JSS MULTISPECTRAL IMAGERS FOR EARTH OBSERVATION MISSIONS

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ABSTRACT

There is an increasing market of low-cost multispectral pushbroom scanners for spaceborne Earth remote sensing. They are typically operated on micro-satellites with strong resources constraints. This leads to instrument designs optimized with respect to minimum size and mass, power consumption, and cost. From various customer requirements, Jena-Optronik has derived the JSS product line of low-cost optical spaceborne scanners in the visible wavelength range. This paper discusses typical requirements, presents design trade-offs, and gives an overview of the JSS imagers.

1. MULTISPECTRAL IMAGERS FOR MICRO-SATELLITE MISSIONS

As a novel class between small snapshot cameras onboard experimental satellites and complex multispectral instruments on large Earth observation platforms, Jena-Optronik develops compact but powerful multispectral scanners that can be operated on a micro-satellite platform in low Earth orbit. These pushbroom scanners employ large CCD line detectors and cover large swath widths at medium ground sampling distance.

The micro-satellites used in low-cost commercial or scientific missions are characterized by overall volumes below 0.5…1.5 m^3 and overall mass in the range of 100…250 kg. To reduce complexity and cost, these satellites buses usually have body-fixed solar generators, strongly limiting the overall power budget. If equipped with suitable batteries, peak power is in the range of 150…300 W for the complete satellite. These budget constraints lead to typical requirements for the optical scanner as a single payload:

- overall volume below 0.1…0.3 m^3
- mass below 30…50 kg
- peak power consumption below 50…100 W
- average power consumption per orbit below 10…20 W

Onboard data storage capacity is expensive in terms of cost and power consumption. Therefore, most systems employ data compression to increase the ground coverage of the imaging scanner. To limit the mass memory size, data compression is performed by hardware solutions in real time during imaging before data storage.

2. TELESCOPE DESIGNS

Jena-Optronik's telescope designs for spaceborne scanners cover lens systems, combined refractive-reflective systems, and all-reflective telescopes.

Whenever very large fields of view are required, lens optics are premium choice, covering aperture angles up to more than 180 deg. Lens optics can be designed and manufactured to very high optical quality at medium cost. However, mass penalties grow severely with aperture.

If available space is very limited onboard a micro-satellite, catadioptric telescopes are interesting candidates. They combine reflective and refractive elements, resulting in very compact designs. However, the combined lens-mirror system is rather sensitive w.r.t. temperature gradients and is limited to small fields of view. The latter is also valid for classical two-mirror reflective telescope designs such as Cassegrain or Ritchey-Chrétien systems. They are suitable for small fields of view (up to 2.0 deg) and high resolution applications. Therefore, three-mirror anastigmat (TMA) telescope designs have become a widespread design solution for fields of view from 2 to 12 deg.

While classical material choices like Invar combined with ultra-low expansion glass ceramics impose enormous mass penalties, modern lightweight designs based on combination of graphite epoxy structures with glass ceramics, or based on SiC / CSiC athermal designs, usually exceed the cost budgets of commercial or small missions. Therefore, the design solution chosen by Jena-Optronik is based on all-aluminum telescopes. Novel ultra-precision milling and polishing techniques now give the opportunity to achieve the necessary optical surface quality for applications in the visible range. An all-aluminum design is quasi athermal and offers the great advantage of applying precision mechanical interfaces between mirrors and structure in a standard material.

The subsequent figure shows the TMA telescope optics design of the JSS-56 imager and its accommodation onboard the RAPIDEYE spacecraft.

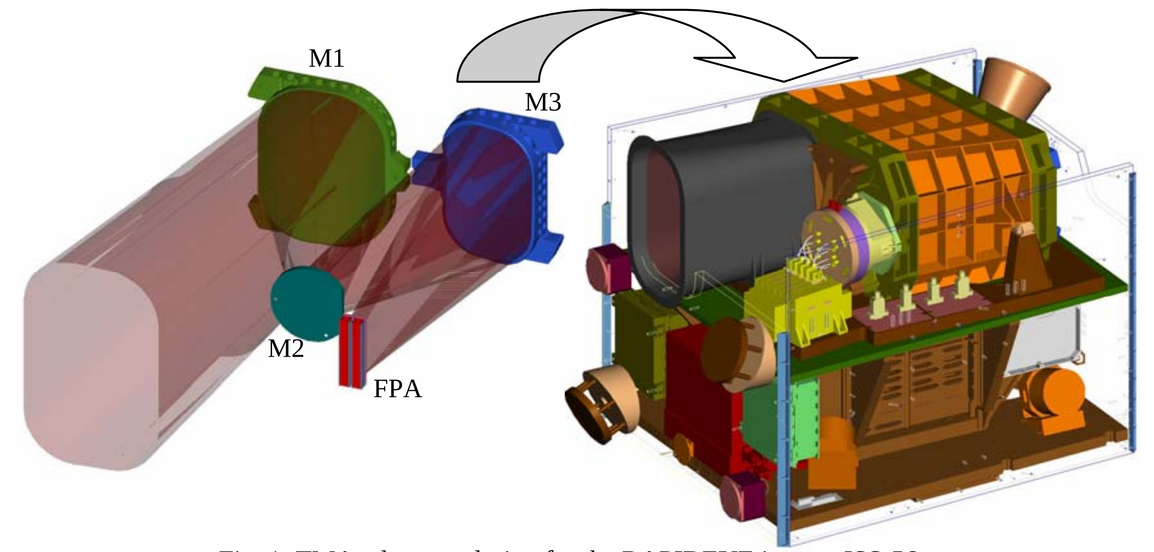

Fig. 1: TMA telescope design for the RAPIDEYE imager JSS-56

3. FOCAL PLANE AND FRONT-END ELECTRONICS DESIGNS

Jena-Optronik's JSS pushbroom scanners utilize CCD line detectors with pixel numbers of 5,000 to 12,000. The JSS-56 employs triple line CCDs with 3×12k pixels in a ceramics baseplate that carries the proximity electronics at its back side. For high-resolution applications like in the JSS-61, TDI CCDs are used to enhance the radiometric budget.

The front-end electronics is placed in a dedicated box in close proximity to the focal plane assembly. For each spectral channel, a dedicated signal chain module sends the required CCD clocks and voltages, and reads out the CCD data. It includes two analog-to-digital converters for odd and even CCD video output, one FPGA, as well as data and command interfaces. The signal chains also include gain amplification and Correlated Double Sampling (CDS). Standard digitization depth is 12 bit. Optional pixel binning is performed in the data processing and control electronics. The JSS-56 front-end design is based on technology developed by DLR in Berlin.

4. ON-BOARD DATA HANDLING

After digitization, the image data pass a typical processing flow comprising data compression (COU – compression unit), data storage (MMU – mass memory unit), data formatting (DFU – data formatting unit), and downlink. The complete function and data flow control is exercised by a dedicated control and spacecraft interface electronics (CIU – control and interface unit). Figure 2 shows the block diagram of the corresponding electronics unit of the JSS-56 imager.

Jena-Optronik's scanners employ DCT for data compression based on a dedicated IP core in a FPGA. Lossless compression is supported by means of differential sampling of the incoming pixel data with subsequent Huffman coding. The MMU utilizes mass memory technology developed by Astrium Germany. The DFU provides CCSDS standard data formatting, encryption, and the data interface to the X-band downlink.

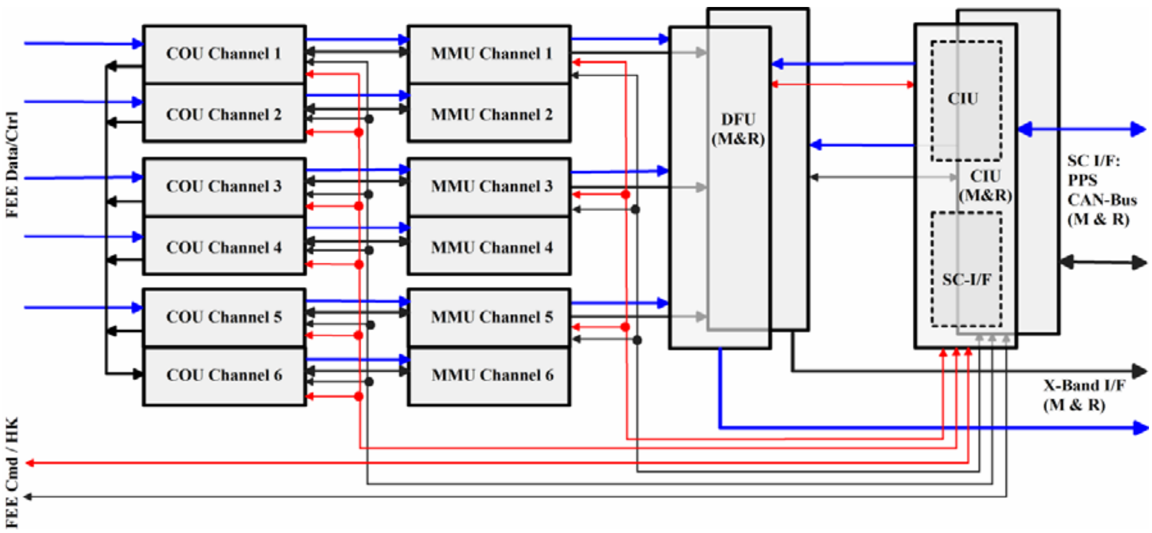

Fig. 2: Data handling electronics of the JSS-56 imager

5. JSS PRODUCT LINE

From currently available mission requirements of various customers, Jena-Optronik has derived the product line of JSS multispectral Earth observation scanners.

JSS-54 is a low-cost scanner for medium resolution equipped with a catadioptric Mangin type telescope such that a rather compact configuration is obtained. The system is optimized w.r.t. minimum power consumption and recurring cost.

The JSS-56 has been described in more detail within this paper. Five of these multispectral scanners will fly onboard the RAPIDEYE spacecraft constellation. The main design issues are maximum swath width at medium resolution, flexible data compression, and sufficient mass memory capacity to store complete image takes. The design is tailored to minimum power consumption and mass.

The third type, JSS-61, represents an intermediate class of instrument between low-cost medium-resolution scanners, and high-resolution type imagers. Its panchromatic channel achieves a GSD of 1.5 m, whereas the multispectral channels remain at medium resolution. The features of current JSS designs are summarized in the table below:

Type	**JSS-54**	**JSS-56**	**JSS-61**
No. of channels	5	5	6
No. of pixels per channel	5 000	12 000	12 000
F# / focal length [mm]	5 / 980	4.3 / 633	4.6 / 2580
GSD @ 600 km orbit height	4.2 m	6.5 m	1.5 m (PAN) 4.5 m (MS)
Swath width @ 600 km orbit height	21 km	77 km	18 km
Telescope type	catadioptric	TMA	Ritchey-Chrétien
Minimum SNR	> 50	> 67	> 50
Digitization depth	12 bit	12 bit	12 bit
Data compression method	None	DCT	DCT
Data storage capacity	10 Gbit	48 Gbit	120 Gbit
Data encryption / formatting	none / CCSDS	Triple DES / CCSDS	Triple DES / CCSDS
Data downlink interface	50 Mbps	2 × 40 Mbps	4 × 50 Mbps
Peak power consumption (simultaneous image take & downlink)	50 W	91 W	180 W
Average power consumption per orbit (including imaging, data retention, downlink)	12 W	15 W	30 W
Overall mass	30 kg	34 kg	96 kg
Overall dimensions imager front-end [mm]	300 dia. × 790	620 × 320 × 740	780 × 880 × 1420
Overall dimensions electronics box [mm]	260 × 315 × 230	280 × 258 × 230	280 × 260 × 420

ACKNOWLEDGEMENTS

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