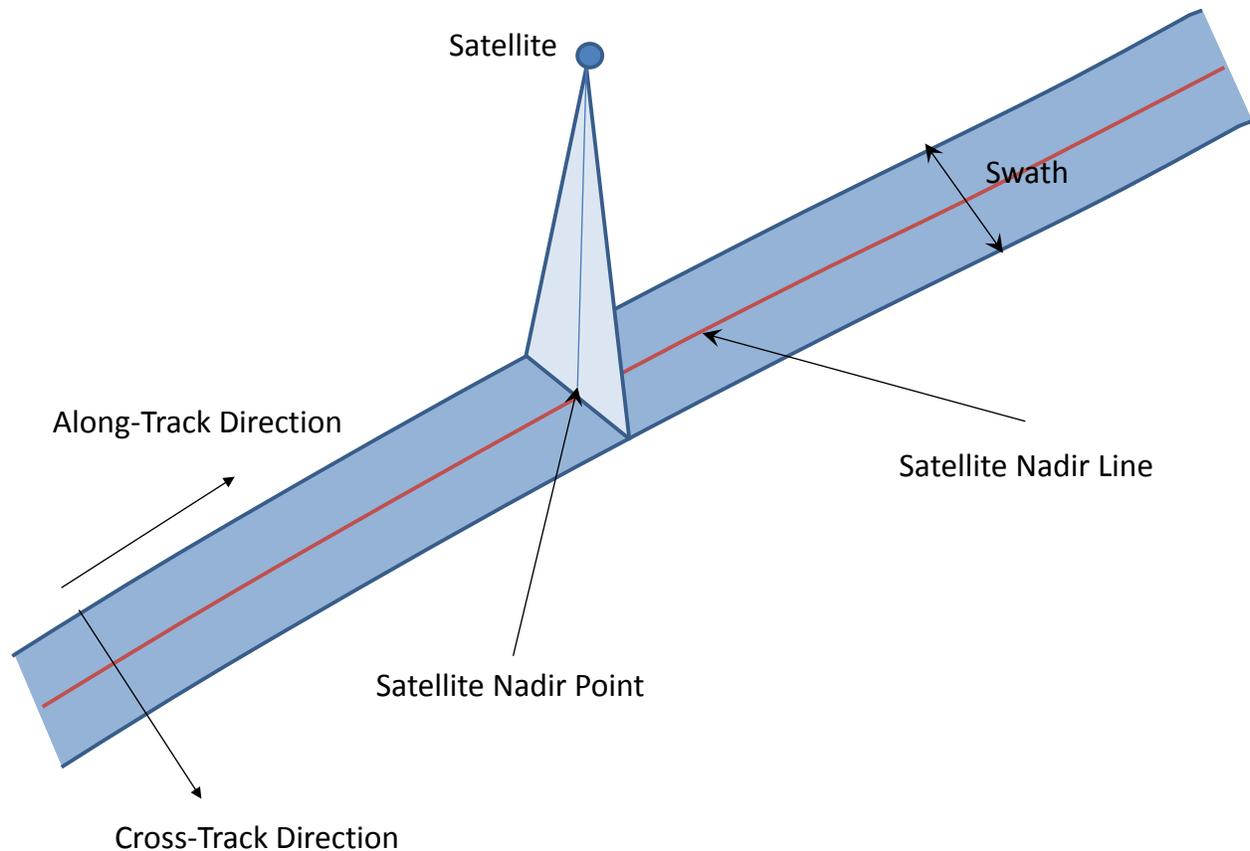


IMAGING GEOMETRIES

As the remote sensing instrument is carried along the satellite orbit, it typically images a strip on the surface along the orbit track. The width of this strip is known as the *swath* imaged by the camera. The direction along the satellite track is known as the *along-track* direction, and the direction orthogonal to the satellite track is known as the *cross-track* direction. The figure below defines these and some other imaging parameters.

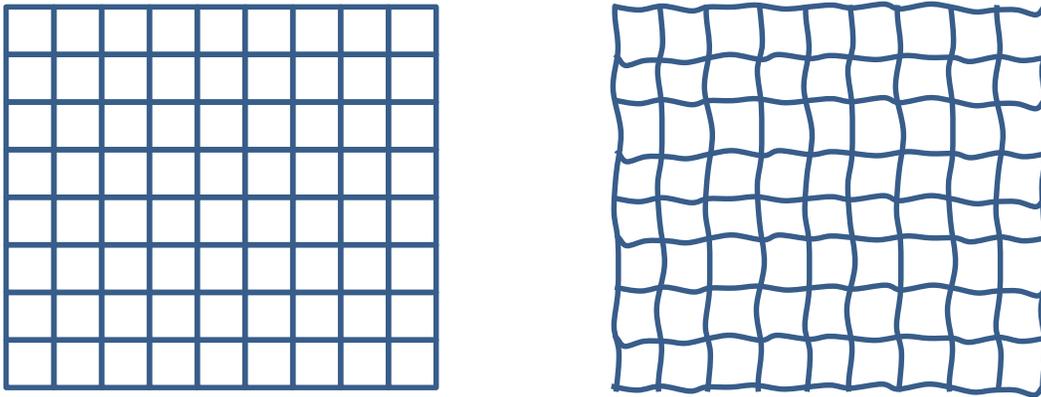


Definition of various imaging terms. Note that this figure shows the imaging strip to be centered on the nadir line. While this is the most common way of implementing visible and near-infrared imaging systems, the swath could also be placed to the side of the nadir line.

Depending on how the sensor acquires and records the incoming signal, imaging systems can be divided into three general categories: framing cameras, scanning systems, and pushbroom imagers.

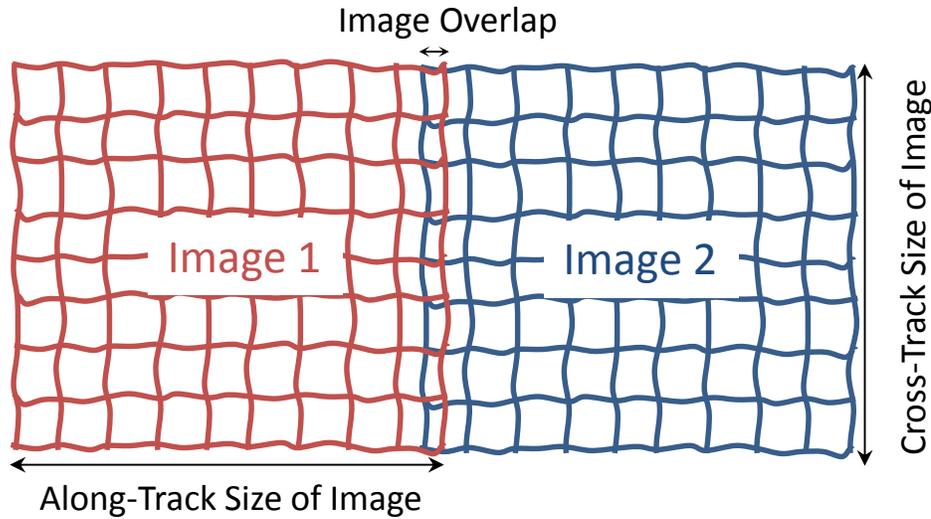
A framing camera takes a snapshot of an area of the surface, which is then projected by the camera optics on a film or a two-dimensional array of detectors located in the camera focal plane. As detector arrays with more pixels become available, framing cameras will become more

common. An example of a framing camera is the panchromatic camera used on the two Mars Exploration Rovers that landed on Mars in January 2004. Framing cameras have the major advantage that excellent geometric fidelity can be achieved because the entire image is acquired at once. This comes at the price that the optics system must typically have excellent response over a wide field of view. The area imaged on the surface by a framing camera is that portion of the surface covered by the projection of the detector array or film frame on the surface. If the surface has no relief, the projection would just be a square which is a scaled version of the detector array. In the presence of relief, the projection is distorted by the local relief. The result is that the edges of the image in the presence of relief would not be straight lines.



The area on the surface imaged by a framing camera is the projection of the detector array on the surface. If the surface has no relief, the projection will look like the “image” on the left. Local relief distorts the pattern to look more like the “image” on the right.

If a framing camera is used to image a long strip in the along-track direction, we must create a strip by taking successive images of the surface. These images would typically overlap slightly in the along-track direction to take into account the fact that the topography of the surface may distort the projection of the detector array on the surface. It is important to remember that the imaging process happens while the satellite platform is moving. To avoid “smearing” the image across the focal plane, we need to “freeze” the image on the detector array while the satellite is moving. One way to accomplish this would be to use a steering mirror that moves synchronously with the satellite to ensure that it always projects the same piece of the surface on the detector array. The steering mirror would point ahead of the satellite initially, and then slowly rotate until it finally points behind the satellite at the surface. Ideally, we would be able to integrate the signals for the entire time it takes the projection of the detector array to move a distance equal to the along-track direction size of the image on the surface. But since we need to get ready to image the next image in the strip, we need to move the steering mirror to point ahead of the satellite for the next image, so we use up some of the time for resetting the steering mirror. The duty cycle of the system describes that fraction of the maximum possible imaging time that we actually use for imaging.



Framing cameras build up strips of images by acquiring successive images in the along-track direction. The images overlap in the along-track direction to ensure that the distortion introduced by the relief does not cause gaps between the images.

When we estimate the time available to integrate the signals to form the image, we need to remember that the projection of the focal plane on the surface moves at a different speed than the satellite. To better understand this, let us consider the spacecraft and the nadir point, *i.e.* the point on the surface directly under the spacecraft. If the satellite is flying at an orbital altitude h above the surface of the planet with radius R , we can calculate the orbital period of the spacecraft to be (see Appendix B)

$$T = \frac{2\pi(R + h)}{v} = 2\pi(R + h) \sqrt{\frac{R + h}{g_s R^2}}$$

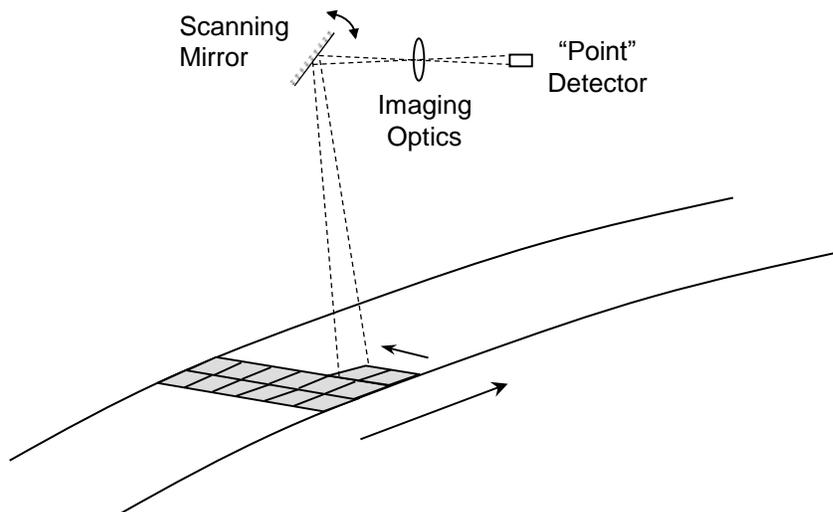
During this same time, the nadir point covers a total distance $2\pi R$. The speed at which the nadir point moves is therefore

$$v_n = \frac{2\pi R}{T} = \frac{R}{R + h} v$$

If the along-track size of the image is x , then the *maximum possible* integration time is

$$T_{max} = \frac{x}{v_n}$$

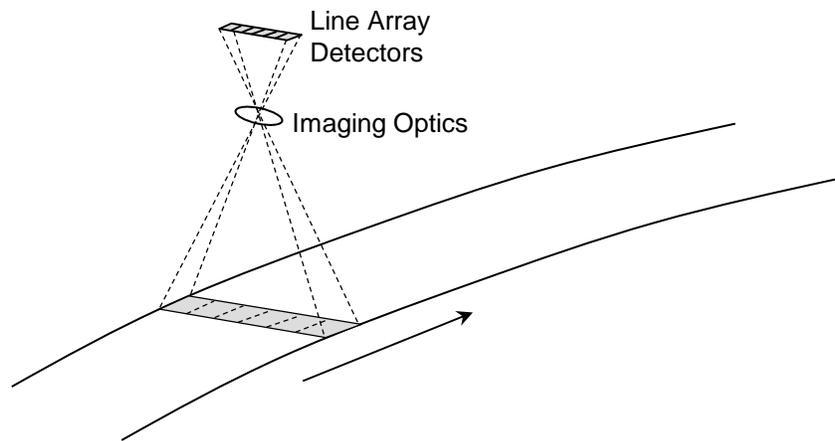
Scanning systems use a scanning mirror that projects the image of one surface resolution element on a single detector. To make an image, across-track scanning is used to cover the imaged swath across the track. In some cases a limited number of detectors are used so that each scan covers a set of across-track lines instead of a single one. In this case, the imaging system is known as a whiskbroom scanner. The platform motion carries the imaged swath along the track. In this case the maximum integration time is determined by two things. First, the total along-track size of the detector projection determines the maximum time we have to complete a single scan across the swath and back. If we scan slower, there will be gaps in the image. Next, we need to divide this time per scan by the total number of pixels across the swath that we image during the scan. In most cases, if the image is N pixels wide, we will image that number of pixels in each direction of the scan for a total of $2N$ pixels imaged per scan.



Whiskbroom scanner geometry.

The major disadvantage of such a system is the presence of moving parts and the low detection or dwell time for each pixel. In addition, images acquired with scanning systems typically have poorer geometric fidelity than those acquired with framing cameras. Examples of scanning systems are the Landsat instruments such as the Multispectral Scanner (MSS) and Thematic Mapper (TM) and the Enhanced Thematic Mapper Plus (ETM+).

Pushbroom imagers delete the cross-track scanning mechanism and use a linear array of detectors to cover all the pixels in the across-track dimension at the same time. This allows a much longer detector dwell time than the cross-track scanner on each surface pixel, thus allowing much higher sensitivity and a narrower bandwidth of observation. Examples of such systems are the SPOT and the ASTER cameras. A pushbroom system can be thought of as a framing camera with an image frame that is long in the across-track direction, and much narrower in the along-track direction. Pushbroom sensors do not require a moving scan mirror in order to acquire an image. As a result, these sensors can be expected to exhibit longer operating life than a scanner. In addition, the fixed geometry afforded by the detector arrays results in high geometric accuracies in the line direction, which will simplify the image reconstruction and processing tasks.



Pushbroom imaging geometry.