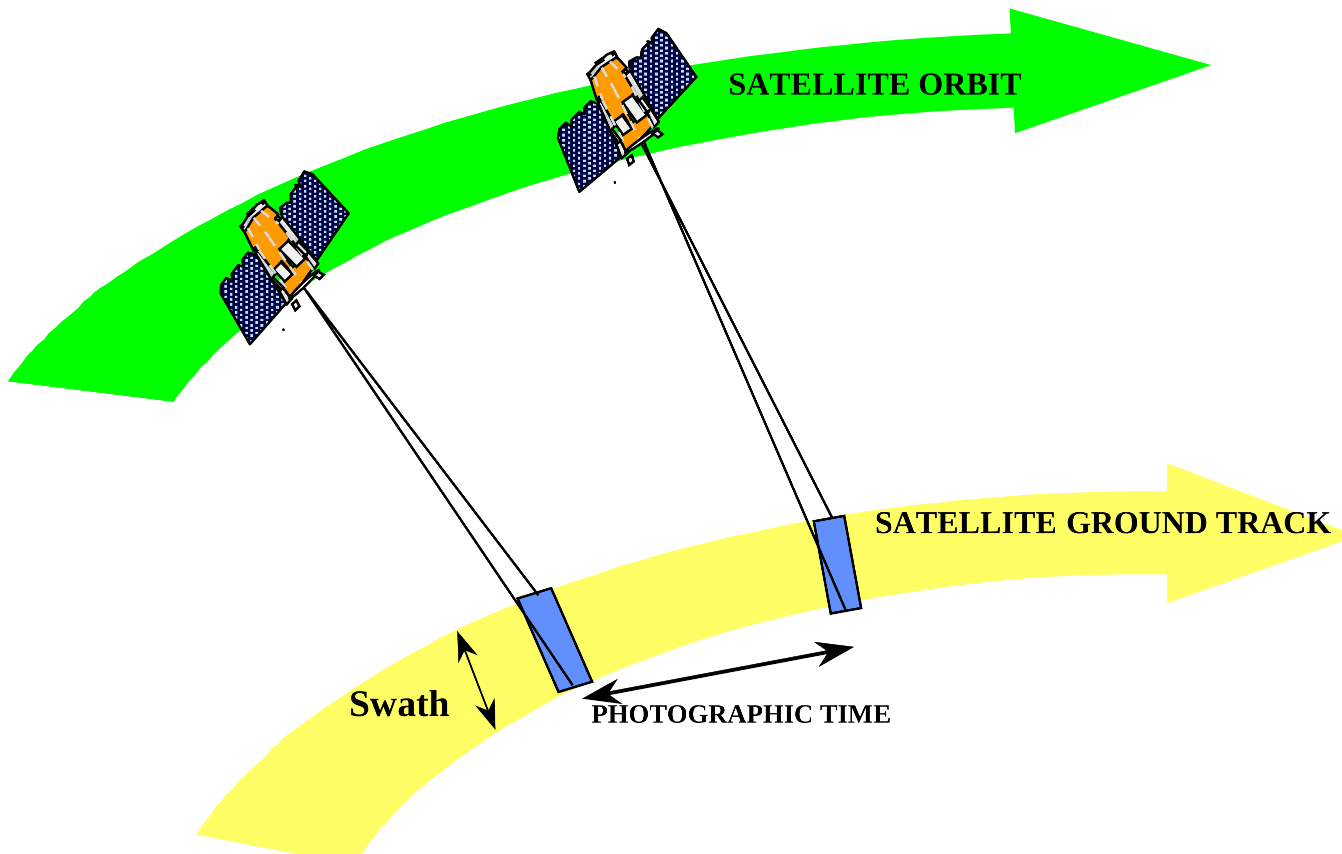
Tutorial on the satellite imaging in a non-synchronous mode (1)

ASYNCHRONOUS IMAGING MODE

Traditionally, remote sensing (imaging) satellites were designed to scan in a synchronous mode, which meant that the scanning velocity of the satellite's camera equals the satellite's ground speed, which, for a circular orbit, is a fixed constant number that only depends on the satellite's orbit height. In such a synchronous mode the satellite's camera is typically designed to acquire images along the satellite ground track or parallel to it through the use of mirrors or other mechanical devices. One should note such imaging satellites were unable to provide stereo pairs along the same pass.

Fig. 1 Synchronous Imaging Mode



Eros A1 has been designed to become a highly (if not the highest) maneuverable imaging satellite as of today. Thus, the design of the EROS A1 satellite allows for a scanning in a non-synchronous mode. Non-synchronous imaging implies that the ground scanning velocity is different than the satellite's ground velocity, and can be adjusted and optimized to light conditions of the imaged area. Since the imaging velocity is much lower than the satellite velocity, the satellite actually bends further backwards as the satellite moves forwards, enabling its detectors to dwell the necessary time ("integration time" or "dwell time") over each imaging area. The low scanning velocity is provided by the backwards movement compensation of the satellite's attitude during the imaging process. Such a compensation movement is produced through the use of the reaction wheels, which are commanded by the attitude and control system, according to the specific geometry that is to be produced, according to the tasking from ground station. Thus, for each local lighting sun conditions (local latitude of the target to be imaged and specific day of the year) the integration time is selected (thus defining the scanning ground velocity) for the satellite's sensor to collect enough light from each pixel and optimize the gray levels conditions of the images. As it is shown in figure 1, the satellite travels a distance on its orbit that is a longer path than the length of image acquired on the ground.

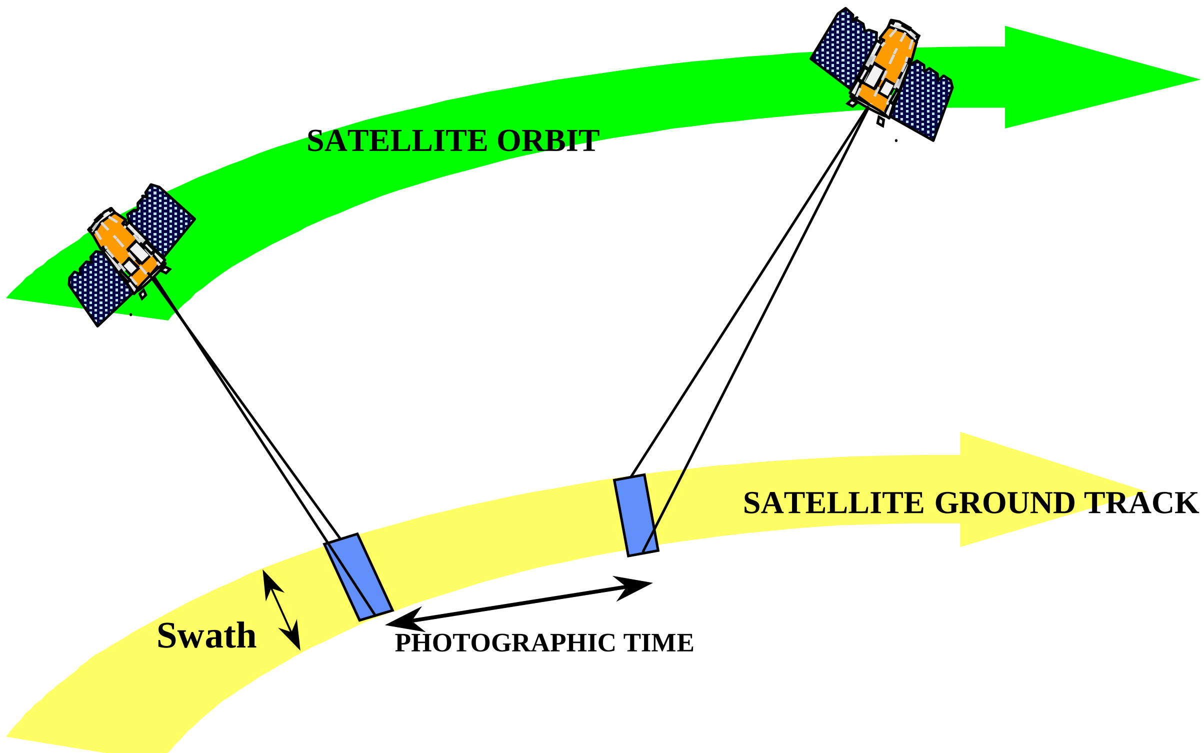


Fig. 2 Asynchronous Imaging Mode

PUSHBROOM SCANNING

The EROS A1 sensor generates imagery via push-broom scanning method, when the earth's surface is scanned by a linear array of CCD detectors aligned like the bristles of a broom that set the width of the swath and scans successive a pixel width lines across the entire swath. EROS A1 imaging sensor consists of one line of 7043 active CCD elements located in the sensor's focal array plane. Each CCD detector collects the light from the correspondent single ground element (pixel). A grouping of such pixel width lines composes the image. As soon as the sensor scans a line of one pixel width, the CCD detectors line samples the signal. Each pixel width line record requires some finite dwell time (one-pixel integration time). In the non-synchronous imaging mode the target area will be scanned at variable scanning velocity, but at constant integration time.

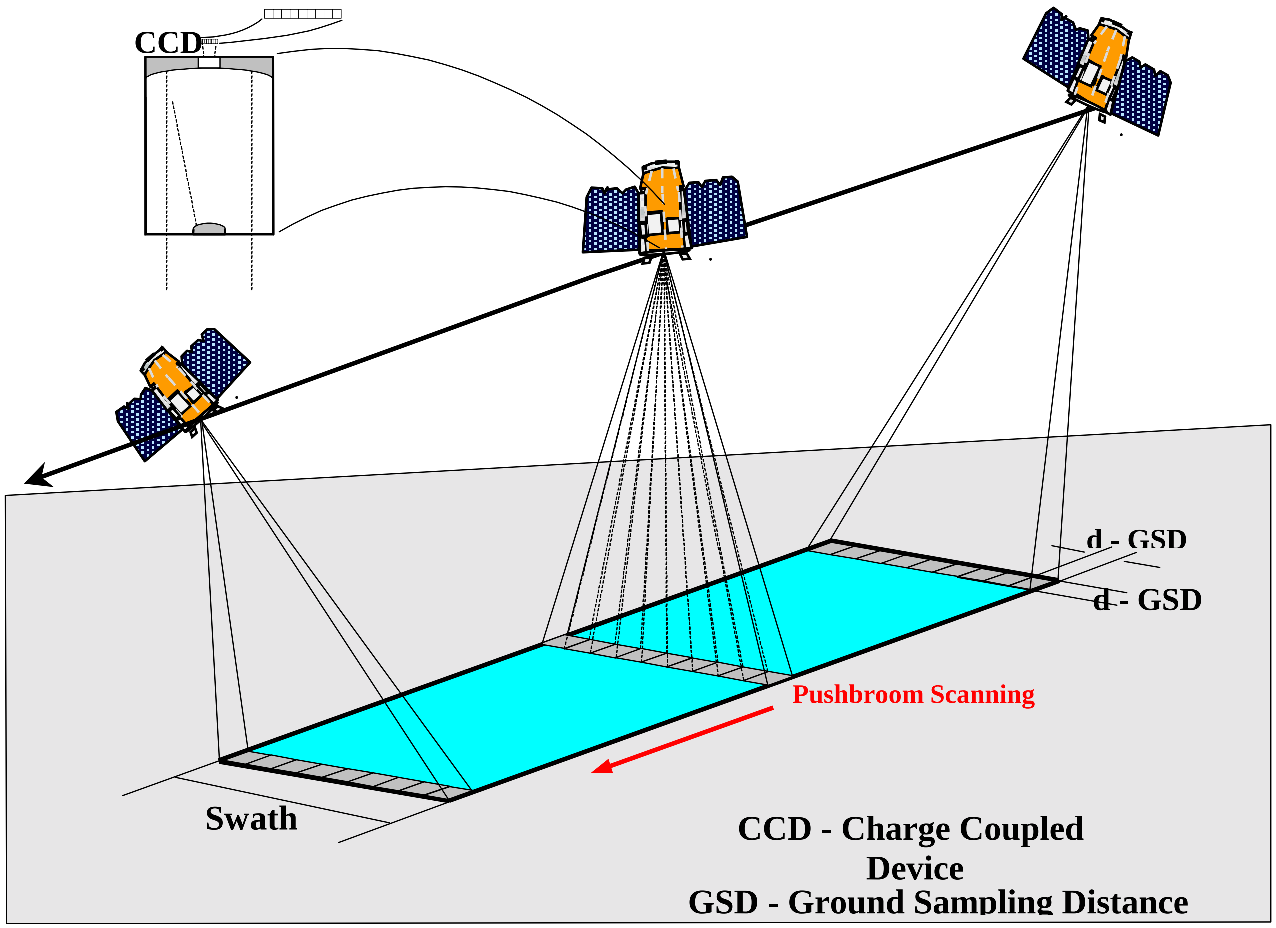


Fig. 2 Pushbroom scanning

GEOMETRIC DISTORTIONS OF THE IMAGEA synchronous imaging satellite of a push-broom type acquires an image that is the collection of the CCD lines acquired by the satellite, as the satellite moves forwards on its orbit. Thus the data that is collected and transmitted by the satellite is an image of rectangular form, with one side of the image being parallel to the CCD line and the other being parallel to the satellite's ground track. Would the earth be flat, then the acquired image by the satellite's camera that is of a rectangular geometrical shape would be a fairly good representation of the actual scene on the ground, being understood that some mild geometrical correction would be required on the two edges to compensate for the fact that the view angle of each pixel is a fix steroid angle and thus as we move along the CCD line from the closest pixel to the ground track to the furthest pixel, the ground distance of the pixels increases..

The earth being a sphere, the actual representation, on the ground, of the (rectangular) image acquired by the satellite is in fact an image of a trapezoidal geometrical shape. Therefore, once the image acquired by the satellite is collected by the ground station, one needs to perform a "geometrical correction" that takes into consideration the above-mentioned effect in order to reproduce an image that reflects as closely as possible the true image on the ground, as represented in Fig. 4.

To summarize, in remote sensing systems the image of a stationary grid on earth is not perfectly reproduced by the sensor. Instead, the geometric characteristics of the scene change as a function of geodetic and intrinsic properties of the imagery system, such as satellite orbit, position, attitude, and scan angle. The results from these imperfections contribute to the overall *Geometric Distortion* of the image.

For non-synchronous imaging satellite such as EROS A1 the imagery's shape is further distorted due to the fact that the scanning angle changes as the satellite bends backwards during the scanning process. Because of that satellite motion and since the camera's Field Of View is constant the ground resolution is changing continuously. Usually, at the beginning of the imaging process the ground resolution is large, becoming minimal as the distance satellite-target becomes minimal, usually around the center of the imaging area and increases again towards the end of imaging area. In those cases (see Figure 3) when the scanning starts and finishes at the same scan angle, the angle from nadir results in increasing pixel size as following:

- in cross-scan direction $d^{*}=d/(\cos\gamma)$;
- in along-scan direction $d^{**}=d/(\cos\gamma)^2$,

where d is Ground Distance Sample =1.8 m, γ – scan angle.

Table below represents relation between the scan angle and pixel size:

Scanning angle, deg	Resolution, m	
	Along Scanning	Cross Scanning
0	1.80	1.80
5	1.81	1.81
10	1.83	1.86
15	1.86	1.93
20	1.92	2.04
25	1.99	2.19
30	2.08	2.40
35	2.20	2.68
40	2.35	3.07
45	2.55	3.60

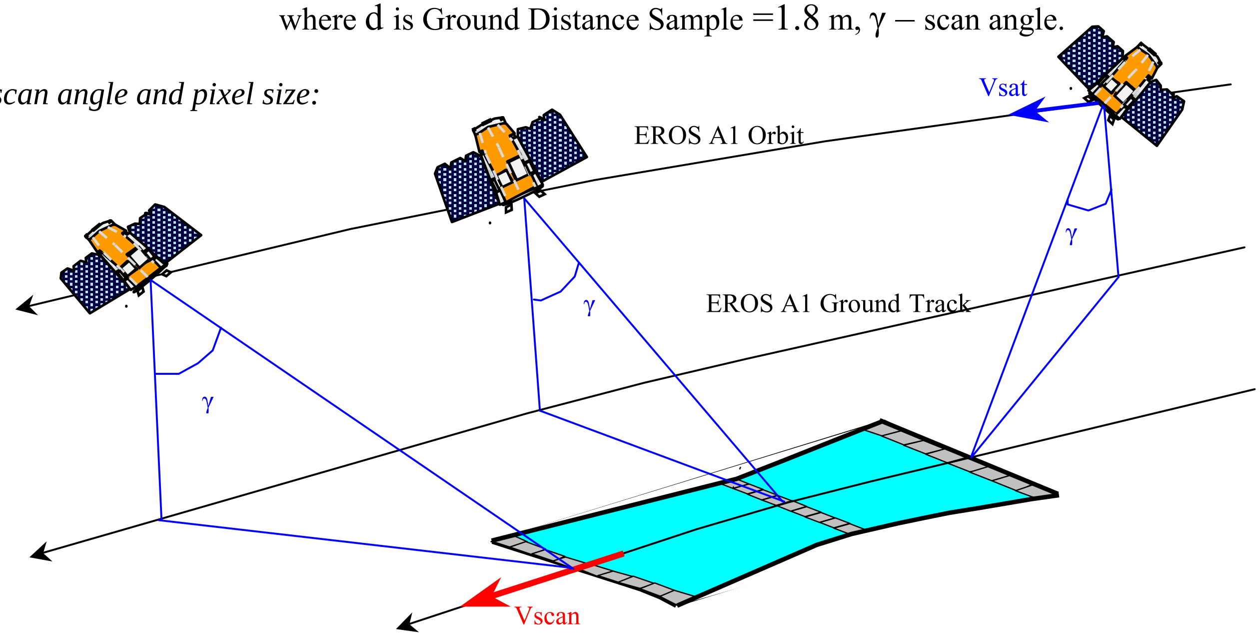


Fig. 3 Scan Angles And The Real Shape Of The Imaged Geographical Area

GEOMETRICALLY CORRECTED IMAGES

Imagery in raw format generated by the EROS A1 sensor incorporates geometrical distortions due to the scan angle changes during the scanning process. In other words, the geometrical shape of the image acquired is not correspondent to the shape of the geographical area of the image. To produce an image geometric integrity of the scanned area map, geometrical correction is to be applied in order to match an image to a map of geographical area of a reference image. Geometrical correction implies raw data recalculations by changing the pixel size, resulting in the different width of the image along the scanning direction.

Geometrically corrected image has a kind of trapezoid look (see fig. 4) in case when the satellite starts and finishes imaging at the same scan angle. For instance, at $T_{integration}$=3.9 ms, a standard 12.5X12.5 km scene can be imaged at ±11 deg scan angle from nadir.

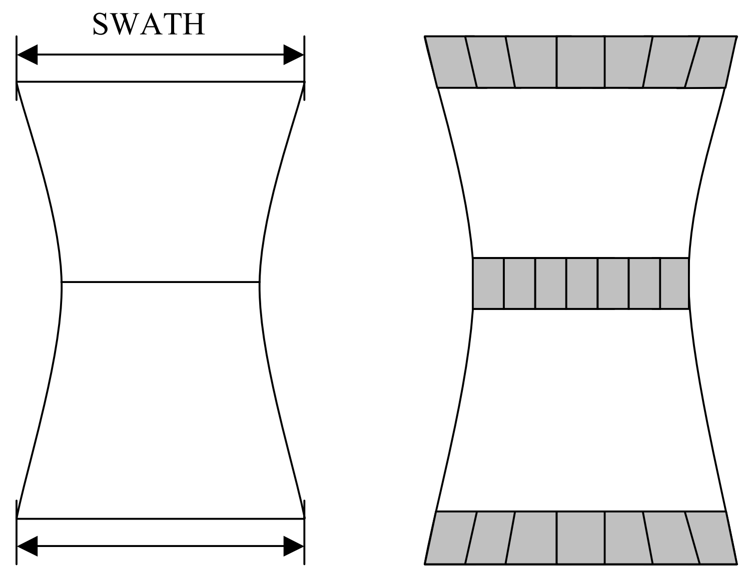


Fig. 4 Shape Of Geometrically Corrected Image

However, the image can be of a different shape (see Fig. 5), depending on the scan angles at the beginning and the end of imaging process, as well as the satellite orbit, position, attitude and distance of the imaged area from the satellite ground track.

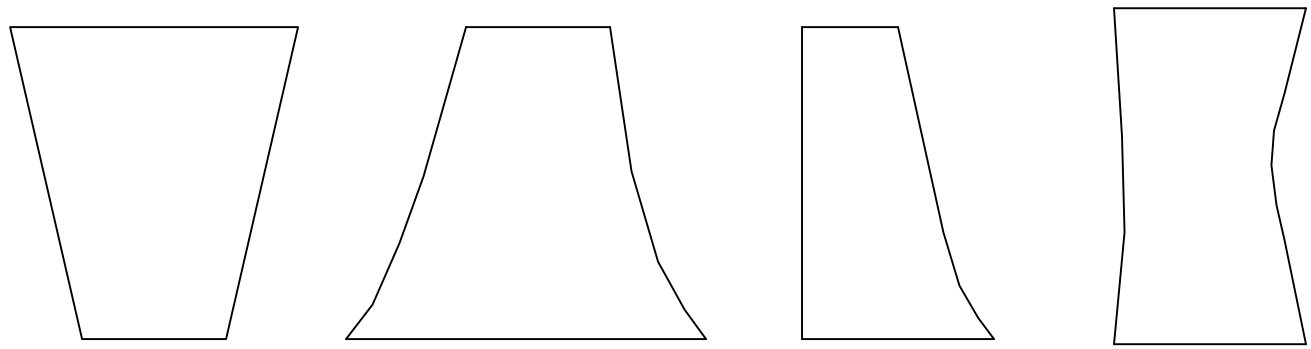


Fig. 5 Possible Shapes Of Images After Geometrical Correction Processing