Multi slope A/D converters. Why the 50 years old technology is still (the only one?) relevant for the highest performance applications?

Jaromir Sukuba,
jaromir@jaromir.sk

Jaromir Sukuba
jaromir@jaromir.sk

Is multislope relevant for today’s metrology applications?

Is multislope the only relevant technolgy for the same?

Is multislope relevant for today's metrology applications? Yes.

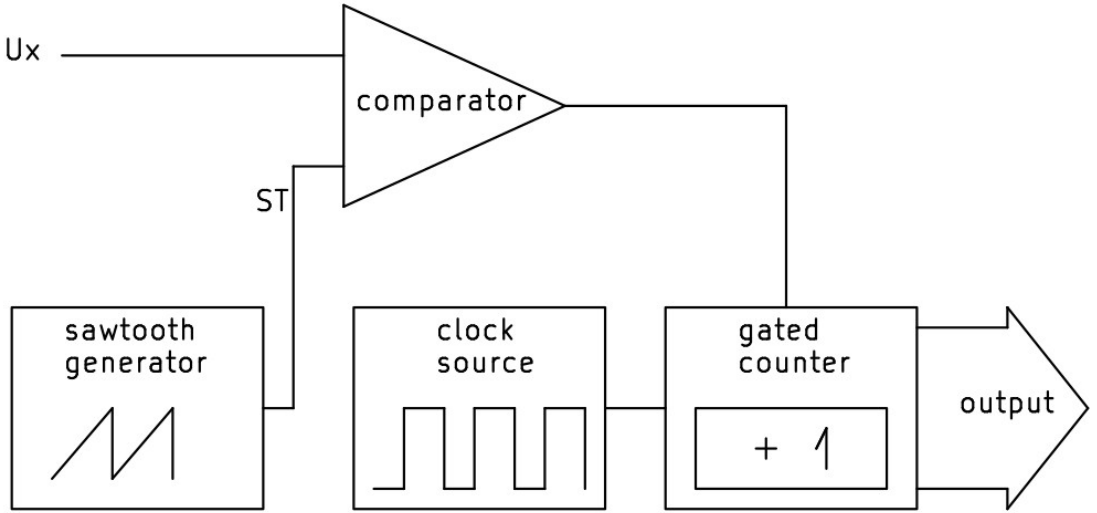
Is multislope the only relevant technolgy for the same? No.

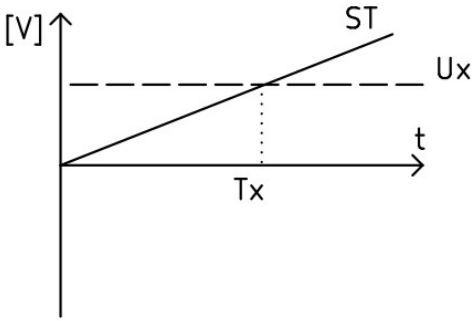
FEI STU, Bratislava

Jaromir Sukuba
jaromir@jaromir.sk

Jaromir Sukuba
jaromir@jaromir.sk

From single slope to dual slope, multislope and charge balance ADC, part 1/6.





Not really an integrating ADC, though typically using integrator.
Requires stable passive components, though there are workarounds for that - AN-260 by Jim Williams [1]

From single slope to dual slope, multislope and charge balance ADC, part 2/6.

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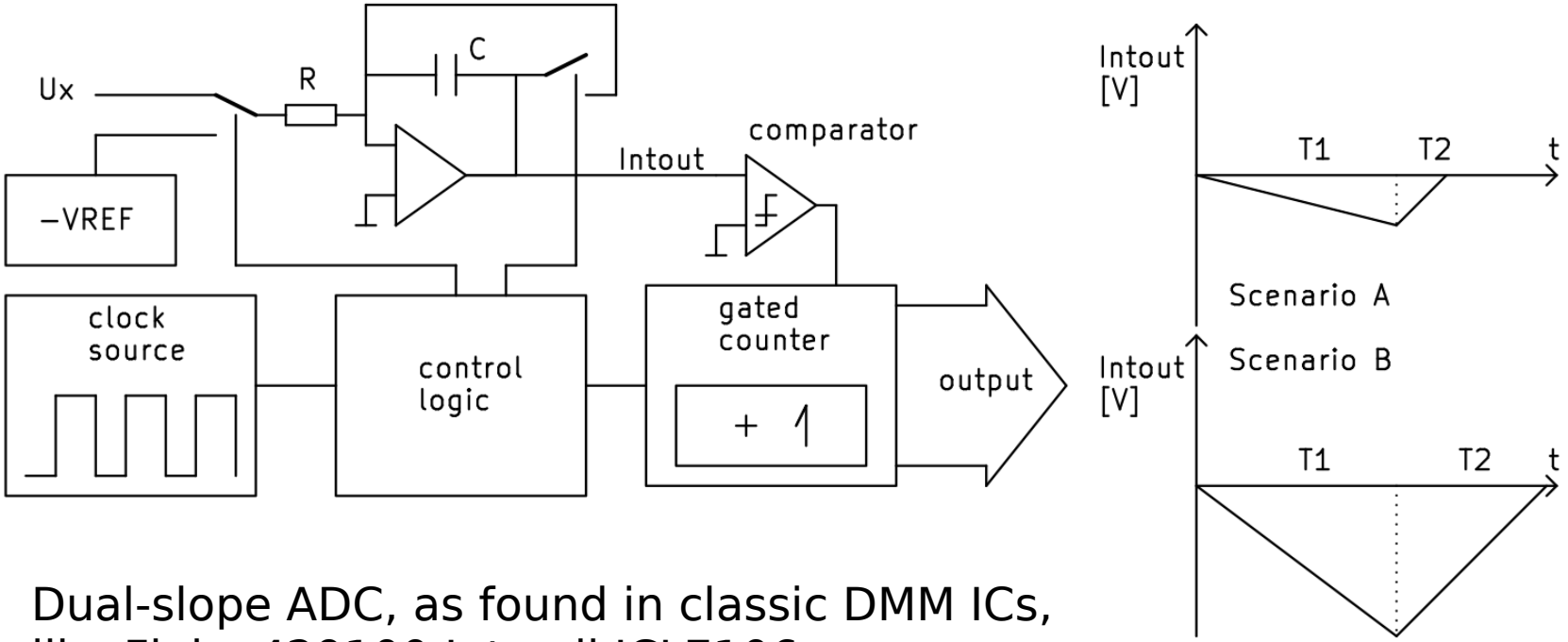
Jaromir Sukuba
jaromir@jaromir.sk



Dual-slope ADC, as found in classic DMM ICs, like ~~Fluke 429100~~ Intersil ICL7106

From single slope to dual slope, multislope and charge balance ADC, part 3/6.

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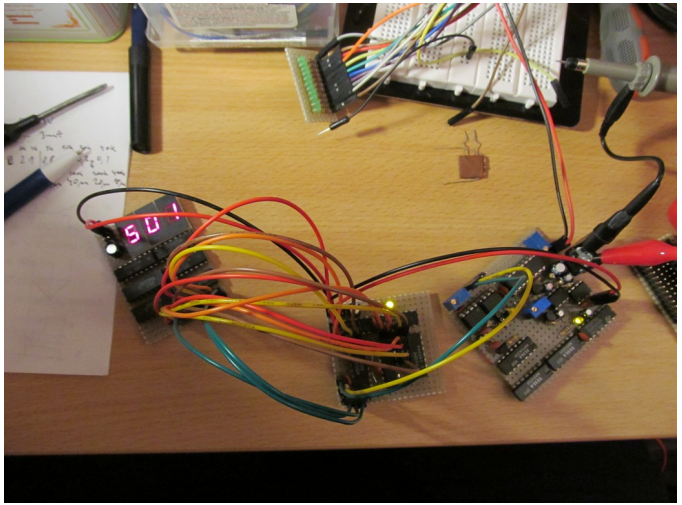
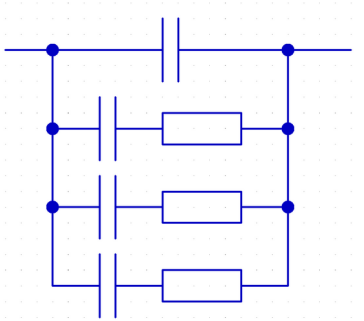
jaromir@jaromir.sk



Suffering from usual problems:
Slow acquisition for given resolution
Limited due to comparator noise/offset and integrator capacitor dielectric absorption (DA)
Integration time not easy to scale



Solution to that? Add more slopes, obviously.

From single slope to dual slope, multislope and charge balance ADC, part 4/6.

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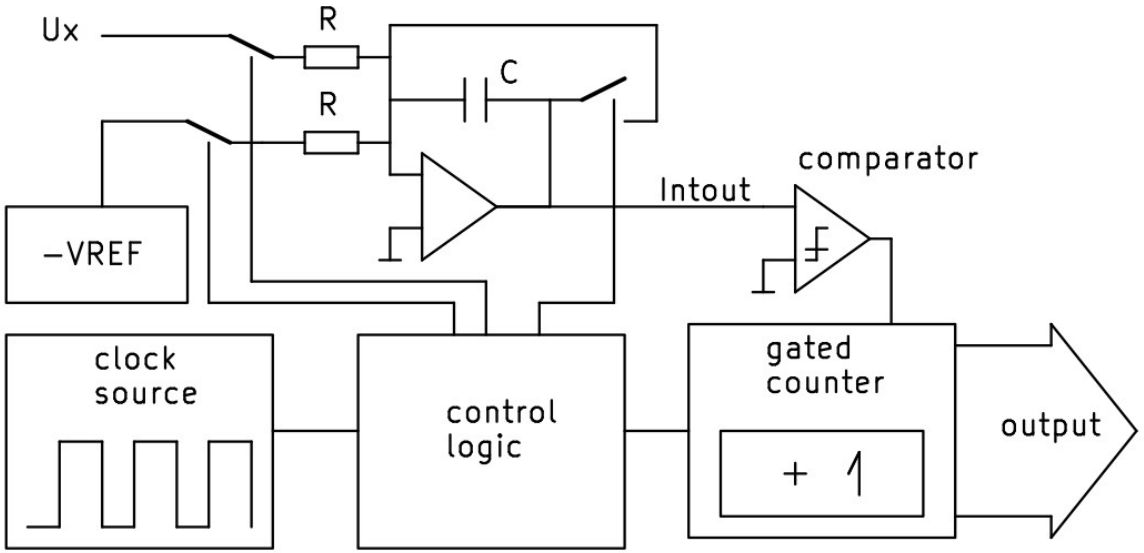
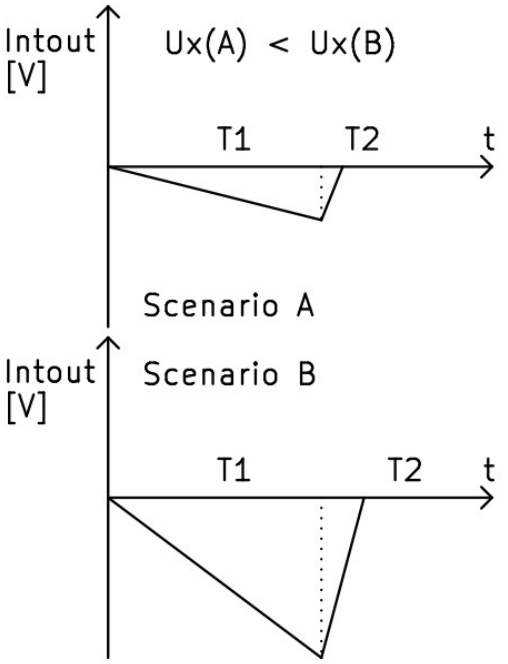
Jaromir Sukuba
jaromir@jaromir.sk





Variant of dual-slope ADC with different runup/rundown resistors for faster conversion. Not much of an improvement on other issues.

From single slope to dual slope, multislope and charge balance ADC, part 5/6.

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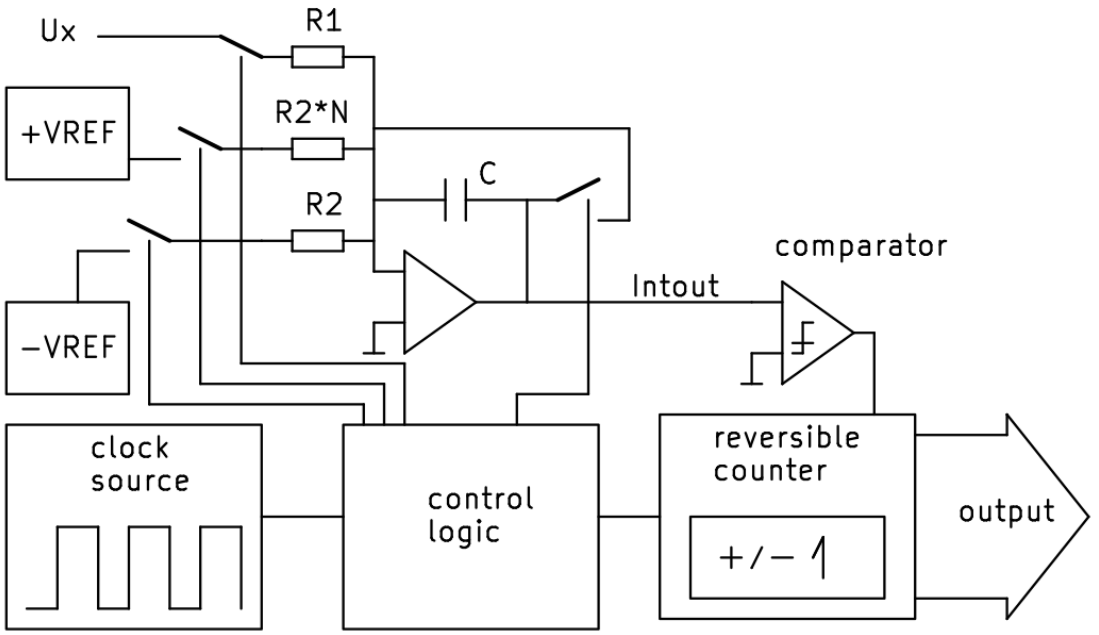
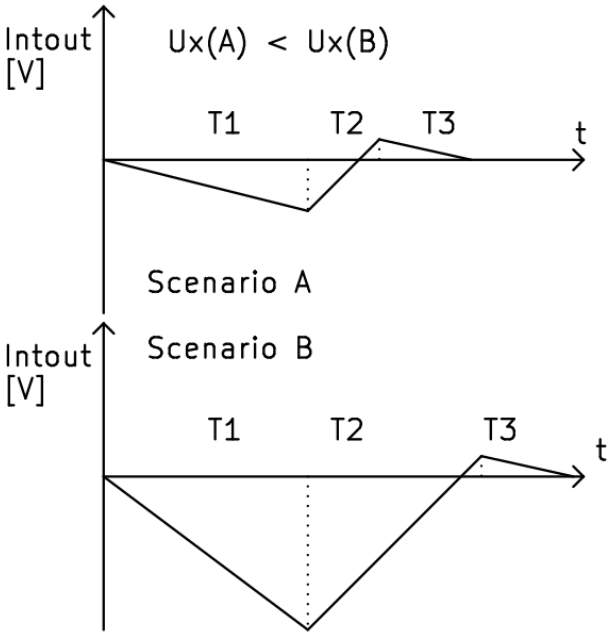
Jaromir Sukuba
jaromir@jaromir.sk

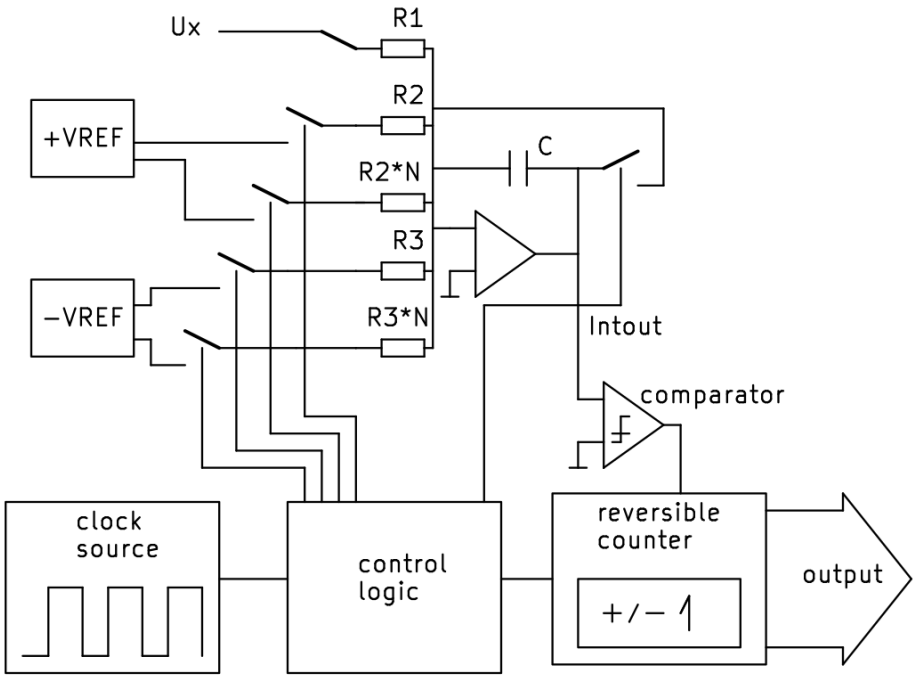


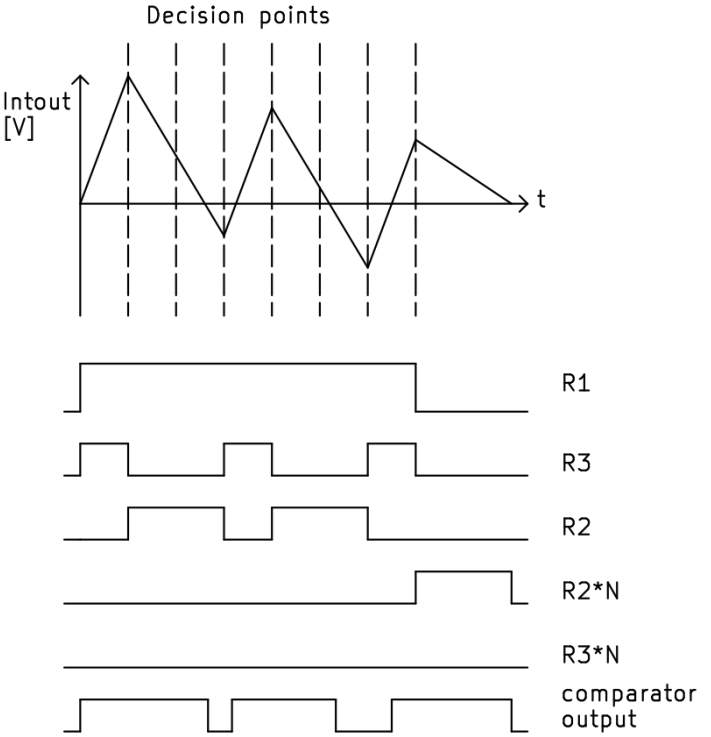


Multislope ADC for faster and more precise rundown, making it somehow easier for the comparator. Still, simple runup.

Jaromir Sukuba
jaromir@jaromir.sk

From single slope to dual slope, multislope and charge balance ADC, part 6/6.

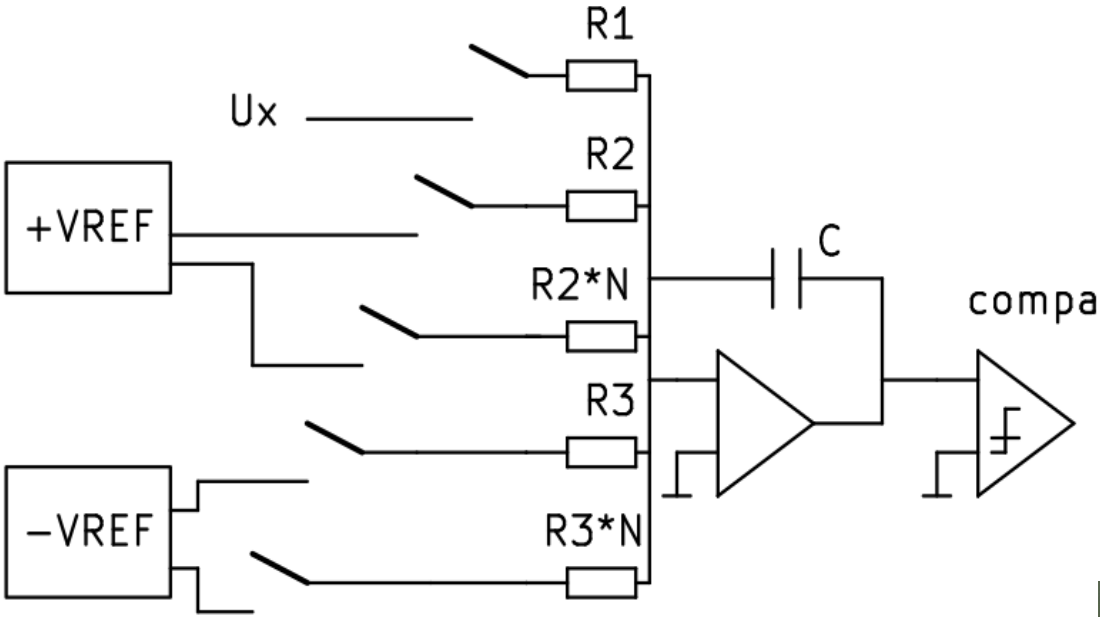




This runup scheme actively “fights” the charge accumulated in the integrator by controlled periodic addition of opposite charge to keep integrator voltage within determined bounds

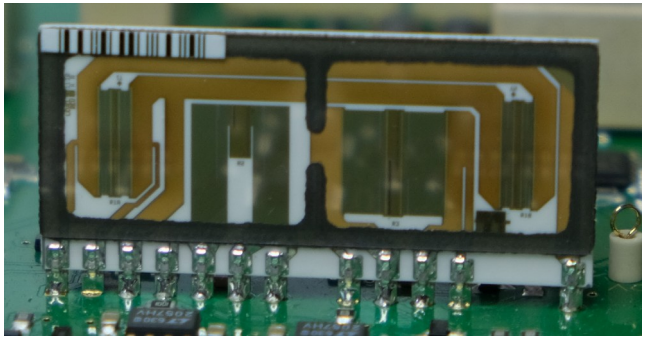
Jaromir Sukuba
jaromir@jaromir.sk

Charge balance ADC, part 1



Critical points:
- reference stability
- resistor ratios
- R1 tempco
- C1 DA
- precise timing

A bit less critical ones:
- switches
- comparator



For variants and more details of this method, see [2] and [3]

Jaromir Sukuba
jaromir@jaromir.sk

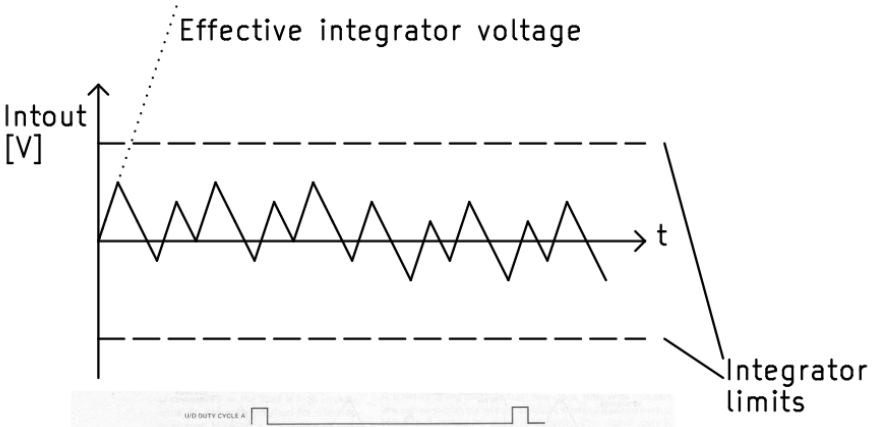
Charge balance ADC, part 2

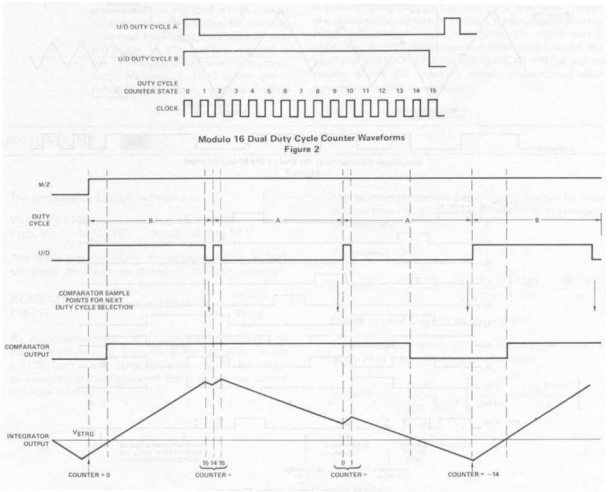
Increased effective integrator voltage (several kV or more)

Lower value integrator capacitor and average charge

Partial result obtained during runup, less weight on the rundown.

Runup can be scaled as needed to find a compromise between noise and acquisition speed

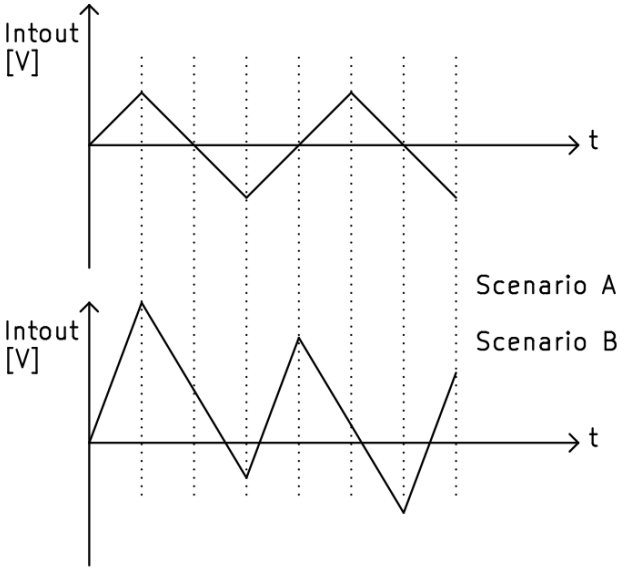


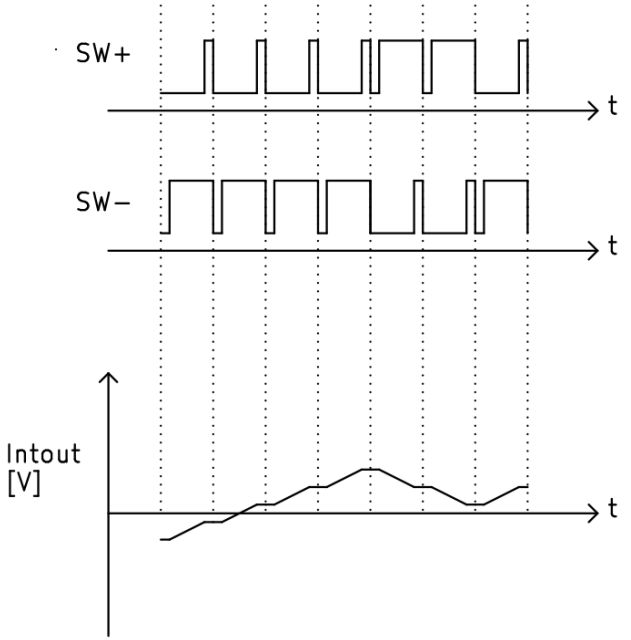


A snippet from Siliconix LD120 DS In 1970s

Jaromir Sukuba
jaromir@jaromir.sk

Charge balance ADC, part 3





Simple runup algorithm would produce different number of switching actions for various runup patterns (input voltages) causing linearity errors

Multiple methods of keeping this number constant [2]

Jaromir Sukuba
jaromir@jaromir.sk

Charge balance ADC, part 4

Charge balance ADC fixed some of the dual-slope issues:

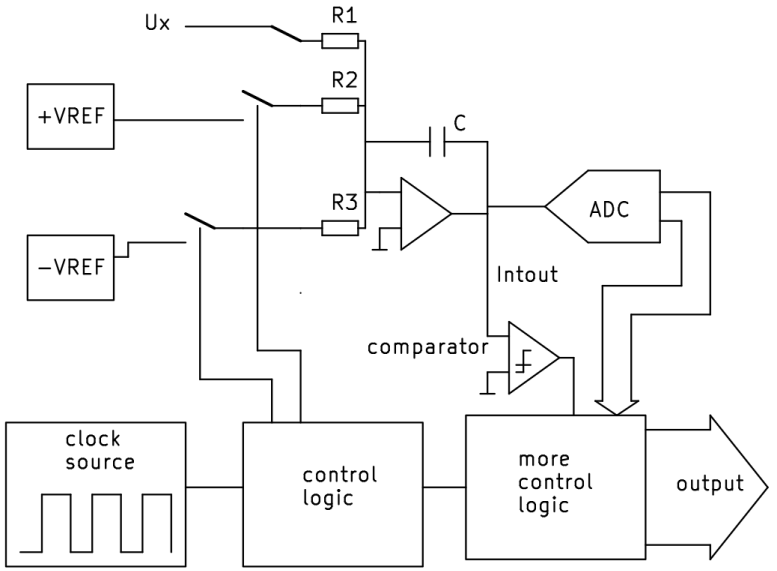
- sensitivity to integrator capacitor DA

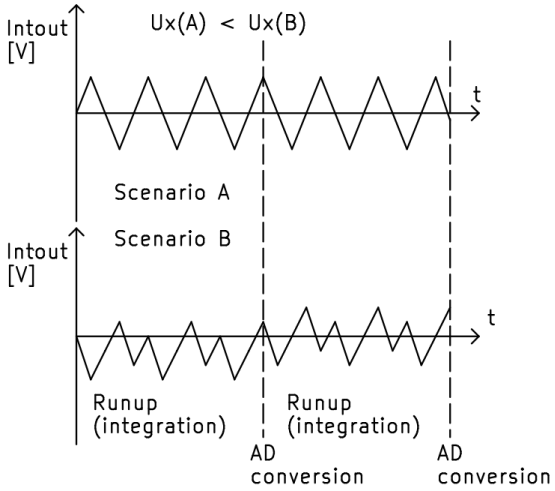
- slow acquisition rate for given resolution

- sensitivity to comparator parameters

- runup is easy to scale now

From multislope to less multislope and sigma-delta, part 1/3





Charge balance (not much of multiple slopes here) ADC with integrator readout ADC, called Multislope III in patent [5]

Jaromir Sukuba
jaromir@jaromir.sk

From multislope to not that multislope and sigma-delta, part 2/3

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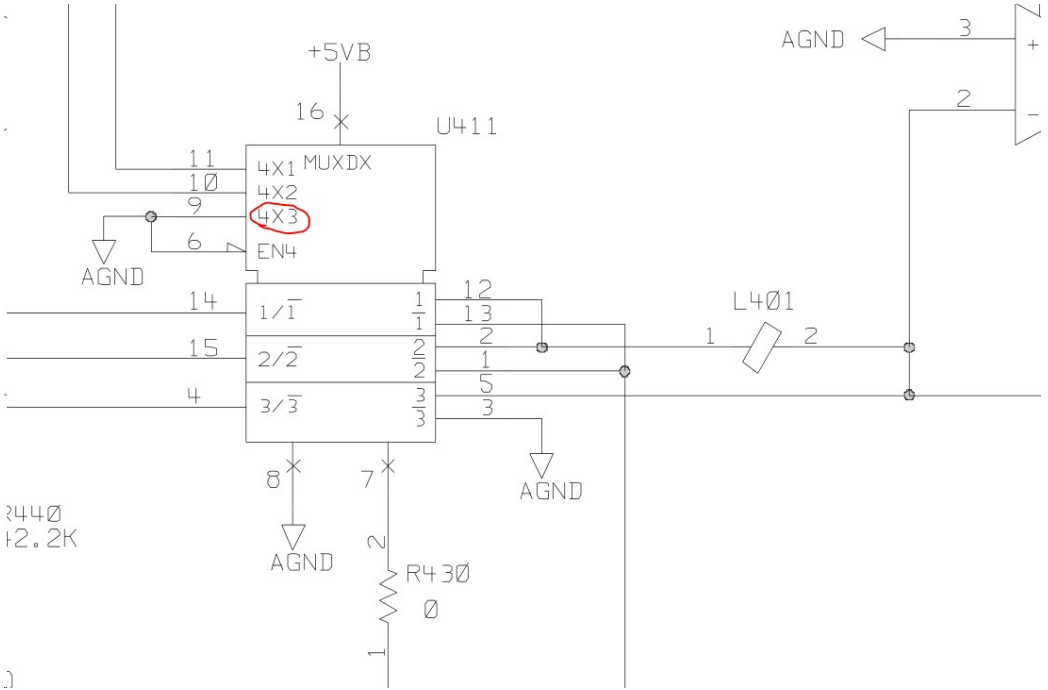
jaromir@jaromir.sk

Input is on all the time

No run-down phase

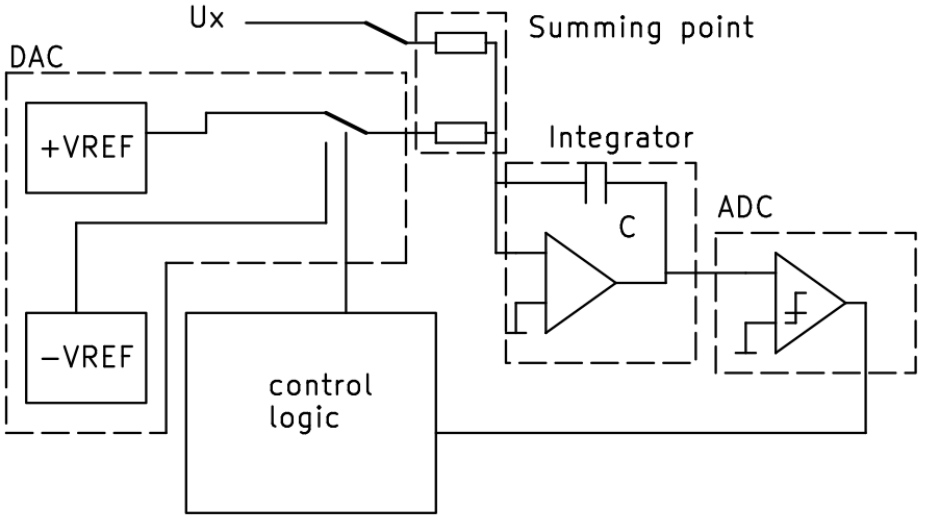
Higher modulation Frequency (100s of kHz for MS III and single MHz for MS V)

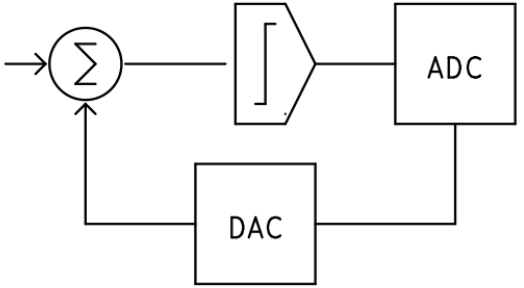


A snippet from 34401A schematics

Jaromir Sukuba
jaromir@jaromir.sk

From multislope to well… uhm… multislope and sigma-delta, part 3/3



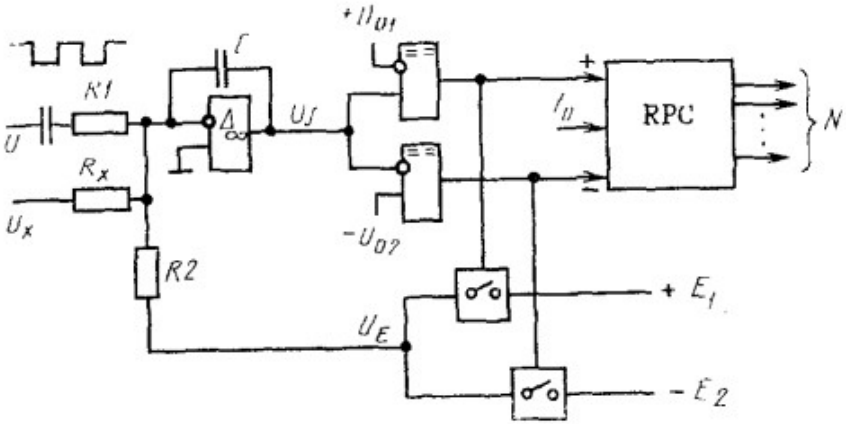


Multislope III and Multislope IV by HP (see patent [6] and [7]) being similar to delta sigma ADCs, filling the spectrum of integrating ADC architectures

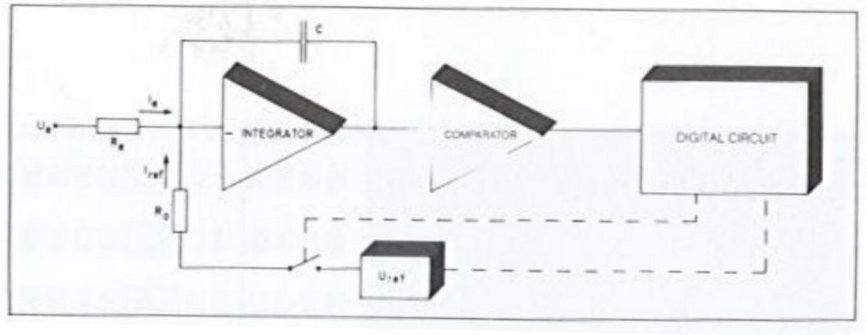
Jaromir Sukuba
jaromir@jaromir.sk

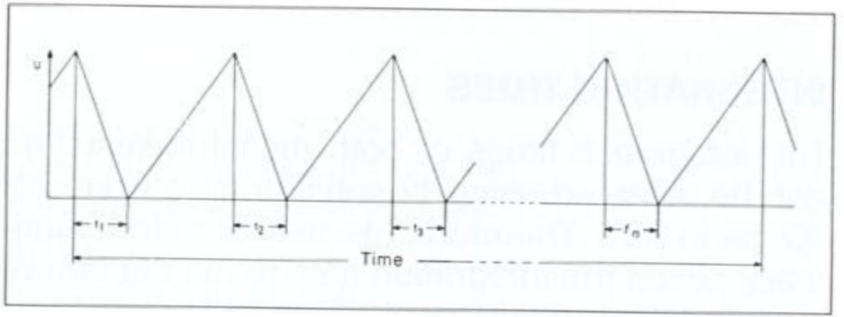
Other long scale integrating ADC principles

Mark-scale (PWM) ADC (patent [8] from 1971 and [9] from 1974), often used in long scale Solartron voltmeters



Multiple ramp ADC (patent [10] from 1972) by Prema





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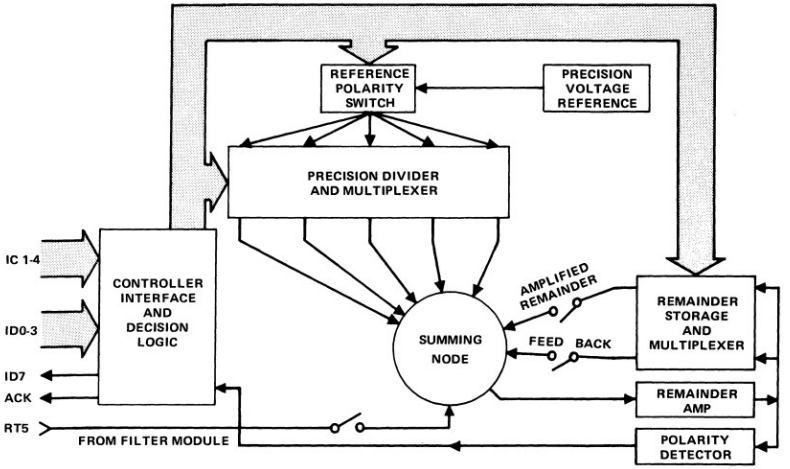
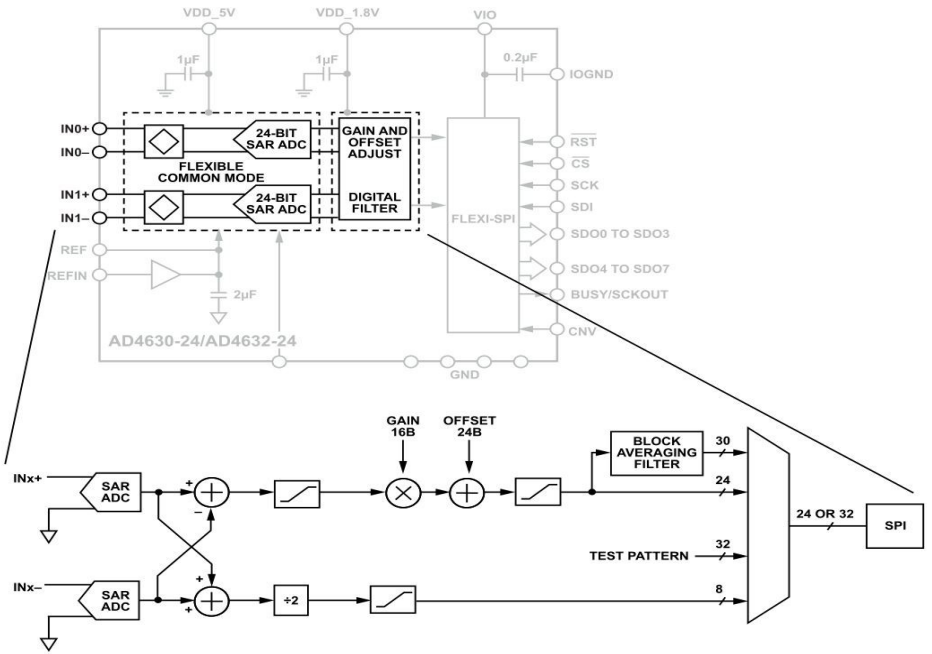
Jaromir Sukuba
jaromir@jaromir.sk

Long scale non-integrating ADC principles

Recirculating remainder ADC (see patent [11] from 1971) by Fluke





Successive approximation register ADC, like AD4630 and derived models
INL: ±0.9 ppm maximum

Jaromir Sukuba
jaromir@jaromir.sk

Summary

Integrating ADCs, especially varaints of charge-balance flavour still dominate the precision ADC sector.

In recent years, new integrated ADCs, like AD4630 and derived models entered the market and offer viable alternative for some high precision applications, while shortening development time and decreasing PCB footprint.

Still, integrating ADCs do offer better linearity, may be easier to integrate into an instrument.

Jaromir Sukuba
jaromir@jaromir.sk

Resources

[1] AN-260 A 20-Bit (1 ppm) Linear Slope-Integrating A/D Converter by Jim Williams
[2] HP journal 4/1989
[3] HP3456A service manual
[4] N.Beev, Measurement of Excess Noise in Thin Film and Metal Foil Resistor Networks 10.1109/I2MTC48687.2022.9806690
[5] Patent US5117227 - Continuously integrating high-resolution analog-to-digital converter
[6] Patent US6876241 - Circuit for generating from low voltage edges higher voltage pulses having precise amplitudes and durations
[7] Patent US6876241 Precision low noise-delta-sigma ADC with AC feed forward and merged coarse and fine results
[8] Patent US3475556 Analogue to digital converter
[9] Patent US3942172A Bipolar mark-space analogue-to-digital converter
[10] Patent US3765012 Analog-digital converter utilizing multiple ramp ingegrating techniques
[11] Patent US3703002 Analog to digital converter and indicator using recirculation of remainder