out your precise location? Here is an analogy, using sound.

Imagine that you are in the countryside, surrounded by mountains. Three of the mountains have a cannon on the summit. At midday, each cannon fires a blank. What do you hear?

WAVELENGTH OF L1 WAVES

$$\text{wavelength} = \text{speed of light/frequency}$$
$$= \frac{3 \times 10^8 \text{ m/s}}{1575.42 \times 10^6 \text{ Hz}}$$
$$= 0.19 \text{ m}$$

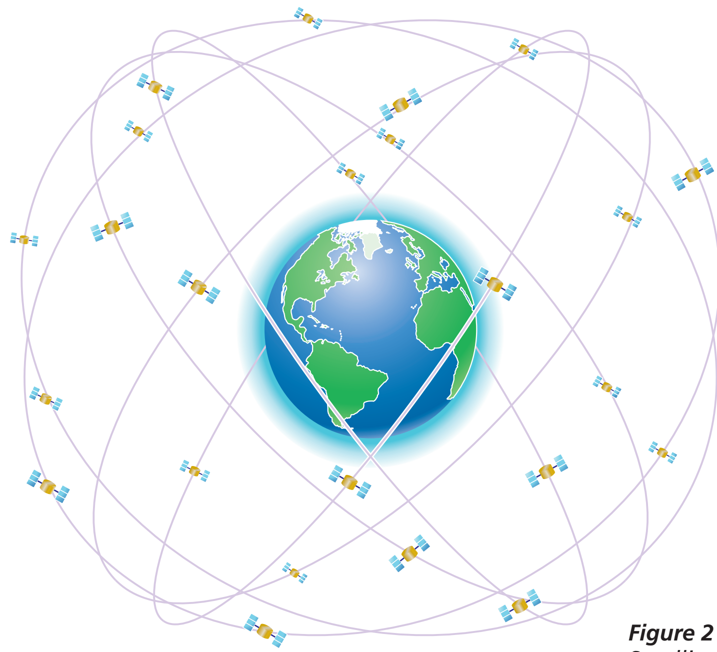

Figure 2 *Satellite orbits.*

If you are the same distance from all three mountains, all three bangs will reach your ears simultaneously. But elsewhere, you are likely to hear three bangs in succession. If you look at your watch, you will be able to determine how many seconds after midday each bang arrives. Knowing the speed of sound, you can work out your distance from each mountain, and find your position. (This technique is known as **triangulation**; you have probably come across it in geography or maths — see Figure 4.)

The GPS system works in the same way, but using radio waves. The signals are transmitted continuously, not just at midday. Of course, in the sound analogy, you need to know which bang has come from which cannon. In the case of GPS, each signal encodes the details of the satellite which transmits it, together with the time.

The advantage of having signals from at least four satellites is that the receiver's computer can work out four things: latitude, longitude and altitude (equivalent to x, y and z coordinates), and the precise time.

GPS satellites are not positioned in a geostationary orbit, alongside telecommunications and television satellites, because this orbit cannot be seen from polar regions.

The European Space Agency plans to establish a second satellite navigation system.

Today's GPS systems are typically accurate to within a metre or so; for surveying purposes, they can be accurate to within 1 cm.

1 MHz = 1 megahertz = 10^6 Hz.

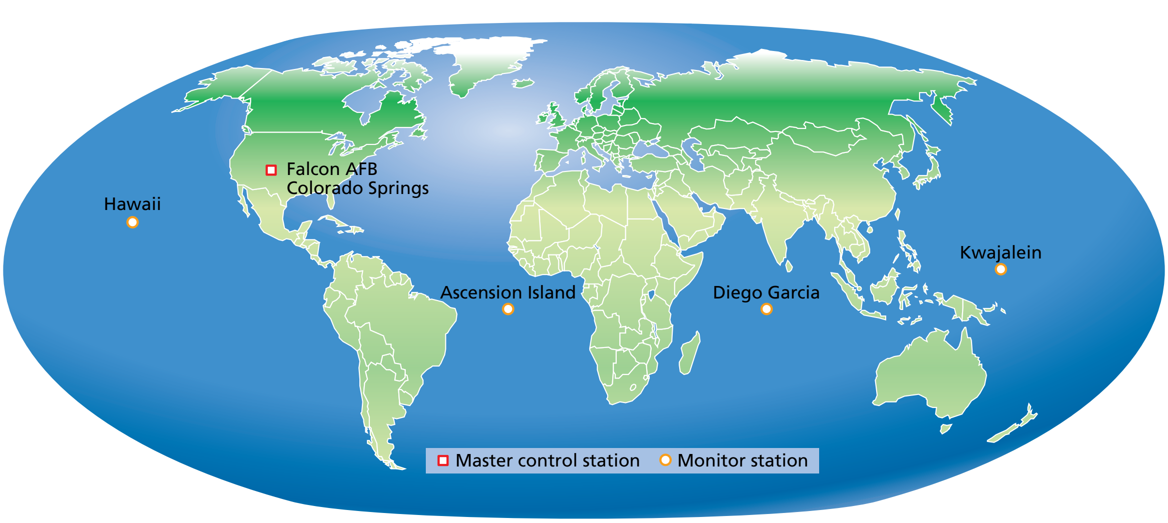

Figure 3 *The central GPS control station is at Falcon Air Force Base, Colorado Springs. The satellites are monitored from four other stations around the world.*

Sailor Ellen MacArthur. GPS is an important aid to navigation.

Rick Tomlinson

Figure 4
How triangulation works.

In addition, your own speed can also be found, using the Doppler effect. This is the change in frequency which occurs when a source of waves and the receiver move relative to one another.

USING GPS

Aircraft and shipping make great use of GPS for navigation. In the past, they used a system called dead-reckoning — by monitoring speed, direction and time taken, they could plot their routes on a map. Usually, they had to travel in this way from one radio beacon to the next. Now, an aircraft using GPS can follow a great circle around the Earth, the shortest distance between two points.

The US government is insisting that all mobile phones should include GPS. This will mean that the rescue services will be able to pinpoint the position of anyone making an emergency phone call. Some people suspect that it will also make it possible to track anyone carrying a phone — this is seen as an invasion of personal privacy.

Cars may combine a GPS receiver with an on-board **geographical information system** (GIS). The GIS is a computer with details of road networks, tourist information and so on, which can alert drivers to useful information as they drive around. A specialised GPS device can warn drivers of high-sided vehicles when they are approaching low bridges; another can warn drivers when they are nearing a speed camera, so that they will slow down. Is this a form of cheating?

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