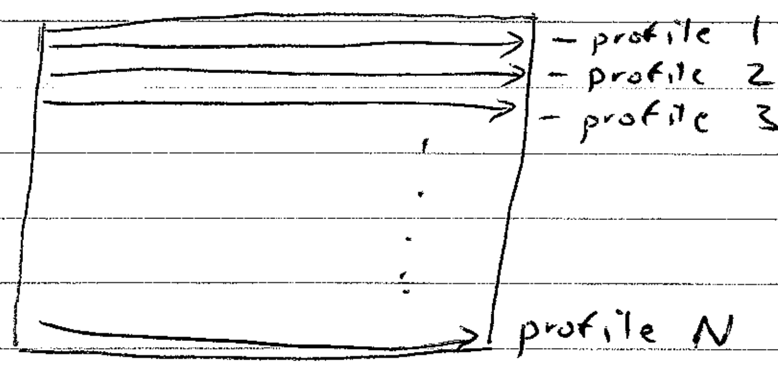
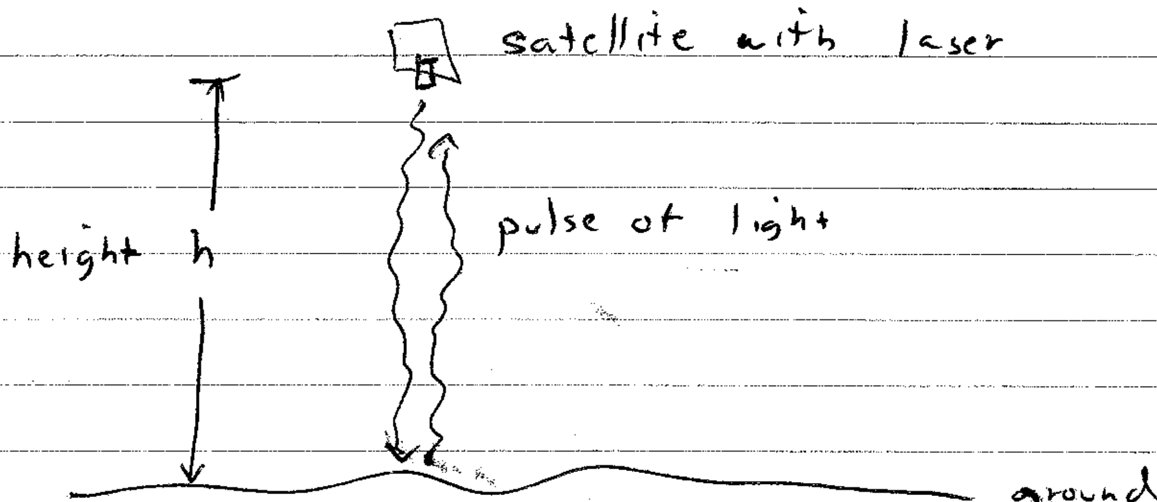
Example of a raster-scan system – Laser Altimeter

We can think of a raster scanning instrument as creating images in 2-D by arranging a set of profiles, each depicting a "line" through the desired 2-D area of coverage. In the case of the TV image this is obvious:



Another example might be an orbital satellite carrying a laser, illuminating the surface below. If we transmit a short pulse of laser light and time how long it takes to return from the ground below, we get a measurement of how high the satellite is above the surface.

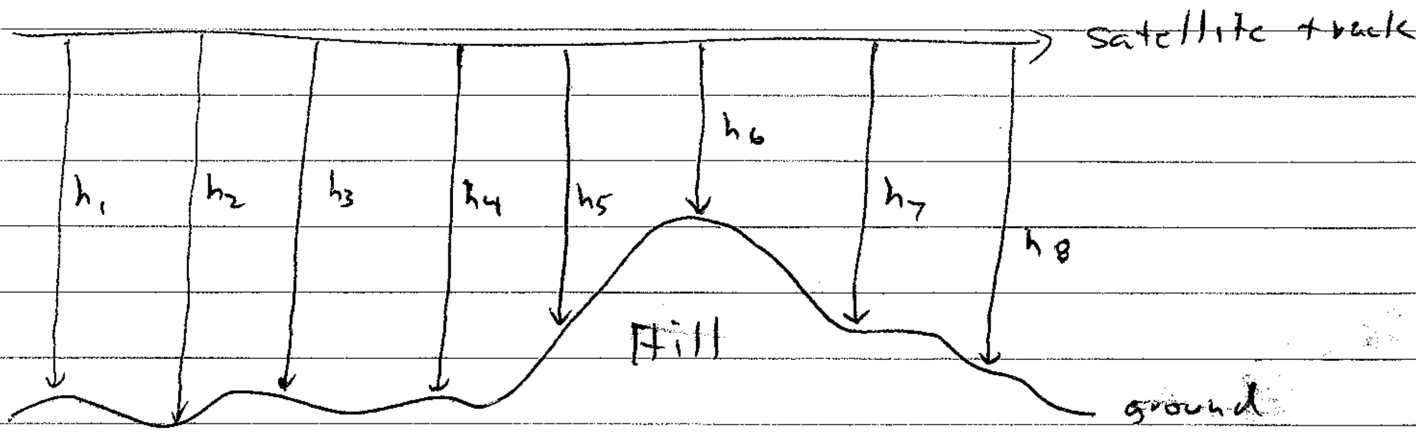


Because we know light travels at the speed of light, measuring the time delay t allows us to infer h:

$$h = \frac{c \cdot t}{2}$$, where c is the speed of light

Where does the factor of 2 come from?

Suppose the satellite is orbiting and sending out a series of pulses. Measuring each time delay gives us a series of height estimates, which in turn yields a cut through the topography.



We can imagine flying over the entire Earth and measuring global topography this way. How would this work in practice? We have to be able to relate orbit position to where we are pointing on the ground. This calculation is part of orbital mechanics.

Basics of orbital mechanics

Newton's laws of motion and gravity can be used to determine the allowed relations between orbital periods, velocities, ellipticities, and so forth. The first solution to this problem is due to Kepler who was interested in describing and predicting the positions of the planets. He found that orbits are elliptical with the center of mass of the sun-planet system at one focus of the ellipse.

Here we are interested in artificial satellites in orbit around the Earth. Since the Earth is so much heavier than the satellite, we can consider the center of the Earth as the focus. We'll also only consider circular orbits, so each orbit is a perfect circle around the center of the Earth.

Orbital mechanics gives the velocity of a satellite around the Earth as

$$v = \sqrt{\frac{\mu}{r}}$$

where μ = geocentric gravitational constant
$= 3.986004 \times 10^{14}\ m^3\ s^{-2}$

r = radius of orbit from center of Earth

Then the period of the orbit is

$$T = \frac{2\pi r}{V} = 2\pi r \cdot \sqrt{\frac{r}{\mu}}$$

Sometimes we use the orbital altitude h rather than r:

$$h = r - r_e$$

where r_e = radius of Earth ≈ 6378140 m. (equatorial value)

As an example, if $h = 570$ km, then $v = 7.6$ km/s and $T = 1$ hour 36 minutes. Such a satellite would orbit the Earth exactly 15 times in 24 hours, or one day.

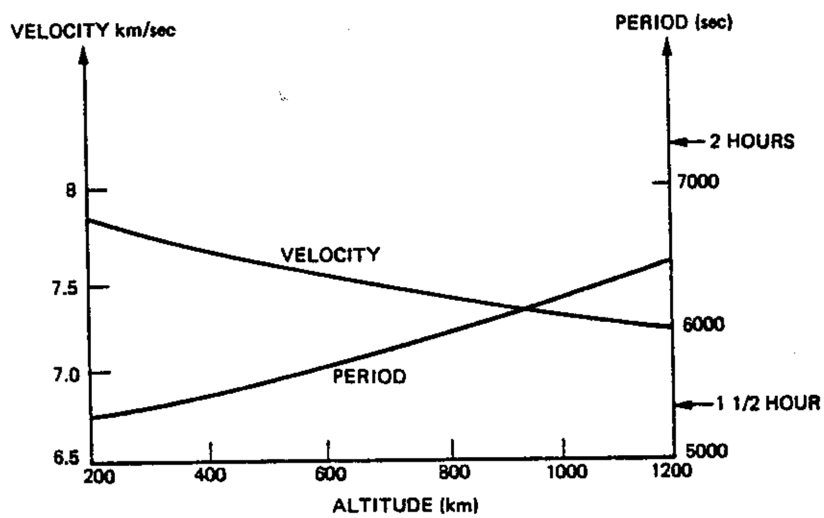
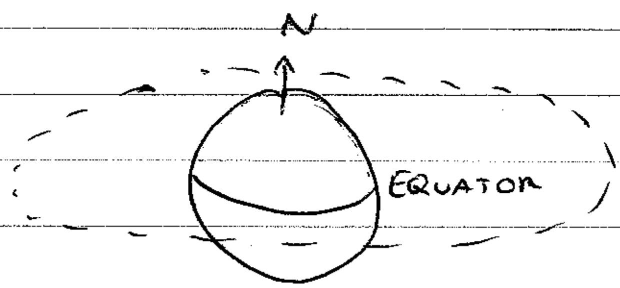
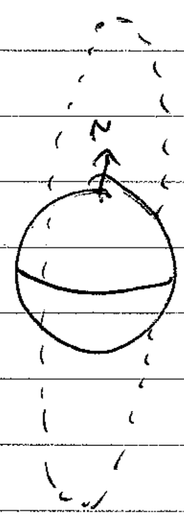


Figure B-1. Orbital velocity and period function of altitude for a circular orbit (case of the Earth).

In addition to altitude and period, we also are concerned with the orientation of the orbit with respect to the Earth's spin axis. Here we will look at two idealized cases, equatorial and polar orbits.



An equatorial orbit, with the satellite always in the plane of the equator



A polar orbit, where the satellite passes directly over each pole on each orbit.

Of course, many other specialized orbits are possible and are used by real spacecraft.

When are equatorial orbits desired?

How about polar orbits?

Location of sub-satellite point

Note that for the polar orbit, it is possible to view the entire Earth. As the satellite orbits smoothly within its orbital plane, the Earth rotates beneath it bringing a new spot on the surface under the satellite each time it passes over. Unless, of course, the orbit is chosen to have a period of exactly 24 hr.

Thus, the latitude of the sub-satellite point depends only on the satellite period, while the longitude repeats with a cycle of 24 hours. These relations allow us to calculate the position of the satellite at any time, given the satellite altitude.

By properly choosing the altitude, then, we can design a laser altimeter system that can map the elevation of every point on Earth. The laser time delays ~~Eton~~ form a "profile" of heights over the Earth. Mapping these heights to latitude and longitude results in a topographic map of the Earth.

Such a space mission has never actually been flown to achieve topography of the full Earth. Can you think why? This technique has been used over portions of the Earth's surface and on the Moon, and is currently part of NASA's Mars program.