Summary of measurements on the prototype PUPE

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Introduction

PUPE stands for 'Pick-Up Processing Engine', a CPCI-based 9 channel acquisition board designed for the PS trajectory measurement system by Beam/Alpha-Data Ltd. The PUPE is equipped with nine LTC2255 14-bit 125MS/s ADCs. The analogue inputs, as well as the RefClk input, are transformer coupled, insulated from ground and from each other. The input impedance is *very* close to 50 Ω. S_{11} is -40 dB up to about 50 MHz and deteriorates a little above that.

Most acquisitions were done on June 27, 2007. Data are acquired using an FPGA bit file and a test program first provided by Derek on June 20, and which underwent several small upgrades since. Data set size for most plots is 8192 samples. Data are windowed prior to Fourier transformation using a normalized Blackman-Harris window.

The zero-input histogram was taken with a 50 Ω terminator at the input of Ch.1a. The ADC bits are left-aligned in the 16 bit data word returned from the hardware, so to get rid of the two trailing zero bits, the raw data were divided by four before histogramming. The distribution (Fig 1) is a little bit wider (σ=2.6) than the one shown in the LTC2255 datasheet (σ=1.3).

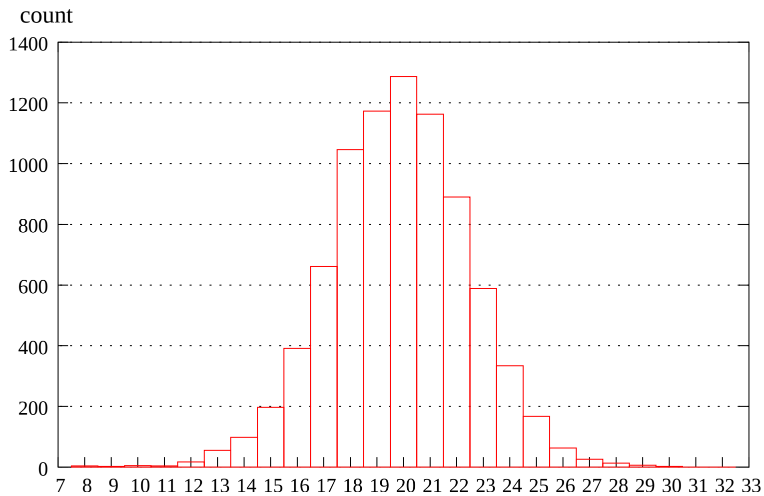

Fig 1: Zero input histogram

Frequency domain measurements

The LTC2255 is specified with a SNR of 72dB, corresponding to an ENOB of 11.7 bits. For 8kS discrete Fourier transforms, we expect the noise floor at $-72-10\cdot\log_{10}(4k) = -108$ dBFS. The spectrum of the zero input, taken from the same data as the preceding histogram, shows a noise floor that approximates this value fairly well, except for a wide bump culminating some 10dB higher, roughly from bins 2000 to 3000, corresponding to frequencies from 30 to 45 MHz (Fig 2).

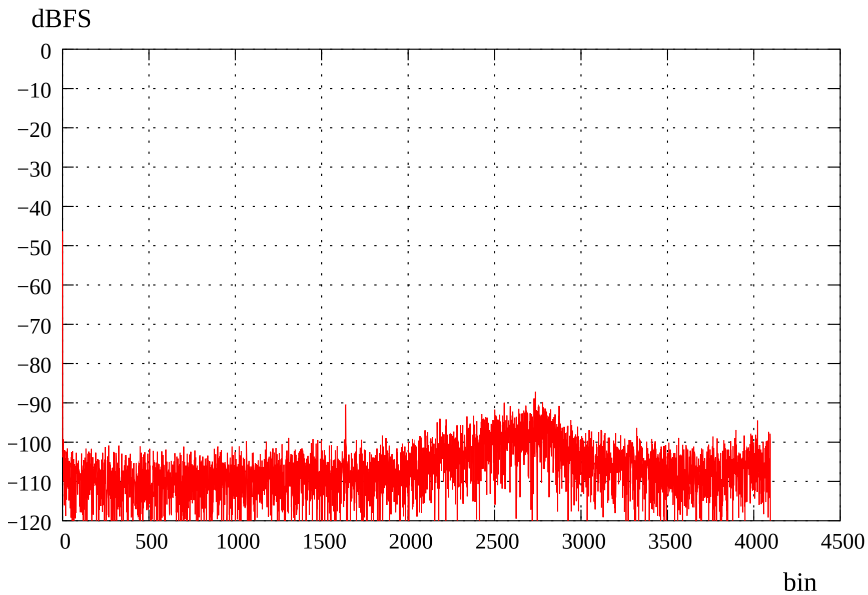

Fig 2: Zero input spectrum

For the following plots, a +10 dBm 10 MHz sinewave signal, produced by an old HP8505A network analyzer has been applied to Ch.1a. Both the zero-input spectrum and the spectrum with signal have been plotted in each figure, in order to accentuate the differences. The signal source isn't really clean enough to adequately test 14-bit ADCs. The noise floor is raised by about 12 dB (Fig 3) and several harmonics are visible. Oddly enough, even though the ADC inputs are already transformer-coupled, it makes some difference whether an external Mini-Circuits T1-6 transformer is used between the source and the ADC. In particular, the noisy bump mostly disappears when the transformer is inserted (Fig 4).

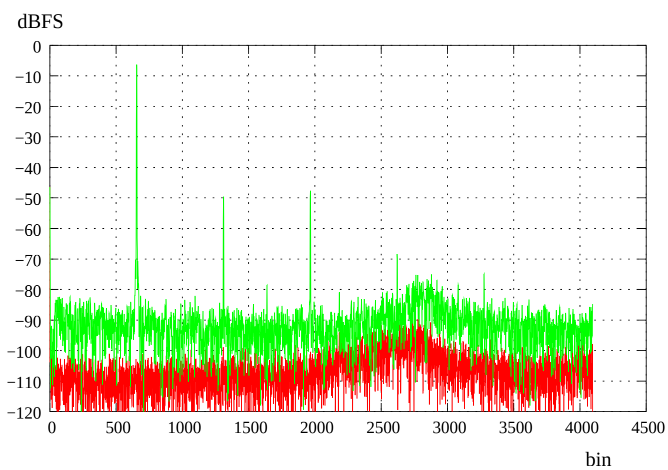

Fig 3: 10MHz, +10dBm, direct coupled

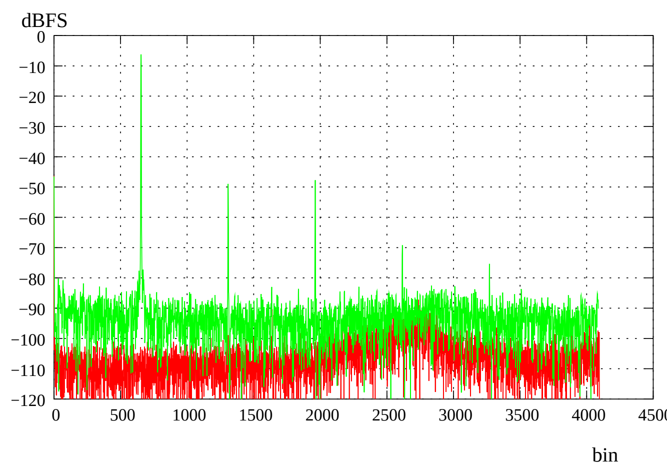

Fig 4: 10MHz, +10dBm, xformer coupled

In order to make sure that the harmonics and noise originate from the HP8505A, and not from the ADC, a 20MHz O(7) Chebychev low-pass filter was inserted, and the input frequency was raised to 16.2MHz to put all harmonics beyond the filter cut-off. The resultant spectrum (Fig 5) no longer shows any significant harmonics and there is a clear drop in the noise level beyond 20MHz (≈bin 1300), conclusively proving that the source is to blame for both wideband noise and harmonics, rather than the ADC. For the noise bump between 30 and 45 MHz, it now makes no difference if an additional transformer is used or not. Again, the zero-input noise is plotted along with the signal data. Even beyond the filter-cut-off, the noise level with signal does not drop quite completely to the zero signal noise level.

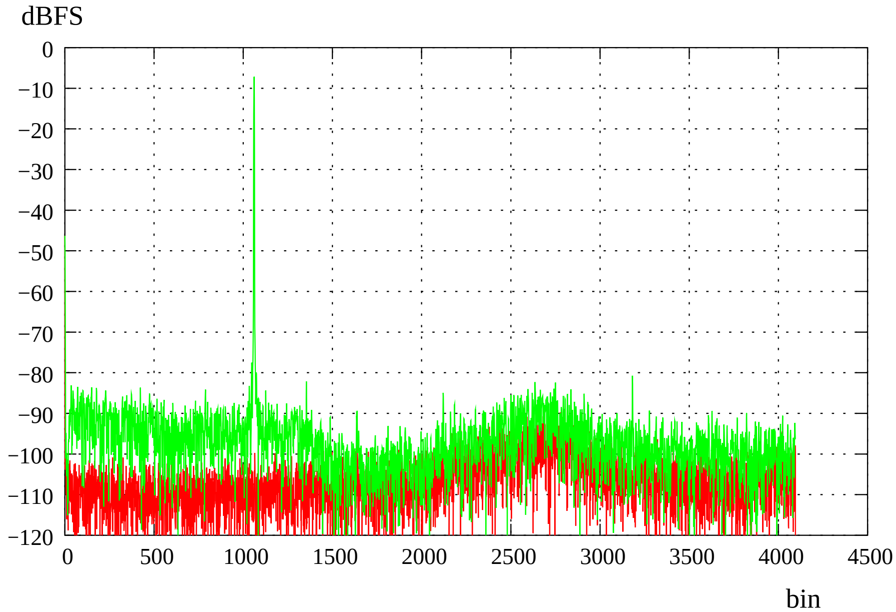

Fig 5: Filtered 16MHz spectrum

Cross-channel coupling (Fig 6) was measured by acquiring from Ch.1a, while applying a 10 MHz, +10 dBm signal to the adjacent Ch.1b, with both looking into 50 Ω impedances. Coupling is about -70 dB. Coupling from more remote channels is insignificant.

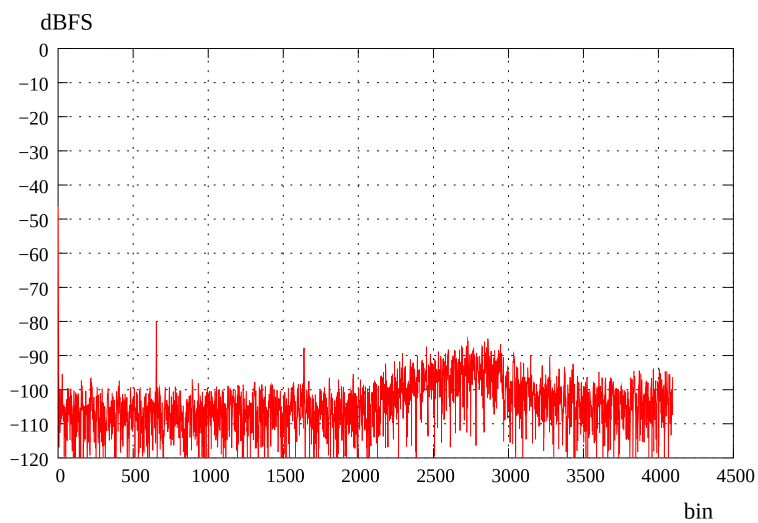

Fig 6: Crosstalk from Ch.1b to Ch.1a

Common mode noise

It was found that grounding the screen-side of an input connector to the module front panel considerably increased the noise level. That prompted a check of the susceptibility to common mode signals. The somewhat awkward setup to do this is shown in Fig 7. Two LEMO 50 Ω terminators were soldered back-to-back, so that their screens are connected, but the central pins remain separate. A 2 ns long coax was connected between the Dig.1 connector (which is connected to the board GND) and Ch.1a via the attached pair of terminators, so that both Dig.1 and Ch.1a see a 50 Ω termination and the connector screens are connected together via the coax. A ferrite toroid with 26 turns of wire was slipped over the coax to form a 26:1 turns ratio transformer through which a signal could be injected. The 26-turn side was connected to the HP8505A NA, which was set to +10dBm. Seen from the NA, this load is essentially an open circuit, causing full reflection, so that the RF voltage applied to the transformer is $1.4V_{RMS}$. (10mW into 50 Ω is $0.707V_{RMS}$.) At the secondary side, that's $1/26^{th}$ of this, $54mV_{RMS}$, or $77mV_{pk}$.

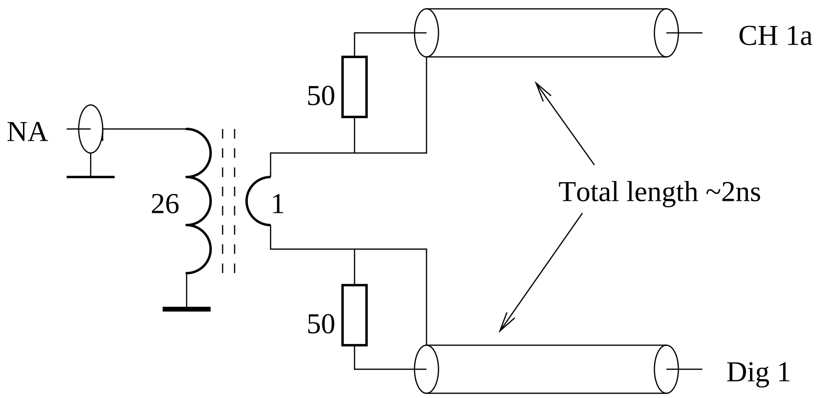

Fig 7: Schematic diagram for CMRR test jig

For low frequencies, almost no signal is seen by the ADC, but at higher frequencies, more and more signal passes through (Fig 8, Fig 9). The noise bump around bin 3000 also gets wider and higher.

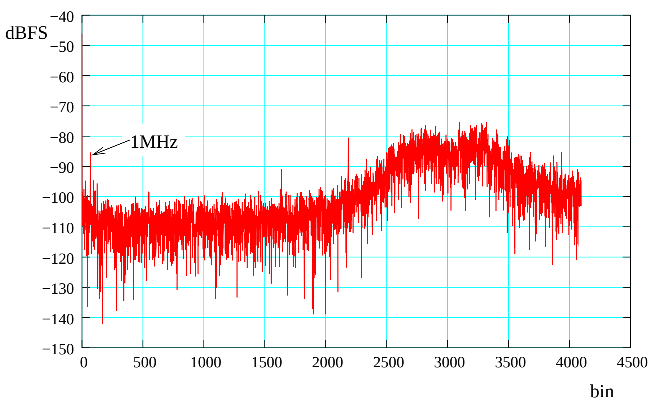

Fig 8: Common mode signal at 1 MHz

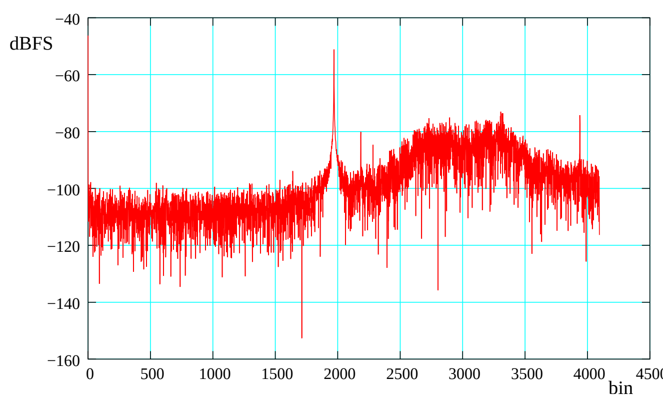

Fig 9: Common mode signal at 30 MHz

I've taken measurements at only a few frequencies. Set out along a log-frequency scale, it appears we're approaching a resonance (Fig 11). Considering the input circuitry of each analogue input (Fig 10), this makes sense: the resonator is formed by the inductance of the loop of the coax and PCB ground, estimated to be in the 1µH ballpark, and the inter-winding capacitance of the ADT1-6T transformer, about 17pF. A circuit model of the setup is depicted in Fig 12 and the simulated frequency response to common mode excitation is shown in Fig 13.

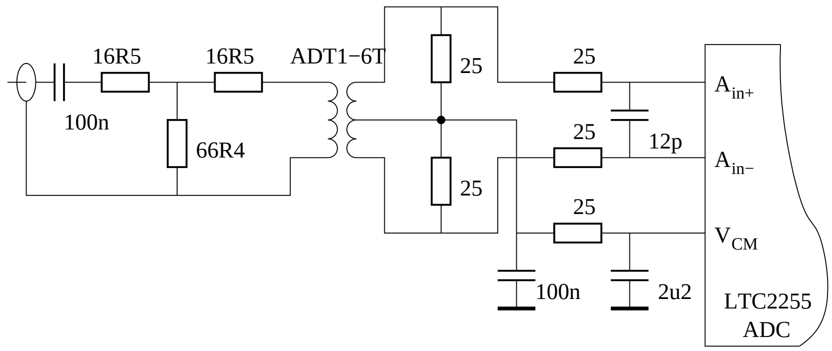

Fig 10: Analogue input circuitry

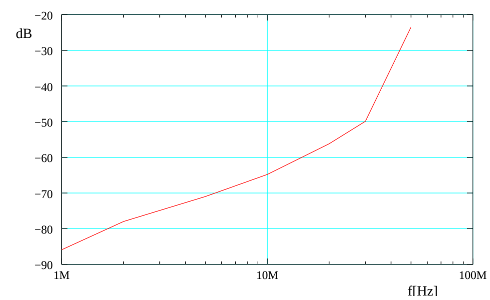

Fig 11: Measured common mode response

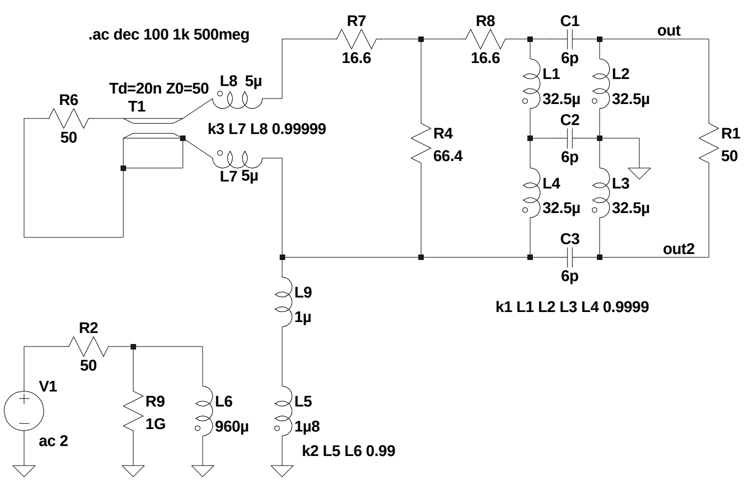

Fig 12: PUPE CMRR response circuit model

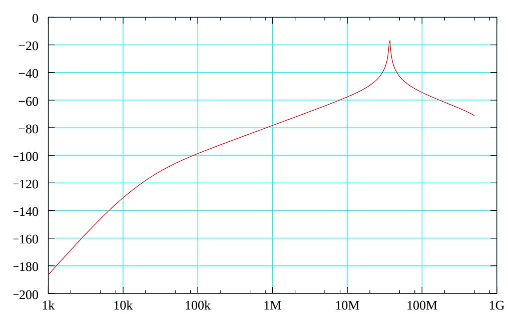

Fig 13: CMRR model response

With reference to Fig 12, the transformer model is composed of L1 to L4, coupled by K1 and with distributed interwinding capacitances C1 to C3. The ADC and associated input circuitry is modelled by R1 and the response of Fig 13 is the signal across its terminals. PU signal source is represented by R6, with Tline T1, L7 and L8 modelling the cable leading toward the PUPE. Source V1 is the common mode excitation, coupled to the cold side of the PUPE input through a transformer composed of L5 and L6, coupled by K2 (See also Fig 7). Inductance L9 represents the uncoupled inductance of the ground loop formed by the cable used to inject the common mode signal and the return path through the PUPE ground plane. This is the inductance that resonates with the parasitic interwinding capacitance of the transformer in the region of 35 MHz. This is also the frequency at which we see the noise peak in the signal spectra, lending additional credibility to this model.

With the T-pad attenuator upside down (Fig 15), the CMRR response is much better (Fig 14), although the actually obtained CMRR now strongly depends on the value of the source resistance R6. It may be worth trying to kill the resonance by feeding V_{CM} to the centre tap of the transformer secondary through a resistance of 1 kΩ or so, and removing the capacitor to GND at that node. That was done for the response plot of Fig 16. This supposes that the ADC inputs do not require any significant common mode bias currents. Whether this works as well in practice remains to be seen.

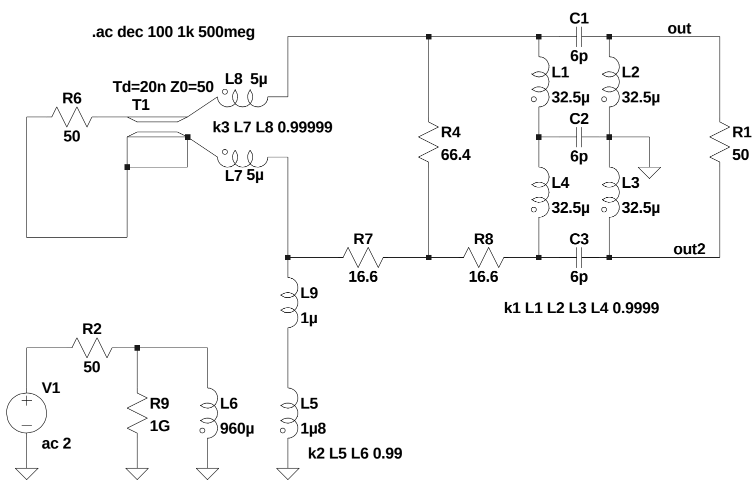

Fig 15: PUPE CMMR model with modified T-pad

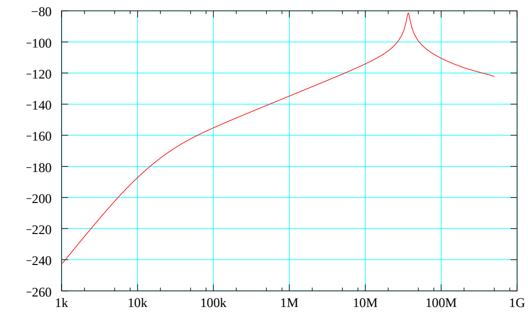

Fig 14: CMRR response with modified T-pad

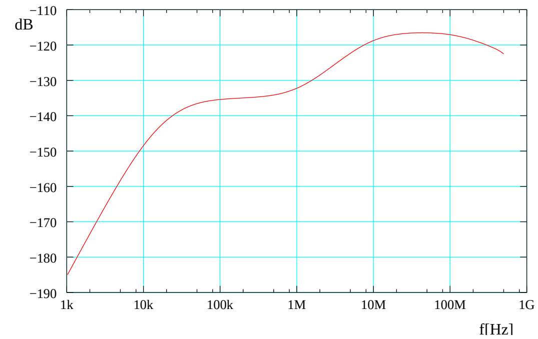

Fig 16: CMRR with transformer centre tap not bypassed to GND

Resolution with actual PU signals

Several raw data acquisitions were used to evaluate the possible resolution of position measurements. These results should be taken as preliminary, as much depends on the details of the position calculation algorithm implemented in the on-board FPGA, which are still in a state of flux. An example data record of an EASTC-type beam acquired at C190 is shown in Fig 17. Assuming the beam position doesn't vary over the 112-turn recording, the position resolution is about 0.25 mm, limited mainly by the PU amplifier noise and the fact that the BLR algorithm used was poorly matched to the characteristics of the channel. The target resolution is 0.1 mm.

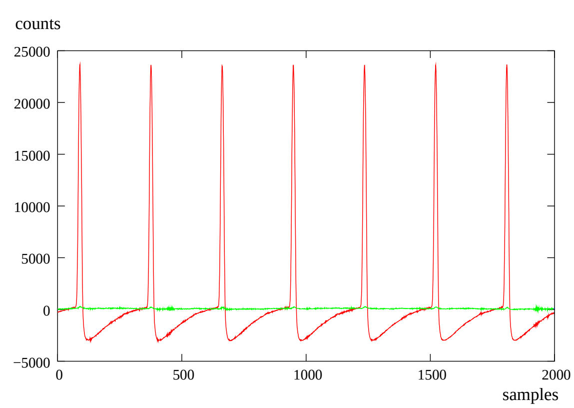

Fig 17: EASTC sum and X signals at C190 (PU25)

Measurements on simulated beam signals from a function generator (Stanford Research DS345) yielded an effective resolution of $4{\cdot}10^{-4}\cdot S_x$ or 30µm, about three times better than the target, so the ADCs would be good enough.