A Handheld Pulser

with Realistic Detector Pulse Shape

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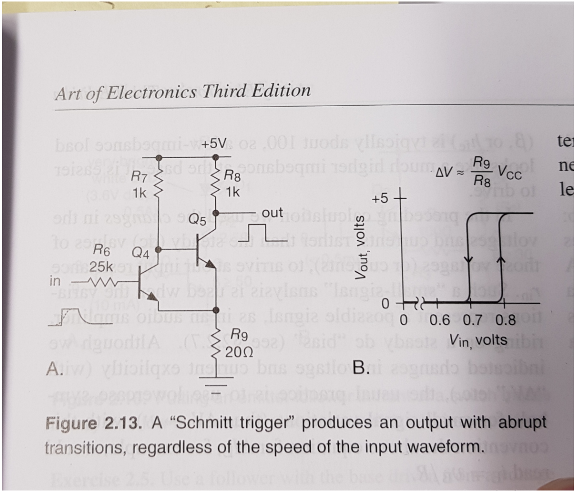
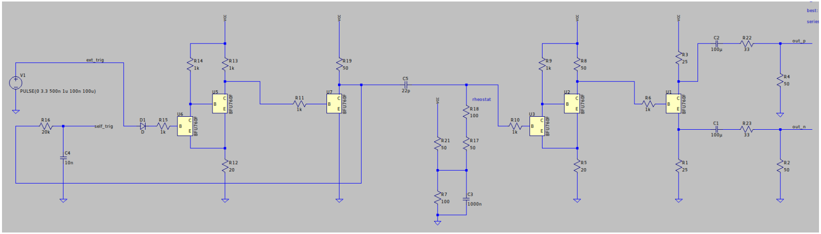
GSI EEL - AESD

21.03.2022

- "Prelude" - The Battery Pulser

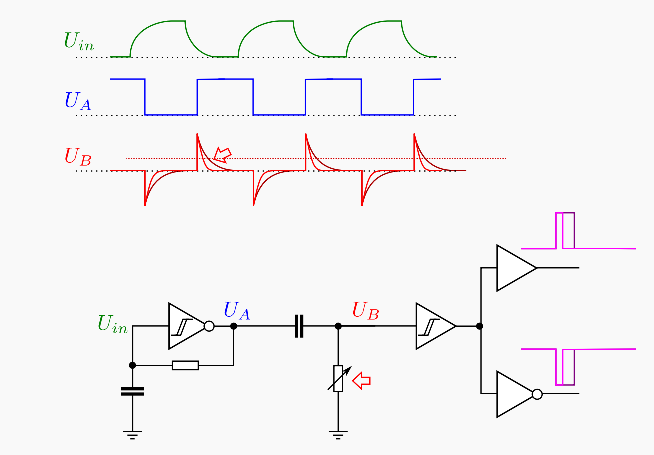


- From Paul Horowitz - The Art of Electronics
- Only two transistors to build a Schmitt trigger?
  → I did not know that!



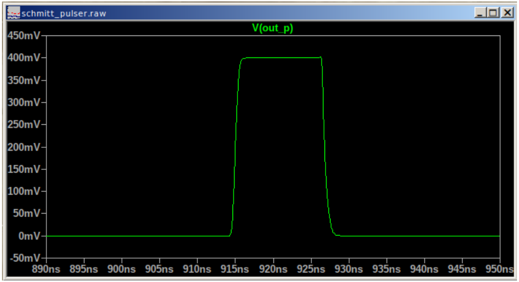
- … It all started with fast transistors (BFU760, $f_T = 45GHz$) and SPICE
- We had a lot of these transistors in stock for building discrete preamplifiers.

Working principle



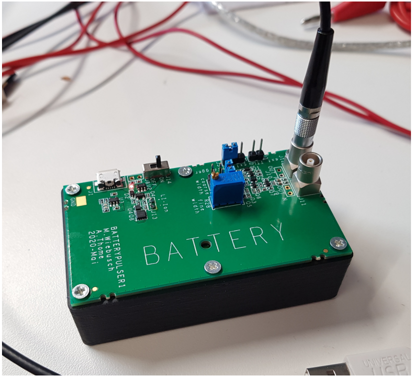
- (all with discrete transistors)

SPICE output



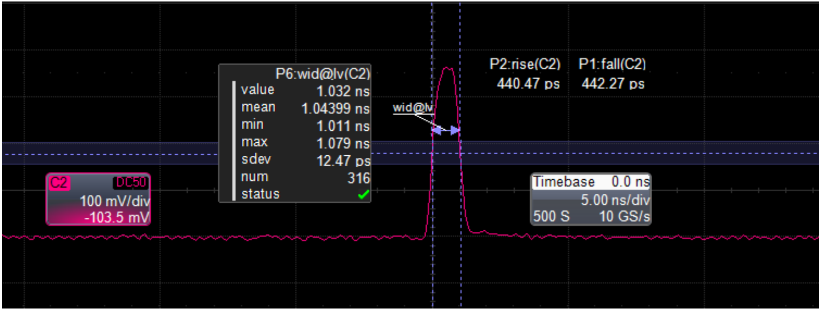
- It is short! (Pulse width down to several ns)
- It is fast! (sub-nanosecond edges!)
- It is clean! (no tails)
- Let's build this!

BatteryPulser1 PCB



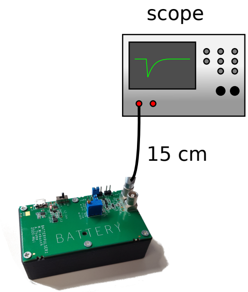
- Positive and negative polarity 50 Ω LEMO outputs, one can always be used as trigger out.
- Adjustable width (multiturn pot)
- On-board Li-Ion charger circuit
- 3d-printed case has space for recycled 18650 Li-Ion cell (from notebook battery)

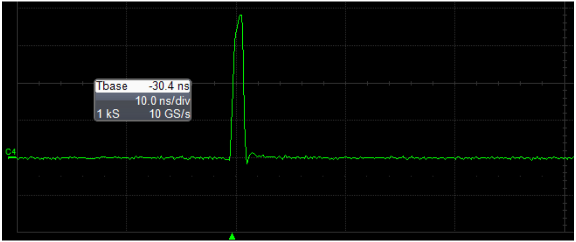
BatteryPulser1 PCB performance

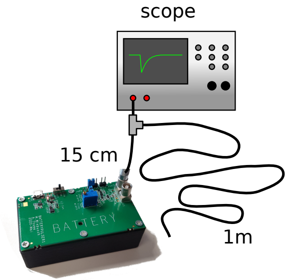


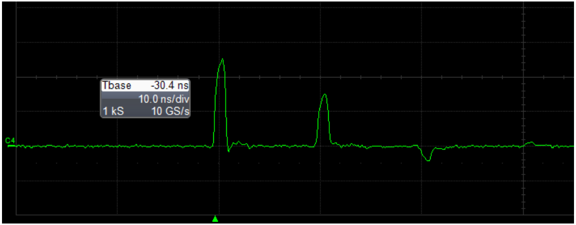
- pulse height = ±400 mV
- FWHM = 1 us down to 1 ns
- edges ≈ 440 ps
- pulse width and timing is extremely stable

Games to play with BatteryPulser1






scope
15 cm
1m


Tbase -30.4 ns
10.0 ns/div
1 kS 10 GS/s
C4

- "Main Course" - The Spectral Pulser

Motivation

Question

- What else can we do with this technology?

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- Can we make pulses that look like detector signals?

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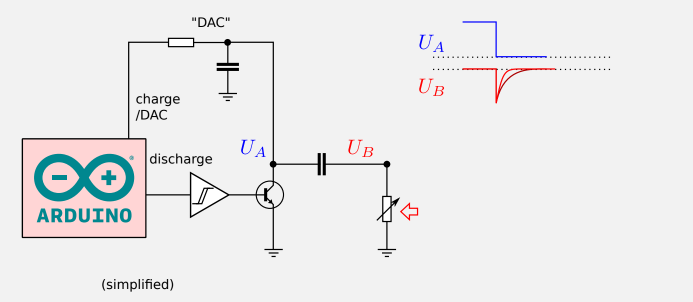
- What else can we do with this technology?
- Can we make pulses that look like detector signals?
- Can we have a charge/amplitude spectrum?

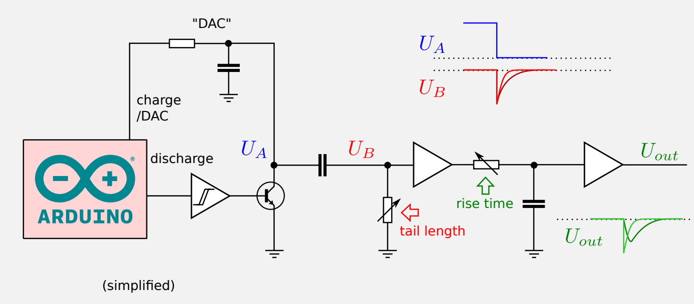
Working principle



general principle

- Use GPIO pin to charge a capacitor to desired amplitude
- Trigger a fast transistor to discharge capacitor → create heaviside edge
- Feed edge into a CR filter to create an exponential pulse. Changing the "R" changes the tail.
- A subsequent RC filter can reduce the steepness of the leading edge

Working principle



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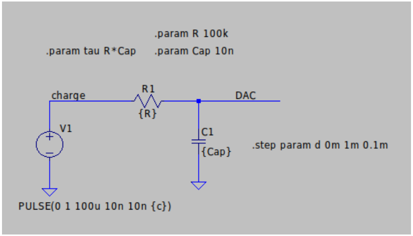
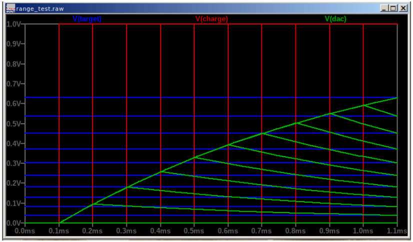
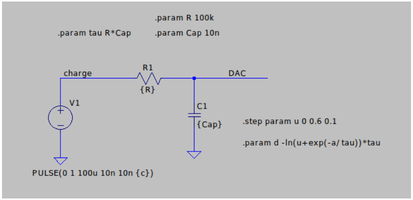
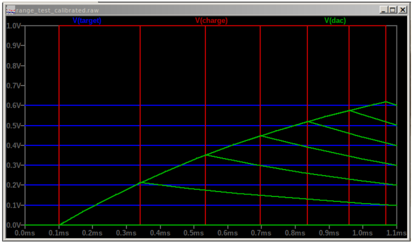
One shot PWM DAC



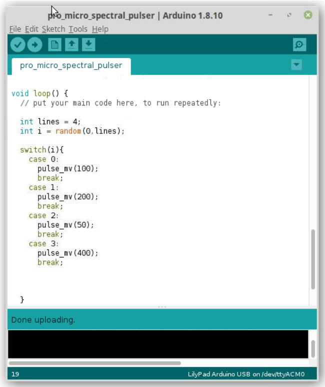


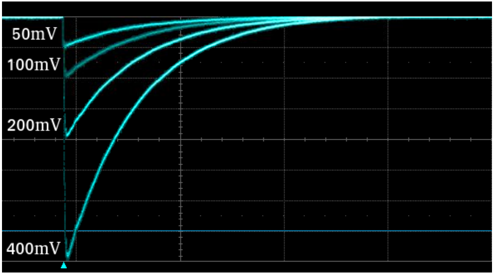
- Combination of RC charge and discharge
- Advantage over "charge-only" DAC:
  - Better precision for small amplitudes
  - No need for Tri-State or sample-and-hold
  - constant sampling time: $T_{charge} + T_{discharge} = T_{sample} = const$
- Above example: $\tau = RC = T_{sample} = 1\,\text{ms}$
- The discharge helps improving the amplitude precision!





- There exists an analytic function to calculate charge/discharge time from desired target amplitude
- $\frac{d}{\tau} = -\ln\left(\frac{U_{DAC}}{3.3\,\mathrm{V}} + e^{-(c+d)/\tau}\right)$
- $d = T_{discharge}, c = T_{charge}, \tau = RC$



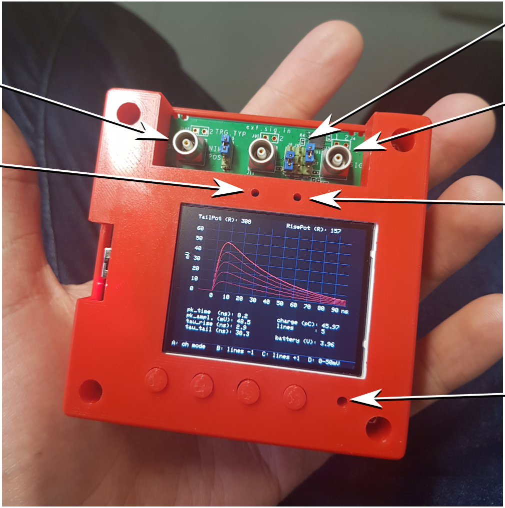


- The math can be done on a microcontroller and hidden behind high level functions

The Device - SpectralPulser1

trigger out

trim tail time



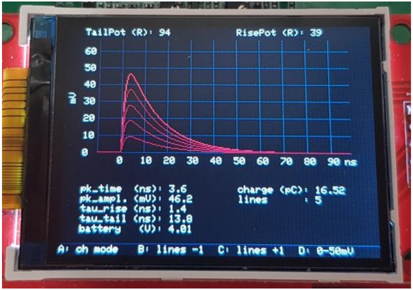
jumpers to select polarity

signal out

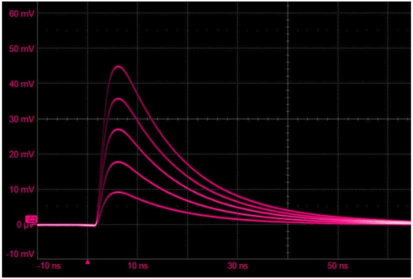
trim rise time

trim amplitude

Preview vs scope



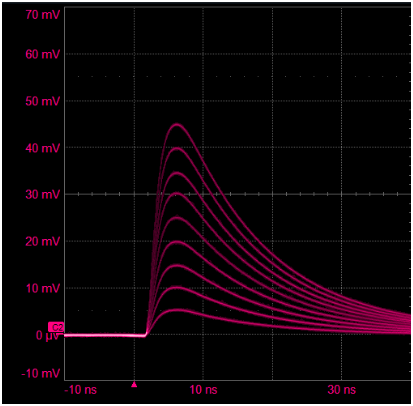
preview

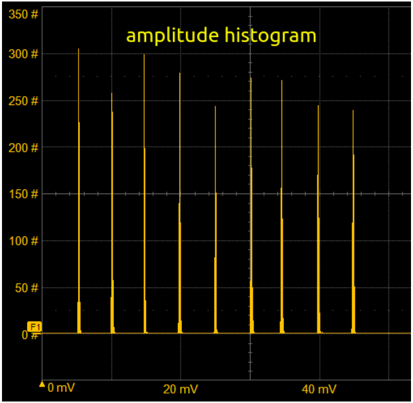


scope (into 50Ω)

- Model circuit behaviour with analytical function
- Plot function and print pulse characteristics on display i.e. peaking time, peak amplitude, τ_{rise}, τ_{tail}, charge
- peaking time: 2 ns to 30 ns
- decay constant τ_{tail}: 3 ns to 110 ns
- Preview is not perfect, but within ≈5% error margin
- 2.2" TFT with ILI9341 controller

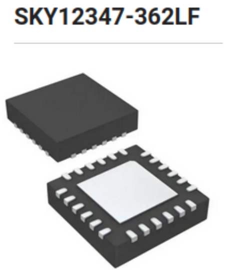
Amplitude histogram





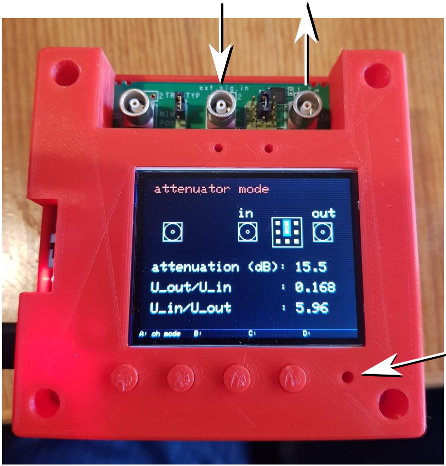
- Amlitude spectrum recorded on oscilloscope
- due to self-similarity of pulse → amplitude spectrum $\propto$ charge spectrum

Dynamic range - Attenuator



- The RC-DAC is only "half the truth"
- To extend the dynamic range a programmable RF attenuator IC is used:
  SKY12347
- 0 dB to 31 dB in 0.5 dB steps
- DC-3 GHz (according to datasheet)
- 1 dB insertion loss
- 50 Ω in, 50 Ω out
- Attenuator sets "coarse" amplitude, RC-DAC sets remaining "fine" amplitude
- SpectralPulser1 has three amplitude ranges:
  0 mV to 500 mV,
  0 mV to 50 mV,
  0 mV to 5 mV
- 0.1 pC to 1300 pC (also depends on τ_{tail})

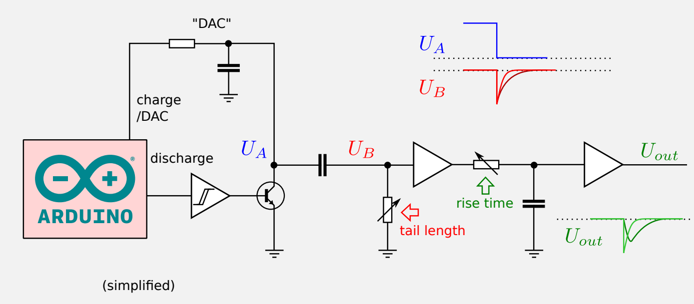
Bonus Feature - Attenuator mode



set attenuation

- What you see is what you get

What about the potentiometers?

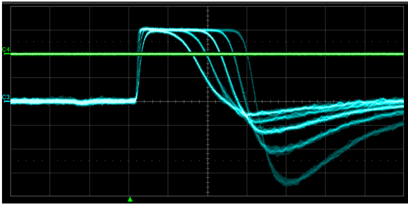


How do we read out the multiturn potentiometers?

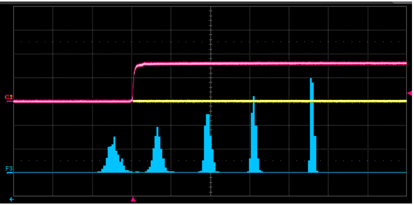
- The trimmers determine the shape of the pulses.
- Cannot use digital potentiometers, not HF compatible.
- The pulses are very fast, only AC properties matter → AC coupling.
- With GPIOs and additional transistors trimmers can be made part of DC voltage dividers, measure voltage drop on trimmer with Arduino ADC pin.
- After each few hundred pulses, read out potentiometers and update plot.

Example - Testing a Preamp

preamp output

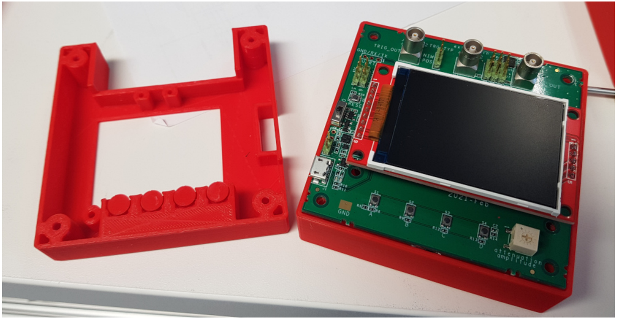


preamp output ToT spectrum



- With scope persistence you can directly see how the amplifier responds to different charges/amplitudes
- Directly see walk!

Case



- 3d printed - designed (coded) in OpenSCAD
- there is room in "the basement" for 1-2 Li-Ion cells

Thank you for you atten(ua)tion