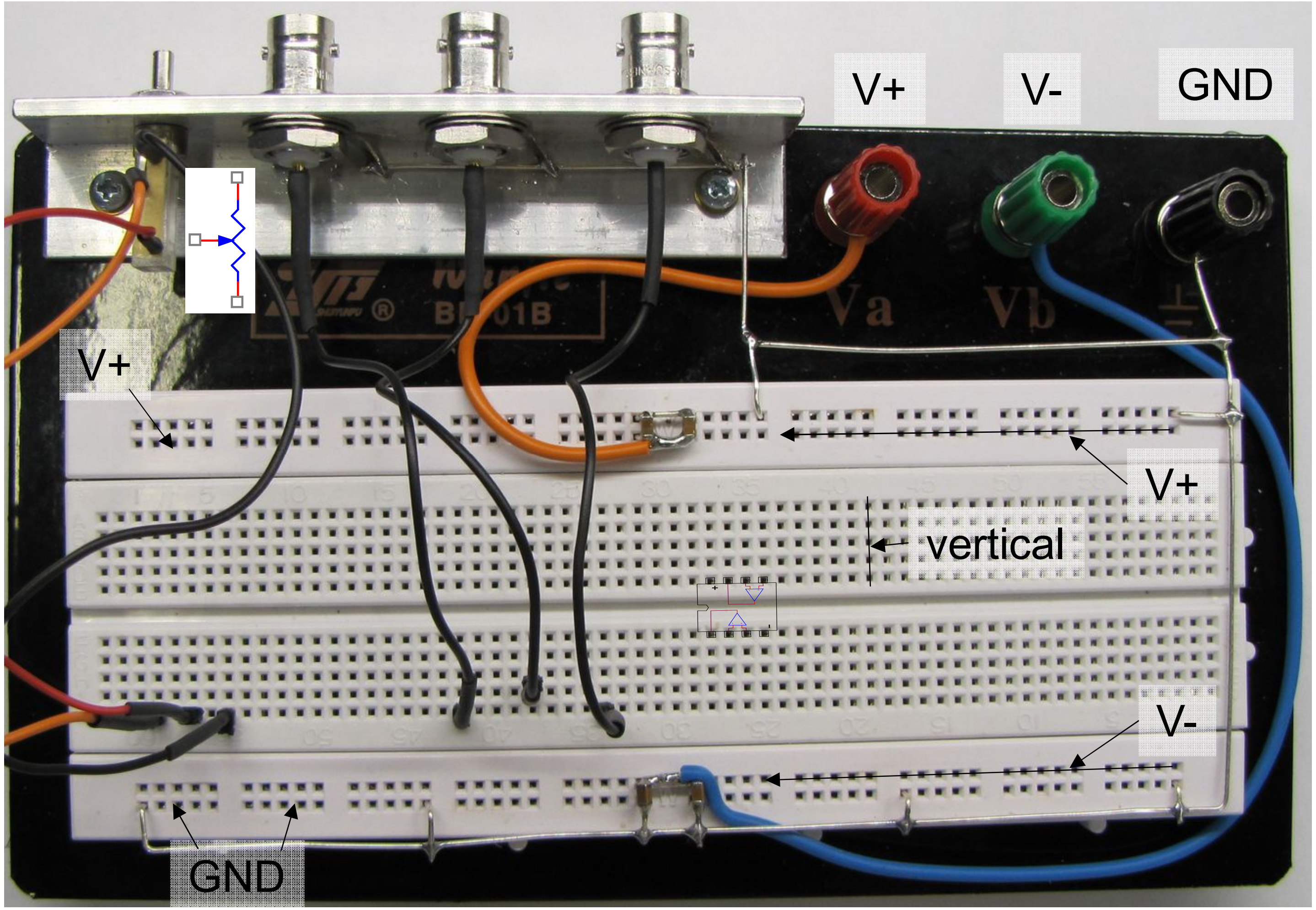
Common part

- Simple RC and CR networks
- Signal propagation
- Operational Amplifiers
  - Non-inverting
  - Inverting
- Triangle generator with Schmitt trigger and Integrator
- Discriminator with comparator

The breadboard

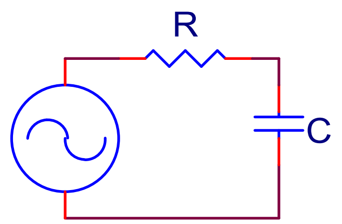


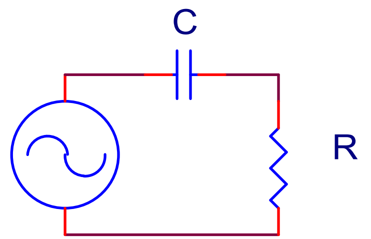
Simple RC and CR circuits

Investigate simple RC and CR networks

measure the

- Attenuation and phase shift at 1Hz, 10Hz, …100kHz, 1MHz with sinus input signal
- Rise/fall time using 1Hz rectangular input signal
- Identify low pass and high pass filter
- Construct a bandpass filter from both



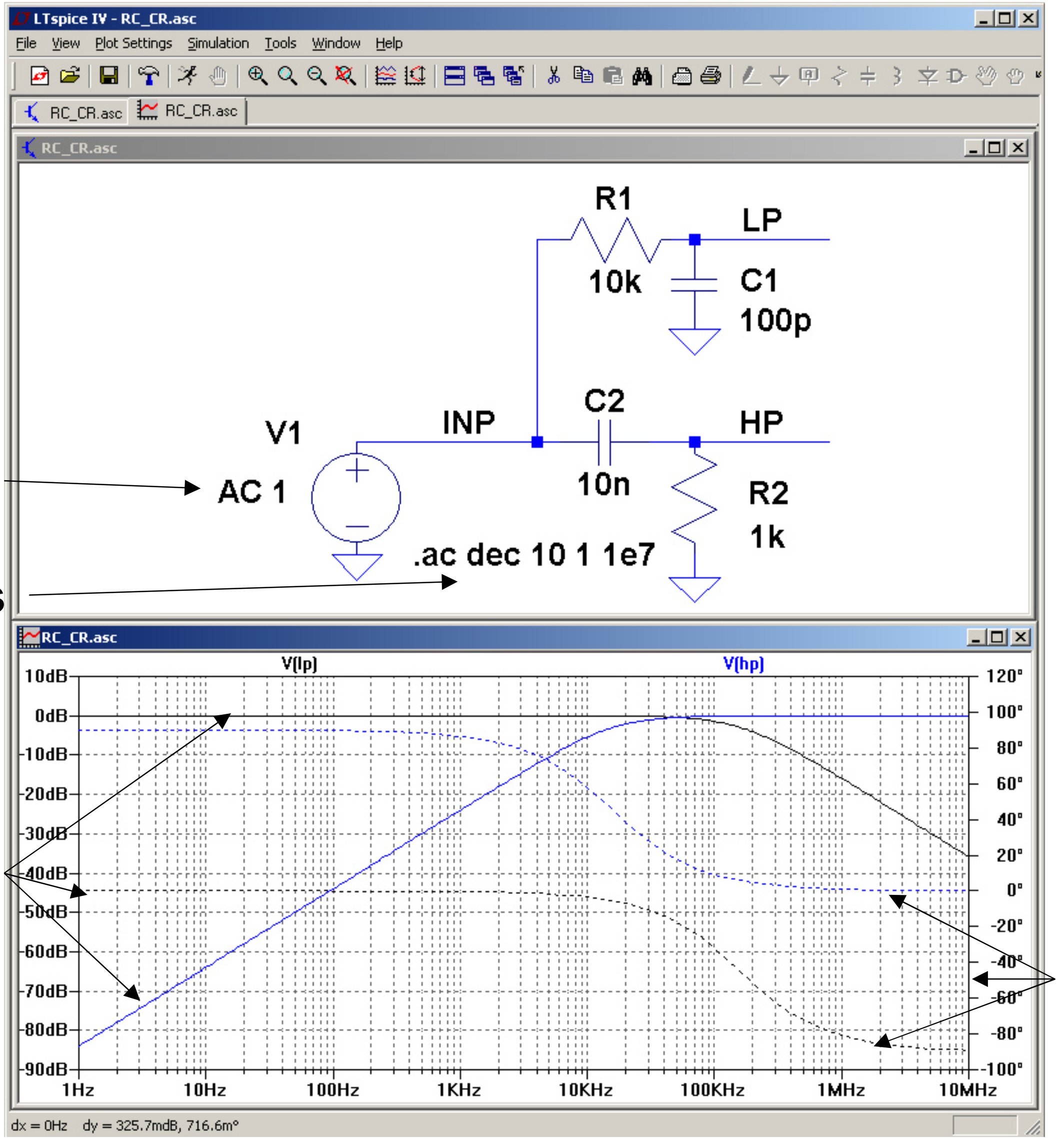


Simple RC and CR circuits

Input AC signal 1V

AC analysis

amplitude



phase

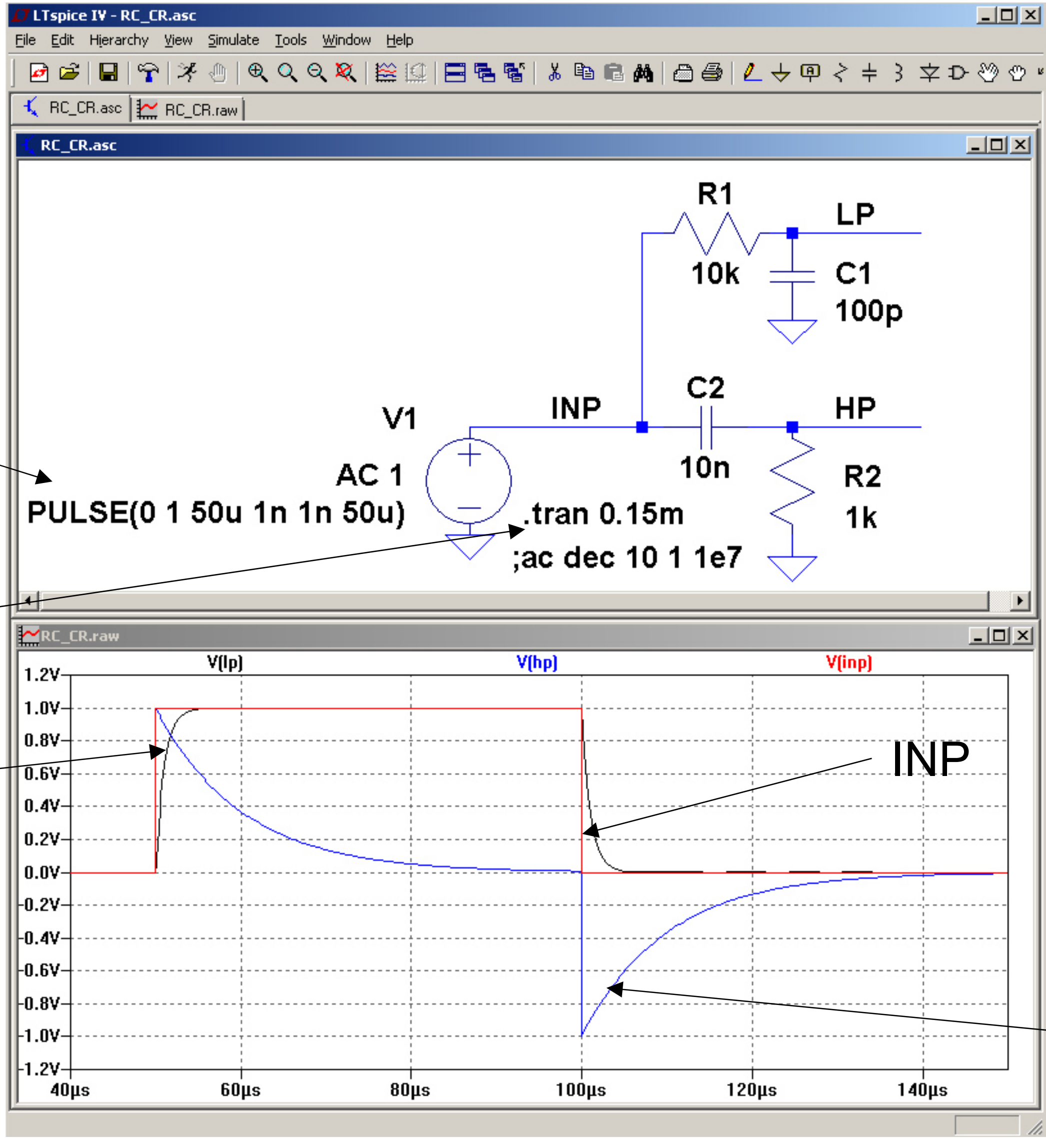
F3 – draw wire
F6 – duplicate
F7 – move
F8 – drag
F9 – undo
Space – zoom fit
Place:
R – resistor
C – capacitor
L – inductor
G – gnd
F2 – component
F4 – label net
Ctrl-E – mirror
Ctrl-R – rotate

Simple RC and CR circuits

Input step signal 1V

Transient analysis

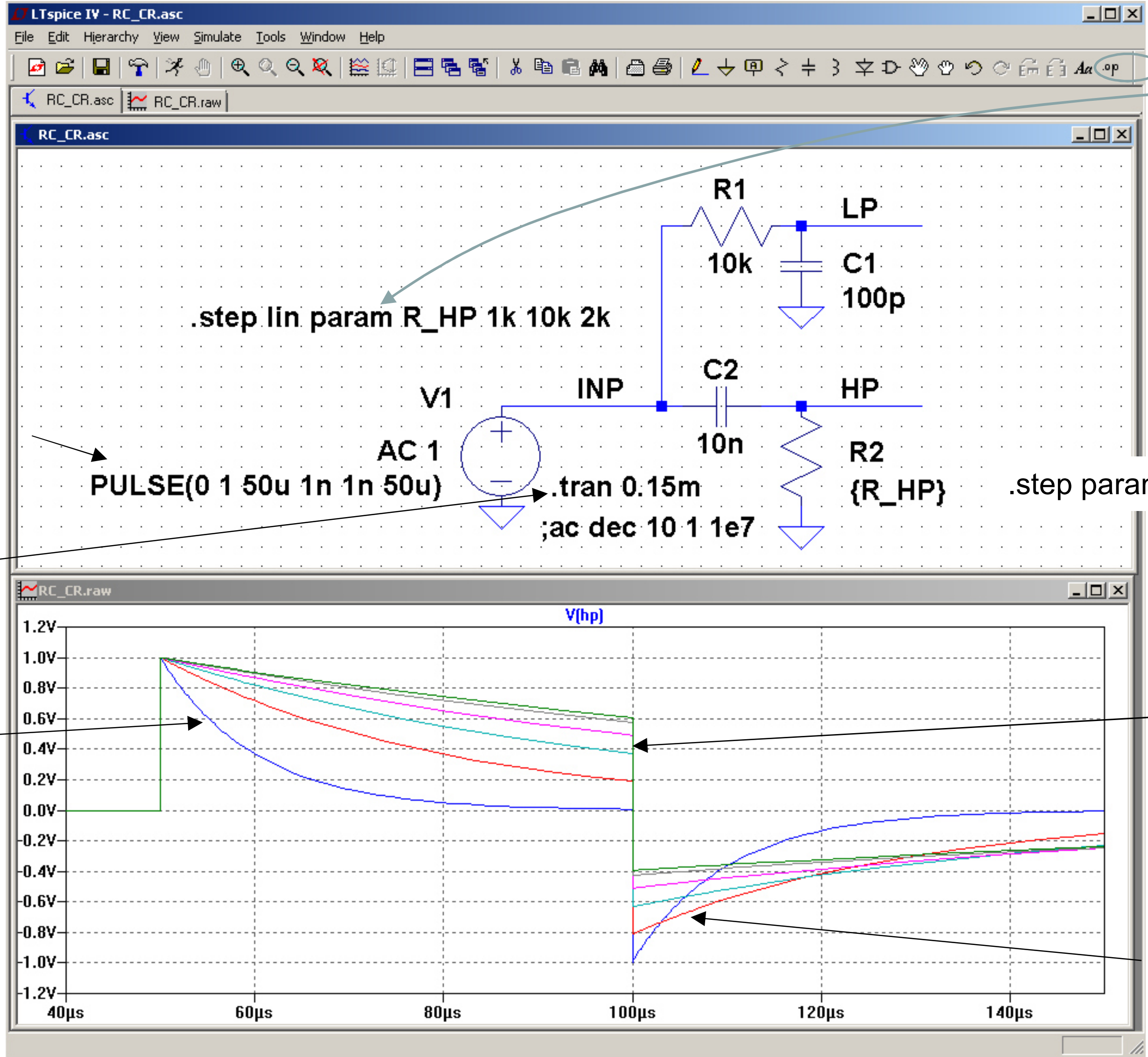
LP



HP

F3 – draw wire
F6 – duplicate
F7 – move
F8 – drag
F9 – undo
Space – zoom fit
Place:
R – resistor
C – capacitor
L – inductor
G – gnd
F2 – component
F4 – label net
Ctrl-E – mirror
Ctrl-R – rotate

Simple RC and CR circuits



Click here to enter the step parameter command

Other possibility:

.step param R_HP list 1k 5k 10k

Input step signal 1V

Transient analysis

1k

5k, 7k, 9k, 10k

3k

Signal propagation

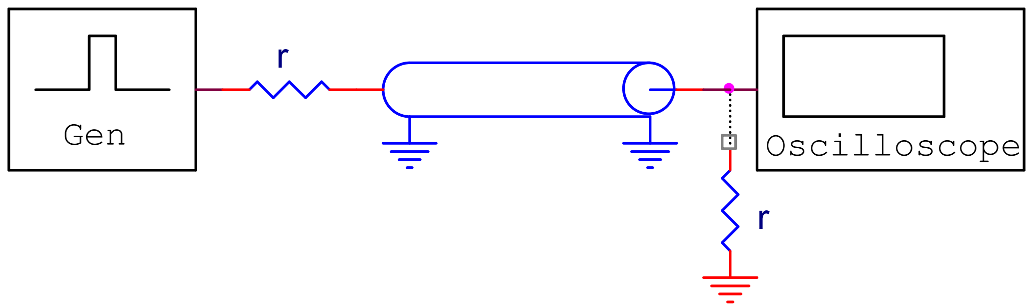
Investigate a piece of coaxial cable (50Ω)

- With the cable from the generator to the oscilloscope and
  - with 50Ω termination
  - with other termination
  - without termination

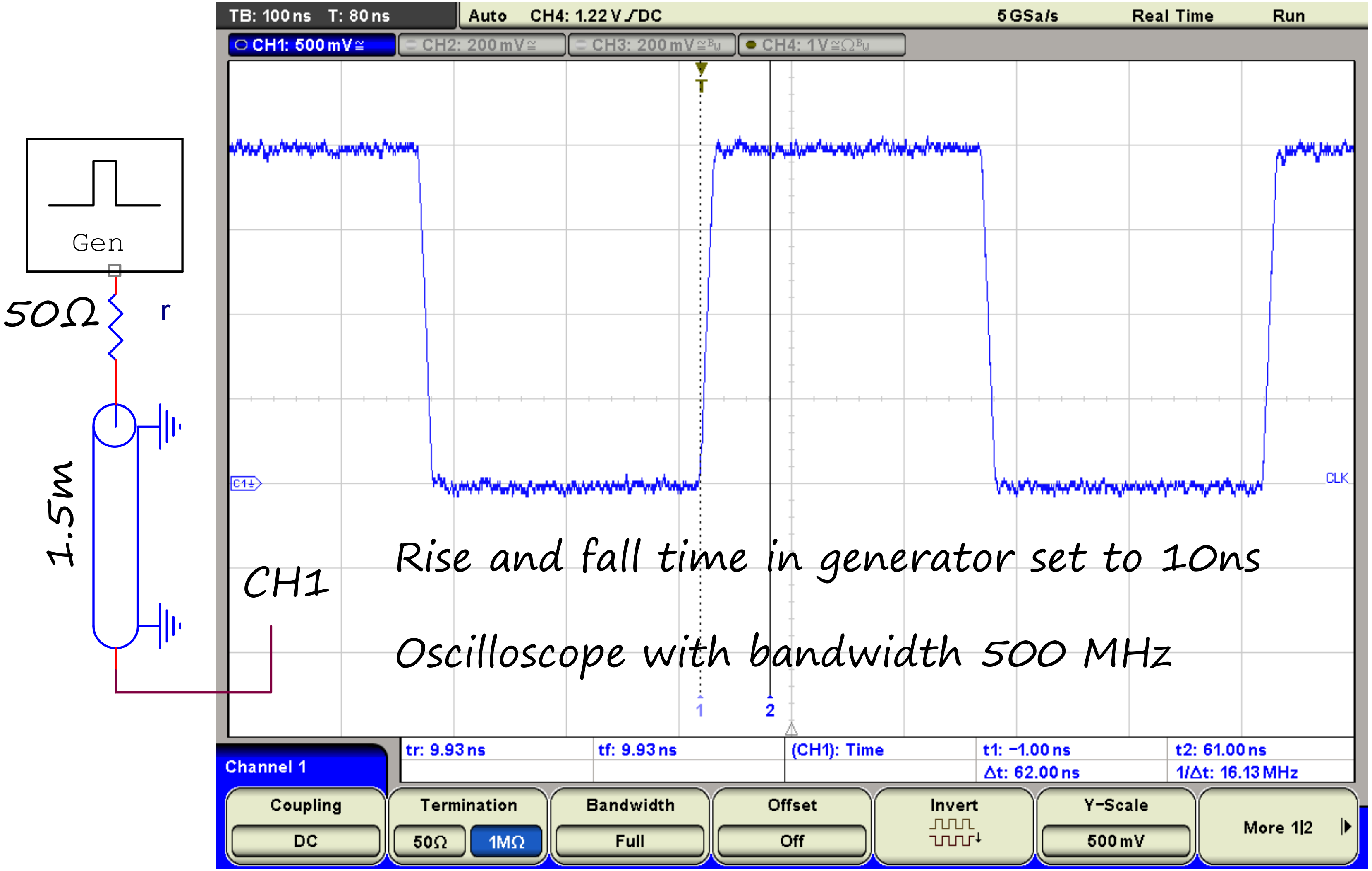
measure the waveform

- with the shortest rise/fall time
- with longer rise/fall time

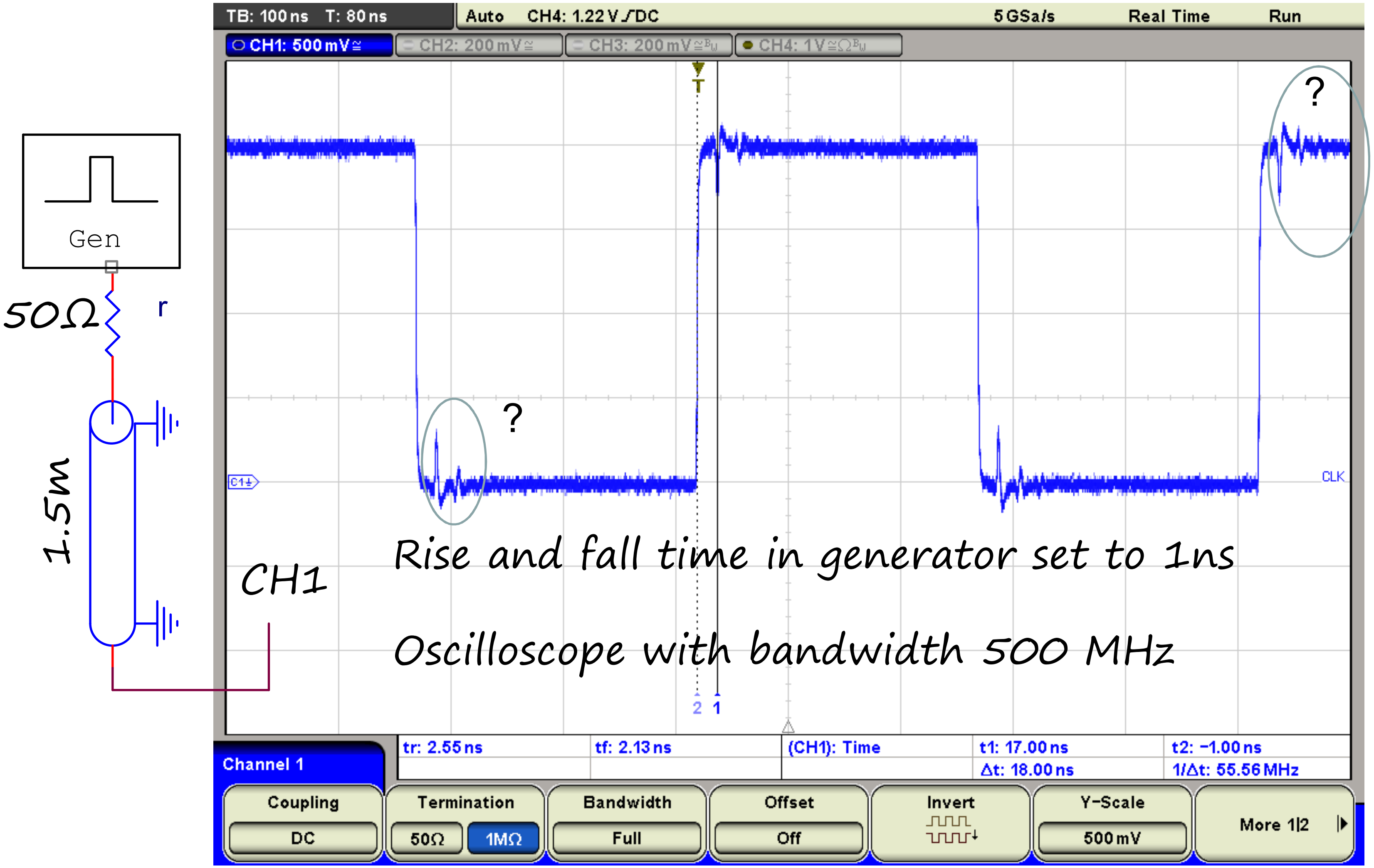
and try to explain the results



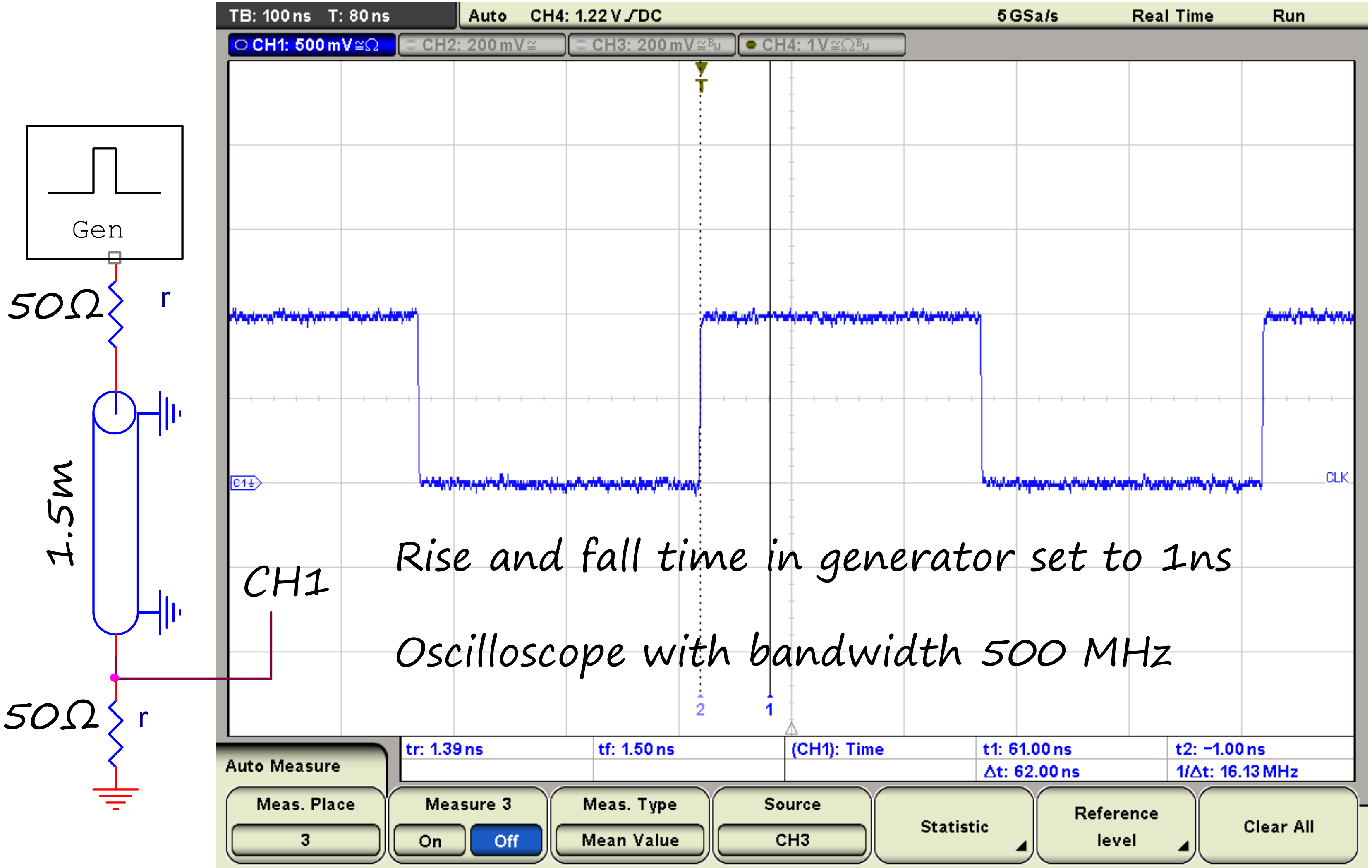
Signal propagation (2)



Signal propagation (3)



Signal propagation (4)

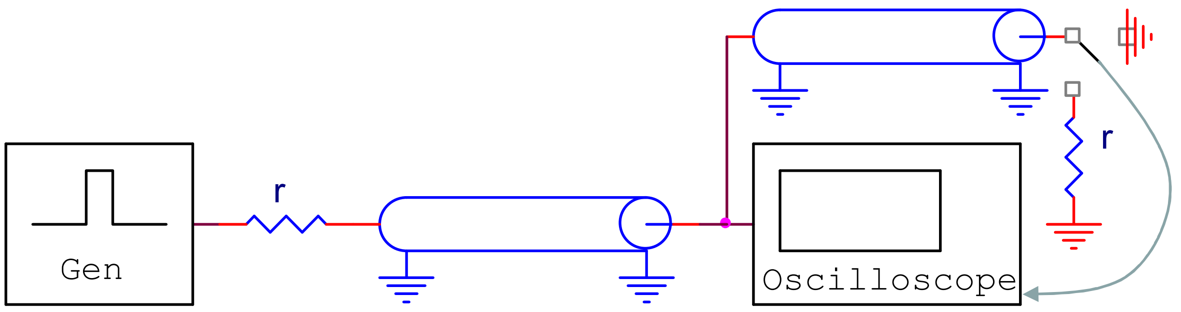


Signal propagation (5)

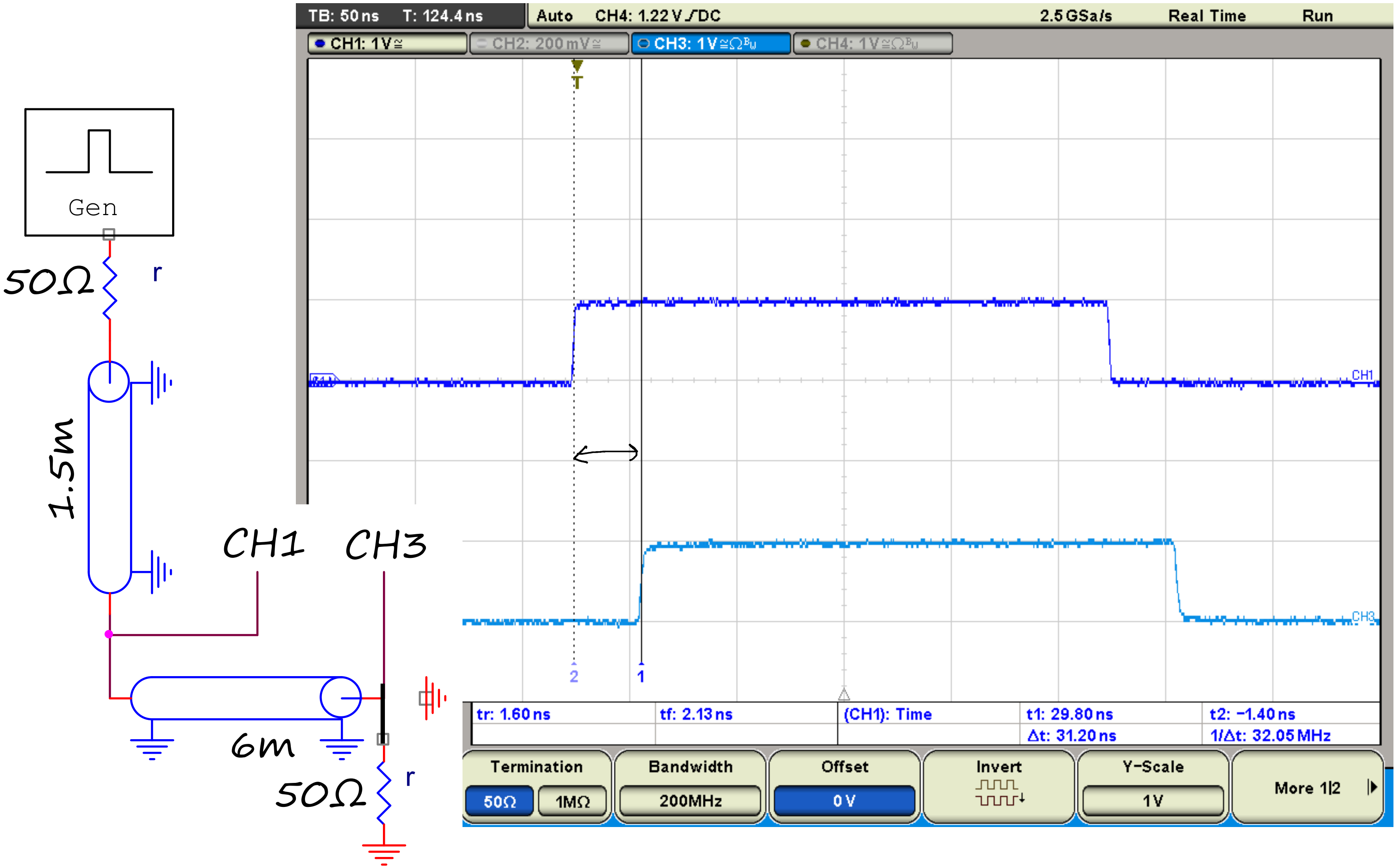
Investigate two pieces of coaxial cable (50Ω)

- With two cables as shown below and
  - with 50Ω termination
  - with other termination
  - without termination
  - with short

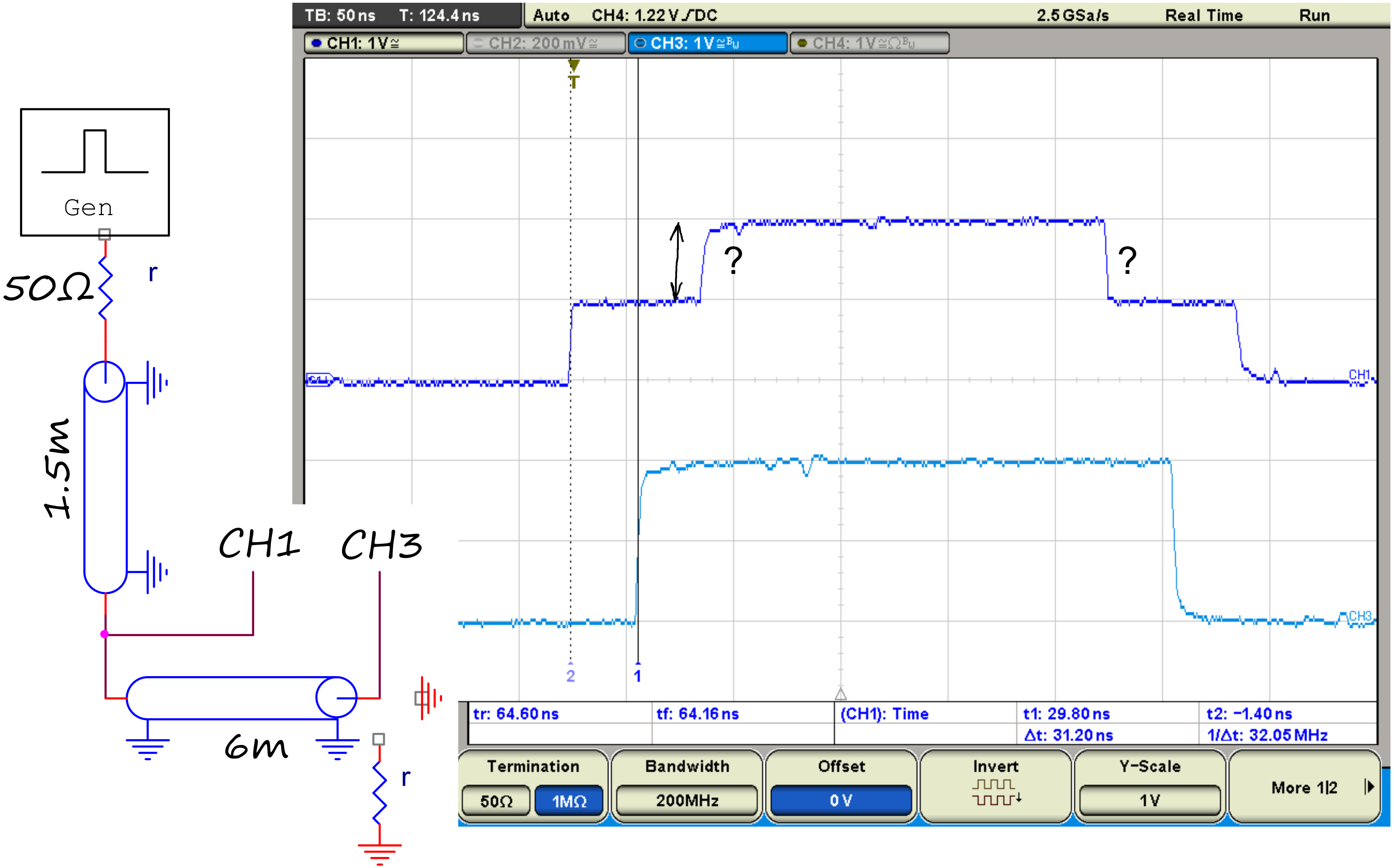
  at the far end of the second cable measure the waveforms and try to explain the results



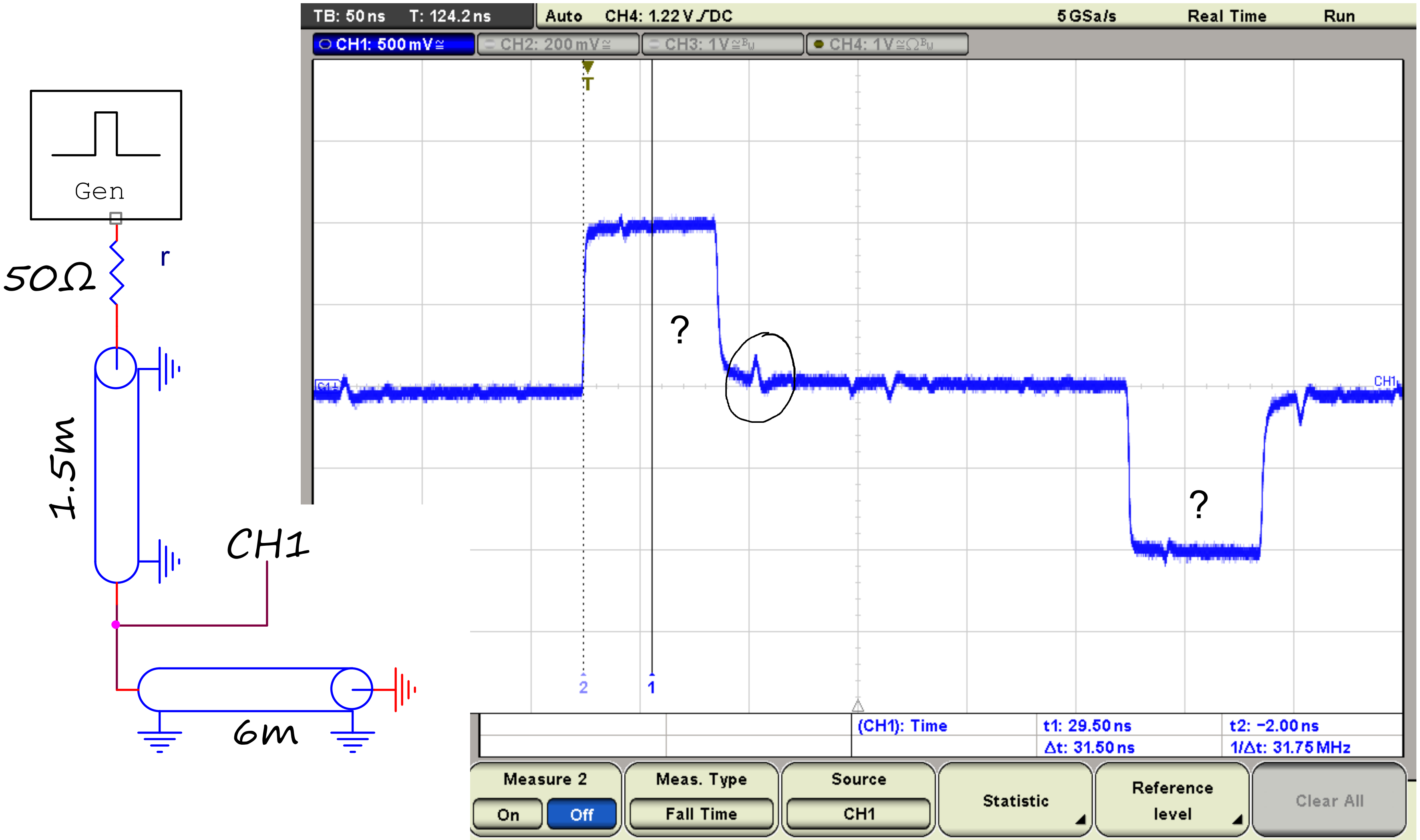
Signal propagation (6)



Signal propagation (7)

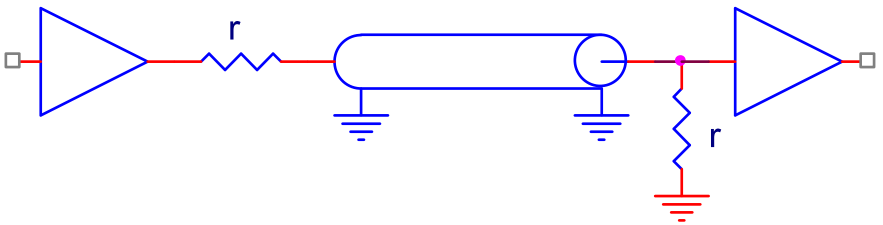


Signal propagation (8)



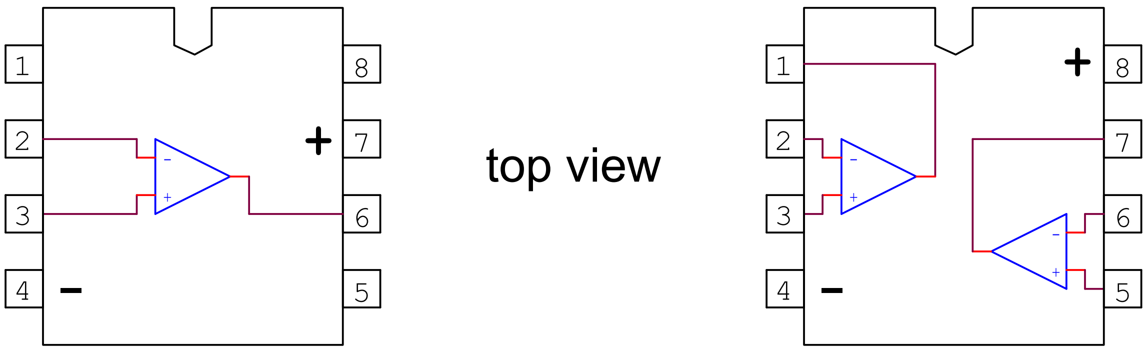
Signal propagation - conclusions

- The fastest component of a signal is its *rise/fall time* T_R
- The characteristic time of a piece of cable is the *transit time* T_T, for typical coaxial cable about 5 ns/m
- If $T_R >> T_T$, the signal is slow and probably the only trouble could arise from the *cable capacitance* (typically around 100 pF/m)
- For fast signals a proper termination corresponding to its *characteristic impedance* is necessary, to avoid signal degradation



Operational Amplifiers

- Ideal and real voltage feedback amplifier (VFA) - parameter
- Negative feedback with VFA
  - Non-inverting amplifier – offset, bandwidth, slew rate
- Positive feedback
  - Schmidt trigger, oscillator
  - Discriminator



Standard Pin-out of single and dual OA in a 8-pin package (DIL-8 or SOIC-8)

Operational Amplifiers in Simulator

LTspice comes with models from Linear Technology. In order to simulate an Op Amp from other manufacturer:

- Using google or a search on the manufacturer web page find a spice simulation model of the Op Amp – this must be a text file – check this with an text editor!
- Instantiate *opamp2* from the [Opamps] directory
- In symbol properties change the line with **value** containing *opamp2* with the name of the file containing the model, e.g. *TL071.lib*
- In the schematic sheet add a spice directive with .op like

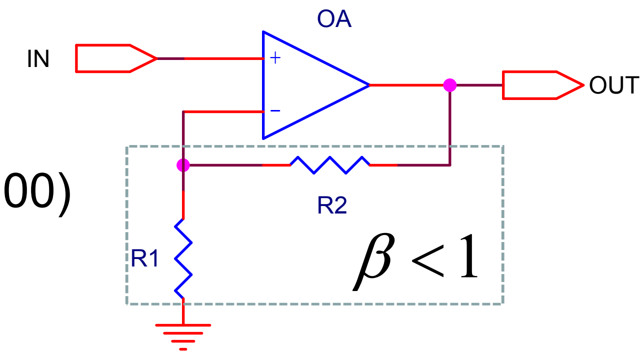
  `.inc TL071.lib` or `.lib TL071.lib`

- Copy the file with the simulation model in the project directory with the proper name (here TL071.lib)

Non-inverting amplifier

For gain=1, ≈10, ≈100

- Calculate the resistors R1, R2
- Measure the offset voltage (only at Gain ≈100)
- Estimate the input bias current

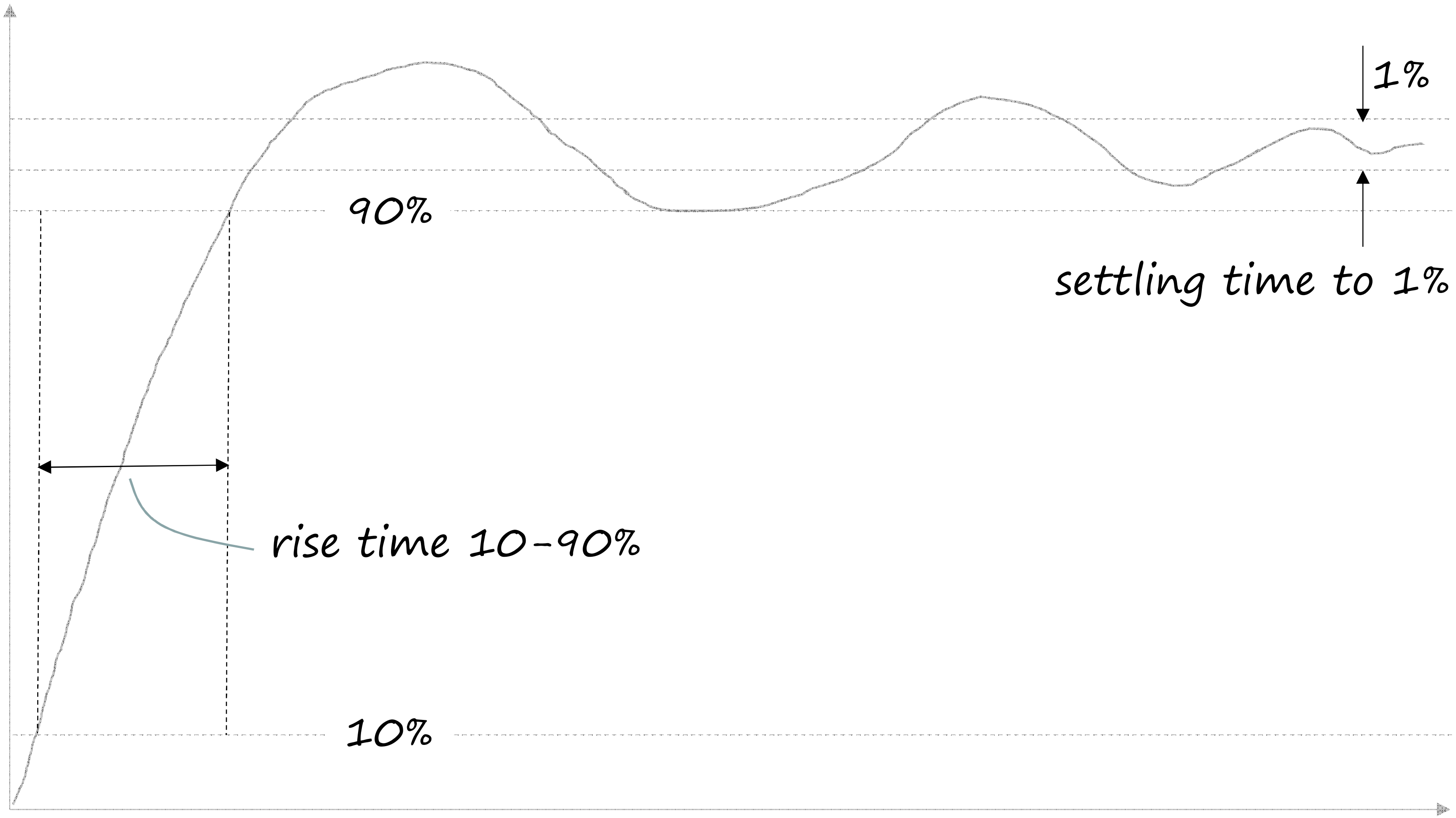


measure the

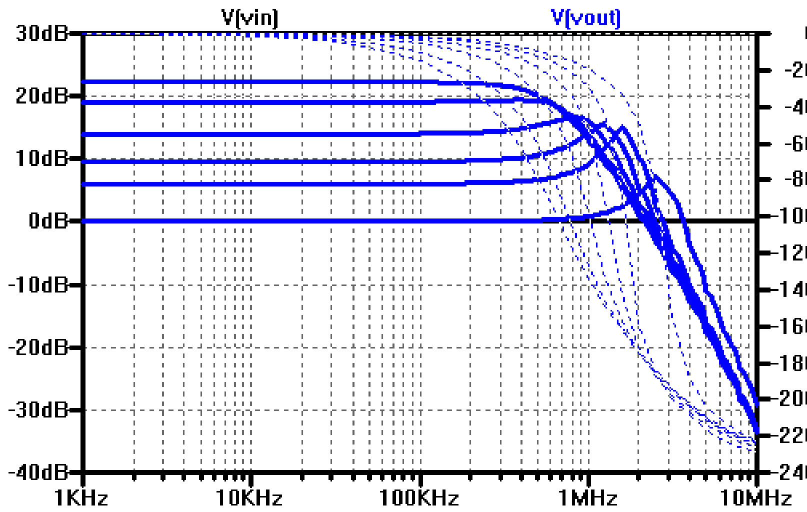
- Gain at 1Hz, 1kHz, 100kHz, 1MHz with small signal sinus (output amplitude = 5% of the full range at 1 Hz) and if possible with large signal sinus (output amplitude = 90% of the full range at 1Hz)
- Output impedance – combine with the previous measurement + measure the output amplitude with proper load (e.g. 1k)
- Rise/Fall time, slew rate and settling time to 1% of the step using 1Hz rectangular input signal and output amplitude 5% and 90% of the full range; repeat the measurements with 100pF capacitive load at the output

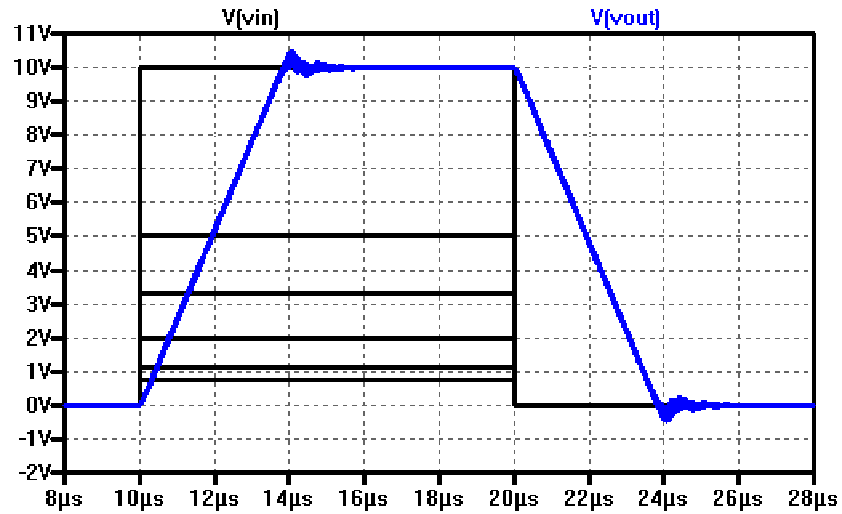
$$K_\beta = \frac{U_{OUT}}{U_{IN}} \approx 1 + \frac{R_2}{R_1} = \frac{1}{\beta} \geq 1$$

Definitions

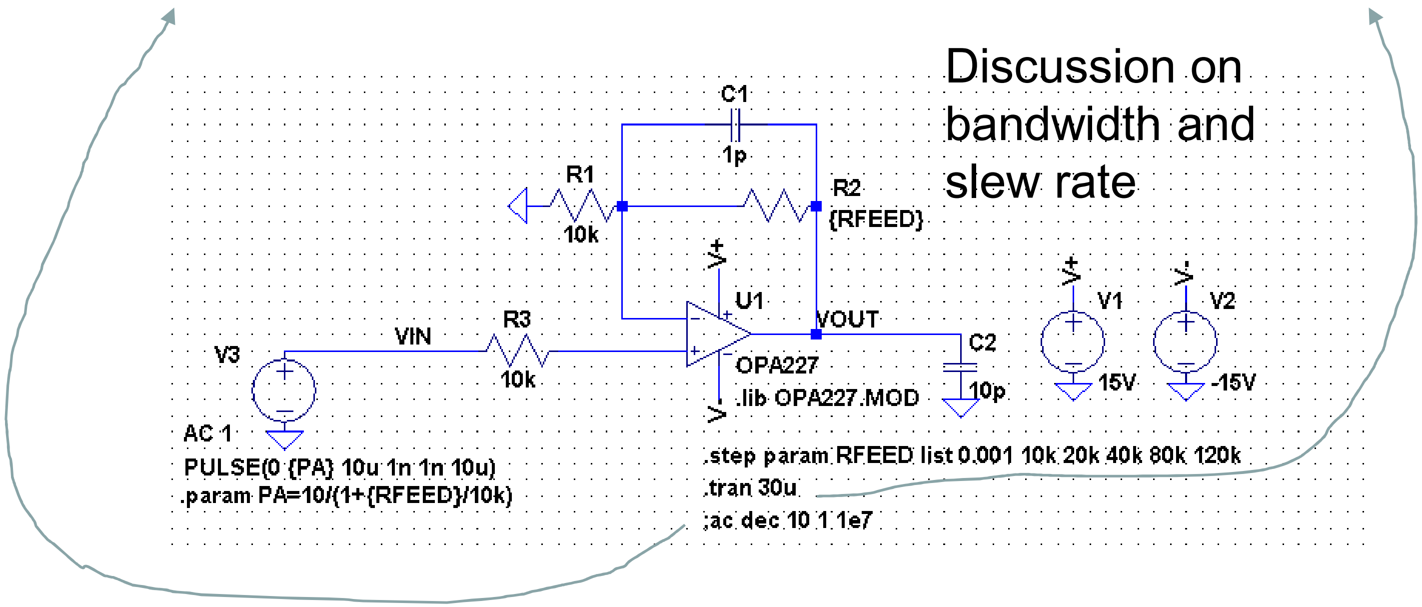


Non-inverting amplifier





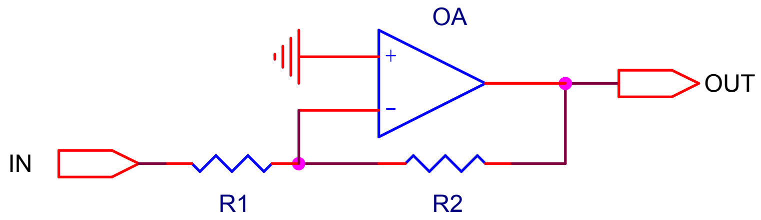
Discussion on bandwidth and slew rate



Inverting amplifier

For gain=-1, -10, -100

- Calculate the resistors R1, R2



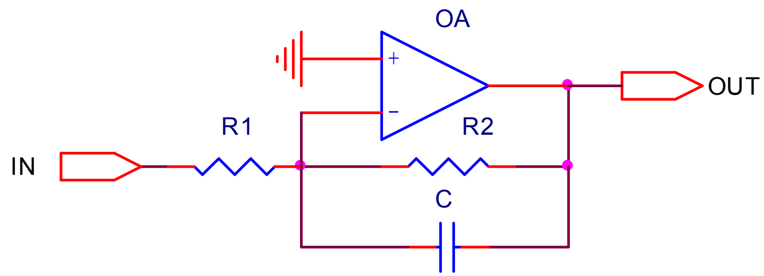
measure the

$$K = \frac{U_{OUT}}{U_{IN}} = -\frac{R_2}{R_1}$$

- Gain at 1Hz, 1kHz, 100kHz, 1MHz with small signal sinus (output amplitude = 5% of the full range at 1 Hz) and if possible with large signal sinus (output amplitude = 90% of the full range at 1Hz)
- The signal at the “virtual ground” – the negative input of the OA while measuring the Gain and again with rectangular input signal and output amplitude about 90% of the full range

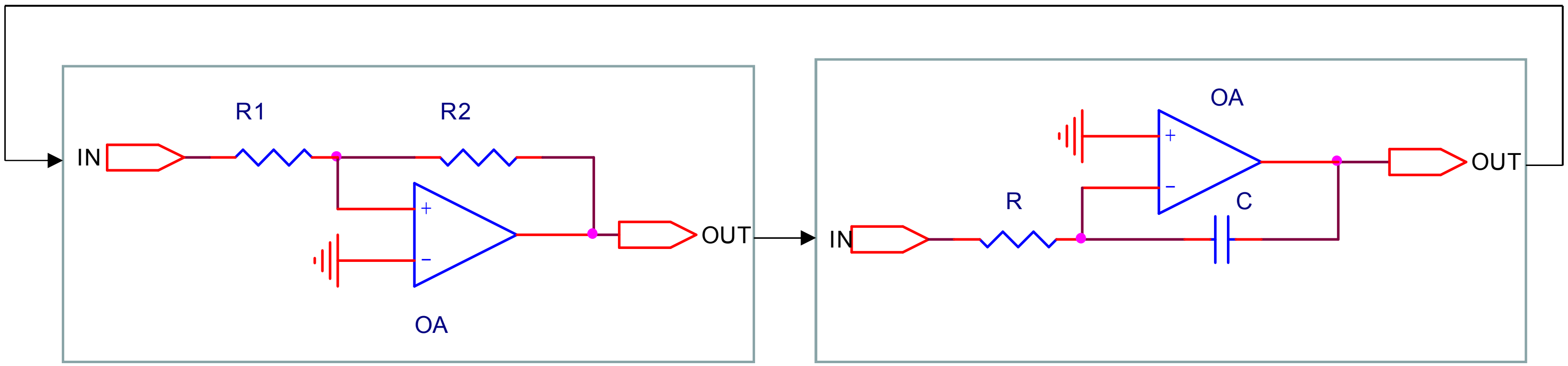
Influence of the osc-probe?

- For Gain=10 add a capacitor in the feedback so, that the bandwidth is limited to 10kHz; measure the Gain at 1Hz, 1kHz, 10kHz, 100kHz using sinus input signal; measure the rise/fall time using rectangular input signal



Triangle generator using comparator and integrator

OPTIONAL!



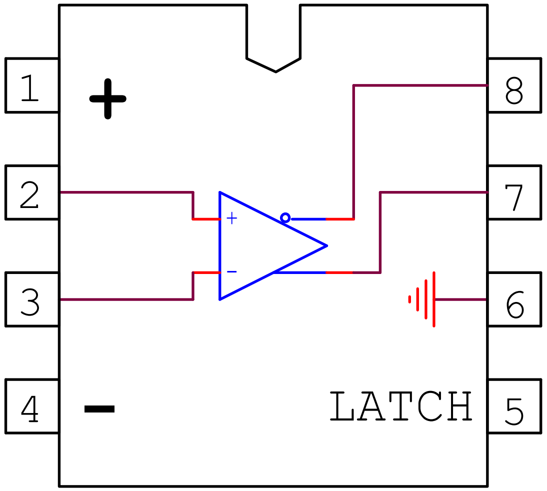
Schmitt trigger

Integrator

- Select the values of R1, R2, R and C in order to get frequency about 1 kHz and output range -10..+10V
- How can be varied only the frequency of the output signal?
- How can be varied only the amplitude of the output signal?

Use OPA2227 or OPA2277 or TL082

Comparator



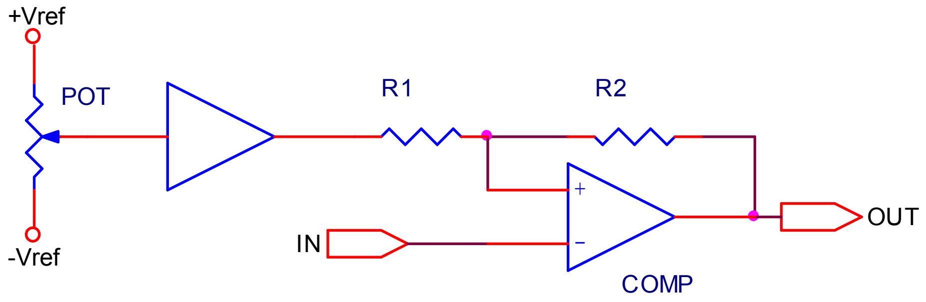
top view

AD8561, LT1016

Warning, the pin-out is NOT so standardized as for the operational amplifier!

In Simulator: if the model is missing, find it in internet (text file!), open the text file in LTspice, go to the line with `.SUBCKT`, then right-click and select **Create symbol**. It is recommended then to edit the symbol, at least to set the proper pin-names. The symbol contains as attribute the absolute location of the model in the file system => remove the absolute path prefix. The generated symbol is by default saved in [AutoGenerated] sub-directory of the lib\sym\ directory of LTspice: ver. XVII in …\MyDocs\LTspiceXVII\, ver. IV in C:\Program Files (x86)\LTC\LTspiceIV\

Discriminator – basic idea



Preferably use a true comparator instead of Op Ampl in this experiment

Investigate the discriminator

- Vary the amplitude and the rise/fall times of the input signal
- Add some high frequency noise to the input signal using a second generator and capacitive coupling
- Adjust the hysteresis according to the noise level
- Measure the input to output delay at different input amplitudes

Applications:

- Single Channel Analyser (SCA)
- Time Over Threshold Analyzer
- Timing

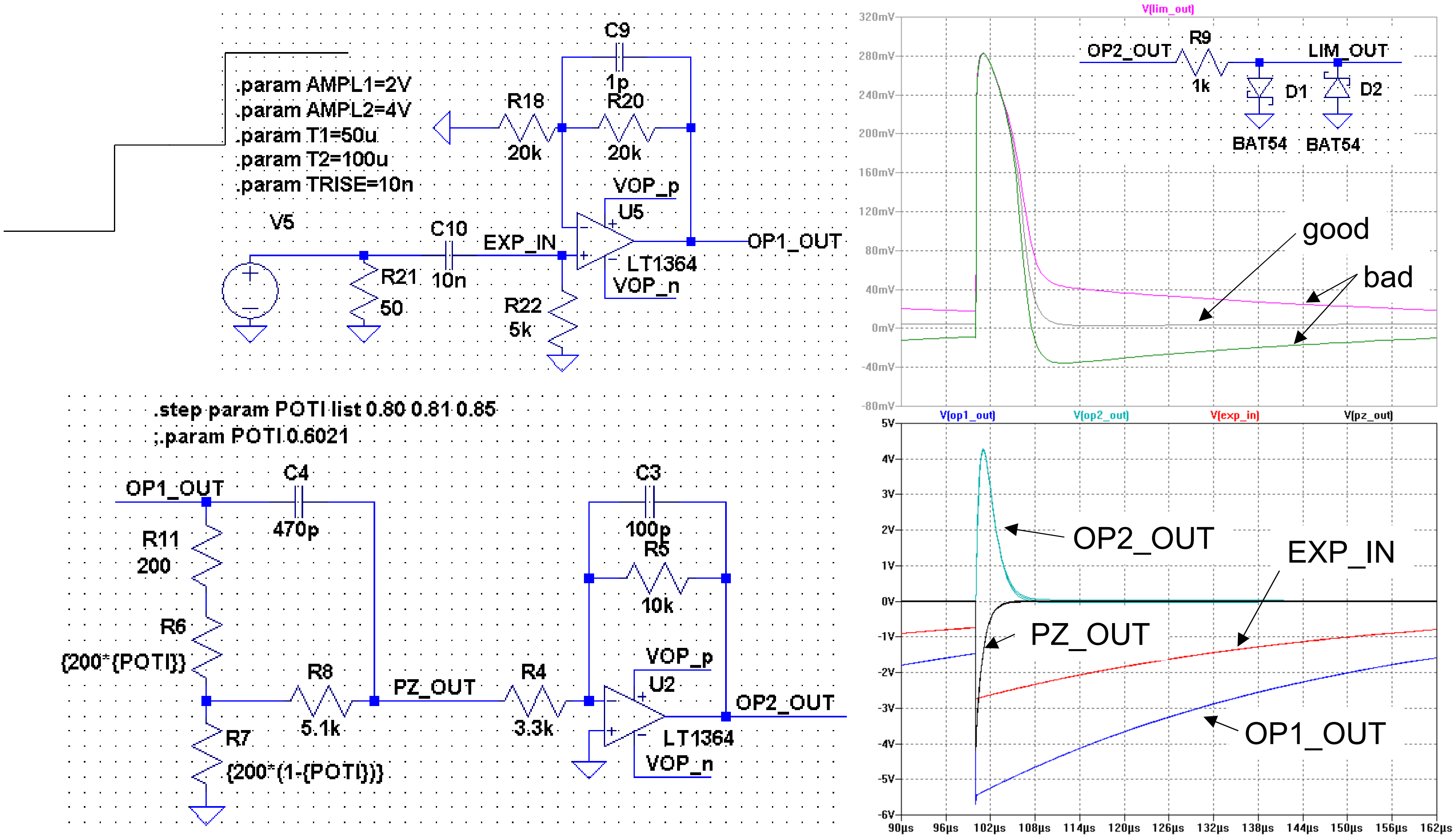
Specific part

- Particle physics experiments
  - Shaping Amplifier and Pole/Zero correction
  - Single channel analyser (SCA)
  - Time over Threshold (ToT)
  - Timing with Leading Edge (LE) and Constant Fraction Discriminators (CFD)
- Optical experiments
  - Constant current sources
  - Temperature measurements
  - Photodiode amplifier
  - PID

Shaping Amplifier

- The preamplifier delivers normally long exponential pulses, which may overlap
- The later amplifier stages have several functions:
  - Invert the polarity if necessary
  - Shorten the pulses with fast return to zero
  - Amplify to a level proper for further processing
  - Shape optimal for the signal to noise ratio and for the further processing (digitization)
- Simulate and build a shaping amplifier, play with the P/Z correction and the shaping parameters (shaping time, gain), vary the delay between the two pulses to see the effect of overlapping

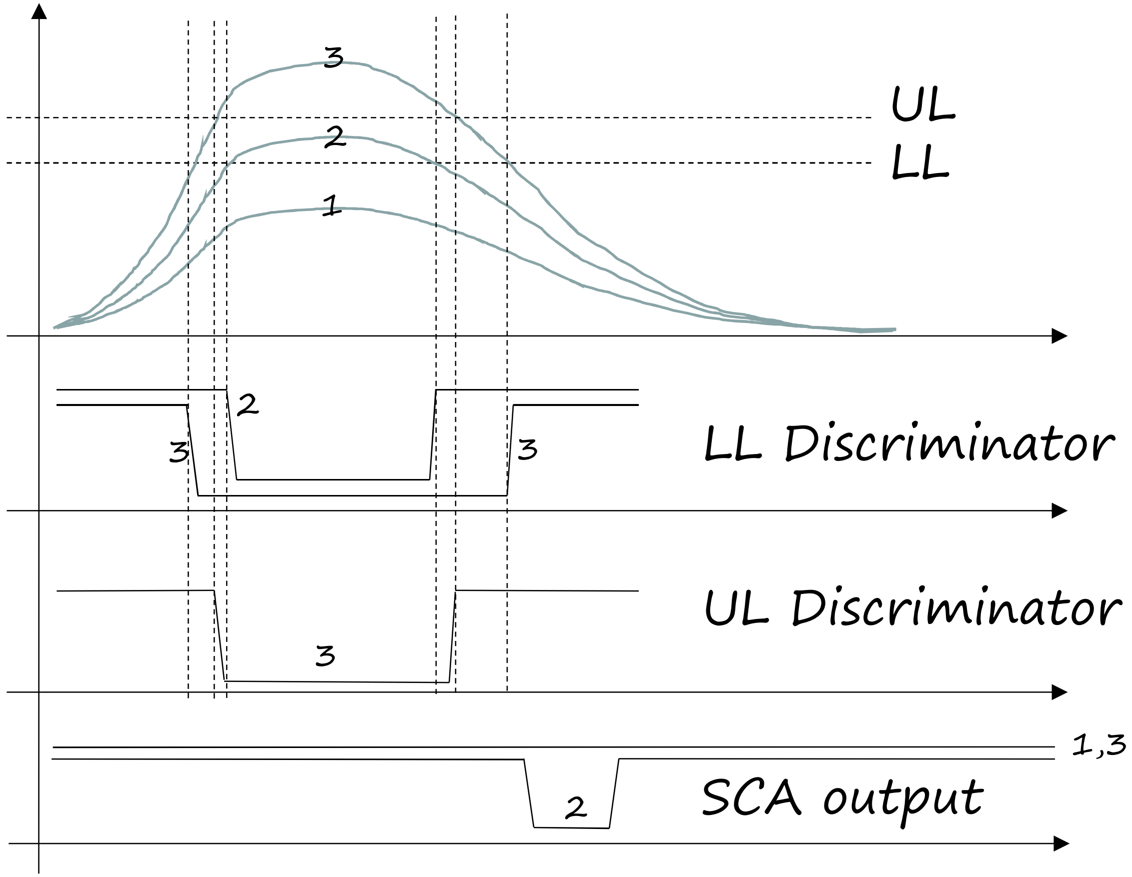
Shaping Amplifier



Possible OpAmp: LT1361 (slowest), LT1364, LM6172 (fastest)

Single Channel Analyzer

Select pulses with amplitude in some programmable window

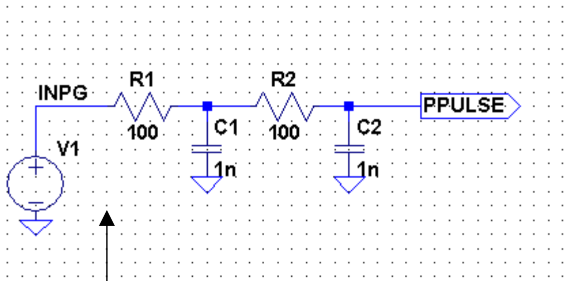


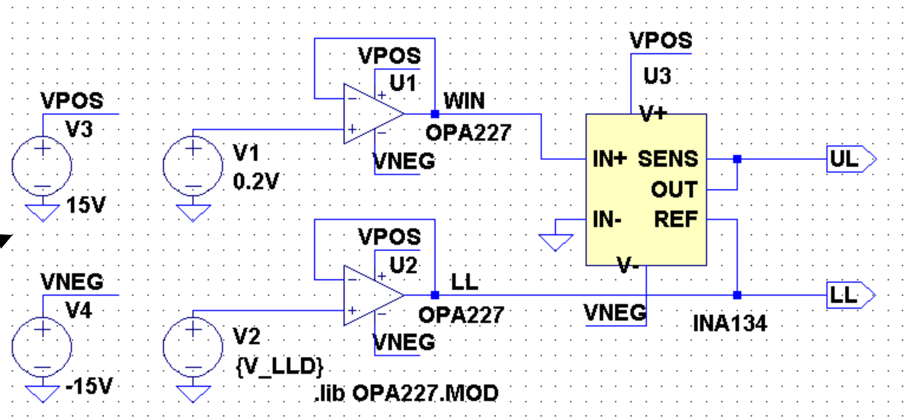
- Use two discriminators for the upper level (UL) and lower level (LL)
- Some logic takes the decision after both discriminators are inactive

Single Channel Analyzer

- Programmable lower level and window so that
  - the window can be moved through the whole range preserving the window size
- Build the upper level as lower level + window
- This is a primitive way to measure the amplitude spectrum of the pulses, but is simple! Normally the window position & width is optimized once and then the pulses are counted for long time

SCA – building blocks



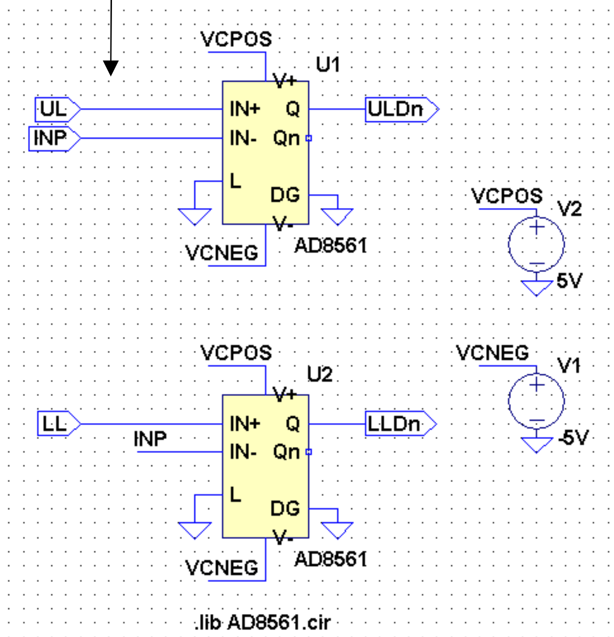


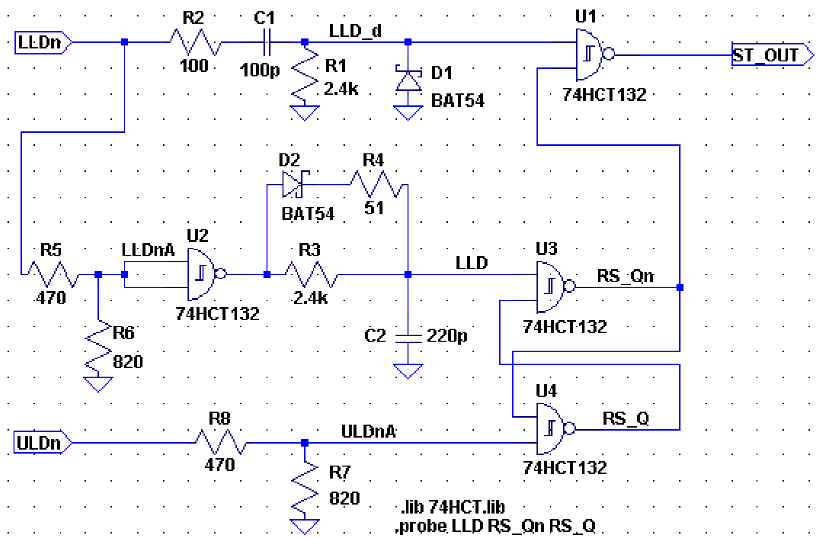
Input pulse

Thresholds

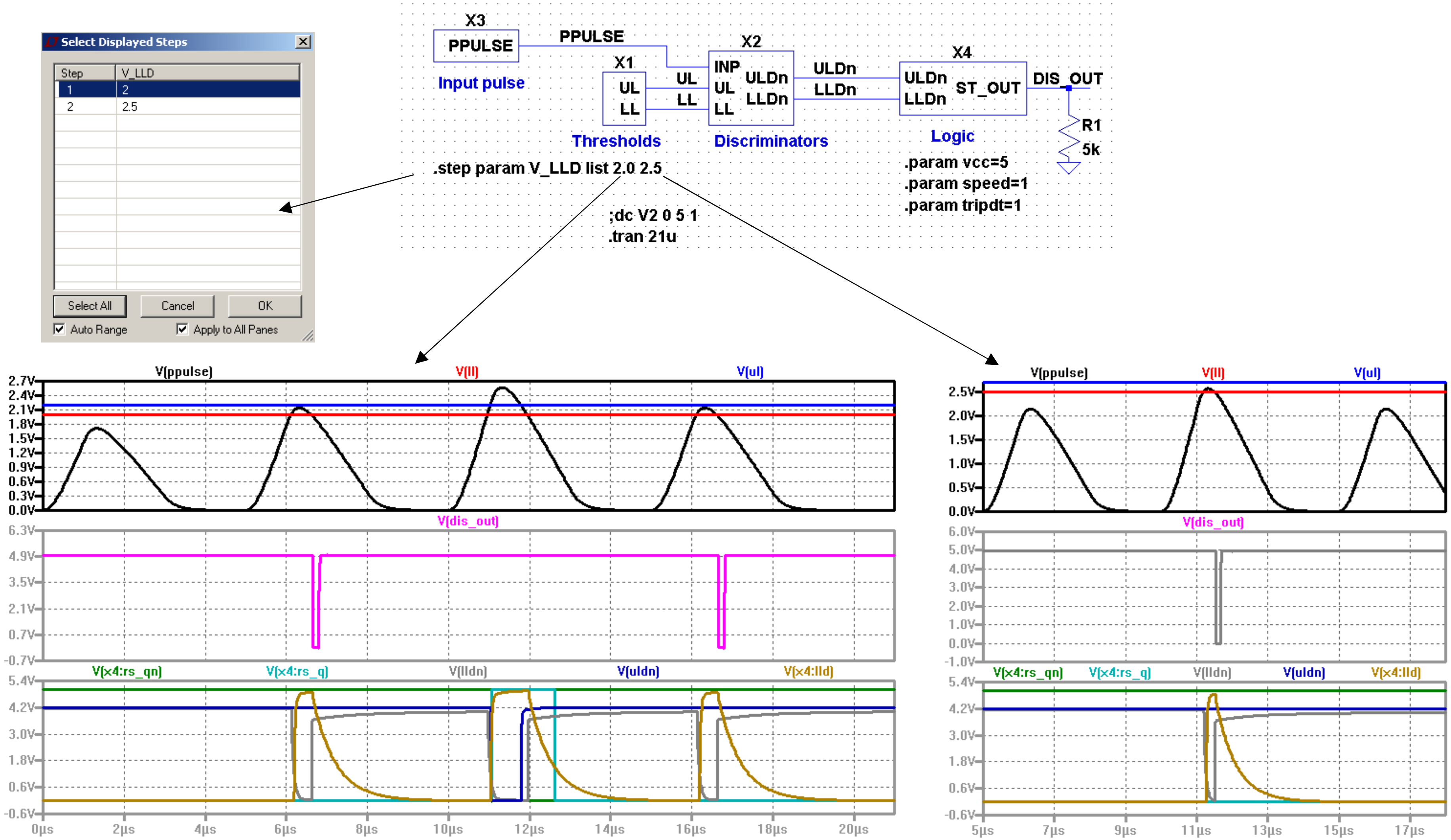
Comparators

Logic



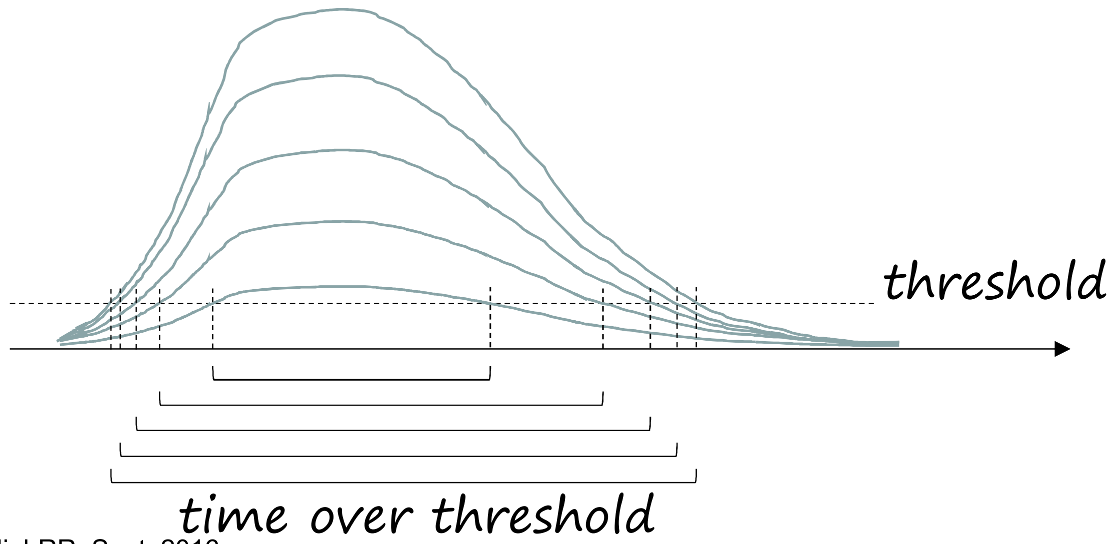


SCA – put all together

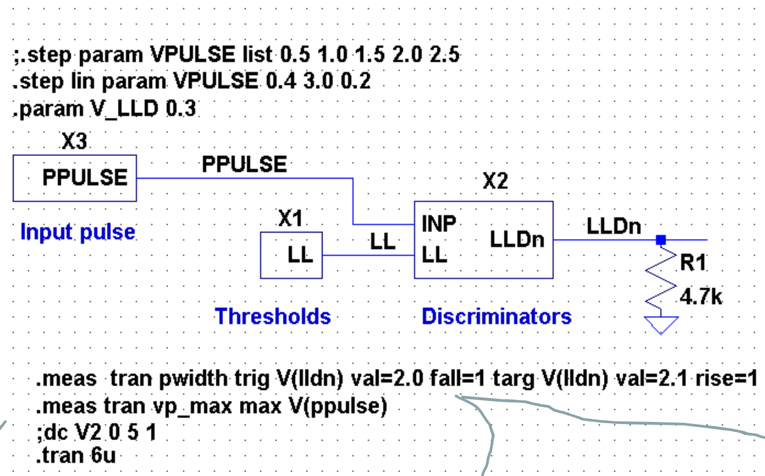


Discriminator – time over threshold (ToT)

- The idea is to measure roughly the amplitude of the pulses
- With a constant threshold, the time over the threshold is a function of the amplitude
- Provided the shape remains stable, the correlation ToT – Amplitude is non-linear but known

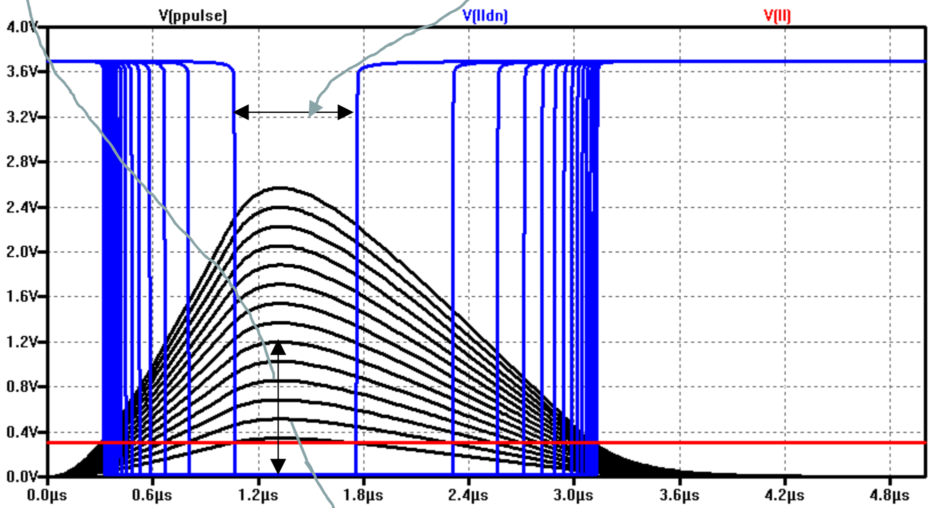


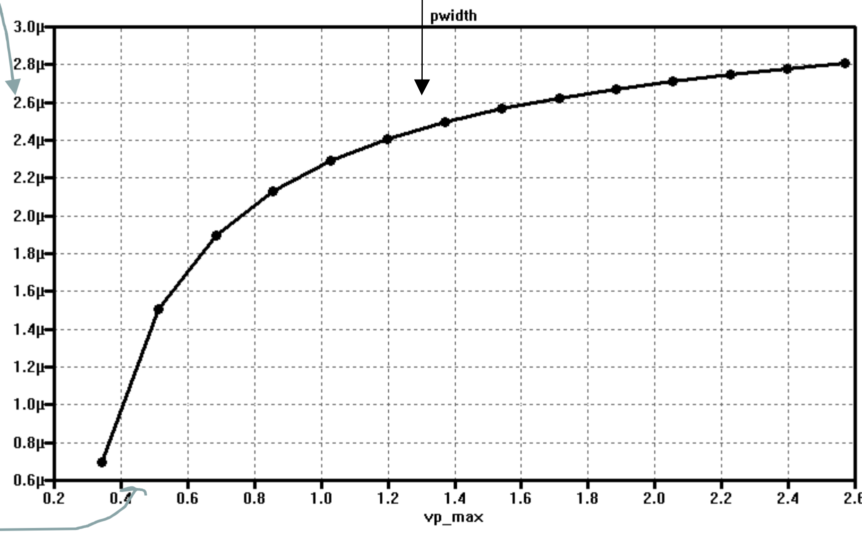
Discriminator – time over threshold



X3 – PPULSE is the same as in SCA
X1 and X2 – half-version of the SCA discriminator

The dependence of the pulse width (the time over threshold) is non-linear and a function of the pulse shape!

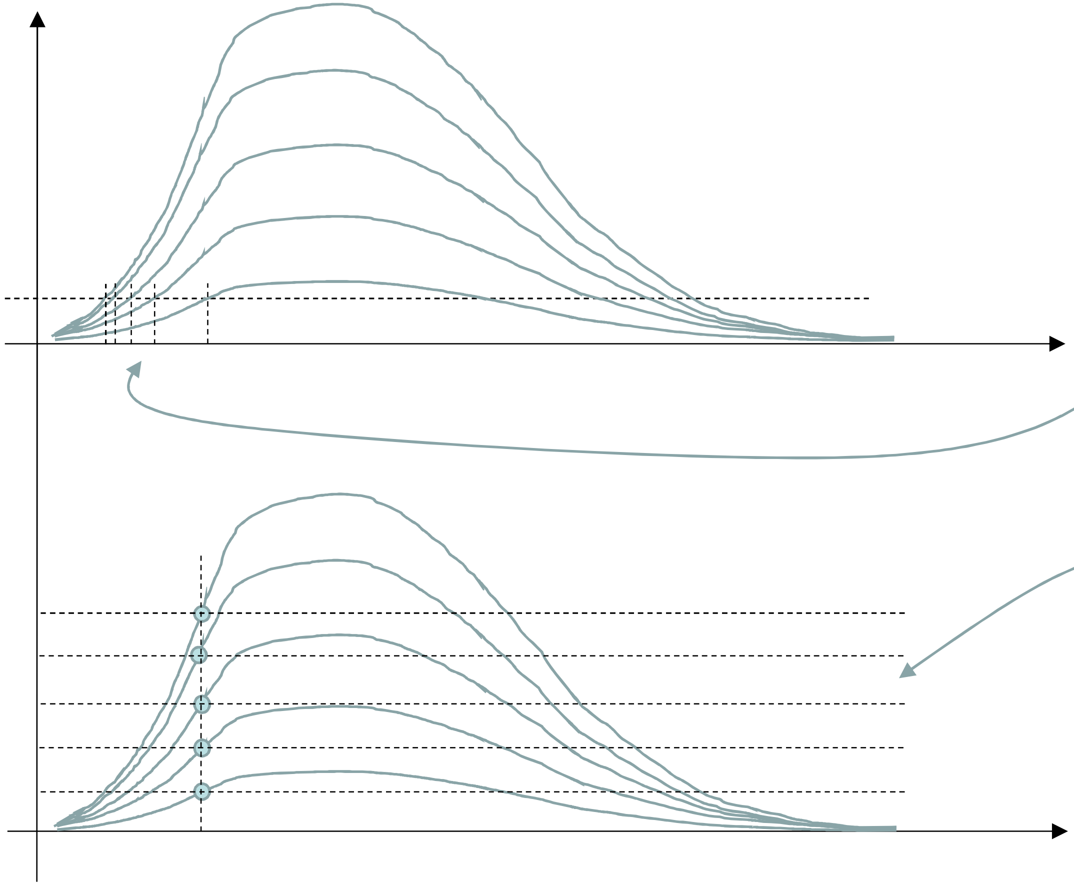




Discriminator – leading edge timing

- The same circuit can demonstrate another typical task in detector experiments – timing
- When measuring the time distance between two detector pulses, the simplest way to get a digital start and stop signals is to use a discriminator with constant threshold
- What is the problem of this solution?

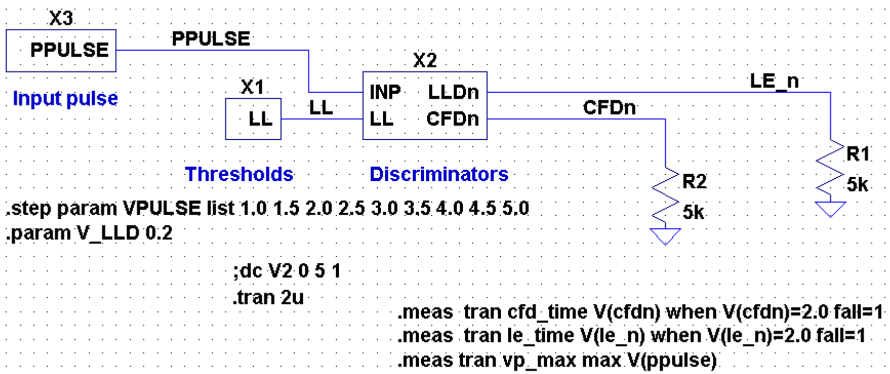
Improving the leading edge timing

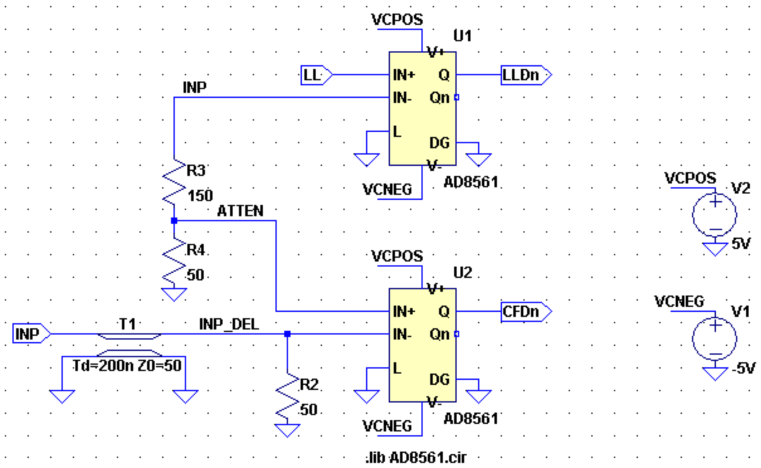


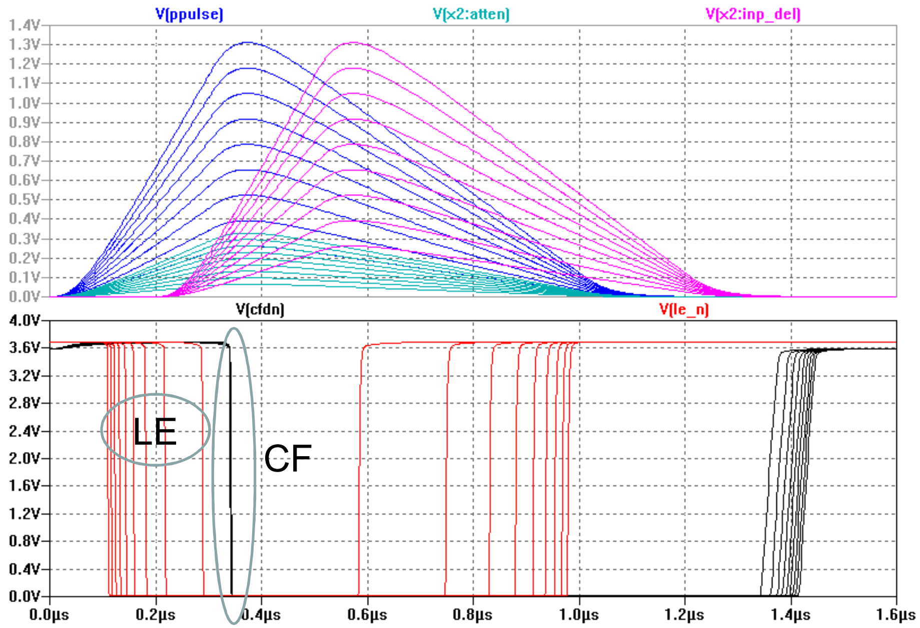
How to compensate for the "time walk"?

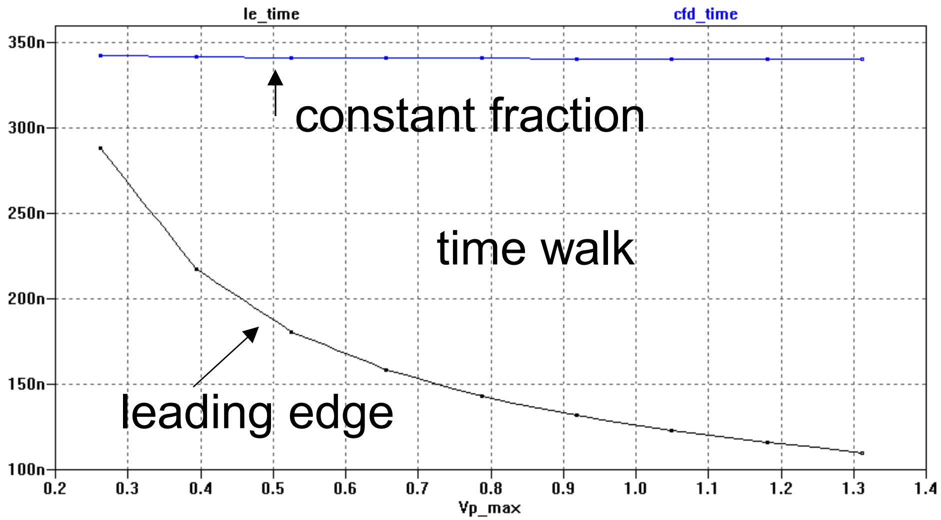
If the threshold is not constant, but depends on the signal amplitude… e.g. is just a constant fraction?

Timing – leading edge vs. constant fraction







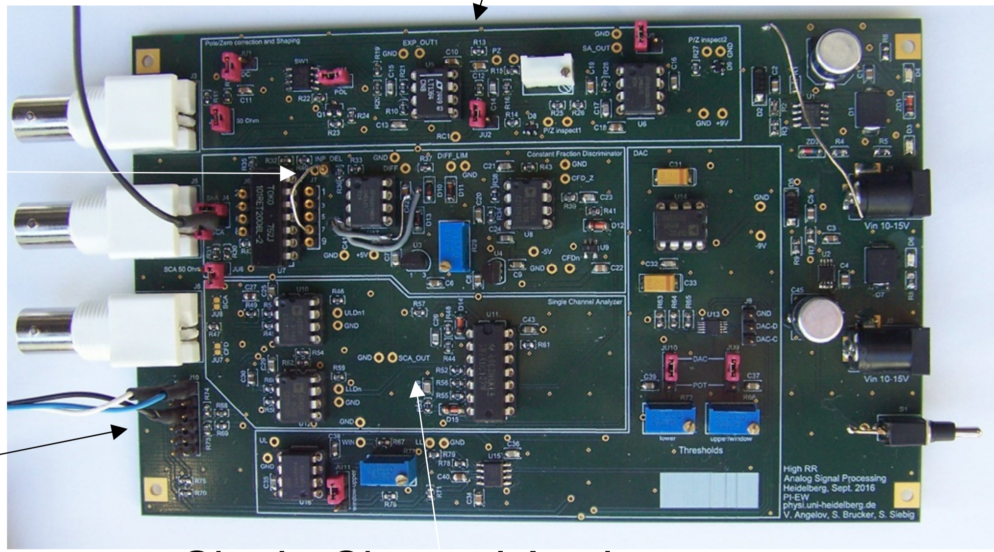


Solder your first board

P/Z & Shaping Amplifier

Constant Fraction Discriminator

All digital signals on a dual PMOD connector



2x 10..15V

on/off

Single Channel Analyzer

Thank you for your attention and patience!