TECHNICAL REPORT

TITLE	**: Technical Report on Pre-amplifiers for multi-wire proportional counters (MWPC)**
AUTHORS	**: S. Venkataramanan, Arti Gupta**
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INTER UNIVERSITY ACCELERATOR CENTRE

(An Autonomous Inter-University Centre of UGC)

Aruna Asaf Ali Marg,

New Delhi 110067 (India) Phone: 2412 6024

Web: www.iuac.res.in

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Technical Report on Pre-amplifiers for multi-wire proportional counters

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Developed by:

Electronics & Radio Frequency Laboratory

Inter University Accelerator Centre

(An Autonomous Inter-University Centre of UGC)

Aruna Asaf Ali Marg

NEW DELHI 110067 (India)

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Technical Report on Pre-amplifiers for multi-wire proportional counters

S.Venkataramanan[1] , Arti Gupta[2]

Electronics Laboratory, Inter University Accelerator Centre,
Aruna Asaf Ali Marg,
New Delhi 110067
[1,2]email: venkat@iuac.res.in, arti@iuac.res.in,

Abstract

As a part of the on going nuclear instrumentation development activities, for HIRA/HYRA at IUAC, we have developed a compact pre-amplifier unit to meet front end electronics requirement of multi-wire proportional counter (MWPC) detector. The unit accommodates seven channels of different types of pre-amplifiers, including two independent channels of charge-sensitive pre-amplifiers and five channels of wideband pre-amplifier, to process the energy and fast timing signals coming from MWPC electrodes respectively. This has been successfully tested with the MWPC detector installed in HIRA/HYRA experimental area and observed performance comparable with the existing homemade set up.

Acknowledgment

We would like to thank Dr D. Kanjilal and Dr. N. Madhavan for their continuous support and providing necessary infrastructure in order to accomplish this project successfully.

Specifications

Charge-sensitive pre-amplifier

Sensitivity	:	- 44 mV/MeV(Si equivalent)
Decay time constant	:	100 μS
Noise (Cd= 0/100/1000 pF)	:	~ 1.3/2.3/12 keV (Si equivalent)
Rise time(Cd= 0/100 pF)	:	~ 23/94 nS
Power requirements	:	60mW@ 12V, 130mW@ -12V, 600mW@ 24V, 250mW@ -24V
Energy output	:	Inverted output with 50 Ω reverse termination
Time output	:	Non-inverted, differentiated

Wideband pre-amplifier

No. of non-inverting channels:		One
No. of inverting channel	:	Four
Input impedance	:	50 Ω
Gain (fixed)	:	~ 250
Bandwidth	:	10 Hz to > 350 MHz
Risetime	:	< 1nS
Stability	:	Gain variation of < +/- 0.15% over long period in all the channels.
Input equiv. Noise	:	< 10 uV rms equivalent input noise
Channel-to-Channel Isolation	:	~ -40 dB

Introduction

Position sensitive multi-wire proportional counters (MWPC) are regularly used in fusion-fission experiments for detection of evaporation residues following fusion and measurements of mass, angle & total kinetic energy of fission fragments. At IUAC, MWPC with four electrode geometry (cathode followed by Y position electrode, anode and X position electrode) are being used as focal plane detector of Heavy Ion Reaction Analyzer (HIRA) and Hybrid Recoil mass Analyzer (HYRA). MWPC with five electrode geometry, having an extra electrode, are used in fusion experiments. The fast timing and position signals from MWPC electrodes further need to be amplified by fast pre-amplifiers while a charge-sensitive pre-amplifier (CSPA) is required to process cathode signal to extract energy information without degrading rise time and signal to noise ratio.

Typical MWPC front end electronics setup using commercial modules would require variety of pre-amplifiers and cables. We have developed a compact custom made pre-amplifier unit, which houses all its components in a die cast aluminum box of dimensions 145mm X 95 mm X 49 mm, for this purpose at IUAC.

Description

Block diagram of newly-developed MWPC pre-amplifier unit is as shown in fig. 1. The unit accommodates seven channels of different types of pre-amplifiers which include two independent channels of charge-sensitive pre-amplifiers and a five channel wideband pre-amplifier. This wideband pre-amplifier has one channel of non-inverting gain while other four are of inverting type to retrieve timing and position information from anode and position electrodes (X_{left}, $X_{right,}$ Y_{up}, Y_{down}), respectively. In order to extract energy information, cathode signal is processed through a charge-sensitive pre-amplifier.

All the input and output interconnections of the wideband pre-amplier are made through SMA connectors in order to preserve bandwidth of the signal, reduce noise and maintain reliability of the connections. A common test input is utilized to test the functionality of both CSPA channels simultaneously. Detector bias is provided through an SHV connector whereas input, output (energy and timing) and test signals are provided through BNC connectors. The unit receives DC supply through a 9-pin D-connector, as per NIM standard.

Charge sensitive pre-amplifier

Charge-sensitive pre-amplifier is based on conventional circuit with low noise JFET transconductance amplifier (Q6) as input stage followed by very high gain transistorized transimpedance amplifier in closed loop with RC network in negative feedback configuration. Generally the first stage of transimpedance amplifier is common base amplifier which makes folded cascode amplifier with input JFET but here we have used current amplifier (Q3) as the first stage which is followed by voltage amplifier (Q4). This configuration increases loop gain as well as improves gain stability and linearity. This output is further buffered through high input impedance FET (Q1) before feeding to output driver stage consisting of class AB push pull amplifier (Q2 & Q5). To improve thermal stability of quiescent current we have used matched pair of output transistors fabricated on the same chip. RC values have been chosen for silicon equivalent conversion gain and decay time of ~ -44mV/MeV and 100uS respectively. The amplifier provides two outputs i.e. Energy and Time for energy and timing spectroscopy respectively. Energy output is reverse terminated by 50 ohm and it's polarity is opposite to the detector input. Time signal has been derived from charge loop output through pulse transformer which provides isolated, non-inverted and differentiated (~150nS) output suitable for timing discriminators. The entire circuit has been assembled on a 4 layer FR4 glass epoxy PCB of size (75mm x 50mm) using high quality SMT components for compactness.

Wideband Pre-amplifier

Wideband pre-amplifier is designed to amplify very fast linear signals with rise time less than 1nS. The circuit is implemented using cascaded ac coupled common emitter amplifiers with common collector stage incorporated as the output buffer amplifier to improve the driving capabilities [1]. To achieve good timing characteristics, microstrip line technique is utilized to realize the PCB. All SMD components are mounted on the top side while continuous ground plane is provided on bottom side which is flush mounted on the aluminum panel of a die-cast box for efficient heat removal. SMA connectors are directly mounted on PCB to reduce parasitics. Four channels are implemented with inverting configuration and fifth channel is implemented with non-inverting configuration. Gain of all the channels are ~ 250. Input protection diodes are wired to clip any transients at the input, thus protecting the amplifier from avalanche related damage. The entire section is shielded

with copper sheet to avoid any unwanted noise pick-up from neighboring channels.

Conclusion

We have successfully demonstrated the possibility of implementing MWPC front-end electronics in a compact modular unit and extracted required information from its various electrodes.

References

1. Allen Mottershed, Electronic Devices and Circuits: An introduction (Prentice hall of India, New Delhi, 1990).

2. https://www.ortec-online.com/-media/ametekortec/manuals/142ih-mnl.pdf

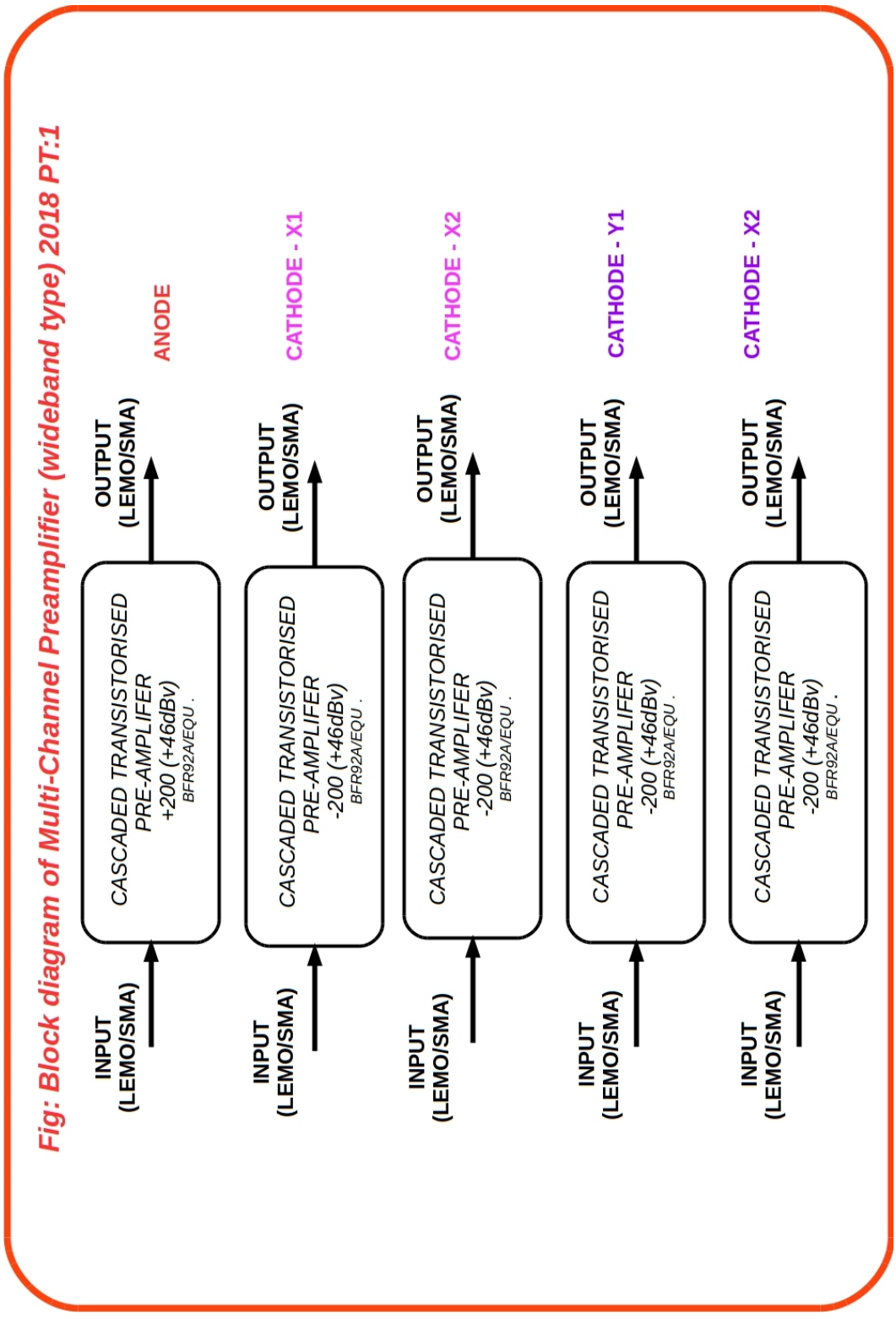
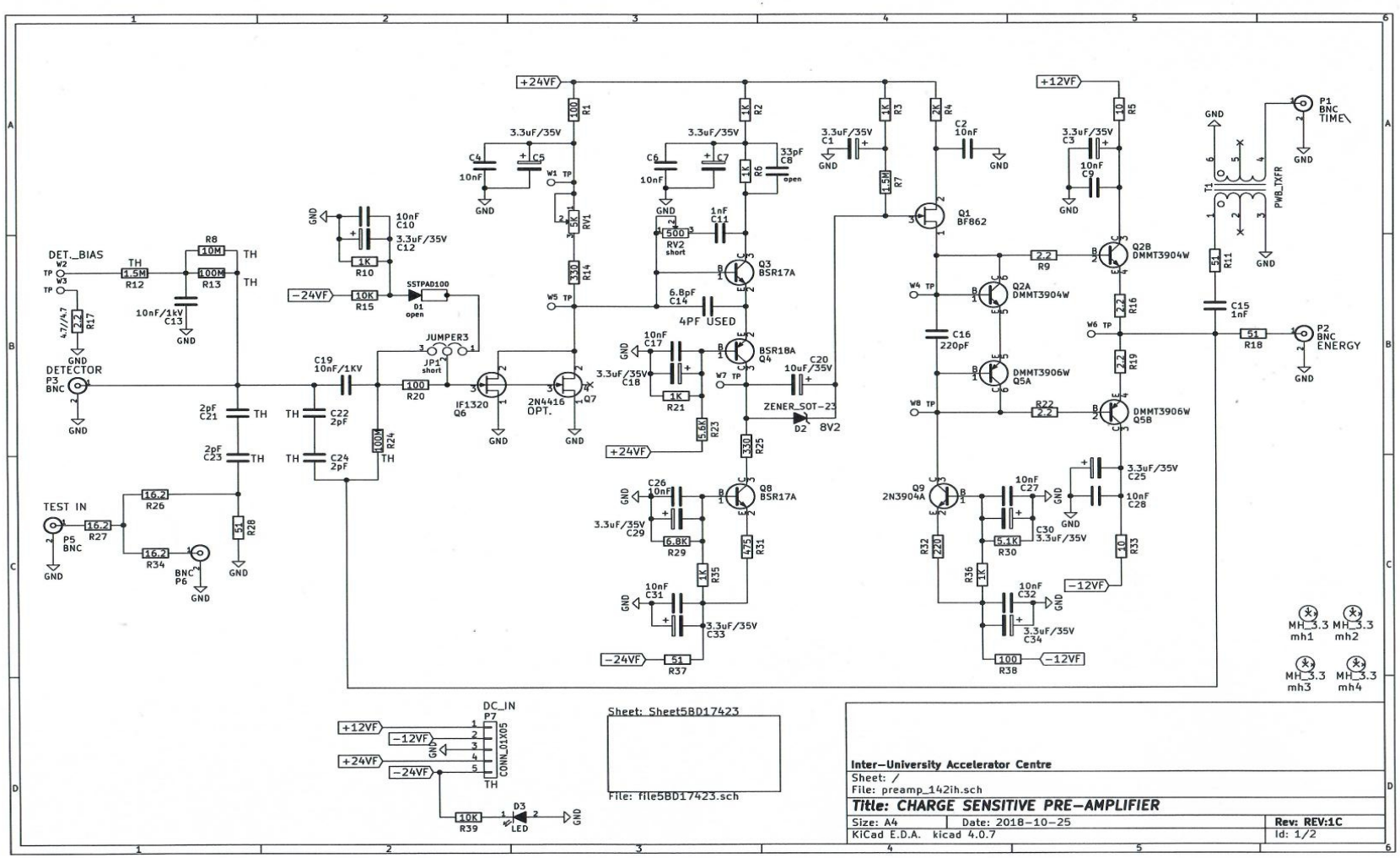


Fig. 1: Block diagram of MWPC pre-amplifier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+12VF
-24VF
-12VF
GND
DET._BIAS
DETECTOR
TEST IN
P1 BNC TIME
P2 BNC ENERGY
P3 BNC
P5 BNC
P6 BNC
DC_IN
P7
CONN_01X05
Q1 BF862
Q2A DMMT3904W
Q2B DMMT3904W
Q3 BSR17A
Q4 BSR18A
Q5A DMMT3906W
Q5B DMMT3906W
Q6 IF1320
Q7 2N4416 OPT.
Q8 BSR17A
Q9 2N3904A
D1 open
D2 8V2
D3 LED
SSTPAD100
ZENER_SOT-23
JUMPER3
JP1 short
RV1 5K
RV2 500 short
4PF USED
MH_3.3 mh1
MH_3.3 mh2
MH_3.3 mh3
MH_3.3 mh4
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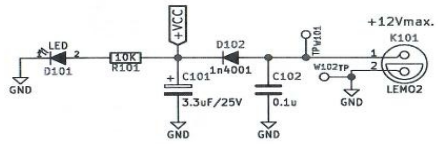
Date: 2018-10-25
Rev: REV:1C
KiCad E.D.A. kicad 4.0.7
Id: 1/2



MH_3.3 MH_3.3 MH_3.3 MH_3.3 MH_3.3 MH_3.3
mh101 mh102 mh103 mh104 mh109 mh111

MH_3.3 MH_3.3 MH_3.3 MH_3.3 MH_3.3
mh105 mh106 mh107 mh108 mh110

Sheet5A9792F5	Sheet5A99DFCA	Sheet5A99E00E	Sheet5A99EC55	Sheet5A99F5A3
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BLOCK DIAGRAM
INTER-UNIVERSITY ACCELERATOR CENTRE

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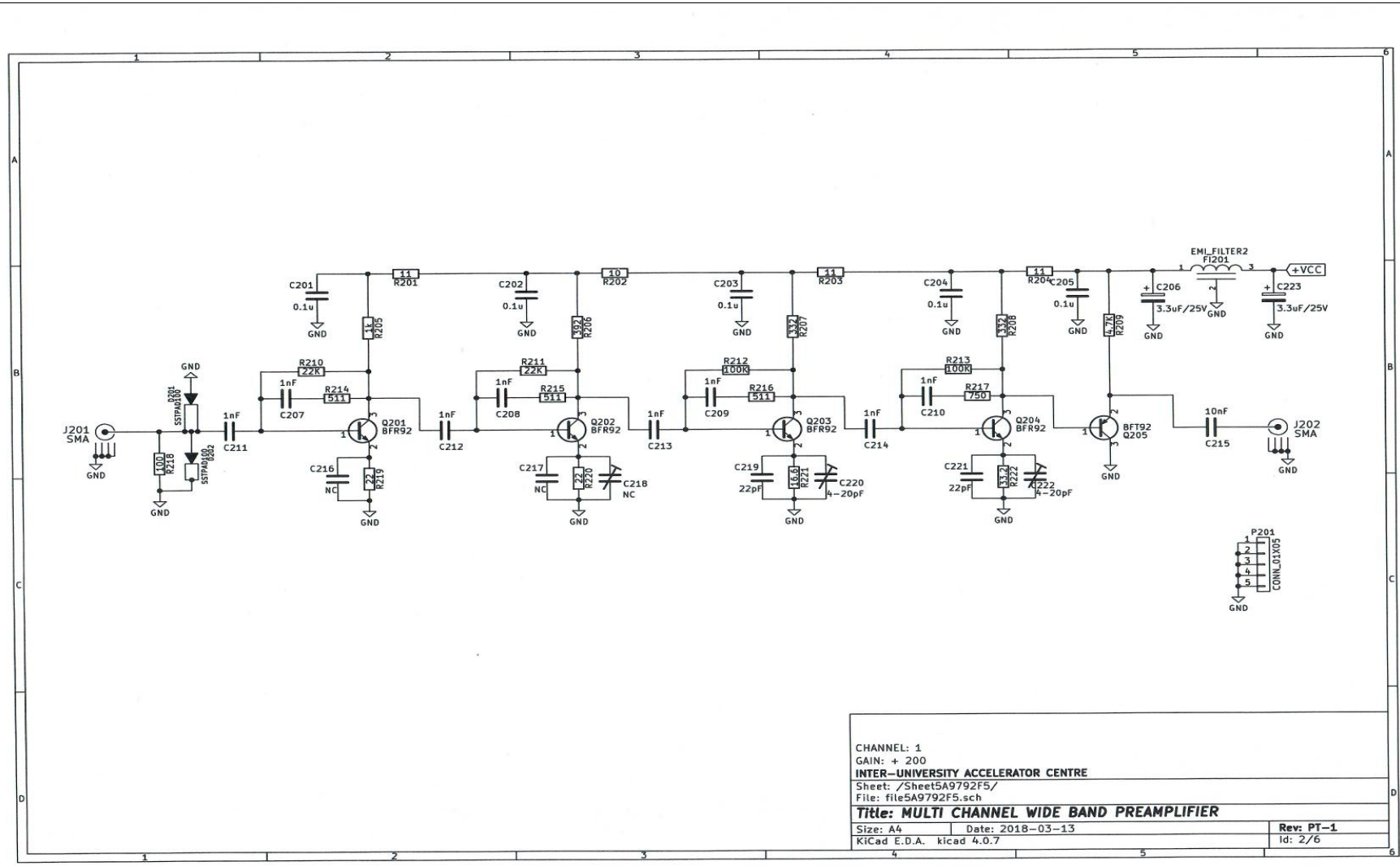
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SMA
GND
100
R218
D201
SSTPA0100
D202
SSTPA0100
1nF
C211
R210
22K
1nF
C207
R214
511
Q201
BFR92
C216
NC
22
R219
GND
11
R201
C201
0.1u
GND
11
R205
1nF
C212
R211
22K
1nF
C208
R215
511
Q202
BFR92
C217
NC
22
R220
C218
NC
GND
10
R202
C202
0.1u
GND
332
R206
1nF
C213
R212
100K
1nF
C209
R216
511
Q203
BFR92
C219
22pF
10.6
R221
C220
4-20pF
GND
11
R203
C203
0.1u
GND
332
R207
1nF
C214
R213
100K
1nF
C210
R217
750
Q204
BFR92
C221
22pF
33.2
R222
C222
4-20pF
GND
11
R204
C204
0.1u
GND
332
R208
C205
0.1u
GND
4.7K
R209
BFT92
Q205
GND
EMI_FILTER2
FI201
+ C206
3.3uF/25V
GND
+VCC
+ C223
3.3uF/25V
GND
10nF
C215
J202
SMA
GND
P201
CONN_01X05
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GAIN: + 200
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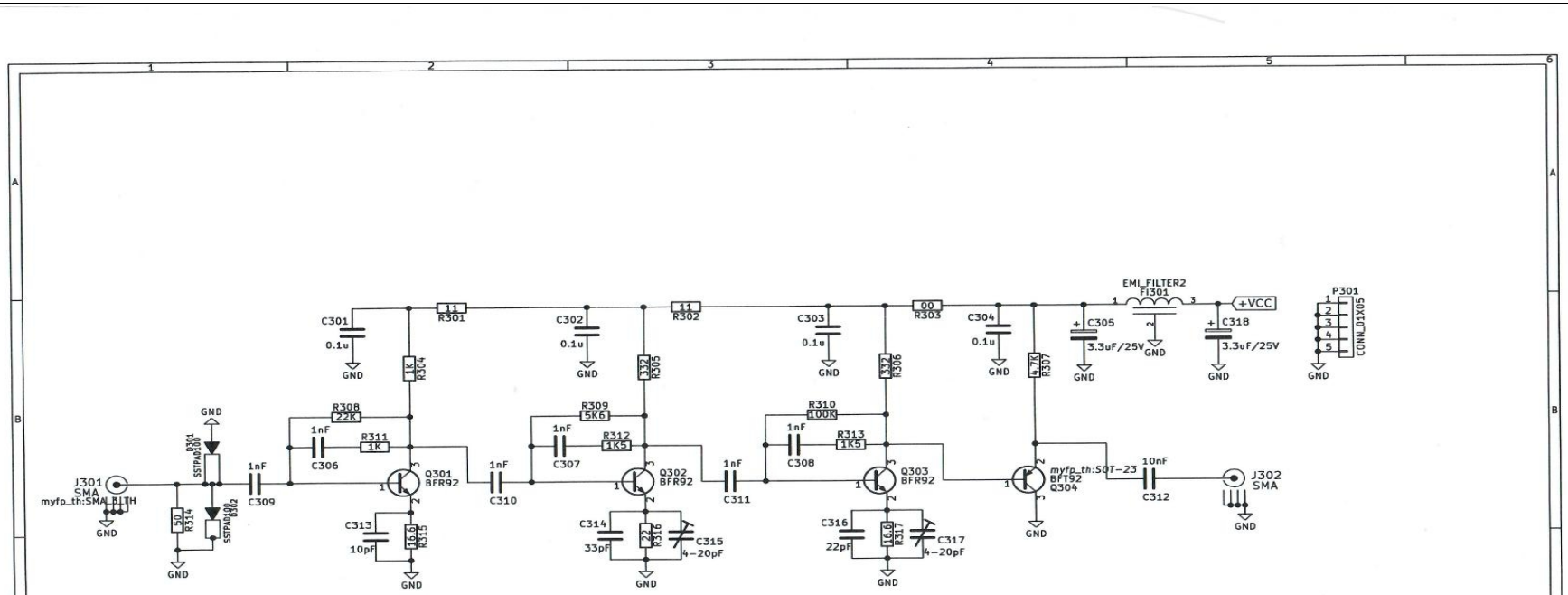

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GAIN: −200
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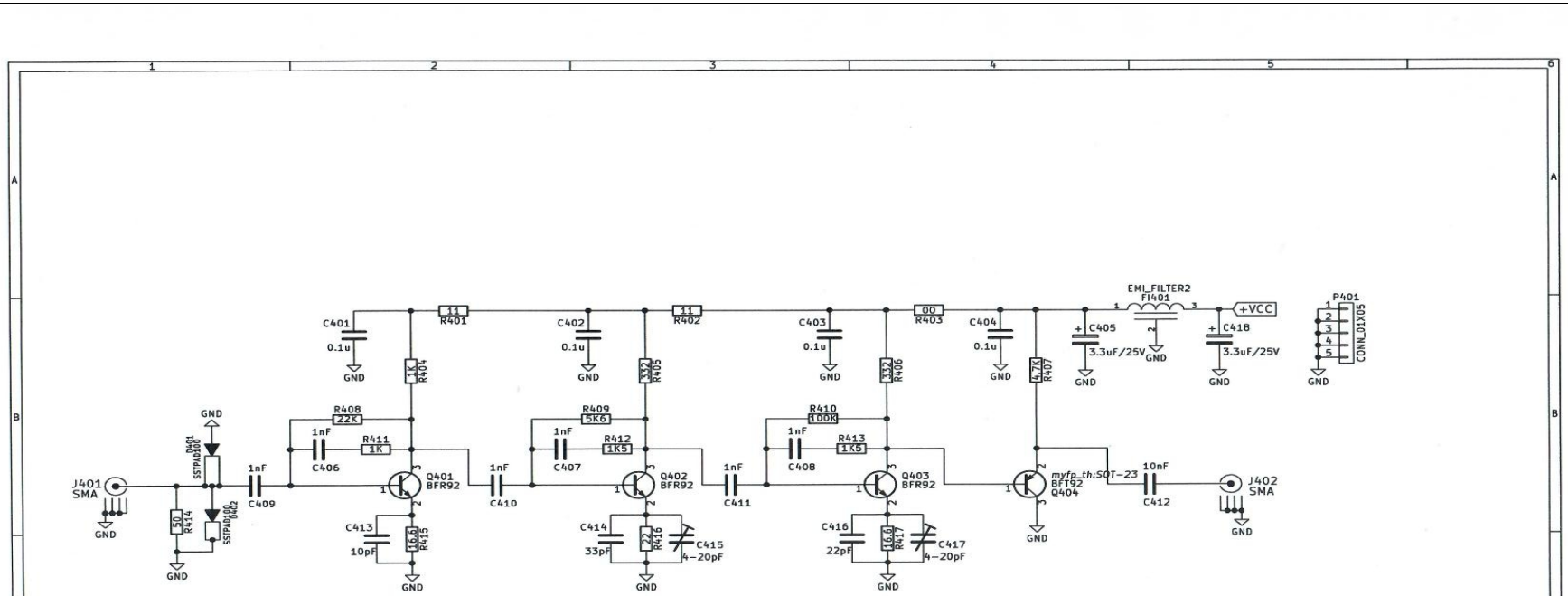

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GAIN: −200

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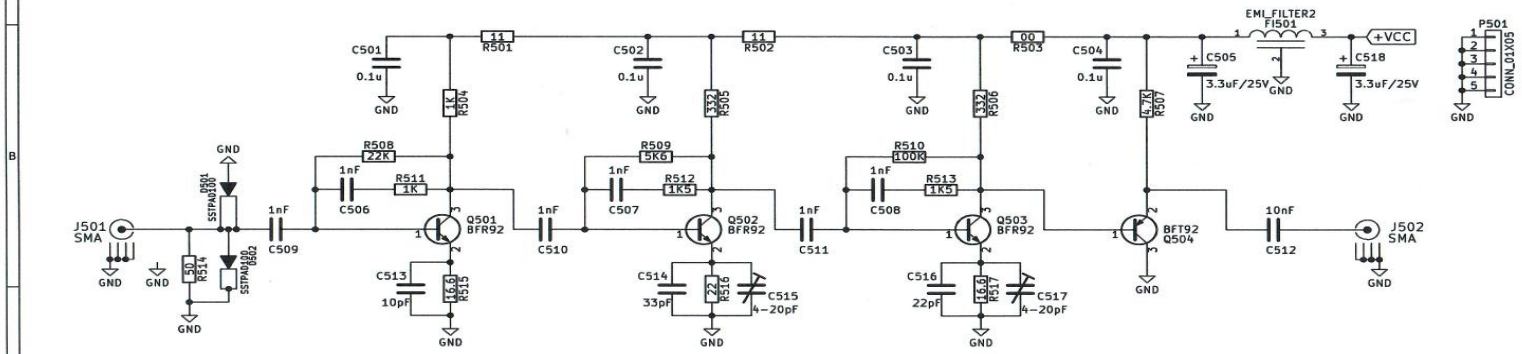

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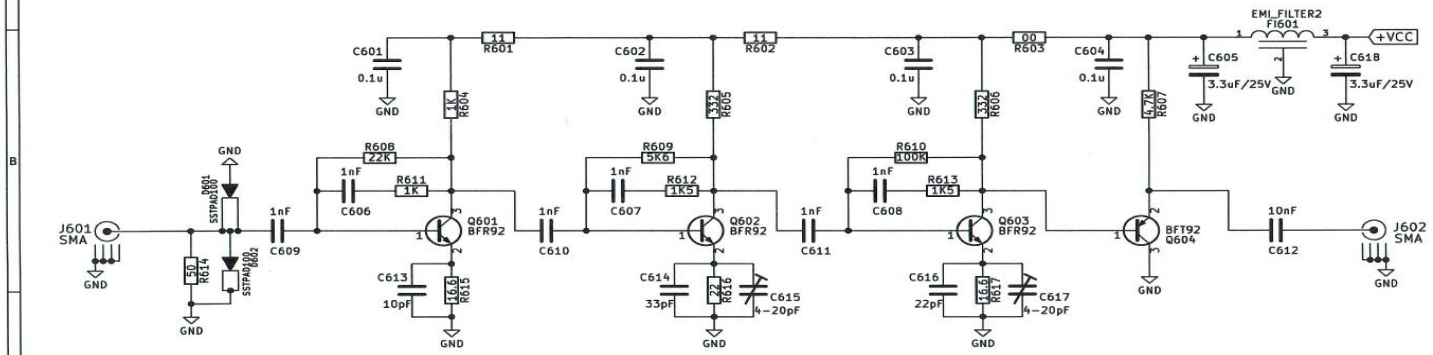

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Size: A4	Date: 2018-03-13	**Rev: PT-1**
KiCad E.D.A. kicad 4.0.7		Id: 6/6

Table 1: Charge sensitive pre-amplifier bill of material

REFERENCE DESIGNATOR	VALUE	QUANTITY	FOOTPRINT
R9, R16, R17, R19, R22	2.2	5	myfp_th:SM_R_0805
R5, R33	10	2	myfp_th:SM_R_0805
R26, R27, R34	16.2	3	myfp_th:SM_R_0805
R11, R18, R28, R37	51	4	myfp_th:SM_R_0805
R1, R20, R38	100	3	myfp_th:SM_R_0805
R32	220	1	myfp_th:SM_R_0805
R14,R25	330	2	myfp_th:SM_R_0805
R31	475	1	myfp_th:SM_R_0805
R2, R3, R6, R10, R21, R35, R36	1K	7	myfp_th:SM_R_0805
R4	2K	1	myfp_th:SM_R_0805
R30	5.1K	1	myfp_th:SM_R_0805
R23	5.6K	1	myfp_th:SM_R_0805
R29	6.8K	1	myfp_th:SM_R_0805
R15, R39	10K	2	myfp_th:SM_R_0805
R7	1.5M	1	myfp_th:SM_R_0805
R12	1.5M	1	Resistors_ThroughHole:Resistor_Horizontal_RM15mm
R8	10M	1	Resistors_ThroughHole:Resistor_Horizontal_RM15mm
R13, R24	100M	2	Resistors_ThroughHole:Resistor_Horizontal_RM15mm
RV2	500	1	SMD_Packages:POT_SMD
RV1	5K	1	Potentiometer_Bourns_3296W_3-8Zoll_Inline_ScrewUp
C21, C22, C23, C24	2pF	4	myfp_th:Dipmica_CD10E
C14	6.8pF	1	cfd_smd:C_0805
C8	33pF	1	cfd_smd:C_0805
C16	220pF	1	cfd_smd:C_0805
C11, C15	1nF	2	cfd_smd:C_0805
C2, C4, C6, C9, C10, C17,	10nF	11	cfd_smd:C_0805
C26, C27, C28, C31, C32			
C1, C3, C5, C7, C12, C18,	3.3uF/35V	11	cfd_smd:MY_TAN_B
C25, C29, C30, C33, C34			
C20	10uF/35V	1	cfd_smd:MY_TAN_B
C13, C19	10nF/1KV	2	myfp_th:C_1812
D1	SSTPAD100	1	cfd_smd:SOT-23
D2	ZENER_8V2_SOT-23	1	myfp_th:SOT-23
D3	LED	1	Socket_Strips:Socket_Strip_Straight_1x02
Q1	BF862	1	cfd_smd:SOT-23
Q2	DMMT3904W	1	mysmd:SOT-363
Q3, Q8	BSR17A	2	cfd_smd:SOT-23
Q4	BSR18A	1	cfd_smd:SOT-23
Q5	DMMT3906W	1	mysmd:SOT-363
Q6	IF1320	1	cfd_smd:SOT-23
Q7	2N4416	1	TO_SOT_Packages_THT:TO-72_4Pin
Q9	2N3904A	1	cfd_smd:SOT-23
T1	PWB_TXFR	1	mysmd:PWB-TXFR
JP1	JUMPER3	1	mysmd:jmpsmd_3
P7	CONN_01X05	1	Socket_Strips:Socket_Strip_Straight_1x05
P1, P2, P3, P5, P6	BNC	5	mulipicity:BNC_COAX
W1, W2, W3, W4, W5, W6,W7, W8	TP	8	myfp_th:tp_1mm
MH1, MH2, MH3, MH4	MH_3.3	4	myfp_th:MountingHole_3-5mm

Table 2: Five channel wideband pre-amplifier bill of material

Id	Designator	Package	Quantity	Designation
1	mh107,mh101,mh102,mh103,mh104,mh106,	MountingHole_2-5mm	11	MH_3.3
	mh108,mh105,mh109,mh110,mh111			
2	C101	MY_TAN_C	1	3.3uF/25V
3	C412,C211,C212,C213,C214,C215,C309,	MYSM_C_0805	21	2.2n
	C310,C311,C312,C409,C410,C411,C509,			
	C510,C511,C512,C609,C610,C611,C612			
4	D102	MELF_Standard	1	1n4001
5	K101	SIP-2SM	1	LEMO2
6	C102,C201,C202,C203,C204,C205,C301,C302,	MYSM_C_0805	22	0.1u
	C303,C304,C401,C402,C403,C404,C501,			
	C502,C503,C504,C601,C602,C603,C604			
7	C207,C208,C209,C210,C306,C307,C308,C406,	MYSM_C_0805	16	1nF
	C407,C408,C506,C507,C508,C606,C607,C608			
8	C216,C217,C219,C221,C313,C314,C316,C413,	MYSM_C_0805	16	22pF
	C414,C416,C513,C514,C516,C613,C614,C616			
9	D201,D202,D301,D302,D401,	SOT-23	10	SSTPAD100
	D402,D501,D502,D601,D602			
10	J201,J202,J301,J302,J401,	SMA_3_TH	10	SMA
	J402,J501,J502,J601,J602			
11	Q201,Q202,Q203,Q204,Q301,Q302,	SOT-23	16	BFR92
	Q303,Q401,Q402,Q403,Q501,Q502,			
	Q503,Q601,Q602,Q603			
12	Q205,Q304,Q404,Q504,Q604	SOT-23	5	BFT92
13	R101	SM_R_0805	1	10K
14	R205,R304,R404,R504,R604	SM_R_0805	5	330
15	R206,R305,R405,R505,R605	SM_R_0805	5	332
16	R207,R208,R214,R215,R216,R217,R306,R311,	SM_R_0805	22	1K
	R312,R313,R406,R411,R412,R413,R506,			
	R511,R512,R513,R606,R611,R612,R613			
17	R209,R307,R407,R507,R607	SM_R_0805	5	4.7K
18	R210,R211,R308,R309,R408,	SM_R_0805	10	22K
	R409,R508,R509,R608,R609			
19	R212,R213,R310,R410,R510,R610	SM_R_0805	6	100K
20	R218,R314,R414,R514,R614	SM_R_0805	5	100
21	R219,R220,R315,R316,R415,	SM_R_0805	10	22
	R416,R515,R516,R615,R616			
22	R221,R222,R317,R417,R517,R617	SM_R_0805	6	18
23	W101,W102	tp_1mm	2	TP
24	P201,P501,P401,P301	shield_0.5inx5	4	CONN_01X05

25	D101	Diode_DO-41_SOD81_	1	LED
		Vertical_AnodeUp		
26	FI201,FI301,FI401,FI501,FI601	EMI_FilteR_NFM61R	5	EMI_FILTER2
27	R603,R602,R601,R503,R502,R501,	SM_R_1210	16	10
	R403,R402,R401,R303,R302,R301,			
	R204,R203,R202,R201			
28	C618,C518,C418,C318,C223,	MY_TAN_B	10	3.3uF/25V
	C605,C505,C405,C305,C206			
29	C218,C220,C222,C315,C317,C415,	C_Trimmer_Murata_TZB4-A	11	4-20pF

Observations and measurements

To evaluate noise and rise time performance of charge-sensitive pre-amplifier, it is characterized for detector equivalent capacitance from stray (0 pF) to 1000 pF (Fig 2 & 3) and compared with general purpose pre-amplifier ORTEC 142IH [2] (Tables III & IV). Typical energy and timing output signals are as shown in Fig 4.

The wideband pre-amplifier is tested with Tektronix fast Pulse generator PG 502 and HP Network analyzer 8752A (300 kHz to 1.3 GHz). Identical performance with voltage gain ~ 250 and bandwidth greater than 350MHz, is observed in all the channels. However bandwidth can be increased to ~ 500MHz by removing input protection diodes. Block diagram of test set-up, output signal and frequency response of inverting & non-inverting pre-amplifiers with & without protection diode are shown in (Fig. 5-11). The unit was tested for long term stability over a period of ~120 hrs and observed gain variation $<\pm 0.15\%$ (Fig. 12 & 13). Details of all the cables and wires required for various interconnections are given in Table III. Later it was tested with α-source ^{241}Am at the focal plane of HIRA. Position resolutions of ~2 mm and ~2.4 mm were obtained in X and Y positions, respectively (Fig. 14).

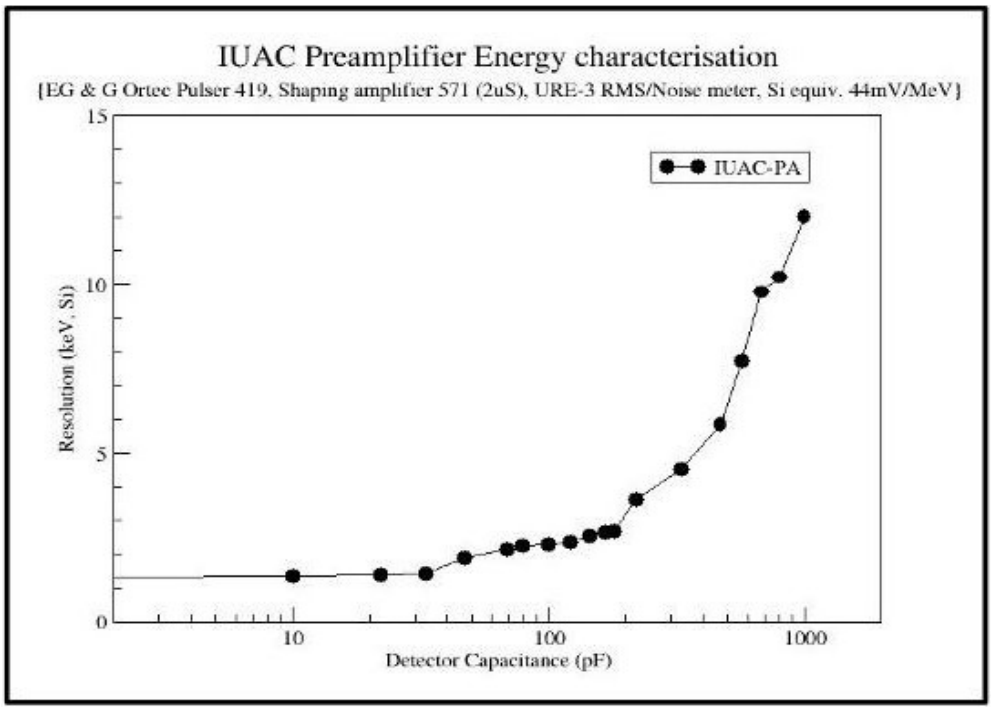

Fig. 2: Charge sensitive pre-amplifier Noise as a function of Detector capacitance

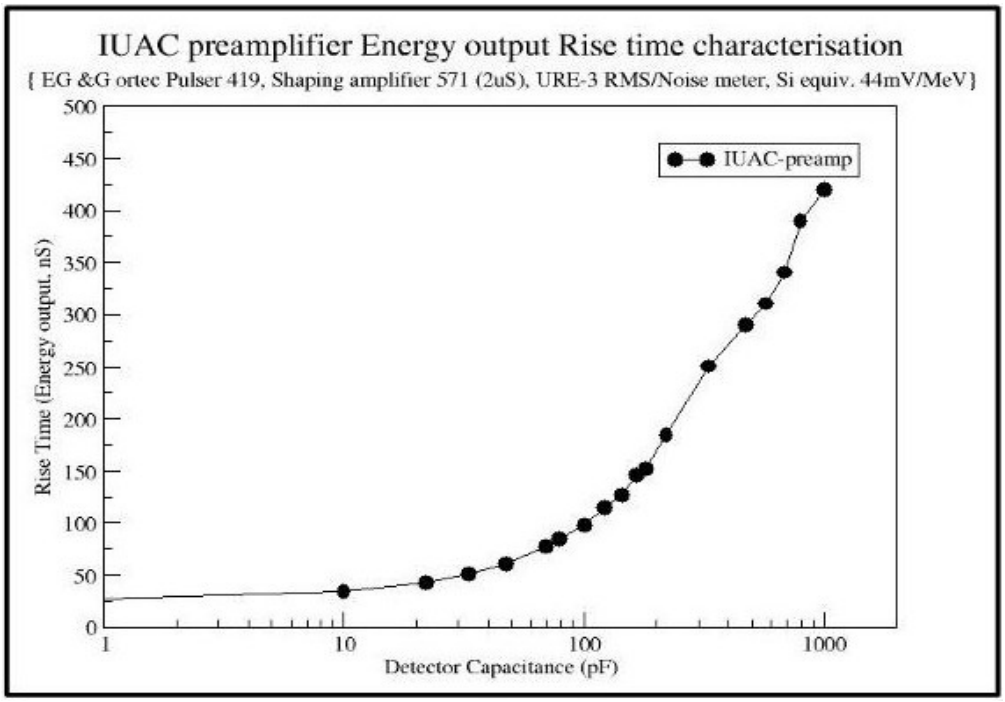

Fig. 3: Charge sensitive pre-amplifier Risetime as a function of Detector capacitance

Table III: Noise comparison between IUAC CSPA and ORTEC 142IH pre-amplifier

Detector equiv. Capacitor (pF)	IUAC CSPA Noise (KeV)	ORTEC 142IH Noise (KeV)
0	1.3	1.9
100	2.3	4.6
1000	12	35

Table IV: Rise Time comparison between IUAC CSPA and ORTEC 142IH pre-amplifier

Detector equiv. Capacitor (pF)	IUAC CSPA Rise Time (nS)	ORTEC 142IH Rise Time (nS)
0	23	20
100	94	50

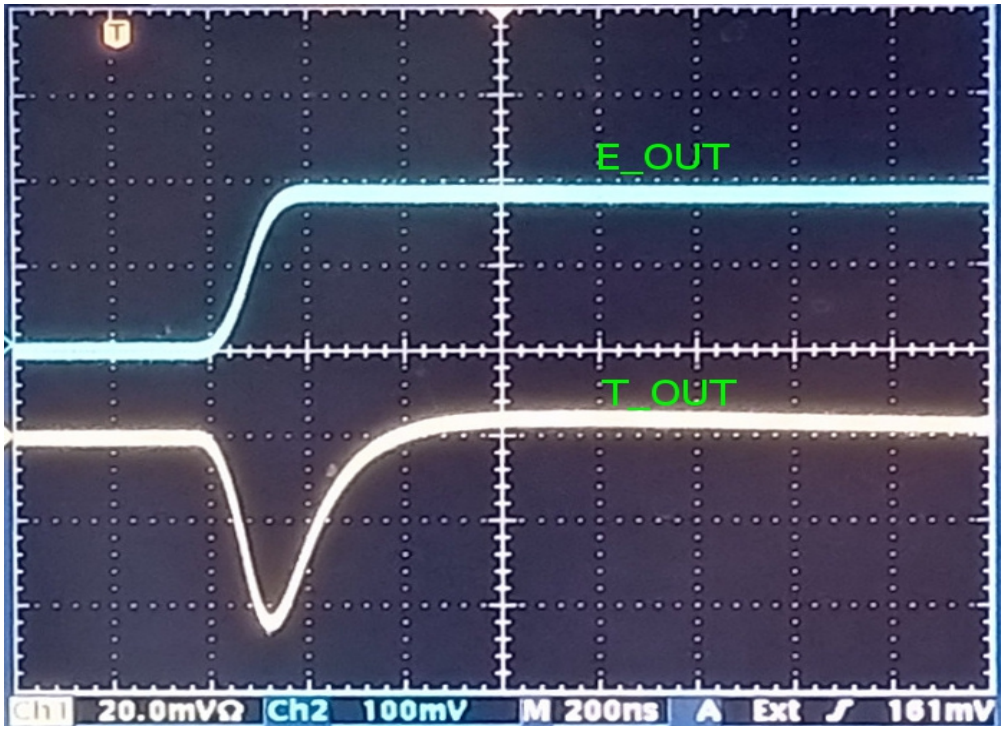

Fig. 4: Typical Energy and Timing output signals of charge sensitive pre-amplifier

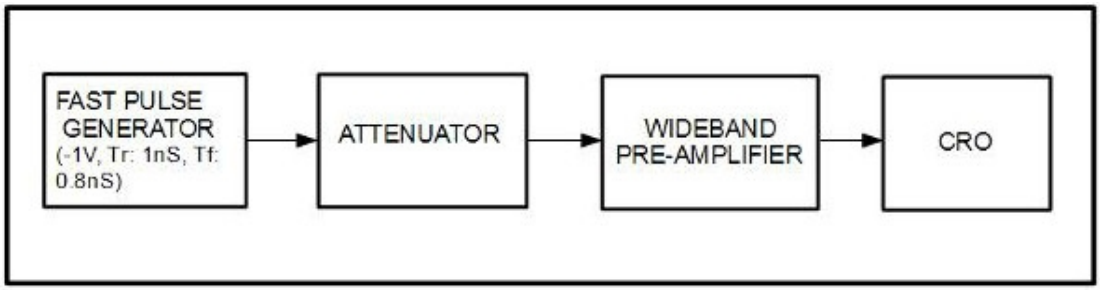

Fig. 5: Block diagram of wideband pre-amplifier test set-up using Pulser

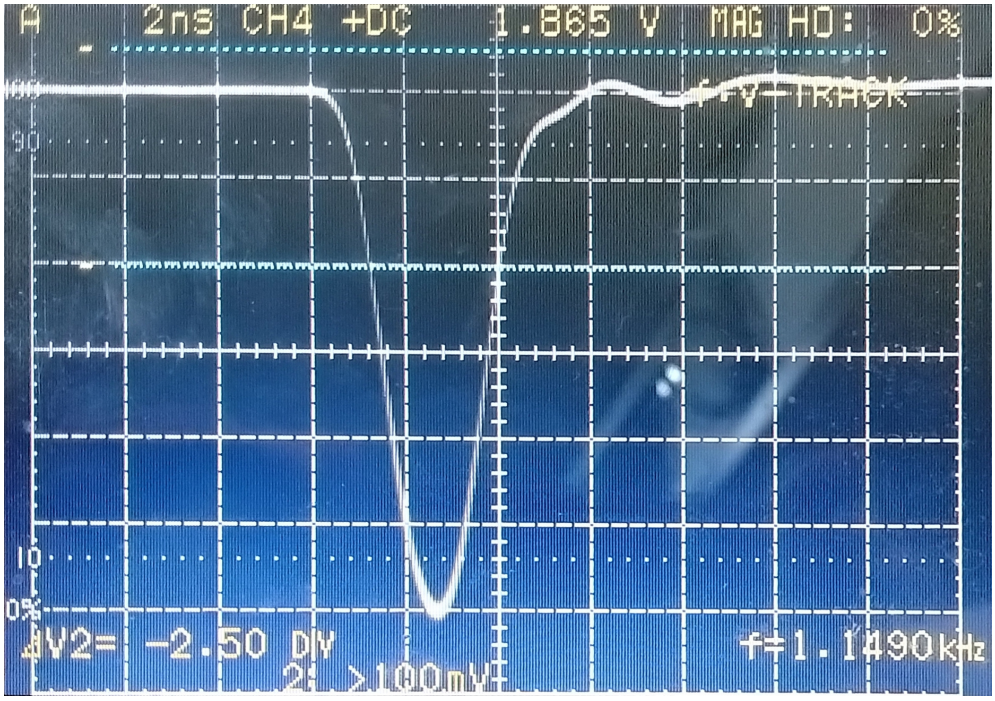

Fig. 6: Typical wideband pre-amplifier output signal using Pulser

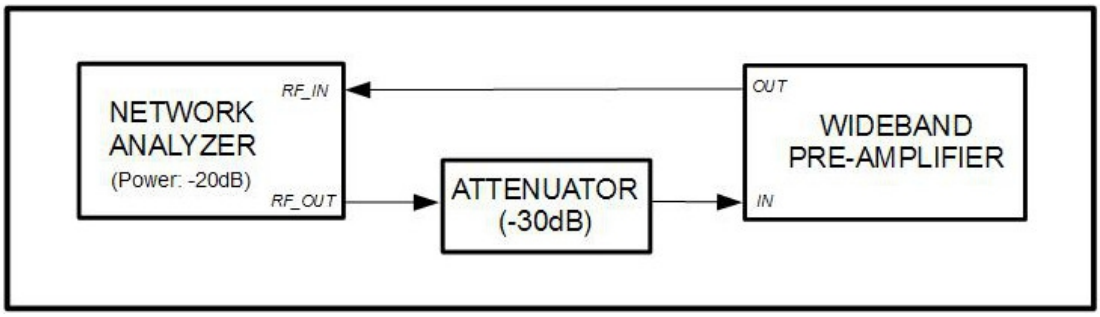

Fig.7: Block diagram of wideband pre-amplifier test set-up using Network Analyzer

Fig. 8: Frequency response of wideband pre-amplifier (inverting) with input protection diode

Fig. 9: Frequency response of wideband pre-amplifier (non-inverting) with input protection diode

Fig. 10: Frequency response of wideband pre-amplifier (inverting) without input protection diode

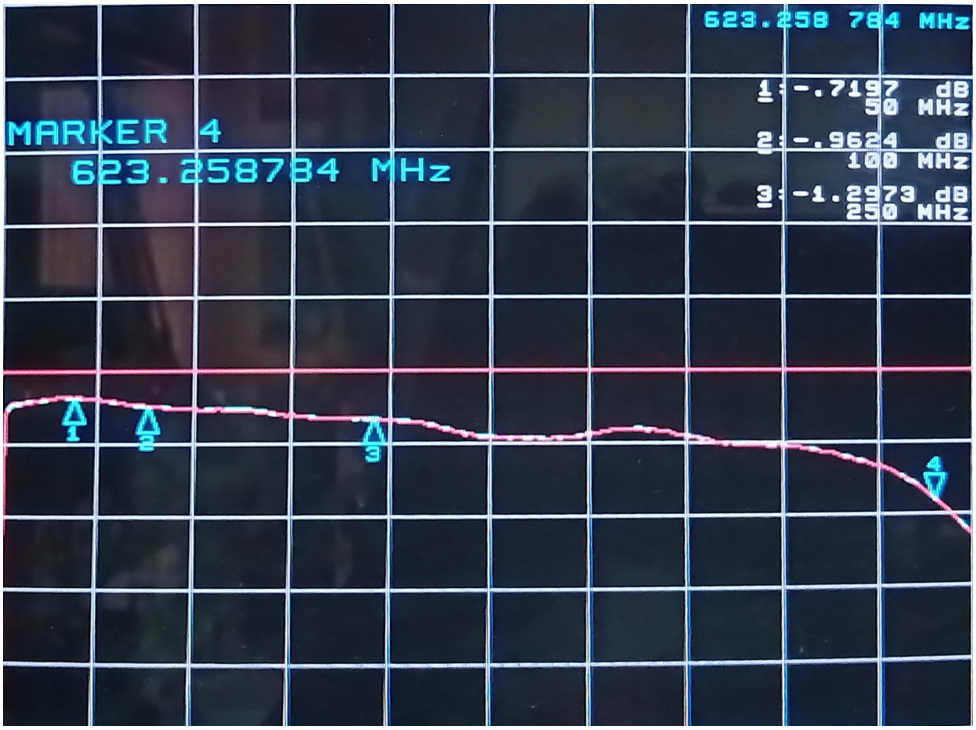

Fig. 11: Frequency response of wideband pre-amplifier (non-inverting) without input protection diode

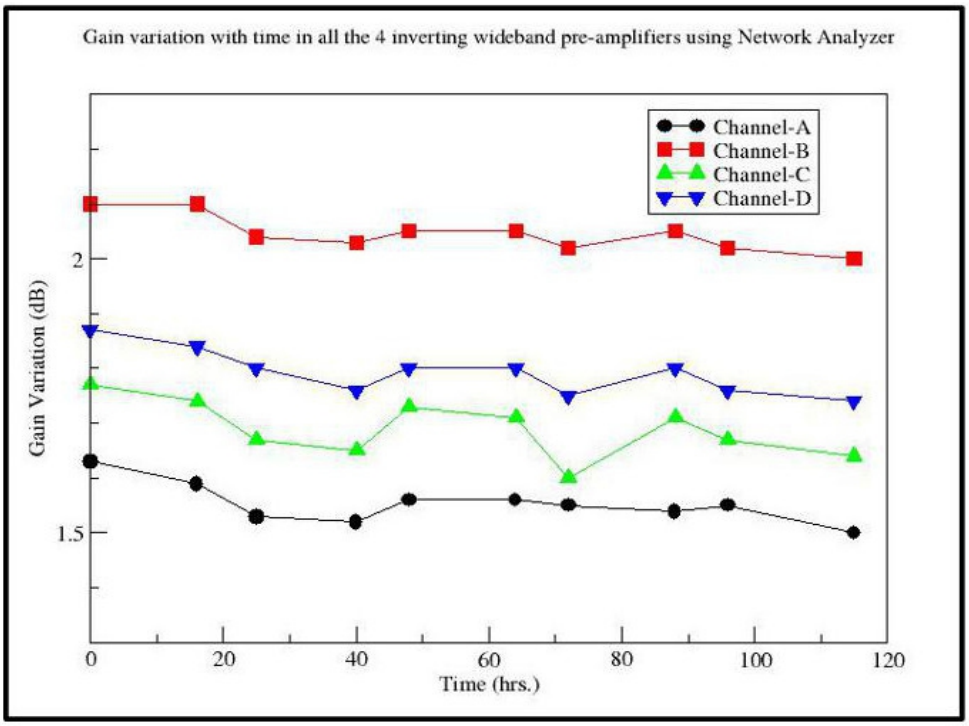

Fig. 12: Gain Variation observed in all four Inverting amplifier channels with time

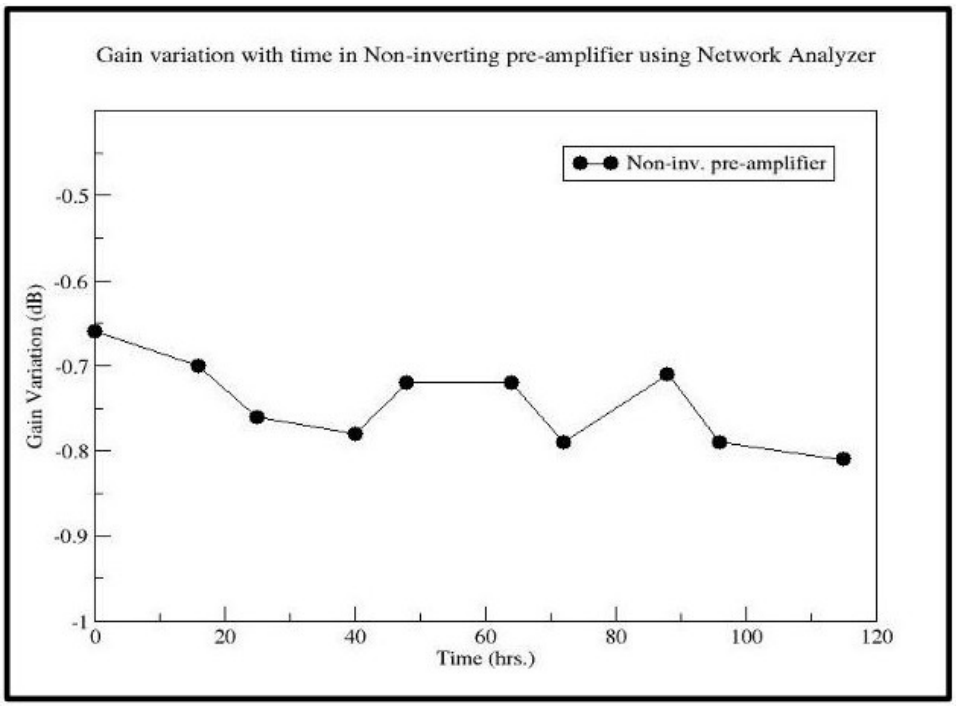

Fig. 13: Gain Variation observed in Non-inverting amplifier with time

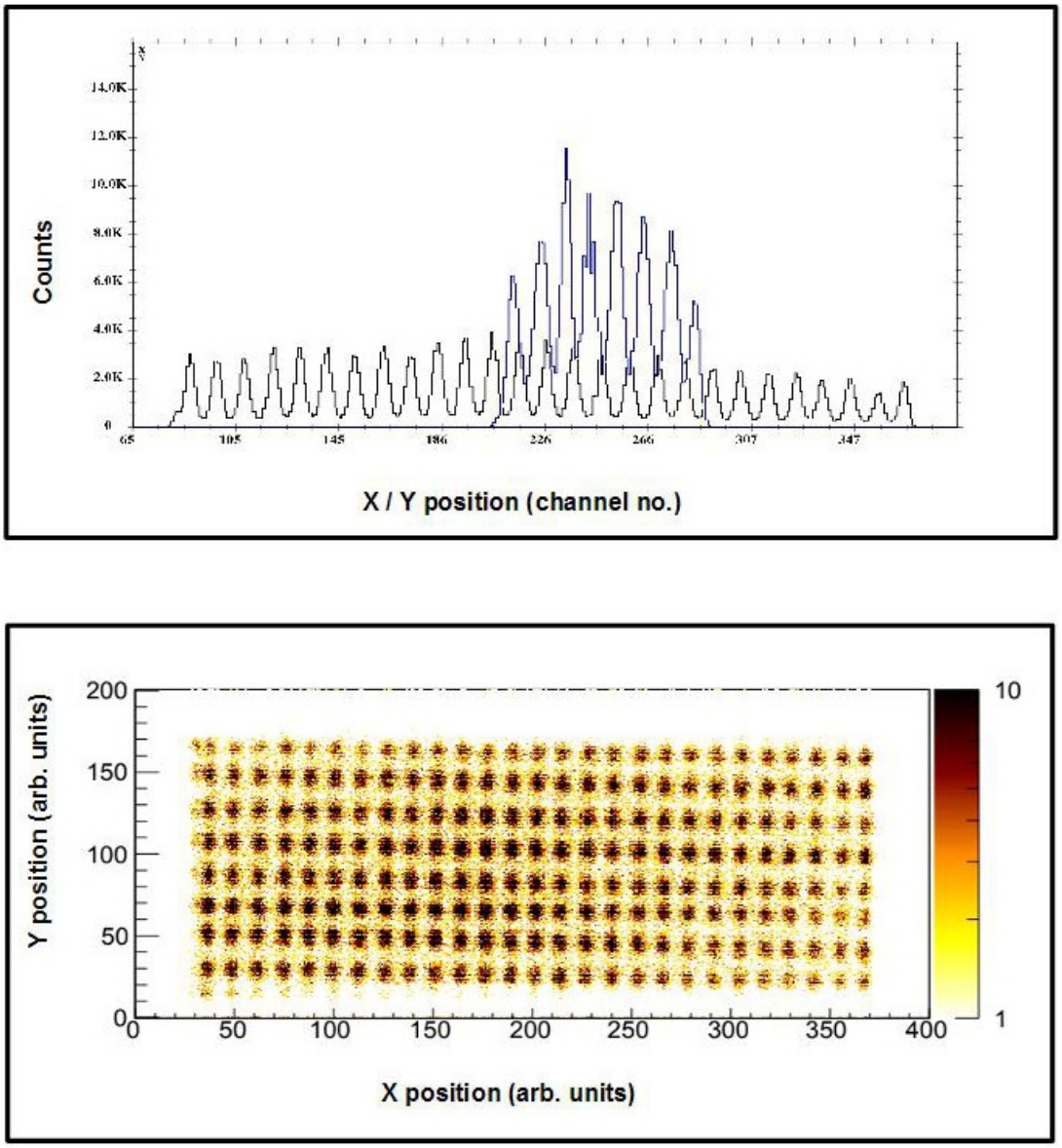

Fig. 14: 1D and 2D spectra obtained from MWPC, tested with ^{241}Am α-source and a mask

Table III: MWPC Pre-amplifier unit cable and wire lengths details

S. No	Description	CSPA channel 1 (mm)	CSPA channel 2 (mm)	WBPA (mm)	Remarks
	Panel Signals				
1	Energy_out	55	55		RG-178
2	Time_out	55	55		RG-178
3	Det_in	55	55		RG-178
4	Test_in		115		RG-178
	Board to board				
1	Test_out (ch2)	125			RG-178
	Power				
1	Det. Bias	180	260		
2	Gnd (bias)	145	210		
3	DC voltage	160		270	Twisted pair
	Board to board				
1	DC voltage (ch1)		120		Twisted pair

Copper sheet (for shielding) dimensions: 85mm x 130mm

Front and inside view of MWPC pre-amplifier unit