

Some measurements at IUCF with the new preamp board

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Characterization of gain and linearity, part I

For this measurement one channel was used, terminated into various load impedances. The unused channel outputs were left open, i.e., saturated. The control lines for the GAS-1 are as Fernando set them (I haven't looked into the settings or tried to change them).

The new preamp board and the interposer board were installed in a shielded box. The test pulse was from a Tektronix AFG3252 generator, and the output was observed with a Tektronix P6247 differential probe (set for 200 MHz BWL) and TDS784D oscilloscope (set for 250 MHz BWL). The test circuit is documented in Figure 1.

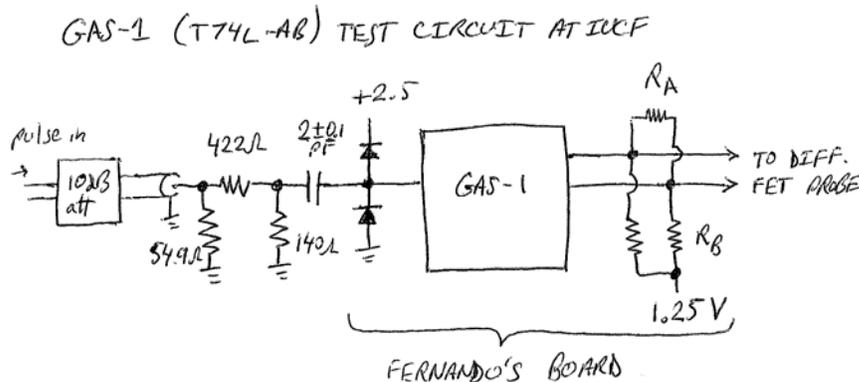


Figure 1. Test circuit, simplified. See preamp board schematics for further details. Effective charge injection capacitance is $157.6 \text{ fF} \pm 5\%$.

A typical response to a voltage step input through the charge injection circuit above is shown in Figure 2. Response to a range of amplitudes is shown in Figure 3, showing the gradual nonlinear response above roughly 250 fC. Note that the peaking time is shifted as well in the nonlinear region, probably indicating some stage of the signal processing is slew rate limited. It could be the output stage, I should come back to check if the peaking time shift is dependent on the load impedance. A quick look shows it is not much dependent on the load impedance, so (I presume) is happening at an earlier stage.

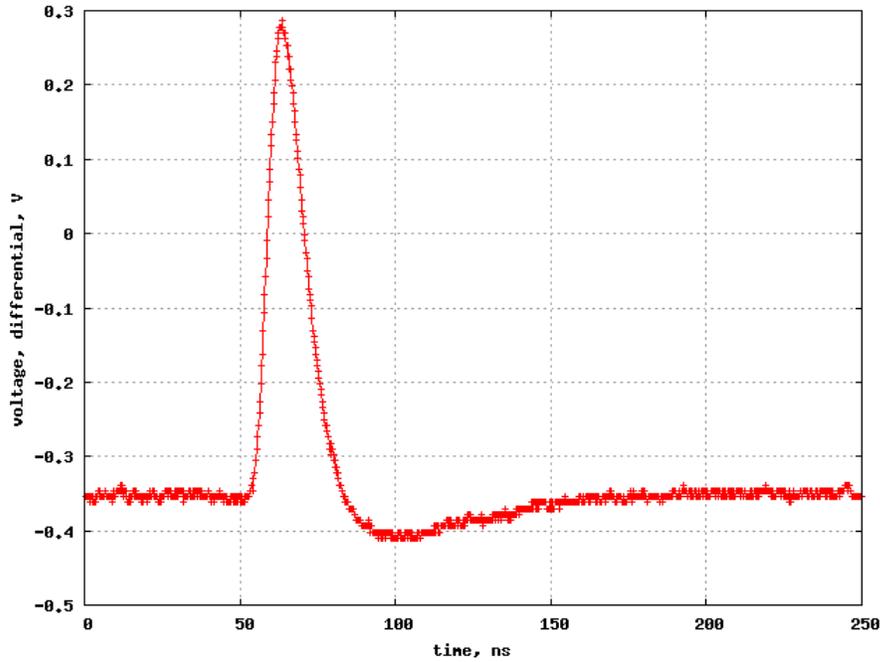


Figure 2. Response GAS-1 to 252 fC $\pm 5\%$ charge impulse. Output load impedance is 100 Ω . The noise here is dominated by probe and oscilloscope noise.

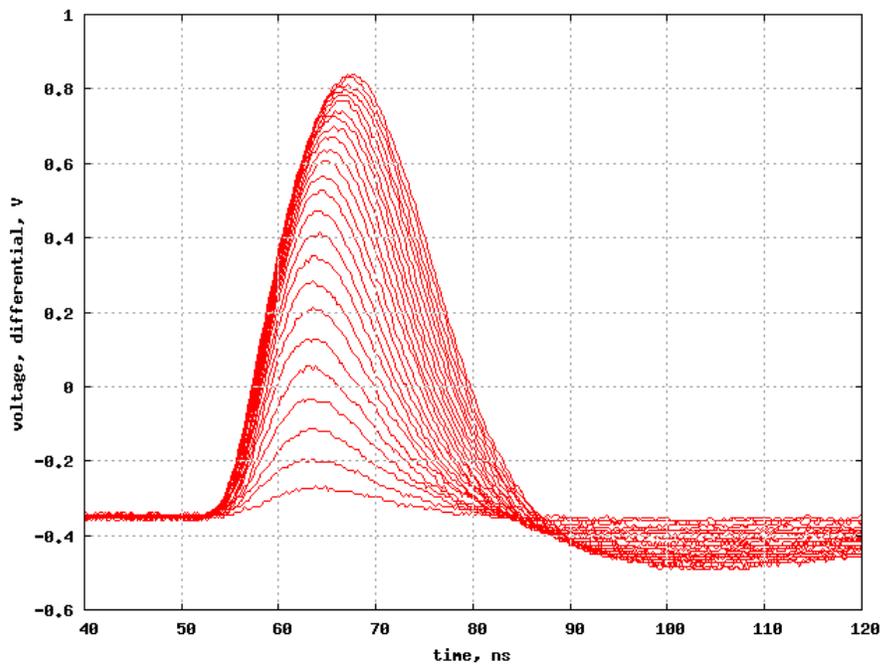


Figure 3. Response to charge impulses $N*31.5$ fC for $N=1$ to 25, output load 100 Ω . The 25 input pulse amplitudes mentioned in Figure 3 were tested with 4 different external output load resistances (see Figure 1):

1. $R_A = \infty$, $R_B = 100 \Omega$ – so 200 Ω differential
2. $R_A = \infty$, $R_B = 50 \Omega$ – so 100 Ω differential
3. $R_A = 100 \Omega$, $R_B = 50 \Omega$ – so 50 Ω differential
4. $R_A = 50 \Omega$, $R_B = 50 \Omega$ – so 33.3 Ω differential

Note that case 2 is roughly equivalent to using the cable with no termination resistors on the preamp board, and case 3 is roughly equivalent to using the cable with termination resistors on the preamp board, “double termination”. I say roughly because the resistor values would in actuality be slightly different.

For each of the combination of amplitude & load resistance one event was stored, and the (leading part of the) waveform was fit to determine the baseline and the peak amplitude of the pulse. The pulse model was $V(t) = t^p e^{-t/\tau}$, which is a good fit to just the leading part of the pulse except for the highest amplitudes where the pulse shape distortion (mentioned above) was too large; these points are therefore discounted below. Results of this are shown in Figure 4, where the measured output voltage pulse height is translated into nominal output current by using the nominal differential load resistance, the parallel combination of R_A , $2R_B$, and I assume 1 k Ω (internal to the chip).

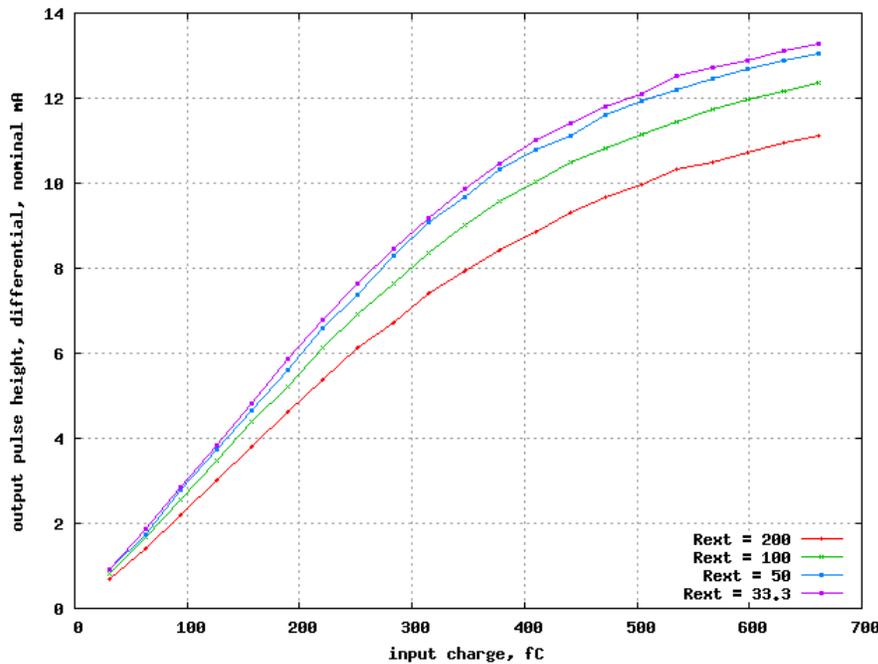


Figure 4. Output differential current pulse height vs. input pulse amplitude, calculated assuming nominal 1 k Ω (differential) internal termination.

One would expect these curves to lie on top of each other, at least for small signals where the output stage may be modeled as a (signal-dependent) current source with a parallel output impedance and a load impedance (independent of the signal). For larger signals the output impedance will obviously become signal dependent so the curves would diverge. The fact that they do not have the same slope at low signal amplitudes, is simply due to the fact that (above) we have an incorrect model of the output impedance of the chip – it is not just 1 k Ω plus or minus some uncertainty, but also of course has in parallel the output impedance of the transistors. It would seem, from this measurement, that about 320 Ω is the actual effective differential output impedance (Figure 5).

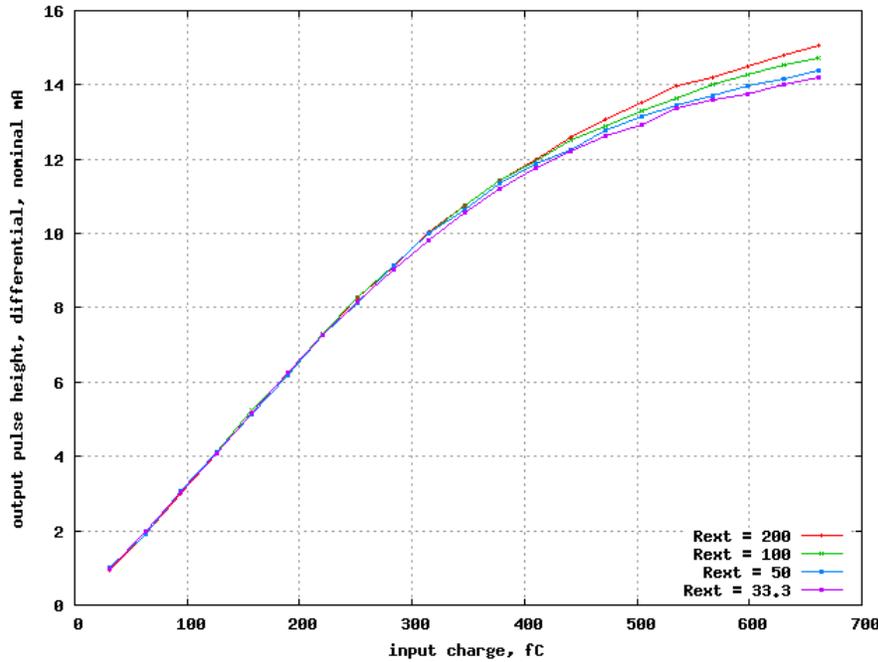


Figure 5. Output differential current pulse height vs. input pulse amplitude, calculation adjusted to assume 320 Ω (differential) internal termination.

Naturally this suggests making a direct measurement of the output impedance. I did this over a band 500 kHz to 50 MHz using a network analyzer with a Mini-Circuits ADT3-6T (50 Ω : 150 Ω) transformer and blocking capacitors to connect to the output of the GAS-1. Each side had a 100 Ω resistor to +1.25 V to ensure a reasonable DC bias point. Unfortunately, or perhaps in hindsight better to say fortunately, the results do not obviously confirm the above. Up to roughly 8 MHz the differential output impedance of the GAS-1 on the preamp board is equivalent to a model of 750 Ω in parallel with 10 pF. I believe this value (750 Ω) is more in line with what would be expected for the output resistance of the transistors in parallel with the internal resistors. Mitch – comments? At higher frequencies such a simple model is just not valid, there are clearly inductive effects coming into play, which might well make it look like 320 Ω for the one particular pulse shape shown above. So, the main conclusions are not to pay too much attention to the above output impedance discussion, and probably to use a termination resistor of 59.0 Ω on each leg of the output to +1.25 V if a good termination is desired at the preamp board. That sets it a little high to help cancel some of reflection from the capacitive loading. Time-domain reflection measurements with the long cable might indicate an adjustment to this value.

DC balance of the outputs

Before installing any termination resistors I measured the common-mode DC imbalance at the output on 4 channels by shorting each outputs' positive and negative terminals. The voltage with respect to ground and current obtained by shorting the output pair to +1.25 V are recorded in the following table:

Common-mode voltage	Imbalance current
0.960 V	-1.431 mA
0.942 V	-1.526 mA

0.948 V	-1.491 mA
0.957 V	-1.435 mA

The GAS-1 supply voltage was 2.502 V and the reference voltage was 1.247 V. Secondly this implies a DC common-mode output impedance of 203 Ω , which is in reasonable agreement with the 750 Ω differential measurement above.* Primarily, the conclusion from this measurement is that we may typically expect the common-mode line voltage in the absence of any external common-mode termination to vary by something of order 300 mV or more over temperature and process variations, *assuming these imbalance currents were really designed to come out zero*. Of course this is an unwarranted extrapolation, we have to measure it on a batch of chips to get some idea of the variation. That probably should be measured. I suspect that a 300 mV shift in the common-mode voltage could imply at least a few percent variation in the signal gain (to differential output) – this is a measurement to be done. A related conclusion is that the +1.25 V termination reference supply on the board, if used, should be capable of sourcing or sinking about 36 mA at least.

Termination and power discussion

I installed termination resistors on the preamp board using current best estimate of the proper value, that is 59.0 Ω . A short (1 m) cable was connected, with a 100 Ω differential termination at the far end. This is my proposed default configuration. At a later date we may go back to explore how much power is saved by omitting the termination resistors on the preamp, and how much the signals are degraded by doing so, and make an informed decision. I prefer to keep the best signal quality possible for the initial measurements.

We can easily make a rough estimate of the power savings from omitting the external terminations on the preamp: The baseline output current (differential) is about 5.3 mA, observed. With termination, the load is 50.5 Ω , voltage is 268 mV, power into cable and far termination resistor is 17 mW for 24 lines. Without termination, the load is 88.2 Ω , voltage is 468 mV, power into cable and far termination is 52 mW for 24 lines. In either case the supply current (and so the total power input) is absolutely the same. So, the power savings on the preamp board from using no termination resistors is 35 mW. That is approximately 2.5 %, I don't see that this is in any way significant. *Much more power could be saved* by addressing the output common mode current of -1.5 mA, which is consuming 115 mW[†], or by omitting the on-chip Thévenin termination (or replacing with bussed terminations to the external +1.25 V source), which are consuming 384 mW.

Characterization of gain and linearity, part II

Now I went back and examined the linearity in response to a step charge input in more detail over the really usefully linear lower part of the range. Results are shown in Figure 6, the first quantitative plot of *nonlinearity*, at least that I have seen. The nonlinearity is better than 0.5 % over the range 0 to ~280 fC, i.e., 0 to ~425 mV. This level of nonlinearity is I suppose perfectly acceptable, although I would like to encourage Simon to introduce an extra nonlinearity, say 2%, in his analysis of cosmic ray data and see what

* With a split termination, the common-mode impedance is R/2 and the differential-mode impedance is 2R.

† I assume a +3.2 V input supply.

effect it has on the cathode position resolution. It must have some effect, but we may guess it is acceptable; best to really check it though. The linearity really starts to degrade above 500 mV, so I will take this as the design full scale range of the ADC system as seen at the preamp board outputs. That is, the combined system of cable, receiver/shaper, and Struck ADC or FADC250 now, and later the combined system of cable and FADC125, will have a 500 mV full scale signal range or just a bit more. Hopefully this will mesh well with the chamber operating gain and signal size, it must be tested.[‡] Revising the gain a little bit will of course be possible.

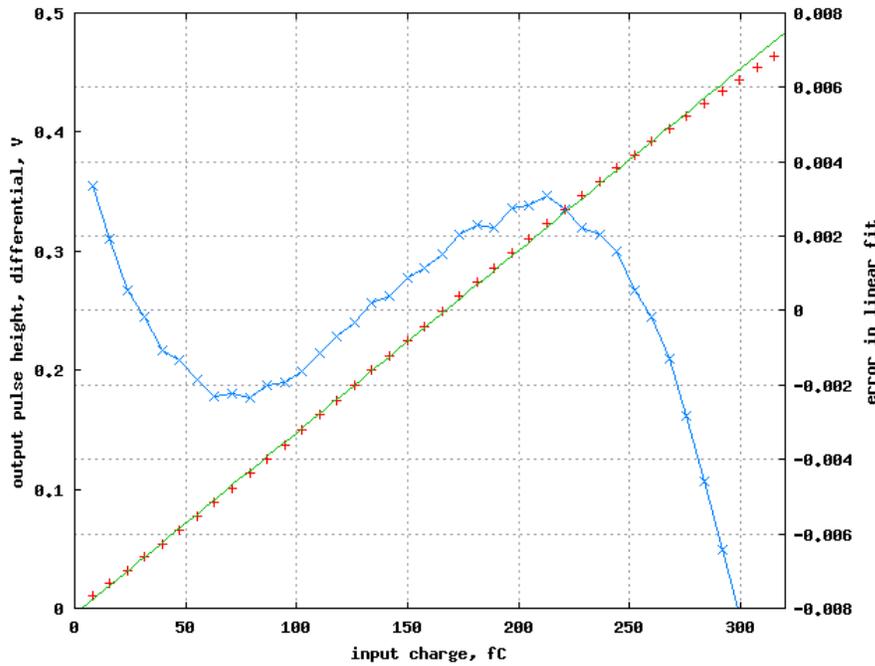


Figure 6. Output differential voltage pulse height vs. input pulse amplitude, for instantaneous (step) charge input. Nonlinearity, i.e., error in linear fit, is shown on the right-hand axis. Note that the fit function consists of a gain *and* an *offset*. Without the offset the results are significantly worse.

Response to chamber pulse shape

The response of the ASIC to real chamber pulses is of course often best investigated with a real chamber at hand. However, in one respect test pulser data is superior – one can easily control how much charge is being injected. (Of course testing with a low energy X-ray source such as ⁵⁵Fe is similarly useful.)

The total charge seen from a straw tube detector up to time t is $Q(t) = Q_0 \frac{\ln\left(1 + \frac{t}{t_0}\right)}{\ln\left(1 + \frac{t_f}{t_0}\right)}$,

where the characteristic time $t_0 = \frac{(a + \lambda)^2 \ln \frac{b}{a}}{2\mu V_A}$ and the final time $t_f = t_0 \left(\frac{b^2}{(a + \lambda)^2} - 1 \right)$.

[‡] Will we be able to really exercise the full range of path lengths in the CDC?

Here, with values for the CDC, $a = 10 \mu\text{m}$ is the wire radius, $b = 8 \text{ mm}$ the cathode radius, $\lambda = 1 \mu\text{m}$ the distance of mean of avalanche above the wire[§],

$\mu = 1.54 \times 10^{-4} \text{ m}^2 / \text{V} \cdot \text{s}$ is the mobility of ions^{**}, $V_A = 1900 \text{ V}$ the bias voltage.

Consequently $t_0 = 1.38 \text{ ns}$ and $t_f = 731 \mu\text{s}$.

I have at hand an arbitrary waveform generator with a $8.192 \mu\text{s}$ record length. That is more than sufficient to simulate a chamber pulse, but the total charge must be scaled appropriately. To generate a signal that simulates a chamber pulse of total charge Q_0 , the

waveform amplitude should be set so that there is a total charge $Q_0 \frac{\ln\left(1 + \frac{8.192 \mu\text{s}}{t_0}\right)}{\ln\left(1 + \frac{t_f}{t_0}\right)}$ in

the pulse. That is a simple matter.

By this means the “canonical” 94 electron (1 cm Ar) pulse with a gas gain of 5×10^4 , that is 753 fC *total* charge, was generated for several values of t_0 bracketing the calculated value above. The waveform generator output, fed to the test circuit of Figure 1, is shown in Figure 7. Results are shown in Figure 8 through Figure 10.

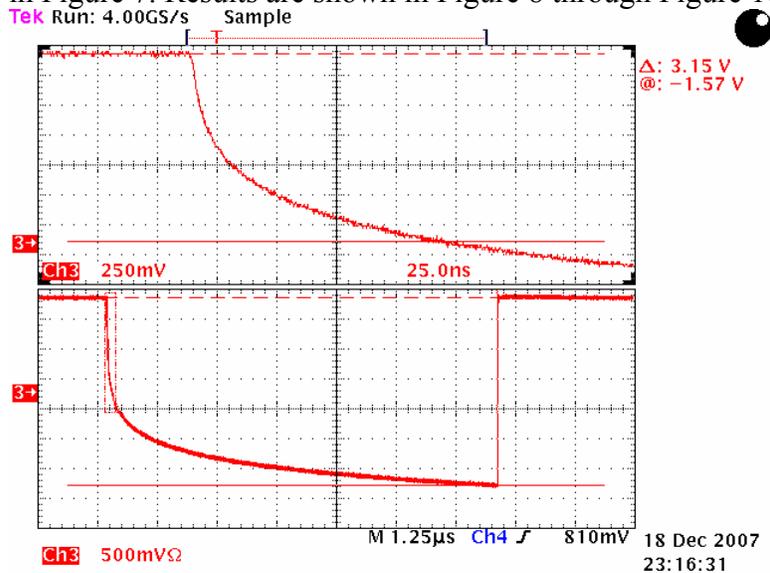


Figure 7. Voltage input to test circuit to simulate a 753 fC CDC signal with $t_0 = 1.38 \text{ ns}$. Upper is zoom of lower as indicated by dashed-line box. Total charge in this pulse, i.e., to $8.192 \mu\text{s}$, is $3.15 \text{ V} \times 157.6 \text{ fF} = 496 \text{ fC}$.

[§] Value is from Sauli paper.

^{**} Again, Sauli paper, I assume 80/20 Ar/CO₂. I don't assume this is necessarily the right value, just $\pm 50\%$.

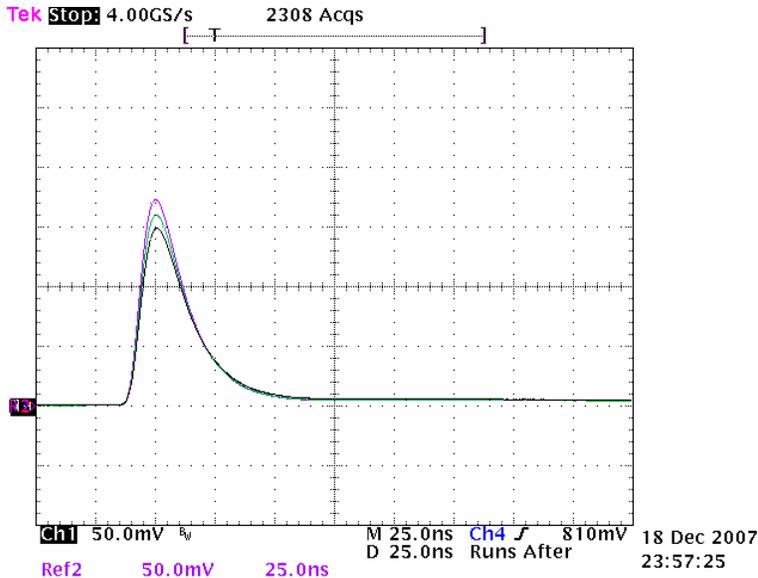


Figure 8. GAS-1 output from simulated 753 fC CDC signal with $t_0 = 1.15, 1.38, 1.66$ ns. Output load resistance is 59.0Ω from each side to $+1.25$ V and 100Ω differential. Averaged waveforms.

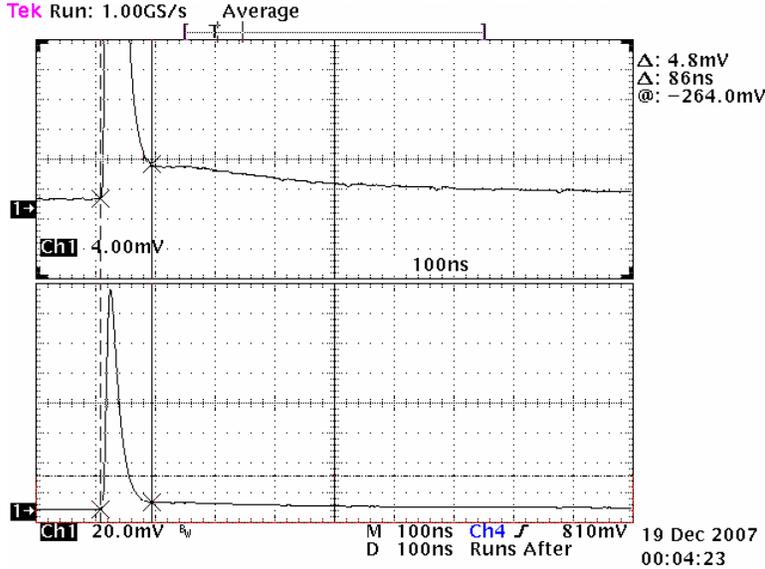


Figure 9. Detail of pulse tail, GAS-1 output from simulated 753 fC CDC signal with $t_0 = 1.66$ ns as above. Averaged waveform. Pulse height 147 mV, tail is within 3% in 86 ns. I think that's actually pretty good!^{††}

At this point, a linearity plot should be taken again using this pulse form. In principle the linearity may be different in some detail with a different input pulse shape, so it should be checked.

^{††} Of course, this conclusion is contingent on my using the correct t_0 value to simulate the real CDC. We have to check it.

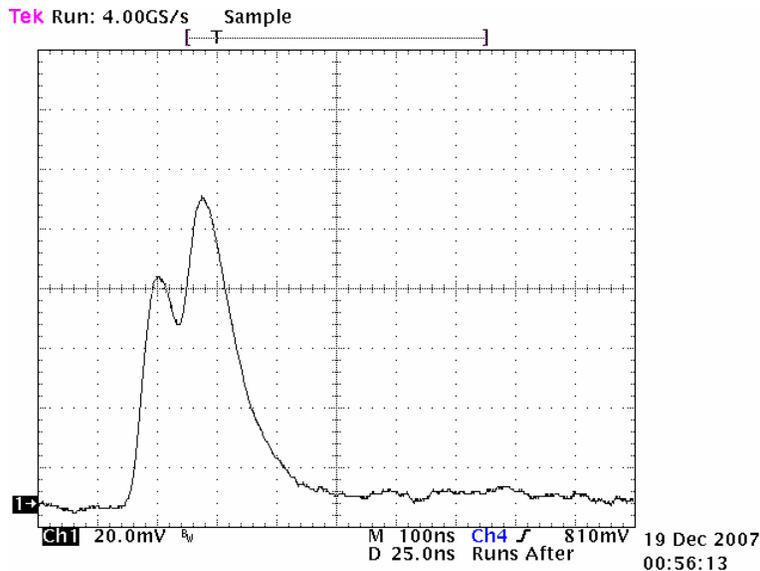


Figure 10. Illustration of a somewhat more realistic pulse shape. Two clusters of 47 electrons each in simulated CDC with $t_0 = 1.38$ ns. Noise level here certainly contains a significant contribution from the scope and test setup, i.e., GAS-1 noise is lower than this.

Also along the lines of linearity, we should have it that integral of pulse is independent of shape, e.g., number and time distribution of clusters, only depends on total signal charge. That should be true to the few % level, it needs checking, I will do this.

Noise and dependence on detector capacitance and resistance

To be done... I will measure the spectrum and total RMS noise with a few capacitances in the range 0 to 100 pF. Note the CDC should be about xx pF to ground. The FDC should be about xx pF between adjacent cathode strips.

Noise from a 10 k Ω and a 200 k Ω resistor will also be checked (if observable). The 10 k Ω value may be too small to be using on the detector, I don't know, let's check it.

TDR measurements of reflection from preamp board

To be done... To confirm or modify the choice of 59.0 Ω resistor.

DC sweep of a forced input current

To be done... This will measure the DC gain of the chip, the bias voltage at the input, DC input impedance, estimate the DC open-loop gain of the input stage. Fairly easy to do, I have a Keithley "sourcemeater" to use.