Study on High Dynamic Range Acquisition Electronics for a Beam Loss Measurement System

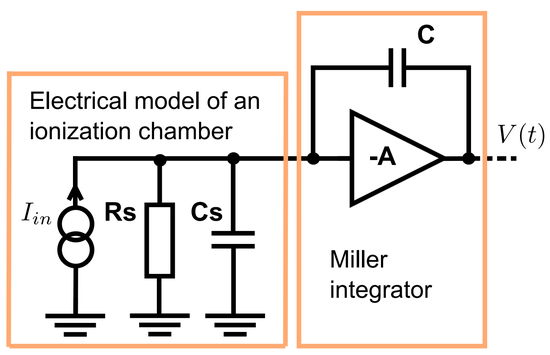
Bernd Dehning, Ewald Effinger, Jonathan Emery, Giuseppe Venturini, Christos Zamantzas
CERN, Geneva, 1211 CH

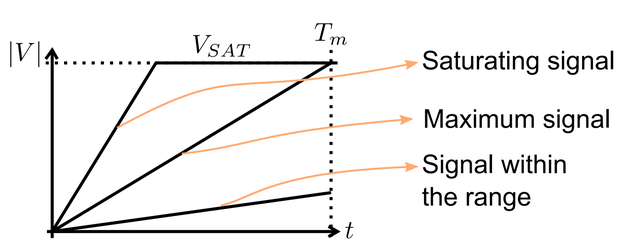
Abstract: The beam loss monitoring (BLM) system detects the energy density deposited by the particles lost from the beam in the accelerator elements. The monitor employed in the CERN accelerator complex is the ionization chamber, whose output signal has to be acquired over a very high dynamic range (DR), eight decades, corresponding to 160 dB. In this work, several possible circuit architectures for the front-end electronics have been studied, compared and implemented. Measurements and observations are reported.

1 Linear circuits

The ouput signal from an ionization chamber is a charge, whose value is proportional to the energy deposited in the monitor by the high energy particles that crossed it.

A front-end amplifier is needed to convert the input current into a quantity that can be digitized, e.g. a voltage. The charge accumulated in the measurement time can be acquired with a charge amplifier, for example a Miller integrator.





$$V(t) = -\min\left\{\frac{1}{C}\int_0^t I_{in}(\psi)\,d\psi, V_{SAT}\right\}$$

→ Insufficient dynamic range (~ 54dB)

$$DR = \frac{Q_{max}}{Q_{min}}$$

Q_{max} the maximum signal that can be acquired

Q_{min} the input signal that produces an output signal of amplitude equal to the noise level

2 Extending the dynamic range

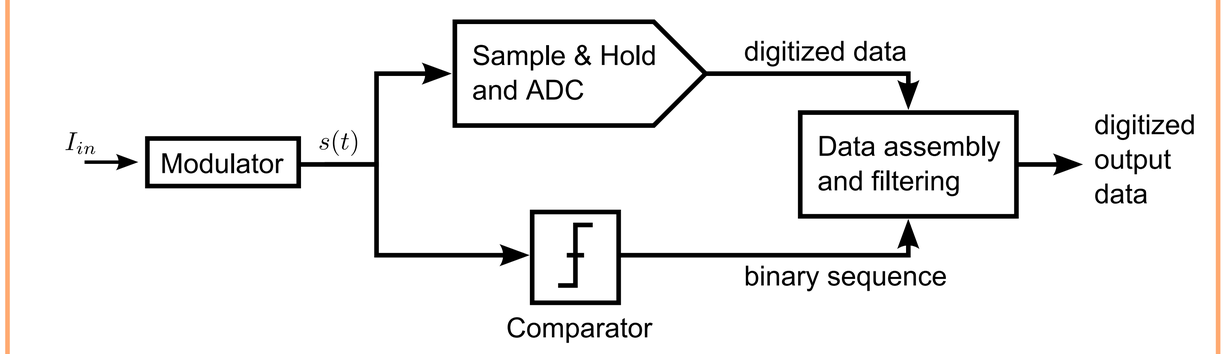
$$DR = \frac{Q_{max}}{Q_{min}}$$

- Increasing the maximum input signal, Q_{max}
- Decreasing Q_{min} (in turn requires lowering the noise level)
- "Modulator" techniques
- Non-linear amplifiers (compressive characteristics)

At the same time, the signal to noise ratio (SNR) should not be noticeably reduced.

Modulator techniques are considered here. They are based on a modulation of a voltage waveform according to the input signal.

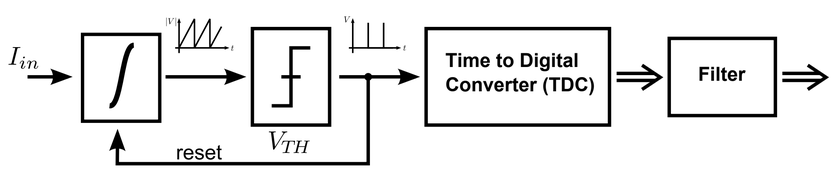
From the analysis of the modulated voltage, it is possible to recover the characteristics of the input signal.



In a given design, only the S&H and the ADC or only the comparator may be present.

3 Modulator techniques

Time-to-saturation

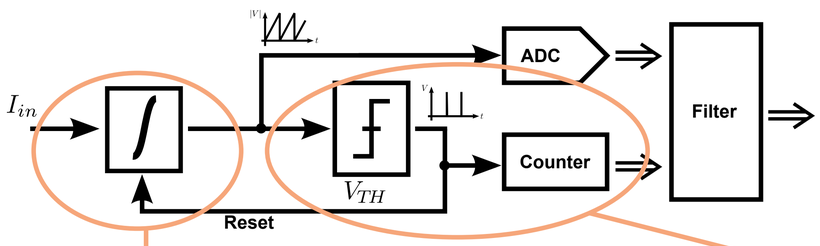


The input signal is integrated until a threshold is reached. When this happens a pulse is generated and the integrator is reset.

The time elapsed between two consecutive pulses is inversely proportional to the integral of the input current.

The conversion time is variable. A fixed conversion time leads to the recycled integrator scheme.

Recycled integrator



The input signal is integrated until a threshold is reached. Then the value stored by the counter is incremented and the integrator is reset.

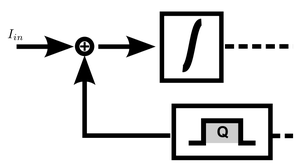
Output:

$$Q = C\,V(T_m) + n\,Q_{REF}$$

n number of resets in T_m

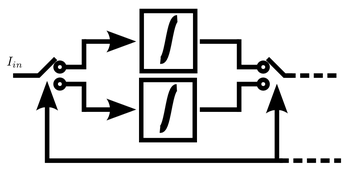
Q_{REF} charge removed each reset

Charge balance integrator



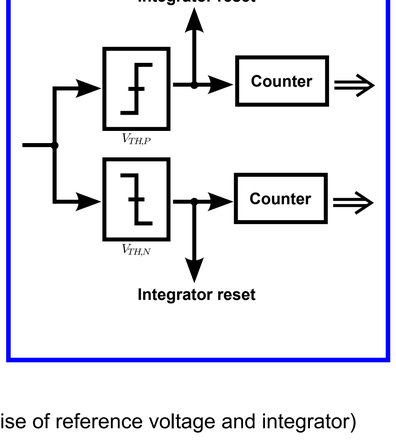
The reset is performed injecting a fixed charge of opposite polarity in the integrator:
- No blind time
- Operation independent of the characteristics of the integrator and threshold voltage

Dual switched integrator



At any time, only one is connected while the other is being reset:
- No blind time
- Reduced power consumption

Bipolar input currents



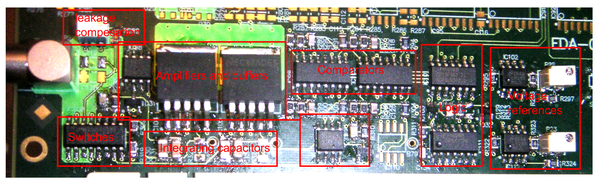
The maximum signal is affected by:
- Maximum input current of the integrator
- Slew rate of the integrator
- Total reset delay
- Comparator offset

The minimum signal is composed by:
- the read-out noise (quantization error, noise of reference voltage and integrator)
- reset noise (kTC, reset dependent)
- variation of the leakage currents at the input (temperature, humidity, aging)

The average switching frequency is proportional to the average input current: it's a current-to-frequency converter.

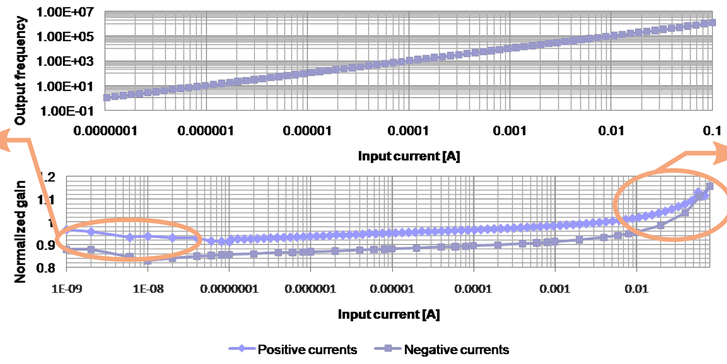
4 Implementations and results

Bipolar dual switched integrator



- Variable measurement window
- Minimum input current: 1nA
- Maximum input current: 100mA → eight decades
- Bipolar input
- Leakage compensation

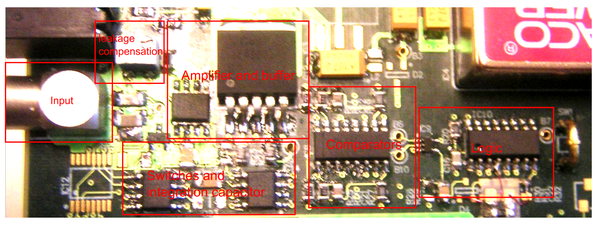
- Integral non-linearity error < 20% on the whole range



- Output drift of the integrator
- Low frequency cut-off
- Imperfect leakage compensation

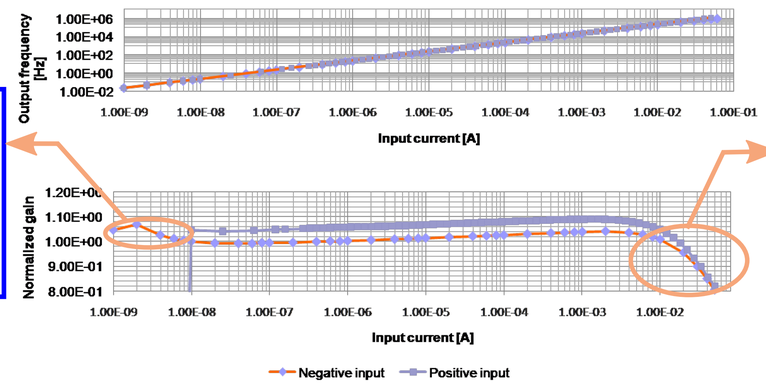
- Incomplete discharge of the integrator
- Bandwidth limit
- Delay of the loop

Bipolar charge balance integrator



- Variable measurement window
- Minimum input current: 1nA
- Maximum input current: 100mA → eight decades
- Bipolar input
- Leakage compensation

- Integral non-linearity error < 20% on the whole range



- Output drift of the integrator
- Low frequency cut-off
- Leakage of the switches

- Partial charge sharing
- Bandwidth limit
- Delay of the loop
- Charge injection

5 Conclusions

Different ways to improve the dynamic range were considered and implemented. Modifications were introduced to allow bipolar input currents and reduce both the complexity and the power consumption. Validation shows that the proposed circuit architectures allow an extension of the DR of the front-end electronics of a BLM system without deteriorating the signal-to-noise ratio.

References

[1] D. N. MacLennan and F. H. Wells, A wide range digitizer for direct coupled analogue signals, Journal of Physics E, S2 vol. 1, 1968
[2] W. Friesenbichler, LHC BLM Front-end Electronics, Master's thesis, CERN, 2002
[3] E. Effinger et alt., The LHC BLM System's Data Acquisition Card, 12th LECC, 2006
[4] G. Venturini, A Study on Acquisition Electronics with a High Dynamic Range for a Beam Loss Measurement System, Master's Thesis, 2009

DIPAC 2009. Geneva, Thursday, 7 May, 2009

giuseppe.guido.venturini@cern.ch