SNS BLM Signal Calibration Constants

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Background

The Beam Loss Monitor (BLM) system is designed to measure beam losses in the SNS using Ion Chambers supplied by BNL to detect ionizing radiation and Neutron Detectors supplied by INR to detect neutrons. Signals from both detectors will be conditioned using the Analog Front End (AFE) circuits designed and built by BNL. The analog outputs will be acquired and processed by VME based computers (IOCs) and ADCs. The AFE circuits are packaged 8 channels to a module in a separate 4 module AFE crate.

Calibration constants are needed to convert the digitized voltages to "physics" units. BNL will calibrate and provide data for the Ion Chambers relating the detector current to dose rate [R/hr] for each detector as a function of bias voltage. The Neutron Detectors were supplied by INR and shipped directly to ORNL so SNS must supply the calibration data for them. Separate calibrations will be provided for the AFE circuits. Each channel has three outputs, each of these with multiple gain states with separate calibration constants. This note will describe these constants and how they must be used to convert the acquired voltages to dose or dose rate.

AFE Signals

There are 3 signal outputs from each channel:

- Fast: An output with a 35 kHz bandwidth. The signal is intended for general data logging and display except for RTBT detectors. The first stage (common to all 3 signal paths) has jumper selectable feedback resistors of nominal values : 620 O (Low Gain), 6.2 kO (Medium Gain) and 62 kO (High Gain). Since the BLM and NDs are current sources, the output voltage is determined only by the feedback resistor. The next stage is an amplifier with computer settable gain of nominal values 1 and 10. Calibrations will be stored for the six gain states. Offsets will be measured actively and subtracted on a pulse by pulse basis in the IOC. The output is read at 100 kSa/sec by a 24-bit ADC, but typical noise in a "quiet" environment is expected to be at the 12 to 13-bit level.

- Slow: An output with a 1 kHz bandwidth. This signal allows finer resolution of low level long term losses. The lower bandwidth reduces the noise and lowers the amplitude of fast, high level losses allowing additional gain without saturation. A fixed gain of 10 amplifier follows the filtered output of the common input stage. While a lower cutoff would further limit the noise, the 1 kHz bandwidth allows a measurement of the baseline for offset subtraction in the IOC, which would not be practical with a lower bandwidth. The output is also read by a 24-bit ADC at 100 kSa/sec and averaged over 600 machine pulses to allow the higher resolution needed to observe the 1 W/m losses at the 1% level.

- Integrated: This signal is a prime input to the MPS system. It provides a measure of the accumulated dose during the pulse and is used to inhibit the beam. In the RTBT line, where the signal is due to a sub-microsecond beam pulse, it is used for data logging. A "Mode" jumper substitutes the integrator output for the Fast signal as input to the Viewing Gain stage. A "leaky integrator" (a large value bleeder resistor across the integrator capacitor) follows the common front-end amplifier. This simple design eliminates the need for timing circuitry to gate the signal and dump the previous pulse's stored charge. However, the RC time constant is a compromise between the linearity of the integration (~6% at the end of the 1 msec pulse) and the amount of residual charge at the start of the next pulse (~3% at 60 Hz). For the short RTBT pulse the error is much less. This was considered acceptable in exchange for the simplicity and reliability of the circuit in a critical application. Six calibration constants are required to define the RTBT gain states.

Considerations in the Calibrations

SNS-ORNL has the responsibility for managing the database used to store the system calibration constants. These will include the detector as well as the electronics calibrations. Details of this database are not known at this time. Some of the considerations for the BLM constants will be discussed.

DETECTORS

The BLM detectors are ion chambers (IC) whose characteristic response consists of a rapid rise at low bias voltage (less than 100 V) followed by a relatively linear region over much of the usable range. At the higher bias voltages there is usually a non-linear rise. It is expected that the IC will operate in the linear region but at times of high loss it may be desirable to move to the upper end of the range to reduce saturation effects. The ICs are calibrated by raising the bias voltage in about 30 steps while measuring the response to a radioactive source. Several approaches for defining the calibration are available. (1) Store the slope and intercept to describe the linear region. (2) Store the coefficients of a polynomial fit to the linear and rising data regions. (3) Store all the data points and do a linear interpolation between points for the specific bias voltage. BNL will provide the full data set for each IC in electronic form, allowing the choice of calibration approach to be made by SNS-ORNL.

The Neutron Detectors (ND) are photomultipliers which respond to light generated by the capture of a neutron in a scintillating material. Lead shielding suppresses the resonse to gammas. The gain of the photomultiplier varies rapidly over many decades as a function of bias voltage. Responsibility for the calibration of the NDs lies with INR and SNS-ORNL personnel who will also determine how the data is stored in the database.

Note: Knowledge of the bias voltage for both BLMs and NDs is required. Conversion of the HV read back signal is not covered in this note.

Electronics

The same AFE electronics design will be used for both the ICs and NDs. Each channel of each AFE module will be tested in the lab using an IOC to measure the outputs as it would in the actual installation. Note that the gains of the individual channels of the ADC are folded into this measurement. It is not planned to separately measure the ADC channel gains since it is assumed they are sufficiently close to ignore the difference. The AP Requirements Table (circa March 2003) indicates a 1% accuracy requirement for the system. It is hard to believe that a 24-bit ADC is not accurate to better than 0.1%, so it is reasonable to ignore the variation in ADC gain. Thus, a laboratory measurement using an arbitrary ADC is acceptable and a separate database entry for the ADC is not needed. While an insitu gain measurement will not be needed, since the cable length will not affect the calibration, it would be highly desirable to walk the tunnel substituting a test source (D-cell battery and 1 GO resistor) for each detector to verify every channel from detector to EPICs screen and check for unexpected gain variations.

A precision pulsed (1 msec) current source is required to calibrate the AFE gains. It should be defined to 0.1% accuracy at each of 3 levels to meet the 1% system accuracy requirement. To calibrate the integrator output, the source must be a pulse of 100 µsec (± 0.5 µsec or better) width. Since the input impedance of the AFE is approximately 470O, the test source impedance need only be greater than 1 MO to simulate a current source.

Conversion From Volts to Physics Units

Fast Output:

Let the BLM Dose Rate Constant be: DRC_{SN} ,

where SN is the detector number. This calibration will be provided by measurements using a cesium-137 source and is a function of HV bias Voltage.

Call the gain of the Fast Channel: $FG_{R,VG}$,

where R is the index to which gain resistor was selected and VG is the index to which Viewing Gain was selected. If the current used to calibrate the gain is I_{cal} and the corresponding measured output voltage is VFG_{cal} , then the Fast Channel gain is:

$$FG_{R,VG} = \frac{VFG_{Cal}}{I_{Cal}}$$

And the Fast Output Dose Rate is given by:

$$FDR = \frac{FV_{out}}{DRC_{SN} \times FG_{R,VG}} \qquad [\mathrm{R/hr}]$$

where FV_{out} is the measured output of the Fast Channel.

Note:
$FG_{R,VG}$ must be determined using a current source to simulate the BLM signal. If a voltage source is used then the gain is also a function of the input resistor which is insignificant when a current source (“infinite” impedance) is used.

There should also be 2 other subscripts for *FG* defining the AFE board serial number and the AFE channel number. These have been omitted for clarity.

Slow Output:

The conversion of the slow output is similar to the fast except that the gain of the second stage amplifier is fixed so only the “*R*” index is needed. In this case

The gain of the Slow channel is: SG_R ,

where *R* is the index to which gain resistor was selected . It is determined by measuring the output voltage VSG_{Cal} corresponding to an input current I_{Cal} .

$$SG_R = \frac{VSG_{Cal}}{I_{Cal}}$$

Then the Slow Output Dose Rate is given by:

$$SDR = \frac{SV_{out}}{DRC_{SN} \times SG_R} \qquad [\mathrm{R/hr}]$$

where SV_{out} is the measured Slow Output.

Integrated Output:

The output of the integrator channel is given by (neglecting the bleeder decay):

$$V_{Iout} = \frac{R_N G_{VG}}{R_i C_f} \int I_{BLM} \bullet dt$$

where R_N is the first stage feedback resistor with index *“N”*, G_{VG} is the Viewing Gain stage gain, R_i is the integrator input resistor and C_f is the integrator feedback resistor. I_{BLM} is the signal current from the BLM, given by:

$$I_{BLM} = DRC_{SN} \times DR(t)$$

with *DR(t)* being the dose rate as a function of time.

Then the output of the integrator is given by:

$$Dose = \int DR(t)dt = V_{Iout} \times \frac{R_i C_f}{R_N G_{VG}} \times \frac{1}{DRC_{SN}} = \frac{V_{Iout}}{IG_{N,VG} \times DRC_{SN}} \qquad [R]$$

Where the Integrator Gain is:

$$IG_{N,VG} = \frac{R_N G_{VG}}{R_i C_f}$$

with the index *N* designating first stage feedback resistor and *VG* the Viewing Gain state.

To measure $IG_{N,VG}$ we require the precision current source, I_{cal}, to be a pulse of width ?T. There is an error due to the leakage resistor across the integrator. However, since the integrator will only be used to measure the RTBT losses where the beam pulse is short, the effect is less than 1% and neglected. The actual BLM signal due to the 650 nsec RTBT pulse is the result of the fast (sub-microsecond) electron component and the slower ion current, lasting 75-100 µsec. This is further modified by the filtering due to cable capacitance and circuit input resistor, and the closed loop bandwidth of the first stage. The fast electron signal is stretched to about 7 µsec but the ion signal is little affected. The integrator output rises to a little more that half value due to the electrons followed by the slower ion signal rise. The signal then decays with the RC time constant of the integrator feedback (about 4.4 msec). The ADC will be sampling at 100 kSa/sec easily allowing the peak value, V_{Ical}, to be found before it has decayed significantly.

$$V_{Ical} = \frac{R_N G_{VG}}{R_i C_f} \int_0^{Peak} I_{Cal}(t)dt$$

Where I_{Cal} is the calibration current, constant for *?T*, the 100 µsec pulse duration.

Then

$$IG_{N,VG} = \frac{R_N G_{VG}}{R_i C_f} = \frac{V_{Ical}}{I_{cal} \times \Delta T}$$

$IG_{N,VG}$ is defined since I_{cal} and *?T* are known.