Booster Beam Loss Monitor Data Acquisition and Presentation Specification

Draft for Review

September 30, 2011

Craig Drennan

Table of Contents

I. Introduction

This note is to specify and document how the Booster Beam Loss Monitor data is collected and processed using the BLM Integrator/Digitizer VME modules. The following sections will describe how the BLM signals are digitized and the data processed into the different types of sums that are used to monitor and manage beam loss in the Booster.

There are several user applications that use different variations of the BLM Integrator data.

1. The base "80 µs Integration Samples" are 500 values read from each BLM channel, each Booster cycle. From these samples are used to derive all the other integration types.

2. The "Full Cycle Sampled Accumulations" is a 32-bit running sum of the 80 µs samples over a single Booster cycle.

3. The Log is taken of the Full Cycle Sampled Accumulations data to reduce the digital data size from 32-bit to 16-bit. This data is what is delivered to ACNET for snapshot plots.

4. The "7.5 Hz Waveform Buffers" manage the Full Cycle Sampled Accumulations for delivery of two cycles of time stamped BLM data every other 15 Hz cycle. This data is used by certain applications, such as B136 BLM Cycle Plot and other JAVA based ACNET applications.

5. The "1 ms Integrated Samples" are used for data logging for historical and Booster studies purposes.

6. The "100 Second Moving Sums" are used for control room bar graph displays and alarms.

You will see that there is an issue with the units of Rads/Second that has been "historically" attached to the Booster BLM data. The Log Integrators were originally used in the Tevatron where beam is in the accelerator for long periods of time. There, accelerator operators were concerned with the rate of beam loss energy impinging on the cryogenic super-conducting transport magnets. The Log Integrators were calibrated according to the number of coulombs/second (amps) in to volts out. Robert Schafer describes the Log Integrators in a note, "Comments on the Tevatron BLM System, 7/22/2003"

> With the 1/16 s leaky integration at the input, the output voltage was a rough indication of the probability of quenching a dipole magnet. Magnet quench threshold measurements made in the left bend of the extraction line to the Meson Area (by Roger Dixon?) showed that a superconducting dipole magnet could be quenched by roughly 0.5 mJ/gram (fast pulse), or 8 mJ/gram-s (slow loss) of radiation in the superconductor[3]. The ratio, 1/16 s, is the "time constant" of the superconducting cable.

For beam loss in the Booster we are more concerned about the total beam loss, or the amount of sudden beam loss at points around the accelerator, and at points in time during the acceleration cycle. For the Booster, the more appropriate measurement would be in Rads of loss, not the rate of beam loss in Rads/Second. However, when the BLM integrator modules from the Tevatron were incorporated into the Booster the units of Rads/Second came along with them. For 30 years the BLM measurements provided an essential number used in tuning the accelerator to reduce beam loss and improve efficiency of the machine. The actual units on the numbers were not of much concern.

You will see that the new BLM integrators measure charge, not so much a rate of charge. Also, other types of sums, currently in use and described below, are meant to represent and accumulation of loss in Rads, not an ever increasing rate of loss in Rads/Second. However, documentation for the front-end Local Applications states that the other sums were derived from numbers scaled to Rads/Second.

To avoid a discontinuity in the BLM Booster beam loss record we are making an effort to scale the new integrator data, from coulombs in to Rads/Second out, to be as close to the older Log Integrators as is reasonable.

II. BLM Digitizer Module Data Acquisition

Integration and digitization of the loss monitor signals are performed by the BLM Digitizer Module. The data representing the digitized signal is buffered on the BLM Digitizer Module using FIFO memory. The output of this memory is accessible by the crate processor via the VME bus.

The module performs the following functions.

1. Digitizes the results of an analog 20.0 µs BLM charge integration into a 16 Bit Word.
2. Every 80.0 µs an average of 4 each 20.0 µs integrations produce a 16 Bit Word that is written to a FIFO memory.

   Note that this is not strictly an 80.0 µs integrated value, but rather an 80.0 µs integrated value divided by 4.

3. 40.0 ms of data is collected at a rate of 12.5 kHz for each Booster cycle, resulting in 500 samples per cycle.
4. The number of BLM channels in a particular location around the Booster Gallery is 12. However in a couple locations, there are as many as 24.
5. A conservative estimate for transferring one 16 Bit Word over VME is 1.0 µs. This leads to a total time of 12 ms to transfer one cycle of data for 24 BLM channels, from the Digitizer modules to the MVME processor board.

(500 samples / channel)*(1 accesses / sample)*(24 channels)*(1.0 µs / access) = 12 ms

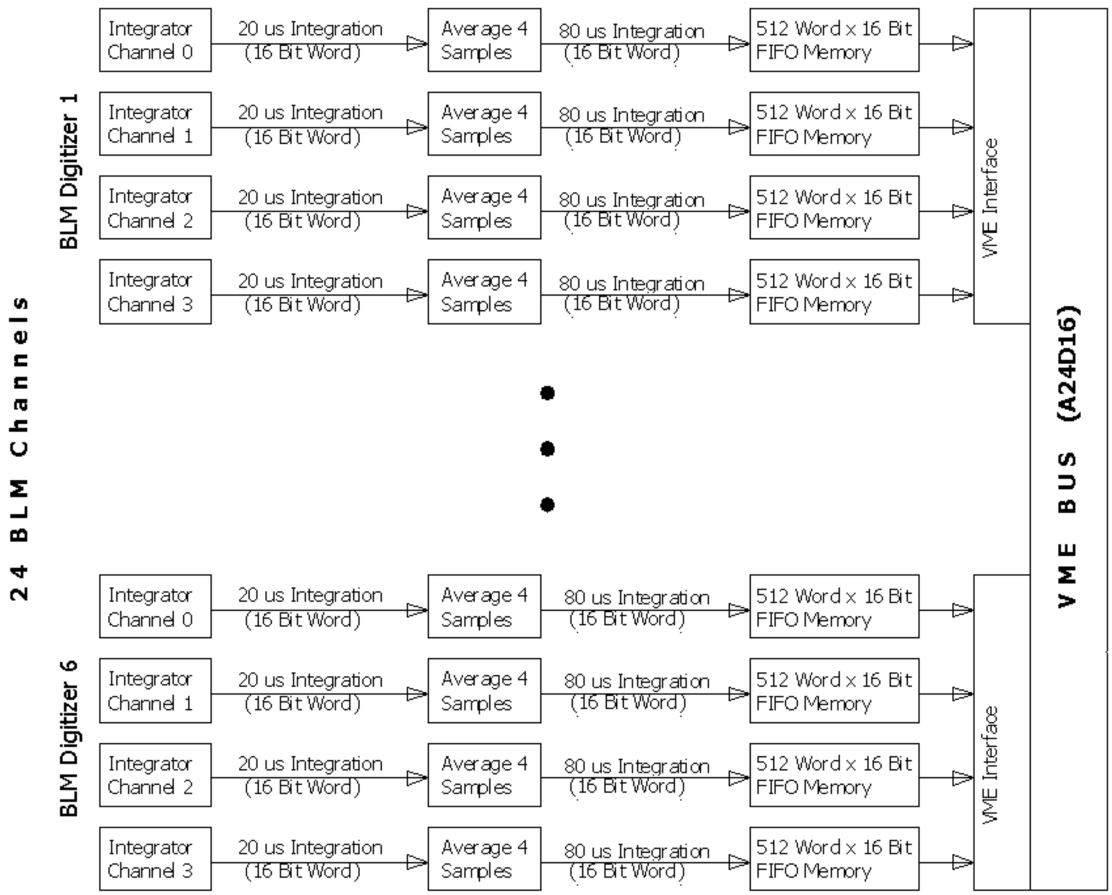


Figure II.1.1 Simplified block diagram of the BLM digitizer data processing

III. Summary of the BLM DAQ Process

The following is a sketch of the BLM data acquisition process. The computation of the various types of sums is explained in more detail in the following sections.

Steps in the Process:

1. Signal digitization and collection is triggered every 15 Hz cycle on event $10.
2. The BLM signals are digitized at a rate of 12. 5 kHz. Each sample represents an 80.0 µs integration interval.
3. After being triggered by event $10, the BLM signals are integrated and digitized for 40.0 ms, producing a FIFO buffer of 500 data points for each device.
4. The front end processor begins collecting data from the BLM Digitizer modules over the VME bus approximately 40 ms after event $10.

5. It is expected that the front end processor will have collected the data from as many as 24 BLM channels by 52 ms after event $10.
6. At this point in the 15 Hz cycle, 500 point buffers will have been filled with the BLM data for the *current* cycle. One for each BLM channel in the crate. This is the base "80 µs Integrated Data".
7. A pedestal for each channel is computed using the first 16 data points from that channel.
8. From the buffers of 80 µs Integrated Data the "Full Cycle Sampled Accumulation" data buffers are computed with the pedestal subtraction applied.
9. Another set of buffers are computed for the Natural Log of the "Full Cycle Sampled Accumulation" data. This conversion also applies a linear mapping to make the new integrator data scale the same as the older Log Integrators.
10. The Full Cycle Sampled Accumulation data is also converted into Rads/Second. These values are also scaled to make the Rads/Second results the same as would have been determined using the older Log Integrators.
11. The "1 ms Integration Samples" buffers are computed by applying the conversion to Rads/Second on every 12^{th} (actually every 12.5^{th}) Full Cycle Sampled Accumulation point, and then differentially determining the loss in each of the 40, 1 ms intervals.
12. Each cycle, for each channel, a total loss value is computed from the Full Cycle Sampled Accumulation data by subtracting an initial point from a final point and converting the difference to Rads/Second.
13. Using values from the total loss per cycle Rads/Second value, the 17 second sums are accumulated
14. Every 250^{th} 15 Hz cycle the "100 Second Moving Sums" are updated by summing the most recent 6, 17 second sums.
15. In the remaining time before the front end is required to begin the VME bus transfers with the BLM Digitizer modules, the front end must service the ACNET requests for data. These include the data logging requests for the "1 ms Integrated Samples", the ACNET B88 bar graph display requests for the "100 Second Moving Sums" data, and Snapshot or other plotting application requests.

IV. Signal Processing: Computing of Various Sums

Recall that within the Digitizer card the charge produced by the BLM ion chamber is integrated, or summed, over a 20 µs interval and is then digitized to produce a number. These 20 µs samples are summed into 80 µs samples. The 80 µs samples are divided by 4 to reduce the word size for transfer over the VME bus.

Within the crate processor the BLM data is stored as several different types of sums. Once the 80 µs samples are transferred to the processor, they are summed to represent longer intervals of time, and they are summed in distinctly different manners to represent the accumulation of BLM charge (beam loss) in different ways.

IV.1 The Base 80 µs Integration Samples

There is a 500 point buffer for up to 24 channels of 80 µs integrated data read from the BLM Digitizers over the VME bus. This data is used to produce the other forms of data described in the sections that follow.

IV.1.1 Ideal Scaling Digitizer Values to Rads and Rads/Second

Note, the conversions in this section are ideal. The actual conversions in use are based partially on a time constant associated with the Log Integrators. It was this time constant that provided the conversion from charge current in, coulombs per second, and volts out. In order for the understanding of how BLM readings relate to Booster tunnel equipment activation and general beam tuning, the scaling used in the installed system will be different than the ideal relationships computed in this section. A later section will detail how the new system is brought to match the older one.

The sealed ion chamber used in the Booster has a scale factor of 70 nano-Coulombs per Rad of radiation that passes though its cross section. The charge produced by the ion chamber is accumulated in the BLM integrating amplifiers. The integration capacitor in the normal operating mode is 100 pF, and the full scale output of the integrator is 10 Volts. Therefore the full scale output in Coulombs is

$$Q = V \cdot C = 10 \cdot 100E - 12 = 1.0\, nanoCoulomb$$

The integrator voltage is digitized with a 16 Bit ADC giving

$$\frac{1.0E - 9\, Coulombs}{65{,}535\, Counts} = \frac{15.26\, femtoCoulombs}{Count}$$

Applying the relationship between Rads and the Coulombs of charge produced by the Loss Monitor Ion chamber we get

$$\frac{15.26\, femtoCoulombs}{Count} \cdot \frac{Rad}{70\, nanoCoulombs} = \frac{0.218\, microRad}{Count}$$

This is the conversion before we *average* four integration intervals together and store the average in the FIFO from which the processor gets its values. Therefore the conversion that is to be applied to the values read from the FIFO's by the processor is

$$\boxed{4 \cdot \frac{0.218\, microRad}{Count} = \frac{0.872\, microRad}{Count}}$$

The measurement made is an integration or summing of charge from the Loss Monitor ion chamber. If we wish to compute Rad/Second, the rate at which radiation is impacting the ion chamber, we must settle for the average rate over some time interval. The smallest time interval is the 20.0 µs interval that the digitized integrator values represent. Since the values written to the FIFO's is the average value over 4 each 20.0 µs intervals one can compute the Rads/Sec rate these values describe

$$\frac{1}{20.0\ microSeconds} \cdot \frac{0.218\ microRad}{Count} = \frac{0.0109\left(\frac{Rad}{Second}\right)}{Count}$$

IV.2 The Full Cycle Sampled Accumulation (BLME Support)

After the 80 µs samples have been read from the Digitizer cards, the data is summed into 500 floating point values of a continuously integrating signal. That is,

$$S(k) = S(k-1) + float\big(A(k)\big), \qquad for\ k = 1 \dots 499$$

$$S(0) = float(A(0))$$

where $S(k)$ are samples of the continuously integrating signal and $A(k)$ are the 80 µs integration samples. There is a 500 point buffer of this kind for as many as 24 BLM channels.

The Log is taken of the Full Cycle Sampled Accumulations data to reduce the digital data size from 32-bit to 16-bit. After taking the Natural Log of S(k) a conversion is applied to scale the new integrator measurements to be like the old Log Integrators.

$$Y^o(k \cdot T) = m \cdot Ln\big(S(k)\big) + b$$

where

$$m = 3276.8 \cdot C_1 \quad and \quad b = 3276.8 \cdot (C_2 - C_1 \cdot 30.3921)$$

This conversion is explained in a later section. This data is what is delivered to ACNET for snapshot plots. The ACNET device names for this type of data have the form B: BLMxxx.

Additionally, the linear Full Cycle Sampled Accumulations data points can be converted to Rads/Second using another relationship that also scales the result to make the new integrator measurements to be like the old Log Integrators.

$$RS(k) = m_2 \cdot S(k)^{b_2}$$

where

$$m_2 = 0.00721196 \cdot EXP[1.057772 \cdot C_2 - 32.1479 \cdot C_1]\ and\ b_2 = 1.057772 \cdot C_2$$

This conversion is applied to select points of the Full Cycle Sampled Accumulation in order to compute the 1 ms integration samples the 17 second sums and the 100 second moving sums.

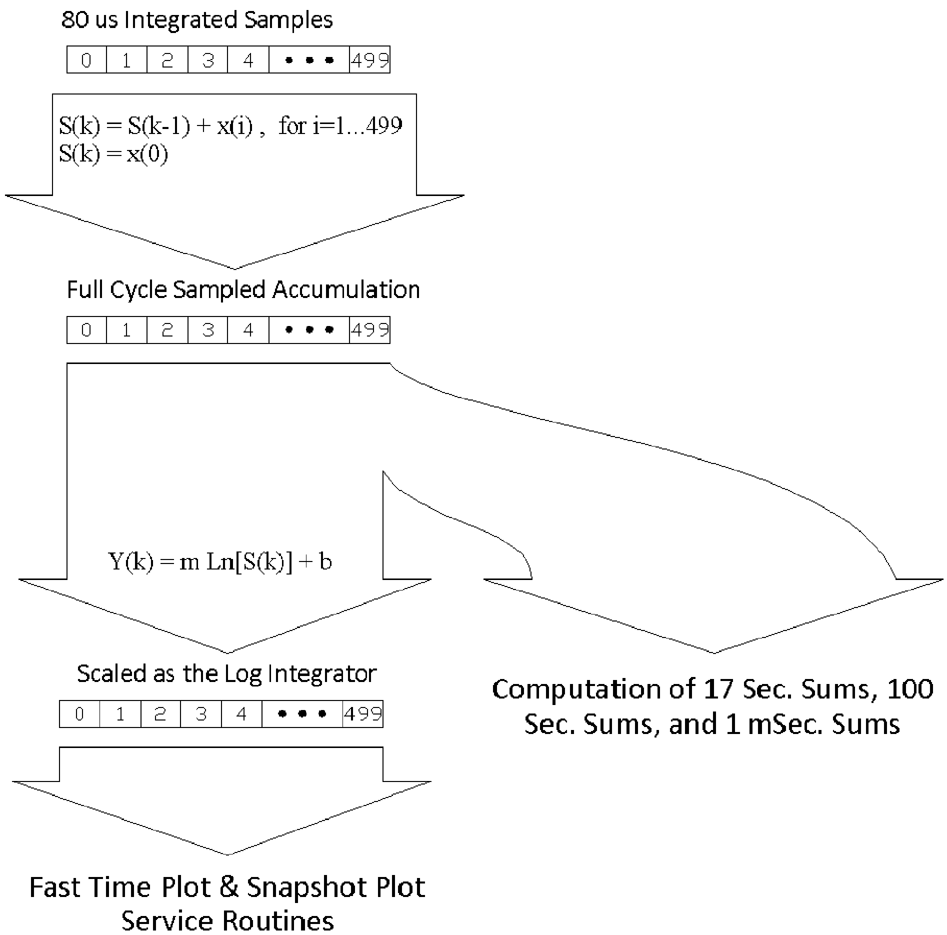


Figure IV.2.1 Illustration of the computed sums

IV.3 The 1 ms Integration Samples

Each cycle, the data is summed into 40 each 1 ms sums. That is,

$$w(0) = RS(11) - RS(0)$$

$$w(1) = RS(23) - RS(12)$$

$$w(2) = RS(35) - RS(24)$$

$$\vdots$$

$$w(39) = RS(499) - RS(488)$$

where $RS(k)$ are the sampled accumulation points converted to Rads/Second and $w(k)$are the 1 ms sums. These sums are double precision floating point values. There is a 40 point buffer of this kind for each of the 12 Booster cycle types, for each of as many as 24 BLM channels in a crate. That is 288 (=12 x 24) of this kind of buffer possible per crate.

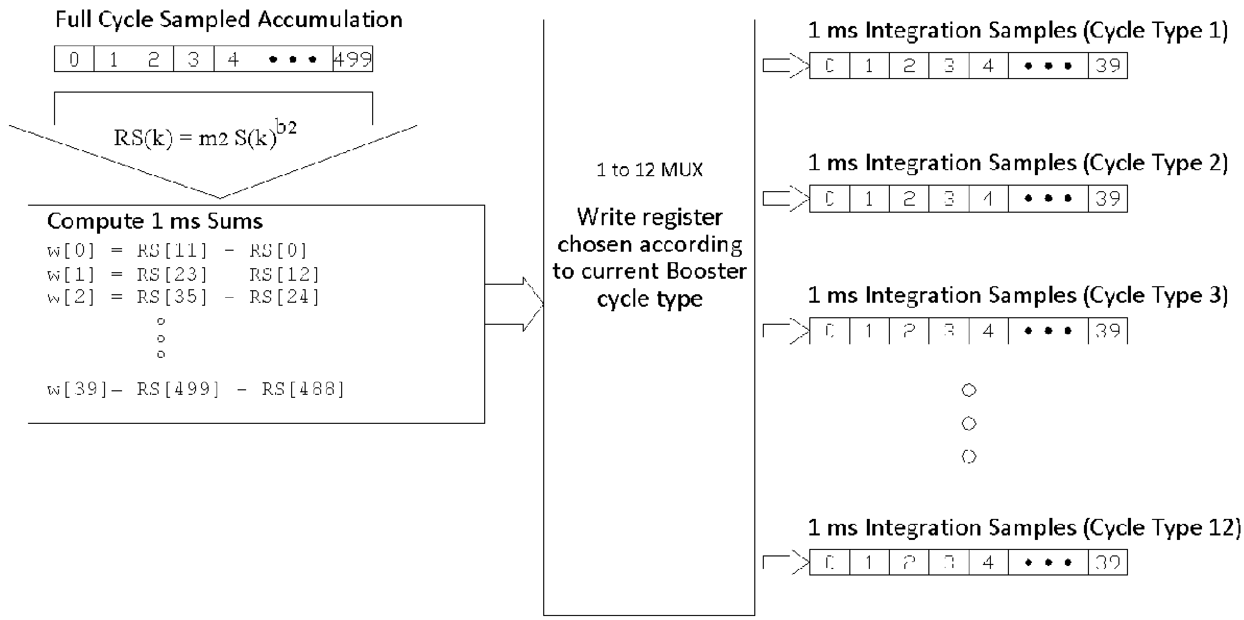


Figure IV.2.1 Illustration of the 1 milli-second sums signal processing

IV.4 The 100 Second Moving Sums (BLMS Support)

For each of the 12 booster cycle types, for each BLM channel, 100 second moving sums are maintained. The 100 second sum is the sum of 6 each, 17 second sums. These 17 second sums are stored in a circular buffer, 6 values deep. Each time a new 17 second sum is added to the 100 second sum, the oldest 17 second sum in the circular buffer is subtracted off.

In order to compute the 17 second sums (which are actually 250, 15 Hz cycles), additional sum registers are maintained for the 12 Booster cycle types, for each BLM channel. When processing the data for a specific Booster cycle type the initial value is subtracted from the final value of the Full Cycle Sampled Accumulation data, having been converted to Rads/Second. This is added to the 17 second sum value for that specific cycle type, for the specific BLM channel.

When a counter counting 15 Hz cycles reaches 250 (~17 seconds) the 100 second sums and their associated circular buffers are updated with the values in the 17 second sum registers. Then the 17 second sums are reset to zero.

Trip settings have been enabled on many of the Booster BLM's, 100 second sum value. This has been done to limit losses in order to prevent excessive activation of the accelerator components. The ACNET devices to which the alarms have been applied are the B:BLxxx0 devices (where xxx is a 3 letter location description). These devices contain sums of the total losses recorded on all beam resets (event 10's) during the last 100 seconds and updated every 17 seconds.

To review, there is a 17 second sum register and a 6 deep circular buffer of 17 second sums for each of the 12 Booster cycle types, for each of as many as 24 BLM channels.

In addition to maintaining these 100 second moving beam loss values, a 100 second moving count of the occurrence of each of the specific Booster reset events (those triggers which initiate the different Booster cycle types) is maintained. These are also updated by maintaining 17 second counts of the Booster reset events and 6 deep circular buffers of the 17 second counts. In this case there are only 12 sets of counts and circular buffers. One set for each Booster reset event.

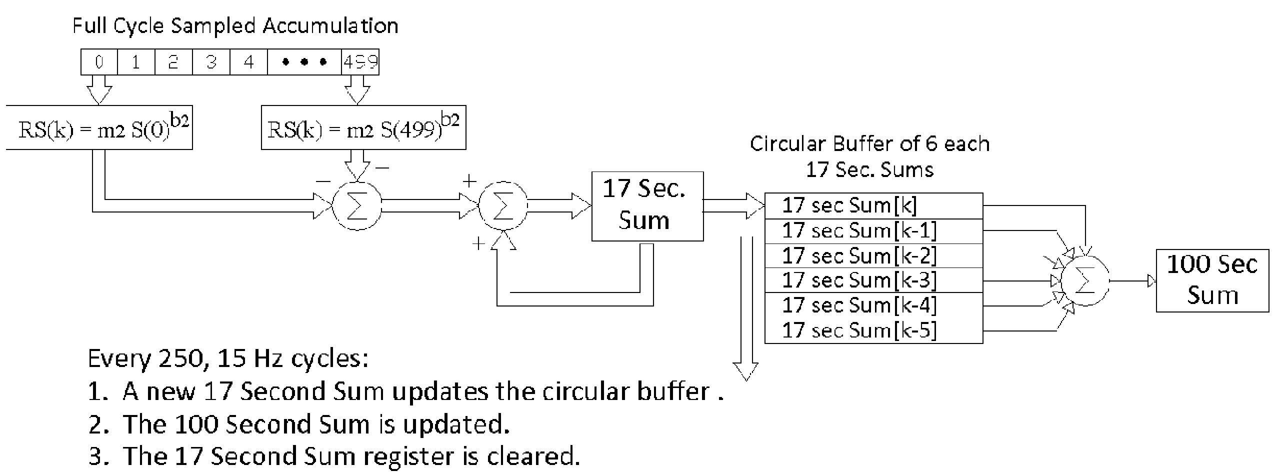


Figure IV.4.1 Illustration of the 100 second moving sums signal processing

IV.5 The 7.5 Hz Waveform Buffers (RETDAT Support)

Requests may be made from ACNET applications to receive data for a specific set of channels on the BLM front-end processor at a 7.5 Hz update rate. Since the Booster cycles at a 15 Hz rate, two cycles worth of data are returned at the 7.5 Hz rate. The data returned is for the specified channel with no distinction with regard to the type of Booster cycle the data was collected over or whether there was even beam in the Booster during the interval. In addition to BLM data channels, there are channels that report the specific Booster reset events that may or may not have occurred over the last 133 ms (inverse of 7.5 Hz). Also along with the data is included the specific “cycle counts” for the two cycles of data in the update response. The cycle count information can be used to correlate the Booster reset event information with the data taken during the cycle the reset event triggered.

The BLM channel data will be the 500 point Full Cycle Sampled Accumulation waveform. For each BLM channel, 2 of these waveforms are transmitted to the requesting ACNET application every 133 ms.

V. BLM Digitizer Calibration

For the sake of existing Booster monitoring and control applications, the scaling between losses in the Booster tunnel and the resulting BLM values delivered to ACNET needs to be considered. The system using the new integrators needs to have the same scaling as the system using the older Log Integrators. The following section presents the scaling for both systems and how the new system must be scaled to match the current system.

V.1 Scaling for the New Integrator

The combination of integrators and analog to digital conversion, results in a conversion between Coulombs of charge in and the resulting 16 bit digitized result out. In the default Low Range mode the integration opamp contains a 100 pico-farad feedback capacitor. This produces a voltage out of the integration opamp of (1/100E-12) (volts/coulomb). The integrator output is then scaled to fit the input range of the ADC digitizer, 0.483 (volts/volt).

The integrator output voltage digitized each 20 μs sampling interval is the sum of the charge collected in the previous 20 μs interval. Note that the final sampling interval we will end up with is 80 μs. The voltage at the input to the analog to digital converter is

$$V^*(t) = \frac{0.4827}{100E-12} \int_{t}^{t+{}^{T}/_{4}} Q_{in}(\tau)\, d\tau\,, \qquad where\ T = \ 80\ \mu\text{s}$$

Let us represent the k_{th} digitized 20 μs integration sample as $Y^*\left(k \cdot {}^{T}/_{4}\right)$. The digitizer outputs a 16 bit value and has an input voltage range of 5 volts.

$$Y^*\left(k \cdot {}^{T}/_{4}\right) = \frac{65536}{5} \cdot V^*\left(k \cdot {}^{T}/_{4}\right)$$

The digitized value written to FIFO memory on the digitizer module, and read by the front-end processor, is the average of 4 of these 20 μs integration samples. These can also be described as scaled 80 μs integration samples.

$$A^*(k \cdot T) = \frac{65536}{5} \cdot \frac{1}{4} \cdot \left[V^*\left(k \cdot \frac{T}{4}\right) + V^*\left(2 \cdot k \cdot \frac{T}{4}\right) + V^*\left(3 \cdot k \cdot \frac{T}{4}\right) + V^*(k \cdot T)\right]$$

$$A^*(k \cdot T) = G_1 \cdot \left[\int_{(k-1)\cdot T}^{k\cdot T/4} Q_{in}(\tau)\, d\tau + \int_{k\cdot T/4}^{k\cdot T/2} Q_{in}(\tau)\, d\tau + \int_{k\cdot T/2}^{k\cdot 3\cdot T/4} Q_{in}(\tau)\, d\tau + \int_{k\cdot 3\cdot T/4}^{k\cdot T} Q_{in}(\tau)\, d\tau \right]$$

$$A^*(k \cdot T) = G_1 \cdot \int_{(k-1)\cdot T}^{k\cdot T} Q_{in}(\tau)\, d\tau\,, \qquad where\ k = 1, 2, 3, \cdots, 500.$$

where

$$G_1 = \frac{65536}{5} \cdot \frac{1}{4} \cdot \frac{0.4827}{100E-12} = 15.8171E12$$

As we will describe below, the Log Integrator outputs are integration over the entire booster acceleration interval. The similar result using the new integrators will be a running accumulation (summing) of the 80 µs integration samples, $A^*(k)$.

$$S(k \cdot T) = S\big((k-1) \cdot T\big) + A^*(k \cdot T)$$

$$S(k) = A^*(1) + A^*(2) + A^*(3) + \cdots + A^*(k)$$

$$S(k \cdot T) = G_1 \cdot \int_{0}^{k\cdot T} Q_{in}(\tau)\, d\tau$$

$$S(k) = G_1 \cdot Q_{sum}(k)$$

V.2 Scaling for the Log Integrator

Scaling for the Log Integrators has been presented by Robert Schafer back around 1982. Reproductions of his plots are provided in Appendix A. The Acnet control system scales the Log Integrator output from what it expects to be the voltage output, V^o, of the integrators to Rads per Second, RS. This conversion is given as

$$RS = d_1 \cdot EXP[d_2 \cdot V^o], \qquad where\ d_1 = 0.00721196\ and\ d_2 = 1.057772$$

This is the expected calibration for the Booster BLM's. Over the years the values produced by the BLM's have been correlated to the activation of equipment in the Booster tunnel, and alarm limits have been established based on these relationships. In replacing the integrators in the BLM system we wish to have the new integrator produce the same numbers with respect to the charge from a BLM, as a result of beam loss, as the old system.

In order to ensure that we understand the calibration of each of the Log Integrators that has been in service we are performing input/output calibration measurements on each one. The calibration involves injecting a known charge profile into the Log Integrator and measuring the voltage output. Figure V.2.1 shows a sample plot of the results with a fit to the equation

$$V^o(t) = C_1 \cdot Ln\left(\int_0^t Q(\tau)\,d\tau\right) + C_2$$

The Log Integrators are digitized to 16 bits with a range of +/-10 volts. The result is

$$Y^o(k \cdot T) = \frac{65536}{20} \cdot V^o(k \cdot T)$$

$$Y^o(k \cdot T) = 3276.8 \cdot \left[C_1 \cdot Ln\left(\int_0^{k \cdot T} Q(\tau)\,d\tau\right) + C_2\right] = 3276.8 \cdot \left[C_1 \cdot Ln\left(Q_{sum}(k)\right) + C_2\right]$$

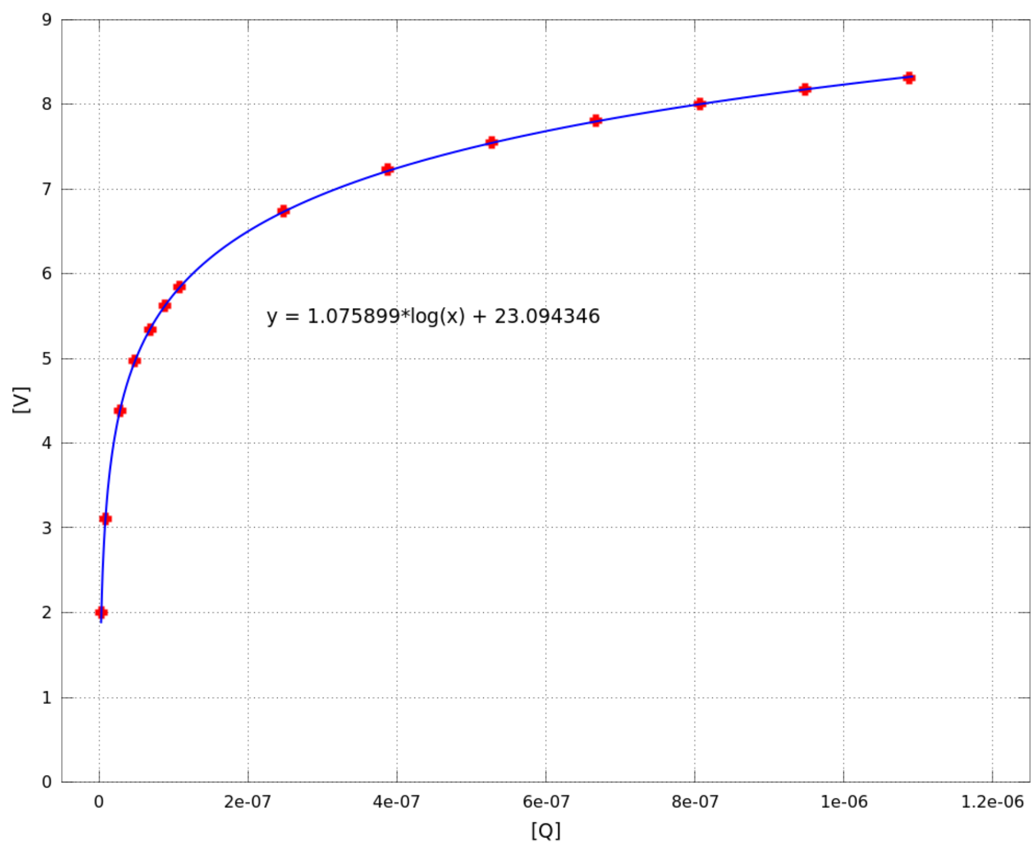


Figure V.2.1 Log Integrator voltage out versus charge in.

V.3 Determining the Conversion Between the Old and the New

In order to scale the values out of the new integrators to be equivalent to what we get from the Log Integrators we begin by solving the relation for the new integrator for $Q_{sum}(k)$.

$$Q_{sum}(k) = \frac{1}{G_1} \cdot S(k)$$

We then substitute this value into the relation for the Log Integrators.

$$Y^o(k \cdot T) = 3276.8 \cdot \left[C_1 \cdot Ln\left(\frac{1}{15.8171E12} \cdot S(k)\right) + C_2\right]$$

$$Y^o(k \cdot T) = 3276.8 \cdot \left[C_1 \cdot Ln\big(S(k)\big) - C_1 \cdot Ln(15.8171E12) + C_2\right]$$

Or

$$Y^o(k \cdot T) = m \cdot Ln\big(S(k)\big) + b$$

Where

$$m = 3276.8 \cdot C_1 \quad and \quad b = 3276.8 \cdot (C_2 - C_1 \cdot 30.3921)$$

This is the logarithmic value that is transmitted to ACNET for use in plotting. Once in ACNET, a final conversion is applied to the data before the data is plotted. This converts the data back to linear form with units of Rads/Second.

$$RS = d_1 \cdot EXP[d_2 \cdot Y^o/3276.8], \qquad where\ d_1 = 0.00721196\ and\ d_2 = 1.057772$$

This is just as it was for the Log Integrator data.

In order to compute the 1 milli-second sums, the 17 second sums and the 100 second sums the linear data $S(k \cdot T)$ needs to be scaled to look like the linear data resulting from the Log integrators and converted to Rads/Second. To arrive at the conversion we substitute the expression

$$Y^o(k \cdot T) = m \cdot Ln\big(S(k)\big) + b$$

Into

$$RS = d_1 \cdot EXP[d_2 \cdot Y^o/3276.8], \qquad where\ d_1 = 0.00721196\ and\ d_2 = 1.057772$$

The result is

$$RS(k) = d_1 \cdot EXP\left[d_2 \cdot \left(C_1 \cdot Ln\big(S(k)\big) + C_2 - 30.3921 \cdot C_1\right)\right]$$

$$RS(k) = d_1 \cdot EXP\left[d_2 \cdot C_1 \left(Ln\big(S(k)\big) + \frac{C_2}{C_1} - 30.3921\right)\right]$$

$$RS(k) = d_1 \cdot EXP\left[Ln\left(\left(S(k) \cdot EXP\left[\frac{C_2}{C_1} - 30.3921\right]\right)^{d_2 \cdot C_1}\right)\right]$$

$$RS(k) = d_1 \cdot \left(S(k) \cdot EXP\left[\frac{C_2}{C_1} - 30.3921\right]\right)^{d_2 \cdot C_1}$$

$$RS(k) = d_1 \cdot EXP[d_2 \cdot C_2 - 30.3921 \cdot d_2 \cdot C_1] \cdot S(k)^{d_2 \cdot C_1}$$

$$RS(k) = m_2 \cdot S(k)^{b_2}$$

where

$$m_2 = 0.00721196 \cdot EXP[1.057772 \cdot C_2 - 32.1479 \cdot C_1] \; and \; b_2 = 1.057772 \cdot C_1$$

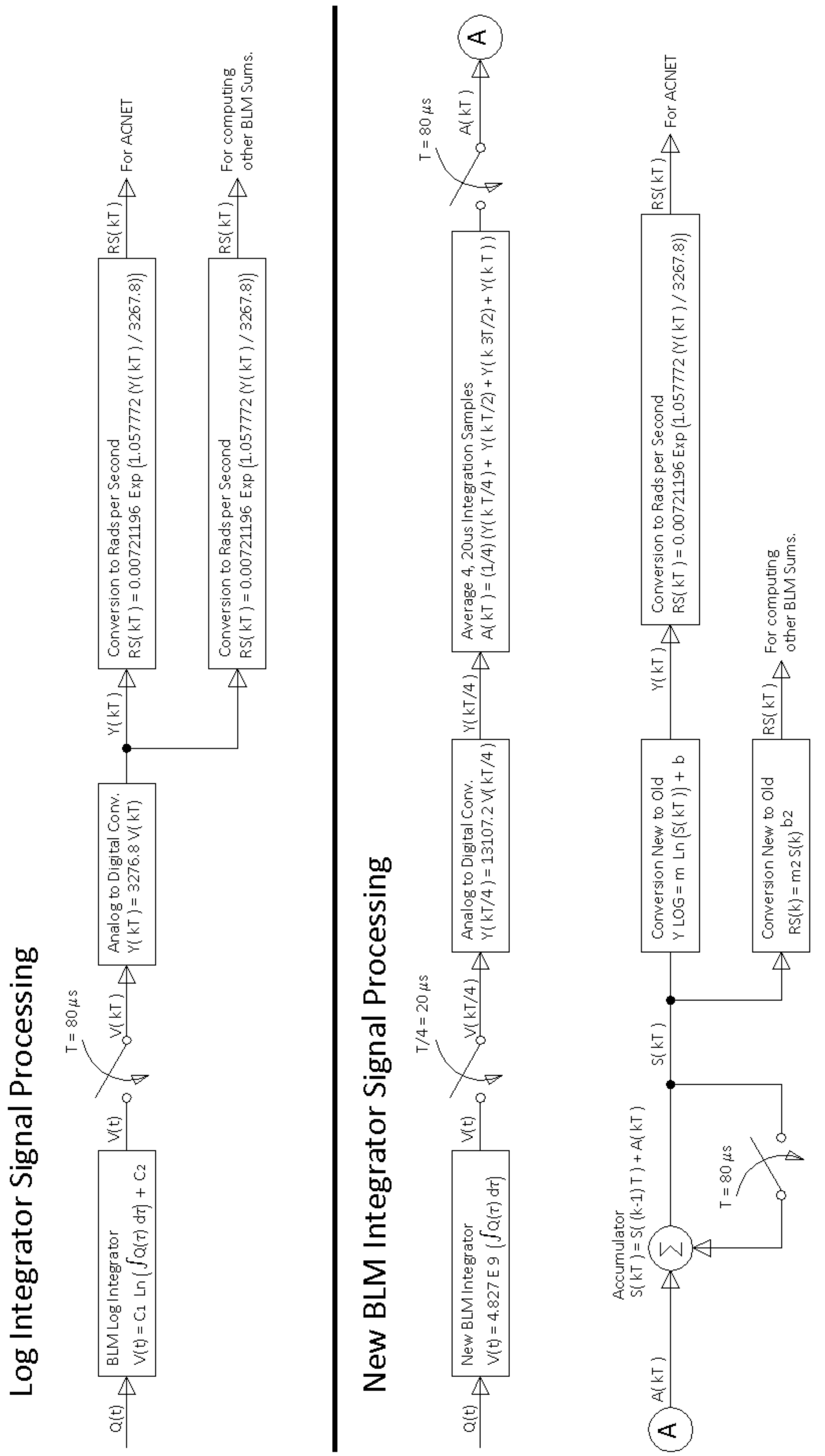


Figure V.3.1 Block diagram of the BLM signal processing comparison between old and new

VI. Providing Coefficients for Local Application BLME

Local Application BLME was written to support the new BLM Integrator Digitizers. As described in the previous section, the new digitizer data needs to be accumulated into a Full Cycle Sampled Accumulation, S(k). Then this linear data needs to be converted to Log form to be sent to ACNET and this linear data needs to be converted to Rads/Second with the same scaling, with respect to charge produced by the loss monitor as the Log Integrators. The previous section determined that we need to perform the following conversions.

Linear to Log

$$Y^o(k \cdot T) = m \cdot Ln\big(S(k)\big) + b$$

Where

$$m = 3276.8 \cdot C_1 \quad and \quad b = 3276.8 \cdot (C_2 - C_1 \cdot 30.3921)$$

Linear to Rad/Second

$$RS(k) = m_2 \cdot S(k)^{b_2}$$

where

$$m_2 = 0.00721196 \cdot EXP[1.057772 \cdot C_2 - 32.1479 \cdot C_1] \; and \; b_2 = 1.057772 \cdot C_2$$

VI.1 Computing the Linear to Log Conversion

Robert Goodwin developed a fast algorithm for computing the Log and included it in the BLME local application. The note on this is "Log the Linear BLM Signal", January 17, 2007. The note can be found on the website for AD/ Controls /Integrated Engineering,

http://www-inteng.fnal.gov/Integrated_Eng/software/software.html

The algorithm employs a lookup table to find the value of $2048 \cdot Log_2\big(S(k)\big)$. What follows is a description of how to the coefficients in the computation are determined.

First Note that

$$Ln(S(k)) = Log_2(S(k)) \cdot Ln(2)$$

Substituting this into our conversion and scaling our numbers up to do the fixed-point integer math we have

$$Y^o(k \cdot T) \cdot 65536 = \big(2048 \cdot Log_2(S(k))\big) \cdot (32 \cdot Ln(2) \cdot m) + b \cdot 65536$$

$$Y^o(k \cdot T) \cdot 65536 = \big(2048 \cdot Log_2(S(k))\big) \cdot a1 + a2$$

Where

$$a1 = 32 \cdot Ln(2) \cdot 3276.8 \cdot C_1 \quad and \quad b = 3276.8 \cdot (C_2 - C_1 \cdot 30.3921) \cdot 65536$$

$$a1 = 72615 \cdot C_1 \quad and \quad b = 214748365 \cdot (C_2 - C_1 \cdot 30.3921)$$

<u>Note that if the coefficient end up too large, we should scale the fixed-point math up something less than 65536.</u>

Appendix A

This appendix contains a copy of Robert Schafer's plots of the response of the Log Integrators.

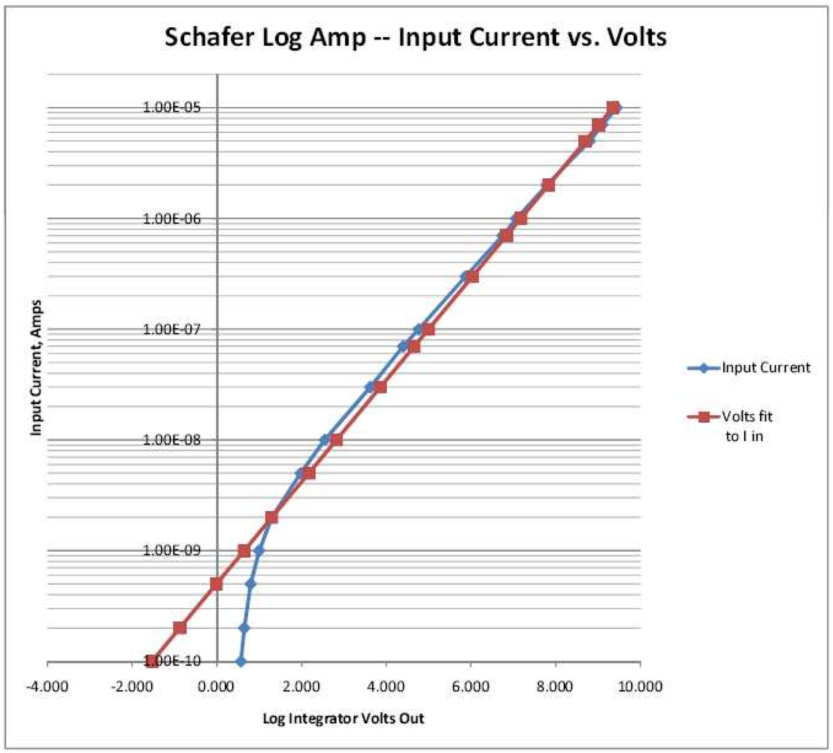
Data From Schafer's Log Amp Plots

I = 70E-9*(R/S)

Vout@20 degC	Vout@40 degC	Mean Vout	Input Current	Rads/Sec	Volts fit to I in	Volts fit to RAD/S
9.100	9.780	9.440	1.00E-05	1.43E+02	9.353	9.353
8.800	9.400	9.100	7.00E-06	1.00E+02	9.016	9.016
8.500	9.100	8.800	5.00E-06	7.14E+01	8.698	8.698
7.520	8.050	7.785	2.00E-06	2.86E+01	7.832	7.832
6.850	7.300	7.075	1.00E-06	1.43E+01	7.177	7.177
6.500	7.000	6.750	7.00E-07	1.00E+01	6.839	6.839
5.650	6.100	5.875	3.00E-07	4.29E+00	6.038	6.038
4.590	4.950	4.770	1.00E-07	1.43E+00	5.000	5.000
4.200	4.600	4.400	7.00E-08	1.00E+00	4.663	4.663
3.500	3.750	3.625	3.00E-08	4.29E-01	3.862	3.862
2.550	2.550	2.550	1.00E-08	1.43E-01	2.823	2.823
1.980	1.980	1.980	5.00E-09	7.14E-02	2.168	2.168
1.300	1.300	1.300	2.00E-09	2.86E-02	1.301	1.301
1.000	1.000	1.000	1.00E-09	1.43E-02	0.646	0.646
0.800	0.800	0.800	5.00E-10	7.14E-03	-0.009	-0.009
0.650	0.650	0.650	2.00E-10	2.86E-03	-0.875	-0.875
0.570	0.570	0.570	1.00E-10	1.43E-03	-1.531	-1.531

Alternate Amps to Volts				
Volts = m*LN(s1*I)	m1		s1	
		9.453833E-01		1.980857E+09
Amps to Volts	m2		b2	
Volts = m*LN(I) + b		9.453833E-01		2.023763E+01
Volts to Amps	c1		c2	
I = c1*EXP(c2*Volts)		5.04832E-10		1.057772

Alternate Rad/Sec to Volts				
Volts = m*LN(s1*R/S)	m		s1	
		9.453833E-01		1.386586E+02
Rad/Sec to Volts	m		b	
Volts = m*LN(R/S) + b		0.945383315		4.662644237
Volts to Rad/Sec	c1		c2	
R/S = c1*EXP(c2*Volts)		0.00721196		1.057772



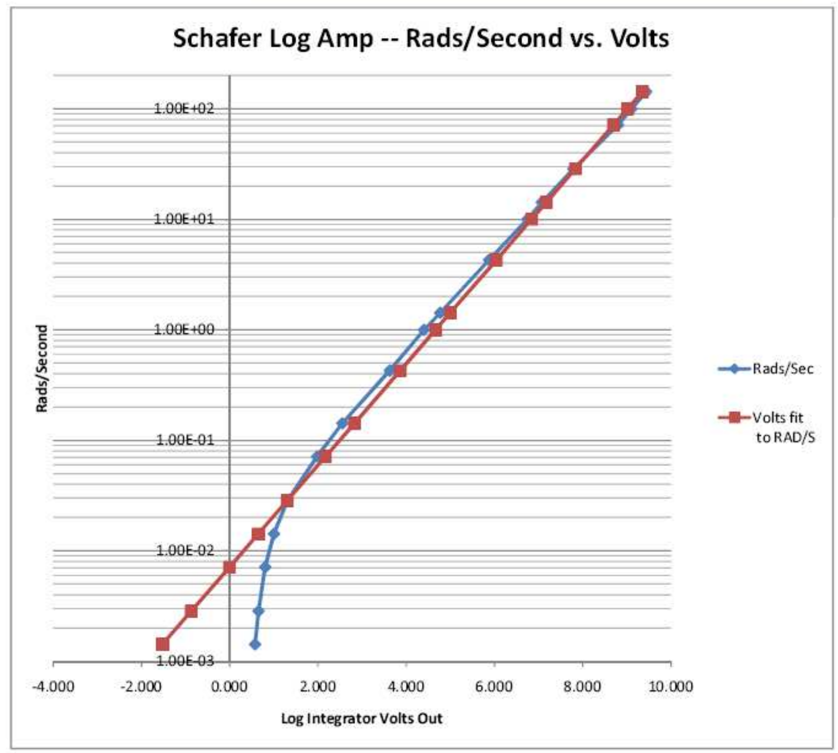


Figure II.2.1 Schafer Log Integrator data relating Current and Rads/Second to Volts out.

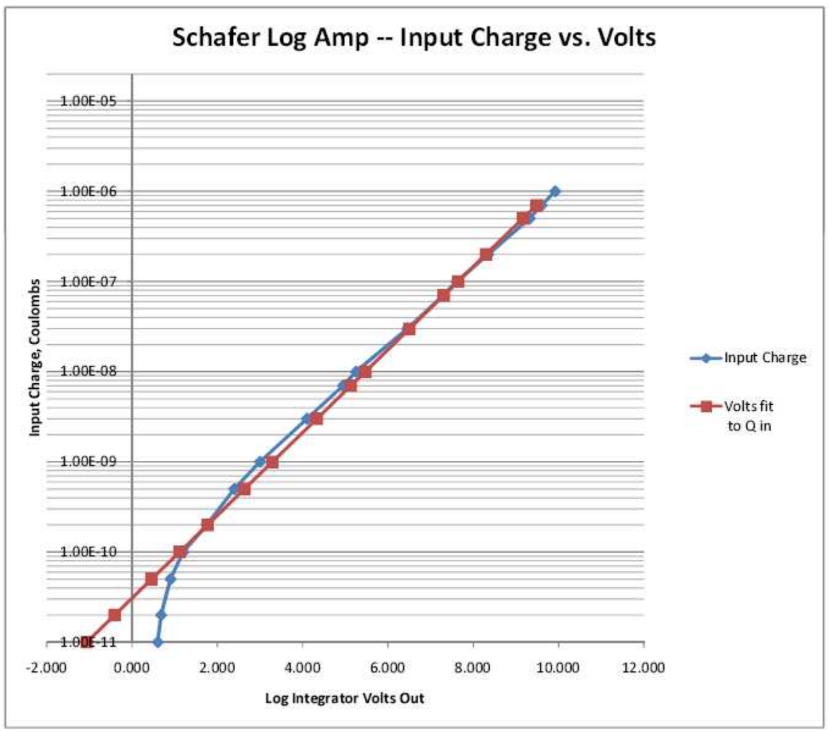
Data From Schafer's Log Amp Plots

I = 70E-9*(R/S)

Vout@20 degC	Vout@40 degC	Mean Vout	Input Charge	Rads	Volts fit to Q in	Volts fit to Rads
9.6	10.25	9.925	1.00E-06			
9.250	9.950	9.600	7.00E-07	1.00E+01	9.484	9.484
8.950	9.700	9.325	5.00E-07	7.14E+00	9.165	9.165
8.000	8.700	8.350	2.00E-07	2.86E+00	8.299	8.299
7.350	7.880	7.615	1.00E-07	1.43E+00	7.644	7.644
7.000	7.580	7.290	7.00E-08	1.00E+00	7.307	7.307
6.200	6.700	6.450	3.00E-08	4.29E-01	6.506	6.506
5.050	5.450	5.250	1.00E-08	1.43E-01	5.467	5.467
4.800	5.100	4.950	7.00E-09	1.00E-01	5.130	5.130
4.000	4.200	4.100	3.00E-09	4.29E-02	4.329	4.329
2.900	3.100	3.000	1.00E-09	1.43E-02	3.290	3.290
2.400	2.400	2.400	5.00E-10	7.14E-03	2.635	2.635
1.750	1.750	1.750	2.00E-10	2.86E-03	1.769	1.769
1.200	1.200	1.200	1.00E-10	1.43E-03	1.113	1.113
0.900	0.900	0.900	5.00E-11	7.14E-04	0.458	0.458
0.680	0.680	0.680	2.00E-11	2.86E-04	-0.408	-0.408
0.600	0.600	0.600	1.00E-11	1.43E-04	-1.063	-1.063

Alternate Coulombs to Volts			
Volts = m*LN(s1*Q)	m		s1
		9.453833E-01	3.247273E+10
Coulomb to Volts	m		b
Volts = m*LN(Q) + b		9.453833E-01	2.288174E+01
Volts to Coulomb	c1		c2
Q = c1*EXP(c2*Volts)		3.07951E-11	1.057772

Alternate Rads to Volts			
Volts = m*LN(s1*R)	m		s1
		9.453833E-01	2.273091E+03
Rads to Volts	m		b
Volts = m*LN(R) + b		0.945383315	7.306769261
Volts to Rads	c1		c2
R = c1*EXP(c2*Volts)		0.00043993	1.057772



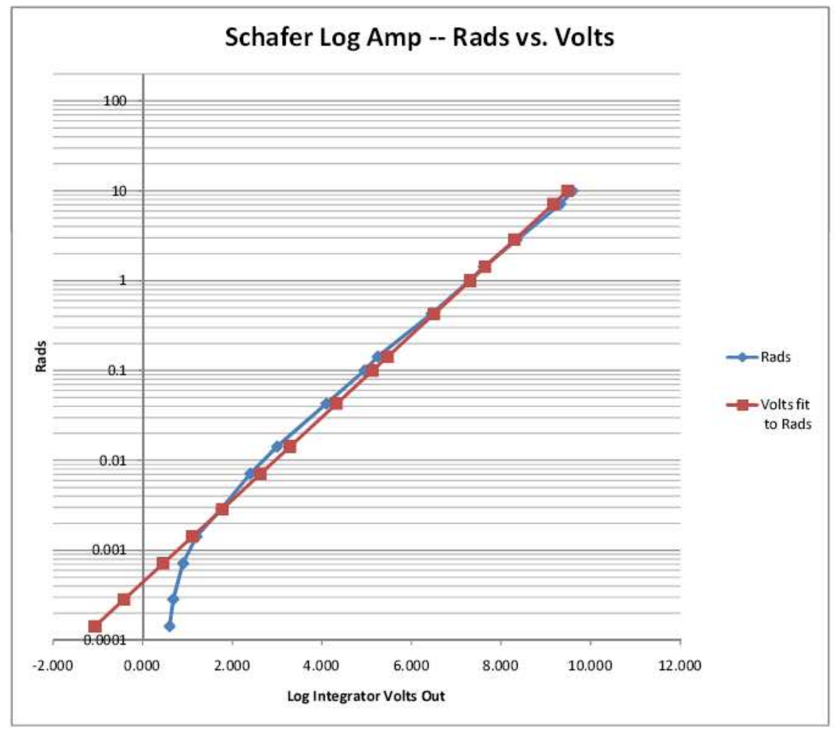


Figure II.2.2 Schafer Log Integrator data relating Charge and Rads to Volts out.