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BTDI DETECTOR TECHNOLOGY FOR RECONNAISSANCE APPLICATION

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ABSTRACT

The Institute of Optical Sensor Systems (OS) at the Robotics and Mechatronics Center of the German Aerospace Center (DLR) has more than 30 years of experience with high-resolution imaging technology. This paper shows the institute's scientific results of the leading-edge detector design in a BTDI (Bidirectional Time Delay and Integration) architecture. This project demonstrates an approved technological design for high or multi-spectral resolution spaceborne instruments. DLR OS and BAE Systems were driving the technology of new detectors and the FPA design for future projects, new manufacturing accuracy in order to keep pace with ambitious scientific and user requirements. Resulting from customer requirements and available technologies the current generation of space borne sensor systems is focusing on VIS/NIR high spectral resolution to meet the requirements on earth and planetary observation systems. The combination of large swath and high-spectral resolution with intelligent control applications and new focal plane concepts opens the door to new remote sensing and smart deep space instruments. The paper gives an overview of the detector development and verification program at DLR on detector module level and key parameters like SNR, linearity, spectral response, quantum efficiency, PRNU, DSNU and MTF.

INTRODUCTION AND BASICS

The application field of BTDI detectors is driven by the user requirement to get the opportunity of more detailed scanning of specific areas from space. In contradiction to “traditional” TDI sensors which have already the advantage of greatly increased integration time which allows the collection of more photons, the bidirectional sensor improves the image quality again.

The development of BTDI line detector BAE Systems CCD21122 is a progression of the CCD TDI image sensor technology developed by BAE Systems (formerly Fairchild Imaging) used for Kompsat-3/3A missions.

Time delay and integration (TDI) charge-coupled device (CCD) are a special class of line detectors for capturing images of moving devices at low light intensity. A TDI detector has multiple rows of pixel lines, so called TDI stages. The partial measurements inside the rows are shifted to the adjacent row synchronously with the motion of the image over the pixel array. The usage of TDI detectors in comparison to normal CCD detectors improves the radiometric and the geometric performance. Theoretically, a TDI detector improves the SNR by $\sqrt{N}$ with N the number of TDI stages [3]. De-synchronization degrades the detector MTF by:

$$MTF(k) = \left| \frac{\sin(\pi \cdot k \cdot |\varepsilon| \cdot N \cdot \Delta x)}{\pi \cdot k \cdot |\varepsilon| \cdot N \cdot \Delta x} \right| \qquad (1)$$

with k spatial frequency, Δx - pixel pitch and ε - relative velocity deviation [3].

Any mismatch of synchronization will blur the image. The full-well capacity and the synchronization of image motion to the row shifting limit the number of TDI stages that can be used.

Bi-directional TDI detectors (BTDI) have the additional advantage to be able to scan in forward and backward direction. In the case of space application this feature allows optimization of satellite design and operation. The satellite bus can make a yaw flip for better solar battery efficiency without degradation of optical performance of the instrument flying backwards. Another application would be the wide area image generation. For the capturing of images larger than the swath of the instrument the backward scanning option avoid yaw flips or new satellite instrument pointing.

TECHNICAL DESCRIPTION OF 12,010 X 64 BTDI CCD ARRAY

BAE Systems CCD21122 (12 k array of two 6k dies)

- Bi-directional TDI image sensor (can be scanned either upwards or downwards)
- 12,010 x 64 array size composed of 2 independent CCD dies (BAE Systems CCD11062) “offset butted” (50 pixel overlap region)
- TDI stages 2, 16, 32, 64 up/down
- 17.5 µm x 17.5 µm pixel size
- 21 cm image length
- AlN package with “side-brazed” pins and capture plate

BAE Systems CCD11062 (6 k die)

- 6,040 x 64 array size
- Bi-directional TDI chip- with 2 outputs up/down and max. pixel rate 20 MHz
- Column anti-blooming capability
- Vertical summing gate to allow on-chip vertical binning
- Horizontal summing gate to allow on-chip x2 horizontal binning

Overview

The BAE Systems CCD21122 [1] is a 12,010 x 64 element TDI image sensor intended for use in space based, earth resource scanning applications.

The pixels are 17.5um x 17.5um in size which produces a total image width of 210 mm.

The unique feature of this sensor is its ability to scan in either the “up” or “down” direction (hence, the term “bi-directional”). The scan direction is user-selectable. In either direction, the output is delivered from a single set of output pins.

In addition, the user has the ability to reduce the number of TDI stages used during image acquisition in order to optimize the output signal level with the expected input illumination level. Instead of utilizing the full 64 rows of TDI, the user can elect to use only 32, 16 or 2 rows of TDI.

The sensor will be housed in a 340-pin, “side-brazed”, custom-designed header made of aluminum nitride (AlN). Its window will be attached to an AlN bezel that is attached to the top of the header.

Architecture

Because a single die that is 210 mm long is not feasible on 6-inch wafer technology, the BAE Systems CCD21122 will be comprised of two identical CCDs (BAE Systems CCD11062) arranged in an “offset-butted’ configuration. Ideally, both dies would be aligned together “end-to-end” to produce the required image width. However, this would create a large dead zone between the active regions and the resulting image would have a large blind region right in the center of the final image. Instead of placing the die end-to-end, the offset-butted configuration places one die slightly lower than the other die and then shifts the die laterally in such a way that the imaging regions of the two dies overlap one another. The overlapped pixels are used for calibration

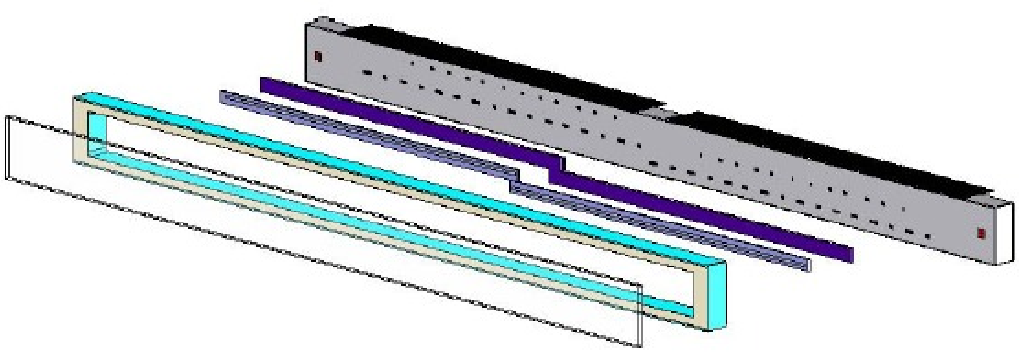

Fig. 1. BTDI Detector BAE Systems CCD21122 Assembly

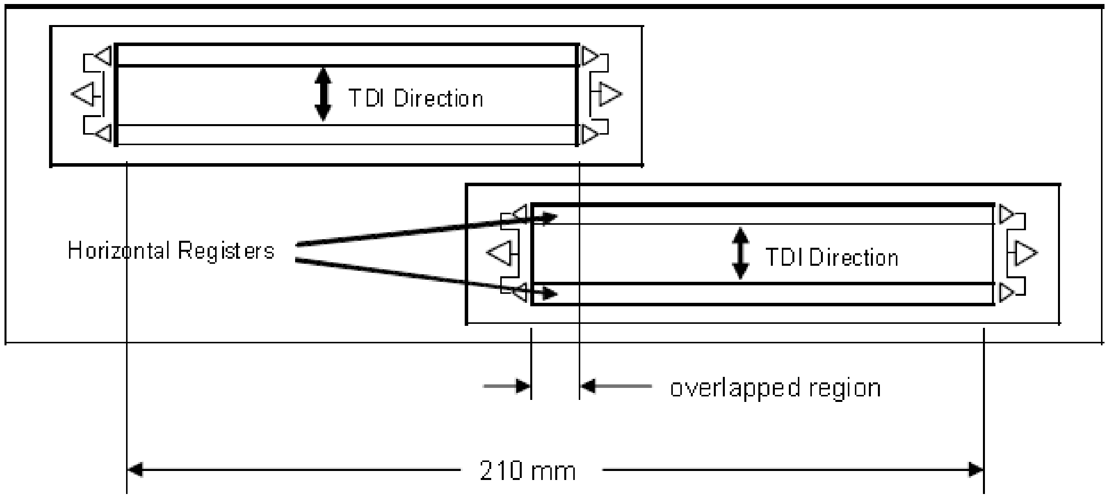

Fig. 2. BTDI Block diagram

purposes. Each die has two horizontal readout registers, one above and one below the imaging region. The charge can be transferred either up or down towards one of the readout registers. The readout registers themselves are divided into two halves, allowing the charge to be read out towards the left or right outputs. One of the unique aspects of this design is the multiplexed output amplifier structure. The desired readout register (top or bottom) is externally selectable by the user enabling a single analog signal chain to be used for the left and right output pins.

INVESTIGATION RESULTS

Test Equipment

In spring 2014 one BTDI BAE Systems CCD21122 prototype was verified at DLR OS with especially developed test developed and heritage from Kompsat-3/3A missions. First step was the test of sensor application and technology approach. For this purpose and to minimize risk and development effort only one of both (electrical independent) dies BAE Systems CCD11062 was applied and measured.

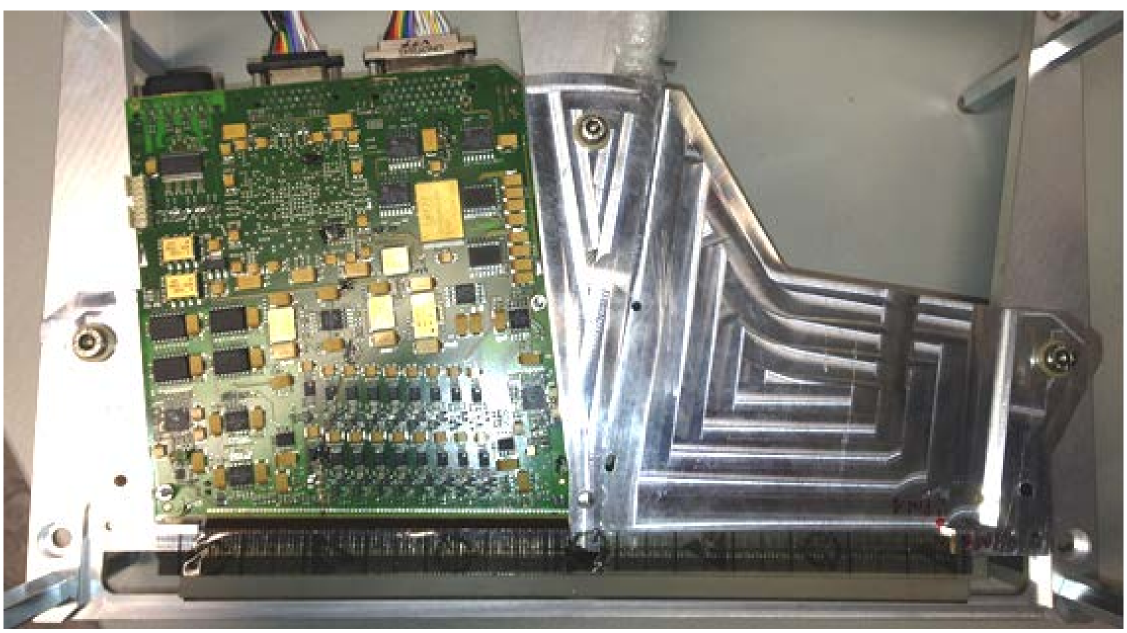

Fig. 3. Top view of BTDI Test Frame and the CCD Controller PCB for one die

Fig. 4. Front view of BAE Systems CCD21122 mounted on Test Frame

All given parameters from BAE Systems CCD21122 Data Sheet and ATP report were verified [2]. After basic investigations of detector functionality (clocking diagram, biasing etc.) the radiometric performance was tested: Dark Signal Noise, Linearity and Photo Transfer Curve.

All tests were performed in combination with an integration sphere and under ambient environment. The measurements were performed in all TDI modes @ 12.5 MHz pixel frequency, i.e. line rate 3.5 kHz) and for both TDI scan directions.

Results

The dark signal noise for the forward direction is shown in Fig. 5. The maximum value of 184e- is higher than the CCD specification of 100e- because it contains also the influence by the FPA electronics.

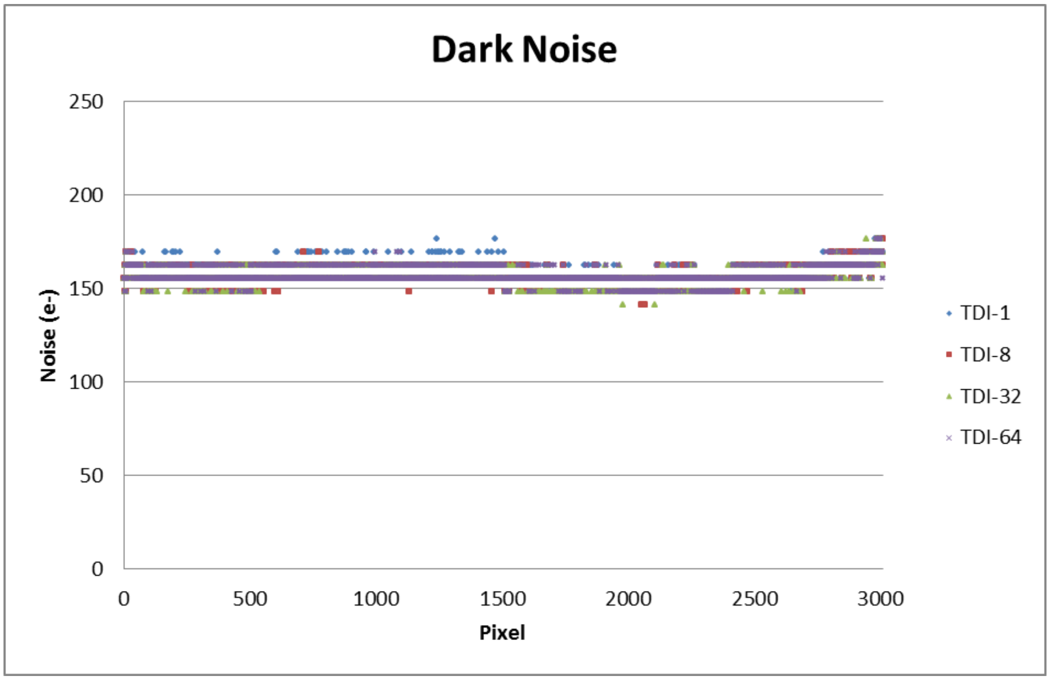

Fig. 5. Test result Dark Signal Noise, forward direction

The linearity of the detector was measured by changing the integration time. Based on the definition of the relative linearity error:

$$E_i = abs\left(\frac{p_i - a \cdot i - b}{a \cdot i + b}\right) \tag{2}$$

With E_i the relative linearity error, p_i the measurement value, a und b the linear regression parameter of all pixel values. As shown in Fig. 6 for pixel 400, but measured for all pixels in both directions and all TDI stages, the non-linearity is smaller than 1 %.

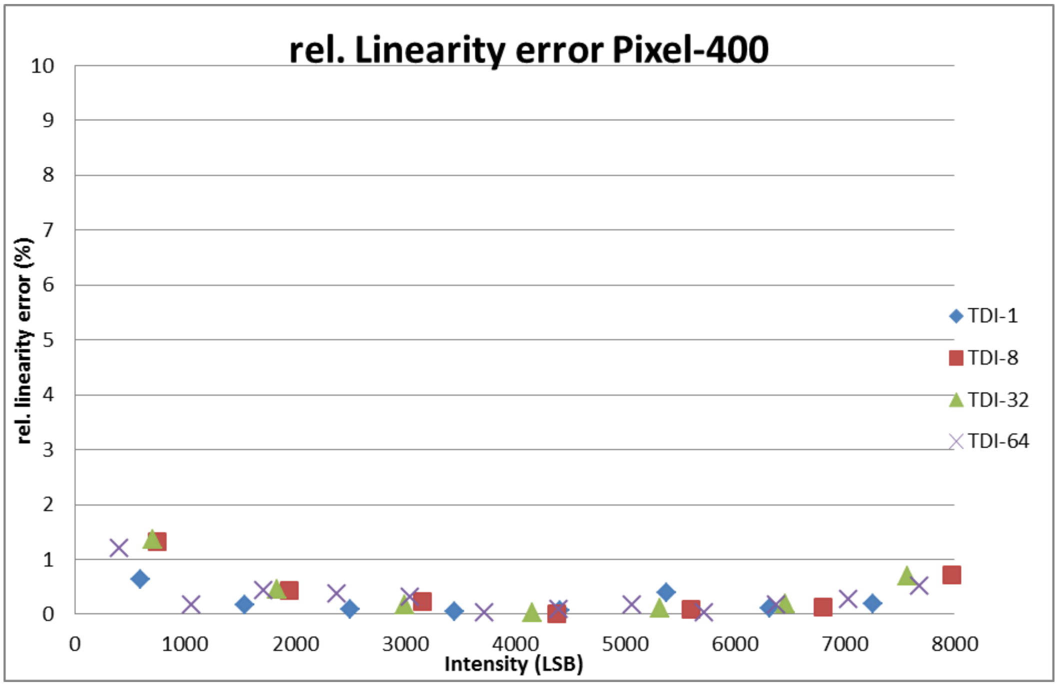

Fig. 6. Test result Linearity Error, Pixel 400, backward direction

The Photo Transfer Curve was measured by variation of the illumination condition, under the same integration time. An analysis of the data of all pixels, under all TDI stages and in both directions proves:

Conversion gain	≈ 2.86 µV/e-
CCD full well	> 830 ke-
Dynamic range	> 4500:1

CONCLUSION

These test results fulfil or even are better than the specified values from DLR and are comparable with the detector performance of Kompsat-3 sensors which have already shown very good image results over the last two and a half years in orbit.

Next investigations will be performed to get the important sensor parameters Quantum Efficiency, Dark Signal Non-Uniformity, Pixel Response Non-Uniformity and the Modular Transfer Function in along-track and across-track direction.

All results are showing the perfect control of imaging sensor technologies by BAE Systems and confirm that the current laboratory model is able to be a candidate for space applications in order to keep the image quality high.

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