A CURRENT DIGITIZER FOR IONISATION CHAMBERS/SEMS WITH HIGH RESOLUTION AND FAST RESPONSE

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Abstract

A current-to-frequency converter (CFC), recently developed, exhibits a response time up to the µs region. The frequency limit is raised beyond 1 MHz, extending the linear range by a factor of 100. The conversion factor reaches 10E-13 C/pulse. The converter is employed, combined with ionization chambers (IC) and secondary electron emission monitors (SEM), to measure the intensity of the extracted beam in the transfer lines adjoining GSI´s heavy ion synchrotron (SIS). Fast intensity fluctuations during the particle spill can be observed.

Reduced hum and noise pickup, better handling and mounting flexibility as well as reduced costs are achieved building up the spill monitoring system with distributed components.

1 INTRODUCTION

Scintillation detectors, read out by photo multiplier tubes (PMT), commonly are limited to counting rates in the MHz range. If one has to cope with larger particle currents, other detectors must be used.

Because of an inherently large dynamic range, and easy data transmission and processing capability, a CFC is commonly employed for the measurement of the detector signals mentioned above. The acquisition and display of a spill´s particle count, the intensity envelope, and accompanying short-time fluctuations are facilitated by periodic readout of a digital counter connected to the CFC´s output.

In a SEM, ion spills extracted from the SIS at produce converter input currents with a dynamic range of ~10^{-12} A up to 10^{-7} A; the IC´s secondary current can reach 10^{-5} A. Spill durations from 10 ms to 10 s occur, and the extracted current does not show a perfect DC structure at all, but contains bursts with fast rise times, owing e. g. to magnet power supply ripple etc.

2 DESIGN CONSIDERATIONS

The existing converters comprised a response time constant of 350 ms, a 10 kHz frequency limit, no remote control and had to be mounted into NIM crates. These characteristics mainly prevented realistic interpretation and correct adjustment of the particle spill’s duration, shape and micro-structure.

2.1 Converter Working Principle

A fast response time combined with a frequency limit as high as possible were the most important design aims. These demands require an electronic circuit [1] [2] with shortest internal propagation delays. A scheme, well known as “pulsed current-balance” or “recycling integration”, was chosen [Fig.1].

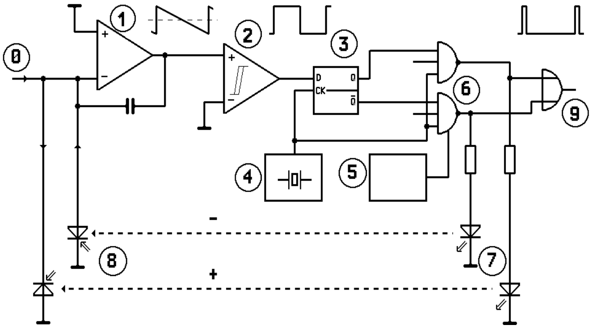

Fig. 1: Pulsed Charge-Balance CFC

Driven by a positive input current (0), the integrator (1) ramps negative. The Schmitt-Trigger (2) switches when the ramp crosses zero. The D-Flip-Flop (3) now passes “High” level to the selected gate (6), which opens for at least one crystal controlled clock (4) pulse of fixed duration, thus powering the opto-electronic “current source” (7,8) in the positive branch. A temperature controlled power supply (5) compensates it´s thermal current gain drift. The integrator is reset by a well defined charge pulse; Schmitt-Trigger and Flip-Flop switch back immediately, and the gate closes for the next clock pulse. Now the cycle starts again and oscillation commences. Every output pulse (9) indicates a fixed charge amount flowing to the input, while the output frequency is proportional to the input current. If the circuit is carefully designed, a linear relation is valid between current and frequency over many decades.

The performance of the circuit is mainly based on speed and precision of the pulsed “current sources” (7,8). Considering an operating frequency of 1 MHz at an input current of 100 nA, the device has to deliver a pulsed charge of 100 fC, e. g. (400 nA * 250 ns). Neither bipolar junction or field effect transistors (JFET) nor diode bridges worked fast enough at this current level. A Silicon PIN-Photodiode (PIN-Pd) with a small active area turned out to be a suitable current source, if it´s load resistance is kept close to zero. The summation point of the integrator (1, Fig.1) has the required characteristics.

Current transfer ratio (CTR)	0.1-0.2 %
CTR temperature coefficient	- 0.14 %/K
Dark resistance at zero voltage	1 GΩ
Shunt capacitance at zero voltage	11pF [3]
Current rise time / 50 Ω load	~ 70 ns

Tab. 1: Electrical characteristics of opto-electronic current source

A Si-PIN-Pd and a GaAlAs-LED, inexpensive devices originally intended for plastic fiber applications, were linked with a short piece of 2mm PMMA light wave guide and confined in a thermo-shrink tube, forming the opto-electronic current source.

3 CONVERTER PERFORMANCE

3.1 Offset current

To preserve the dynamic range also at low current level, the converter input has to be designed with great care for current leakages. Using the best state-of-the-art operational amplifier (OP) and a selected integration capacitor, and by routing all connections to the summation point (0) off the printed circuit board via a PTFE standoff insulator, the only leakage current remaining is the shunt or “dark” resistance of each PIN-Pd. Their effect can be trimmed out by the OP´s offset voltage control.

The bias current of the OP´s JFET input stage is clearly below 1 pA at 293 K. When temperature rises, this error current doubles about every 5 K (Fig. 2).

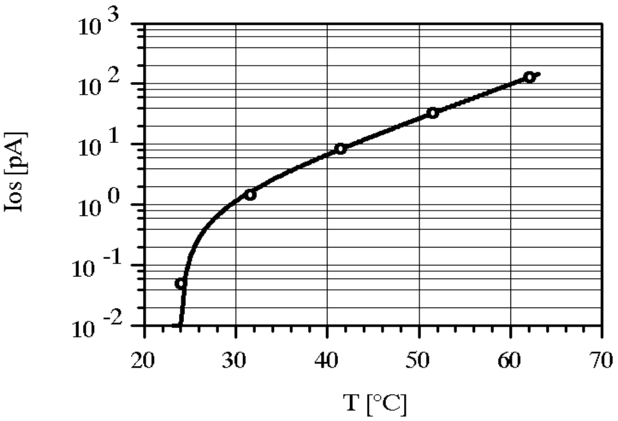

Fig. 2: Offset current of CFC vs. Temperature

3.2 Gain Linearity and Accuracy

Conversion factor calibration and linearity measurements (Fig. 3, 4) were performed using a Keithley 261 current calibrator, which was believed to add less than 3% error, and a HP digital counter.

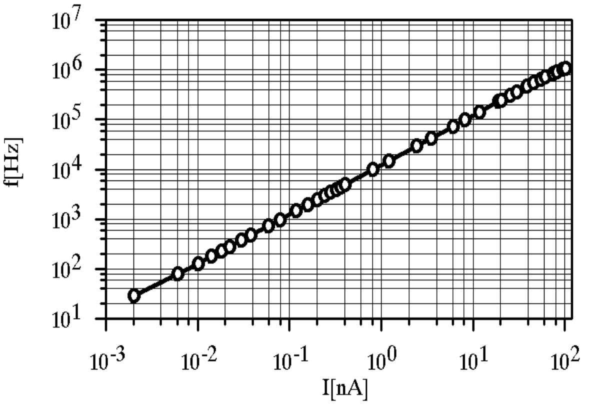

Fig. 3: Output frequency of CFC vs. Input current

At low currents, linearity is affected by the isolation resistance of the integration capacitor (>10 GΩ) and the open loop gain limit of the OP, as well as it´s bias current (see above) and voltage, and finally the resistance of the calibrator, or the detector respectively. The linearity error at high currents depends on the OP´s unity gain frequency of ~ 8 MHz[4], introducing about 40 ns propagation time into the charge-balancing loop, and the limited current rise time of the reset current source (Fig.4).

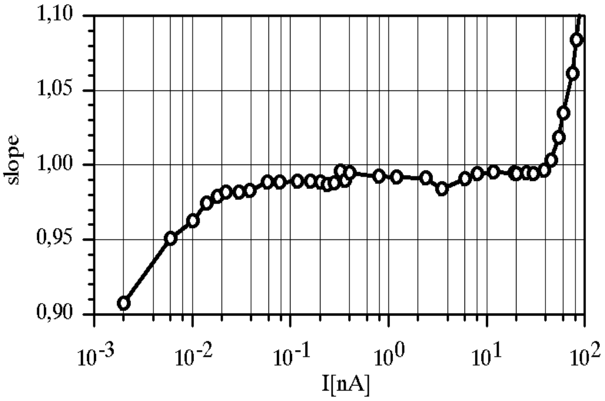

Fig. 4: Linearity error of CFC (slope of Fig. 3)

3.4 Frequency Stability

The output pulse rate stability of the CFC is shown in Fig. 5. It was measured at 10 nA input current (1 % full scale excitation) and displays the pulse event counts in 1000 intervals of 1ms length; a typical distribution due to random sampling is evident.

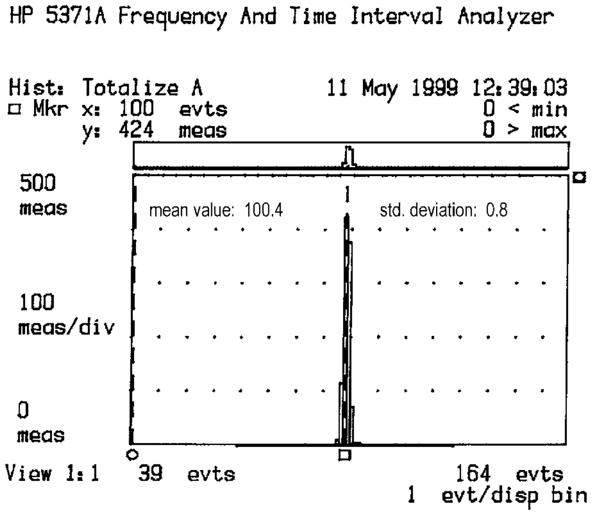

Fig. 5: Pulse count distribution of CFC, 10 nA input current, 1ms counting intervall

3.5 Time Response

The CFC´s response time depends on the propagation delay times inside the charge-balance loop, totally about 70 ns, and half of oscillator´s clock period - 250 ns - , but mostly on the momentary working frequency. After an input current step, the new frequency normally settles within 3 reset cycles, exhibiting no creep or overshoot. The response to fast fluctuations in an ion spill, detected with an IC and a scintillator at the same time, is shown in Fig. 6. The first peak of the displayed interval and the entire middle part of the spill have driven the CFC into overload; this condition obviously causes no latch-up effect.

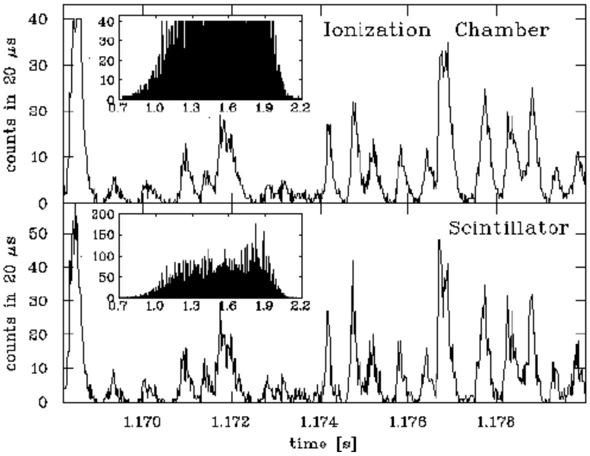

Fig. 6: Fluctuations in a Bi-spill, detected with an IC-CFC set and a SZ simultaneously

4 CONCLUSION

This new CFC is suitable for current measurements between 1 pA and 10 µA, e. g. from ionization chambers or secondary electron monitors as well as photo multiplier tubes or vacuum gauges. It has a linear range of nearly 6 decades and a fast time response – an improvement of several orders of magnitude, if compared to the converter type used in the past.

Two switchable current ranges (100 nA, 10 µA) , polarity selection, overload detection, a test current, an additional NIM output and a remote control are a matter of course.

Each converter has it´s own plug-in power line adaptor. Output pulse transmission is performed by differential RS-485 line drivers via fast optocouplers, allowing for floating operation and a transmission line length of up to 200 m. Specially designed counter stations and interfaces provide data processing and device control.

It has to be mentioned, that gain and offset stability of the new converter, if compared to the earlier type, could not be fully preserved.

The CFC described above is filed under patent no. DE 195 20 315.

6 ACKNOWLEDGEMENTS

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