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Hotlink based Soft X-ray Diagnostic on ASDEX Upgrade

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Abstract

The paper presents the new design of the Soft X-ray diagnostic for the ASDEX Upgrade tokamak based on small pinhole cameras and planar diode arrays. Details of the optical system together with the Hotlink acquisition system are given. A special part is devoted to the description of the data structure and an introduction for newcomers. Examples of analysis are presented for sawtooth precursor and fast particle instabilities (Toroidal Alfvén Eigenmodes, cascades, etc.).

Contents

1 Introduction

Soft X-ray cameras are one of the main plasma diagnostics in current fusion research. The plasma temperature in tokamaks has its maximum in the soft X-ray spectral region (100eV to 10keV). The detection of Soft X-ray radiation from the fusion plasma allows investigating various MHD instabilities and impurity transport and provides information on equilibrium data, e.g., the plasma centre.

The energy spectrum of Soft X-ray radiation consists of a continuum of free-free bremsstrahlung, free-bound recombination radiation, and bound-bound line radiation. Continuum radiation arises from electron-ion collisions and from recombination. Line radiation is a result of transition in an ion from one to another excitation state, which can also occur when a recombination process leaves an ion in an excited state.

The bremsstrahlung can be estimated for a Maxwellian velocity distribution, assuming a hydrogen model for the impurity ions. The radiated power $d\varepsilon$ per unit volume in the energy interval dE is:

$$\frac{d\varepsilon(E)}{dE} \sim n_e^2 Z_{eff}\, g_{ff}(T_e, E)\frac{\exp\left(-E/T_e\right)}{\sqrt{T_e}}, \qquad (1)$$

where $Z_{eff} = \sum_k n_k Z_k^2 / n_e$ is the effective ion charge, g_{ff} is the Gaunt factor, which is close to unity, and n_e, T_e are the electron density and temperature, respectively.

The continuous part of the recombination radiation can be described by a formula similar to (1) with an additional factor that depends on the element, the specific ionization state and on the electron temperature, in a way that at higher temperatures, recombination radiation gets weaker with respect to bremsstrahlung.

Line radiation becomes important for impurities that are not fully ionized in the plasma region of interest. It is a complicated interplay of excitation and ionization rates. There are tabulated values for the total radiation of various elements as a function of temperature. Tungsten radiation, e.g., is dominantly line radiation for temperatures below 20 keV.

The Soft X-ray detectors at ASDEX Upgrade measure the energy integrated total radiation power with an energy dependent detection probability, $f_{sum}(E)$, which is determined by the diode properties and the 75 µm thick Beryllium filter foil in front of the detectors (see section 2.4.1.). The detected radiation power is the integral over energy of the radiated power per energy interval multiplied by $f_{sum}(E)$. Since photon energies below 1 keV are blocked by the Beryllium, line radiation from light impurities is negligible for the Soft X- ray diagnostic, therefore they affect the Soft X-ray radiation mainly via *Z_eff*. However, for ASDEX Upgrade with the full tungsten wall coverage, tungsten line radiation can even exceed the continuous radiation seen in Soft X-ray diodes significantly and the radiated power can no longer be estimated from density and temperature values. A more detailed description of the X-ray radiation from plasmas can be found in Ref.[1].

This paper gives a description of the Soft X-ray pinhole camera system[1] for ASDEX Upgrade, a medium size tokamak with $R_0 = 1.65m$, $a = 0.5m$, $I_p \le 1.4MA$, $B_t \le 3.9T$. The requirements for the Soft X-ray design were:

- Low cost, since the diodes deteriorate with neutron irradiation and have to be replaced frequently, every 1-2 years.
- Small cameras, since the previous large divertor camera was not compatible with the tungsten divertor, and to allow additional cameras around the poloidal cross section, also on the high field side.

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[1] The former design of Soft X-ray cameras is reported in Ref.[2].

- The possibility to investigate fast particle MHD instabilities like Toroidal Alfvén Eigenmodes (TAEs) with frequencies of few hundred kHz, which is one order of magnitude larger than frequencies of instabilities like sawteeth precursors and Neoclassical Tearing Modes (NTM).

It will be shown in this report that the new Soft X-ray system has successfully achieved these goals.

The price of one chip (with 15 to 22 used diodes on each) is about the same as that of a single diode in the former design. Moreover, the diodes do not show large degradation after one campaign, whereas the (large) diodes were significantly affected in performance - not only in sensitivity - after only several weeks of operation. Furthermore, the small cameras with the universal head are much cheaper in design and manufacturing.

The smaller cameras can be mounted on the high field side and underneath the tungsten divertor. They use existing gaps between the tiles and do not require a special hole, as was the case for the former design.

The new Hotlink based acquisition system has a sampling rate of up to 2 MHz for 10s, whereas the former transputer system had a maximum data capacity for 1.74 s at 500 kHz (accordingly longer for reduced sample frequencies). The increased sample frequency of 2 MHz allows to detect various fast particle instabilities at several hundred kHz, as will be shown in chapter 6. The sample time can easily be extended, if needed, requiring only an extension of the memory installed in the workstation.

Chapter 2 gives details on detectors and camera system. Chapter 3 describes the data acquisition system. The most important information for newcomers is in chapters 4 and 5, which describe the shotfile data structure and programs for data analysis. Some results are presented in chapter 6.

2 Camera systems

For detection of the Soft X-ray radiation mentioned above it is convenient to use pinhole cameras. In this part we give information about the diodes and report on details of the camera design.

2.1 Detectors

The detectors inside the cameras are Centronic Series 5T detectors (LD35-5T). This is a linear array of 35 diodes on a single silicon chip. Due to the camera geometry, it is advantageous to use only the more central diodes on the chip (see 2.4.2.). The photo of a single array is shown in figure 1.

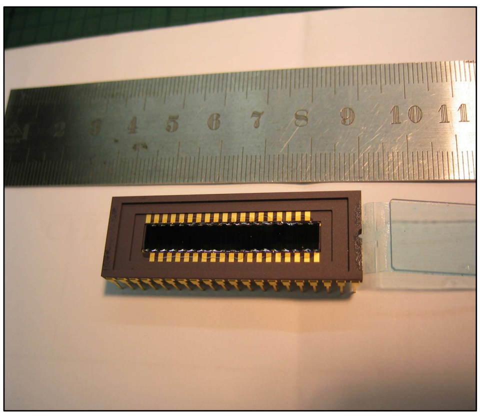

Figure 1. Photo of chip with a diode array.

<u>The geometrical parameters of the diodes are the following:</u>
Diode width: 0.96 mm
Diode length: 4.6 mm
Separation between the diodes: 0.03 mm
Diode area: $4.42 mm^2$

2.2 Pinhole cameras

The current Soft X-ray system at ASDEX-Upgrade consists of 8 cameras having one to three heads, depending on the available space and angle requirements. Each head contains one diode array and has its own pinhole and Beryllium filter foil (to block low energy photons up to around 1 keV from the detectors), and can therefore be considered as a single small Soft X-ray camera. The geometry of the heads is universal. This means that the focal length, the Beryllium filter and the diode array position are the same in all heads (except I camera, see below). A sketch of this head is shown in figure 2.

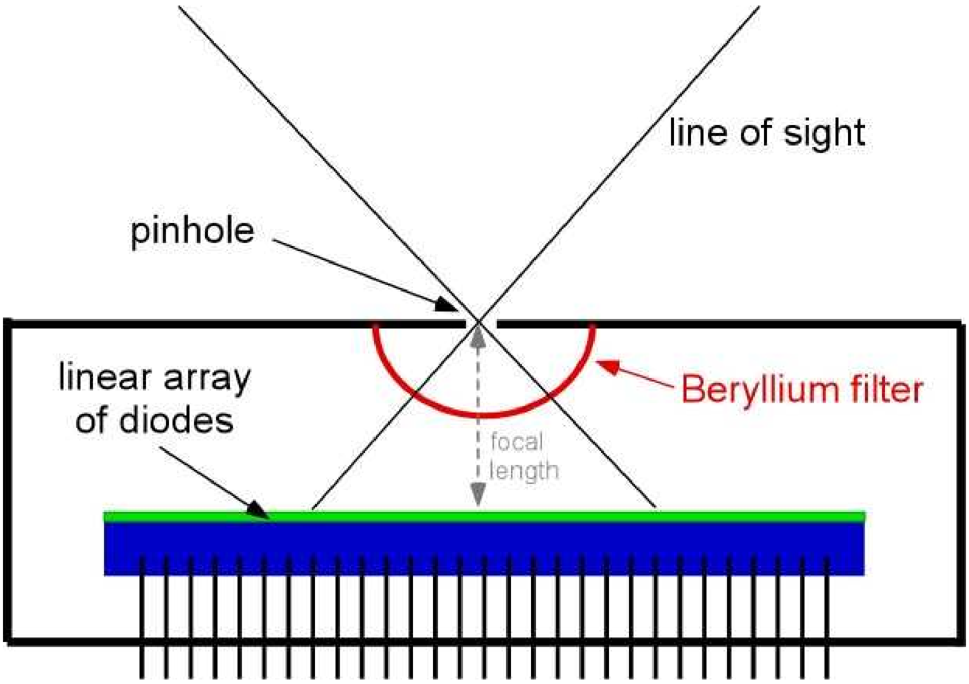

Figure 2 Sketch of the Soft X-ray head. The head design is identical for all cameras

The pinhole centre corresponds to the middle of the diode array. The curved 75 μm Beryllium filter is mounted directly behind the pinhole, so that the effective Be thickness is the same for all lines of sight. Photos of some cameras are shown in figure 3.
The I camera forms an exception: only the central head (number 2) has a 75 μm Beryllium filter. The other two heads are reserved for special purposes: The head with sight lines to the top (number 1) currently has a 25 μm Be filter foil. The head pointing downwards (number 3) had coated diodes (with a layer of 350 nm SiO2 plus a 100 nm layer of Aluminium) from #21496 (March 2007) to #25890 (December 2009). From #25891 (2010) on, the detector will be shielded from soft X-ray photons by a metal plate to monitor the neutron background signal.

The radiation filters can be changed in the future according to diagnostic requirements. You find the information on applied filters in the CSX files (see 4.4.4) in the parameters FILT-MAT and THICKNES.

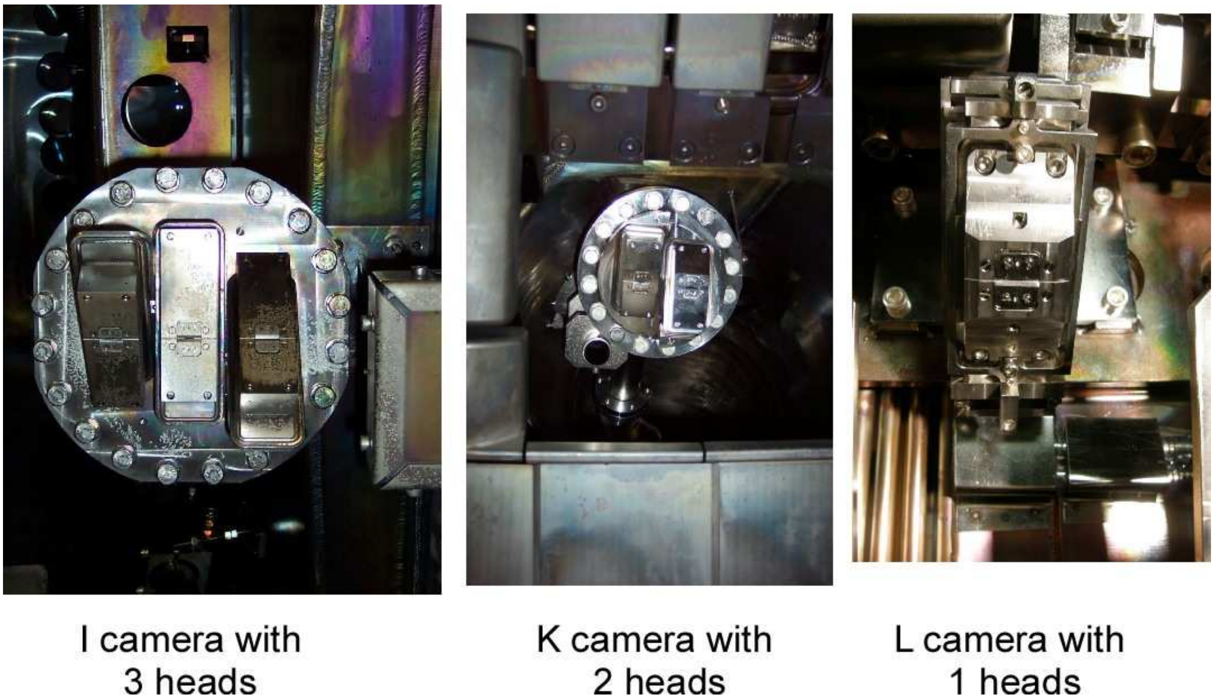

Figure 3. Three Soft X-ray cameras with different numbers of heads are shown.

2.3 Position of the cameras

ASDEX-Upgrade is equipped with 7 cameras in sector 11 and one camera in sector 5. The cameras in sector 11 are located in different poloidal but almost at the same toroidal position. The camera heads are oriented such that the diodes on an array are different in poloidal but identical in toroidal position. The diode surface normal has a negligible toroidal component. Thus, these cameras create a net of almost 200 lines of sights in one poloidal plane.

Cameras J, I and H are on the low field side (see figure 4). They are identical and each of them has 3 heads. The K camera is at the upper low field side, above the PSL, and has 2 heads. The G camera is mounted at the bottom, inside the divertor, and equipped with one head. L and M cameras are on the high field side, at the top (L) and the bottom (M) of the inner heat shield. The F camera is a divertor camera, identical in design and poloidal position, but in a different toroidal position as camera G. Thus, in the poloidal cross section, F and G have identical lines of sights, giving the opportunity to determine the toroidal mode number from Soft X-ray signals.

The positions of all cameras and lines of sight are shown in figure 5. The main information about cameras is presented in table 1.

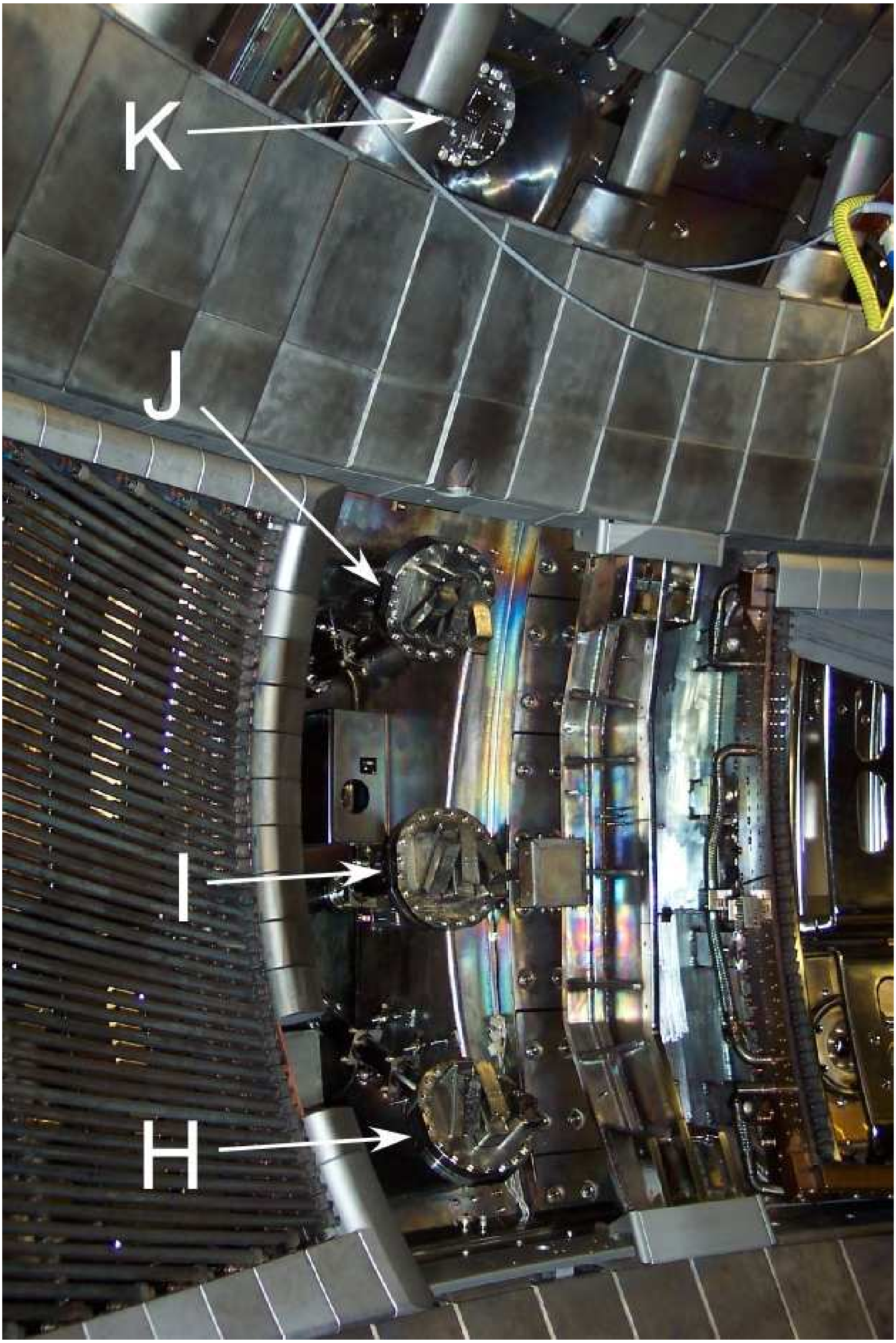

Figure 4. Photo of the Soft X-ray cameras K, J, I, H inside the torus.

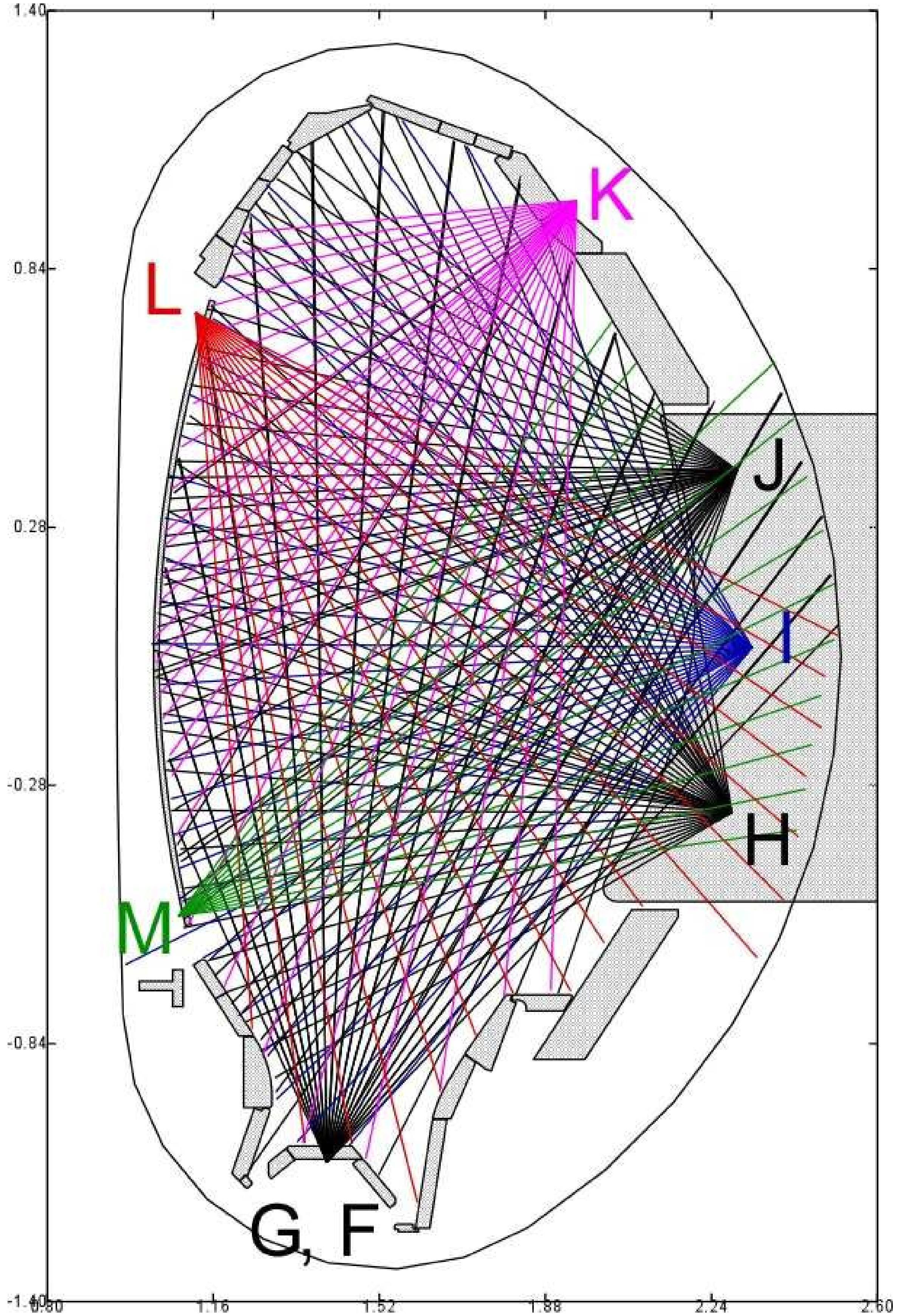

Figure 5. Shown is the projection of the Soft X-ray lines of sight to the poloidal cross-section, in which the camera pinhole is located. All cameras are plotted in one figure. The component of the lines-of-sight perpendicular to this plane (i.e., in toroidal direction) is very small. The divertor cameras G and F have identical poloidal positions.

Camera	Sector	Pinhole				Diode			Camera	
		R[m]	z[m]	Length [mm]	Width [mm]	Length [mm]	Width [mm]	Separation [mm]	Focal Length [mm]	angle [deg.]
F	5	1.4058	-1.0967	5.0	0.3	4.6	0.96	0.03	14.0	78.8
G	11	1.4067	-1.0965	5.0	0.3	4.6	0.96	0.03	14.0	78.9
H1	11	2.2853	-0.3389	5.0	0.3	4.6	0.96	0.03	14.0	103.8
H2	11	2.2853	-0.3389	5.0	0.3	4.6	0.96	0.03	14.0	143.8
H3	11	2.2853	-0.3389	5.0	0.3	4.6	0.96	0.03	14.0	-176.2
I1	11	2.3280	0.0192	5.0	0.3	4.6	0.96	0.03	14.0	131.6
I2	11	2.3280	0.0192	5.0	0.3	4.6	0.96	0.03	14.0	171.6
I3	11	2.3280	0.0192	5.0	0.3	4.6	0.96	0.03	14.0	-148.4
J1	11	2.2960	0.4038	5.0	0.3	4.6	0.96	0.03	14.0	167.1
J2	11	2.2960	0.4038	5.0	0.3	4.6	0.96	0.03	14.0	-152.9
J3	11	2.2960	0.4038	5.0	0.3	4.6	0.96	0.03	14.0	-112.9
K1	11	1.9480	0.9881	5.0	0.3	4.6	0.96	0.03	14.0	-148.1
K2	11	1.9480	0.9881	5.0	0.3	4.6	0.96	0.03	14.0	-118.2
L	11	1.1219	0.7446	5.0	0.3	4.6	0.96	0.03	14.0	-53.0
M	11	1.0846	-0.5629	5.0	0.3	4.6	0.96	0.03	14.0	30.9

Table 1. Main information about the geometry of the Soft X-ray cameras is given. The heads are treated as individual cameras here, with the number of the head (1 to 3) following the camera name (only in case of several heads in one camera). In the torus, the length is oriented in toroidal, the width in poloidal direction. The camera angle is the angle of the chip normal with respect to the horizontal line pointing outward in counter clock direction. The toroidal angle between F and G cameras is 135 degree.

2.4 Energy range of the detected radiation and geometrical calibration

2.4.1 Detected energy range

The spectral range detected by the Soft X-ray system has two limits. The first limit is the *lower limit* which is mainly defined by the thickness of the Beryllium filter foil in the cameras. The present filters with 75 µm thickness block all radiation with energies below ≈ 1 keV, as shown in figure 6. Without the filters, the diodes also detect low energy radiation and would be dominated by visible light. (The Bolometry diodes diagnostic in ASDEX Upgrade, XVR, works this way.) The *upper limit* at higher energies is determined by the thickness of the active layer of the silicon diode. Since the diodes are not operated fully depleted, this can be smaller than the diode thickness, but it is also not identical with the depleted layer thickness.

In order to determine the total response function for the Soft X-ray system we have to consider the thickness and material of each intervening layer. The radiation must pass through absorbing layers (Beryllium filter with thickness $d_{Be} = 75\mu m$, diode passivation layer with thickness $d_{Si_3N_4} = 0.55\mu m$ and diode dead layer with thickness $d_{dead} = 0.6\mu m$) and must be absorbed in the active layer with thickness $d_{active} = 200\mu m$. The detection probability is,

$$f_{sum}(E) = \exp\left(-\mu_{Be} d_{Be} - \mu_{Si} d_{dead} - \mu_{Si_3N_4} d_{Si_3N_4}\right) \cdot \left(1 - \exp(-\mu_{Si} d_{active})\right) \qquad (2)$$

where the absorption coefficients, $\mu_* = \mu_*(E)$, are functions of the photon energy E. Figure 6 shows sensitivity curves for different active layer thicknesses. The thin absorbing layers on the diode itself have been neglected and the lowest active layer thickness is assumed to be equal to the diffusion length of 200 μm determined in (M. Anton [3]). The maximum active layer thickness is given by the thickness of the Si substrate (380 μm).

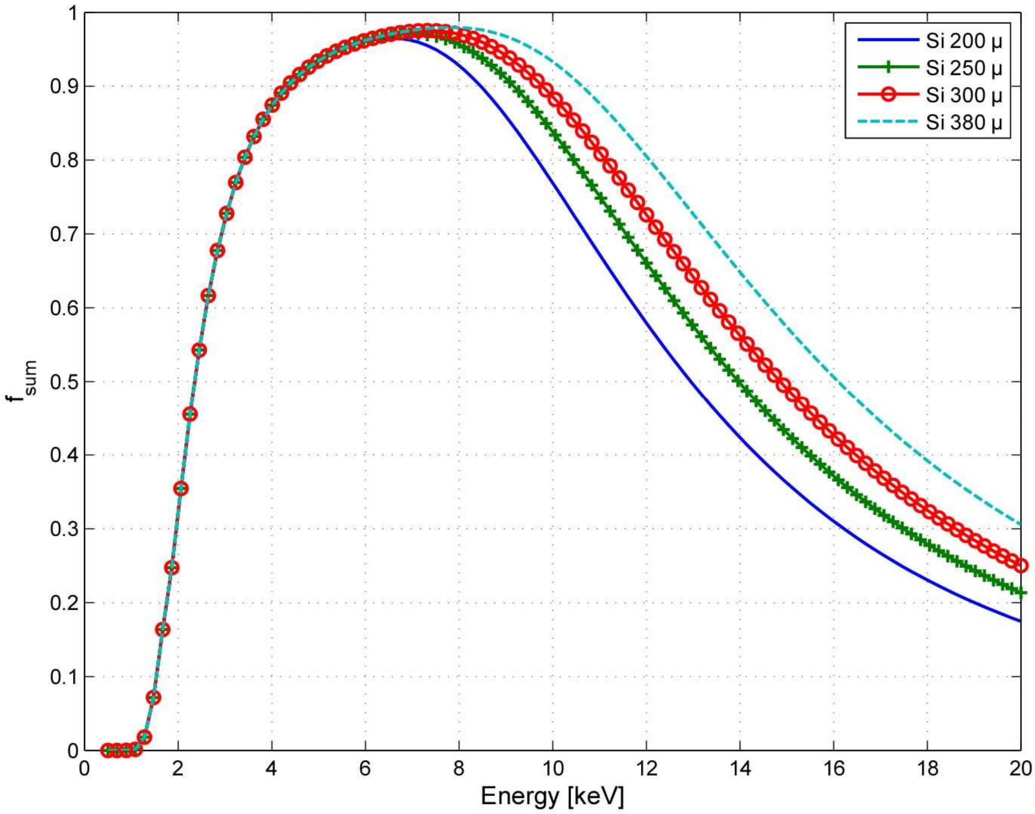

Figure 6. Calculated spectral sensitivity of the diodes with 75 μm beryllium filter for different thicknesses of the active layer is shown.

The emissivity measured by a Soft X-ray camera is an integral which combines formulas (1) and (2)

$$\varepsilon = \int_0^\infty f_{sum}(E) \cdot \frac{d\varepsilon(E)}{dE} dE \, .$$

2.4.2 Geometrical effects in calibration

The effective pinhole and diode areas and the distance pinhole-diode are a function of the diode position on the chip. Therefore one has to take into account a geometrical factor, which is different for the lines of sight:

$$G = \frac{P_x P_y D_x D_y \cos^4 \alpha}{4\pi \Delta^2} \left[1 - \frac{1}{6} \frac{D_y^2 + P_y^2}{\Delta^2} \cos^2 \alpha + \frac{D_x^2 + P_x^2}{\Delta^2} \left(\sin^2 \alpha - \frac{1}{6} \right) + O\left(\frac{D_x, D_y, P_x, P_y}{\Delta} \right)^4 \right]$$

(3)

Here the diode dimensions $D_x = 0.96mm$, $D_y = 4.6mm$, are used along with the pinhole dimensions $P_x = 0.3mm$, $P_y = 5mm$, the camera focal length $\Delta = 14mm$, and the sight line angle with respect to the camera normal, α [4, 5].

An additional geometrical factor appears for the cameras G, F, L and M due to an external restriction of the camera view in toroidal direction. These cameras are mounted behind divertor and heat shield, respectively, and look through gaps between the tiles.

The calibration does not take into account the change of the effective layer thicknesses for the individual diodes due to the varying angle of incidence, which in principle results in different spectral response functions for the sight lines. This effect mainly modifies the high energy side The low energy side is dominated by the curved Beryllium foil, which provides identical filter thickness for all lines of sights and avoids further geometrical corrections and changes in the spectral response. To avoid large variations in the spectral response, the inclination of the sight line angle to the chip normal should be kept low. Therefore not all diodes on the chip are used. The effective active layer thickness for the outermost connected diodes in the camera heads is between 12 % (Cameras H, I, J) and 32 % (camera M) larger than for the central diode. Assuming an active layer thickness of 200 µm, the effective active layer thickness varies from 200 to 263 µm. Since this only affects photon energies well above 7 keV, only small deviations of the spectral sensitivity should be expected for the whole system.

3 Data acquisition system

3.1 Main components of the acquisition system

The main components of the acquisition system for a particular line of sight are shown in figure 7. The Soft X-ray diodes are operated in current mode with 5V reverse bias voltage. The current from the diode is converted into voltage and amplified by a preamplifier mounted close to the torus. The further amplification is done in main amplifier devices, which also contain the analogue-to-digital converter (ADC) and the Hotlink sender. In the main amplifiers the diode dark currents are compensated and then shifted by a fixed offset before the discharge. Thus the signals without detected radiation are close - but not quite at - the zero level of the ADC. This allows to have a large data range independent of the dark current and still to see the full noise level of the signals even without radiation.

From the Hotlink sender the data are sent to the Hotlink receiver, a PCI bus card, and are written directly into the memory of SUN Ultrasparc computers. This scheme allows storing the whole discharge with very high sampling rate (2MHz). One SUN is capable to work with 2 Hotlink cards simultaneously, where each Hotlink card receives 8 signals. There are 13 SUN computers for the Soft X-ray diagnostic with 208 signals in total. Each SUN has its own name which is the same as the diagnostic name (currently SXA to SXN, without SXE).

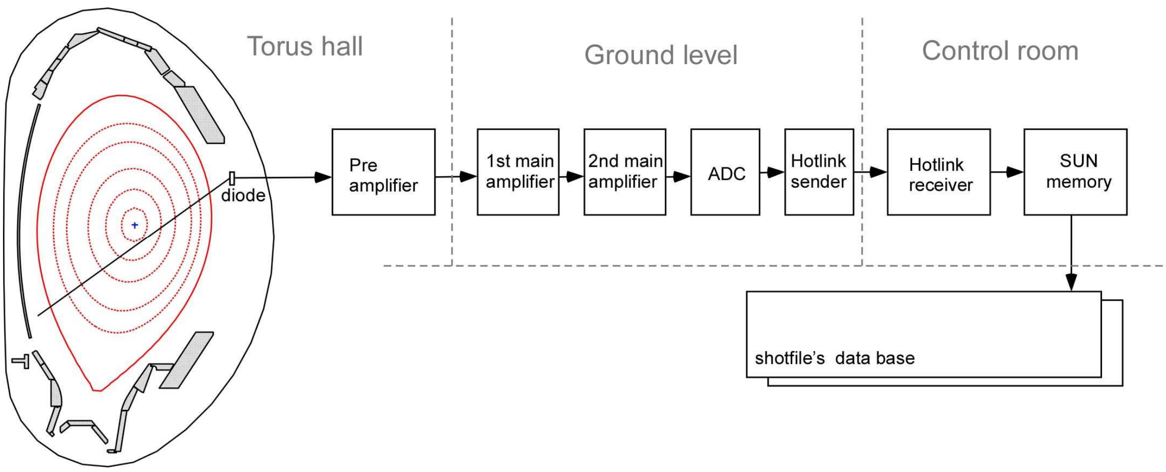

Figure 7. Scheme of the Soft X-ray data acquisition system is shown.

3.2 “Fast” and “Slow” part of the Soft X-ray system

The Soft X-ray diagnostic has two types of main amplifiers. One part (80 channels) is equipped with 12 Bit ADCs, has 500kHz sampling rate and variable low-pass filter frequency, which is typically slightly below 80 kHz. The highest possible filter frequency is 159 kHz, but the signals tend to get strong oscillations with frequencies above 80 kHz, especially with high amplification. Such data cannot be used anymore, so the frequency is usually kept below this value. The filter function for two cut-off frequencies is shown in figure 8 (top). The observed frequency range is sufficient for the investigation of “standard” MHD instabilities (sawtooth precursors, tearing modes, fishbones, etc.).

The other 128 channels are supplied with main amplifiers with 14 Bit ADCs, 2MHz sampling rate and a fixed filter frequency of 500kHz. This part of the diagnostic can in addition be used for the investigation of fast MHD phenomena (TAEs, etc.). Each SUN computer (each diagnostic) operates either with 16 fast or 16 slow channels.

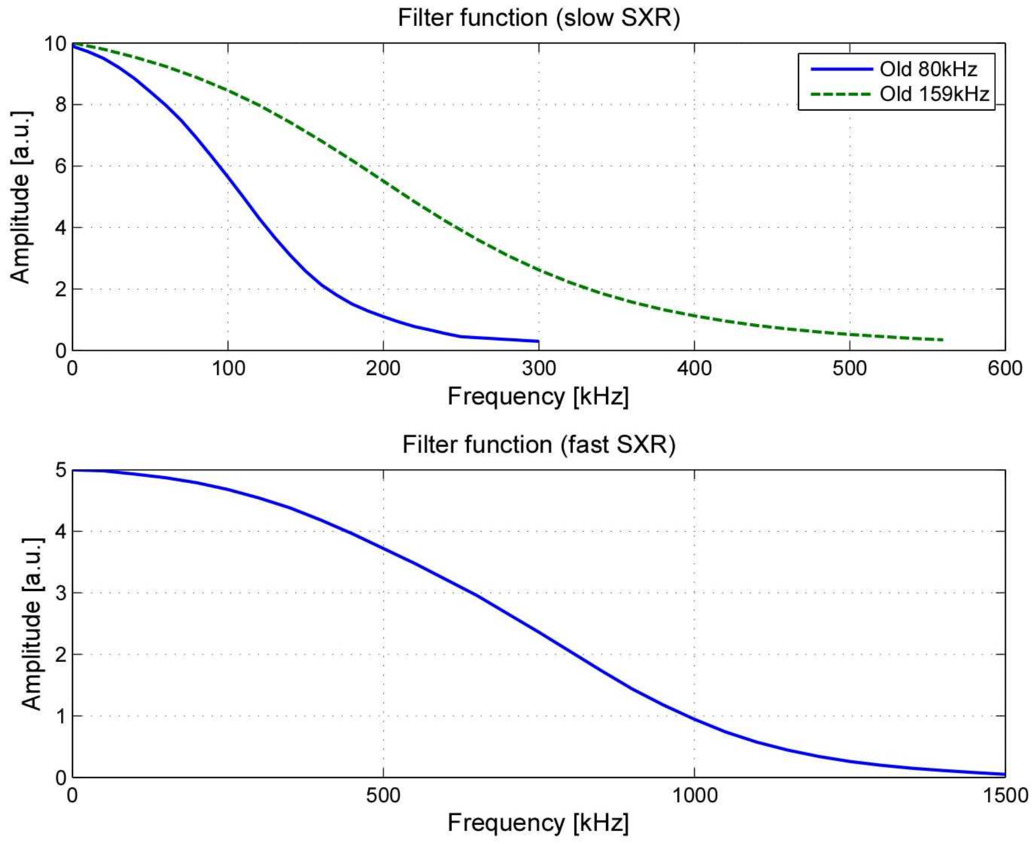

Figure 8. Measured filter function of the main amplifiers for slow Soft X-ray system (80 kHz and 159 kHz settings) and fast Soft X-ray system (fixed 500kHz filter).

4 Shotfiles related to the Soft X-ray diagnostic

In this section we describe the Soft X-ray shotfile structure and how to read in data from shotfiles.

4.1 General information about Soft X-ray shotfiles

Up to #19471 the Soft X-ray data were stored in the diagnostic SXR, which was the only shotfile directly related to the Soft X-ray detectors [2]. The new Hotlink based diagnostic described here started from #20728 (January 2006). However, due to wrong sample frequency the time base of the slow channels is corrupt up to #20806. We recommend to use the command line tool SXinfo (see below) to see whether there are major problems for the discharge you are interested in.

There are two categories of shotfiles related to the Soft X-ray diagnostic. The first contains the level 0 data (meaning the data directly recorded from the experiment) of all 13 diagnostics: SXA to SXN (without SXE, which is a diagnostic for 1-d deconvolution of Soft X-ray signals). In addition there are 2 level 1 shotfiles for each (useful) discharge:

The first is SSX, containing the downsampled (to 5 kHz) data (in ADC units) of all signals in one shotfile, so that the user does not need to know in which diagnostic the raw signal is stored. The SSX time resolution is sufficient for the identification of sawtooth crashes, and convenient for overview plots. A further advantage is that the level 1 shotfiles are always accessible, while the large level 0 Soft X-ray shotfiles are migrated to tape when they have not been touched for a while, and it can take some time to get access to the migrated data.

The other important level 1 diagnostic is CSX, where the calibration objects are stored (identical for the level 0 data and the downsampled SSX data). In addition, there is a lot information on filter, electronics, geometry and more, for all signals in these calibration objects.

Shotfiles at ASDEX Upgrade are stored in the following structure:

/afs/ipp-garching.mpg.de/u/augd/shots/NNNN/DD/DIA/NNNNN[.E]

where NNNN stands for the first 4 digits of the discharge number, DD for the directory (SX for the level 0 Soft X-ray shotfiles, and L1 for the level 1 shotfiles), DIA for the diagnostic name, NNNNN for the discharge number, and E for the edition number (only for level 1 shotfiles).

An example of a level 0 shotfile of the Soft X-ray diagnostic is:

/afs/ipp-garching.mpg.de/u/augd/shots/2500/SX/SXA/25000

An example of a CSX and an SSX shotfile is:

/afs/ipp-garching.mpg.de/u/augd/shots/2500/L1/CSX/25000.1
/afs/ipp-garching.mpg.de/u/augd/shots/2500/L1/SSX/25000.1

4.2 Soft-X-ray (level 0) shotfiles

To view the shotfile header (all information that are not signals) type

xsfed <shotfilename>

with the full path of the shotfile. You can see more details by double-clicking on parameters or on 'next page'. In the level 0 shotfiles you will find the following objects (example for SXC):

Name	Type
SXC	DIAGNOSTIC
SIGNALS	LIST
PREPARE	LIST
ACQUIRE	LIST
CONTROL	LIST
Hot1X	DEVICE
Time	TIME_BASE
M-Hot	MAP_FUNC
H_059	SIGNAL
.... (15 more signals)	
CH_059	PARAM_SET
... (15 more paramsets)	

Out of the first 8 objects only “Time” is needed to read out signals. The rest is for diagnostic control only.

Each line of sight is a separate signal with a unique name: the camera name followed by the number of the diode within the camera (not within the head). For example H_053 is a central (with respect to the plasma) line of sight from the diode in the centre of the middle H chip (H2), whereas H_018 is an edge channel corresponding to the central diode on the H1 chip.

The parameter sets are only a link to the parameter sets of the same name in the calibration shotfile (CSX). The data can be read uncalibrated (digital values) or calibrated, which means relative calibration, since the exact response function of the diodes is not known. For calibrated data, the calibration parameters are automatically taken from the CSX shotfile (for discharge numbers larger than #21427). Also, to access the additional information stored in the calibration objects, you can read the required parameter via ddparm for the signal directly, without having to know the calibration object's name or location.
See the description of shotfile reading routines on the ASDEX Upgrade webpage: (http://www.aug.ipp.mpg.de/wwwaug/ → Documentation → Data access and evaluation → shotfile system) for more information and examples of programs.

4.3 The Verst object and other calibration parameters

Rem.: *For general use you can skip this paragraph, since the full calibration is provided in the calibration objects!*

The diagnostic SXI plays a special role: it is the so-called master diagnostic. The required settings for the amplifiers (and also the low-pass filter frequency for the 500 kHz diagnostics) is controlled by the DEVICE Verst, which is only stored in SXI shotfiles (and is then copied to the CSX shotfiles to allow fast access).

In Verst the binary coding of the amplifier steps, which is different for pre- and main amplifiers, is stored. The first page in Verst shows a number of settings, out of which only filter can be of interest for you: this is the cutoff-frequency of the electronic low-pass applied in the 500 kHz signals. This is followed by a table with 4 columns, showing the factors of the 3 amplification steps (pre amplifier: VV and 2 main amplifier steps: HV1 and HV2) and the bias voltage (BiasVolt) for the first 128 addresses. This page is only a human-readable translation of the parameters shown on the next page. The next page allows access to the full parameter sets (up to 255 values) in their original form.

The meaning of the preamplifier values (VV) is the following:

VV value	pre ampl. sensitivity	Sensitivity
0	3.75 µA/V	7.366E4 V/W
1	15.625 µA/V	1.768E4 V/W
2	62.5 µA/V	4.42E3 V/W
3	250 µA/V	1.105E3 V/W

Here Sensitivity means the overall sensitivity of the system diode plus preamplifier (i.e., the voltage at the preamplifier output per power absorbed in the active layer.) The general value 3.62 W/A, which describes the Silicon sensitivity in the X-ray range, was used.

The main amplifiers provide an amplification of $\left(2^{HV1} \cdot 2^{HV2}\right)$ where HV1 and HV2 are the values (ranging from 0 to 5) of the two main amplification steps.

The BiasVolt values have no meaning anymore, since the bias voltage is now fixed in the hardware. The applied Bias voltages are not stored in a shotfile. Typically, 5 V are applied, but there are also other bias voltages used. The bias voltage plays only a minor role for the signal amplitude. Changes are recorded in the SXJournal on the Webpage.

Before the discharge the Verst data are sent to the main amplifiers, where each device selects the settings from the data stream according to its own address. The index of the corresponding values in the VV, HV1 and HV2 arrays is this address minus 1.

The basic amplification and ADC type are different for the two diagnostic parts (slow and fast):

Electronic step	500 kHz	2 MHz
ADC range	$(2^{12}-1)/10$V	$(2^{14}-1)/5$V
Fixed offset	0.1V	0.05V
Fixed gain	8*0.69	4*0.62

Furthermore, the geometric calibration of each signal depends on the position of the corresponding diode on the chip. All these parts of the calibration are considered in the calibration objects stored in the CSX shotfile.

4.4 CSX calibration shotfile

CSX is the calibration diagnostic for the Soft X-ray diagnostics. Its shotfileheaders contain the following:

CSX DIAG
SIGNALS LIST
Verst DEVICE
CF_006 PARAMSET comment on channel status
....(a lot more PARAMSETs)

There is one parameter set (PARAMSET) for each possible signal of the Soft X-ray diagnostics - i.e., all the diodes that have a cable going out of the torus - are in this list. This number is larger than the number of signals really stored in the shotfiles. The comment contains address, diagnostic name and sample rate if the signal is recorded, and a remark that it is not active if not. Double-clicking in xsfed on the parameter set and then 'nextpage' shows 33 parameters (their name, data type and number of values). To see the values double-click on the parameter.

The first 9 parameters represent the linear calibration. NCALSTEP is the number of calibration steps considered. Each step consists of a factor (MULTIAnn) and a shift (SHIFTBnn). The Multiplication is applied first.

Calib Step	Description	Value (500 kHz)	Value (2 MHz)	Dim
MULTIA00	1/(ADC*Fixed gain)	4.424E-04	1.231E-04	V
SHIFTB00	-(Offset/Fixed gain)	-1.812E-02	-2.016E-02	V
MULTIA01	1/(Sens.*HV1*HV2)			W/V
SHIFTB01	neutral	0	0	
MULTIA02	Geometric calib.			$1/m^2$
SHIFTB02	neutral	0	0	
MULTIA03	neutral	1	1	
SHIFTB03	Offset correction			W/m^2

The description of the steps is given in the following table.

The first step treats all fixed electronic parts. It is identical for all signals of the same type (slow or fast). Offset in SHIFTB00 is the fixed offset from the main amplifiers. The second step contains the variable electronic calibration, including diode sensitivity. The third calibration step treats the geometrical calibration originating from diode and pinhole dimensions as well as external viewing restrictions from tiles. The last step stores an offset correction, calculated from the time range 0.01 to 0.025 s.

The calibration is automatically applied when the Soft X-ray data are read out calibrated (from #21428 on, for earlier discharges see below). It is also possible to apply fewer than NCALSTEP calibration steps, but to do so you have to read out the raw (uncalibrated) data and the calibration parameters from the calibration parameter sets and calculate the (partial) calibration. At the moment there is no way to do this directly using the shotfile reading routines, but has to be done with an individual code.

The remaining parameters have to be read out directly (i.e., from diagnostic CSX, not via the level 0 diagnostics), they are not used for calibration but serve as a convenient way to store the main information on the signals:

ADDRESS	Address of the main amplifier with which this diode is connected.
THETA	Angle of the line-of-sight
RPINHOLE	Major radius of the pinhole position
ZPINHOLE	z value of the pinhole position
REND	Major radius of a point on the line-of-sight that is approximately on the opposite vessel boundary
ZEND	z value of a point on the line-of-sight that is approximately on the opposite vessel boundary
FILT-MAT	Material of the filter in front of the diodes
THICKNES	Thickness of the filter
VVsensit	The pre amplifier sensitivity (explanation for the 4 steps corresponding to the values 0 to 3 is in the table above)
SX_DIAG	diagnostic in which this signal is stored
CAMANGLE	Angle of the chip normal
D_Width	Diode width (lenght in poloidal direction)
D_Length	Diode length (length in toroidal direction)
D_Gap	Gap width on chip
P_Width	Pinhole width (length in poloidal direction)
P_Length	Pinhole length (length in toroidal direction)
Foc_Len	focal length (distance chip surface – pinhole plane)
Lwid_pol	poloidal width of line-of-sight (in degrees)
Lwid_tor	toroidal width of line-of-sight (in degrees)
Tor_Pos	toroidal position of the camera
ADCrange	highest output value of ADC (4095 for 12 Bit ADC; 16383 for 14 Bit ADC)
SampFreq	sample frequency (500 kHz or 2 MHz)
V_Range	voltage range of ADC (10V or 5V)
V_Offset	hardware fixed voltage offset before ADC

For discharges starting from #21428, these parameters can be accessed via ddparm (see http://www.aug.ipp.mpg.de/wwwaug/ → Documentation → Data access and evaluation → shotfile system) for the signal directly, without knowing name and location of the calibration object. Of course, access through the calibration object in the CSX shotfile works as well.

Up to #21427 the calibration objects were stored directly in the level 0 shotfiles. This internal calibration was wrong and could not be corrected. Still, a calibration shotfile CSX has been created later, which stores the correct calibration sets and also the other information. However, the automatic access through the signal does not work in these cases. It is possible to calibrate the data before #21428 using the CSX shotfile, but this requires special procedures. We recommend to contact one of the responsible persons to get correct calibration for these shots.

4.5 SSX shotfile with downsampled Soft X-ray data

SSX is the level 1 diagnostic for down sampled (to 5 kHz) Soft X-ray data from all level 0 diagnostics. It is provided for each "useful plasma shot". Advantages of SSX are the very fast access time (level 1 diagnostics are always online and the amount of data is much smaller than in the level 0 SX data), the possibility to plot and analyse larger time ranges, and the fact that all signals are in one diagnostic. The time resolution is sufficient for sawtooth identification and well suited for overview plots.

SSX shotfiles can have fewer signals than all the level 0 shotfiles in total, since signals with a FIFO error diagnosed on the corresponding Hotlink card (serving 8 signals) are not considered. Those signals can still partially be useful, but this has to be checked individually. Contact the responsible persons if you need to have confirmation for such signals.

The data can be accessed with standard reading routines (see description and examples of shotfile reading routines in different languages (FORTRAN, C, IDL, Perl, Python, Matlab) on the webpage: http://www.aug.ipp.mpg.de/wwwaug/ → Documentation → Data access and evaluation→A basic example for reading a shotfile in various programming languages.)

5 Programs related to the Soft X-ray diagnostic

In the following, some programs that can be used for Soft X-ray data analysis are discussed. It is necessary to mention that ASDEX Upgrade has a universal data base which means that Soft X-ray signals can be accessed via standard subroutines and many other programs are also able to handle and plot the Soft X-ray data directly.

5.1 Command line tools for Soft X-ray diagnostic

SXinfo <shotnumber>

SXinfo is a routine that prints warnings for the SX diagnostics for a given shotnumber. Mainly structural errors like wrong signal names or rather global problems are taken into account. Problems with individual signals are also described, as far as they are known and well defined. Still, there is no guarantee for completeness.

WhichSX [<shotnumber>] [<signal_name>]

WhichSX finds the diagnostic name and address for Soft X-ray signals. Type 'WhichSX -h' for a description.

5.2 Visualization of the lines of sight with diaggeom

The program **diaggeom** (author: Christoph Fuchs) depicts the diagnostic, in which the individual signal names are stored, when you right-click on the line of sight. Figure 5 in this report was created with this program.

5.3 Data analysis with mtr

The IDL based **mtr** program (author: Marc Maraschek) is an efficient and often used tool for MHD analysis, not only for Soft X-ray data. It allows a wide range of tools that are adjusted to the different purposes/diagnostics. For Soft X-ray data you do not have to know in which diagnostics the signals are stored. The program does it for you. It can be called from command prompt by typing: **mtr**.
In the main configuration window the global settings can be adjusted: experiment, diagnostic, signals, shot number and time window. The program provides for Soft X-ray data:

- mean profiles of Soft X-ray radiation and various plotting tools

- fast Fourier transformation for determination of mode location and structure (poloidal mode number *m*)
- toroidal mode number *n* determination from comparison of F and G signals
- plasma centre determination from Soft X-ray signals
- 1-d deconvolution for selected time range and channels

5.4 Plotting signals with cview

The IDL based **cview** program (author: Garrard Conway) can be used for reading and displaying ASDEX Upgrade signals. It is especially suited for overview plots which include different signals, for example, plasma current, magnetic diagnostic, Soft X-ray and ECE. It is a universal routine, which means that you have to put in all information on the signals, like the diagnostic name. The program can be called from the command prompt by typing: **cview**.

5.5 Spectral analysis with xspecamp

The IDL based **xspecamp** program is a convenient tool for spectral analysis. It uses shifted Fast Fourier Transformation to produce spectrograms for a given signal. Furthermore, it can track mode frequencies and depicts mode amplitudes. The program can be called from the command prompt by typing: **xspecamp**. The spectrogram in figure 10 in this report was made with this program.

5.6 Tomographic reconstruction

The soft X-ray tomography program (author: Asher Flaws) combines the signals from the many different Soft X-ray sight lines to reconstruct a poloidal cross section of total emissivity (or perturbation of the emissivity) [6]. The user interface is written in MATLAB, the core algorithm in FORTRAN (the same algorithm was used in W7-AS tomography). The program requires installation for each user account. More information and a description of the installation procedure are in the WEB (http://www.aug.ipp.mpg.de/wwwaug/ → Diagnostics → Soft X-Ray measurements → Soft X-ray tomography).

5.6.1 Maximum entropy tomography

Reconstructions using pure Maximum Entropy does not require any equilibrium mapping and can be carried out over the entire poloidal cross section of the plasma. However, the resolution often is too poor to clearly resolve MHD modes with m > 2. This method is suited for reconstructing the bulk plasma emissivity: sawtooth crashes, disruptions, the internal kink and large $m \leq 2$ magnetic islands.

5.6.2 Rotation tomography for the mode reconstruction

Reconstructions using Rotation tomography achieve better resolution than pure Maximum Entropy by adding virtual sight lines. However, this type of reconstruction can only be done within the separatrix and relies on the equilibrium mapping for rho poloidal and theta star. This method is suited for reconstructing individual MHD modes but **not** for reconstructing the bulk plasma emissivity, sawtooth crashes or disruptions. An example of the reconstruction of a (1,1) mode and its (2,2) harmonic before the sawtooth crash from Ref.[7] is shown in figure 9. This is also an example of combined use of fast and slow parts of the diagnostic.

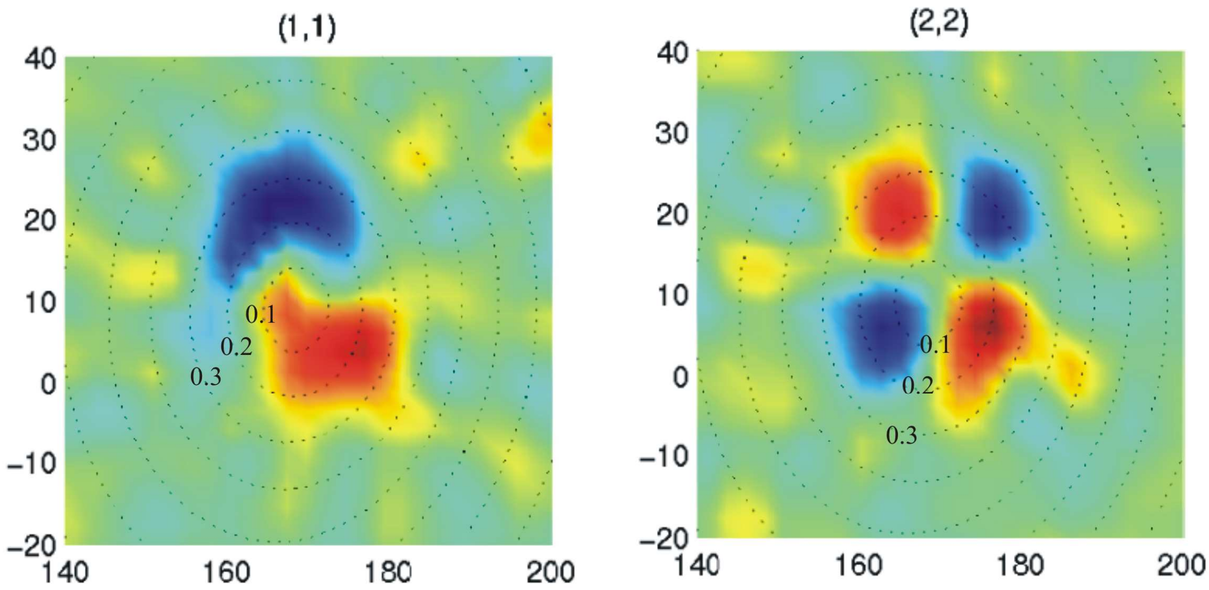

Figure 9. Tomography of the perturbed part of Soft X-ray emissivity for (1,1) mode and its 1st harmonic (2,2) before the sawtooth crash [7].

6 Examples of Fast Particle Instabilities observed by the Soft X-ray diagnostic

Thermonuclear plasmas are characterized by significant populations of suprathermal particles with velocities much larger than the thermal velocity. In spite of the small amount of such particles they can provide a substantial part of the pressure and will be much more important in bigger devices like ITER (fusion-driven α particles). In ASDEX Upgrade such fast particle population is produced by ion cyclotron resonance heating (ICRH) and neutral beam injection (NBI). The interaction of such particles with MHD modes leads to a wide range of high frequency instabilities (from 50-60kHz up to 300-400kHz). In this section we present examples of fast MHD instabilities as they are seen on Soft X-ray signals.

Figure 10 shows the spectrogram of a discharge with several types of fast particle modes. In the current rise phase, low toroidal *n* number modes are observed with frequencies that increase rapidly with time, chirping up from 50kHz to 200kHz, as clearly seen on the spectrogram. These modes, Alfvén Cascades (or **R**eversed **S**hear **A**lfvén **E**igenmodes), are expected when the minimum value of the safety factor profile, q_{min}, passes through low order rational values, particularly at integers and half-integers. At the same time, standard Toroidal Alfvén Eigenmodes (TAEs) are also present (slow evolution from 110kHz to 190kHz). Beta Induced Alfvén Eigenmodes (BAEs) appear at a later time point as shown in the figure (60-90kHz). One can see that these modes cover a large frequency range and good temporal resolution is crucial for their detection and identification. Analysis of Soft X-ray signals allows not only to identify the frequency behaviour from the spectrogram but also the localization of the mode with Fourier transformation (at the beginning of the cascade) and the shape of the eigenfunction as shown for the TAE case $\left(|\xi| \approx \tilde{I}_{SXR} / \nabla \langle I_{SXR} \rangle\right)$. Knowledge about TAEs and cascades can be used to precisely constrain the safety factor profile and provide a qualitative measure of the fast particle evolution. Further application of the Soft X-ray diagnostic for investigation of fast particle modes in ASDEX Upgrade can be found in recently published papers [8-14]. At present, analysis of the Soft X-ray signals is the main tool for localization of such fast particle modes in ASDEX Upgrade tokamak.

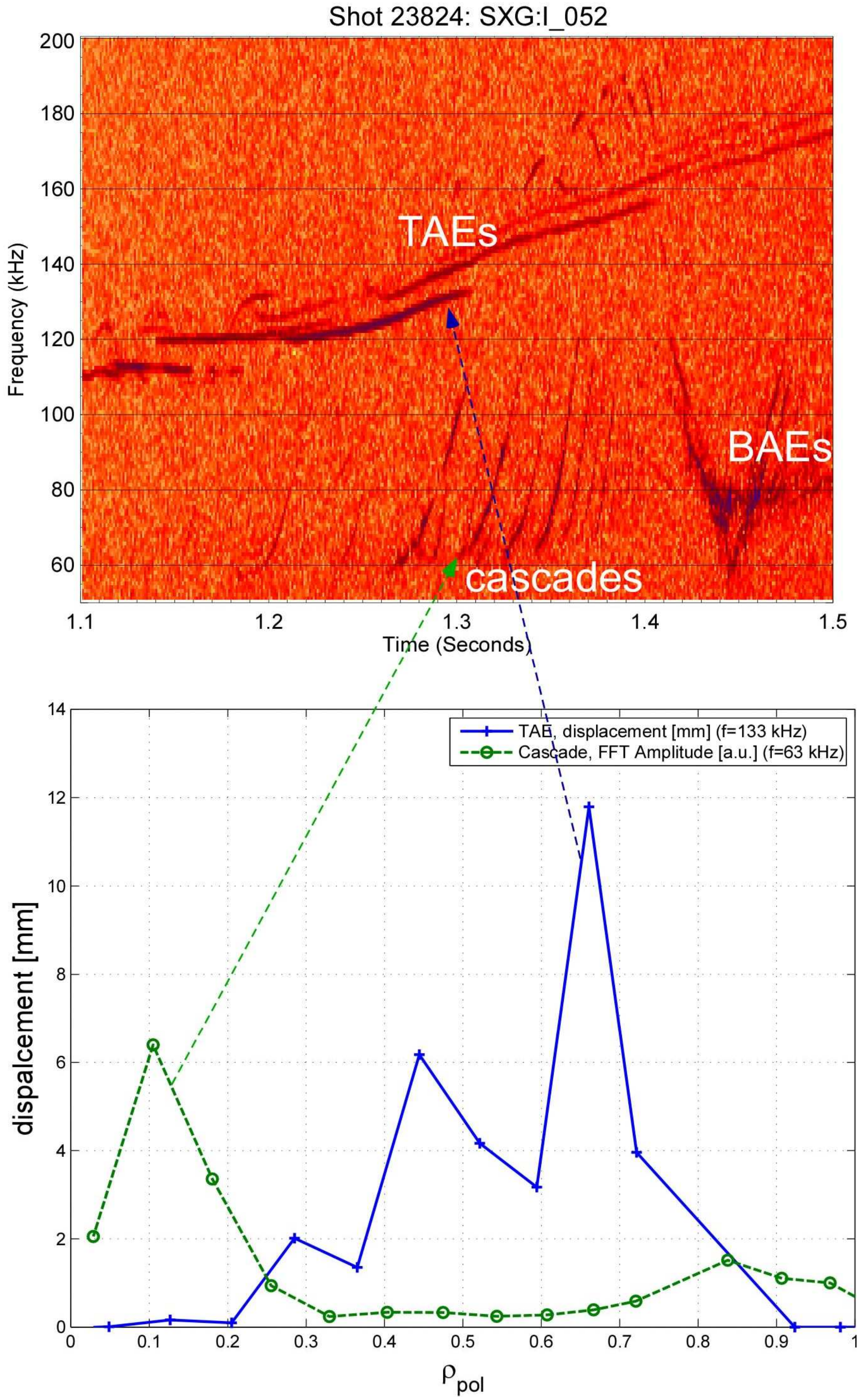

Figure 10. Spectrogram of a fast line of sight (I_052) is shown together with results of the reconstruction of the MHD modes. Particular instabilities (TAE, BAE, cascades) are marked.

7 Summary

The new Soft X-ray system for ASDEX Upgrade tokamak combines a low cost and small size solution with the possibility to investigate fast MHD events (TAEs, BAEs, cascades, etc.). The Soft X-ray system is also intensively used for the investigation of standard MHD instabilities (sawtooth, NTM, fishbones, etc) as well as for impurity fluxes (in combination with bolometry). Soft X-ray data can provide information on the plasma centre, which is important for equilibrium reconstruction. The diode array chips are replaced each 1-2 year of operations simultaneously in all cameras, to keep signal degradation low.

In addition to this report, we recommend the information from the ASDEX Upgrade webpage on the Soft X-ray diagnostic (http://www.aug.ipp.mpg.de/wwwaug/ → Diagnostics → Soft X-Ray measurements). This online information is updated together with hardware and software changes.

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It is a pleasure for us to acknowledge the excellent support from the whole ASDEX Upgrade team.

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Apendix A: IDL routines

The IDL routine for Soft X-ray data are stored under
/afs/ipp/u/mrm/idl/user_contrib/mrm/diag_sxr/.
They connected via a soft link into the standard AUG IDL search path
+/afs/ipp/u/augidl/idl/uset_contrib/,
which should be always included in the IDL_PATH environment variable.
The system variable !libddw should point to the standard value, /usr/ads/lib/libddww.so, i.e. !libddww='/usr/ads/lib/libddww.so'.

• List of Routines

• Routine Descriptions

• ANALYZE_SXR_NAMES

[Next Routine] [List of Routines]

```
 NAME:
        ANALYZE_SXR_NAMES

 PURPOSE:
        Integral part of the MTR programme, which can also might
        be useful for extracting single cameras for furhter data
        analysis.

 CATEGORY:
        AUG data retrieval routines.

 CALLING SEQUENCE:
        ANALYZE_SXR_NAMES, group,my_signames,my_diag_names,my_indices, $
                cameras,cam_ind, $
                signames, diag_names, indices

 INPUTS:
        group:          Group or selected camera from mtr-prgramme.
        my_signames:    Original signal names from shotfile.
        my_diag_names:  Original diagnostic names from shotfile.
        my_indices:     Original indices from shotfile, indicating
availability.

 OUTPUTS:
```

```
        cameras:        List of selected camera(s).
        cam_ind:        List of selected lines of sight(s).
        signames:       Resorted/selected signal names.
        diag_names:     Resorted/selected diagnostic names.
        indices:        Resorted/selected indices.

 RESTRICTIONS:
        Makes only sense in the AUG environment.

 EXAMPLE:
        get_sx__names,25845,my_signames, my_diag_names, my_indices, $
                cameras, cam_ind, available_cams
        group = 'I'
        analyze_sxr_names,group,my_signames, my_diag_names, my_indices, $
                cameras,cam_ind, $
                signames, diag_names, indices
        print,cameras   ; now only 'I' included
        print,cam_ind   ; corresponding lines of sight
        print,signames  ; now only 'I' included
        print,diag_names; now only 'I' included
        print,indices   ; now only 'I' included


 MODIFICATION HISTORY:
        Written by:     M.Maraschek
        Feb, 2010       Start of this documentation, written long before.
```

(See /u/mrm/idl/user_contrib/mrm/diag_sxr/analyze_sxr_names.pro)

- # GET_SSX_NAMES

[Previous Routine] [Next Routine] [List of Routines]

```
 NAME:
        GET_SSX_NAMES

 PURPOSE:
        This procedure reads the available signalnames corresponding
        to the cameras and lines of sight of the Soft X-Ray diagnostic
        level-1 files at ASDEX Upgrade for a specific discharge.

 CATEGORY:
        AUG data retrieval routines.

 CALLING SEQUENCE:
        GET_SSX_NAMES, shot, my_signames, my_diag_names, my_indices, $
                cameras, cam_ind, available_cams

 INPUTS:
        shot:           Shot number for which the information on the
available signals
                        should be retrieved from the shotfile.

 OUTPUTS:
        The signal names, availability, cameras and lines of sight for
        given AUG discharge.

        my_signames:    Signal names of all available SIGNAL's.
        my_diagnames:   Diagnostic in which each my_signames entry is
stored.
```

```
        my_indices:     String array with the camera name for each signal.
        cam_ind:        Array of the line of sight index for each signal.
        available_cams: String array of the available cameras.

 KEYWORD PARAMETERS:
        NSIGNALS:       Number of available signals.
        SEPARATOR:      Separator between camera and index in signalname,
default='_'.
        EXP:            Experiment in which data should be searched,
default='AUGD'.
        DIAG:           Diagnostic in which data should be searched,
default='SSX'.
        ED:             Edition for which data should be searched,
default=0l.
        HELP:           Show this help.

 RESTRICTIONS:
        Works only in the AUG afs environment togehter with the libddww.

 EXAMPLE:
        get_ssx_names,25845,my_signames, my_diag_names, my_indices, $
                cameras, cam_ind, available_cams, diag='SSX', exp='AUGD'
        for i=0,n_elements(my_signames)-1 do begin
                print,i,my_signames[i],my_diagnames[i],my_indices[i], $
                        cameras[i], cam_ind[i]
        endfor
        for i=0,n_elements(available_cams)-1 do print,i,available_cams[i]

 MODIFICATION HISTORY:
        Written by:     M.Maraschek
        Feb, 2010       Start of this documentation, written long before.
```

(See /u/mrm/idl/user_contrib/mrm/diag_sxr/get_ssx_names.pro)

• GET_SX__NAMES

[Previous Routine] [Next Routine] [List of Routines]

```
 NAME:
        GET_SX__NAMES

 PURPOSE:
        This procedure reads the available signalnames corresponding
        to the cameras and lines of sight of the Soft X-Ray diagnostic
        from the raw files (level-0) at ASDEX Upgrade for a specific
discharge.
        The routine automatically checks all diagnostics, which are
        available for a given shot.

 CATEGORY:
        AUG data retrieval routines.

 CALLING SEQUENCE:
        GET_SX__NAMES, shot, my_signames, my_diag_names, my_indices, $
                cameras, cam_ind, available_cams

 INPUTS:
        shot:           Shot number for which the information on the
available signals
                        should be retrieved from the shotfile.
```

```
 OUTPUTS:
        The signal names, availability, cameras and lines of sight for
        given AUG discharge.

        my_signames:    Signal names of all available SIGNAL's.
        my_diagnames:   Diagnostic in which each my_signames entry is
stored.
        my_indices:     String array with the camera name for each signal.
        cam_ind:        Array of the line of sight index for each signal.
        available_cams: String array of the available cameras.

 KEYWORD PARAMETERS:
        NSIGNALS:       Number of available signals.
        SEPARATOR:      Separator between camera and index in signalname,
default='_'.
        EXP:            Experiment in which data should be searched,
default='AUGD'.
        PREFIX:         Diagnostic name prefix, default='SX'
        NUM_DIAGS:      Number of PREFIX* diagnostics to be searched for,
default=14l
        HELP:           Show this help.

 RESTRICTIONS:
        Works only in the AUG afs environment together with the libddww.

 EXAMPLE:
        get_sx__names,25845,my_signames, my_diag_names, my_indices, $
                cameras, cam_ind, available_cams, exp='AUGD'
        for i=0,n_elements(my_signames)-1 do begin
                print,i,my_signames[i],my_diagnames[i],my_indices[i], $
                        cameras[i], cam_ind[i]
        endfor
        for i=0,n_elements(available_cams)-1 do print,i,available_cams[i]

 MODIFICATION HISTORY:
        Written by:     M.Maraschek
        Feb, 2010       Start of this documentation, written long before.
```

(See /u/mrm/idl/user_contrib/mrm/diag_sxr/get_sx__names.pro)

- # READ_SSX

[Previous Routine] [Next Routine] [List of Routines]

```
 NAME:
        READ_SSX

 PURPOSE:
        Read level-1 SSX data from Soft X-Ray camera data at
        ASDEX Upgrade in the AUG envoronment.

 CATEGORY:
        AUG data retrieval routines.

 CALLING SEQUENCE:
        READ_SSX, shot, trange, time, data, info

 INPUTS:
        shot:   shot number for which data should be read
```

```
        trange=[t_start,t_end]:
                time range for data reading

 OUTPUTS:
        Time vector and array of data for all Soft X-ray channel
        sorted in level-1 SSX file.

        time:   time vector of the retrieved data
        data:   data array with channels and time as the 2 index fields
        info:   information structurre containing the geometry
                and data information for all channels

 KEYWORD PARAMETERS:
        DIAG:           Diagnostic in which data should be searched,
default='SSX'.
        ED:             Edition of requested shotfile, default=0l.
        EXP             Experiment in which data should be searched,
default='AUGD'.
        FILE:           Data file containing a preselection of signal names
(from sel_dlg.pro).
        NO_CALIB:       Suppress calibration and read raw data.
        NO_HOTLINK_CORR:Suppress hotlink corrections.
        SIGNAMES:       Array of requested signal names.
        SMOOTH:         Smooth interval in seconds for data smoothing.
        HELP:           Show this help.

 RESTRICTIONS:
        Works only in the AUG afs environment togehter with the libddww.

 EXAMPLE:
        shot = 25845
        time_range = [2.,3.]
        get_ssx_names,shot,my_signames, my_diag_names, my_indices, $
                cameras, cam_ind, available_cams, diag='SSX', exp='AUGD'
        ind = where(cameras eq 'I')
        my_signames = my_signames[ind]
        my_diag_names = my_diag_names[ind]
        my_indices = my_indices[ind]
        cameras = cameras[ind]
        cam_ind = cam_ind[ind]
        read_ssx,shot,time_range,time,data,info,signames=my_signames
        plot_wid,data,time

 MODIFICATION HISTORY:
        Written by:     M.Maraschek
        Feb, 2010       Start of this documentation, written long before.
```

(See /u/mrm/idl/user_contrib/mrm/diag_sxr/read_ssx.pro)

- # READ_SXR

[Previous Routine] [Next Routine] [List of Routines]

```
 NAME:
        READ_SXR

 PURPOSE:
        Read old level-0 SXR data from Soft X-Ray camera data at
        ASDEX Upgrade in the AUG envoronment. This routine only
        works for the old transputer based diagnostic SXR.
```

```
 CATEGORY:
        AUG data retrieval routines.

 CALLING SEQUENCE:
        READ_SXR, shot camera indices time data

 INPUTS:
        shot:   shot number for which data should be read
        camera: Name of the requested camera. Only one at a time.
        indices:SFH structured indices of the requested signal. See the
example.

 OUTPUTS:
        Time vector and array of data for the old Soft X-ray
        data structure from the level-0 SXR shotfile.

        time:   time vector of the retrieved data
        data:   data array with channels and time as the 2 index fields

 KEYWORD PARAMETERS:
        DIAG:           Diagnostic in which data should be searched,
default='SXR'.
        ED:             Edition of requested shotfile, default=0l.
        EXP             Experiment in which data should be searched,
default='AUGD'.
        CALIB:          Request physically calibrated data.
        PHYSDIM:        String with physical dimension as stored in the
shotfile.
        TIME_WINDOW:    2 dimensional array with requested time window.

 RESTRICTIONS:
        Works only in the AUG afs environment togehter with the libddww.

 EXAMPLE:

read_sxr,18000,'A',[[10l,1,1],[12l,1,1]],time,data,time_win=[2.,3.],/calib
        plot_wid,data,time,findgen(2)

 MODIFICATION HISTORY:
        Written by:     M.Maraschek
        Feb, 2010       Start of this documentation, written long before.
```

(See /u/mrm/idl/user_contrib/mrm/diag_sxr/read_sxr.pro)

• READ_SX_

[Previous Routine] [Next Routine] [List of Routines]

```
 NAME:
        READ_SX_

 PURPOSE:
        Read level-0 SSX data from Soft X-Ray camera data at
        ASDEX Upgrade in the AUG envoronment.

 CATEGORY:
        AUG data retrieval routines.

 CALLING SEQUENCE:
```

```
        READ_SX_, shot names time data r z theta phi phaseshift

 INPUTS:
        shot:           shot number for which data should be read

 OUTPUTS:
        Time vector and array of data of the requested names,
        i.e. channels of the Soft X-ray cameras from the
        hotlink based level-0 files.

        time:           time vector of the retrieved data
        data:           data array with channels and time as the 2 index
fields
        r:              R coordiante of pinhole.
        z:              Z coordiante of pinhole.
        theta:          theta coordiante of pinhole.
        phi:            phi coordiante of pinhole.
        phaseshift:     future use.
        info:           information structurre containing the geometry
                        and data information for all channels

 KEYWORD PARAMETERS:
        DIAGS:          Array of iagnostics for reading the data
accorinding to the names.
        TIME_WINDOW:    2 dimensional array with requested time window.
        EXP             Experiment in which data should be searched,
default='AUGD'.
        PREFIX:         Diagnostic name prefix, default='SX'
        NUMDIAGS:       Number of PREFIX* diagnostics to be searched for,
deault=14l
        NO_CALIB:       Suppress calibration and read raw data.
        NO_CORRECT:     Suppress hotlink corrections.
        NCALSTEP:       Read uncalibrated raw data and perform NCALSTEP
calibration steps.
        SX__PARAMS:     Geometry parameters from shotfile.
        VERST:          Data from VERST object form shotfile.
        F_SAMPLE:       Array of sampling rates for all channels.
        DEBUG:          Print additional debug information.
        HELP:           Show this help.

 RESTRICTIONS:
        Works only in the AUG afs environment togehter with the libddww.

 EXAMPLE:
        shot = 25845
        time_range = [2.2,2.3]
        get_sx__names,shot,my_signames, my_diag_names, my_indices, $
                cameras, cam_ind, available_cams
        ind = where(cameras eq 'I')
        my_signames = my_signames[ind]
        my_diag_names = my_diag_names[ind]
        my_indices = my_indices[ind]
        cameras = cameras[ind]
        cam_ind = cam_ind[ind]
        ind = where(my_indices eq 1)
        my_signames = my_signames[ind]
        my_diag_names = my_diag_names[ind]
        my_indices = my_indices[ind]
        cameras = cameras[ind]
        cam_ind = cam_ind[ind]
        read_sx_,shot,my_signames,time,data,r,z,theta,phi,phase, $
                time_win=time_range,diags=my_diag_names
        plot_wid,data,time
```

```
 MODIFICATION HISTORY:
        Written by:     M.Maraschek
        Feb, 2010       Start of this documentation, written long before.
```

(See /u/mrm/idl/user_contrib/mrm/diag_sxr/read_sx_.pro)

• READ_SX_PARAMS

[Previous Routine] [Next Routine] [List of Routines]

```
 NAME:
        READ_SX_PARAMS

 PURPOSE:
        This routine read all the geometry and calibration information
        for the hotlink based level-0 and level-1 files from the
        corresponding calibration file.

 CATEGORY:
        AUG data retrieval routines.

 CALLING SEQUENCE:
        READ_SX_PARAMS, shot, diag, names, params, verst_params

 INPUTS:
        shot:           Shot for which SXR information is requested.
        diag:           Diagnostic name for which information is requested
                        (level-0,level-1 or calibration file).
        names:          Array of names for requested signals (real signal
names or PARAM_SET's).
                        Note: All names must be contained in the requsted
diagnostic.

 OUTPUTS:
        In the params and verst_params objects all inforamtion on a
specific
        line of sight of the SXR diagnostic is given back.

        params:         Complete geometry and calibration information
array.
        verst_params:   Verst object from shotfile (SXI or CSX).

 KEYWORD PARAMETERS:
        EXP:            Experiment in which data should be searched,
default='AUGD'.
        ED:             Edition of requested shotfile, default=0l.
        DEBUG:          Print additional debug information.
        HELP:           Show this help.

 RESTRICTIONS:
        Works only in the AUG afs environment together with the libddww.

 EXAMPLE:
        shot = 25845
        read_sx_params,shot,'SXC',['H_053''I_053'],p,v          ; raw data,
level-0
        help,/st,p,v
        read_sx_params,shot,'SSX',['H_053''I_053'],p,v          ; raw data,
level-1
```

```
        help,/st,p,v
        read_sx_params,shot,'SXC',['CH_053''CI_053'],p,v        ;
calibration, level-0
        help,/st,p,v
        read_sx_params,shot,'SSX',['CH_053''CI_053'],p,v        ;
calibration, level-1
        help,/st,p,v
        read_sx_params,shot,'CSX',['CH_053''CI_053'],p,v        ;
calibration from calibration file
        help,/st,p,v

 MODIFICATION HISTORY:
        Written by:     M.Maraschek
        Feb, 2010       Start of this documentation, written long before.
```

(See /u/mrm/idl/user_contrib/mrm/diag_sxr/read_sx_params.pro)

• SXR_GET_CAMERAS

[Previous Routine] [List of Routines]

```
 NAME:
        SXR_GET_CAMERAS

 PURPOSE:
        This procedure extracts from the original signal names
        in the level-0 or level-1 from the SXR diagnostic
        the corresponding cameras and indices from the
        lines of sight and summarizes the overall available cameras.

 CATEGORY:
        AUG data retrieval routines.

 CALLING SEQUENCE:
        SXR_GET_NAMES, signames, cameras, indices, real_cams

 INPUTS:
        signames:       The list of all signal names as given back
                        from the shotfiles.

 OUTPUTS:
        Short informative resorted camera and line of sight information.

        cameras:        List of the corresponding camera for each signal.
        indices:        List of the corresponding indices for eahc camera.
        real_cams:      List of the overall available cameras.

 KEYWORD PARAMETERS:
        DEBUG:          Print additional debug information.
        SEPARATOR:      Separator between camera and index in signalname,
default='_'.

 RESTRICTIONS:
        Only makes sense in the AUG environment.

 EXAMPLE:
        get_names,25845,'SSX',names
        sxr_get_cameras,names,cameras,indices,real_cams
        for i=0,n_elements(real_cams)-1 do begin
                ind = where(cameras eq real_cams[i])
```

```
                for j=0,n_elements(ind)-1 do begin

print,string(i,real_cams[i],j,cameras[ind[j]],indices[ind[j]])
                endfor
        endfor

 MODIFICATION HISTORY:
        Written by:     M.Maraschek
        Feb, 2010       Start of this documentation, written long before.
```

(See /u/mrm/idl/user_contrib/mrm/diag_sxr/sxr_get_cameras.pro)
