# Smart Sensors in Spacecraft Monitoring Applications

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# Overview

Spacecraft monitoring using visual systems

Visual Telemetry System for Envisat and TeamSat

Integrated Radiation-tolerant Imaging System -1

Visual Monitoring Camera for XMM

Visual Monitoring Camera extension for Cluster-II

Integrated Radiation-tolerant Imaging System - 2

Integrated Radiation-tolerant Imaging System - 3

Digital micro-imager for planetary exploration

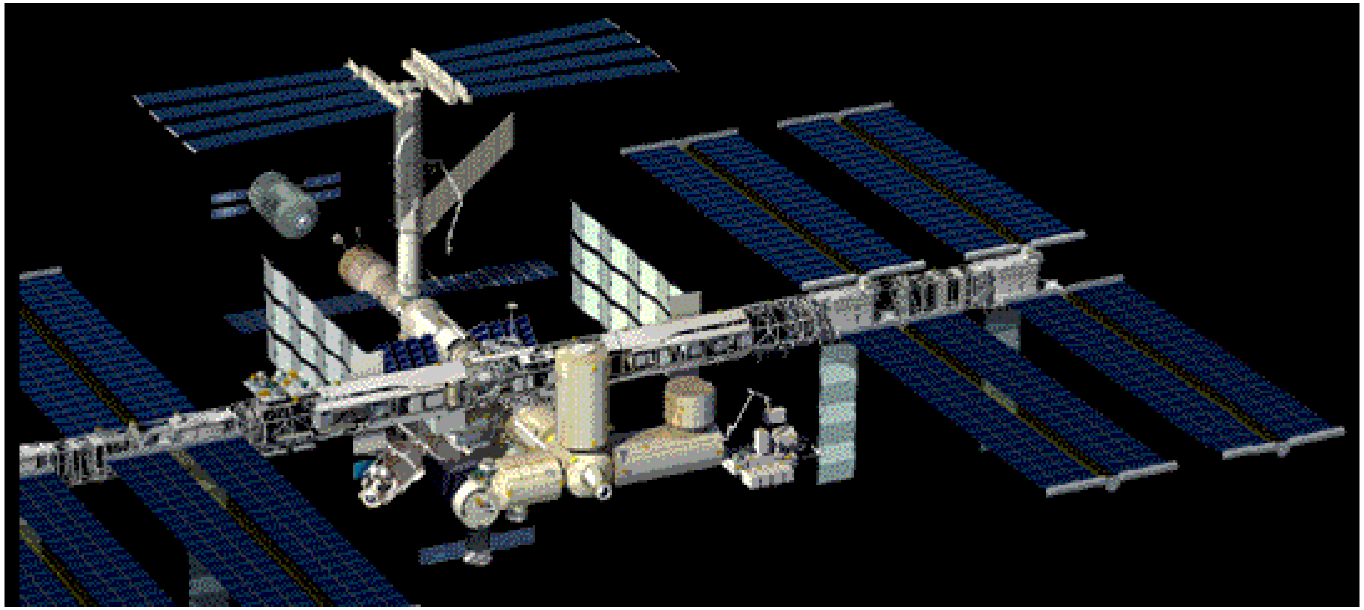
Future monitoring cameras

Conclusion

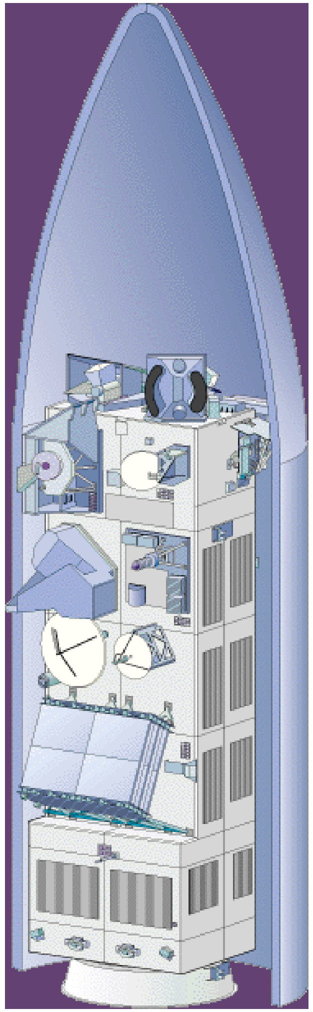
# Introduction to spacecraft monitoring

**To provide feedback of spacecraft status during deployment of antennas, instrument booms, solar panels, etc.**

**Classical approach using indirect information collection from sensors is becoming impractical when spacecraft and space stations grow larger and have more appendices.**



# Spacecraft monitoring using visual systems



**New approach using direct visual confirmation of spacecraft condition giving additional benefits:**

- **Detect vibrations and deformation**
- **Spacecraft surface damage**
- **Failure diagnostics**
- **Minimal impact on spacecraft design**
- **Pictures of separation, e.g. launcher and spacecraft, spacecraft and planetary probe**
- **Pictures with public relations value, e.g. launcher, spacecraft in orbit, earth in background etc.**
- **One image tells more than thousand words**

# Requirements on visual monitoring sensors

Small and cheap in use: unobtrusive employment on spacecraft

Versatility in interfacing to:

- Instrument controller (currently using ESA TTC-B-01, 28 V)
- Spacecraft telecommand/telemetry system (direct)
- Central computer which controls cameras, processes images
- Payload computer for image processing
- Local image processor, for intelligent cameras

Adhere to space specific protocols such ESA Packet Telemetry and Telecommand standards.

Radiation hard or tolerant.

CMOS technology for system-level integration has been identified as an enabling technology.

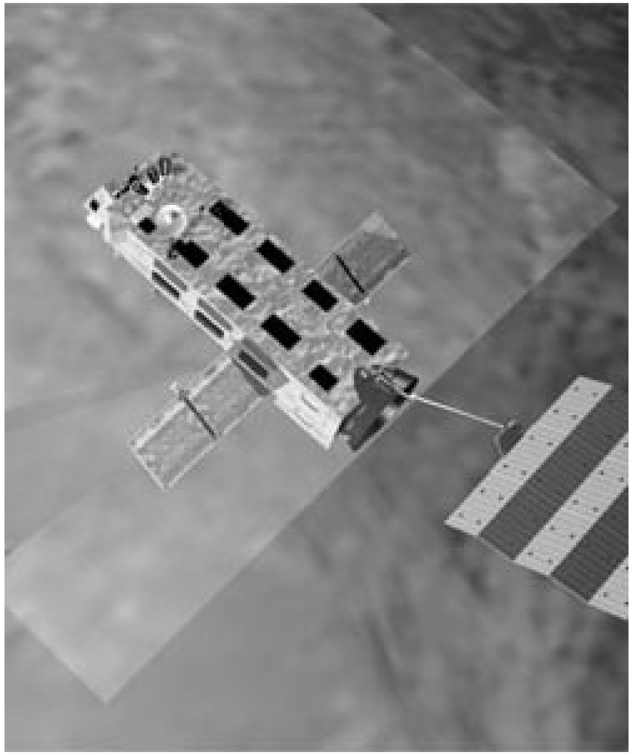
# Visual Telemetry System

**The first visual monitoring system that ESA developed was for the ENVISAT earth observation mission. The spacecraft has many antennas and booms that need to be observed.**

**Three cameras were to be connected to a master unit, which in turn was to be connected to the instrument controller.**

**The intention was to compress images and store them locally before being transferred to the instrument controller.**

**The system was finally not employed due to integration and schedule difficulties. The spacecraft was not designed with visual monitoring in mind, making late add-on integration cumbersome.**



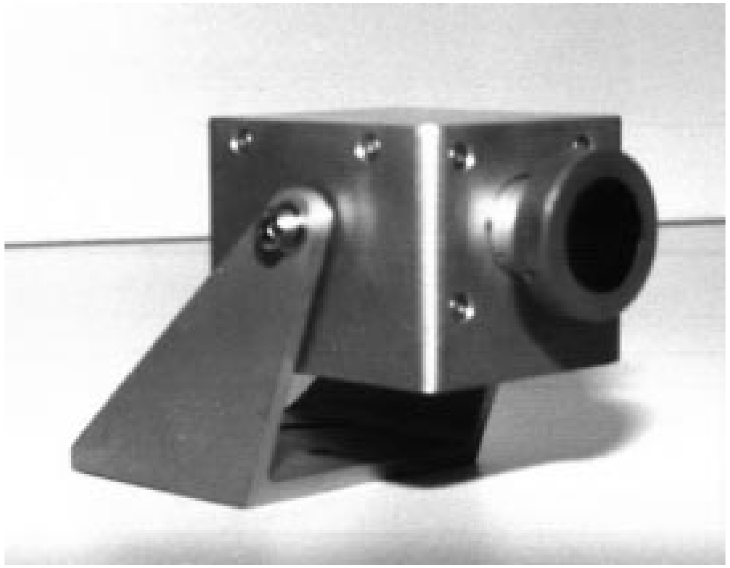
# Visual Telemetry System components

Master Unit (2000 g) [Matra Marconi Space (UK)]

- Interface to eight cameras and spacecraft (TTC-B-01, 28V)
- DPS based JPEG compression and storage with image timeline

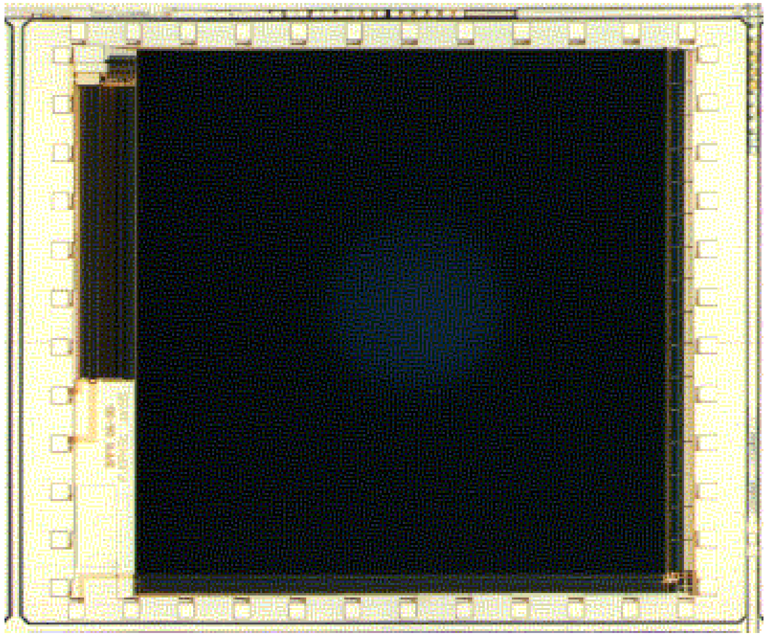
Camera (195 g, 6x6x5 cm) [Delft Sensor Systems (B), IMEC (B)]

- Capture one fully corrected image at a time
- Integrated functions: calibration, windowing, subsampling, interleaving, imager non-uniformity correction
- Control functions and interfaces implemented in an Actel 1280 FPGA

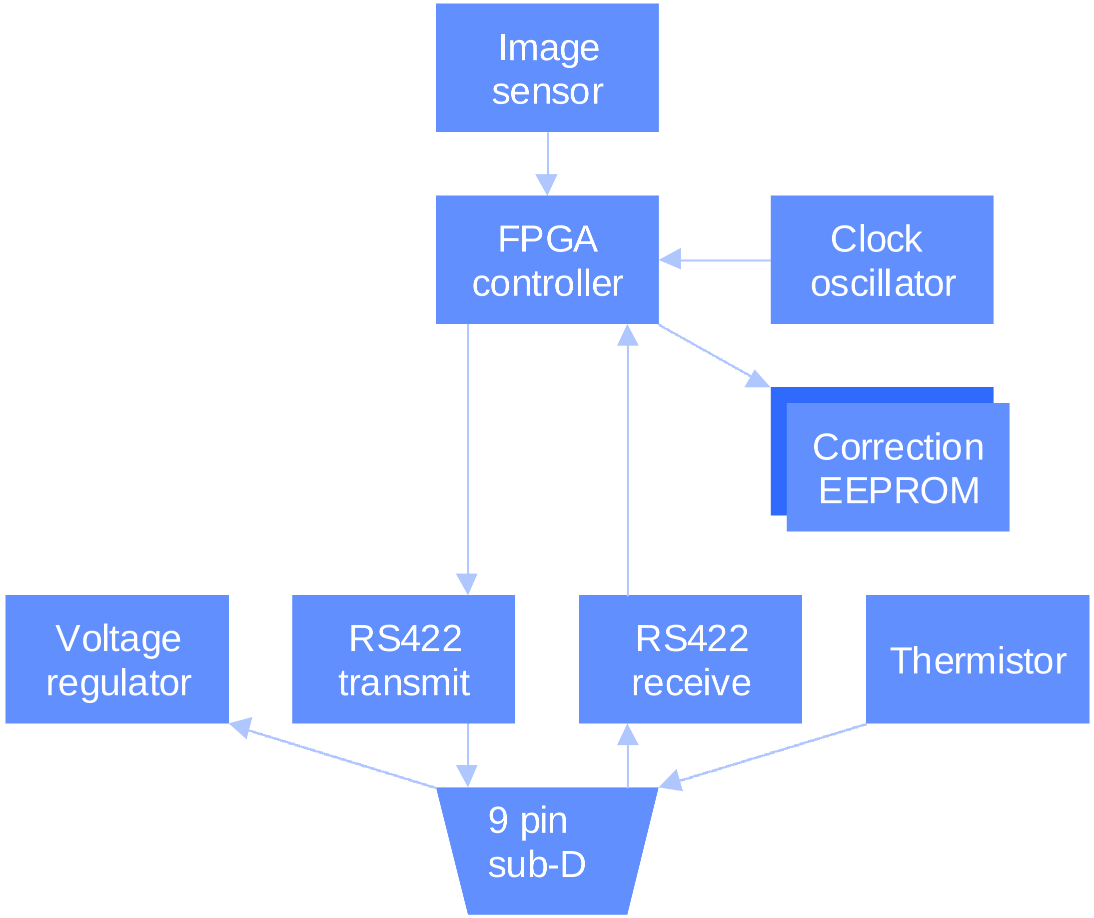


# VTS camera specification

- Based on the FUGA15 direct readout CMOS Active Pixel Sensor imager chip [IMEC (B)]
- Format: 512 x 512 pixels
- Frame rate: one frame per second
- Optical dynamic range: 120dB, log-compressed for implicit adaptation to any scene contrast
- Electrical SNR: 43dB
- Digitisation: 7 bits gray-scale,
- RS-422 3.125MHz serial interface

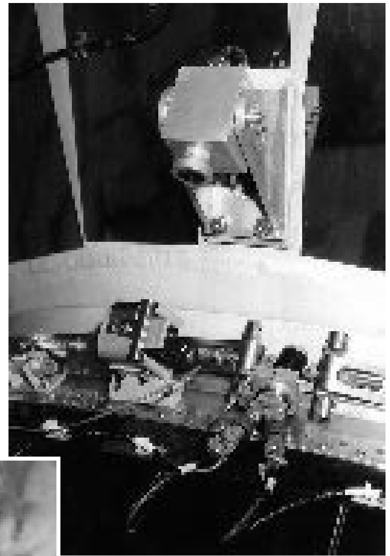


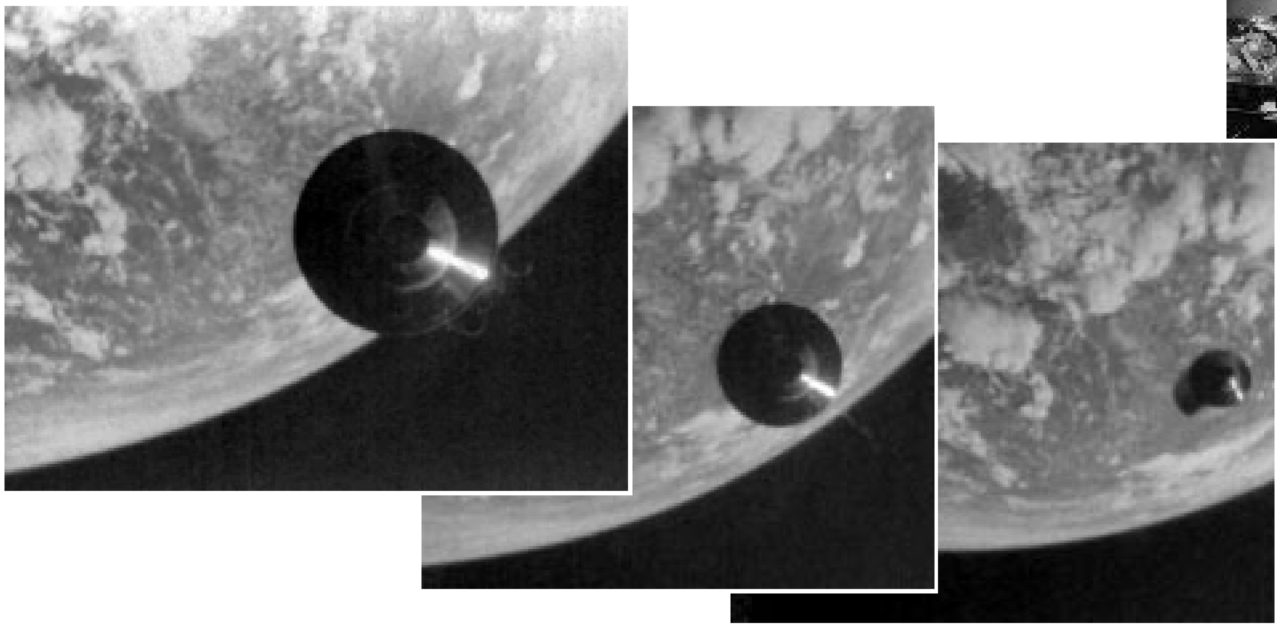
# VTS camera architecture



# VTS on TeamSat and Ariane 502

Three VTS cameras were mounted on the TeamSat satellite launched on the Ariane 502 test flight and used for observing the separation between the spacecraft and the launcher.





# Integrated Radiation-tolerant Imaging System Series

**Integrated Radiation-tolerant Imaging System (IRIS) is a series of running ESA developments aiming at a single chip monitoring imaging system:**

**IRIS-1**

- **Sensor and ADC only**
- **Control logic and spacecraft interfaces in an FPGA**
- **Silicon available and chosen for space flight**

**IRIS-2**

- **Integration of sensor and logic**

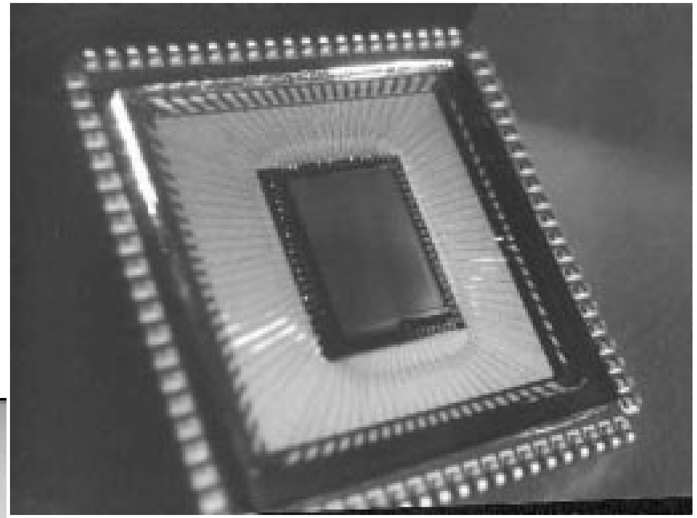
**IRIS-3**

- **High resolution and local image memory, with companion compression chip (wavelet algorithm)**
- **Radiation-tolerant chip set**

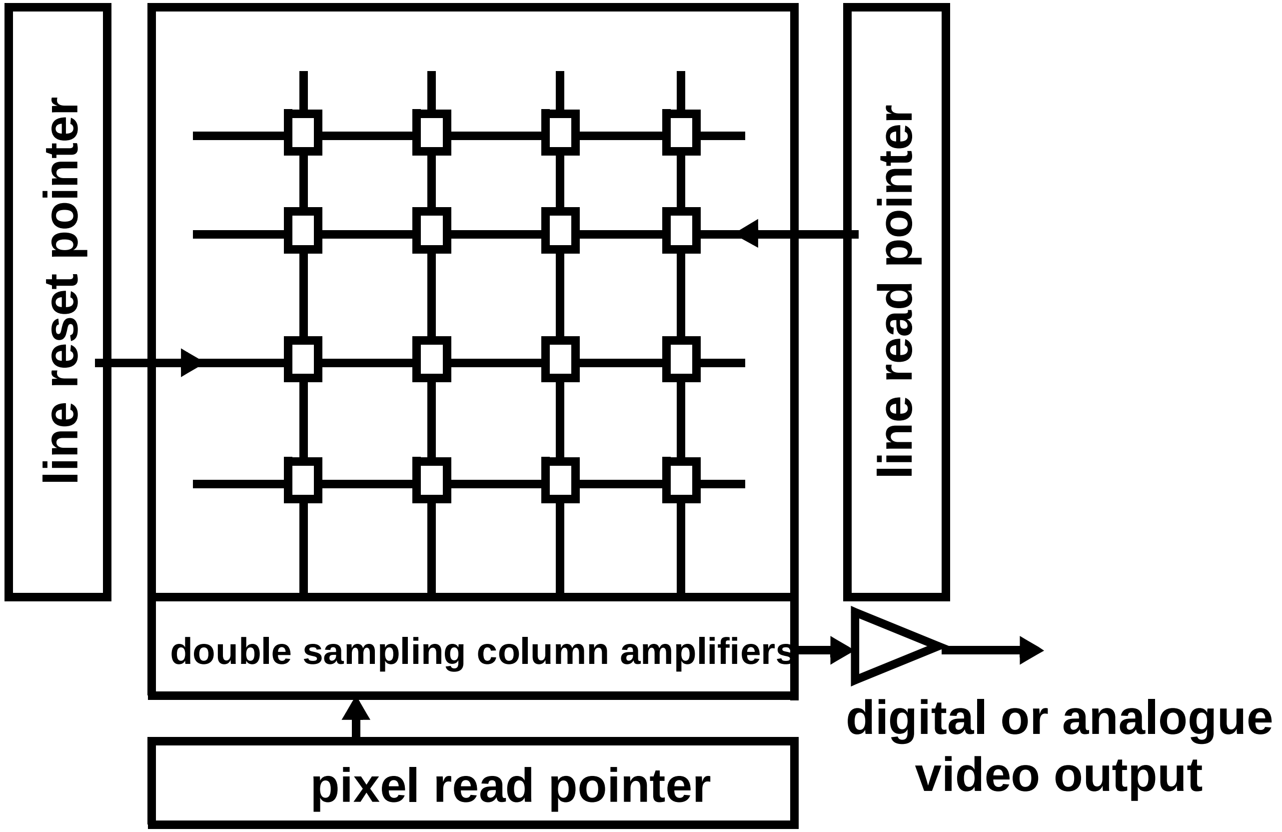
# Integrated Radiation-tolerant Imaging System - 1

Sensor specification:

- 640 x 480 pixels
- 8 bits digitisation on-chip
- 10 images per second
- optional colour filters
- support for windowing
- on-chip double sampling for image non-uniformity correction



# IRIS-1 block diagram



# Visual Monitoring Camera

Firstly to observe the separation between the XMM spacecraft and the upper stage of an Ariane launcher vehicle. Secondly to observe the deployment of the solar panels. Also, provide visual feedback for public relations purposes.

To be developed and integrated with spacecraft in less than one year.

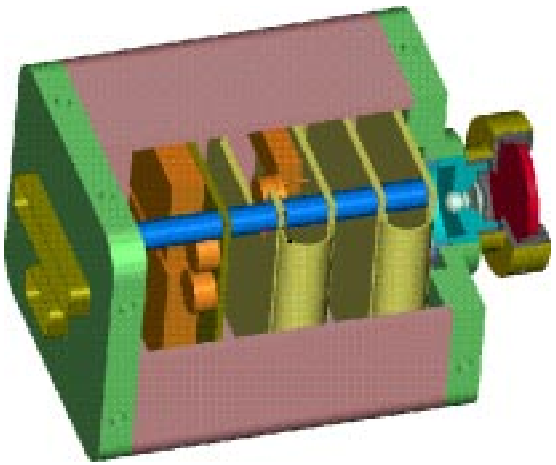
To be interfaced directly to instrument controller using traditional spacecraft interface and power distribution system.

Two cameras to be mounted looking along the shaft of the spacecraft in the direction of the launcher.

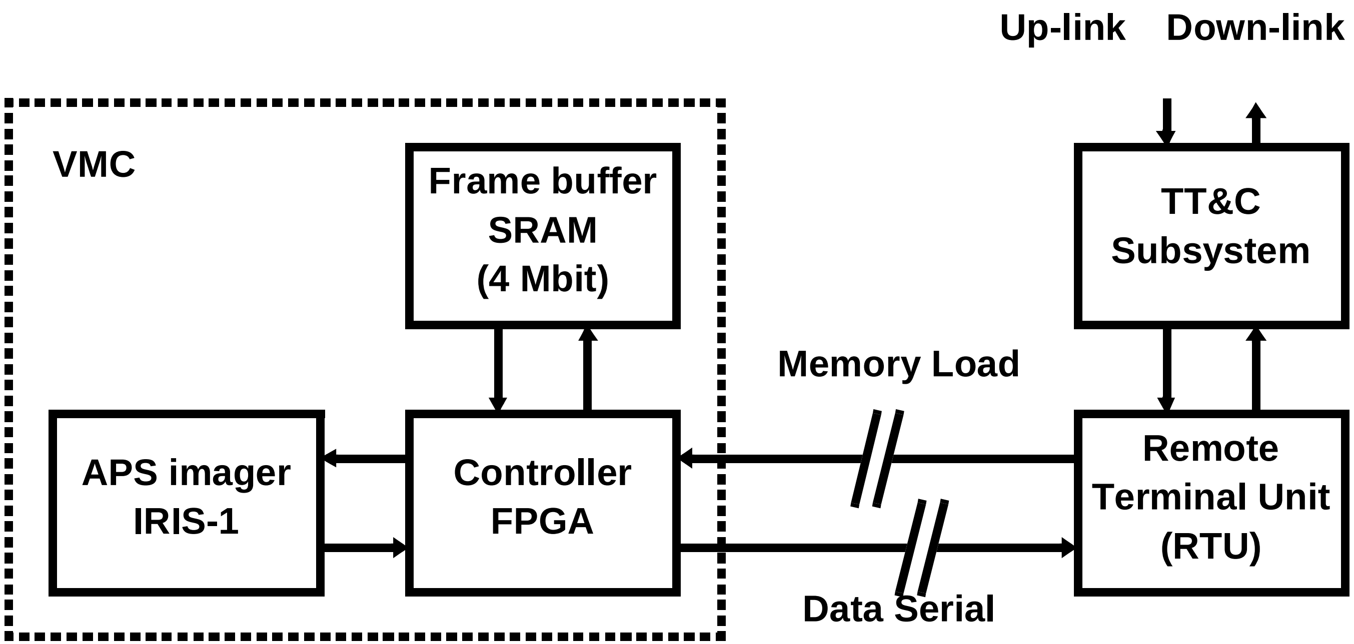
There was no space/budged for an additional processing unit onboard.

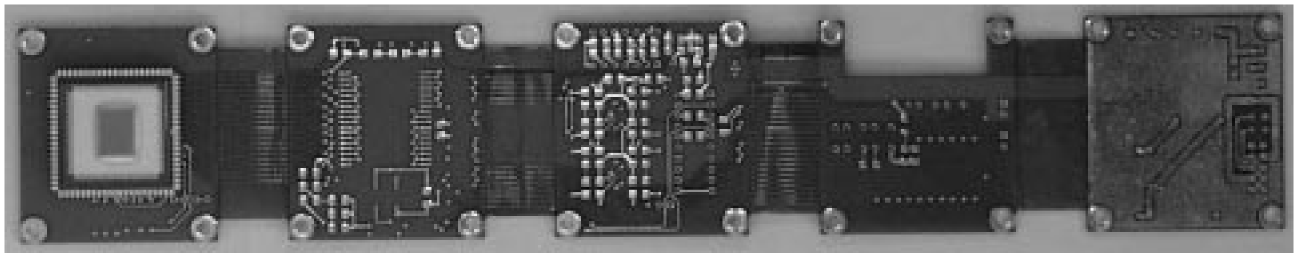
# VMC specification

- Sensor type: IRIS-1 or FUGA15 (colour or gray scale)
- Image capture speed: 200ms
- Local buffer memory: one image
- Image download speed: one image per second
- Autonomous or command-interactive operation
- Programmable event-triggered timer for capture of first image
- Interfaces: TTC-B-01 up to 1MHz or RS-422 like up to 3.125MHz
- Power supply: either 28Vdc or 10Vdc
- Power consumption: 5.0W & 28V or 2.0W @ 10V
- Dimensions: 6x6x10 cm, 430 g



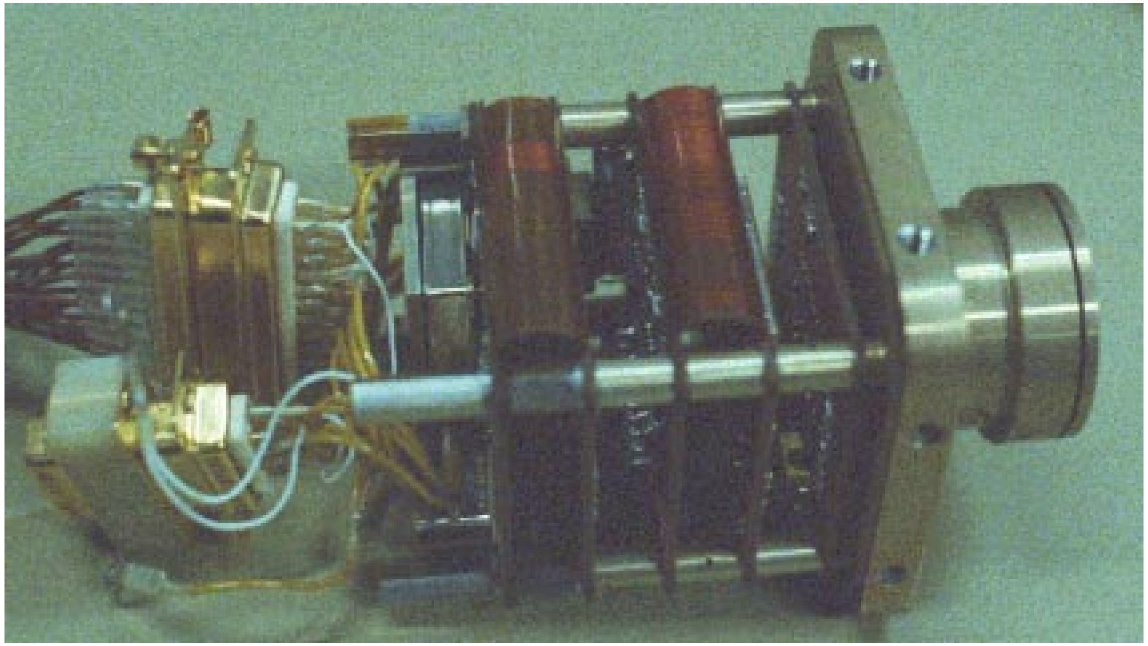
# VMC electrical design



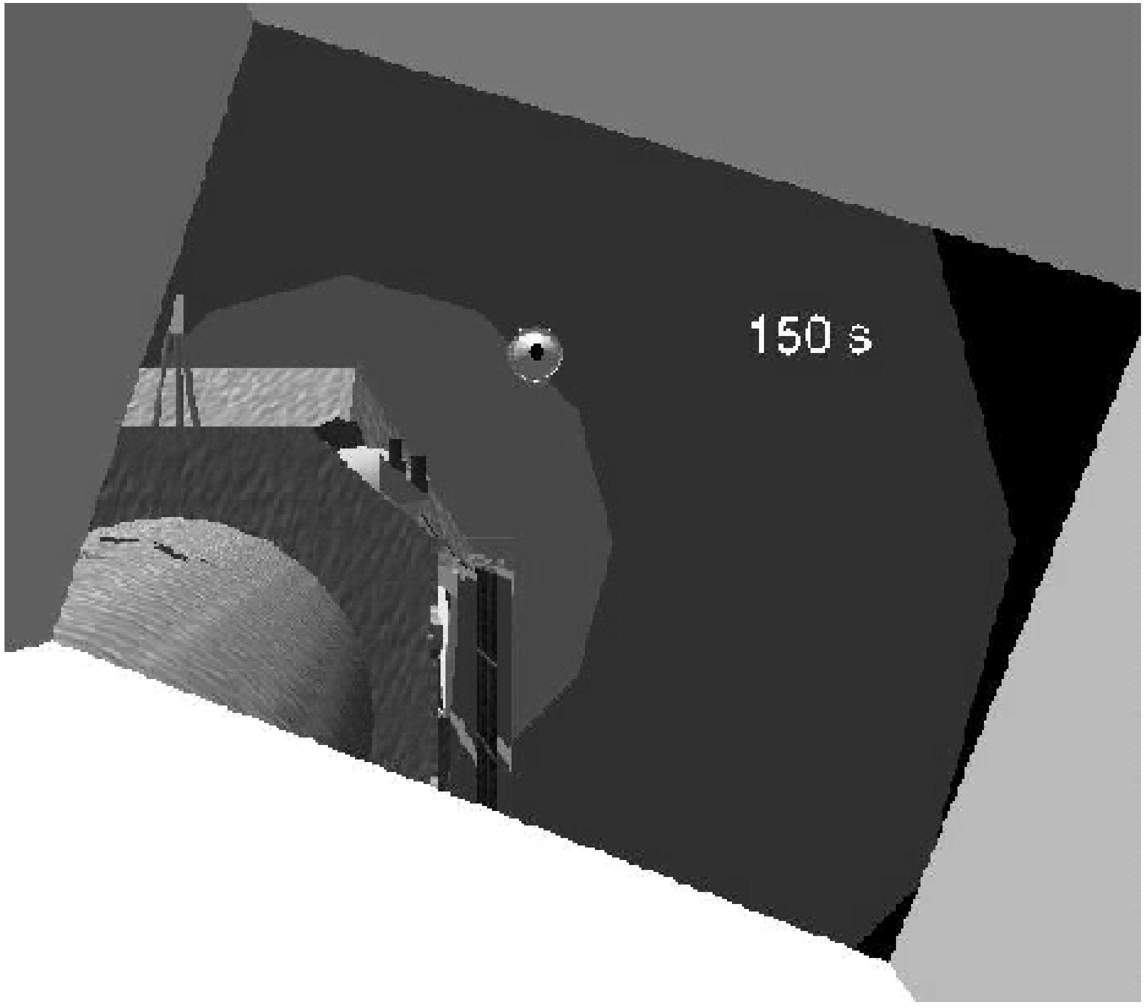



# VMC mechanical design

**Flexible printed circuit board used for interconnecting five boards. The first board carries the imager, the second carries the FPGA and memory, the third the spacecraft interfaces, the fourth power converter and conditioning, and the fifth carries the connectors.**



# Predicted VMC view of XMM separation



# VMC extension for Cluster-II

**The VMC will now also be used on the Cluster-II mission. Cluster-II comprises four spacecraft that are launched two at the time. A camera will be mounted on the upper spacecraft and capture the separation sequence.**

**An image will be taken every three minutes, capturing the separation between the upper and lower spacecraft, and between the lower and the upper stage of the launcher.**

**This will be done by storing 27 images in an extension unit. The extension unit will be similar to the VMC in terms of dimension and mass.**

# Integrated Radiation-tolerant Imaging System - 2

**Operational miniature radiation-tolerant camera with few components:**

- **IRIS chip, power supply and line drivers**

**Easy to use as stand-alone camera on spacecraft**

- **Standard ESA interfaces and packetising protocol**

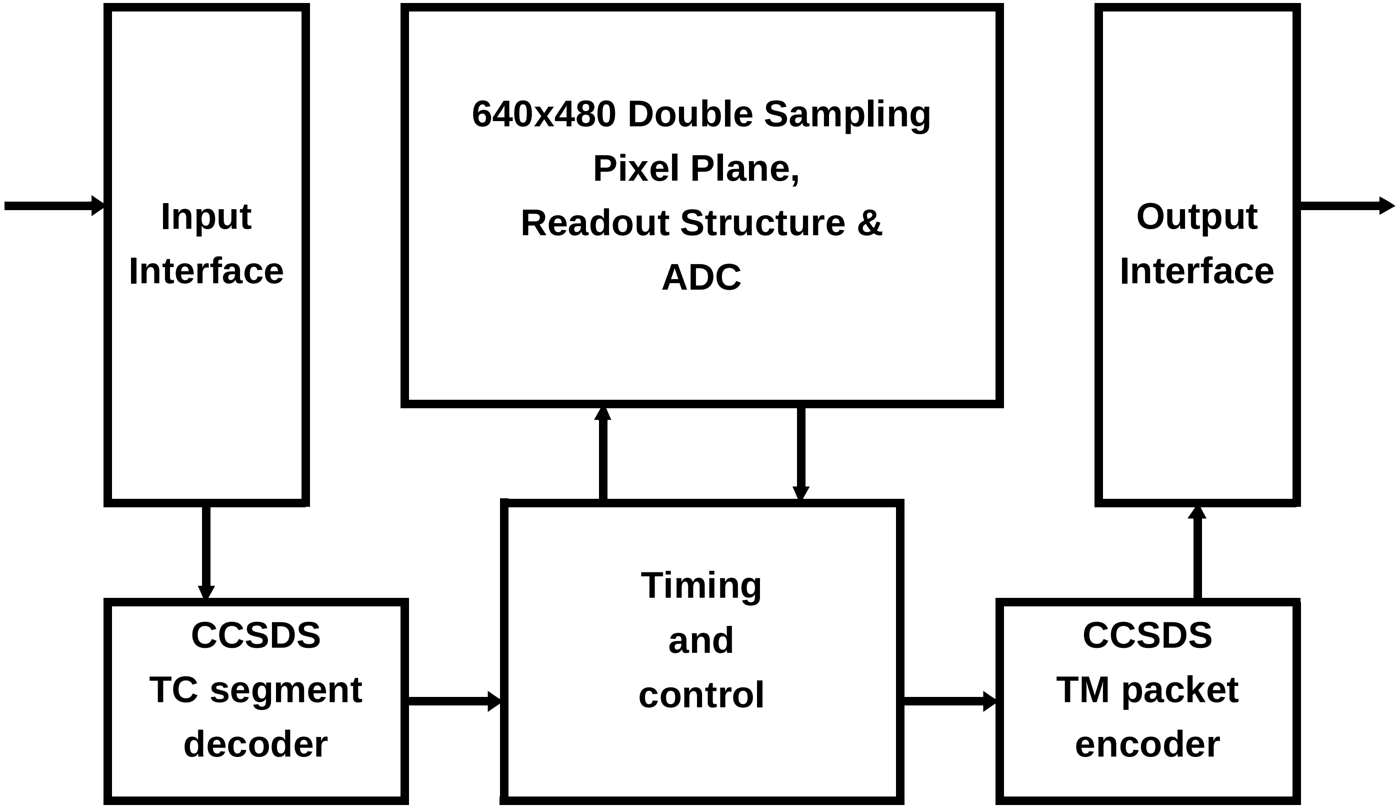
**Application areas:**

- **Monitoring and visual telemetry**
- **Low-grade earth and planetary imaging**
- **Low-end image gathering on small platforms such as planetary probes lander and rover near imaging**
- **Robotics (high frame rates and windows)**
- **Spacecraft optical guidance and navigation**

# IRIS-2 sensor specification

- **Format: 640 x 480, pitch 14um**
- **Architecture: integrating 3-transistor photo diode pixel, double sampling column amplifiers**
- **Speed: 3Mps, up to 10 full frames per second, more when windowed or subsampled**
- **Windowing, subsampling, interleaving, digital pixel binning**
- **Standard spacecraft interfaces**
- **Serial digital command interfaces**
- **Serial and parallel digital pixel data interfaces**
- **Analogue pixel data output**
- **Raw data or CCSDS/ESA standard packetisation**
- **8-bit ADC**

# IRIS-2 sensor architecture

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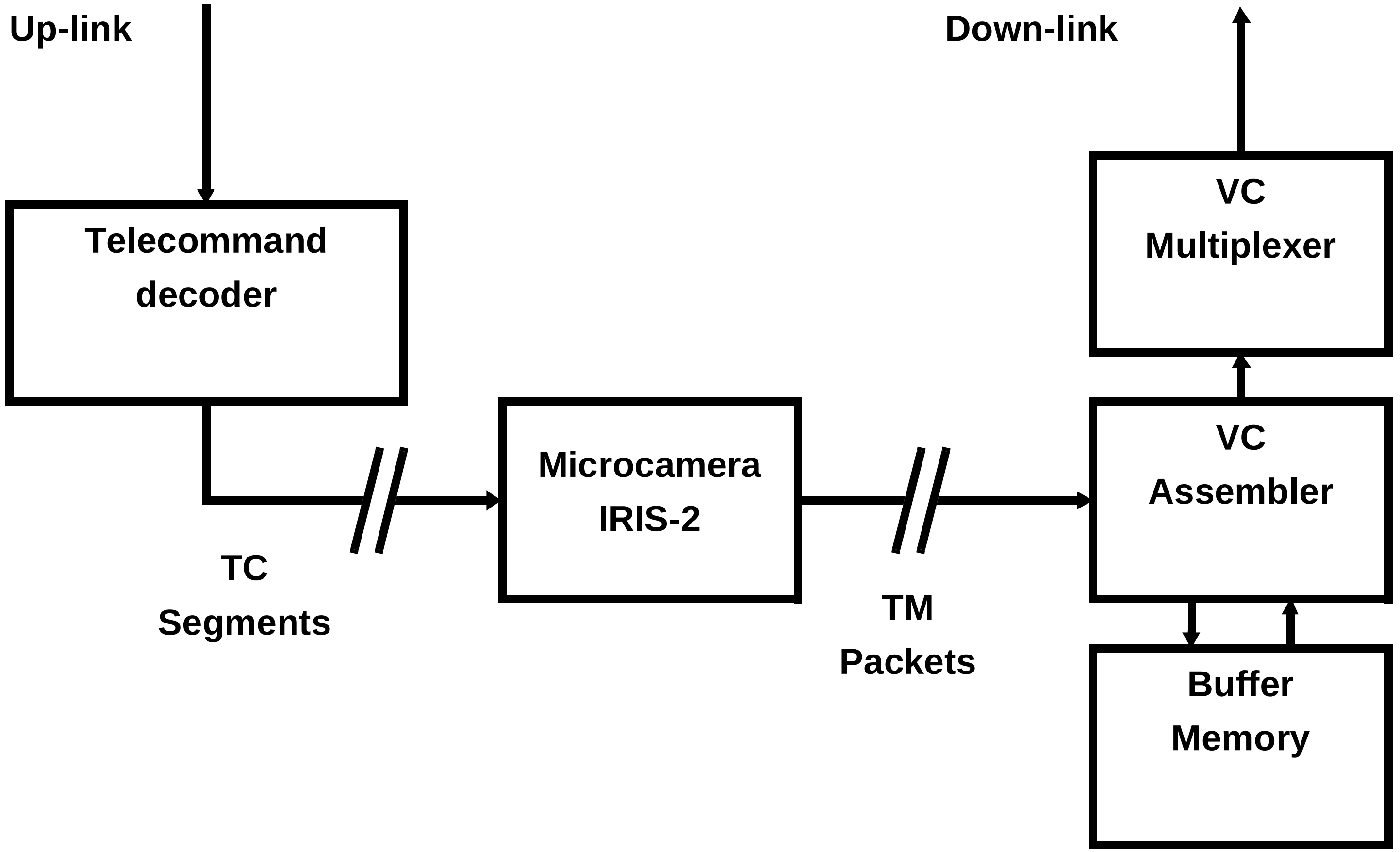
Microelectronics Section

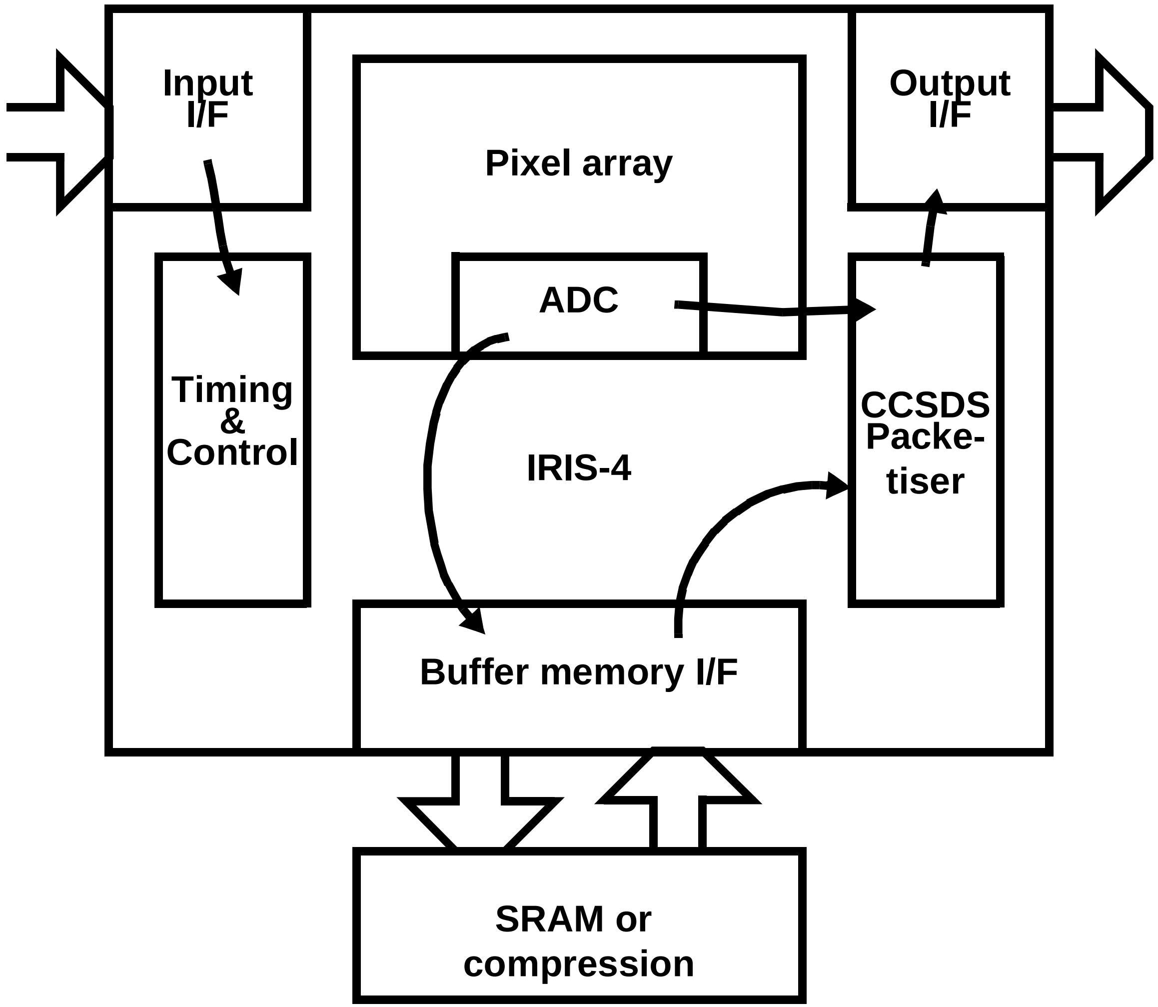
# Envisaged spacecraft integration of IRIS-2



# Integrated Radiation-tolerant Imaging System - 3

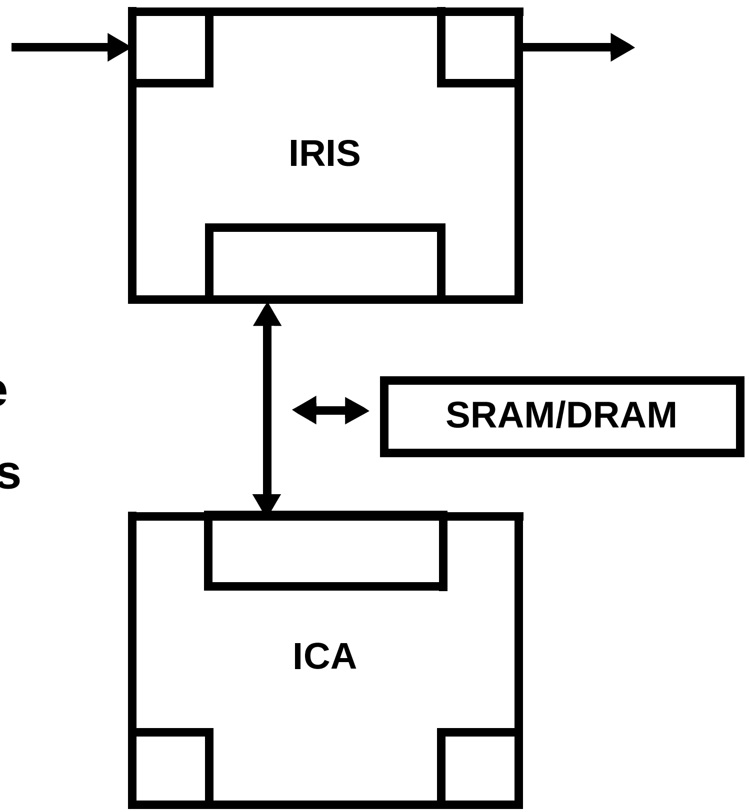
- **Sensor size: 1024 x 1024 pixels, 10 bits resolution**
- **Colour imaging capability, by overlaying a colour filter matrix**
- **Performance: visual and near infrared spectral response; 3 lx sensitivity low noise, high anti blooming, low pixel non-uniformity, high fill factor and quantum efficiency**
- **Frame rate: at least 10 Hz for the full frame at 10 bit pixel depth, higher full frame rates using lower pixel resolutions**
- **Readout options: sub-windowing, interlacing, local memory**
- **Radiation tolerance: target total dose 50 krad, latch-up free and low sensitive to SEUs**
- **Operating temperature: -40 °C to +65 °C as a minimum range**
- **Power consumption: 400 mW at maximum frame rate, featuring a low power mode, single 5 V supply**

# IRIS-3 sensor architecture



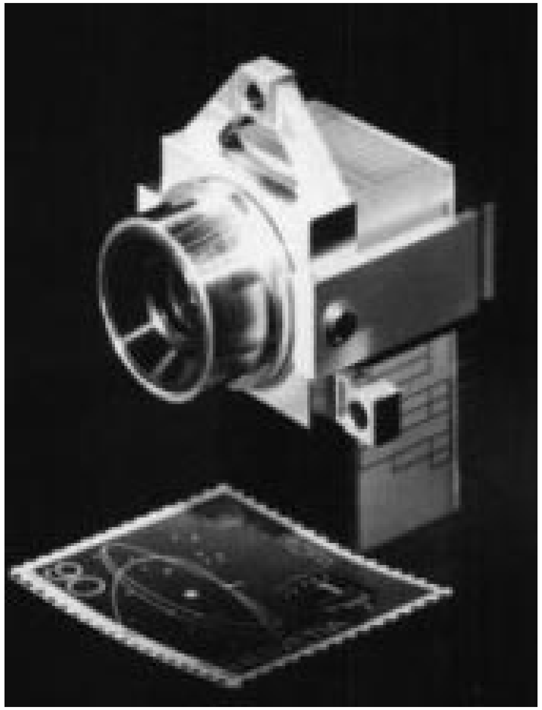
# IRIS-3 companion: Image Compression ASIC

- Wavelet compression - MPEG4 candidate
- Image size of 1024 x 1024 pixels, supporting windows
- Pixel size from 8 to 12 unsigned bits per pixel
- High compression throughput
- Typical compression ratio between 3 and 40, user selectable
- Will store 100 compressed images (using a compression ratio of 10) in external memory protected by error correction code
- Tightly coupled with IRIS-3



# Digital micro-imager for planetary exploration

- Resolution: 1024x1024 pixels
- A/D conversion: 10 bits/pixels
- Integrated electronics comprising sequencer, converter, local picture storage
- Power consumption: 2.7 W, 3 supplies
- Selectable outputs: serial RS422 at 10 Mbit/s or 57600 bauds
- Easy operation and data acquisition
- Total weight: 35 g including optics, opto-mechanical interface and electronics
- Field of View for the prototype: 41°, F:14



# Micro-imager electrical architecture

Based on TH 7888 frame transfer CCD, with a dedicated packaging suited to be incorporated in the 3-D technology.

CCD driving interfaces and CCD output buffering board, based on ICL circuits.

CCD video signal sampling and A/D conversion board. This processing board includes two twin circuits: a Correlated Double Sampler TH 7982, and a A/D converter TS 83510.

CCD clocks generator board, based on an Altera FPGA.

I/O and control board, including a 16Mbit DRAM for image storage, RS-422 drivers for the serial links and an Actel FPGA for camera control and data throughput.

The design is based on some 30 electrical components.

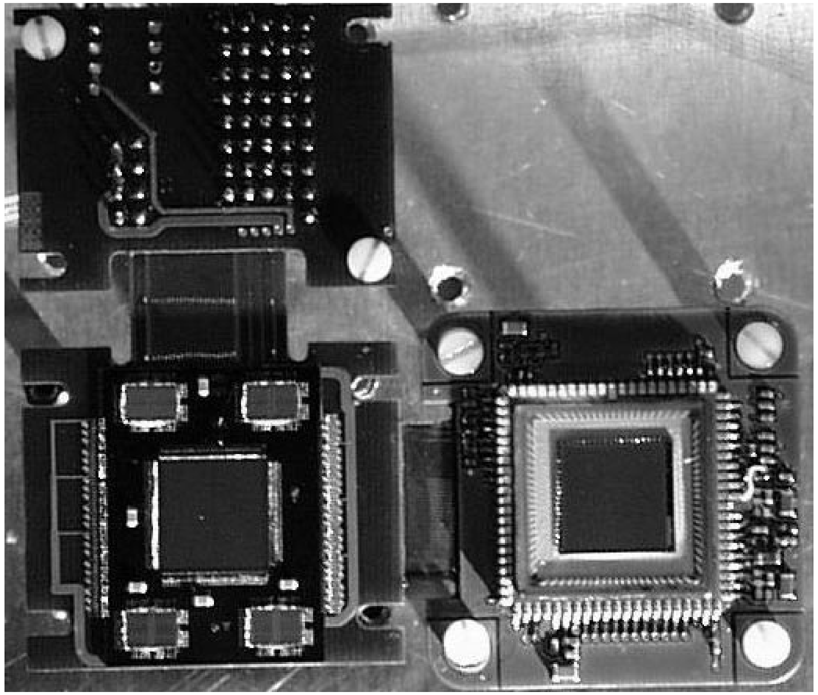
Developed by CSEM (Ch) and 3D-Plus (F).

# Other developments

Attitude Sensor Concepts for Small Satellites is a study which aims to develop a celestial body tracker based on novel technologies such as CMOS APS and MCM integration. [IMEC (B), Sira Electro-Optics (UK), Oerlikon-Contraves (CH), IMT (CH)]

Specifications of imager part:

- 512x512 pixels, 25um pitch for high sensitivity
- Same architecture as IRIS
- 10 frames per second, 1000 windows per second
- FPGA controller: multiple windows, pixel thresholding, edge detection, correction of dark current non-uniformity



# Future imagers and cameras

**Cameras that are under ESA development or being planned:**

- **IRIS-2 Demo: evaluation camera built with commercial parts (potentially with IEEE 1355 interface).**
- **VMX: planned new generation camera based on the IRIS-2 imager, new Actel FPGA 3 V technology and 64 Mbit DRAM memory storage (25 to 100 images, without compression).**
- **VMC-IRIS-3: evaluation camera with built-in compression based on VMC housing, suitable for demonstration flight.**
- **IRIS-4: planned 2048 by 2048 colour imager with on-chip colour processing and image compression companion chip.**
- **Video: planned high frame rate camera with high speed interconnect such as IEEE 1355 (SpaceWire).**

# Conclusion

To further reduce the mass of the cameras one needs to address the mechanical implementation in addition to the reduction of the number of electrical components.

Three dimensional packaging and Multi Chip Modules offer the possibility do design small cameras even if based on many components.

Combining the two approaches, mechanical and electrical miniaturisation, will ultimately lead to monitoring cameras that will only carry a small cost overhead when integrated on a spacecraft.

The expectations are that all future spacecraft will use monitoring cameras. The role of the cameras will change with the improvement of performance. Their tasks will move from still images to real time video, from gray scale to colour, from one or two per spacecraft to multiples, etc.

# Point of Contact

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