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Behavior of the SNS Front End Emittance Device

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Abstract

The SNS Front End 2.5 MeV Emittance Device was first tested with beam from the RFQ on February 1, 2002. The hardware is simple in concept, but has some non-obvious behavior that needs to be understood before the output data can be used to construct renderings of phase space intensities, and compute emittances. This note documents the wiring, channel mapping, offset subtraction, channel sensitivity calibration, and probable slit scattering.

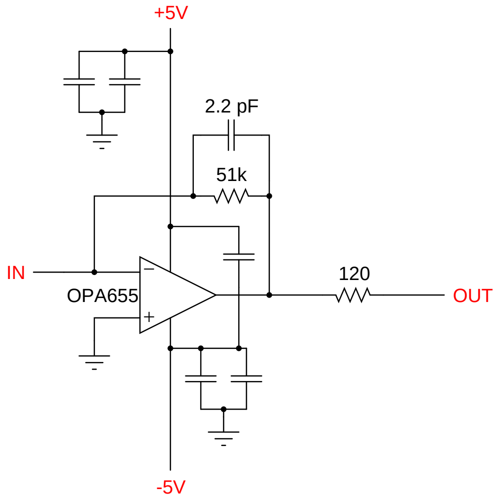

Figure 1: Schematic of one preamplifier channel

1 INTRODUCTION

The SNS Front End emittance device is made up of a slit (0.044 mm opening) and a 32-wire harp (0.5 mm pitch, 0.1 mm diameter), each of which are on a motorized translation stage. The beamline assembly can be rotated (as a unit, once let up to air pressure) to collect data on different axes. The wires are connected to a 32-channel preamplifier, and then the signals are sent to a VME-based 32-channel waveform digitizer, and the data is made available over the network through EPICS.

We maintain a consistent wire and channel nomenclature, with the wires numbered from 1-32, starting with 1 farthest away from the flange. Channel 32, closest to the flange, is internally and intentionally connected not only to wire 32, but also to the harp's back plate.

2 PREAMPLIFIER

The harp wires are connected to a head-mounted preamplifier through 0.4 m of 0.4 mm diameter Formvar wire in vacuum (carefully mounted to minimize cross-capacitance between channels), a 32-pin Astro Seal 21927-04 vacuum feedthrough, and another 0.07 m of air-side wiring. The preamplifier has an inverting current-to-voltage topology, and is built around an OPA655 (selected for its very low input current noise), see figure 1. Most of the feedback resistors used to set the gain are precision ($\pm 0.1\%$) 51 kΩ, metal film surface mount components. Metal film resistors give nearly perfect noise characteristics, unlike carbon film resistors. Some channels have different gain resistors, as discussed later. The preamplifier is built as two 16-channel boards, according to two mantras: "Keep it simple, stupid," and "Test components, calibrate systems."

With a 2.2 pF parallel feedback capacitor, this circuit acts as a two-pole low pass filter with -3 dB bandwidth of about 2.5 MHz. Examination of the filter's response to a square wave using an oscilloscope shows no ringing and 120 ns rise time.

These preamplifiers purposefully have no offset adjustment; the OPA655 has an intrinsic voltage offset (± 2 mV) small enough to not interfere with acquisition, and the pulsed nature of the beam allows easy offset measurement in software. Adding trim components would harm the high frequency behavior of the preamplifier, increase failure modes, increase the labor to assemble and test the boards, and probably still not eliminate the need for a software-based offset trim.

Table 1 cross references which pins are used to connect the channels from the harp wires, through the preamplifier, and into the data acquisition board. A wire harness forms the "Y" between the air-side of that connector, and the two DB-25 input connectors for preamplifier boards A and B.

3 DATA ACQUISITION

The ICS145 data acquisition card contains 32 channels of 16-bit sigma-delta digitizer, each based on an AD9260,

Channel DB-37 pin	Vacuum Feedthrough	Preamp DB-25	Preamp OPA655	signal ODD-44	return ODD-44	Notes
1	G	25	U111	33	32	
2	X	12	U121	19	18	
3	F	11	U131	4	3	
4	g	23	U141	35	34	
5	E	22	U211	21	20	1
6	W	9	U221	6	5	2
7	D	8	U231	37	36	
8	V	20	U241	23	22	
9	C	19	U311	8	7	
10	B	6	U321	39	38	
11	f	5	U331	25	24	
12	A	17	U341	10	9	
13	U	16	U411	41	40	
14	T	3	U421	27	26	
15	e	2	U431	12	11	
16	S	14	U441	43	42	
17	d	25	U111	33	32	3
18	R	12	U121	19	18	1
19	P	11	U131	4	3	
20	Y	23	U141	35	34	
21	H	22	U211	21	20	
22	Z	9	U221	6	5	
23	J	8	U231	37	36	
24	h	20	U241	23	22	1
25	K	19	U311	8	7	2
26	a	6	U321	39	38	
27	b	5	U331	25	24	
28	L	17	U341	10	9	
29	M	16	U411	41	40	
30	c	3	U421	27	26	
31	N	2	U431	12	11	
32	j	14	U441	43	42	4

The top half of the table refers to preamplifier board A, and P6 of the ICS145.
The bottom half of the table refers to preamplifier board B, and P7 of the ICS145.
Notes:
1 - Connection to two wires, feedback resistor changed to 25.5 kΩ.
2 - Not used.
3 - Connected to slit with 25 Ω load, bypassing preamplifier.
4 - Connected to both wire 32 and backplate, feedback resistor changed to 5.52 kΩ.

Table 1: Channel cross reference

which we run at a nominal 2 MS/s. The 16-bit bipolar output signal is conventionally represented as an integer between -32768 and 32767, which corresponds to ± 1 V on the input terminals of the ICS145. For ordinary channels with their inverting amplifier and 51 kΩ gain set resistor, full scale is $\mp 19.6\,\mu$A.

The 0.5 μs per time step starts at the rising edge of the TTL "RF On" trigger signal provided from the Klystron gallery. For the first $\sim$15 μs, the RFQ is filling, and no real beam current arrives at the detector. Thus, the first $\sim$30 samples are a clean zero input current baseline which should be used to measure channel offsets. The next $\sim$15 μs represent the transient when the RFQ is nearly full, but the field is not stable and therefore neither is the beam.

Acquisitions are triggered by the hardware on every (5 Hz nominal) beam pulse, and even hit the dual-port RAM on the ICS145. The emittance scan software only grabs this data when the slit and collector are in their desired positions, and then moves on.

4 ADAPTING TO THE REAL WORLD

Channel 32 (the back plate) is AC coupled with a 1.0 μF capacitor, allowing the plate to be biased. Most runs have used a bench power supply set to +40 V, with a 5 kΩ series resistor (much higher than the input impedance of the current-mode amplifier).

The current on the harp back plate is much higher than that on individual wires, so a 6.19 kΩ resistor was added in parallel with its 51 kΩ gain set resistor, making full scale on this channel (32) $\mp 181\,\mu$A.

Three pairs of wires (5 and 6, 17 and 18, 24 and 25) are shorted within the harp assembly itself. While the harp assembly tested good at the factory, these defects were discovered on the bench just before the unit was inserted into the beamline. The shorts could have developed either in shipping or during handling at LBNL. The manufacturer will repair the unit before MEBT tests begin.

If two amplifiers are left connected to these wire pairs, the amplifiers are still nominally stable, but large currents flow between them. So we disconnected one of each pair of amplifiers, leaving two wires connected to one amplifier, and the other amplifier unused. Amplifiers 5, 18, and 24 now collect current from two wires, not one, and would be at risk of saturating unless their gain were reduced. We paralleled two 51 kΩ resistors on these channels, so that their full scale is doubled to $\mp 39.2\,\mu$A. Channels 6, 17, and 25 are not connected to any wire.

The slit current is routed into the data acquisition system, using the otherwise unused channel 17. This connection bypasses the current preamplifier (and its signal inversion), so the signal level is set by the two 50 Ω terminating resistors in the circuit, for a full scale of $\pm$40 mA.

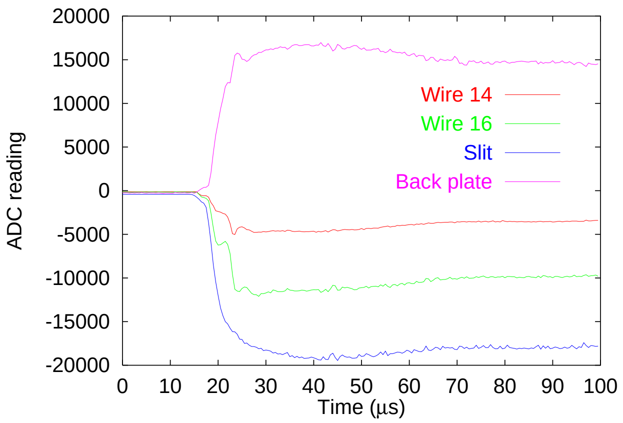

Figure 2: Example current waveforms

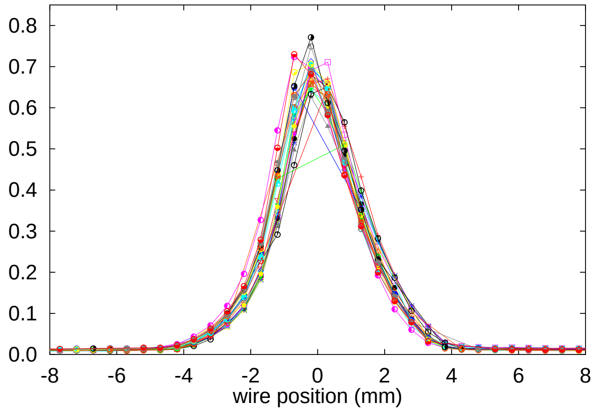

Figure 3: Wire signals for fixed slit

5 MEASUREMENTS WITH BEAM

Example current waveforms acquired during a beam pulse (shot number 50 of MEBT_Dia0100.mda) are shown in figure 2. Since the preamplifiers invert the signal, the negative going wire signals represent positive current collected by the wire. The H^- beam itself is of course negative, so the observed polarity means that the wires' secondary electron emission coefficient is greater than unity. The currents picked up by the slit and back plate are negative, as expected. Remember that the slit current is not inverted because its signal is not preamplified.

To measure the responsiveness of individual wires, we took scans with the harp taking 0.5 mm steps, while the slit was held fixed. By plotting each wire's response as a function of its approximate position (harp position plus the wire number times 0.5 mm), as shown in figure 3, we can see that each wire responds about the same as every other wire. The y axis value for each data point is computed as the average from time point 140 to time point 180, with a baseline subtracted based on the average of time points 1 through 25, and normalized to the value of channel 17, the slit current.

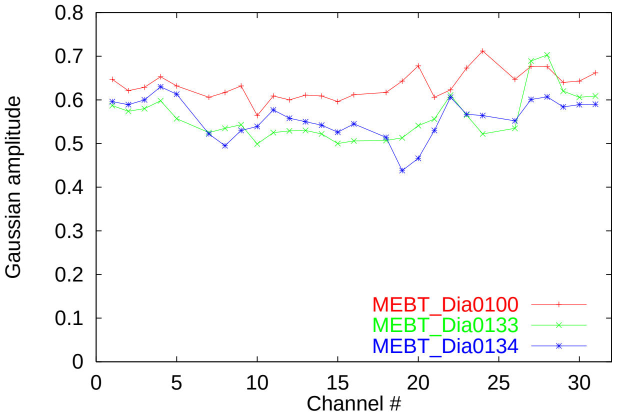

Figure 4: Signal strengths measured for each channel

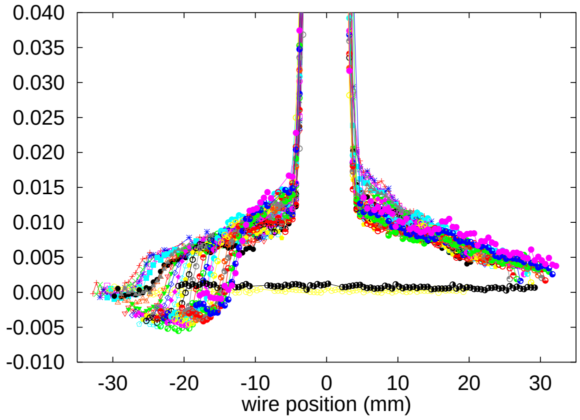

Figure 6: Broad tail in collected current

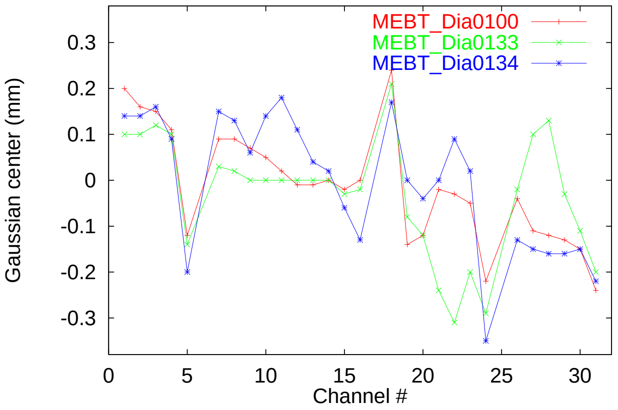

Figure 5: Deviations of wire centroid from nominal 0.5 mm pitch

These curves were fit to a Gaussian with σ=1.25 mm. The amplitudes of these Gaussian fits (shown in figure 4) are particularly interesting, since they represent a wire sensitivity factor, by which measurements should be scaled to get a self-consistent measurement of actual H^- wire current. There are systematic per-wire variations that can be explained by differences in secondary electron emission. A few wires (different on each run) have substandard data because of arcs in the source and LEBT. More experience with the system needed before reliable calibration numbers can be determined.

The center position of each Gaussian fit is shown in figure 5. The outliers at channels 5, 18, and 24 are expected—these are the shorted wire pairs, that should appear at "channel" 5.5, 17.5, and 24.5. The overall trend of the curve represents a 1% inconsistency between the harp step (0.5004 mm) and the wire pitch spacing. Most or all of this deviation can be explained because the slit was not perfectly fixed during the run. As a temporary workaround to avoid a software quirk, the slit moved 0.0025 mm when the harp moved 0.5004 mm.

Other interesting physics shows up if we replot the data of figure 3 over a broader scan dimension, and expanded vertical scale, shown in figure 6. The long tails, which have a $\sigma \approx 20$ mm, seem much too broad to represent a tail in x' from the RFQ, especially after the 400 mm drift between the end of the RFQ and the slit. This data does appear consistent with slit scattering, and it might make sense for emittance analysis software to deconvolute the measured data to account for this effect.

The current step that appears between -30 and -12 mm in figure 6 is apparently due to secondary electrons emitted from the grounded front plate of the harp. These electrons are attracted towards the +40 V backplate, and some fraction land on the (virtually) grounded wires. The edge appears when the beam centroid moves about 13 mm higher than wire 32, and is bigger on higher numbered wires.

6 ACKNOWLEDGEMENTS

The mechanical design of this emittance gear is primarily due to Steve Virostek and Matt Hoff, based on beam physics requirements from John Staples. The harp itself was purchased from Princeton Scientific. Electronic assembly and wiring was provided by Nathan Ybarrolaza, Co Tran, and Bill Lau. EPICS software to support the ICS145 and motion control was written by Carl Lionberger and Ernest Williams. Beam operations were led by Rainer Thomae. All the Front End technicians helped in one way or another, and Don Syversrud deserves special mention. Emittance software of John Staples and Saeed Assadi necessarily incorporates the data manipulation described in this note.