FIRST TEST RESULTS WITH A CCD CAMERA DEVELOPED BY INPE

SIQUEIRA, M.A.A.; LOPES FILHO, A.; MATOS, J.D.; CUNHA, R.P.
Instituto de Pesquisas Espaciais - INPE
Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq
Caixa Postal 515 - 12200 - São José dos Campos - SP - Brasil

ABSTRACT

In the course of 1983, the Instituto de Pesquisas Espaciais (INPE) (Brazilian Space Research Center) developed a prototype of an airborne opto-electronic camera for multispectral imaging. This camera is based entirely on solid-state principle and the Earth's surface is imaged by continuously scanning lines which are normal to the flight direction. A self-scanning, high resolution Charge-Coupled Device (CCD) linear array serves as the sensor. The Brazilian Bandeirante aircraft was used for a test flight during this year. The images produced by the camera were quite satisfactory.

1. INTRODUCTION

In the framework of the Brazilian Complete Space Mission (MECB), an airborne multispectral imaging system based on the use of pushbroom scan technology was developed at the Instituto de Pesquisas Espaciais (INPE) during 1983. The main objective of this experiment was the preliminary identification of the technical problems associated with the use of a linear array of detectors for imaging applications, aiming the development of the imaging sensors for the future brazilian remote sensing satellites that will be launched in the early nineties.

2. PUSHBROOM SCAN TECHNOLOGY

Pushbroom scanning is a term which describes the techniques of using the forward motion of a satellite or aircraft platform to sweep a linear array of detectors oriented perpendicular to the ground track across a scene being imaged. This technique is illustrated in Figure 1, which shows an optical system imaging the ground scene on a linear array of detectors. One array is typically used for each spectral channel. Satellite or aircraft motion provides one direction of scan and electronic sampling of the detectors in the crosstrack dimension provides the orthogonal scan component to form an image. The detector array is sampled at an appropriate rate so that contiguous lines are produce.

There are two principal advantages to pushbroom scan technique using long linear arrays of solid-state detectors. First, complex mechanical scan mechanisms are eliminated. Second, this approach allows the radiation flux from the scene to be integrated during the time required for the instantaneous field-of-view (IFOV) to advance the dimension of one resolution element on the ground. For a quantitative indication of what this means, consider that the dwell time per resolution element in the LANDSAT Multispectral Scanner (MSS) is 14 microseconds. Using the pushbroom approach and the same orbital conditions, the dwell time can be increased to approximately 12 milliseconds for the same resolution element dimensions. This allows an increase of more than a factor of 850 in the signal generated and stored at each detector position. The improvement in signal-to-noise ratio is significant, and permits smaller aperture optics to be used, with a consequent reduction in size and weight.

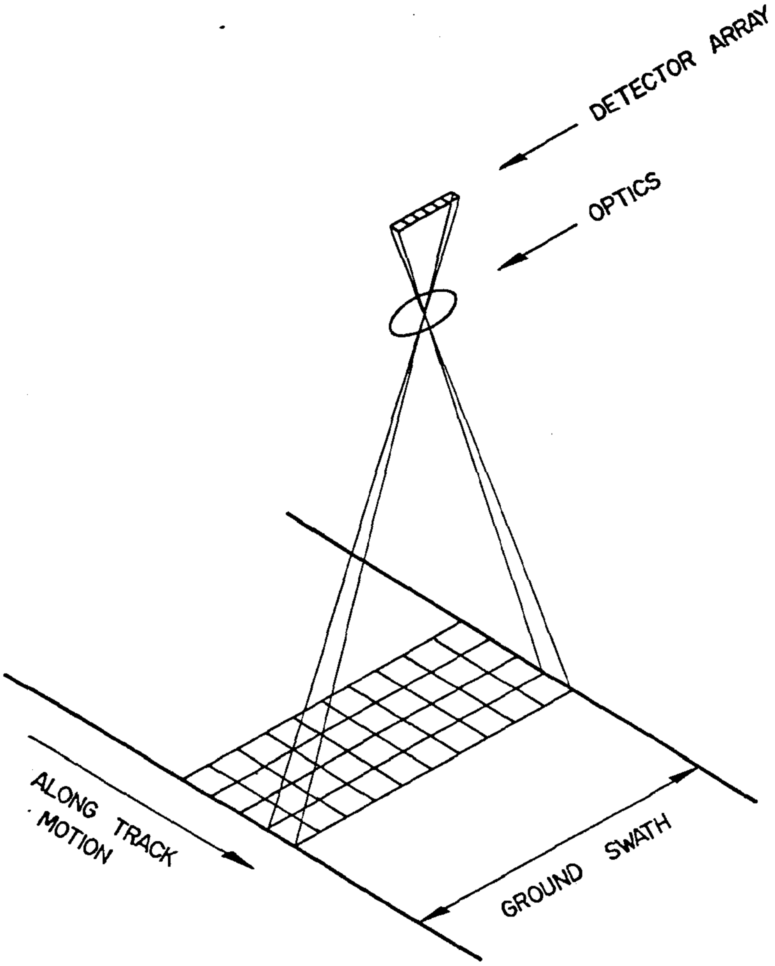

Fig. 1 - Geometry of pushbroom scan technique.

Another advantage of solid-state technology is that high crosstrack geometric fidelity is achieved along each linear array to the extent that the position of each individual detector is precisely known. Besides the goemetric accuracy within a single array, accurate positioning of arrays for each spectral band in the image plane with respect to each other allows very close multispectral registration of the resulting images.

The main disadvantages to solid-state approach are that it is necessary to calibrate many more detectors and that infrared sensitive long arrays are still not available.

It is clear that operation in a pushbroom scan mode has many desirable features. The Charge Coupled Device (CCD) technology provides the many thousand element detector arrays required to subtend the crosstrack swath for earth resource applications.

3. IMAGING SYSTEM COMPONENTS

Figure 2 shows a block diagram of the imaging system that consists of the following components:

. Optoelectronic Camera.

. High Density Tape Recorder.

. Power Module.

. Oscilloscope.

4. THE OPTOELETRONIC CAMERA

The Optoeletronic Camera consists of five major parts as shown in Figure 3: the optical objective (1), bandpass interference filters mounted on a rotating wheel (2), the CCD linear array detector (3), the sensor electronic board (4) and the mainframe (5).

The detector is the commercially available Fairchind CCD 122 silicon linear array. The array contains 1728 photosensors with 13 μm center to center separation. The photosensitive area of each element is 13 μm by 13 μm. The main characteristics of the CCD detector utilized are listed on Table 1.

The optical design of the instrument was governed by the detector array geometry and the decision to use a commercially available lens to minimize costs. The Hasselblad Distagon f/4 - 50 mm objective that was chosen has seven elements and is well corrected inside of the 24.7^{o} field--of-view (FOV) of the camera. The objective was set at f-stop of 5.6 during data acquisition to provide maximum irradiance at the detector without saturation. The individual detectors of the CCD array have an instantaneous field-of-view (IFOV) of 0.25 milliradians, which is within the resolving power of the objective (0.12 milliradians).

The bandpass filters used are of the multilayered interference design. The bandpass transmitted through this type of filter changes with the angle of incidence of light. For example, the transmitted radiant energy from ± 30° off the normal axis is blue shifted by approximately 40 40 nm compared to radiation transmitted on axis. For the type of lens used it was decided to mount the filters between the lens and the CCD detector (image space) so that negligible blue shift resulted compared to the filter bandwidths. The filters were mounted on a rotating wheel and the selected one was positioned manually in front of the CCD detector. Figure 4 shows the transmitance curves of the three filters used in the camera.

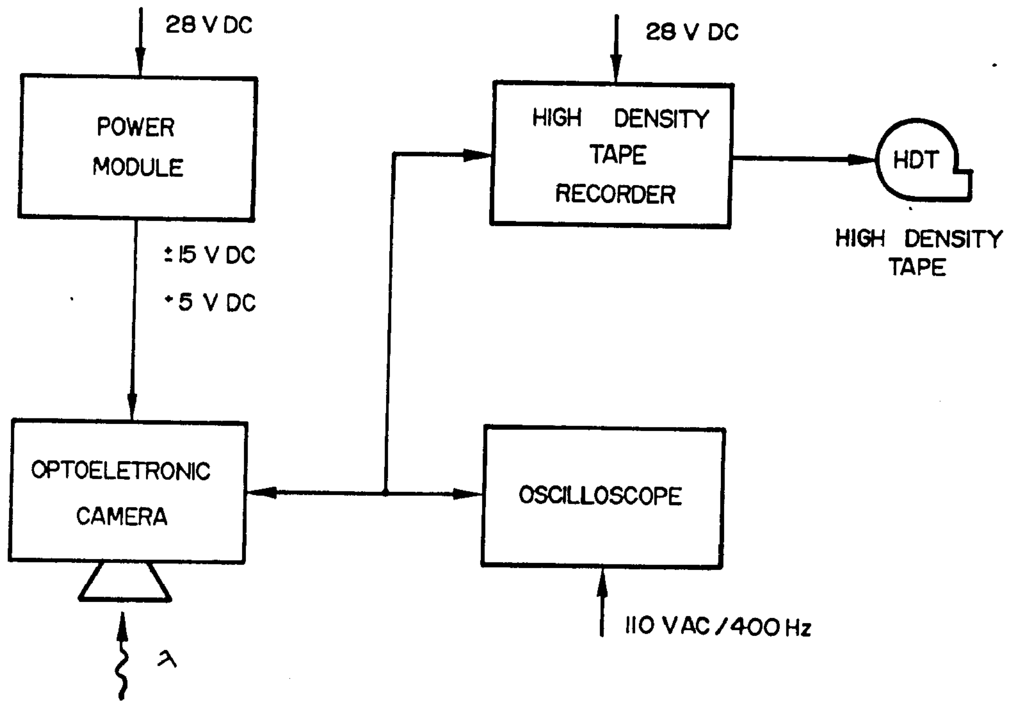

Fig. 2 - Block diagram of the imaging system.

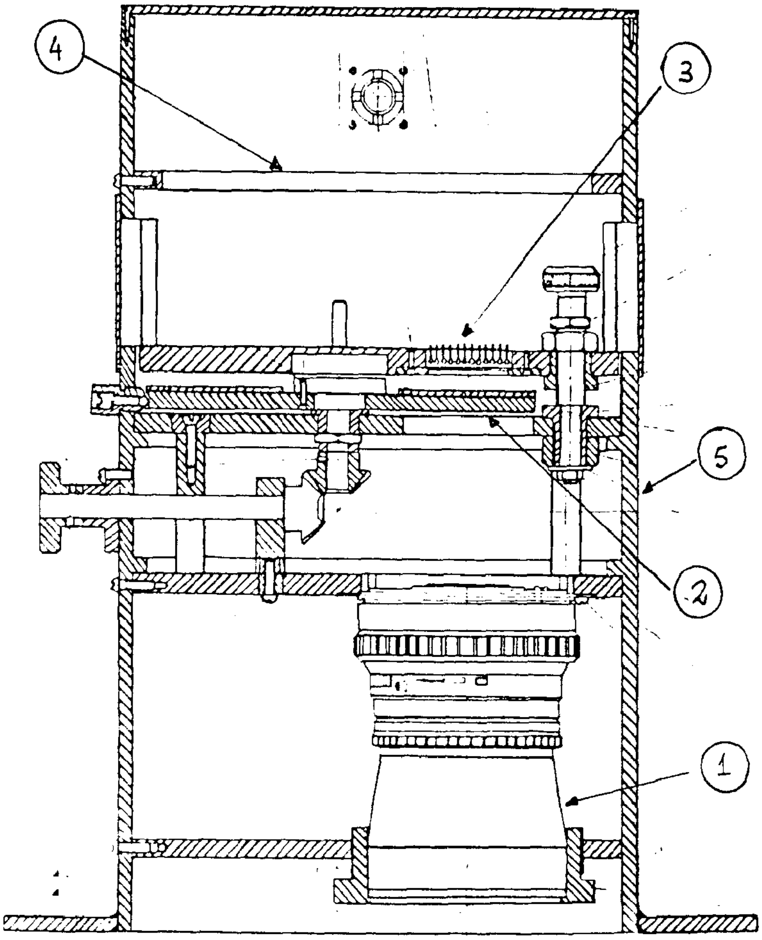

Fig. 3 - Schematic diagram of the Optoelectronic, Camera:
1) Optical Objective.
2) Interference Filter.
3) CCD detector.
4) Electronic board.
5) Mainframe.

The camera electronics operates the CCD detector in an integrating mode and provides signal processing and clocking. The integration time was set at 7.6 milliseconds and for an aircraft ground velocity of 100 m/s the line frequency was 132 Hz. At an altitude of 10000 feet this results in a ground resolution of 0.76 m.

5. CAMERA SIGNAL RECORDING AND MONITORING

The camera was attached to the cabin floor of a brazilian Bandeirante aircraft. The tape recorder, Bell and Howell model M14E, and an oscilloscope were fastened to a rack attached to the side of the aircraft cabin.

TABLE 1

FAIRCHILD CCD 122 MAIN CHARACTERISTICS

Type: n-channel isoplanar buried-channel
Number of photoelements: 1728
Photoelement size: 13 μm x 13 μm
Dynamic Range: 2500:1 (relative to RMS noise)
RMS Noise Equivalent Exposure: 0.0002 μJ/cm²
Saturation Expourse: 0.4 μJ/cm²
Charge Transfer Efficiency: 0.999995
Peak-to-peak Noise: 2.0 mV
Responsivity: 3.5 V.cm²/μJ
Saturation Output Voltage: 1.4 V

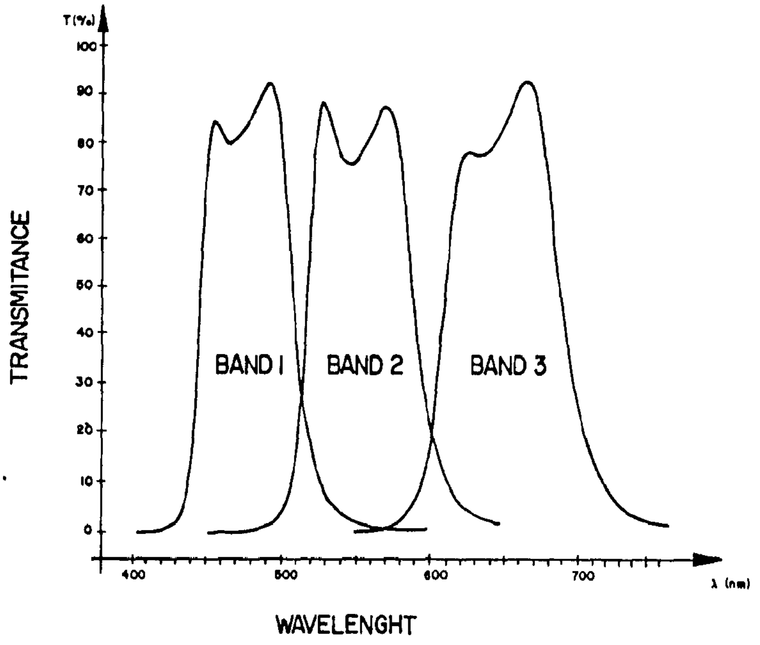

Fig. 4 - Transmitance curves of the filters used in the camera.
Band 1: 450-510 nm
Band 2: 520-590 nm
Band 3: 610-690 nm

The tape recorder, a high density type configured for direct recording mode, has a recording bandwidth of 400-2MHz. The camera output video signal frequency modulated a carrier that was then recorded, using a recorder tape speed of 120 ips.

The oscilloscope was used for real time monitoring of the output of the camera.

6. CAMERA SIGNAL REPRODUCING

The same tape recorder that was used to record the camera output video signal during the flight test was also used to play it back in the laboratory with a tape speed of 15 ips. Figure 5 shows the block diagram of the system used to reproduce the recorded signal and to generate computer compatible tapes (CCT) and photographic films.

In this system, the recorded video signal of the camera is digitalized with an 8-bit resolution using an A/D converter, model DEC LPS-11, interfaced with a minicomputer DEC PDP 11/45. The digitalized data are temporarily stored in a disk storaging system and can be transferred to an image processing system (General Electric Image 100) for analysis and visualization of the images, to a CCT recorder or to an image recorder to the generation of photographic films.

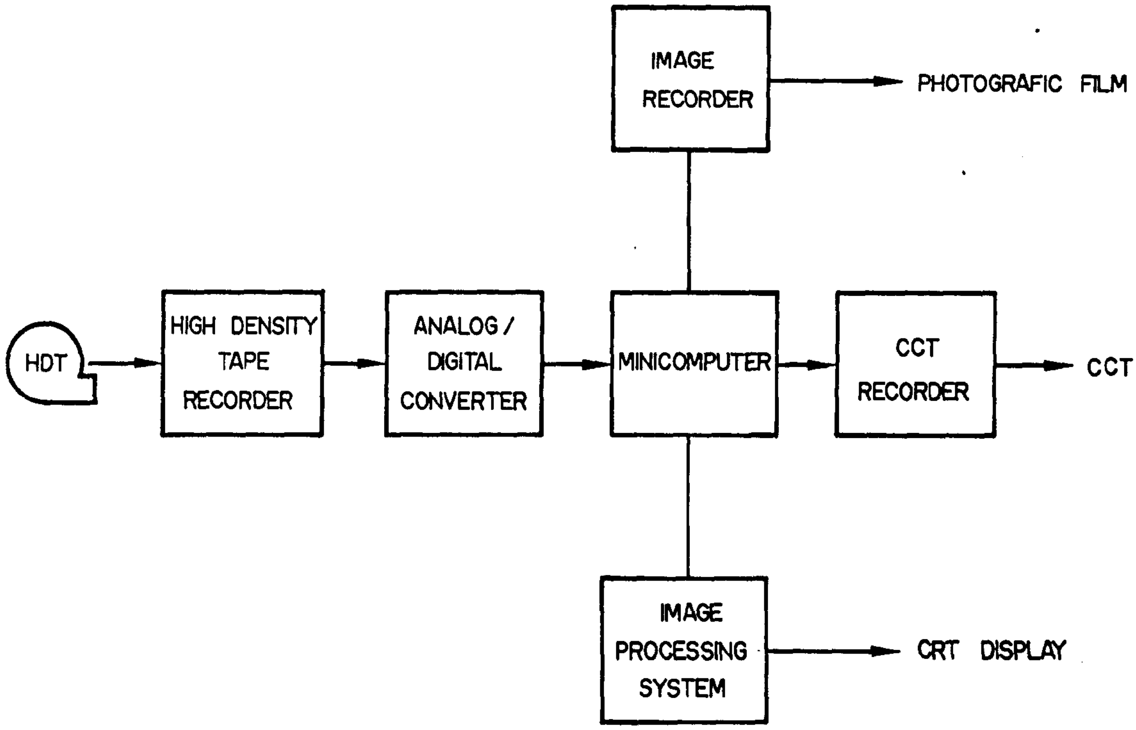

Fig. 5 - Block diagram of the system used to generate CCT's and Photographic films from the HDT generated during the flight test of the camera.

7. FLIGHT TESTS AND RESULTS

The imaging system was tested in February 1984 on board of INPE's Bandeirante aircraft. The flight was performed near local noon, at an altitude of 10.000 feet and for an aircraft ground velocity of approximately 360 Km/h. For such conditions, the expected ground resolution of the camera is 0.76 m and the swath width 1.3 Km.

In spite of analog recording of the data and the absence of roll/pitch/yaw compensation - the camera was firmly mounted on the floor of the aircraft cabin and no attitude data could be recorded for geometrical correction - the quality of the pictures obtained was quite satisfactory. Some minor problems occurred during the conversion of HDT/CCT that resulted in small relative displacement between image lines. Figure 6 shows an image produced with the system in Band 3, without any corrections.

Fig. 6 - Example of image produced with the CCD camera in Band 3. (Partial view of INPE's main facilities in S.J.Campos/SP).

After this first test several improvements are under way, adding a microcomputer to control the experiment introducing, a visual display for real time monitoring and visualization of the images produced during the flight and recording of data in digital mode instead of in analog mode. This new version of the system will be tested in the near future.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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FAIRCHILD CCD IMAGING CCD 122 Specifications Data Sheet.