# The JET Multi-Camera Soft X-Ray Diagnostic

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## INTRODUCTION

A new soft X-ray detector system has been constructed for the pumped divertor phase of JET which incorporates a number of enhancements over the previous system in both hardware and data acquisition. The hardware improvements include: six independent views of the plasma at one toroidal location (as opposed to two in the old system), spatial resolution improved from 7cm to 3cm, frequency response increased from 30kHz to 100kHz and improved toroidal mode resolution. These enhancements will allow the study of MHD activity in finer detail. The tomographic reconstruction of soft X-ray emissivities will be improved to include Fourier terms up to cos(5θ) compared with only cos(2θ) before. Also through the implementation of a fast central acquisition and trigger system, data from a range of diagnostics will be available at high bandwidth to allow processing of plasma phenomena of far greater complexity than was possible before.

**GENERAL LAYOUT OF NEW SXR SYSTEM** Figure 1 shows the general layout of the new SXR diagnostic at octant 2 of the JET torus. Five separate assemblies have been constructed to house the detectors - 35 channel PIN diode arrays. A sixth assembly (not shown), identical to the vertical camera, has been installed at octant 7 for the purpose of toroidal mode number identification.

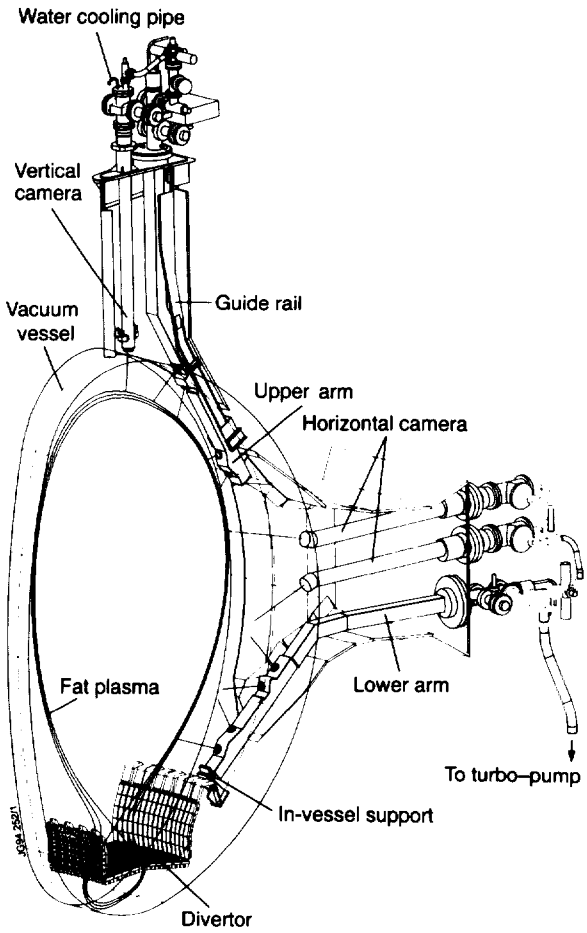



*Figure 1. General view of 5 new SXR diagnostic system assemblies. The central viewing lines of each camera (11 in all) are shown in the figure.*

## FEATURES OF THE SXR CAMERA ASSEMBLIES

To obtain views of the plasma from a number of directions at one toroidal location requires the installation of cameras around the vessel wall away from access ports. As JET operates with the vessel at elevated temperatures (up to ~300$^{o}$C), this has required various novel features to be incorporated into the system design, see Figure 2. These include: the use of 35-channel PIN diode arrays mounted in pairs to provide six independent views of the JET plasma; (each compact camera pair has a ~90$^{o}$ viewing angle ), up to four arrays enclosed in a single water-cooled secondary vacuum assembly and a dedicated turbo-pumping system to reduce convective heat losses. Each camera views the plasma through a 250µm thick Be window which provides SXR energy filtering and isolation of the primary and secondary vacua. An enclosed single element version of the diode is included to allow subtraction of neutron and gamma ray backgrounds during high performance discharges together with a pair of infra-red emitting diodes for calibration. A 1mm thick tungsten contoured aperture plate enables precise viewing definition of both low and high energy X-rays and the copper content (required for conductive cooling of diodes) has been minimised to reduce possible forces on assemblies from eddy currents during plasma disruptions. Removal of single-camera assemblies whilst maintaining the torus under vacuum will be possible.

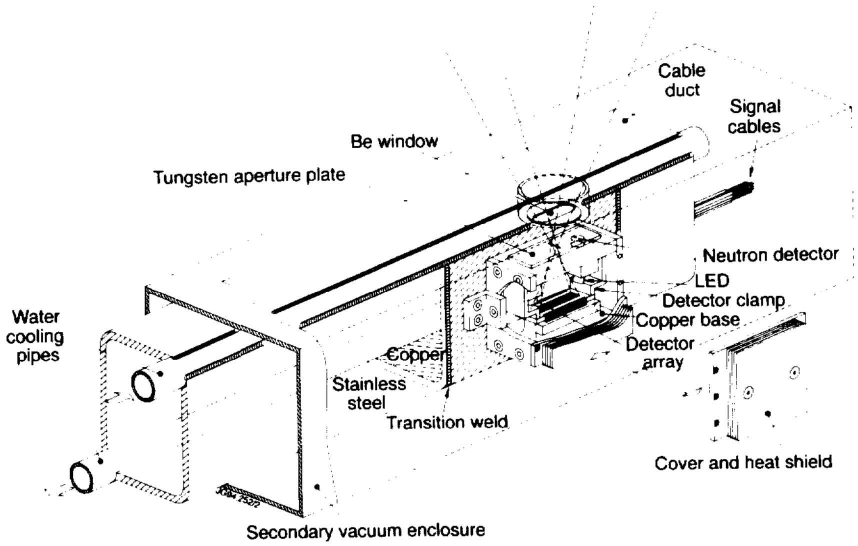



*Figure 2. Schematic of camera assembly in one of the multi-camera arms*

## DETECTOR PERFORMANCE

The detectors used are Centronic LD35-5 PIN photodiode arrays. Normally designed to operate in the visible, these type of detectors have been found to work well in the SXR region[1]. Each array consists of 35 elements with anodes 4.5mm by 0.96mm at 1mm spacing with common cathodes. In this application we use only every other channel in each array, i.e. 18 channels per array, (except in the vertical and toroidal cameras where every element is used). The unused channels have their anodes shorted to the common cathode as floating channels were found to affect the gain of neighbouring elements by up to 20%. The detectors are operated in **photoamperic mode;** that is with zero bias into low impedance amplifiers. This has the advantage of minimising noise and dark current and removing the possibility of cross-talk through a common power supply for the bias voltage. Tests were carried out (using LEDs) which showed that the gain was stable against small variations in bias voltage around 0V and that the frequency of response was adequate for the 100kHz band width, originally specified.

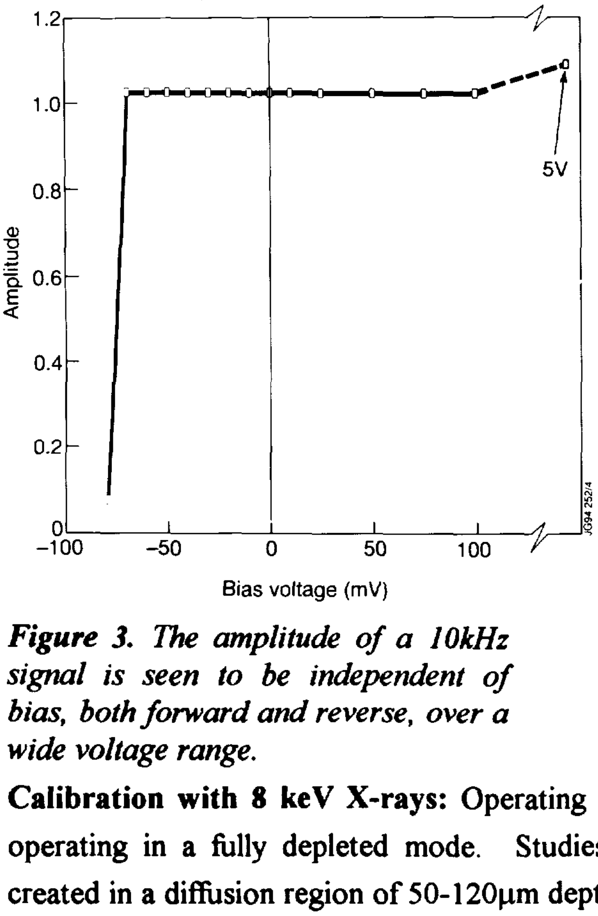



*Figure 3. The amplitude of a 10kHz signal is seen to be independent of bias, both forward and reverse, over a wide voltage range.*

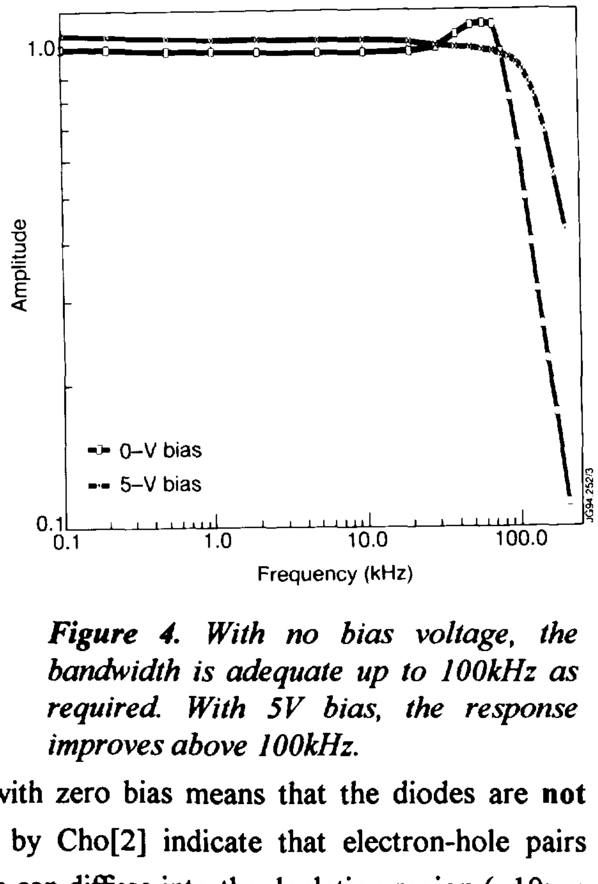



*Figure 4. With no bias voltage, the bandwidth is adequate up to 100kHz as required. With 5V bias, the response improves above 100kHz.*

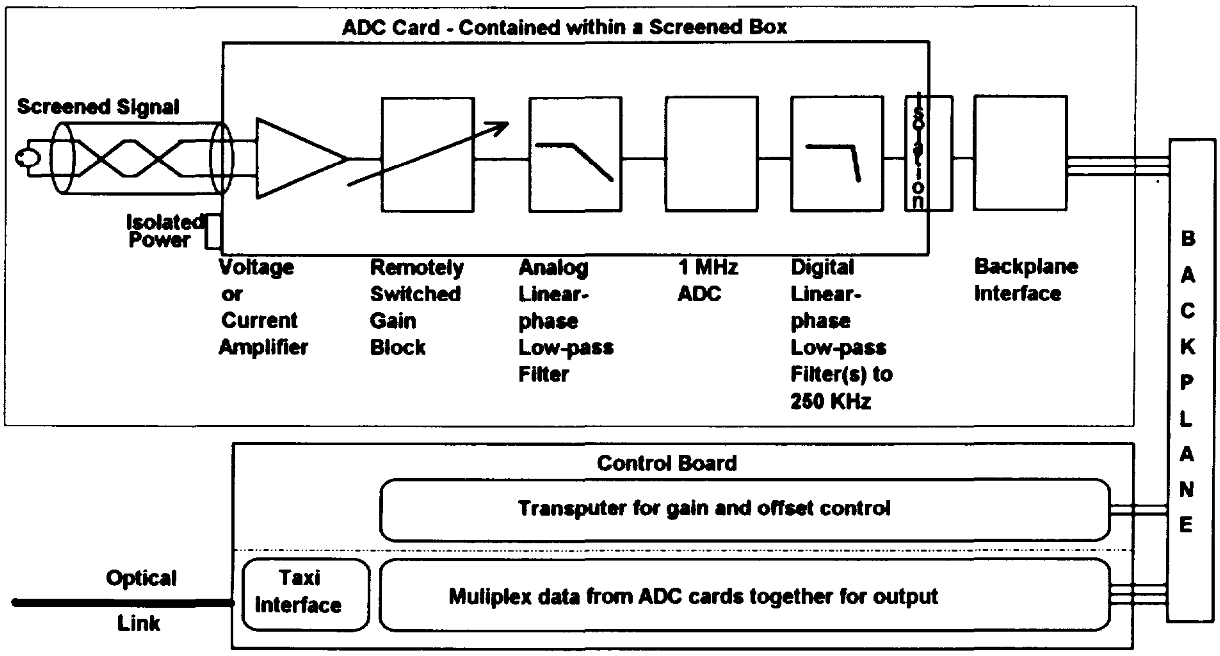
**Calibration with 8 keV X-rays:** Operating with zero bias means that the diodes are **not** operating in a fully depleted mode. Studies by Cho[2] indicate that electron-hole pairs created in a diffusion region of 50-120μm depth can diffuse into the depletion region (~10μm with zero bias) and contribute towards signal current. For 8 keV X-rays this would lead to a collection efficiency in the range 55% to 85%. The relative calibration of all diode elements for 8 keV X-rays was carried out at MIT. A variation in efficiency comparable to that mentioned above was found between the best and worst detectors. In practice, a selection was made of the 12 best arrays out of a total of 28 tested, leading to a variation of only ±3% for all central channels and ±4% for all edge channels.

**Radiation Effects:** With the small volume of each detector, and through the use of zero-bias operation, large dark (or leakage) currents are not expected. Possible problems may occur if the neutron fluence through a diode exceeds $10^{13}$ $cm^{-2}$. This corresponds to a total yield of ~$5.10^{19}$ neutrons from JET plasmas. Under these conditions effective doping concentrations can change with n-type inverting to p-type. However, self-annealing of the detectors should occur due to the pulsed nature of the neutron source which should extend their life.

## ELECTRONICS

The front-end electronics for each camera is contained in a single rack-schematically illustrated below. Each ADC card is powered from an isolated linear power supply in order to reduce noise. The single ended current-source to voltage input amplifier has gain and DC offset adjustment. An 8-pole analogue filter is included to prevent aliasing from out of band signals or noise. Output from the ADC, a 12-bit device sampling at 1 MHz, is fed through two digital filters which lower the sampling frequency to 250kHz at 16 bits, for a pass band to 100kHz and stop band of 125 kHz. Each ADC card is optically isolated with data passed via the backplane to the Control card. Each Control card contains a Transputer to provide a programmable facility for setting gains / DC offsets and driving the calibration LEDs. .The control card multiplexes the data from up to 19 ADC cards and transmits the data via a single TAXI / fibre-optic interface to the diagnostic area. The back-end data collection and trigger system uses Texas Instruments TMS320C40 (C40) microprocessors to provide a fast storage and central trigger system for the SXR data. Other JET diagnostics including magnetics, ECE, reflectrometry and H-alpha, are to be incorporated into the C40 central trigger system to enable simultaneous collection of data at 250 kHz from these diagnostics.

**Schematic of the front-end electronics**




**STATUS** The diagnostic hardware has been completely installed onto JET together with water cooling and vacuum systems. The ADC cards have been fabricated and tested. The Control card is currently undergoing prototype testing with complete testing of the data acquisition system expected in the next few weeks.

**REFERENCES** [1] Camacho JF and Granetz RS, Rev. Sci. Instr. 57 (3), 1986, p417

[2] Cho T et al, Phys. Rev. A, 46(6), 199