ROCKET-SPACE DEVICE ENGINEERING AND INFORMATION SYSTEMS
Vol. 3, Iss. 1, 2016, pp. 31–35

Analysis of Matrix Photodetectors Application for Scanning Systems

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Abstract. The paper deals with the design concept of the equipment and its functioning used for remote sensing of water areas. Various constructions of the device have been analyzed according to modern requirements for this class of equipment. The article shows that the usage of matrix photodetectors allows the required signal-to-noise ratio to be obtained. A scheme of the apparatus involving optical-mechanical scanning combined with the matrix photodetector is offered. It is demonstrated that the application of matrix photodetectors with relevant characteristics for a scanning system enables the required signal-to-noise ratio to be achieved for the model of radiation from water surface in defined spectral bands by means of redundant quantity of light-sensitive elements. The interpolation algorithm of signal processing from the photodetector, which permits one to reduce data flow with minimized geometrical distortion, is described. The results of modeling showed that the offered conception of the apparatus would be effective for remote sensing of the World Ocean. A device involving the offered scheme will be sufficient for modern metrological requirements.

Keywords: Earth remote sensing, ocean color, scanning system, matrix photodetector, interpolation algorithm

Joint Stock Company "Russian Space Systems" is faced by a task to create a target equipment – the scanner of color of an open sea surface, which has to be a part of the space complex intended for the solution of problems of hydrometeorological and oceanographic support [1, 2]. To fulfill such tasks including monitoring of the ocean, the scanners, such as SeaWiFS, MODIS, and VIIRS [3] have been already brought to life and checked. The spectral range of the equipment operation of the Earth remote sensing (ERS), which is responsible for the ocean chromaticity, is from 0.4 to 0.9 μm (see Table 1). The orbit parameters (sun-synchronous, altitude of 700-850 km) and geometrical parameters of the equipment (viewing angle is > 100°, resolution at nadir is ~ 1 km) are similar.

Table 1. Comparative characteristics of color scanners in the range of 0.4-0.9 μm.

SeaWiFS		MODIS		VIIRS	
Spectral band, nm	Bandwidth, nm	Spectral band, nm	Bandwidth, nm	Spectral band, nm	Bandwidth, nm
402-422	20	405 - 420	15	402-422	20
433-453	20	438 - 448	10	436-454	18
480-500	20	483 - 493	10	478-498	20
500-520	20	526 - 536	10	-	-
545-565	20	546 - 556	10	545-565	20
-	-	662 - 672	10	-	-
660-680	20	673 - 683	10	662-682	20
745-785	40	743 - 753	10	744-759	15
845-885	40	862 - 877	10	845-884	39

Since the device under development has to solve problems of monitoring of water areas of the World Ocean, it is necessary to consider a so-called "water" radiation model. The equipment under development has to provide the signal-to-noise ratio of > 500 when surveying water areas. The maximum spectral radiance ascending from a water surface is located on the wavelength of 410 nm; the spectral density of radiance on this wavelength is 95 W/m^2×sr×μm (according to the model used during creation of the specialized scanner for research of the World Ocean SeaWiFS [4]). The minimum brightness of the radiation ascending from the water surface is equal to ~7 W/m^2×sr×μm (spectral range with the central wavelength of 860 nm). The calculations executed have shown that none of the known traditional approaches for creating the ERS equipment (namely: using one- and multielement detector in combination with optical-mechanical scanning, multielement (linear) receivers including in the TDI mode, and also the matrix receivers, which are carrying out frame survey of the underlying surface) allows one to meet the specified requirement at the acceptable weight dimension characteristics. The parameters of a "water" model specified above define a task as surveying the objects of small brightness. At the same time, the spectral density of radiance from the top layers of a cloudy surface on the border of the dense atmosphere can reach value of 660 W/m^2×sr×μm (see Fig. 2). Therefore, the problem of creating a scanner operating in all dynamic range of the brightness scenes and providing necessary viewing angle and resolution, and also meeting the imposed metrological requirements regarding the signal-to-noise ratio (> 500 when surveying water areas), is very difficult.

The approach to the solution of the set task is in use of a high-speed low-format matrix CMOS-photodetector in combination with optical-mechanical scanning and accumulation of a digital signal. Use of a matrix photodetector of a bigger dimension is inexpedient for two reasons: first, in the chosen scanning scheme it is necessary to use the photodetector with a high frame rate (time for reading the whole matrix is ~ 1.92 ms), secondly, with increase in dimension of a photodetector geometrical distortions significantly grow when projecting the matrix on the Earth's surface.

The schematic diagram of the multichannel device based on the principle of the optical-mechanical scanning using the matrix detector operating in the mode of a digital TDA (the time delay and integration mode of a signal), and scanning geometry are given in Fig. 1. The device has to make survey of a water surface with the resolution of 500 m at nadir at an altitude of 820 km in a swath 2800 km (a viewing angle is 110°).

As it is shown in the Figure above, the schematic diagram of the device under development includes a flat scanning mirror, lens, and matrix photodetector. The scanning mirror is one-sided and makes rotation in one direction during scanning with the subsequent reverse.

In the focal plane of the objective there is the matrix photodetector with dimensions 128×128, working at frequency of 520 frames/sec.

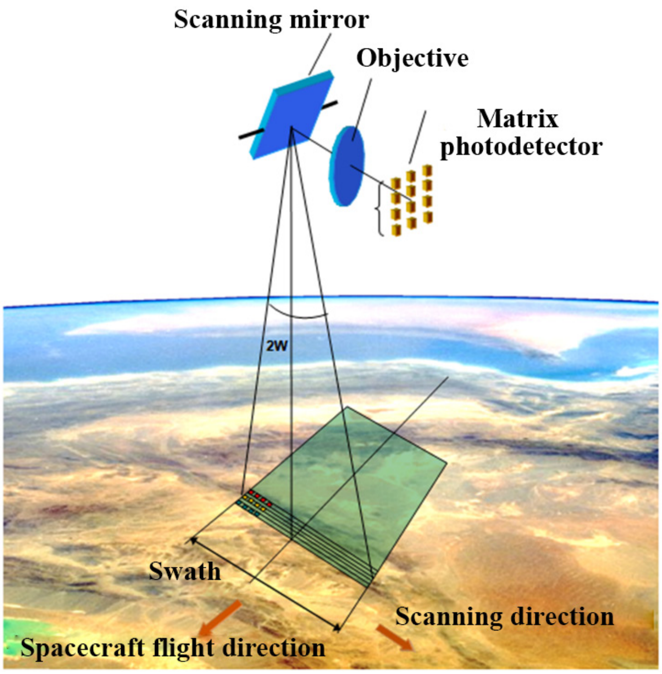

Fig. 1. The schematic diagram of scanning of the underlying surface

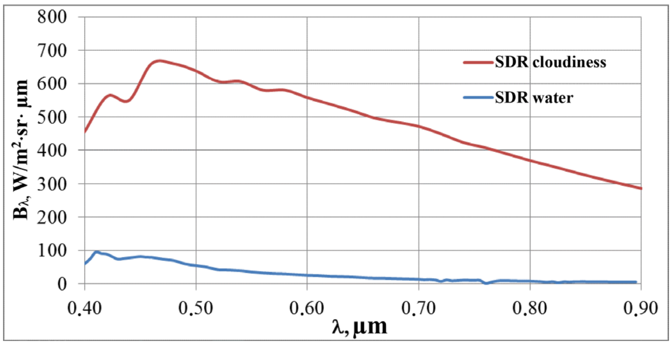

Fig. 2. The absolute spectral density of radiance of the water surface and overcast used by the SeaWiFS developers

The calculation results of the signal-to-noise ratio for the water surface are given in Table 2. It is clear that the matrix of photocells with dimensions 128×128 is capable to provide the necessary signal-to-noise ratio in the set spectral channels on condition of digital joining of readout. If this operation is carried out at ground processing, then information stream from a board is about 820 Mbps. Therefore, there is need to reduce the information stream. To do this it is offered to put the signals received by various matrix photocells, an interpolation method in the signal processing unit (SPU), which is a part of the equipment [5].

The idea of signals integration is in dynamic display of the geometrical ratios taking place when scanning objects in a space of under surveying to the space of random access memory of the onboard signal processing device. Readout at the output of the joining algorithm is equivalent to the readout from a virtual line, geometrically corresponding to the first line of a matrix. Each set of readout from a virtual line is a superposition of the readout received in different time points from all lines of a matrix.

The problem of readout integration is that due to orbital movement of a spacecraft in the focal plane of the scanner objective the movement of the Earth's surface image both in the direction of scanning and perpendicular to it is also taking place. The first, in principle, owning to a right choice of angular speed of optical-mechanical development can be coordinated with the frequency of matrix polling in such a way that during the matrix polling the image of the allocated object moves exactly to one pixel. As for the second, the image shift monotonously increases from the first matrix up to the last, at the same time movement speed depends on the angle of view in a difficult manner [6].

The principle of readout integration is that readout of the 1st, 2nd, …, and 128th lines of a photodetectors matrix are recorded in each column of a memory matrix the dimension 128×128 of the cells at the rate of frames frequency. Thus, in some timepoint the 1st line is recorded in the 1st column, 2nd is recorded in 128th, 3d is recorded in 127th, …, and 128th in 2nd. In the following interrogation cycle 1st is recorded in 2nd, 2nd is recorded in 1st, 3d is recorded in 128th, …, and 128th is recorded in 3d; and etc. At the same time readout from all lines except the 1st are multiplied by 2 weight coefficients (interpolation coefficient) and recorded in consecutive cells of the corresponding column of a matrix of memory (are summarized with contents of these cells). A "ready" counting is consistently read out from each column of a matrix of memory after being recorded with the counting from the last, 128th line of a matrix of photodetectors. Thus, the resultant counting represents the sum with scales 255 realization of single accumulation of an analog signal. In the course of the described algorithm (in real time) the following have to be calculated: a current shift as a function of a line number and the current angular position of an axis of sight, increment of a cell address as a whole part of shift and weight coefficients equal to $(1-d)$ and d, where d is a fractional part of shift.

Table 2. The absolute spectral density of radiance B_l and the signal-to-noise ratio of a water surface model in the range of 0.4–0.9 µm

l, µm	$B_{l,}$ W/m^2×sr× µm	Signal-to-noise ratio at single readout	Signal-to-noise ratio at integration of signals received for 128 readout cycles
0.410	95	86	945
0.440	78	81	887
0.490	60	75	821
0.550	36	61	673
0.640	21	50	554
0.670	17	46	510
0.745	11	56	618
0.860	7	51	561

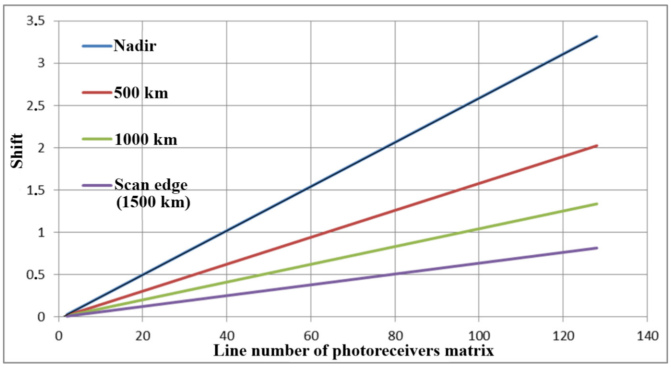

Fig. 3. Sizes of shifts for 4 provisions of an axis of sight regarding a nadir

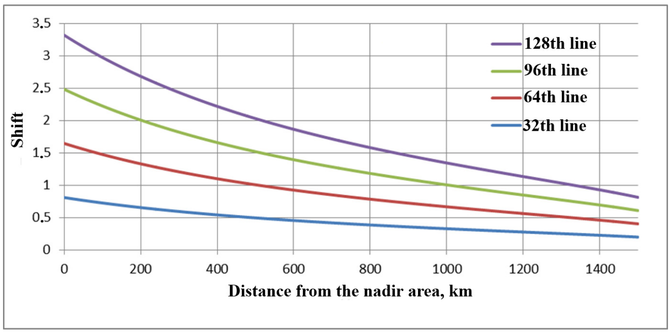

Fig. 4. Dependence of shift on distance relative to a nadir for lines with numbers 32, 64, 96 and 128

The calculation results of shifts of elements coordinates for several positions of an axis of sight concerning a nadir are in the following Figure (Fig. 3): .

The dependence shown in Fig. 4. with a good accuracy (an error no more than 0.6%) is approximated by a two-dimensional function – a linear one depending on a line number of a matrix photodetector (see Fig. 3) and a cubic one depending on the current position of the axis of sight (see Fig. 4). According to this function, in SPU there should be calculated the address shifts and interpolation coefficients. In Fig. 5 superposition of the 1st and 24th lines of a matrix photodetector is shown.

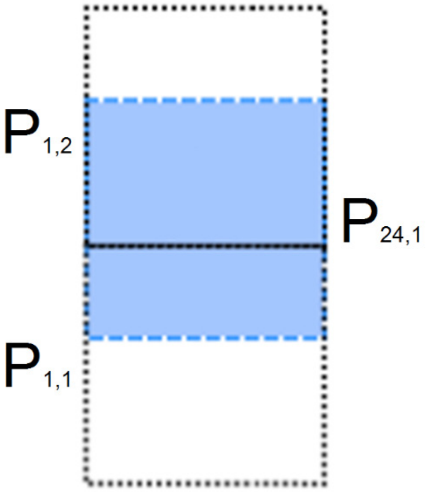

Fig. 5. Elementary counting from the 1st pixel of the 24th line is joined with counting from the 1st and 2nd pixels of the 1st line with the corresponding weight coefficients

The reduction of the information stream by 128 times is result of work of the algorithm, as the signal at the SPU output is a convolution on 128 interpolated lines of a matrix. As a result of interpolation, the full optical transfer function (OTF) of the system worsens a little, since OTF of the virtual line received as a result of convolution operation coincides with OTF of a matrix line of photodetectors only at special speed ratios and the direction of the image movement in the focal plane and values of frame frequency of interrogation of a matrix.

In addition, using the linear approach in interpolation algorithm also brings some distortions. However, as the OPF parameters of a "lens – matrix photocell" system are not too high, the marked distortions are admissible.

The described building scheme of the scanning equipment permits one to meet the modern metrological requirements imposed to the ERS equipment intended for determination of water areas chromaticity of the World Ocean. The developed interpolation algorithm makes it possible to reduce considerably the information stream from a spacecraft board without loss of radiometric resolution and with the minimum geometrical distortions.

References

1. Akimov N.P., Zaytsev A.A., Solov'ev A.M. Prakticheskaya realizatsiya sovremennykh metrologicheskikh trebovaniy, pred»yavlyaemykh k perspektivnomu skaneru tsvetnosti KA "Meteor-M" No. 3 dlya issledovaniya akvatoriy [The implementation of modern metrological requirements for the perspective colour scanner of "Meteor-M" No. 3 spacecraft for water areas study]. *Sbornik trudov VI Vserossiyskoy nauchno-tekhnicheskoy konferentsii "Aktual'nye problemy raketno-kosmicheskogo priborostroeniya i informatsionnykh tekhnologiy"* [The proceedings of the VI Russian scientific and technical conference "Current problems of rocket and space device engineering and information technology"], 2013. (in Russian)

2. Romanov A.A. *Osnovy obrabotki i analiza dannykh kosmicheskogo distantsionnogo zondirovaniya okeana* [Data processing and analysis fundamentals of space ocean remote sensing]. Manual. Moscow, MFTI, 2003, 272 p. (in Russian)

3. Remote Sensing of ocean colour in coastal, and other optically-complex, waters. *Reports of the international ocean-colour coordinating group*. IOCCG, Dartmouth, Canada, 2000, No. 3, 140 p. Available at: http://www.ioccg.org/reports/report3.pdf.

4. *NASA. Official site of the Sea-viewing Wide Field-of-view Sensor project*. Available at: http://oceancolor.gsfc.nasa.gov/SeaWiFS/.

5. Zaytsev A.A. Optimizatsiya kharakteristik fotopriemnoy optiko-elektronnoy sistemy sputnikovoy apparatury, prednaznachennoy dlya resheniya zadach opredeleniya tsvetnosti akvatoriy [Characteristics optimization of the photodetective optoelectronic system of the space equipment dedicated to determination of the water area color]. *Vypusknaya kvalifikatsionnaya rabota bakalavra prikladnykh matematiki i fiziki* [A graduation thesis of the bachelor of applied mathematics and physics]. Moscow, 2012, 45 p. (in Russian)

6. Shovengert R.A. *Distantsionnoe zondirovanie. Modeli i metody obrabotki izobrazheniy* [Remote sensing. Models and methods of image processing]. Moscow, Tekhnosfera, 2010, 560 p. (in Russian)