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CIMEX : A PROTOTYPE INSTRUMENT TO OBSERVE FROM SPACE THE AMAZON FOREST IN THE NEAR AND SHORTWAVE INFRARED

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ABSTRACT : CIMEX (CCD Imaging Instrument Experiment) will fly on-board the NASA Shuttle in the frame of the HITCHHIKER program in mid 1999.
The main requirements of the mission are :
- 2 spectral bands : (B1) 1.55 - 1.70 µm and (B2) 2.08 - 2.35 µm
- Field of view : 8°, hence swath of 40 km on ground
- Spatial sampling on ground : 80 m
- Minimum radiance (W/m²/sr/µm) : 0.5 in B1, 0.23 in B2
- Maximum radiance (W/m²/sr/µm) : 46 in B1, 40 in B2.

The instrument will be installed in a canister equipped with a motorised door assembly : then low data bit rate, moderate weight and dimensions, low consumption are required.
The instrument is under the responsibility of the Brazilian space agency : Instituto Nacional de Pesquisas Espaciais (INPE).It is composed of the following sub-assemblies :
- the Optical Block and Detection Assembly (OBDA) developed by AEROSPATIALE under INPE contract : it consists in two identical cameras with cooled focal planes, fixed onto a structure ensuring the interband registration.
- the Camera Electronics Package (CEP) developed by INPE

1 - MISSION OF CIMEX

The CCD Imaging Instrument Experiment - CIMEX is a co-operation program between the U.S. National Aeronautics and Space Administration (NASA) and the Brazilian Space Agency (AEB)/National Institute for Space Research - INPE. The program establishes that a remote sensing instrument will be developed,integrated and operated on-board of the Space Shuttle as a HITCHHIKER Small Payload. The flight is scheduled for mid 1999.

The main objectives of the experiment are summarized below :

Design and development of imaging instruments in Brazil with an emphasis in the short-wave infrared domain

Investigation of the radiometric effects at non-conventional times of day for remote sensing data acquisition (ideally same test site at different times of day , possible similar test sites at different locations)

Quantification of sensors radiometric calibration through image quality evaluation (IQE) and an effort to compare it by achieving inter-calibration of this sensor with reference to on-going remote sensing missions

Thematic mapping and vegetation studies mainly for Amazon region, including forest fire detection using the spectral band B2 which is in the range 2.08 - 2.35 microns

1.1 - Operational scenario

The following items describe the conditions which shall be met for a proper operation of the CIMEX experiment

June-to Aug period of the year is ideal, since the cloud coverage conditions are optimum over 75 % of Brazil

Largest variation of data collection geometry is possible with an orbit inclination of 28.5° For this orbit inclination, in a typical 7-day experiment, a total coverage is expected. In contrast, it can be observed that 57° orbit inclination reduces time of flight over Brazil by 40 % and 99° by 45 %

. Morning coverage of Brazil with descending orbit

. Low altitude (mean value 343 km) is desired with repeating coverage

Data acquisition geometry requirement is NADIR looking towards Earth

1.2 - CIMEX main characteristics

Ground resolution 80 m
Spectral bands B1 .55 to 1.70 µm B2 2.08 to 2.35 µm
Swath width > 40 km
Radiometric sensitivity < 1 % (noise equivalent reflectance difference for visibility of 13 km)
. Interband registration < 0.3 pixel
. Data rate < 1 Mbit / second
Quantization levels 256

2 - IMPLEMENTATION IN THE NASA SPACE TRANSPORTATION SYSTEM

The experiment will be located inside a HITCHHIKER canister equipped with a motorized door assembly - HMDA (figure 1)

Therefore, the system design will follow the small payload philosophy which is constrained to a low data bit rate, moderate weight and dimensions,and low power consumption

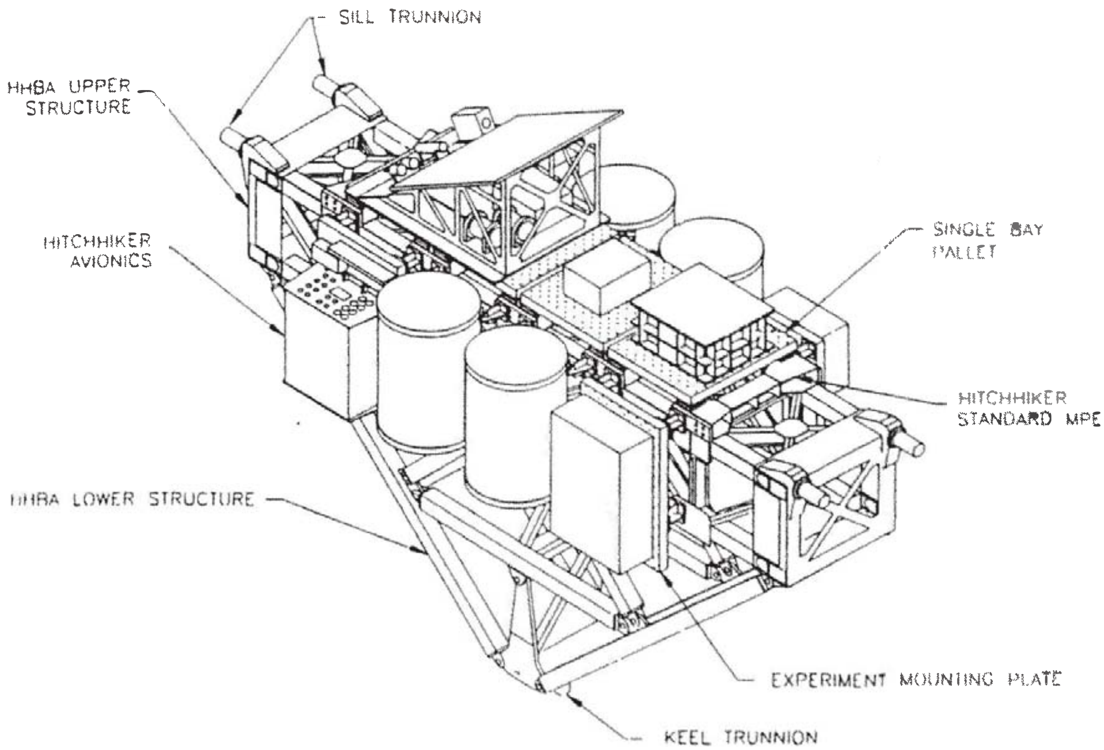


Figure 1 : HITCHHIKER Cross-Bay Bridge configuration

3 - GENERAL DESCRIPTION OF THE INSTRUMENT

3.1 The CIMEX Payload

It is composed of two main sub-assemblies

The Optical Block and Detection Assembly (OBDA) includes the 2 cameras and the associated proximity electronics, structure and thermal control

The OBDA consists of a single module which is fixed to the CIMEX Top Endplate

The Camera Electronics Package (CEP) is fixed to the CIMEX bottom Endplate. This bottom Endplate is supported by a strutted structure which is fixed to the CIMEX Top Endplate.

The CEP comprises a box of circuits boards for the functions of power conditioning, timing generation, CCD clock drivers, analog video processing, digital data processing and interface circuits.

The CIMEX electronics circuits will be implemented with low power CMOS and HCMOS components (class B)

The interface circuit connects the CIMEX Electronics to the HITCHHIKER Avionics

A 80C51 microcontroller is responsible for the generation of the frame GMT and EDT (Error Detection) information

The Power Circuit is responsible for power conditioning and power consumption monitoring. DC/DC converters are used to generate the analog and digital circuit voltages

3.2 The CIMEX Ground Support Equipment (CGSE)

The CGSE is composed of the CIMEX Control Monitoring Terminal (CMT) and a Scene Simulator. The CMT is composed of a microcomputer which can be interfaced directly to the Payload or to the GSE of NASA. For this reason, the CMT is equipped with two types of interfaces: one is connected to the GSE of NASA,the second is connected directly to the Payload. All the operations of the CIMEX Payload in the pre-flight and on-orbit phases shall use the most adequate interface.

The Scene Simulator will provide a calibrated reference to check the camera operation.

4 - OPTICAL BLOCK AND DETECTION ASSEMBLY

4.1 - Focal plane assemblies

The necessity to use an on-the-shelf detector compliant with the requirements of the spectral domain (B1 and B2), pitch, number of pixels (≥ 500) led to a detector developed by SOFRADIR (France)

The detector is a 576 x 2 two dimensional detector array of photovoltaic Mercury Cadmium Telluride (MCT) and CCD multiplexing as an integral part of the focal plane.

The focal plane array is integrated into a dewar and is cooled down to typically 150K by a Stirling cycle rotary microcooler from RICOR (Israel) / L'AIR LIQUIDE (France) reference K508, suitable for severe environmental conditions

The 576 x 2 detector array has a very high sensitivity with quantum efficiencies near 0.7. The pixel size is 28 x 28 μm^2 and the pitch is 14 μm in the across scan direction(figure 2)

The detector array is hybridized to a CCD with 16 electrical outputs. This CCD can operate in TDI mode. This mode will not be used in the CIMEX application, and all the pixels will be readout. Each detector has 16 electrical outputs.

The sampling period is approximately 10 ms, which corresponds to 72 m at an altitude of 185 nautical miles. 13 pulsed voltages, 7 bias voltages are necessary to operate the detector.

The charge handling capacity is 2.4 pC, and the dynamic range around 2V. The video output rate is 7.5 kpixels / second for each video output. This slow rate is related to the large sampling time and the large number of video outputs

The operating temperature will be adjusted in order to optimize the radiometric performances regarding the short wavelengths. It will be around 150K

The cool-down time will be approximately 10 minutes with a power consumption of 12W. When the operating temperature is reached, the power consumption becomes 5W.

Modifications of the standard SOFRADIR Integrated Detector Dewar and Cooler Assembly have to be made in order to withstand the high vibration levels at launch, with random levels of 4.5g^2/Hz between 50 and 150 Hz, and 0.2 g^2/Hz between 155 and 600Hz

The thermal interface of the Detection Block is identical to the mechanical interface

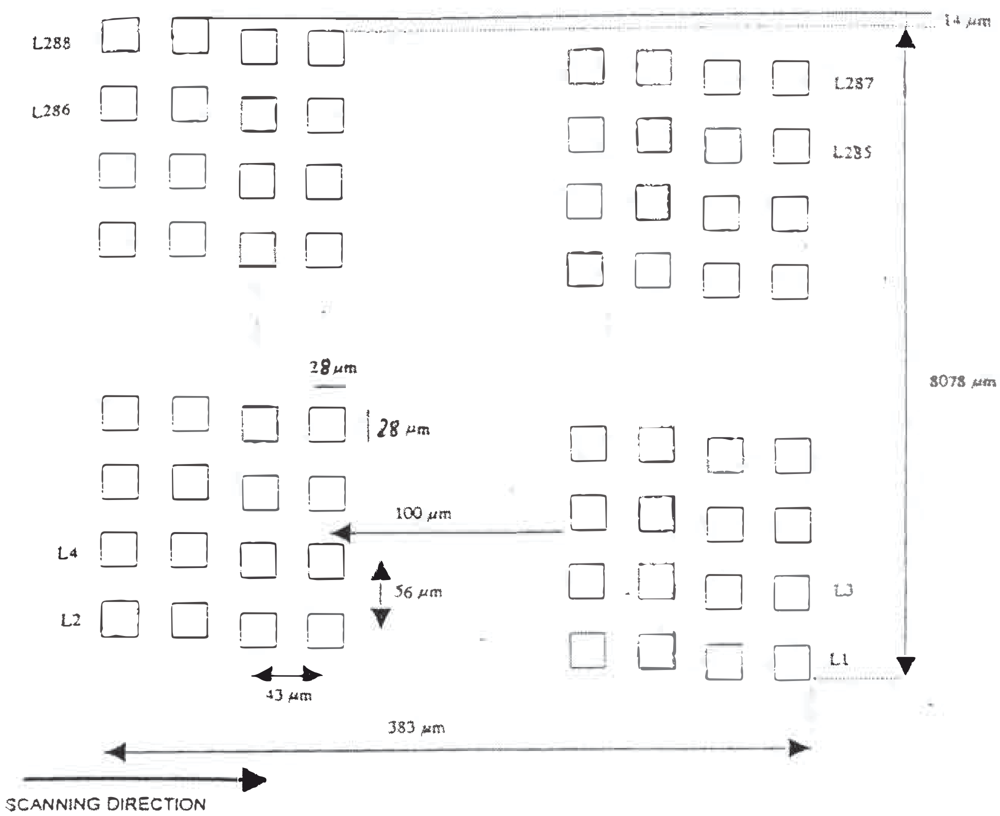


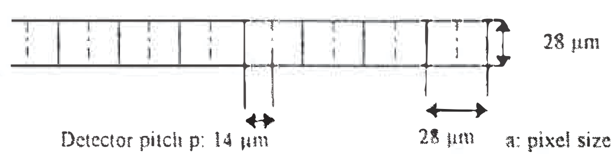
Figure 2 Detector array topology

There is no filter inside the dewar in order to allow the compatibility of the detector with the two bands A cold shield inside the dewar limits the detector FOV to reduce straylight effects, in spite the contribution of such effects is low in these spectral ranges.

The optical dynamic range at detector input is near 100 for detector B1 and near 200 for detector B2, and the straylight is always less than 10 times the lowest signal which has to be detected.

4.2 - Image spatial sampling

The 4 lines of pixels are used and form the following sampling of the image after reconstruction



With a detector size twice larger than the pixel pitch, the MTF of the raw image is almost equal to zero at the Nyquist frequency, but does not present any aliasing effect (figure 3).
It is possible to restore the image MTF for all frequencies below 0.9 x Nyquist frequency.
In order to have 0.9 x Nyquist frequency = 1/2 x 80 m, the sampling spatial period on ground is chosen as 72 m, corresponding to the detector pitch = 14 µm.

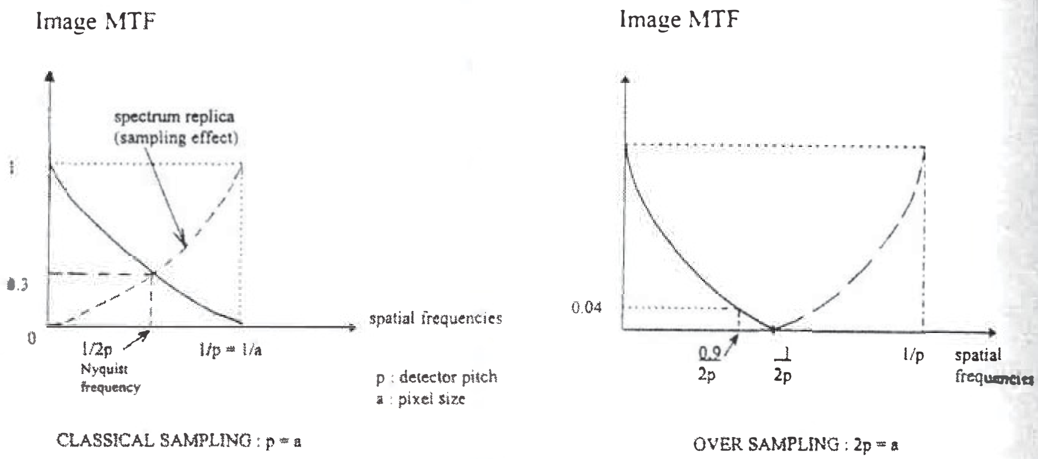


Figure 3 Image oversampling

4.3 - Optical sub-assembly

In order to increase the commonality of the 2 cameras, the 2 lenses are identical although they operate in 2 different spectral bands, (figure 4). The 2 high performance band pass filters are placed on front of the lenses. The lenses are designed with low distorsion and manufactured so that the focal lengths (respectively the distorsion laws) are quite similar.
The development of the sub-assembly is made by the company REOSC.

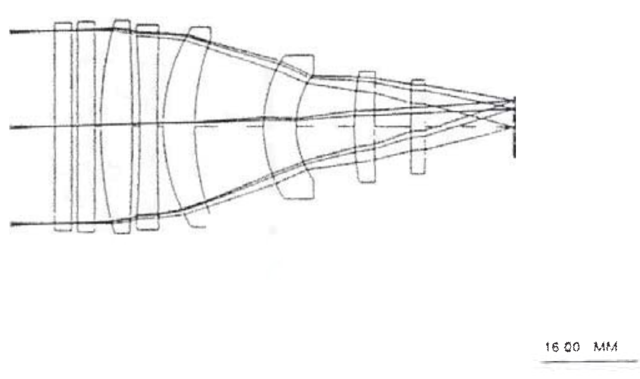


Figure 4 Optical lay-out of the 2 lenses

4.4 - Electrical design

Inside the OBDA, the functions have been limited to those which need to be integrated close to the detector for image quality reasons detector biases, clock filtering, video signal preamplification

The microcooler electronics are integrated to the microcooler package

The functions performed in the OBDA are integrated in the Detector Electronic Box The video processing functions, including A/D conversion on 8 bits, are included in the Camera Electronic Package.
The reliability of the OBDA is closely related to the detector figures which have already been demonstrated through other programs

Performance obtained with a non redundant design allow reliability performance better than 0 99 for a 15 days mission and 25 hours operating time during the mission.

4.5 - Mechanical and thermal : design description

OBDA is composed of

- A circular radiator plate interfacing the CIMEX experiment top plate - through isolating washers - and supporting
  - on the external face, covered with SSM 2 alignment cubes (nominal & redundant) and 2 baffles
  - on the internal face the cradle, the Detector Electronics Box, the thermostats and heaters
- A cradle supporting the 2 cameras by means of registration adjustment devices
- A cover enveloping the whole inner part of OBDA Its main function is to contribute to the Detector Block thermal regulation thanks to conductive copper braids and its own thermal conductance and capacity. It also supports the MLI blanket.The cover and MLI feature windows for the connectors.
- A electrical harness routed between the 2 detection blocks and the Detector Electronic Box

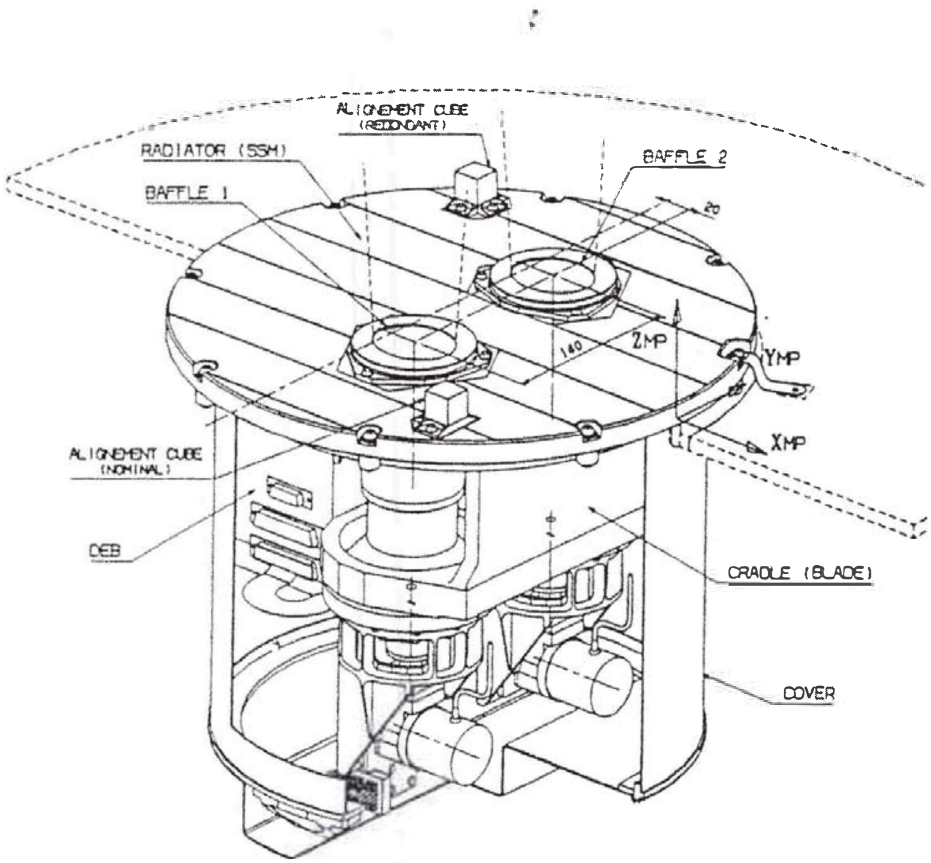


Figure 5 Optical Block and Detection Assembly

5 - IMAGE PROCESSING

CIMEX raw images will not be available for users exploitation, because of several effects, due to the acquisition process, and will then require an on-ground correction.

The image quality performance of CIMEX products is obtained on processed images only, and these image processings are strongly involved in the global performance

Considering only the correction of acquisition process effects, four different processing steps are identified :

* Image re-organisation
* Detector response equalization, traditional in CCD technology
* MTF restoration, required by the specific array detector structure
* Geometric resampling

The first three steps are required, but the last one is optional

Image re-organisation

This step corresponds to the following operations

* geographical ordering of the received pixels
* backup detectors management in the array detector structure (figure 2), each detector has a backup companion used to compensate from dead detector events. If both nominal and redundant detectors are valid, it is possible to consider the averaged digital count, as a resultant pixel. If both detectors are dead, the corresponding image column must be synthesized from an interpolation amongst its neighbours

Detector response equalization

Traditional in this kind of technology, response equalization consists in applying linear coefficients correction to every detector. These coefficients may have been provided by an on-ground (before launch) test, or may have been acquired during the mission, on reference sources

MTF restoration

The CIMEX raw image MTF value, measured at the Nyquist frequency, is almost equal to zero
This is due to the array detector structure, where the detector size is twice larger than the pixel pitch (detector size = 28 microns; pixel pitch = 14 microns)
At Nyquist frequency (1/2x14 microns^-1) the detector MTF is equal to zero (assuming a nominal 'square' spatial response). This frequency corresponds to a 72 meters ground sampling distance, in nominal acquisition conditions.

The MTF restoration process consists in inversing the spatial filtering of the image. This operation is called 'deconvolution' For more than 40 years, a large number of techniques have been developed, and the most classical are 'inverse filtering', and 'Wiener filtering'.
Depending on MTF knowledge, noise level and knowledge, and aliasing effect (which is absent from CIMEX), these techniques allow to restore spatial information up to 0.9 Nyquist frequency
This value (only indicative) corresponds to a 80 meters ground sampling distance, for CIMEX.
In the figure 7, one can observe the raw image MTF, and an example of a restored MTF

Geometric registration

Finally, different geometric resamplings of CIMEX images may be planned, for instance in order to superimpose it to a map or another image of the same area.

The geometric transformation can be constructed from the mission auxiliary data (orbit and attitude estimations), or from ground control points visually 'measured' by an operator
A particular case is the inter-band registration, where the geometric transformation can be measured by means of a dense correlation process between the two spectral bands This leads to a very precise deformation measure, allowing sub-pixel corrections

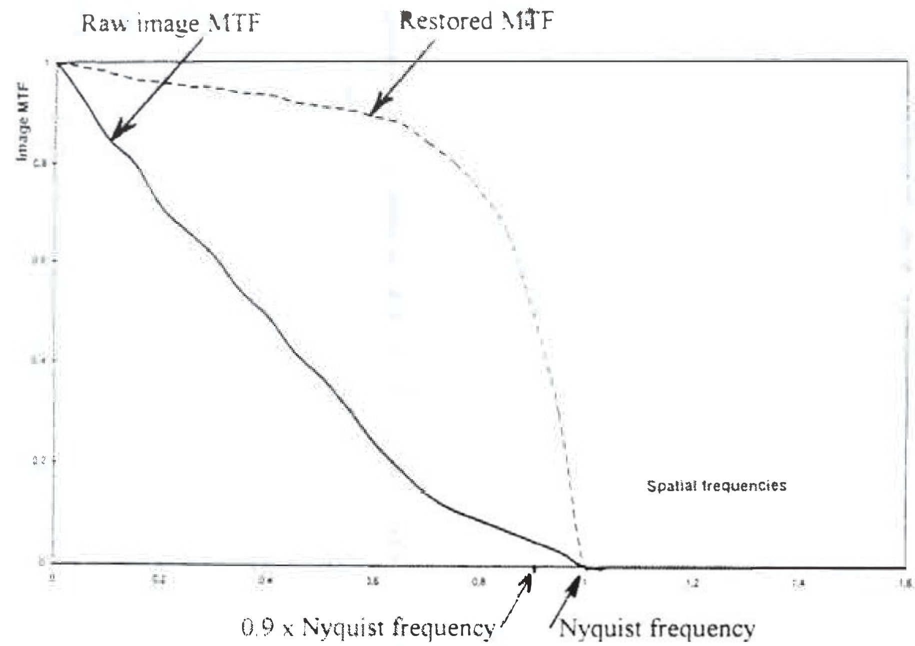


Figure 7 Example of raw image and restored MTF

6- CONCLUSION

CIMEX is designed to acquire images in 2 registered bands 1.55 - 1.70 µm and 2.08 - 2.35 µm, with a ground resolution of 80m and a swath width of 40 km.
The instrument will be placed in a HITCHHIKER canister on - board the NASA Shuttle Cargo - Bay
The development of the instrument is in progress and the flight is scheduled in mid 1999.