<u>Test of the 'Bess-Experiment' Fujitsu Preamplifiers using a Charge Injector</u>

October 2000, P.-R. Kettle

In total 16 channels in the form of 4 modules were available for testing. The basic test setup is shown in Figure 1. It comprises of a standard negative NIM signal which produces a known charge at the output of the Charge Injector CC. The signals are measured using a LeCroy digital sampling oscilloscope LC574AM.

<u>Setup:</u>

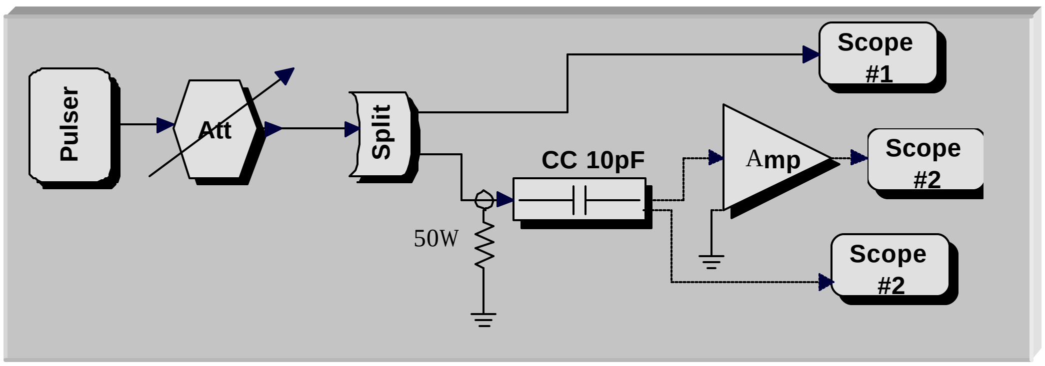
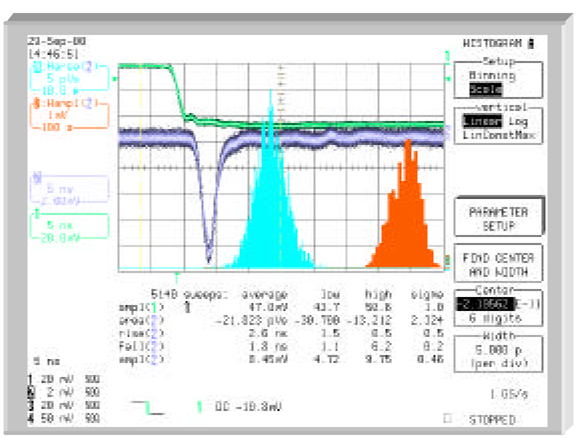


Figure 1: Test setup using a 10pF Charge Injector CC.

<u>Signal Characteristics:</u>

Figures 2 & 3 show the input and output signal characteristics for the Charge Injector and the preamplifier respectively. The five signal measurements are: amplitude of NIM i/p signal (green), and charge, fall-time, rise-time, as well as the amplitude of o/p signal (blue). Histogram A (light blue) shows the charge of signal 2 and histogram B (red) shows the pulse-height of signal 2. All measurements are time gated, shown by the yellow cursors.



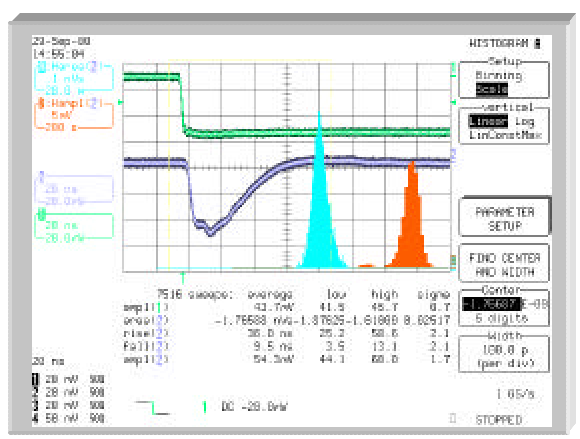


Figure 2: shows the NIM i/p pulse & analogue o/p signal *of the Charge Injector.*

Figure 3: shows the NIM i/p pulse & preamplifier o/p signal *as well as Histograms of Charge & pulse-height.*

The charge output from the Chargr Injector $\mathbf{Q_{CC}}$ is given by $\mathbf{Q_{CC} = V_{NIM}\ C_{CC}}$ (N.B: *the measured units of the oscilloscope are pVs and must be divided by 50W to obtain pC*). When measured into 50Ω, the output voltage of the

Charge Injector V_{CC} » V_{NIM} / 5.534 . In Figure 3 the preamplifier o/p pulse is measured into 50Ω, the ouput impedance of the Fujitsu.

For comparison, Figure 4 shows the preamplifier output pulse when the i/p is shunt terminated in 96Ω (i/p impedance of Fujitsu) –this should be compared to the non-terminated case shown in Figure 3. For correctly terminated signals the rise-time $\tau_R \approx$ 4.5 ns and the fall-time $\tau_F \approx$ 32 ns similar to the values in [1].

Rise-time t_R » 4.5 ns

Fall-time t_F » 32 ns

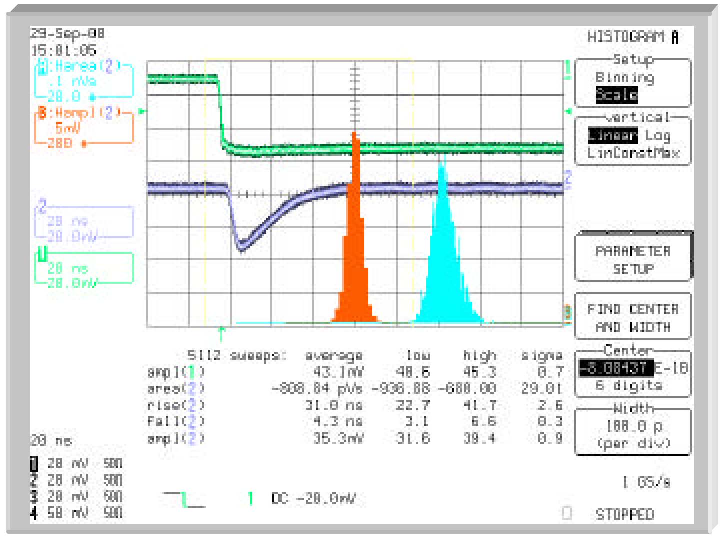


Figure 4: The same as Figure 3 but with 96W shunt termination at i/p to the preamplifier. The o/p impedance is 50W .

Gain Comparison of the Fujitsu Preamplifiers:

Table 1 shows the measured values for the 16 Fujitsu preamplifiers, together with mean and standard deviation of the quantities. The voltage gain factor G_V is defined as follows: $G_V = V_{PA} / V_{CC}$, where V_{CC} » V_{NIM} / 5.534. It should be remembered that V_{CC} is measureed into 50 Ω. The charge gain factor G_q is given by the relationship: $G_q = Q_{PA} / Q_{CC}$, where $Q_{CC} = V_{NIM}\ C_{CC}$. It should be noted that the output parameters for all channels are within a 4% variation of their respective means.

Preamp. #	Channel #	Vnim [mV]	D Vnim [mV]	Vpa [mV]	D Vpa [mV]	Integral [nVs]	D Integral [nVs]	Qpa [pC]	D Qpa [pC]	Gv	Gq
1	1	48.7	0.7	55.1	2.4	2.120	0.094	42.4	1.9	6.26	87.06
	2	48.8	0.7	51.8	3.8	2.114	0.084	42.3	1.7	5.87	86.64
	3	49.1	0.7	49.4	3.6	2.071	0.030	41.4	0.6	5.57	84.36
	4	48.8	0.7	55.3	1.9	2.154	0.030	43.1	0.6	6.27	88.28
2	1	48.8	0.6	54.6	2.8	2.209	0.028	44.2	0.6	6.19	90.53
	2	48.8	0.6	52.2	3.7	2.189	0.028	43.8	0.6	5.92	89.71
	3	48.9	0.6	52.3	2.7	2.175	0.029	43.5	0.6	5.92	88.96
	4	48.8	0.6	55.6	2.0	2.245	0.027	44.9	0.5	6.31	92.01
3	1	49.6	0.7	55.5	1.7	2.030	0.026	40.6	0.5	6.19	81.85
	2	49.7	0.7	53.5	2.5	2.025	0.026	40.5	0.5	5.96	81.49
	3	49.6	0.7	52.3	2.8	2.002	0.026	40.0	0.5	5.84	80.73
	4	49.7	0.7	56.5	1.6	2.048	0.023	41.0	0.5	6.29	82.41
4	1	49.4	0.7	56.3	3.0	2.153	0.075	43.1	1.5	6.31	87.17
	2	49.0	0.7	54.0	3.3	2.149	0.054	43.0	1.1	6.10	87.71
	3	48.9	0.7	53.8	3.3	2.134	0.031	42.7	0.6	6.09	87.28
	4	49.0	0.7	57.3	2.2	2.172	0.029	43.4	0.6	6.47	88.65
	Mean	49.1	0.4	54.1	2.0			42.5	1.4	6.1	86.6
										0.2	3.3

Table 1: Shows the measured quantities for the 16 Fujitsu preamplifiers tested, as well as their statistical significance. The time gate was 100ns for all measurements and approximately 5000 sweeps were made per measurement.

From the above measurements one can conclude that the mean absolute gain of the Bess-type Fujitsu preamplifier is :

Absolute gain factor: 110 mV/ pC

Charge gain: 87

This is a factor of two lower than in the Fermilab report [1]. However, it should be noted that this gain is dependent on the load resistance used, the higher the resistance the lower the gain but the heat dissipation is also significantly lowered, which was probably a factor for the Bess-experiment. Also the method used in [1] to measure the gain involved the use a 100 Ω series resistor. Figures 5,6 below compare the use of series resistor and show that the pulse shape is affected somewhat (reflections) though the charge and pulse-height remain unchanged.

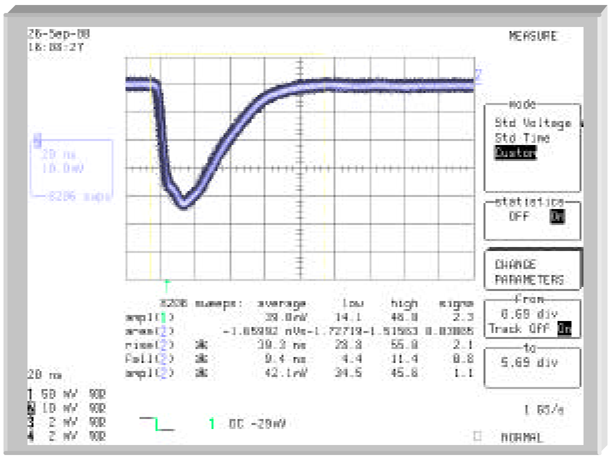


Figure 5: Preamplifier o/p With 100W series resistor at i/p series resistor.

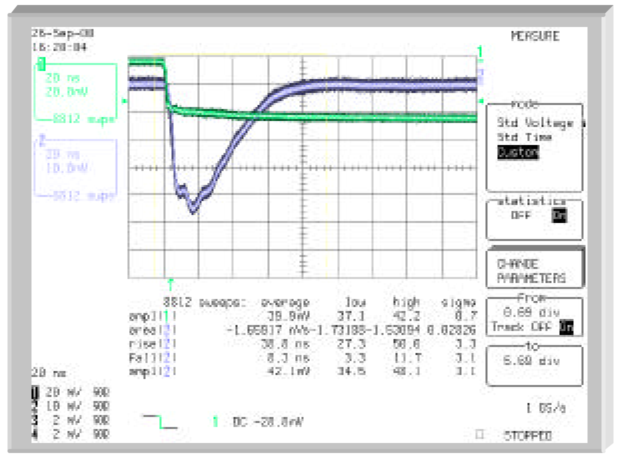


Figure 6: same as Figure 5 but Without 100W .

Impedance Measurement:

A variable shunt resistance R_L was placed at the input to the preamplifier and adjusted until the o/p pulse-height was equal to half the pulse-height for $R_L = \infty$. The measured value of the shunt resistance R_L should then equal the input impedance of the preamplifier, i.e. $R_L = Z$. It should be noted that this Value is 2.2 times lower than the expected value of 96Ω.

Impedance Measurement R_L = 43 W

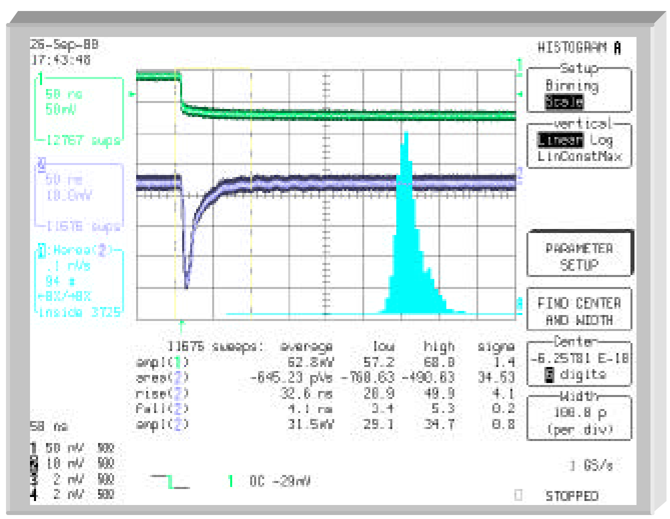


Figure 7: Impedance measurement R_L tuned to give $V_{PA} = 0.5(V_{PA})_{RL=\infty}$.

Linearity & Dynamic Range Check:

Table 2 shows the measured gain values versus preamplifier input voltage and charge for Preamplifier #3, channel #4. Figure 8 shows the Voltage gain characteristics, which clearly shows that the output voltage is linear to only about 60mV into a 50Ω output.

Att. Factor [db]	Vnim [mV]	DVnim [mV]	Vcc [mV]	Vpa [mV]	DVpa [mV]	Qarea [nVs]	DQarea [nVs]	Qpa [pC]	DQpa [pC]	Qin [pC]
8	49.5	0.8	8.9	55.3	1.3	2.063	0.026	41.3	0.5	0.50
0	123.6	0.5	22.3	70.2	0.9	3.586	0.021	71.7	0.4	1.24
1	110.8	0.7	20.0	70.8	1.2	3.467	0.023	69.3	0.5	1.11
2	98.3	0.6	17.8	71.1	1.0	3.273	0.021	65.5	0.4	0.98
3	90.0	0.6	16.3	70.2	1.7	3.220	0.021	64.4	0.4	0.90
4	75.2	0.6	13.6	68.7	2.4	2.856	0.023	57.1	0.5	0.75
5	69.0	0.6	12.5	66.7	3.2	2.684	0.022	53.7	0.4	0.69
6	61.1	0.6	11.0	62.9	3.2	2.448	0.023	49.0	0.5	0.61
7	54.5	0.5	9.8	59.2	2.5	2.222	0.023	44.4	0.5	0.55
8	49.6	0.6	9.0	55.1	1.4	2.052	0.023	41.0	0.5	0.50
10	39.5	0.8	7.1	45.6	1.4	1.675	0.027	33.5	0.5	0.40
12	32.2	0.7	5.8	37.0	1.7	1.355	0.027	27.1	0.5	0.32
14	25.8	0.6	4.7	29.8	1.3	1.091	0.027	21.8	0.5	0.26
16	19.8	0.4	3.6	23.7	0.9	0.883	0.027	17.7	0.5	0.20
17	18.0	0.3	3.3	20.8	0.9	0.791	0.027	15.8	0.5	0.18
18	15.8	0.3	2.9	18.2	0.9	0.694	0.025	13.9	0.5	0.16
22	10.2	0.3	1.8	12.1	0.8	0.446	0.028	8.9	0.6	0.10
26	6.7	0.2	1.2	7.8	0.6	0.283	0.022	5.7	0.4	0.07
28	4.6	0.2	0.8	5.9	0.7	0.184	0.022	3.7	0.4	0.05
30	3.7	0.7	0.7	5.1	0.9	0.154	0.044	3.1	0.9	0.04

Table 2: Measured gain characteristics for amplifier #3, channel #4.

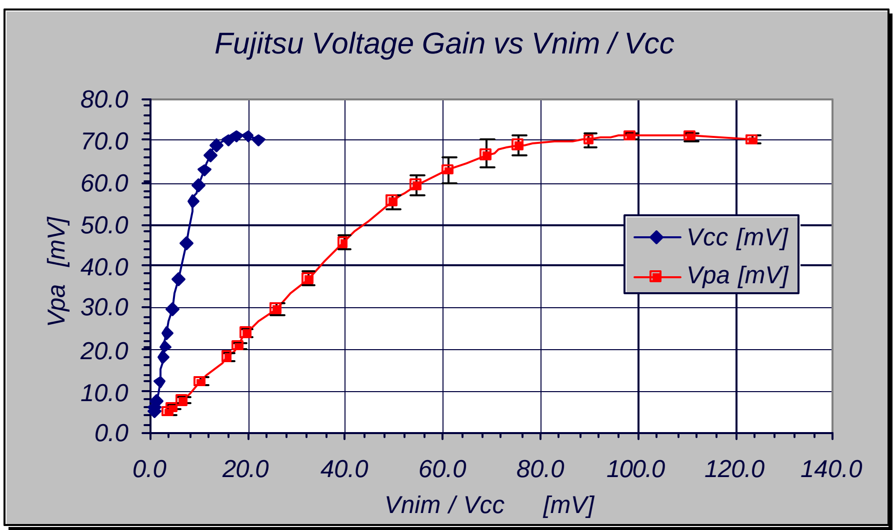


Figure 8: Voltage Gain linearity Characteristics. The blue curve shows Vpa vs. Vcc While the red curve shows Vpa vs. Vnim.

Figure 9 shows the Charge Gain characteristics, also for preamplifier #3, channel #4. Charge saturation occurs at between (750 – 900) fC at the input to the preamplifier.

Charge saturation occurs at (750-900) fC i/p charge

Voltage saturation occurs at 60mV i/p voltage

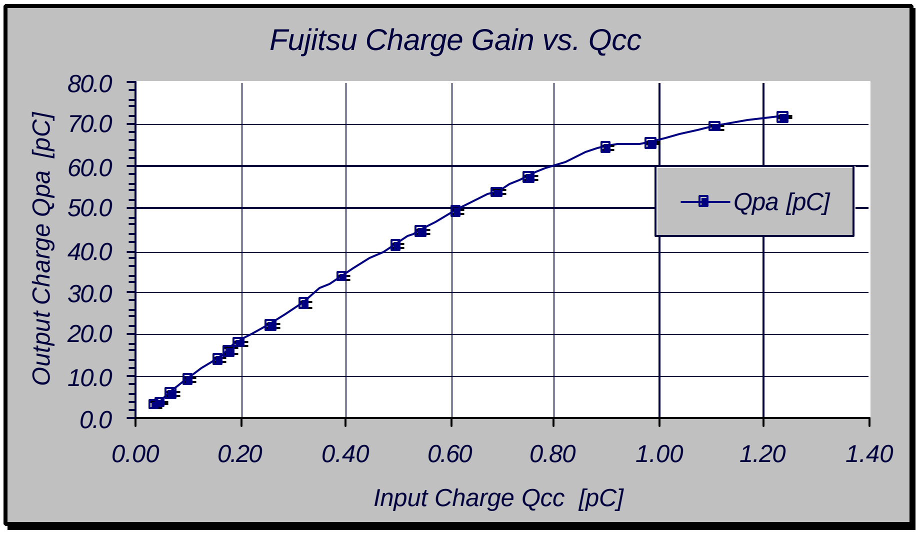


Figure 9: showing the Charge Gain characteristics of the Bess-Fujitsu preamplifier. Qcc is the i/p charge from the Charge Injector while Qpa is the preamplifier o/p charge.

Cross-Talk:

The cross-talk or induced signal on neighbouring channels was investigated by injecting a charge, in this case, of 458fC to the i/p of channel #4 and measuring the respective output pulse-heights from channel #1-3. Figure 10 shows the output pulse for channel #1, together with the real signal. The cross-talk corresponds to about 7.5% on this and up to about 9% on some of the other channels and has the opposite polarity of the correct signal. Table 3 gives a summary of the measurements. The maximum cross-talk reached when the amplifier is drive to the start of saturation is about 10%.

Maximum Cross-talk: ~ 10% **of output & of opposite Polarity**

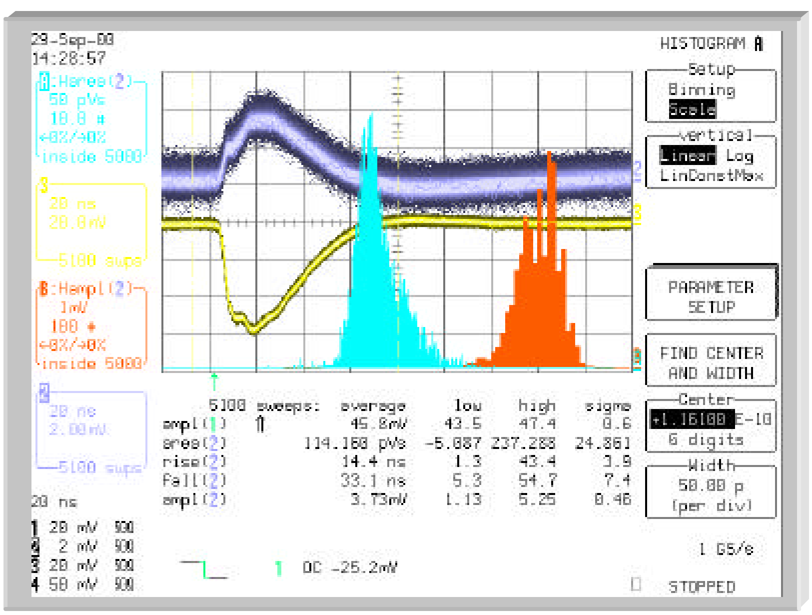


Figure 10: shows the cross-talk or the induced charge on neighbouring channels, here scope trace 3 (yellow) shows the real signal and trace 2 (blue) shows the induced signal. The light-blue histogram shows the area of the induced signal in pVs, corresponding to 2.3pC of o/p charge. The red histogram correspond to the pulse-height of the induced signal.

V_{NIM} [mV]	Channel 1 V_{c-t} [mV]	Channel 1 Q_{c-t} [pC]	Channel 2 V_{c-t} [mV]	Channel 2 Q_{c-t} [pC]	Channel 3 V_{c-t} [mV]	Channel 3 Q_{c-t} [pC]	Channel 4 V_{PA} [mV]	Channel 4 Q_{PA} [pC]
72.6 ± 0.5	5.0 ± 0.5	—	—	—	—	—	—	—
45.8 ± 0.6	3.7 ± 0.5	2.3 ± 0.5	4.0 ± 0.4	2.4 ± 0.6	4.4 ± 0.9	2.4 ± 0.6	50.4 ± 1.4	—
18.0 ± 0.4	2.1 ± 0.3	—	—	—	—	—	—	—

Table 3: Measurements of cross-talk for a 458fC pulse injected into channel #4. Channel #1 is also compared for various input charges between (180 – 726)fC.

Noise measurement:

Figure 11 shows the preamplifier output pulse attenuated by 50dB, thus allowing the noise to be measured with the same settings as a normal measurement (gate-width). The averaged peak-to-peak noise is (1.6 ± 0.3)mV

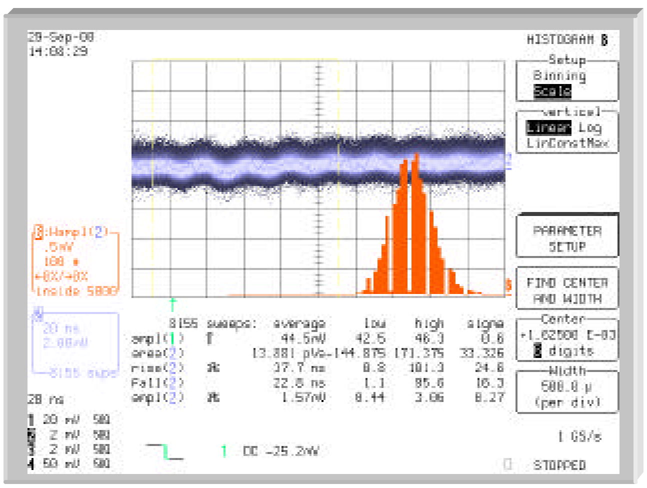


Figure 11: Preamplifier signal attenuated by 50dB showing the averaged peak-to-peak residual noise of (1.6± 0.3)mV. 1fC » 6240 e

Comparison with Other Preamplifiers:

A comparison was also made to other preamplifiers, such as the Saclay CPLEAR strip-preamplifier as well as fast linear types that are more suited to digital sampling techniques such as flash ADCs (FADS) or the 'Domino Sampling Chip' waveform digitizer (DSC) [2]. Table 4 show normalized measured values of the different preamplifiers measured under the same charge input conditions. The sigma of the noise in the last line of Table 4 is taken from the sigma of the pulse-height histogram shown in Figure 11. Table 5 compares the noise characteristics of the four preamp-

Characteristics	Fujitsu	Saclay	LeCroy 612A	PSI FA106
I/p Impedance [Ω]	96	70	50	100/50
O/p Impedance [Ω]	50	50	50	50
I/p Charge [fC]	502 ± 8	502 ± 7	502 ± 7	502 ± 6
O/p Voltage [mV]	53.3 ± 1.8	71.1 ± 1.6	82.7 ± 4.2	67.2 ± 2.1
O/p Charge [pC]	41.3 ± 0.7	28.8 ± 0.3	5.6 ± 0.7	8.1 ± 0.2
Gain [mV/pC]	110	142	165	134
Noise p-t-p [mV]	1.6± 0.3	1.1 ±0.2	1.4 ± 0.2	1.3 ± 0.2
Noise sigma [µV]	214	202	193	187

Table 4: A comparison of preamplifier characteristics for a given charge injection

lifiers under different conditions. The measurements were done by histograming the peak-to-peak pulse-height, 300ns after the start of the output pulse for a duration of 100ns and over 5000 sweeps. The delayed gate ensures only the noise on the signal is taken for the measurement. The values in table 5 correspond to the sigma of the histogram. As can be seen from the measurement of the Fujitsu with power 'Off' most of the noise is still present.

Noise Characteristics	Fujitsu	Saclay	LeCroy 612A	PSI FA106
I/p Charge [fC]	487	487	487	487
Gain [mV/pC]	110	142	165	134
O/p Noise σ [μV] Power Off	160	—	—	—
O/p Noise σ [μV] No i/p	162	151	200	179
O/p Noise σ [μV] with i/p	214	202	193	187

Table 5: Shows the noise characteristics of the four preamplifiers when measured in a time gate of 100ns, 300ns after the pulse output (i.e. only measures noise). The values correspond to the sigma of the pulse-height histogram.

Tables 6 and 7 show respectively the measured characteristics of the LeCroy 612A and the Saclay preamplifiers.

(i) LeCroy 612A:

					LeCroy 612A					
Att. Factor [db]	Vnim [mV]	ΔVnim [mV]	Vcc [mV]	Vpa [mV]	ΔVpa [mV]	Qarea [pVs]	ΔQarea [pVs]	Qpa [pC]	ΔQpa [pC]	Qin [pC]
0	124.8	0.8	22.6	212.3	10.4	639	32	12.8	0.6	1.25
1	112.3	0.8	20.3	189.1	9.3	573	33	11.5	0.7	1.12
2	99.9	0.8	18.1	171.8	8.7	519	31	10.4	0.6	1.00
3	88.5	0.8	16.0	152.5	8.4	439	31	8.8	0.6	0.89
4	74.8	0.8	13.5	133.3	6.7	418	23	8.4	0.5	0.75
5	66.9	0.7	12.1	116.6	6.0	379	24	7.6	0.5	0.67
6	61.1	0.8	11.0	103.9	5.1	348	21	7.0	0.4	0.61
7	54.6	0.7	9.9	91.8	4.5	318	22	6.4	0.4	0.55
8	43.7	0.7	7.9	81.8	4.3	242	22	4.8	0.4	0.44
10	37.4	0.6	6.8	64.1	2.9	225	22	4.5	0.4	0.37
12	28.5	0.4	5.1	50.4	2.6	184	21	3.7	0.4	0.29
14	23.7	0.4	4.3	39.9	2.0	158	20	3.2	0.4	0.24
16	19.3	0.3	3.5	30.9	1.4	121	21	2.4	0.4	0.19
17	17.6	0.3	3.2	26.8	1.3	111	20	2.2	0.4	0.18
18	15.5	0.3	2.8	24.5	1.1	100	19	2.0	0.4	0.16
22	9.8	0.3	1.8	15.3	0.8	72	23	1.4	0.5	0.10
26	5.9	0.4	1.1	7.9	0.4	34	21	0.7	0.4	0.06
28	4.5	0.2	0.8	6.6	0.4	25	21	0.5	0.4	0.05
30	3.5	0.5	0.6	5.2	0.5	19	19	0.4	0.4	0.04

Table 6: measured characteristics of LeCroy 612A Preamplifier

(ii) Saclay Preamplifier:

					Saclay					
Att. Factor [db]	Vnim [mV]	ΔVnim [mV]	Vcc [mV]	Vpa [mV]	ΔVpa [mV]	Qarea [pVs]	ΔQarea [pVs]	Qpa [pC]	ΔQpa [pC]	Qin [pC]
0	126.1	1.7	22.8	135.0	3.6	3349	15	67.0	0.3	1.26
1	111.7	1.7	20.2	126.7	3.6	3052	15	61.0	0.3	1.12
2	99.5	1.7	18.0	118.4	3.7	2774	15	55.5	0.3	1.00
3	88.1	0.8	15.9	108.0	3.6	2507	15	50.1	0.3	0.88
4	78.7	0.8	14.2	96.4	3.7	2272	15	45.4	0.3	0.79
5	70.4	0.7	12.7	88.4	3.2	2051	15	41.0	0.3	0.70
6	62.3	0.7	11.3	79.3	2.8	1837	15	36.7	0.3	0.62
7	55.5	0.7	10.0	71.6	2.0	1642	13	32.8	0.3	0.56
8	49.2	0.7	8.9	64.0	2.0	1474	13	29.5	0.3	0.49
9	44.0	0.7	8.0	56.8	1.8	1323	13	26.5	0.3	0.44
10	39.3	0.7	7.1	50.7	1.7	1189	13	23.8	0.3	0.39
12	31.6	0.6	5.7	40.3	1.5	956	13	19.1	0.3	0.32
14	25.0	0.4	4.5	31.4	1.2	755	12	15.1	0.2	0.25
16	18.5	0.3	3.3	25.6	0.7	553	12	11.1	0.2	0.19
17	16.3	0.3	2.9	22.5	0.8	490	12	9.8	0.2	0.16
18	14.7	0.3	2.7	19.8	0.8	452	12	9.0	0.2	0.15
22	9.7	0.3	1.8	12.4	0.7	287	11	5.7	0.2	0.10
26	6.6	0.2	1.2	8.1	0.5	183	10	3.7	0.2	0.07
28	5.4	0.2	1.0	6.4	0.5	152	11	3.0	0.2	0.05
30	3.8	0.5	0.7	4.9	0.5	116	11	2.3	0.2	0.04

Table 7: measured characteristics of Saclay Preamplifier

Figures 12 and 13 show the voltage- and charge-gain characteristics of the preamplifiers. It can be seen that for charge sensitive measurements, such as ADC measurements, the Fujitsu and Saclay preamplifiers are more suited, with the Saclay one having a larger dynamic range in the linear region than the Fujitsu one. For digital measurements where pulse-height is the sensitive measure the LeCroy preamplifier is more suited, having a much larger dynamic range.

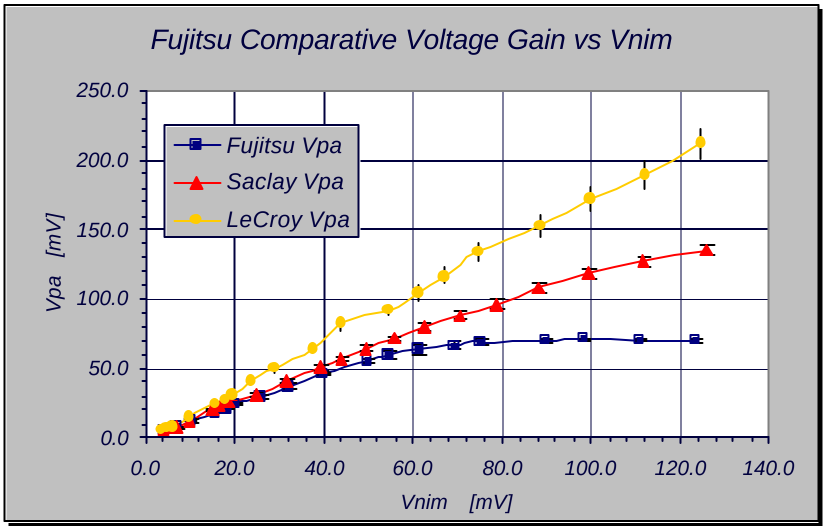


Figure 12: Comparative measure of the voltage gain & dynamic range of the preamplifiers under study

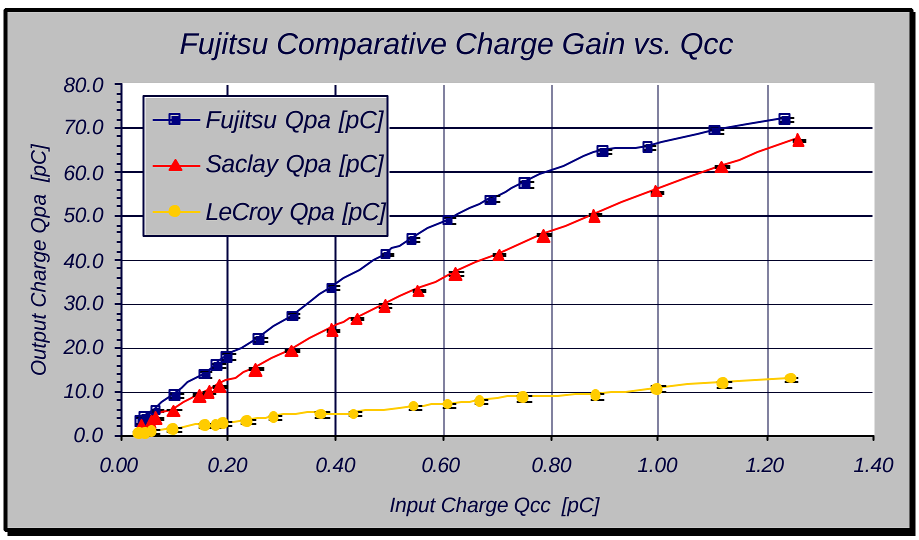


Figure 13: Comparative measure of the charge gain & dynamic range of the preamplifiers under study

Post-Amplification Possibilities:

Since the Fujitsu amplifier starts to saturate for input charges above about 900fC, corresponding to an o/p charge of about 65pC or a voltage of 65 mV some post-amplification will be needed to allow digital signal processing using the DSC (100-300 mV) or if charge analysis is needed using e.g. LeCroy 2249A ADCs (full range 256pC). The present available possibilities for post-amplification are:

- PSI FA106, a 16-fold bi-polar fast amplifier with 2x16 outputs and a gain of 10.
- LeCroy 612, a 12-fold negative i/p fast amplifier with 2x12 outputs and a gain of 10.
- PSI TFA100A, timing filter amplifier, 6-fold, rise/fall time adjustable and variable gain up to 20.

Table 8 shows a comparison of the Fujitsu preamplifier when combined with the above mentioned three post-amplifiers.

	Fujitsu + PSI FA106	Fujitsu + LeCroy 612	Fujitsu + PSI TFA100A
Saturation Input Charge [fC]	350	820	894
O/p Saturation Voltage [mV]	450	678	1450
O/p Saturation Charge [pC]	364 ± 6	620 ± 16	1500 ± 16

Table 8: Saturation limits of Fujitsu used in conjunction with a post-amplifier

Conclusions:

The present study was intended to find a quick viable solution to read-out the wire and vernier cathode signals from the mini prototype drift chamber of the MuEgamma Experiment. This chamber is to be tested under beam conditions in the πM1 Area of PSI. The chosen solution is not intended to necessarily be the final one and is rather, a compromise, to be able to read-out both the wire and cathode information digitally and analogue wise, in order to measure the characteristics of the chamber.

The implementation of the Fujitsu chip in the Bess-Experiment circuit limits the gain to a factor two-times less than possible, with a non-linear behaviour starting at about 900fC of input charge. The output voltage is also limited to about 60mV into 50Ω, after which saturation starts, reaching a maximum output voltage of 70mV. This has the consequence that post amplification is probably needed. A summary of the Fujitsu properties found are given below.

Summary of Fujitsu Properties

Rise-time t_R » **4.5 ns**
Fall-time t_F » **32 ns**
Absolute gain factor: 110 mV/ pC
Charge gain: 87
Charge saturation occurs at (750-900) fC i/p charge
Voltage saturation occurs at 60mV i/p voltage
Maximum Cross-talk: ~ 10% **of output & of opposite Polarity**

The total number of channels to be readout during the forthcoming test are:
- 8 wires read-out at both ends — 16 anode channels
- 3 vernier strips per wire — 24 cathode channels

The proposed read-out system for the wires is shown in Figure 14, here the combination of Fujitsu and FA106 seems to match the characteristics of both the LRS 2249A and the DSC. A similar scheme could be used for the vernier strips though here instead of the Fujitsu the Saclay preamplifier would be used in combination with the LeCroy 612 or if sufficient channels are available the TFA100A could be used since sufficient amplification would be guaranteed.

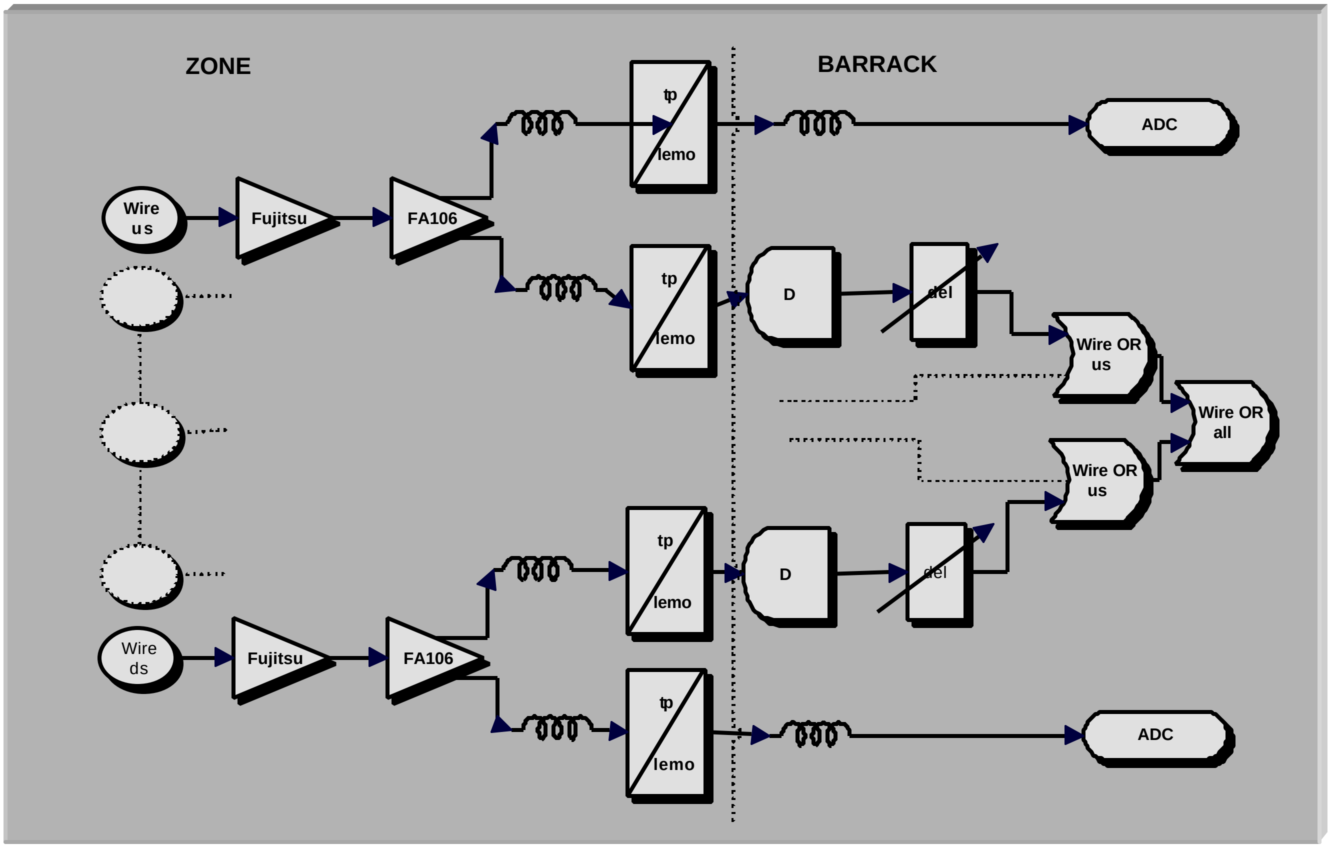


Figure 14: Proposed read-out scheme for the wires of the PSI mini-prototype test chamber.

References:

[1] R. J. Yarema, Fermilab Report TM-1284, 2563.800 Nov. 1984.

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