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Advanced Detectors and Instruments for Small Satellites

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Abstract: This paper presents some approaches to the development of advanced detectors and to miniaturized instrument design which are pursued in the Institute of Space Sensor Technology and Planetary Exploration of DLR (the German Aerospace Center). The instrument design approach is demonstrated for a low-weight (3 kg) dual camera system with narrow-angle in-track stereo and wide-angle multispectral features. Each camera has its own signal processor and 0,5 GBit mass memory. The activities for advanced detector development are concentrated on two different kinds of detectors and instrumentations: infrared detector arrays and instruments at wavelengths out to about 240 µm, and superheterodyne receivers in the submillimeter and far-infrared spectral ranges.

Zusammenfassung: *Neue Detektoren und Instrumente für kleine Satelliten.* Dieser Beitrag zeigt einige Möglichkeiten für das Design hochentwickelter Detektoren und miniaturisierter Instrumente auf, die im Institut für Weltraumsensorik und Planetenerkundung des DLR verfolgt werden. Die Herangehensweise beim Instrumentendesign wird an einem leichten (3 kg) Dual-Kamera-System demonstriert, das sowohl relativ hoch auflösende Stereoaufnahmen als auch multispektrale Übersichtsaufnahmen ermöglicht. Die Aktivitäten auf dem Gebiet der hochentwickelten Detektoren werden auf zwei verschiedene Detektor- und Instrumentierungsarten konzentriert: Infrarot-Flächendetektoren und -Instrumente im Wellenlängenereich bis etwa 240 µm und Superheterodyn-Empfänger im Submillimeter- und fernen Infrarot-Bereich.

1 Introduction

Due to the progress in different fields of technologies used for detector development and for instrument design, the application of small satellites for Earth observation becomes increasingly attractive. This paper shows a design approach for a miniaturized, low-weight (3 kg) dual camera system with narrow-angle in-track stereo and wide-angle multispectral features. This approach was enabled due to the progress in the high integration microelectronics technology and the application of Multichip Module (MCM) technology as well as due to the application of special materials and design principles for the construction elements and the housing.

The activities for advanced detector development are targeted to future projects with largely increased performance parameters. There are two directions: infrared detector arrays and instruments at wavelength out to about 250 µm and superheterodyne receivers in the submillimeter and far-infrared spectral region.

In this paper, the sequence of description of detectors and instruments starts with the VIS/ NIR region of the electromagnetic spectrum heading to the IR and then to the submillimeter region. At the same time, the emphasis changes from the instrumentation aspects to the advanced detector aspects.

2 Miniaturized Camera Design

In the large class of imaging systems, pushbroom imagers using CCD line arrays are currently of high interest because they are targeted for small satellite applications with severe mass and power consumption constraints. CCD line arrays can be produced with a high number of CCD elements having small dimensions to obtain a high potential ground resolution. For multispectral imaging, such CCDs can be covered individually

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with filters to meet the actual application requirements. Even along-track topographic imaging is possible using the three-line geometry. This stereo principle has already been implemented in two stereo cameras of DLR: High Resolution Stereo Camera (HRSC), and Wide-Angle Optoelectronic Stereo Scanner (WAOSS).

It is obvious, using CCD lines with different spectral filters also multispectral imaging can be obtained by means of push broom imagers.

In order to show the potential of a miniaturized push broom camera design, a hypothetical dual camera system (DCS) may serve as an example. The tasks of that camera system are considered to be:

- synoptic observation of atmospheric and surface features and their dynamics in three spectral bands
- topographic mapping of the Earth with medium resolution
- support to data interpretation of other remote sensing instruments of the small satellite which may observe across-track in all angles from nadir to limb.

The DCS shall be implemented as a monoblock structure with two independent cameras:

- WACI – Wide-Angle Colour Imager
- NASI – Narrow-Angle Stereo Imager

Each Camera consists of:

- Optics
- Focal Plane Module (FPM) with three CCD lines, 7 μm pixel distance
- Front End Electronics (FEE) including 14 bit-ADC
- 32 bit DSP for camera control, data correction, data preprocessing and data compression
- 0,5 GBit Mass Memory (MM)
- Spacecraft-Interface (IF)
- Power Supply Unit

The low weight design of DCS can be achieved by using:

- special materials and design, principles for the construction elements and the housing
- high integration microelectronics technology

Tab. 1: Technical Data and Performance Characteristics.

DCS		
mass	3 kg	
power consumption	18 W	
dimensions	160 mm × 150 mm × 130 mm	
S/C-Interface	MIL-1553 / RS 422	
	WACI	NASI
focal length	16 mm	90 mm
FOV	≤ 180° (fish eye)	18.5°
IFOV	0,44 mrad	78 μrad
CCD: lines	3	3
active pixels	6180	4200
pitch	7 μm	7 μm
convergence angle	± 1,1°	± 10°
spectral bands	3 (R, G, B)	1 (panchrom., TBD)
radiometric resolution	8 bit	8 bit
radiometric dynamic	14 bit	14 bit
DPU	TMS 320 C 40	TMS 320 C 40
Mass memory	0.5 GBit	0.5 GBit
compression	S/W (e. g. JPEG)	S/W (e. g. JPEG)
ground pixel size: Δx, Δy *)	285 m (nadir)	50 m
Δz	–	> 50 m
swath width *)	limb-to-limb	210 km

*) circular Earth orbit, H = 650 km.

– application of Multichip Module (MCM) technology to the digital electronics

The 3 kg, 18 W dual camera system can be realized as a cube with roughly 150 mm side lengths.

3 Infrared Detector Arrays

Infrared wavelengths longwards of 1 μm bear great potential for the exploration and surveillance of our immediate environment, the earth's surface, its oceans and atmosphere, as well as for observations of our planetary system, the milky way and out to the most remote galaxies. The Infrared Array Technology group of the DLR Institute concentrates on the design and development of detectors and instruments for infrared astronomy, currently at wavelengths out to about 240 μm (see Fig. 1).

Of course, the results from this group can be and are used in earth observation applications. The experience s of the Infrared Array Technology group are based on different projects, e. g. for the Infrared Space Observatory ISO (since 1995) and for the Kuiper Airborne Observatory (KAO, NAA). To meet the requirements coming from new porjects, the group is expanding its test and assembling capabilities for IR ans FIR detector arrays. For wavelengths up to 40 μm commercially available devices will be used but their instrumental set-up and operation will be customized to the needs of specific projects.

Longer wavelength Ge-arrays and stressed detectors are not commercially available and will be developed in house. Together with several European and US partners large detector arrays are being developed for the instrumentation of SOFIA and FIRST. In collaboration with industrial partners new readout electronics need to be developed to meet the stringent requirements of airborne and space astronomy. It is planned to built a far-infrared photometric array camera as part of the German SOFIA instrumentation and operate it as a PI-type instrument.

4 Far-Infrared Technology for Super-Hetero-Dyne Spectrometers

The Heterodyne and Laser Techniques group of the Institute of Space Sensor Technology investigates the earth atmosphere and astronomical objects in the submillimeter and far-infrared spectral regions (λ = 50 μm–1 mm, ν = 300 GHz–6 THz) using superheterodyne receivers (see Fig. 2). In these sensors, the weak incoming signal

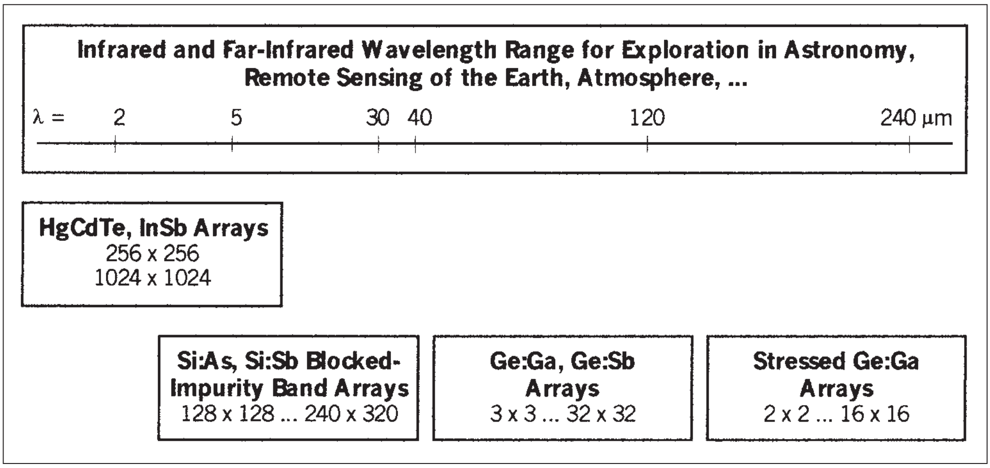

Fig. 1: Infrared and far-infrared wavelength range and commonly used detector arrays.

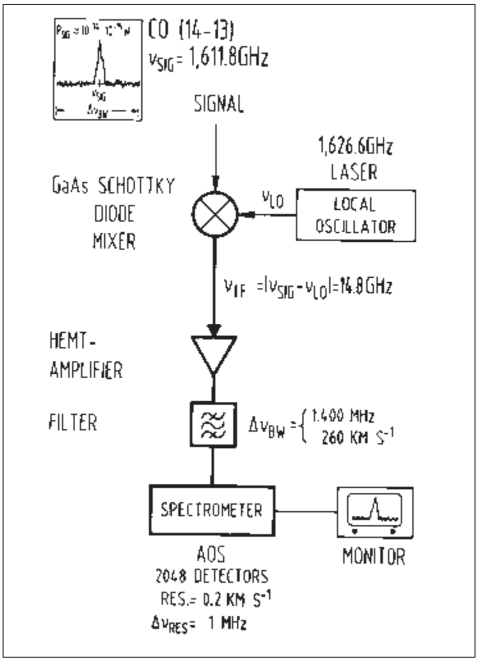

Fig. 2: Block scheme of a superheterodyne receiver.

is superposed to a strong fixed frequency radiation in a nonlinear detector. At the output of the detector, the difference or intermediate frequency (IF), which is typically in the 1–18 GHz range, is further amplified and filtered by off the shelf commercially available micro-wave components. The IF is further split by a spectrometer back-end into its high spectral resolution components which yield the scientific information. In atmospheric chemistry, the scientific goals are the better understanding of the chemical and physical processes in the middle atmosphere (10–80 km altitude) which are important for ozone depletion and global warming.

The group's main work is in the 1–6 THz spectral region. A typical state of the art heterodyne receiver for this frequency range consists of a GaAs Schottky barrier diode mixer in a corner cube mount and a FIR gas laser LO which is optically pumped by a carbon dioxide laser. The signal and LO beams are combined using a power splitting (Mach-Zehnder) or polarization switching (Martin-Puplett) interferometer (diplexer). As spectroscopic back-end an acousto-optical spectrometer is used. The group pursues several ways to develop more sensitive heterodyne spectrometers. In collaboration with the University of Virginia the newest Schottky diodes produced there are characterized and investigated. One result of this characterization is that for a specific diode at optimum LO power the optimum current is proportional to the frequency.

Together with different cooperation partners, further activities are directed to the development of FIR solid state laser local oscillators and superconducting hot-electron bolometers.

Considering future spaceborne applications, the choice of detector is defined by the application. For long term monitoring missions of the earth atmosphere room temperature Schottky diodes will be preferred. However, for the THz region, this depends on the development of space qualified optically pumped gas lasers or THz solid state local oscillators. For shorter term applications, where liquid He operation is possible, the higher sensitivity and lower LO power requirements of low temperature superconducting Hot Electron Bolometers will be of advantage. Such a system could be operated with a tunable solid state LO source, for example a multiplied Gunn oscillator.

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