Bolometric System for the CASTOR Tokamak

Technical description

INTRODUCTION

Bolometric system for the CASTOR tokamak is intended for measurements of electromagnetic radiation loss power from plasma. Its main features are fast response time and improved signal-to-noise ratio achieved owing to utilization of semiconductor detectors with wide-band spectral sensitivity. Note that the detectors do not measure energy losses with low energy (less than 5 keV) neutral particles. The system ensures 16 channel measurements which allow obtaining of radial profiles of the radiation losses. The system is not piezosensitive and its signal is not affected by microwave radiation.

The system includes two main parts: Detector Measuring Head (pinhole chamber) and Preamplifier Unit with power supply.

Measuring Head is placed inside vacuum vessel on the bottom port flange of the CASTOR tokamak. It is fixed by two screws in predefined position which ensures the full view of poloidal plasma cross-section. Detector signals are brought to Preamplifier Unit through a vacuum-tight connector placed on the same flange.

Preamplifier Unit is to be located at a possibly close distance to the tokamak vessel. The Unit provides signal amplification to the level needed for data acquisition system of CASTOR tokamak.

MAIN PARAMETERS

- Spectral range of sensitivity – 1 – 10000 eV
- Linear part of sensitivity range (±8%) – 100 – 5000 eV
- Number of channels – 16
- Total angle of view – 36^o
- Detector channel etendue – 0.003 – 0.02 mm^2*sr[*]
- Output sensitivity – $5*10^4 – 10^6$ V/W[**]
- Output voltage range – 0 … +5 V
- Channel frequency band – 0 … 100 kHz
- Operating temperature range – +10 … 50^oC
- Max. vacuum baking temperature – $+150^oC$

[*] determined by the width of the changeable aperture slit.
[**] determined by the changeable feedback resistors in the Preamplifier Unit.

DETECTOR ARRAY*

AXUV-20EL silicon photodiode linear array is manufactured by ***International Radiation Detectors Inc.*** (IRD, Torrance, Ca. USA, *www.ird-inc.com*) for absolute radiometry measurements in vacuum ultraviolet, extreme ultraviolet and soft X-ray (XUV, wavelength range 2 to 1800 A, energy range 7 eV to 6000 eV) spectral region. National standard laboratories NIST (USA) and PTB (Germany) have approved the use of AXUV-series IRD photodetectors as secondary standards with ±4% uncertainty in 30 eV to 6 keV range.

Applying of IRD advanced nitridation technology results in low rate of detector surface carrier recombination yielding ultimate internal quantum efficiency preserved stable up to 1 Grad absorbed radiation dose (when tested with 10.2 eV photons) and 4-week exposure to 100% relative humidity atmosphere.

The calibration (spectral sensitivity) curve of the AXUV detectors provided by the manufacturer is shown in fig. 1. More information about the detectors, if necessary, can be obtained from the IRD web site *www.ird-inc.com* and publication [1]; information about using these detectors as bolometers in tokamak experiments from [2–5]. A possible method of such bolometer calibration accounting for non-linear part of spectral sensitivity curve is described in [6].

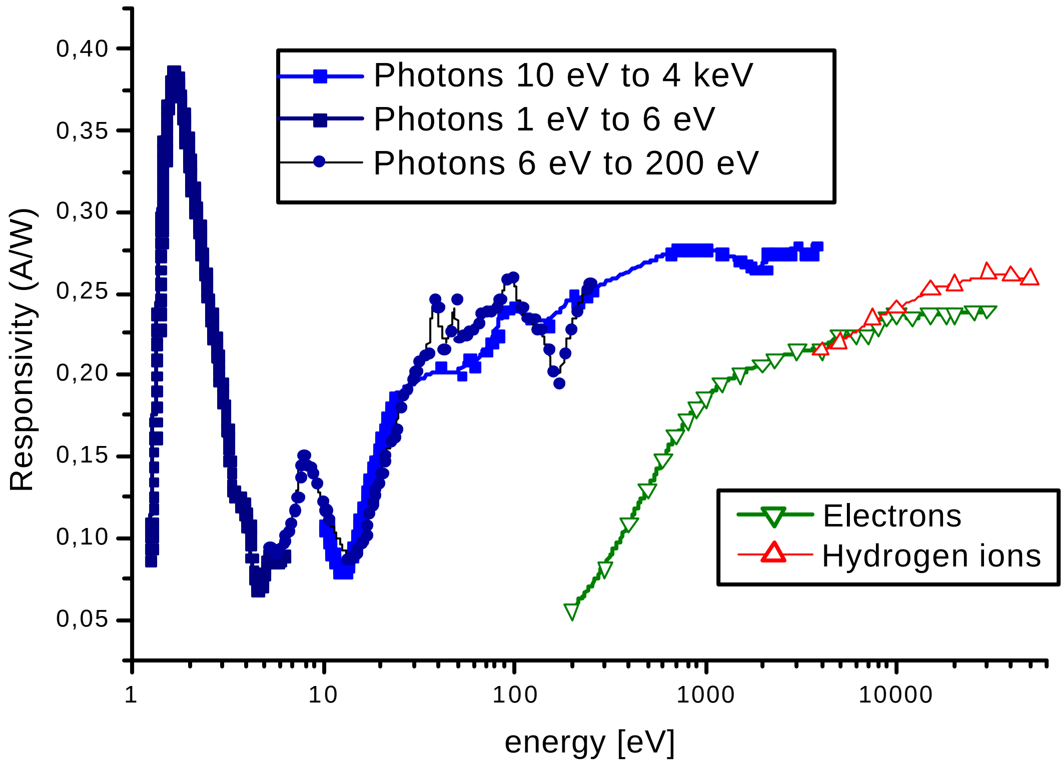


Fig. 1. Calibration curve of AXUV detectors (dependence of responsivity in amperes of photocurrent per watt of incident power, on energy of incident particles [photons, electrons, hydrogen ions]).

---

* Detector array is not included in the delivery and is to be installed before using the system on CASTOR.

The array geometry with the correspondence of pins is shown in fig. 2. Note that only 16 central elements (with numbers 3..18) are used in the system. Element 3 looks at the innermost part of the plasma.

<u>***Specifications***</u> (at room temperature)

- Sensitive area – 3 (×20) mm^2
- Array length – 31.75 mm
- Element size - height – 4.0 mm
  - width – 0.75 mm
- Inter-element spacing – 0.144 mm
- Package material – Ceramic
- Responsivity – 0.26 A/W ± 5% (at $h\nu$=1... 5 keV)
- Shunt resistance – 300 MΩ
- Capacitance at 0 V bias – 500 pF
- Rise/fall time (10-90%) – 0.2 µs

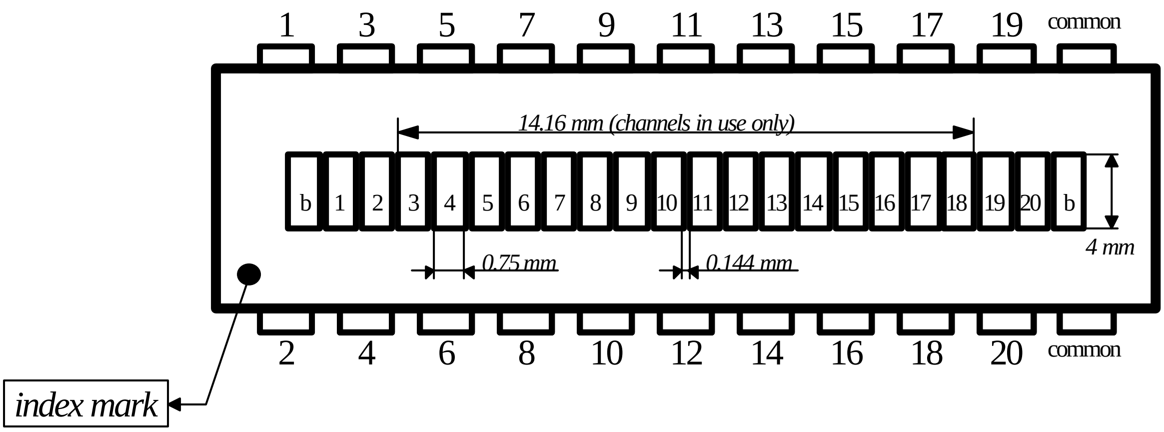


Fig. 2. Geometry of AXUV-20EL array (not to scale; b - blind element).

MEASURING HEAD and geometry of detector installation

The Measuring Head is to be fixed by two screws M4 and M6 (screw holes are pos. ***A*** in fig. 3) in a predefined position on the flange of the CASTOR tokamak port (fig. 5).

The layout of the Head is shown in fig. 3. The ***housing*** of the Head is made of aluminum and has one removable side (cover) with screw fastening. Fig. 4 represents sketch of the housing (without cover). The housing is kept under the potential of the tokamak vessel. The Head interior is shielded from electric noise by electrostatic ***screen*** having the potential of the system common wire.

One of the changeable ***aperture slits*** is installed in the hollow on the upper side of the housing. The set of slits includes three items having widths 0.15, 0.3 and 0.8 mm, any of which can be easily fixed in working position by two M2 screws (pos. ***B*** in fig. 3).

The ***detector array*** is installed in a 22-pin ***teflon socket*** fixed by two teflon poles on the bottom side of the housing. Washers of identical thickness of ~0.. 1 mm can be put under the poles for the adjustment of the detector field of view. Detector signals are brought out by shielded teflon cables through a teflon collar inserted in a hole in the lateral side of the housing.

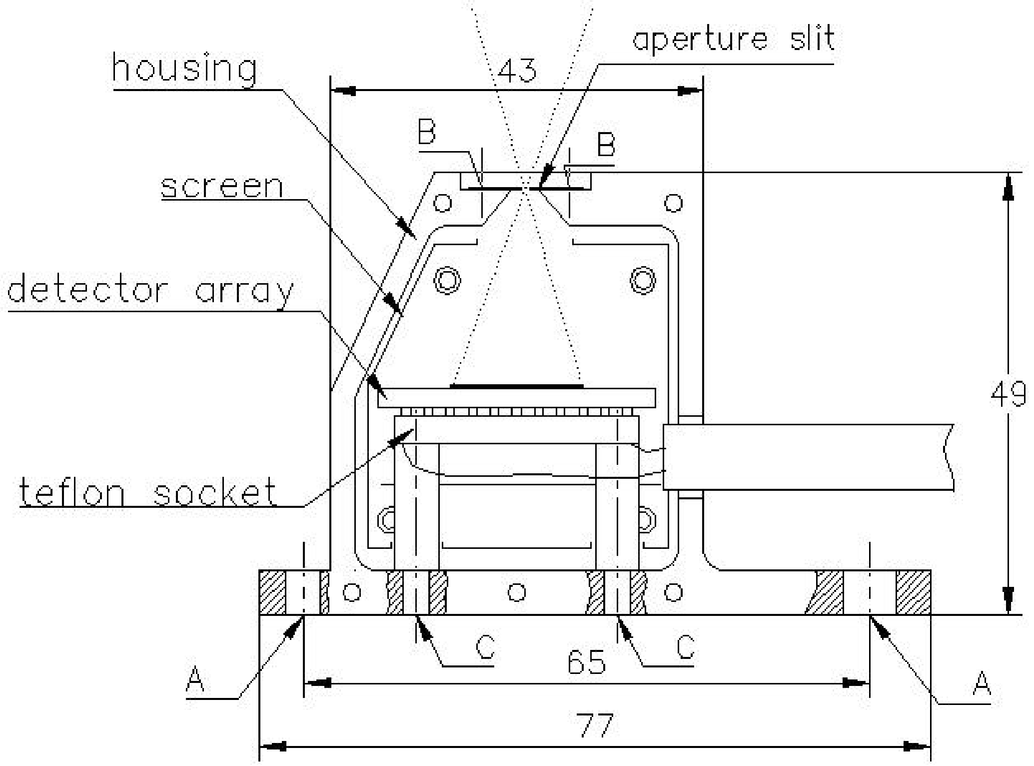


Fig. 3. Layout of the measuring head.

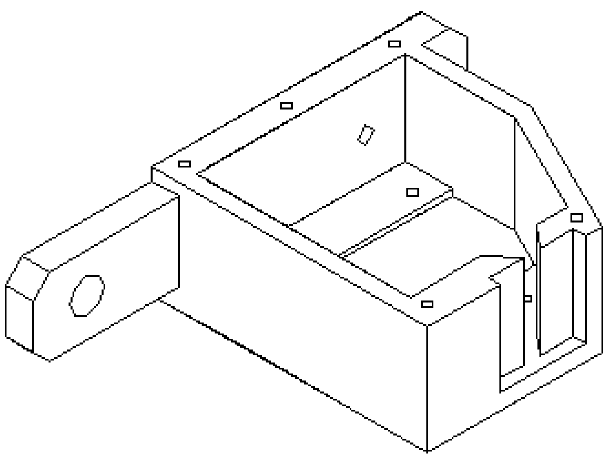


Fig. 4. Sketch of the Measuring head housing.

Geometry parameters of the head installation

The main geometry parameters of the Measuring Head installation are shown in fig. 5.

1.	Vacuum vessel minor radius **r**, mm	102
2.	Plasma radius R_{pl}, mm	85
3.	Plane of aperture slit – center of plasma distance **L**, mm	267
4.	Plane of aperture slit – flange tube junction distance (average) L_{fl}, mm	177
5.	Horizontal shift of aperture slit from toroidal axis ΔX_c, mm	9.5
6.	Angle shift of direction to plasma center from normal to plane of aperture slit α_c, deg	2.0
7.	Total angle of view α_{tot}, deg	36

Individual chord parameters (refined by lamp calibration [see below] with slit 0.15 mm)

α_{ci} – central angle of i-th channel view;

$\Delta\alpha_i=\alpha_i-\alpha_{i-1}$ – angle region of i-th channel view;

R_i – outer radius of plasma ring, viewed by i-th channel.

Channel	α_{ci}, deg	$\Delta\alpha_i=\alpha_i-\alpha_{i-1}$, deg	R_i, mm	Channel	α_{ci}, deg	$\Delta\alpha_i=\alpha_i-\alpha_{i-1}$, deg	R_i, mm
1	-20.5	2.21	89.5	9	-1.2	2.52	9.6
2	-18.3	2.28	79.7	10	1.3	2.52	21.3
3	-16.0	2.33	69.5	11	3.8	2.51	32.9
4	-13.6	2.38	59.0	12	6.3	2.49	44.4
5	-11.2	2.43	48.1	13	8.8	2.47	55.7
6	-8.8	2.47	36.9	14	11.2	2.43	66.7
7	-6.3	2.49	25.5	15	13.6	2.38	77.4
8	-3.8	2.51	13.9	16	16.0	2.33	87.8

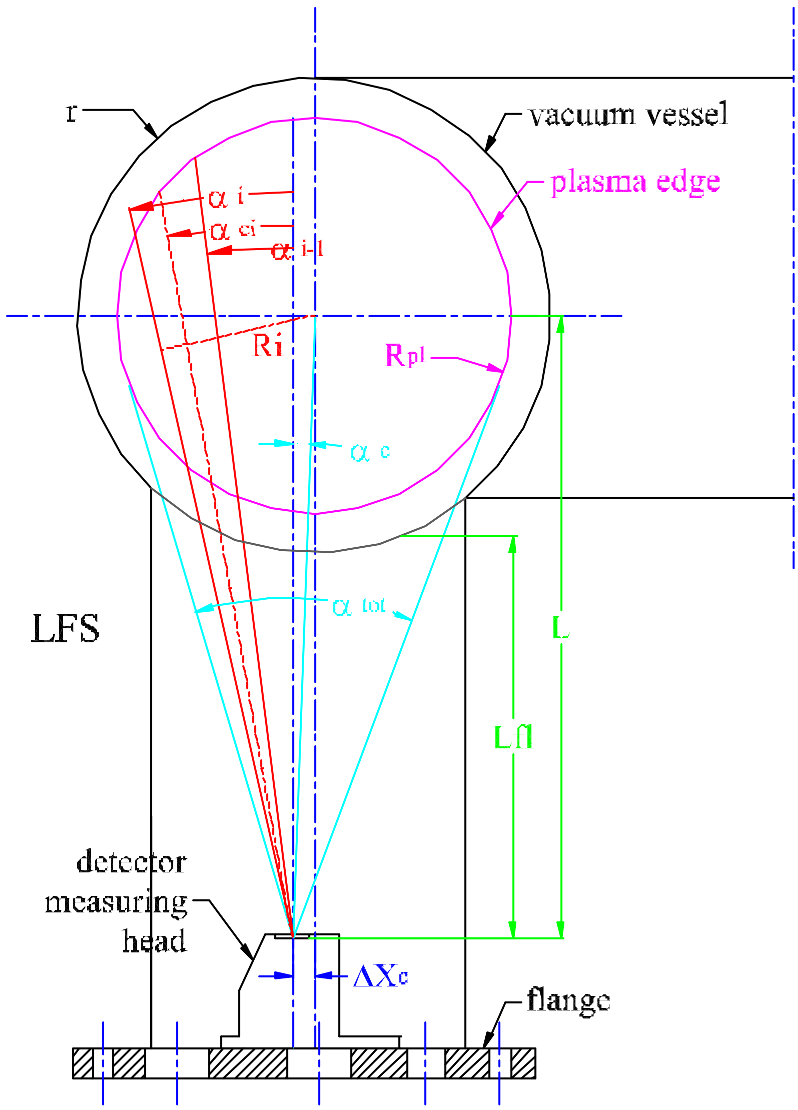


Fig. 5. Geometry of the Measuring Head installation.

PREAMPLIFIER UNIT

Preamplifier channels operate as linear current-to-voltage converters. Single supply, rail-to-rail, low power FET-input dual operational amplifiers AD822AN are used, having the following main features:

- Input bias current – 0.5 nA max. at T_{max}=+85°C
- Input offset voltage – 1.2 mV max. at T_{max}
- Offset voltage drift – 2 μV/°C typ.
- Unity gain bandwidth – 1.8 MHz
- Slew rate – 3 V/μs
- Input voltage noise – 16 nV/Hz$^{1/2}$ at f=1 kHz
- Input current noise – 0.8 fA/Hz$^{1/2}$ at f=1kHz
- Capacitive load drive – 350 pF
- Single supply capability – from +3 V to +36 V
- Quiescent current – 2 × 0.8 mA
- Rail-to-rail output swing – 10 mV max. output DC saturation voltage
- Below ground input range – Down to -0.2 V

Electric scheme of preamplifiers (fig. 6) can be presented as eight identical modules (AMP1 - AMP8). Each module includes two-channel operational amplifier and two RC feedback circuits.

Feedback resistors R_f (preset values 510 kΩ±1%) are placed in dual panels NR1 - NR8 and can be changed without resoldering to adjust the current-to-voltage conversion coefficient:

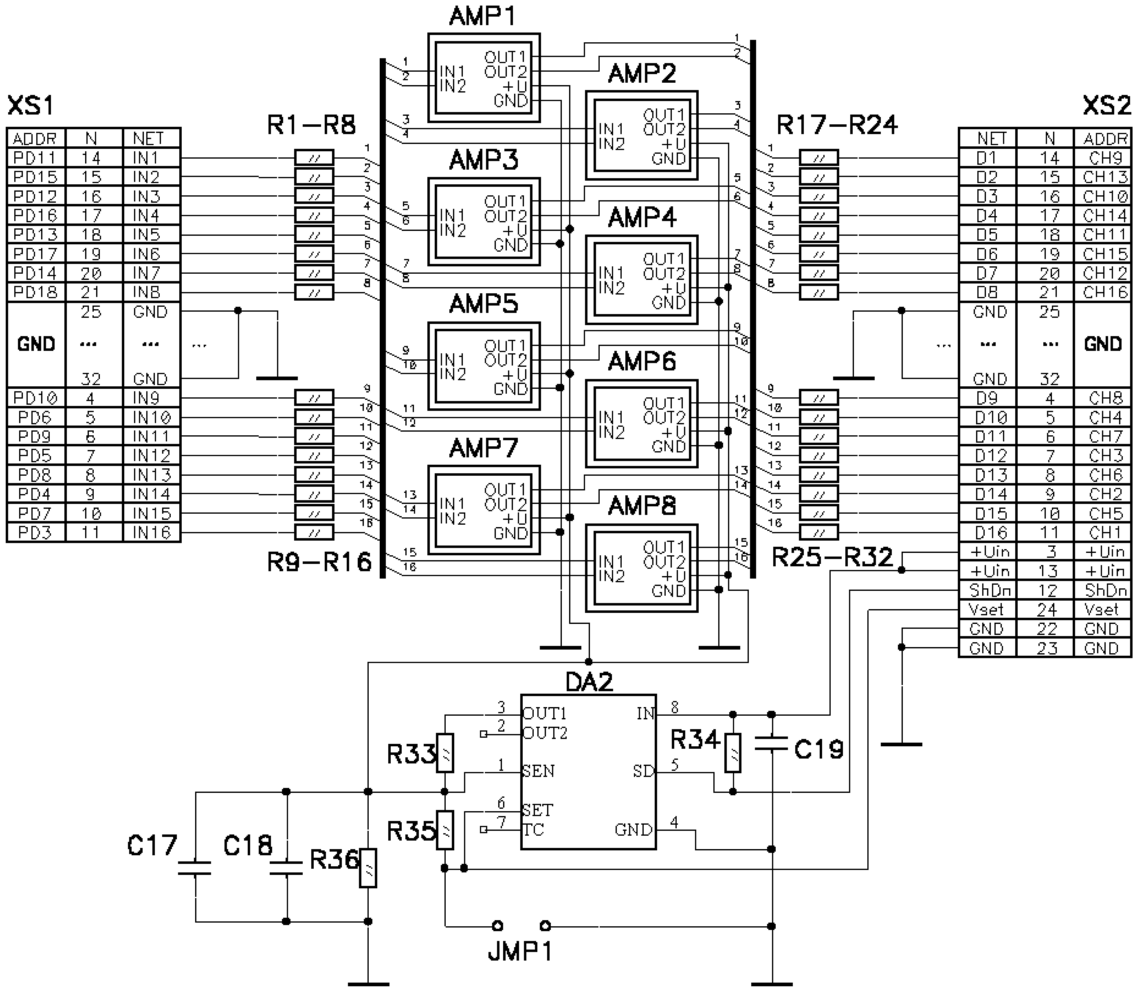
$$K_{amp}=U_{out}/I_{in}\ (V/mA)=R_f\ (k\Omega).$$

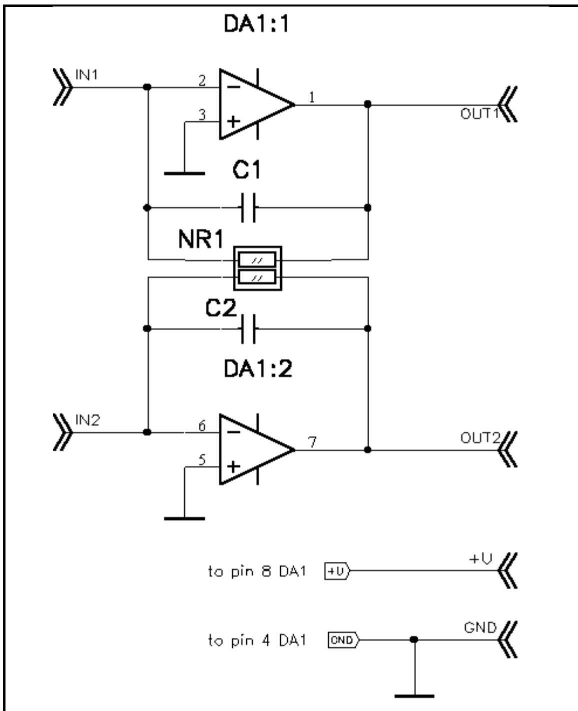
Values of feedback capacitors C1 - C16 are chosen for the required frequency bandwidth:

$$C_f=1/(2\pi R_f f_{max}).$$

Input and output sets of resistors NR9, NR10 and NR11, NR12 are needed for signal conditioning / filtering and overload protection.

ADM663A micro power linear voltage stabilizer (DA9) is used for supply voltage stabilization, short circuit protection and remotely controlled power on/off switching. With jumper JMP1 installed, the supply voltage of amplifiers equals to +5 V. The short circuit protection current level is determined by R1 as





Scheme of module AMP1 – AMP8.

Specification

Position	Type	Value
DA1 – DA8	AD822AN	–
DA9	ADM663AAN	–
C1 – C16	Capacitor KM-5A	3.3 pF
C17 – C19	Capacitor K10-17b	2.2 µF
NR1 – NR8*	Two resistors C2-23 0.125	510 kΩ 1%
R1 – R16	Resistor MLT 0.125	3.9 kΩ 5%
R17 – R32	Resistor MLT 0.125	1.0 kΩ 5%
R33	Resistor MLT 0.125	20 Ω 5%
R34	Resistor MLT 0.125	39 MΩ
R35	Resistor MLT 0.125	2.7 MΩ 5%
R36	Resistor MLT 0.125	300 kΩ 5%
JMP1	Jumper	–
XS1, XS2	Connector RP15-32	–

Fig. 6. Electric scheme of Preamplifier Unit.

* Changeable. Given is preset value.

I_{max}=500/R1(Ω)=25 mA. The output of stabilizer switches off when pin 12 (shdn) of output connector XS2 gets not grounded. When JMP1 is removed, Pin 24 (Vset) of XS2 can be used for the adjustment of the preamplifier output voltage range.

The supply voltage of stabilizer +9 V is passed from external power supply through pin 13 of XS2.

View of Preamplifier Unit board is shown in fig. 7. The board is fixed by metal poles inside a standard aluminum housing having dimensions 120.5×120.5×59.2 mm. The housing is electrically connected to the common wire of preamplifiers circuit (GND).

Input and output connectors XS1 and XS2 (type RP15-32) are placed on opposite lateral sides of the housing. The correspondence of the connectors pins to detector channels can be found from Fig. 6, where

- columns N on both XS1 and XS2 symbols mean number of connector pin;
- PD** in ADDR column on XS1 means number of detector (number of AXUV pin, 3 … 18 in use, 3 looks at the innermost part of plasma – HFS, 18 at LFS);
- CH** in ADDR column on XS2 means output number of channel from 1 (looking at HFS) to 16 (LFS).

Note that except for connection of input/output signal wires, pin 13 of XS2 should be connected to "+" of the external power supply, pin 22,23 to its "–" and pin 12 should be externally grounded (connected to GND circuit of preamplifier) to switch on the stabilizer.

POWER SUPPLY

Standard ~220 V/+9 V on-plug adaptor (type BPS–A 9–0.35) is used as external power supply.

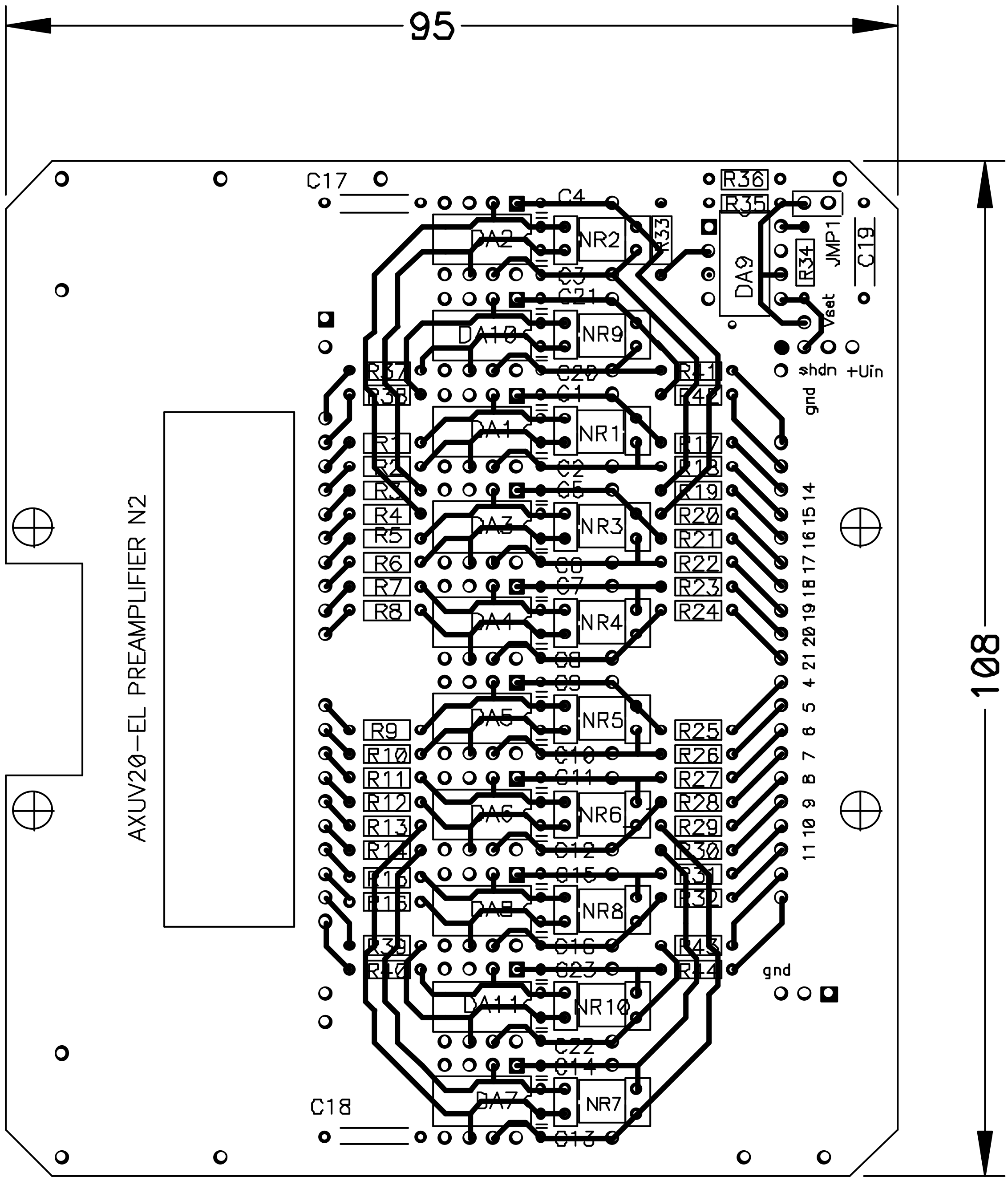


Fig. 7. Preamplifier Unit board (view from the component side, copper pour regions are not shown).

LAMP CALIBRATION

The calibration of the geometry of Measuring Head field of view was made with a "point" light source – small halogen lamp (filament spiral diameter 3 mm, bulb diameter 10 mm) supplied with a stabilized voltage. The calibration scheme is shown in fig. 8 (distance between line of lamp movement and aperture slit was ***b***=472 mm). The results of calibration (made with 0.15 mm aperture slit) are given in fig. 9. The angle fields of view of individual detectors can be found from these curves.

Moreover, it is seen that channel amplitudes fit well with the red curve $U=U_{8,max}*\cos^3[\alpha(x)]$, which (for the geometry of the calibration) represents the channels amplitudes for the case of quite identical sensitivities of all detectors. It can be concluded that the real sensitivities of detectors differ not more than ±2% from channel to channel (at least, for visible light).

LITERATURE

1. R. S. Korde and L. R. Canfield, Proc. SPIE **1140**, 126 (1989).
2. R. L. Boivin, J. A. Goetz, E. S. Marmar, J. E. Rice, and J. L. Terry, Rev. Sci. Instrum. **70**, 260 (1999).
3. Alekseyev, G. Petrov, A. Kurnosov, A. Chernoby, A. Amosov, D. Portnov, A. Bolov, and R. Korde, Plasma Devices Op. **7**, 139 (1999).
4. V. A. Soukhanovskii, D. Stutman, M. Iovea et al., Rev. Sci. Instrum. **72**, 737 (2001).
5. I. Furno, H. Weisen, J. Mlynar et al., Rev. Sci. Instrum. **70**, 4552 (1999).
6. D.S. Gray, S.C. Luckhardt, E. Hollmann et al., Proceedings of the 27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 2000, Vol. **24B**, pp. 1681-1684

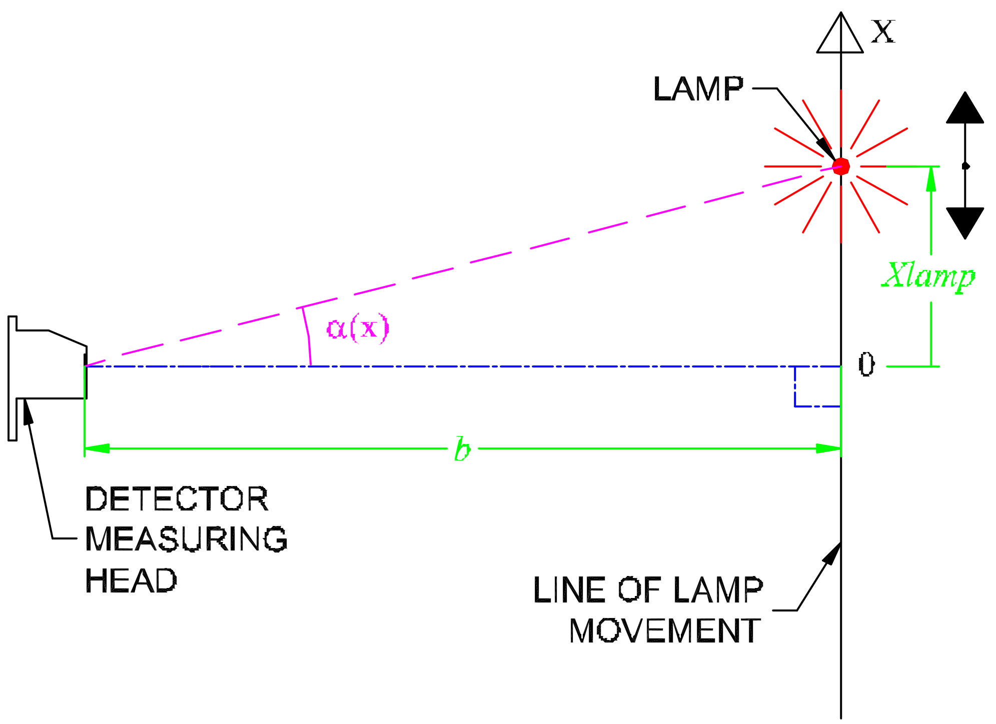


*Fig. 8. Geometry calibration layout (distance **b** equals to 472 mm).*

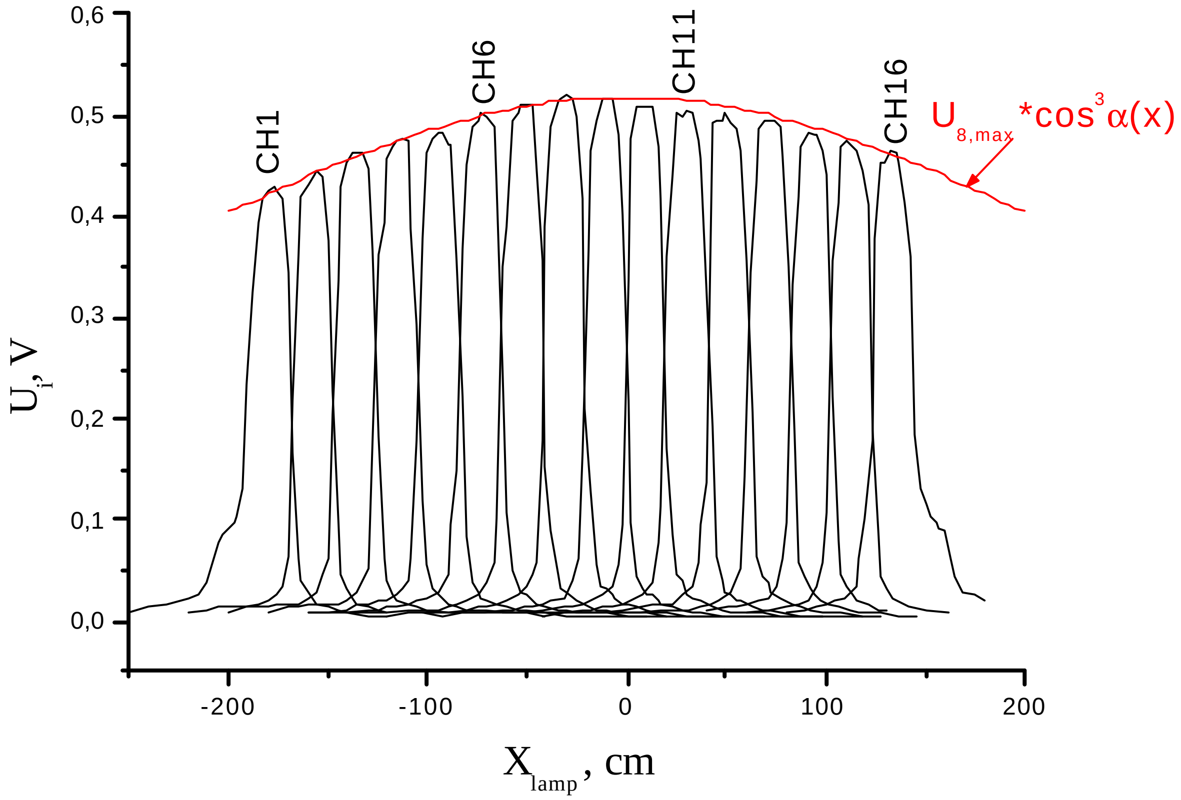


Fig. 9. Results of lamp geometry calibration.

X_{lamp} – lamp coordinate along the line of lamp movement;

U_i – output voltage of i-th channel preamplifier.

Black lines – individual channels signals,

red line – curve of channels amplitudes, if sensitivities were exactly the same (normalized to the 8-th channel).