SNS EMITTANCE SCANNER, INCREASING SENSITIVITY AND PERFORMANCE THROUGH NOISE MITIGATION, DESIGN, IMPLEMENTATION AND RESULTS

J. Pogge

ORNL, Bethel Valley Rd, Oak Ridge, USA

Abstract

The Spallation Neutron Source (SNS) accelerator systems will deliver a 1.0 GeV, 1.4 MW proton beam to a liquid mercury target for neutron scattering research. The SNS MEBT Emittance Harp consists of 16 X and 16 Y wires, located in close proximity to the RFQ, Source, and MEBT Choppers. Beam Studies for source and LINAC commissioning required an overall increase in sensitivity for halo monitoring and measurement, and at the same time several severe noise sources had to be effectively removed from the harp signals. This paper is an overview of the design approach and techniques used in increasing gain and sensitivity while maintaining a large signal to noise ratio for the emittance scanner device. A brief discussion of the identification of the noise sources, the mechanism for transmission and pick up, how the signals were improved and a summary of results.

Keywords: Emittance, Noise Reduction

INTRODUCTION

The SNS inline MEBT Emittance Scanner, is located in the MEBT Diagnostics D-Box. This diagnostics array houses the X and Y emittance harps, a faraday cup, and several X and Y slits to facilitate beam quality monitoring prior to entrance into the first DTL. Because of the rather compact nature of this diagnostics array and its close proximity to the RFQ, the MEBT chopper, and the active tuning stubs, the emittance device is located in a high-noise environment. Although the original system worked extremely well, the newer more compact mechanical design of the harp assembly, coupled with additional control and RF devices mounted on the MEBT, soon made the signals from this design unusable as additional noise sources were added close to the harp assemblies.
EMITTANCE SCANNER IMPLEMENTATION

The emittance scanner vacuum hardware is described in [1]. The electronic amplifiers were originally designed at LBNL [3] and later re-designed and implemented at ORNL, see [1]. The present data acquisition system is based on a 4U rack mount PC with an ICS-645 digitizer with 16 channels of a 5 MHz sample rate per channel. A National Instruments 7334 motion control card is used to control position of the harp and slit in the beam pipe. There are two scanners, one for the horizontal plane and one for the vertical plane. One motion controller supervises one slit and one harp. A collision avoidance scheme is needed to avoid the horizontal and vertical slits (harp) from being inserted at the same time, as they would collide. The collision avoidance disables the forward motion of the other slit or harp by activating the other’s forward limit switch. The slit and harp are shown in 1, courtesy of T. Roseberry.

Figure 1. A CAD drawing of the slit and harp.
Identifying Noise Sources

Upon first inspection of the system installation, several noise sources were quickly identified. The first and among the strongest noise sources were the many stepper motors in close proximity to both the signal cables and the harp itself. Figure (2) shows the worst-case noise on an emittance scan. Pulses from both the emittance harp and slit driver as well as the stepper motor driven stub tuner on the nearby RFQ are plainly visible throughout.

Initially a request was made to the software engineers to turn off the motors immediately after moving either the slit or the harp into its intended position. The new mechanical design incorporated an acme type screw rather than a typical ball screw, leaving the motors on in a holding current mode is unnecessary. Figure (3), shows the improvement by this action.
The second area investigated was the location and nature of the emittance cabling. The harp wires were brought out of the vacuum feedthrough to a shielded stranded 28 AGW cable approximately 3m to the electronic amplifier box. As shown in figure (4). This left the relatively low current signals susceptible to induced noise from the surrounding control and RF cables. It had been decided to re-design the electronics box with two distinct goals in mind. A noise reduction paradigm used on many SNS diagnostics was followed.

1) Identify and incorporate any improvements to the electronic design and layout itself.

2) Locate the amplifiers as close as possible to the harp, and transmit the amplified signals via a differential driver over shielded twisted pair, to further reduce unwanted induced noise.

Figure (4) Original Amplifier Box
Improvements to the Scanner Electronics.

The original emittance amplifier see [3] worked very well under controlled environment during initial testing and commissioning of the RFQ, and MEBT section of the SNS front end. As the MEBT expanded and more systems were brought online however it became apparent that the circuit was susceptible to noise induced on the input cables of each of the 32 channels. The original circuit is shown below in figure (5), it is a simple inverting amplifier with a low noise JFET input. The harp wire is brought directly into the inverting input of the op-amp.

![Figure(5) Original amplifier](image)

Current into the amplifier is due almost entirely to the interaction of the beam with the harp wire. Since this is a singled ended input, a unique situation occurs in terms of circuit analysis. Current is present on the single ended wire without an appreciable voltage. Therefore the addition of a single resistor in series with the input harp wire has the following effect on the circuit, the voltage gain is reduced significantly, while the current gain doesn’t change appreciably at all. The current through the resistor will be the same, as caused by the beam interaction of the wire. Any induced voltage due to outside sources will be reduced however. This noise fix is rather simple, but not so intuitive. An op amp is effectively a current device; Kirchoff’s current law states that the sum of the current in must equal the sum of the current out. No other appreciable currents exist on the inverting input other than that created by the interaction of the beam with the wires. Any additional noise may have a significant voltage, but negligible currents, therefore using the following equations for gain at the input to the inverting amp net the following results. R1 has an effect on voltage gain but no effect on current gain.

\[
V_{\text{out}} = - \frac{R_2}{R_1} V_{\text{in}}
\]

The current gain for the same circuit is

\[
V_{\text{out}} = - I_{\text{in}}(R_2)
\]
This made the first fix to the noise problem rather simple, the 25 pin D connector was removed from each preamplifier assembly and a 10K ohm resistor placed in series with each of the harp signal wires. This was done without removing the electronics while MEBT commissioning was still ongoing.

Simply adding the 10K ohm resistor divides the induced voltages, but has little effect on the beam current incident on the harp wire. Figures (6) shows the experiment schematic for the improved preamp.

![New Test Amplifier](image)

**Figure (6) New Test Amplifier**

The immediate result was rather dramatic, as seen in Figure (7). The baseline noise was reduced by the expected order of magnitude. An analysis of the noise in Figure (7) revealed 2Mhz and 13 MHz components both signals present in the source generation approx 10 ft from the signal cables.

![Reduced Voltage noise](image)

**Figure (7) Reduced Voltage noise**
Making Additional improvements

The complete solution would be to incorporate the changes found, clean up the circuit layout, and add some features requested by Accelerator Physics.

The circuit was re-designed with a higher bandwidth low noise op-amp, the output of which is connected directly to a differential amplifier driver. This will mitigate any noise induced into the system as the signal is sent from the amplifier box to the digitizer. Any additional low pass filtering will be done in the driver stage after the original signal is amplified. The new layout uses on-board extremely low-noise (< 50uV) voltage regulators, and takes advantage of a 6-layer PCB design, separating the power planes from the signal path. See Figure (8) for the new preamplifier/bias supply package. The box is heavily shielded, approx 5” x 8” x 3”, and is designed to be mounted within 12” of the harp connector, in a compacted area near the D-Box assembly. Accelerator Physics had also requested that the harp wires be biased with 100 Vdc to lessen the effects of secondary emissions. The board on the left is a small 0 to 250Vdc bias power supply controlled through the main connector assembly. A new improvement soon to be added allows all the high voltage generated and confined to the box and the short cable directly connected to the vacuum feedthrough. Some of the remaining noise has been due to the relatively long HV cable coming from the rack to the D-Box via the RF cable tray.

![Figure (8) single axis 16 Channel preamp and driver](image)

Each of the 16 channels was differentially amplified and driven down shielded twisted-pair cable approx 50 ft to the receiving amplifier and ADC interface mounted in a single 2U rack mount chassis. To incorporate a second request from the physics group, the receiving differential amplifier was constructed using a 35 MHz VCA (voltage controlled amplifier). This allowed the experimenter to select between attenuating or amplifying the resulting signal between -35db and +35db. This allowed studies to be done on the source when it exceeded the nominal 38mA beam current and allowed halo studies on very small short cycle pulses < 10mA beam current.
Results

All of the intended goals had been met by the redesign; the electronic boxes are compact and easily replaced through two simple connectors. The array of BNC cables at the digitizer was replaced by a single 62-pin shielded twisted-pair cable. Figure (9) shows the final installation of the preamplifier boxes underneath the signal cable tray directly above the D-Box assembly.

Figure(9) New assembly Mounting
The results were rather dramatic, a further reduction in the background noise to < 500uV, with an adjustable gain over a 50db.range. Figures 10-12 show typical emittance plots after improvements were made.

Figure (10) Low noise raw plots

Figure (11) Phase Plot

Figure (12) 2D Scan Reconstruction
SUMMARY

Improvements were made to the preamplifier assembly in both their fundamental design and the environment in which they were used. Careful study of the noise sources allowed dramatic reduction in noise with significant improvement in signal sensitivity. Additional control features allowed the researchers to manipulate the data collection in ways more interesting to the experiment being performed at the time. Simplifying the overall cabling and design reduced noise further and made it possible to replace a defective unit in minutes rather than hours, saving on downtime. We are continuing to improve both the hardware and software design to make this diagnostics system more useful in future iterations.

ACKNOWLEDGEMENTS

This paper describes only the hardware; many people have worked on the scanner design, vacuum hardware, software, installation, etc. Sasha Alexandrov provided guidance and specifications for improvements, Viktor Gaidash expert electronics skill, Saeed Assadi proof of feasibility and initial design. T. Roseberry made the CAD drawing of the Slits and Harps.

References