CCD camera system design for the beam diagnostic by using OTR*

YU Ying(于莹)[1,2] YANG Ke-Hu(杨克虎)[2] DAI Jian-Ping(戴建枰)[2;1)]

1 (Graduate University of Chinese Academy of Sciences, Beijing 100049, China)
2 (Institute of High Energy Physics, CAS, Beijing 100049, China)

Abstract In this paper, a new CCD camera system used in the OTR beam measurement is presented, the basic principle of OTR beam measurement and the application of CCD chips—ICX208CL and AD9929 in camera system design are introduced in detail.

Key words OTR, CCD camera system, CCD chips

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1 Introduction

As a moving charge approaches and crosses the boundary between two different media, the fields must somehow reorganize themselves. It is in this process of reorganization that some of the fields are "shaken off" as transition radiation. When the transition radiation has the obvious character of angular distribution, this phenomena will be called "OTR" (Optical Transition Radiation) . The existence of transition radiation was theoretically predicted by Frank and Ginzburg in 1946[1], and was paid more attention by using it on the beam measurement from 1975. This radiation is emitted over the visible spectrum; therefore, optical imaging techniques can be used to acquire the OTR signal and then reconstruct beam size and position at the dielectric surface. It is widely used in the accelerator area in and out abroad[2].

As the distribution of the OTR has the relationship with the angular distribution of the electron beam, the higher of the energy of the electron beam, the smaller of the angular distribution and the more obvious of the contrast of the apex in the OTR pattern. Meanwhile, since the light of OTR is comparatively feeble, some capability of the system (such as noises, sensitivity) may have some effects on the OTR image signals, may do harm to the results. Traditional cameras cannot satisfy the demand. However, the strip cameras are too expensive. Generally we choose CCD cameras to do the experiments, it can reflect the comparative light intensity between the visible band and infrared band.

This paper aims at illuminating the CCD camera system design in detail, analyzing the electron parameters' effect, and emphasizing the choice of the CCD chips according to the demand of OTR.

2 Principle of OTR

Because Optical Transition Radiation has the obvious character of angular distribution, we can use OTR to measure electron beam. When the beam approaches and crosses the boundary between vacuum and metal media, the angular distribution of the radiation can be described by the Ginzburg-Frank formula as:

$$\frac{\mathrm{d}^2U}{\mathrm{d}\omega\mathrm{d}\Omega}=\frac{e^2}{4\pi^3\varepsilon_0 c}\frac{\beta^2\sin^2\theta}{(1-\beta^2\cos^2\theta)^2},$$

where β is electron's velocity; θ is the angle between the radiation and beam directions; ε_0 is the dielectric constant of the metal media in the vacuum.

When the beam penetrates the aluminum foil by the angle of 45°, we can observe the OTR light in the direction of vertical to beam (Fig. 1 is the sketch of one foil OTR angle distribution), and get the correlative image and light intensity distribution through

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1) E-mail: jpdai@ihep.ac.cn

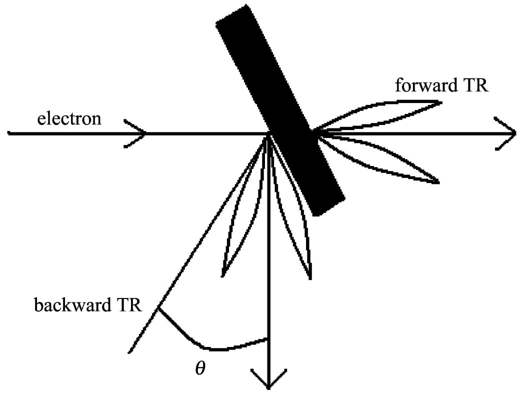

Fig. 1. Sketch of one foil OTR angle distribution.

the camera lens. When the captured camera video signal is processed by Digital Signal Processing (DSP) and computer, the final beam information can be obtained. When the camera is in the image plane, the size and position of beam size can be measured. When the camera is located in the focal plane, the angle distribution of OTR can be measured and the energy can be calculated. When the injection angle is 45°, the OTR radiation angle distribution of different energy electrons is apparently different. The dual peak asymmetry of OTR spectrum reduced with the growth of electron energy. When the Electron energy is 4 MeV , the dual peak differ more than 60%, while is 30 MeV, they differ less than 8%[3]. The distance between dual peak reduces with the growth of the energy, the reduction is approximately in direct proportion to γ^{-1}, so half-height width of the peak reduces with the increase of the energy.

3 CCD camera system design

3.1 Hardware design

CCD camera system mainly consists of the CCD image sensor, high integration CCD analog front ends, power supply and the DSP chips for the digital signal processing (Fig. 2 is the hardware structure chart).

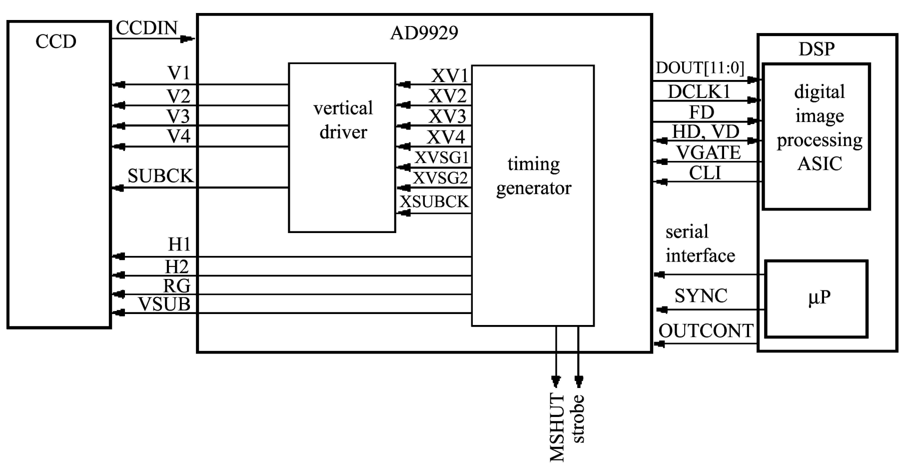

Fig. 2. Structure chart.

3.2 Introduction of the CCD chips[4]

3.2.1 CCD image sensor

We choose Sony ICX208AL—0.25 inch CCD image sensor with the types of black and white, its effective pixels are 768(H)×494(V), and total number of pixels are 811(H)×508(V), Fig. 3 is the pin chart of ICX208AL.

Periphery driver circuits supply the vertical drive timer Vφ 1 ∼ 4, horizontal drive timer Hφ 1 ∼ 2 and ϕSUB, ϕRG. ICX208AL can complete the charges integral and the transition of the pixel charges which are the analog signals that have some relationship with the light intensity, then, the analog signal can be converted to the digital signals by using the AD9929's analog processing.

3.2.2 CCD analog front ends

We choose AD9929 which is produced by ADI as the high integration CCD analog front ends. The single chip circuit integrates the programmable CCD timing generator circuit and magnifies driver circuit. It also integrates a complete analog front end, including 36 MSPS CDS, 6∼40 dB VGA, black level clamping circuit with changeable level and 12bit 36 MSPS A/D converters. Fig. 4 is the pin assignment of the AD9929. Additionally it provides the mechanical shutter, flash control features, and one serial input port communicated with the processor.

AD9929 is an analog front end combined with a full-function programmable timing generator (AFETG). It includes a complete analog front end with A/D conversion and a vertical and horizontal timing generator which is allowed to be directly connected to CCD image sensors and adjusted precisely. The flexibility and characteristic of this chip enable us to achieve the higher performance of the image application.

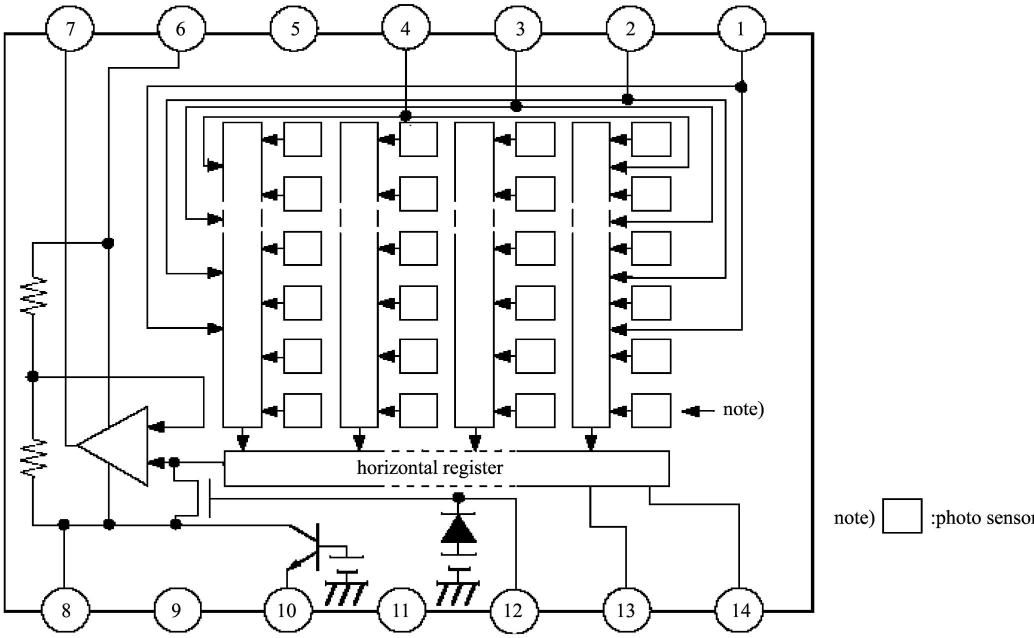

Fig. 3. ICX208AL pin chart.

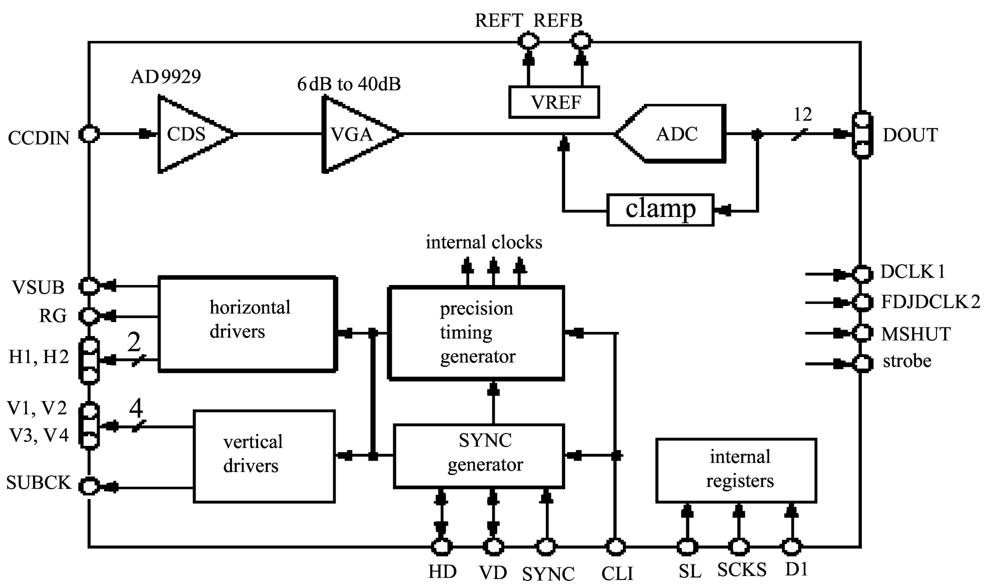

Fig. 4. AD9929 pin assignment.

3.2.3 Power source

The power source adopts MAXIM's single chip MAX1567 which is a complete power-supply solution for digital cameras. It includes six high-efficiency DC-to-DC conversion channels. Step-up converter promotes the voltage of lithium battery to +5 V. The other converters will not start up until this one reaches the stable working station beyond 1024 oscillation cycle. The main converter is configured as voltage dropping output through connecting the SUSD pin to the ground, or is configured as voltage rising output through connecting the high level. The power source of the main converter and voltage dropping converter is provided by the +5 V output of voltage rising converter. Auxiliary converter AUX2 is inverse output, provide −7.5 V voltage input for CCD sensor and AD9929 vertical clock driver. AUX1 provide +15 V output for CCD and AD9929 vertical clock driver.

3.2.4 DSP chip

We adopt ADSP-BF537 Blackfin processor from ADI. The max core clock frequency is 600 MHz. There are plenty of peripherals，including Parallel Peripheral Interface(PPI), SPI, UART, TWI, Ethernet MAC, CAN 2.0B Interface, Full-Duplex Synchronous Serial Ports (Sports) and Timer/Counters with PWM Support which can be further extended to the peripheral connecting capability. The processor has 12 peripheral DMA channels that support automatic data transfers with minimal overhead for the processor core. The DMA supports transfer data between memory spaces or between a memory space and a peripheral. The ADSP-BF537 processor DMA controller supports both 1-dimension (1D) and 2-dimension (2D) DMA transfers, and the 2D DMA transfer is very useful in the image capture system because of the large data amount of the image[5]. In our design, we choose the ADDS-BF537-EZLITE which is an evaluation board of ADSP-BF537 as our main board to control AD9929, to capture image, to execute some digital image process algorithm and to communicate with PC machine.

In this design, DSP receives data from AD9929 through the PPI port (Fig. 5) which is worked to cooperate with the DMA controller to transfer image data to off-chip memory. The PPI is a half-duplex, bidirectional port accommodating up to 16 bits of data[6]. It has a dedicated clock pin and three multiplexed frame sync pins which are used in the image transferring as filed, vertical and horizontal sync signals. It can work in fully ITU-R 656 Modes and General-Purpose PPI Modes. This time we work with the three external syncs to receive General-Purpose mode.

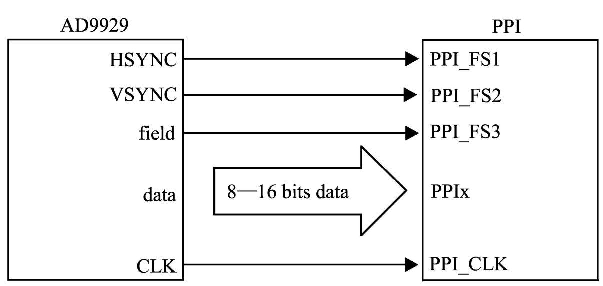

Fig. 5. The configuration of the PPI port and AD9929.

The PPI is linked to the DMA channel 0 default. We configure this channel to 2D mode, and several specific register must be initialized. The X counter specifies the number of transmissions per image line, and the Y count specifies the number of lines to be transmitted per image frame, the initial starting address register points to the address where the first pixel data will save in the memory. After this initial procedure, the PPI starts to detect a frame transfer start and receives data from AD9929. Then the 2D-DMA transfers this data to memory row by row automatically. This procedure doesn't need the processor's intervene, so releases the processor from the large data transfer task.

3.3 Software design

The tasks of the software run in the DSP are:

1) Communicating with AD9929. The software initializes DSP and ensures it to work in the right mode. The complicated driver clock signals for the CCD sensor are generated, whch are critical to achieve the best performance from the CCD.

2) Synchronizing with the OTR light. Due to the weakness of OTR light and shortness of the pulse time, it is very difficult for normal camera to get the high resolution. In OTR measurement it is difficult to synchronize the image with the OTR beam. AD9929 has an external sync pin to synchronize external signal. This indirectly synchronizes the image captured. With the high resolution of the timing generator it can precisely control the electronic shutter to capture some specific OTR light during the exposure time.

3) Initializing the PPI registers and DMA0 registers.

4) Conducting digital image process algorithm to improve image quality and solve the OTR measurement problem. The beam section plane image of beam flux and OTR angular distribution image can be obtained, so the emittance of the beam flux and other important parameters can also be obtained.

5) Adopting the AD9929 to get the sampling data, meanwhile, vertical synchronization, horizontal synchronization and frame synchronization signals are fed into the DSP to process through the PPI parallel port of DSP. Additional external synchronization signal is controlled by the external DSP, once the DSP send the sync signal, the VD and HD will be synchronized, so the time to collect the image is controlled[7].

6) Developing this program by using C language and debugging it in the integrated develop environment Visual DSP++ 4.0. Then the full synchronization function can be realized. It is one of the advantages of Ad9929.

4 Results

We have developed this system, and it can work reliably. Fig. 6 is the beam profile captured by CCD camera, Fig. 7 is the vertical driver clock generated by AD9929, Fig. 8 is the horizontal driver and reset gate clock and the analog signal output of CCD sensor.

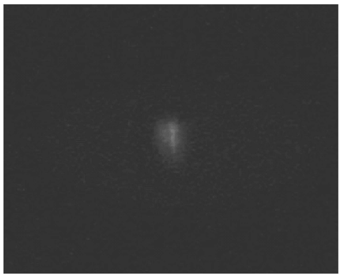

Fig. 6. Beam profile captured by CCD camera.

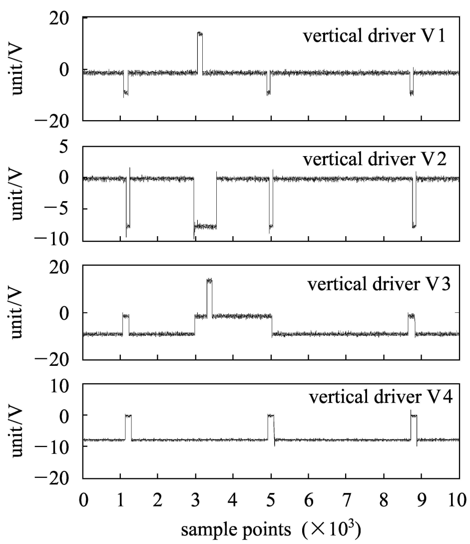

Fig. 7. The vertical driver clock.

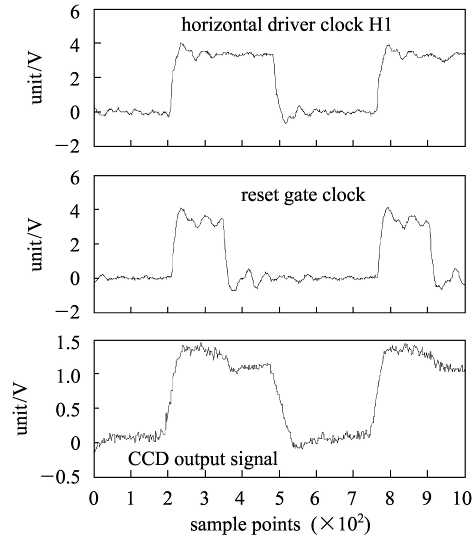

Fig. 8. The horizontal driver and reset gate clock and the analog signal output.

5 Conclusion

As stated above, we adopted the DSP on the basis of traditional CCD camera. Thus it eliminates the signal attenuation of general USB and 1394 interface, moreover it eliminates the bothers of driver design and data acquisition card. Various DSP computing method can satisfy the requirements from many aspects such as measurement of emittance and measurement on optics. It save the cost and has the characters of high performance, low power consumption and friendly to use.

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