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# SHEN-GUANG III Core X-ray Framing Cameras

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**Abstract**: The XFC system was designed to record time-dependent X-ray emission from SGIII targets using an interchangeable family of snouts for measurements such as two-dimensional spatially or one-dimensional spectrally time resolved images of target features. The SGIII core XFC were designed to fit within an aluminum air-box with a large capacity cooling plane and were fitted with an array of environmental-keeping sensors. These designs of the instrument are different from earlier generations of XFC, in part, to an innovative impedance matching scheme, temporal window adjustable of 0.07～1.5 ns, advanced phosphor screens, pulsed phosphor circuits, precision assembly fixture, unique system monitoring, and complete remote computer control. The preliminary applications of advanced phosphor screens and pulsed phosphor circuits was given.

**Key words**: Inertial confined fusion; X-ray framing camera; Diagnostic instrument manipulator

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## 0 Introduction

The SHEN-GUANG III Facility (SGIII) is a glass laser-based facility designed to provide experimental capability for high-energy-density science inertial confined fusion, and basic science experiments. The SGIII will be a 64 beam frequency-tripled ($\lambda = 0.35$ m) Nd: glass laser system. It is designed to deliver an on-target energy of 0.2MJ in a 3 ns～5 ns laser pulse. The framing camera system will record time-dependent X-ray emission[1] from SGIII targets using an interchangeable family of snouts for measurements such as two-dimensional (2D) spatial imaging using an X-ray pinhole imaging snout[2]. The cameras will be constructed according to the SGIII diagnostic standards.

The SGIII will designed, constructed six common diagnostic instrument manipulator (DIM) for the core X-ray framing camera and X-ray streak camera, thus the camera will fit inside DIM. During the start up of SGIII, these cameras will be used to resolve and measure the temporal synchronization of X-ray emission from any individual laser beams focused on a single disk target. These cameras will then be used on a wide range of experiments to record spatially resolved emission from laser targets, hydrodynamic instability growth information, shock-front propagation, and time history for implosion physics[3]. In this article, we present the physics requirements and the derived specifications for the SHEN-GUANG III core X-ray framing camera. We also describe the conceptual layout and control system for the framing camera system.

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## 1 Requirements

Physics requirements for the X-ray framing camera define the type of snouts and the specific performance requirements for the X-ray framing camera[4]. Applications for the framing camera both during SHEN-GUANG III start up and subsequent physics experiments require four types of snouts. The first type is a filtered X-ray pinhole imager that uses an array of pinholes[1]. The second type is a Bragg crystal spectrometer for spectrally resolved measurements. The third type is a Kirkpatrick- Baez microscope to obtain high-resolution 2D imaging. The last type uses an array of pinhole or slit in combination with a transmission grating for spectrally resolved 1D spectrally resolved imaging[5]. The physics requirements derive the specifications for the framing camera, such as X-ray energy-sensitivity range, sweep temporal and spatial resolution, and sweep time windows[6]. The specifications are listed in Table 1.

**Table 1 XFC specifications**

| Item | Specification |
|---|---|
| X-ray energy range | 0.1～10 keV |
| Spatial resolution | 20 lp/mm at CTF of 50% |
| Photocathode active area | $4\times6.6\times36\ mm^2$ |
| Photocathode | Au |
| Temporal window | 0.07～1.5 ns |
| Phosphor screen size | 45 mm fiber-optic interface to 36 mm by 36 mm |
| Readout device | Kodak KAF-16800,4k by 4k CCD |
| Phosphor screen | aluminized P43 baised on ITO |
| Dynamic range | 100∶1 |
| Operate in vacuum | 3×10-5 to 5×10-7Torr |
| Leak rate | 0.01 Torr 1/s |

The X-ray energy range of interest extends from 100 eV to 10 keV. Low-energy sensitivity is required to record low temperature hohlraum drive radiation[7]. High-energy sensitivity is required for face-on radiography through high-Z metal foils for hydrodynamic instability growth or solid-state materials experiments. Flexibility for a wide range of photon energies is achieved with a Au photocathode covered on four microstrip lines of microchannel plate (MCP). The photocathode active area is $26.4\times36\ mm^2$, including four 6.6 mm×36 mm microstrip lines. The resolution goal of 20 line pairs per mm at a contrast transfer function of 50% is required to accurately measure the trajectory of a thin-film foil as it is accelerated away from the side of the hohlraum. Temporal resolution window adjustable of 0.07 ～ 1.5 ns provide flexibility to measure beam synchronization (0.07 ns window) and also measure radiation-wave propagation, breakout, and shock trajectories for precision equation-of-state measurements[8]. The dynamic range is required to be at least 100∶1 with sufficient sensitivity to record single-photon events with an gated MCP. The MCP output is of 45 mm diameter with a P43 phosphor. Fiber optics couple the phosphor screen to a 4 K by 4 K optical charge-coupled device (CCD) with a 9 μm-square pixels[8].

The X-ray framing camera is designed to work with the DIM[9]. It operates on +28 V direct current (DC) supplied in the DIM. Communication between the camera and SGIII data acquisition is done by fiber-optic Ethernet, shown as Fig. 1. Three optical fibres for trigger signal input are provided to the gate pulser of MCP, 10 microsecond square-wave pulser of phosphor field and CCD. The trigger signal will be +5 V into 50 Ω. Operation is in a vacuum of $3\times10^{-5}$ to $5\times10^{-7}$ Torr with a maximum allowable leak rate into the target chamber of less than 0.01 Torr $S^{-1}$. A DIM may not dissipate more than 10 W of heat into the target chamber. In order to stay within the 10 W limit, a water cooling system is used to limit the heat dissipation from the diagnostic into the DIM.

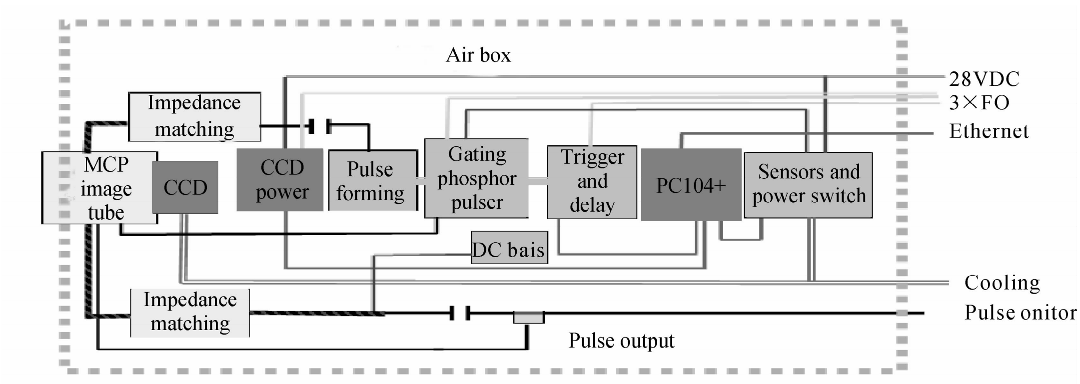


Fig. 1 Block diagram of the core X-ray framing camera.

## 2 Description and module prototype

A conceptual layout for the core XFC shown in Fig. 2. The system is made up of five basic electrical and mechanical components: the air box (including cooling plane and mounting structure), MCP image tube, CCD camera, gating electronics package, and PC104+ onboard computer plus a box-keeping sensor package. The camera is placed in an aluminum air box. The MCP image tube extends through the box so that the MCP image parts of an apparatus and impedance-matching systems are in vacuum, while the CCD and electronic controls are at nominal air pressure and temperature.

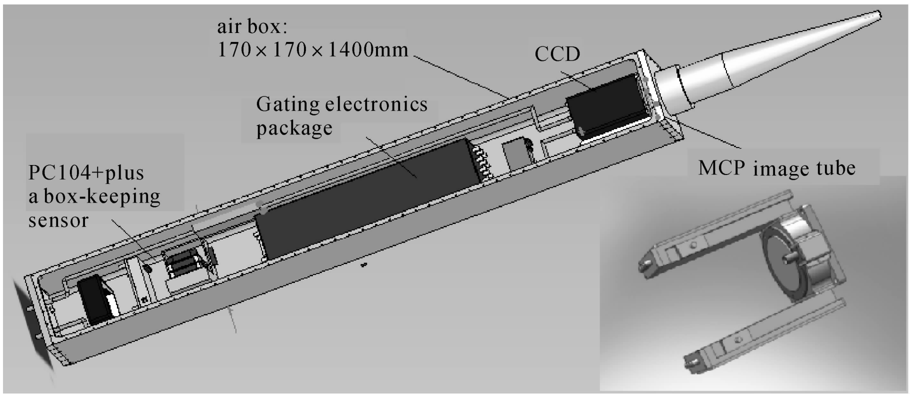


Fig. 2　Preliminary electrical/mechanical layout.

The air-box size is approximately 17 by 17 by 140 cm. The box provides a rigid structure and serves as a hermetically sealed Faraday cage to protect the electronics from the transient electromagnetic noise in the SGIII target chamber environments. Modular packaging of the electronics provides internal electromagnetic interface and electromagnetic pulse (EMI/EMP) shielding and quick replacement of parts. Additional EMI/EMP protection is provided by the use of fiber-optic cables and nonmetallic cooling lines. The camera uses the 36.88 mm by 36.88 mm Kodak KAF-16800 CCD. The CCD pixel layout is 4k by 4k with 9 m-square pixels. The CCD provides more spatial resolution than required, so binning will be used to increase the signal-to-noise ratio.

The MCP image tube is to propagate a high-voltage gate pulse across a microwave transmission stripline deposited on the MCP front surface, see shown as Fig. 1. The short burst of electrons liberated from the gold photocathode is amplified in the MCP and proximity focused onto a P43 phosphor coated fiber-optic faceplate (FOFP)[10]. Past impedance-matching systems have used either a direct Ohmic mismatch or a shaped transmission line[11]. We used a printed circuit, surface mount impedance transformer going from 50 to the strip impedance of 12.5 Ω[9]. This has the advantage of minimizing reflections back to the gate pulse source and optimizing the energy to the stripline.

P43 ( Peak wavelength :540 nm ) phosphor undercoated with a indium tin oxide (ITO) integrated with two gold tabs for the pulsed phosphor and monitor launch[13]. The phosphors have been developed in Research Center of Laser Fusion. Fig. 3 is a phosphor test by a longer tungsten filament at an acceleration voltage of 5 kV and 20cm from the phosphor surface. To increase light efficiency by up to 100 % and to reduce stray light, it is advantageous for most applications to seal the phosphor coating with an aluminium layer on top of it. As a standard, a 40 nm to 50 nm coating is recommended.

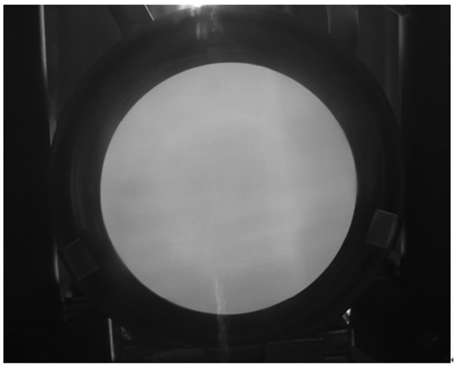

Fig. 3　Filamentary cathode testing for P43 phosphor undercoated with ITO

Pulsing the phosphor screen versus direct current biasing has the advantage of increasing the electric field between the MCP and FOFP, and minimizing the transverse energy of the electrons while avoiding electrical breakdown between the two surfaces. Fig. 4 is phosphor-pulser module. This module is miniaturized down to 130 × 95 × 95 $mm^3$. Its output width is 10 s square-wave pulse, and its amplitude is adjustable from 2 kV to 10 kV, see Fig. 5. The preliminary applications show that the pulser not only provide a simple quantitative imagery approach, but also improve particularly inhibit discharge capability of framing image-converter[10].

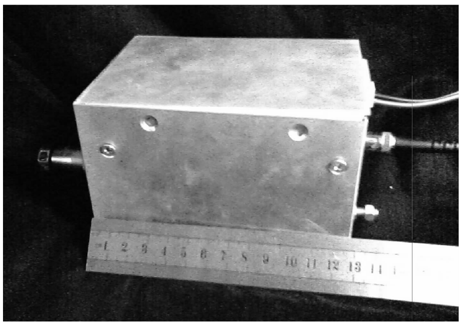

Fig. 4　Modular phosphor-pulser.

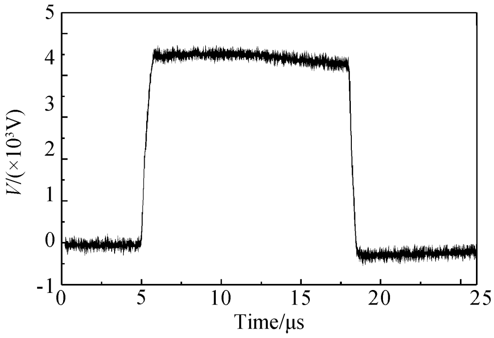


Fig. 5 Typical output of phosphor-pulser.

The gating electronics package will be completely computer controlled by interfacing with a standard RS232 connection. The electronics package includes four gating modules that have an output of 2 kV each with an electrical gate width of 0. 2 ~ 1. 8 ns using changeable pulse forming modules (PFMs) [12]. These pulses can be delayed up to 30 ns each in 25 ps steps. Also included are four separate dc bias power supplies for independently modifying the gain on each stripline plus dc and pulsed power supplies.

The requirement that no more than 10 W be radiated into the target chamber from each DIM forces active cooling of the air box, especially in the case where multiple diagnostics may be placed in the same DIM[9]. A plane caliduct coupled to a thermoelectric cooler transfers heat from the air box into the low-conductivity cooling water. This cooling system also transfer heat from the camera′s CCD thermoelectric cooler.

Instrument operations are intended to be compatible with the SGIII, 2 h/shot cycle allowing for remote instrument monitoring and adjustment of sensitivity, timing, voltages, current, and health, see Fig. 2. Once a user decides on a spectrometer or imaging nose cone to be placed in front of the detector and the instrument is configured, it is translated into the target chamber. Communications with the camera will be established using the transmission control protocol/internet protocol (TCP/IP) Ethernet based diagnostic computer. The diagnostic computer is local in the target bay and acts as the liaison between the front-end processor and XFC. Following confirmation of XFC functionality and health, XFC begins listening to the SGIII integrated timing system for the shot countdown or SGIII shot life cycle, and a CCD background image is acquired and stored remotely. At shot time, optical triggers are sent to the pulser, phosphor, and CCD camera and an analog trigger monitor is sent out to a digitizing oscilloscope located in the shielded SGIII mezzanine. The CCD camera is then read out and the information is stored remotely with all the camera settings in hierarchical data format file format. Concurrently, the system health (temperature, pressure, vacuum, voltage, and current) is periodically polled, logged, and displayed in the diagnostic control room station. If a critical parameter shows out of range, initially a warning would be displayed. If the parameter continues to increase out of range, the system is programmed to shut itself down.

## 3 Conclusion

The conceptual design of SHEN-GUANG III - XFC system have accomplished. The performance specifications have get across comment from the SHEN-GUANG III expert groups. Preliminary results that will be presented in the future demonstrate very good repeatable uniformity between imaging strips, improved spatial resolution, and no detectable impedance reflections.

**References**

[1] KILKENNY J D. High-speed proximityfocused x-ray cameras [J]. *Laser Part Beams*, 1991, **9**, 49-69.

[2] SHAN Bing, CHANG Zeng-hu, LIU Jin-juan, *et al*. Gated MCP picosecond X-ray framing camera[J]. *Acta Photonica Sinica*, 1997, **26**(5): 449-455.

[3] CAO Zhu-Rong, JIANG Shao-en, CHEN Jia-bin, *et al*. Diagnostic technology of time-and space-resolved soft-X-ray spectra[J]. *Acta Physica Sinica*, 2007, **56**(6): 5330-5334.

[4] BRADLEY D K, BELL P M, LANDEN O L, *et al*. Development and characterization of a pair of 30~40 ps X-ray framing cameras[J]. *Rev Sci Instrum*, 1995, **66**(1): 716-718.

[5] OERTEL J A, ARCHULETA T N, SCHRANK L S, *et al*. The large format X-ray imager [J]. *Rev Sci Instrum*, 2000, **72**: 701-704.

[6] BRADLEY D K, BELL P M, KILKENNY J D, *et al*. High speed gated X-ray imaging for ICF target experiment (invited) [J]. *Rev Sci Instrum*, 1992, **63**(10): 4813-4817.

[7] ZE F, KAUFFMAN R L, KILKENNY J D, *et al*. A new multichannel soft X-ray framing camera for fusion experiments [J]. *Rev Sci Instrum*, 1992, **63**(10): 5124-5126.

[8] Spectral Instruments, 420 North Bonita Ave, Tucson, AZ, http://www. specinst. com.

[9] OERTEL J A, ARAGONEZ R, ARCHULETA T, *et al*. Gated x-ray detector for the National Ignition Facility[J]. *Rev Sci Instrum*, 2006, **77**: 10E308-1-10E308-4.

[10] CAO Zhu-rong, DING Yong-kun, ZHANG Hai-ying, *et al*. Vacuum-arc discharge damage to X-ray framing camera[J]. *High Power Laser and Particle Beams*, 2007, **19**(2): 321-326.

[11] CAO Zhu-Rong, DING Yong-kun, Zhang Hai-ying, *et al*. Electrical pulses timing of X ray framing cameras(accepted) [J]. *Acta Photonica Sinica*, 2009.

[12] CHANG Zeng-hu, SHAN Bing, LIU Xiu-qin, *et al*. Picosecond X-ray framing camera using gated MCP[J]. *Acta Photonica*

Sinica, 1995, **24**(6): 501-508.

[13] BAI Xiao-hong, LIU Jin-yuan, BAI Yong-lin, *et al*. Study of the phosphor screen with the transparent conducting film[J]. *Acta Photonica Sinica*, 2006, **35**(2): 176-179.

# 神光 III 核心 X 射线分幅相机

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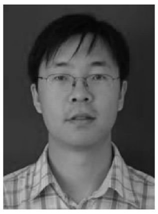
**摘　要**：神光 III 装置核心 X 射线分幅相机将用于激光装置性能验收实验和宽范围的高能量密度物理、惯性约束聚变物理及基础物理实验研究. 相机系统主要为记录神光 III 装置靶的时间分辨 X 射线发射设计，利用可更换的鼻椎实现具有二维空间分辨或者一维谱分辨的靶形貌时间分辨图像. 神光 III 装置核心 X 射线分幅相机将被嵌入到一个铝制空气包中，空气包具有大容量冷却平板和一个特制的环境监测传感器阵列. 相机设计很多部分不同于早期 X 射线分幅相机，如一套全新的阻抗匹配方案，曝光时间从 0.07-1.5 ns 可调，先进的荧光屏，脉冲屏压电路，准确的模块定位，独特的监控系统和完全远程计算机控制. 其中先进的荧光屏和脉冲屏压电路已经获得初步应用.

**关键词**：惯性约束聚变；X 射线分幅相机；诊断搭载平台



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