DEVELOPMENT OF IMAGING SPECTROMETER USING BACK ILLUMINATED CCD

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Designing of a small-size portable imaging spectrometer (IS) is discussed for remote sensing of the Earth. The IS is intended for observation from the airborne or from satellite. The IS makes possible to register spectra in the 400-900 nm wavelength region with exposition of 100-500 ms, output rate 1-5 MHz, exposition of 100-500 ms, resolution 2-3 nm and 250 spectral channels. In these applications the most appropriate CCD detection system are investigated. For the concrete purpose a scientific CCD back illuminated full frame array is choosen with 27• m square pixel. Performed controller with blackfin DSP BF533 with internal CCD interface and possibility of SDRAM control is described.Usin a LAN adapter allows connection with LAPTOP to transfer colected data.

Keywords: DSP, spectrometer, back illuminated CCD keywords

1. INTRODUCTION

The existing remote sensing satellites perform Earth observation from 3 to 7 spectral channels only. For better precision and accuracy of the studies some increase in the number of spectral channels are required [1]. The main problems in development of small-size portable imaging spectrometers for remote sensing result according to next circumstances: the development of this kind of equipment is quite unique for particular application; the expensive market available similar equipment is able to partially satisfy the specific application requirements [2].

Our project involves development an imaging CCD spectrometer for: remote sensing of the Earth for observation from the airborne or from satellite; uniform spectral characteristic in the 400-900 *nm* range; maintenance of high sensitivity and low noise; facile link interface to archiving systems. There are kinds of spectrometers on the market with the number of spectral channels from 16 to 32 but they do not meet our requirements completely [3].

The progress in the electronic circuitry and new realization of CCD arrays with bettered characteristics stimulates development of portable small-size image spectrometric systems possessing high resolution, number of spectral channels, and low price. In the paper are analyzed also features of choice the type of the CCD arrays according to the concert application.

2. CRITERIA FOR SELECTION OF CCD ARRAY

The final set of improvements in CCDs is directly related to significant gains, which have been made in the silicon processing industry. The end result is today's back illuminated (see Fig.1) and also inverted phase CCD which has very low dark current even though it operates at temperatures substantially above the 77K temperature of liquid nitrogen. MPP devices can operate at room temperature now for 8 minutes before the dark current fills the well.

Choosing the correct CCD for an application requires knowledge of the wavelength of the incident photons, the spatial resolution required, the dynamic range of the scene. Scientific CCDs are nearly ideal detectors because of the following properties: high quantum efficiency (QE), large dynamic range, uniform response, and low noise.

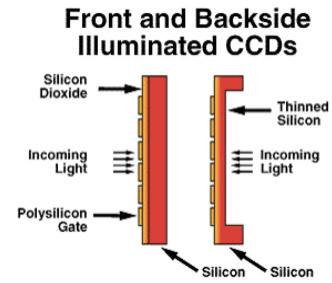

Fig.1 General appearance of front and back illuminated CCD

The quality of a CCD is generally specified by its quantum efficiency (as a function of wavelength), its readout noise, and charge transfer efficiency.

The quantum efficiency is never totally uniform over the entire chip. Pixel-to-pixel variations in QE are typically a few percent. Little is known about the possibility of such variations in different devices, but it is likely that they exist at some level. QE may also be enhanced by the addition of an anti-reflective coating. Quantum efficiency hysteresis is an important parameter that measures the QE instability as a function of time, operating characteristics, and incident light. There are many physical factors that can contribute to this problem.

If we select the larger area of a CCD (the more pixels it contains), and the higher CCD grade it will increase the price of the CCD. On the other hand the smaller CCDs are faster to read out, and subsequent image display, processing and archiving are all proportionally faster. It is usually possible to upgrade a system CCD at a later date should you need more resolution or sensitivity.

There is also an important CCD technology called multi-phase pinned (MPP) that reduces the dark current further. Most CCDs are now available in MPP versions [4], although such devices tend to have lower peak signal capacity (with the standard high full-well capacity but with 100 to 1000 times lower dark current).

Dark current is a source of signal inside the silicon of the CCD that is time- and temperature-dependent. Two factors should be considered. One of them is the dark current rate and the other is the shot noise inside the dark current signal (see Fig. 2).

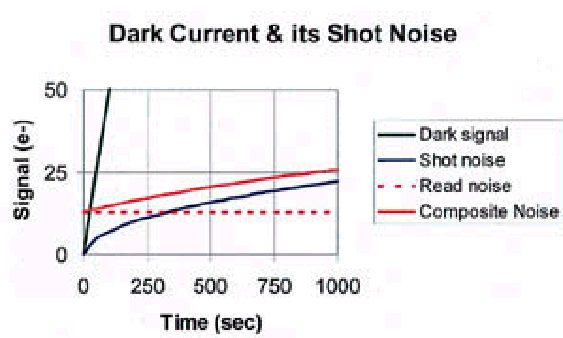

Fig.2 Characteristic of dark current

For nearly all applications thermo-electric (Peltier) coolers are the best choice for convenience and give a satisfactory level of dark current. Air-cooled heat exchangers are operationally most convenient and provide cooling to about 65^{o}C below ambient temperature. Liquid cooling can reduce the temperature by a further $10^{o}C$ giving dark currents, which are a factor of 3 lower than with air-cooling. For the longest integration times without loss of full well capacity, liquid nitrogen cooled vacuum dewars are available.

In array detectors, readout noise is often important. Readout noise can actually come in two different forms: fixed pattern and random noise. The latter is what people usually refer to as readout noise. Fixed pattern noise is noise which is introduced in the readout process but which has the same spatial pattern over the detector from exposure to exposure. Readout speed: typically 25 microsec/pixel for array detectors. However, the chips can in many cases be read at a variety of speeds.

Another consideration is full-well capacity. While the value for full well is highly dependent on a number of factors. Applications requiring wide dynamic range or the best signal-to-noise ratio possible in high-illumination settings would tend to need CCDs with the highest possible full-well capacity.

A detector system can be characterized by its dynamic range. At the bright end, the system is limited by either the full well of the detector (or the number of electrons at which the detector goes significantly non-linear), or alternatively by the limitation of the A/D converter (e.g., if an A/D converter has 16 bits, you can never see counts higher than 10^{16}.

Charge Coupled Device (CCD) detectors come in three major readout architectures, Full Frame (FF), Frame Transfer (FT) and Interline (IL). Each of these formats has certain advantages as well as limitations that will be considered.

Manufacturers of CCD sensors grade devices according to the number and type of defective pixels. Unfortunately, each CCD manufacturer uses a different scheme to grade devices.

The basic processing steps applicable to all array detectors, i.e. regardless of whether instrument is imaging or spectroscopy include [5]: A/D correction; bias level subtraction; bias structure subtraction (super bias); linearity correction; dark current subtraction (super dark); preflash subtraction, or deferred charge correction; shutter shading correction; flat field correction; additional complicated things (scattered light, amplifier hysteresis correction, similarly, CTE correction, hot pixel fix up, residual image subtraction, pixel area correction, fringing sky subtraction).

3. Description of CCD Spectrometer Implementation and Experiment

The developed imaging spectrometer consists of (as shown in Fig.3) three main parts. The first one is the optical part, which is built, in classical scheme with primary objective, entrance slit, concave diffraction grating and camera objective. For the second part was chosen a back illuminated CCD array (TK 512M) installed in focal plane of the spectrometer optical block. The third part is a control block build from CCD array controller, DSP, image memory, LAN adapter and a power supply.

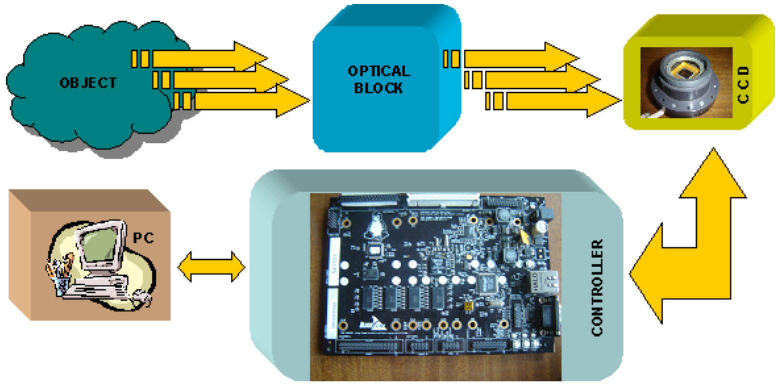

Fig.3 Block diagram of the imaging spectrometer

Parameters of the spectrometers are: resolution 2-3 *nm*; 250 spectral channels; registered spectra in the 400-900 *nm* wavelength range with exposition of 100-500 *ms*; output rate of 1-5 *MHz.*

TK 512M CCD image sensors are 100% fill-factor devices intended for use in moderate-resolution scientific applications where high dynamic range, broad spectral sensitivity, high quantum efficiency (Fig.4), and low noise are required. There are 16 extended pixels in the serial register between the first pixel in the array and the output amplifier. These extra pixels can be used to determine the system offset. The summing well is used to noiselessly sum charge packets on-chip prior to being read out. Multi-pinned phase (MPP) operating mode significantly reduces background dark current for longer integration time and/or higher operating temperatures. The CCD is thinned to approximately 13 µm and illuminated from the back surface. Its back illuminated design offers increased quantum efficiency and sensitivity. The main characteristics of the CCD array sensor are resumed in Table 1.

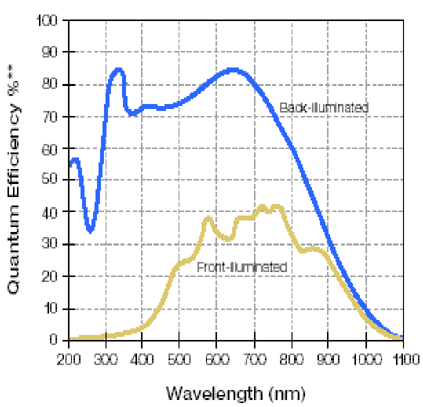

Fig.4 Quantum efficiency dependence on wavelength

Tab.1 Typical characteristics of CCD image sensor TK 512

CHARACTERISTICS	TYPICAL
Format	512x512
Flatness, *µm*	±10
CTE	0,99999
Noise rms e^- at 50k *pixels/second data read*	5
Dark current (MPP), *pA/cm*^{2}	10
Well capacity, *e*$^-$	350 000
Sensitivity, *µV/e*$^-$	2.8
Pixel size, *µm* Image area, *mm*	24x24 12.3x12.3

The video signal from the CCD receiver is amplified and transferred to the AFE – AD video processor AD9826 of "Analog Device" that work in CDS mode. The offset is controlled from 9-bit PG. On this way dynamic range of ADC is optimised. At the out of AFE a 16 bit video signal is got. The CCD control is performed by CPLD. The drive pulse buffer used for generating the pulse timing sequence and the operating mode of the CCD. To reduce the development time stamp board on the base of microprocessor BF 533 is used. It contain 128 MB SDRAM and LAN controller. The used processor has embedded PPI for video signal. The output of AFE is connected to this interface The received data are saved in SDRAM. According to duration of the experiment the buffer can be filled and after that the data are transferred to the PC by the LAN or a cyclic buffer is organised which save and read tha data simultaneously (see Fig.5).

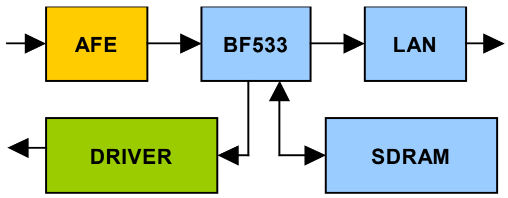

Fig.5 Block diagram of the control block

Additional possibilities of the designed image spectrometer are:

- Connection with LAPTOP to transfer collected data;
- Application for investigation of ecological pollution, vegetation index and reconnaissance;
- Small size and weight – to assemble on unmanned aircraft – to reduce the price of collected scenes.

Some of results of investigations with the spectrometer are shown on Fig.6-9 respectively.

4. Conclusions

A small-size portable spectrometer is designed for remote sensing of the Earth. The spectrometer is intended for observation from the airborne or from satellite. In these applications the most appropriate CCD detection system are investigated.

For the concrete purpose of the project a scientific CCD back illuminated array is chosen according to premeditated defined criteria. A controller with black fin DSP BF5333 LAN adapter utilized for connection with LAPTOP to transfer collected data.

Developed spectrometer can be used for invesigeted of ecological pollutions, reconnaissance or vegetation index of agricultural cultivation. The small size and weight of the spectrometer also permit it to be assembled on unmanned aircraft and this is a precondition for decrease cost price of collected scenes.

5. References

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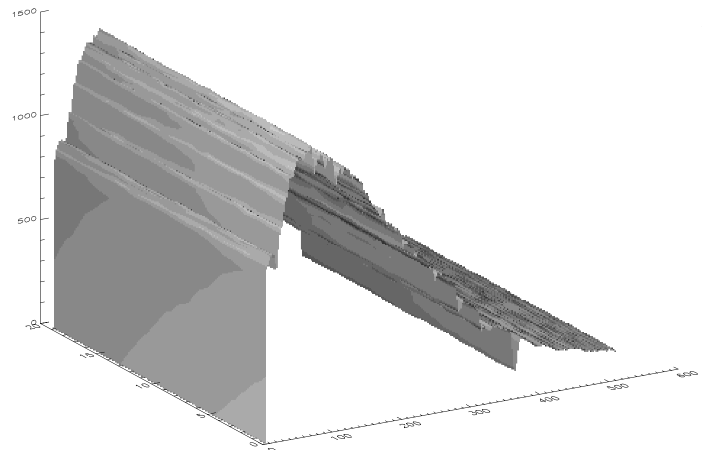

Fig.6 Spectrum of the sky

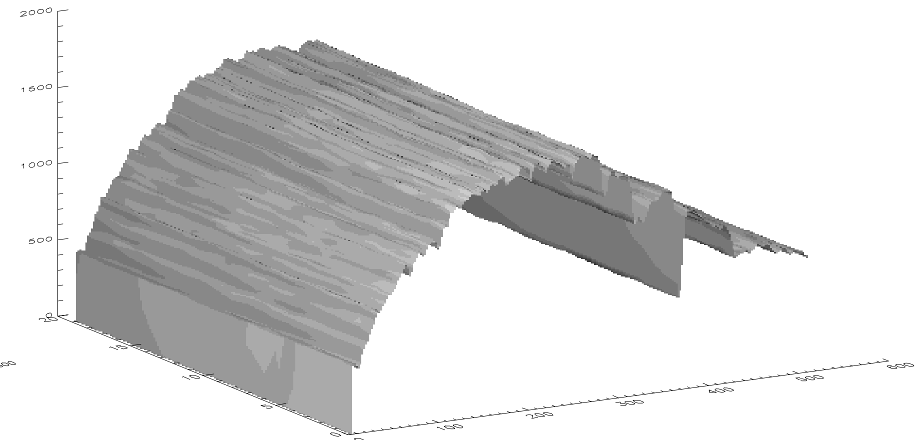

Fig.7 Spectrum of the sun during a clear sunny day while a reflection of the barium sulfate screen is measured

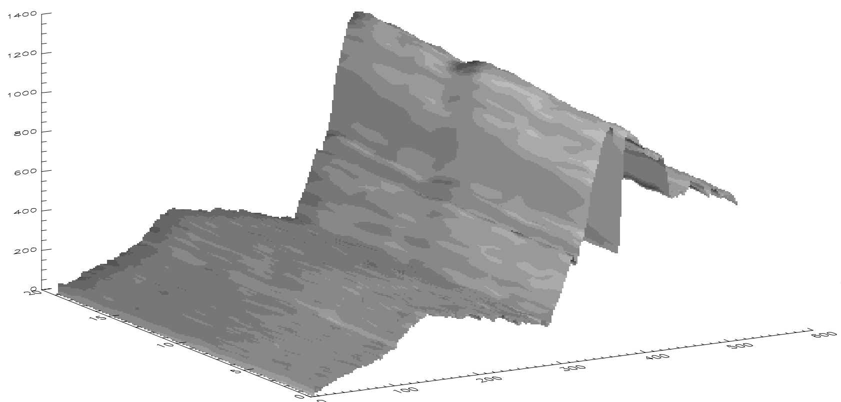

Fig.8 Vegetation spectrum. The data can be used for estimation of vegetation index

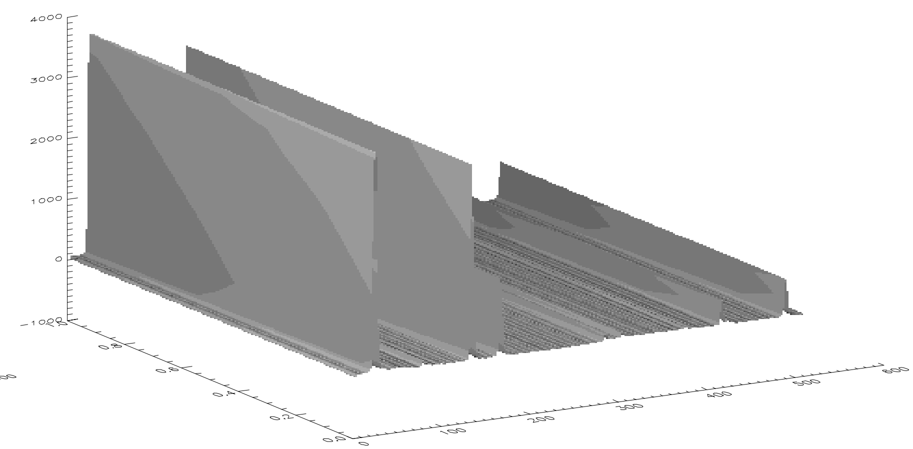

Fig.9 Spectral range calibration with mercury lamp. The spectrum line can be seen which are used for calibration as well as for resolution assessment