DAPHNE V2A – Active undershoot mitigation

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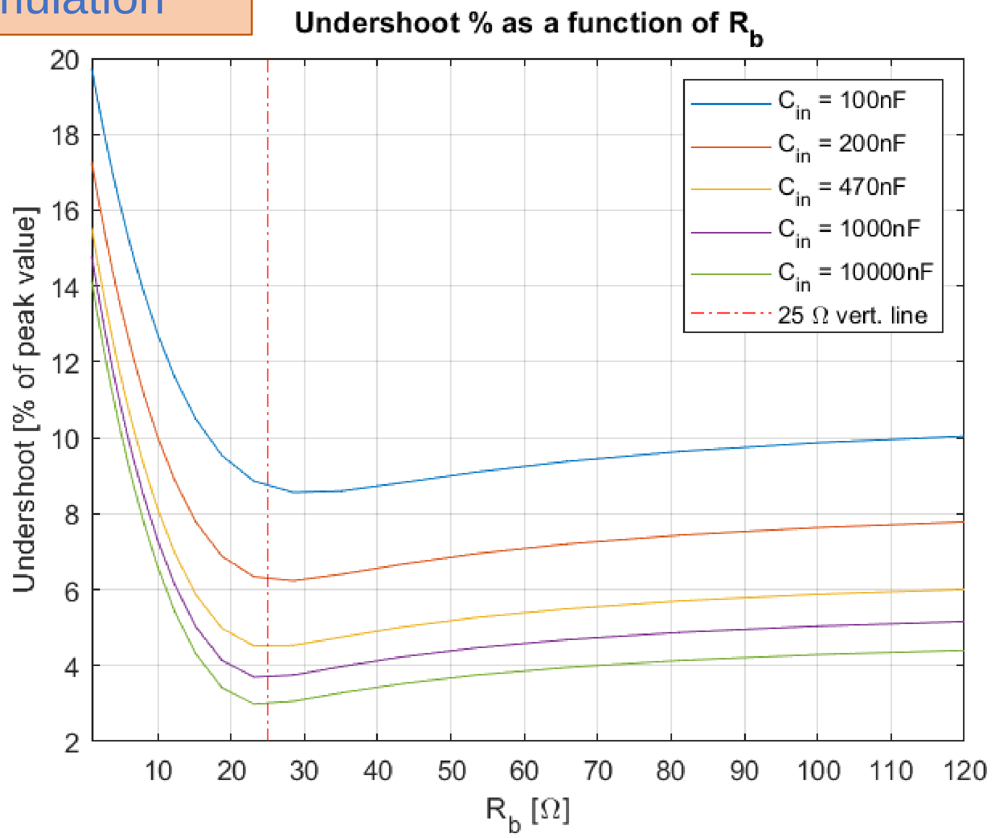
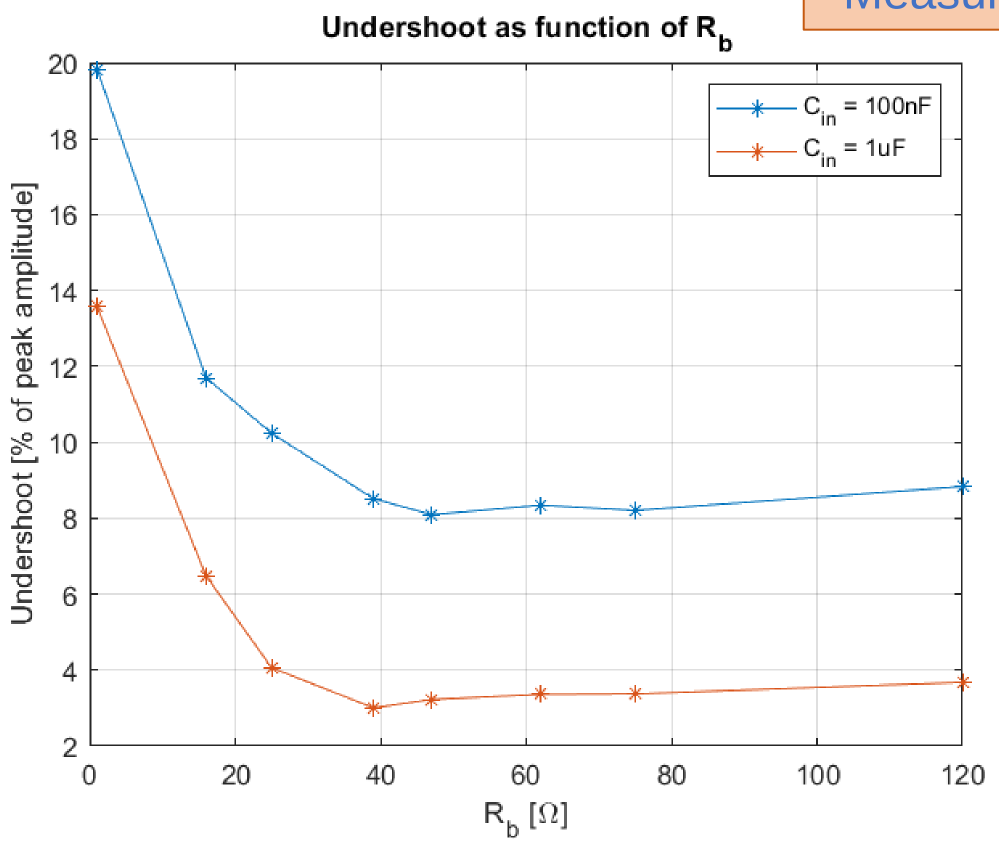
Background: Test with warm receiver

Simulation

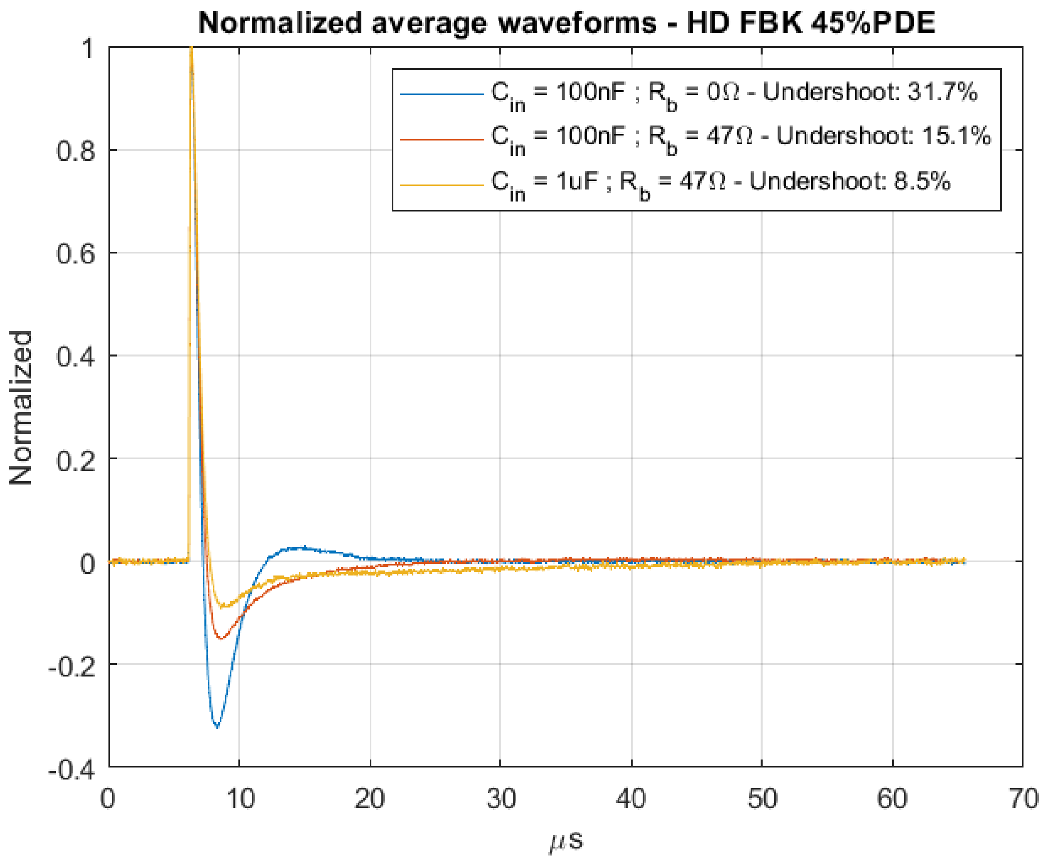


Measurements

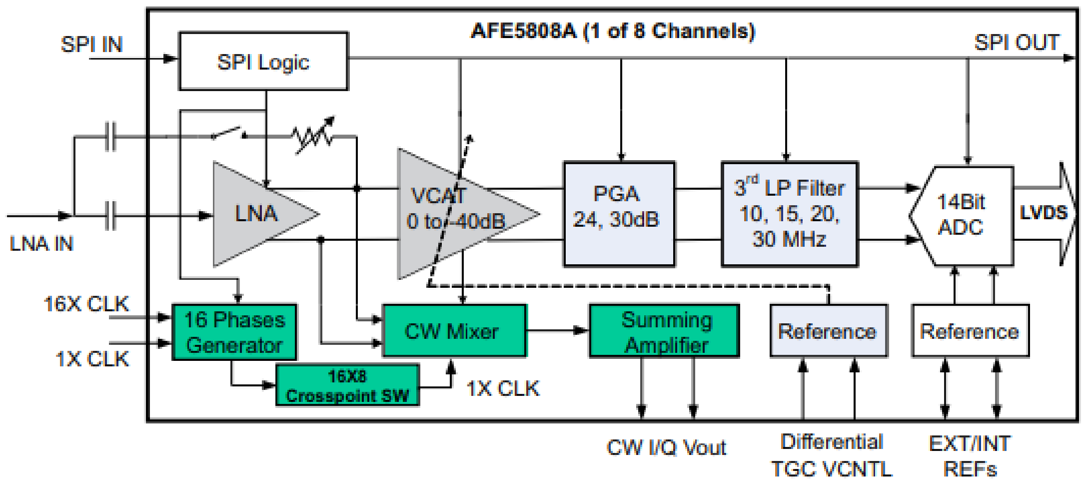


- Undershoot mitigation studies were done in order to find a passive configuration that reduces the undershoot behaviour observed in DAPHNE V2A.
- A termination resistor R_b was added to the center tap of the transformer stage.

Background: Tests with DAPHNE

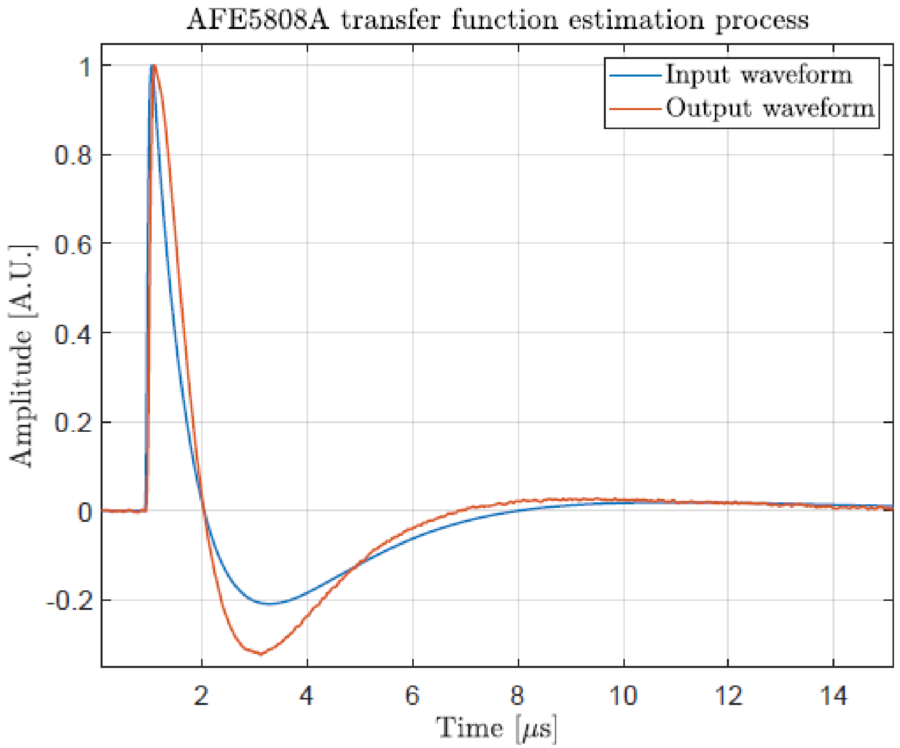


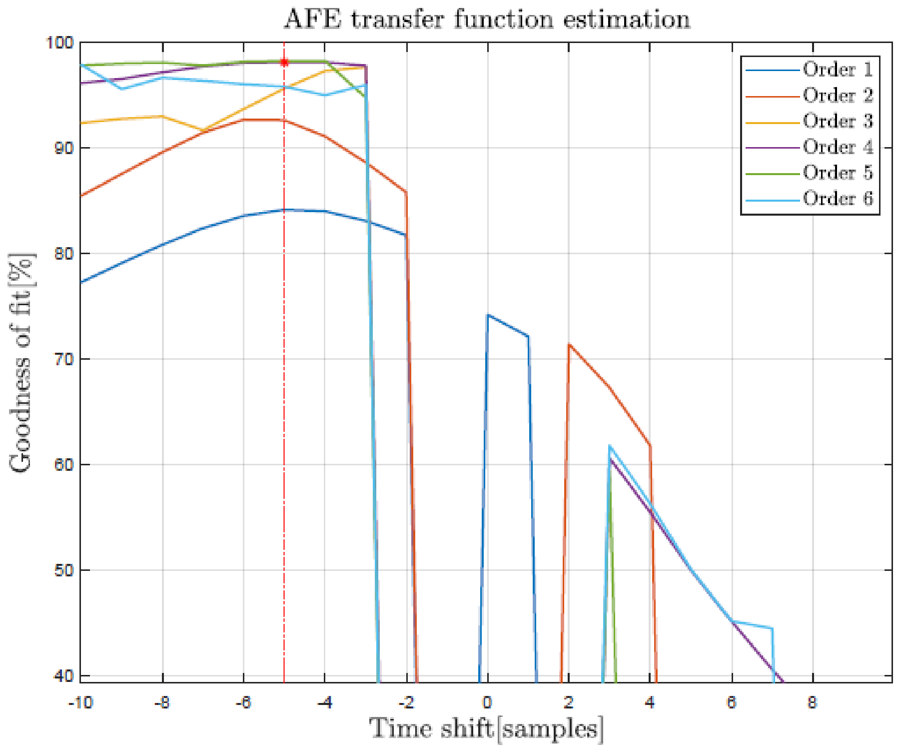
AFE5808A amplification and ADC chain



- As expected, we see a reduction in the undershoot behavior. What was not expected is the large contribution of the AFE chip. (e.g., 3% vs 8.5%)
- Simulation of the complete SPICE model (coldamp + AFE chip) using TI model do not reproduce this issue. Also, mismatches between DAPHNE acquired waveforms and waveforms acquired with other systems have been reported, something that is also unexpected according to the provided model.

DAPHNE transfer function estimation





- A transfer function estimation algorithm using MATLAB was developed to .
- The input of the algorithm is the normalized waveform produced by the coldamp SPICE simulation and the output is the normalized acquired waveform for a given SiPM.
- The algorithm shifts the input, and for increasing transfer function orders, it calculates the best fit of the response.

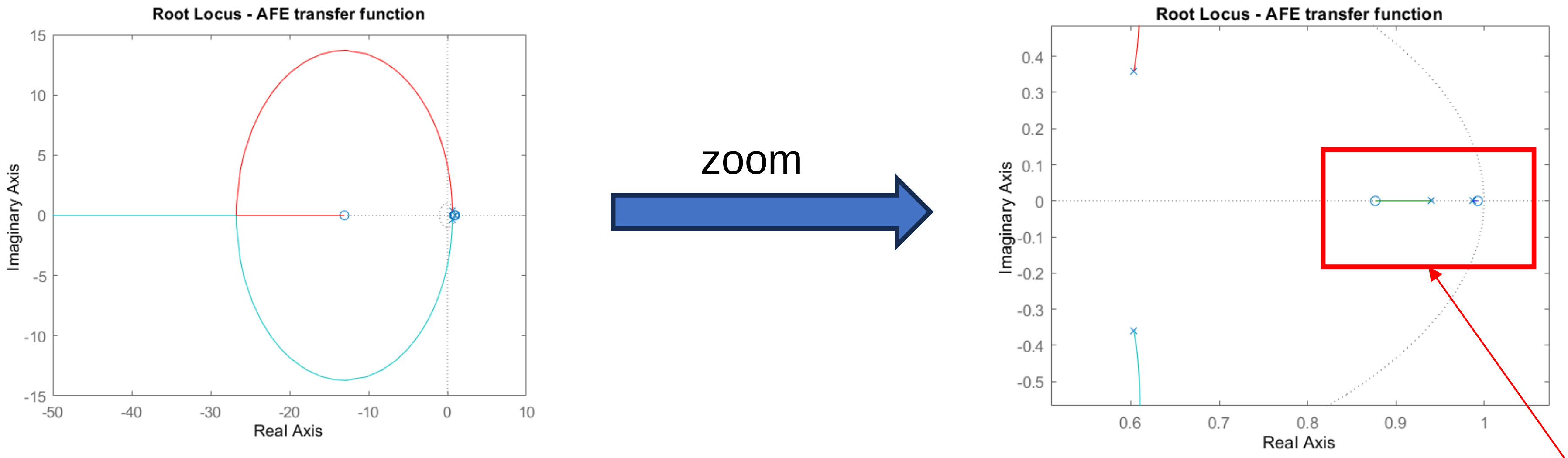
DAPHNE transfer function estimation

DAPHNE AFE black box model			
Coefficient	Value	Coefficient	Value
a_0	0	b_0	1
a_1	0.015460914687967	b_1	-3.133926515721090
a_2	0.173086942873436	b_2	3.747375020292871
a_3	-0.364112533234608	b_3	-2.071251591053136
a_4	0.175765001118347	b_4	0.458032007871133

$$H(z) = \frac{a_0 + a_1 z^{-1} + a_2 z^{-2} + a_3 z^{-3} + a_4 z^{-4}}{b_0 + b_1 z^{-1} + b_2 z^{-2} + b_3 z^{-3} + b_4 z^{-4}}$$

- The estimation process reaches a maximum goodness of fit at an order of 4.

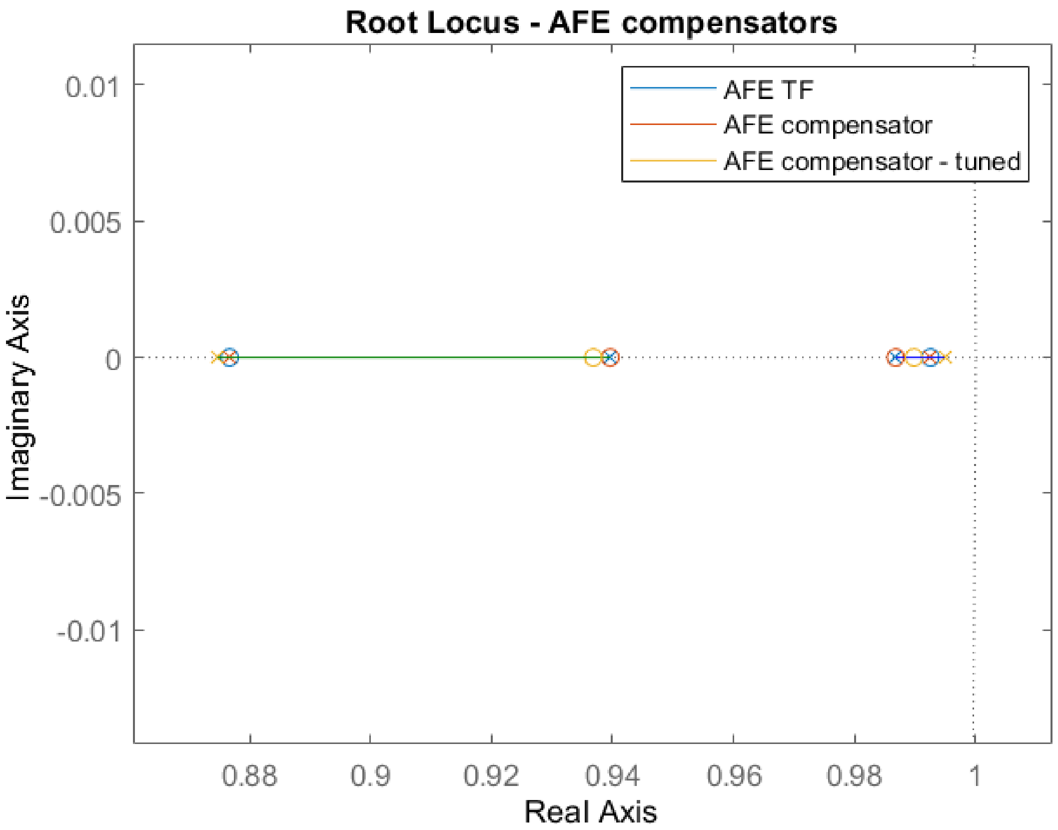
DAPHNE transfer function compensation



- Analyzing the root locus of the transfer function, we found the sets of zeros and poles pairs causing the excess undershoot behaviour introduced by the AFE chip.
- Since both zeros and poles pairs are located inside the unitary circle, the compensator, i.e. the inverse of this function, is stable and can be implemented as an online IIR digital filter.

Poles causing the undesired undershoot

DAPHNE transfer function compensation



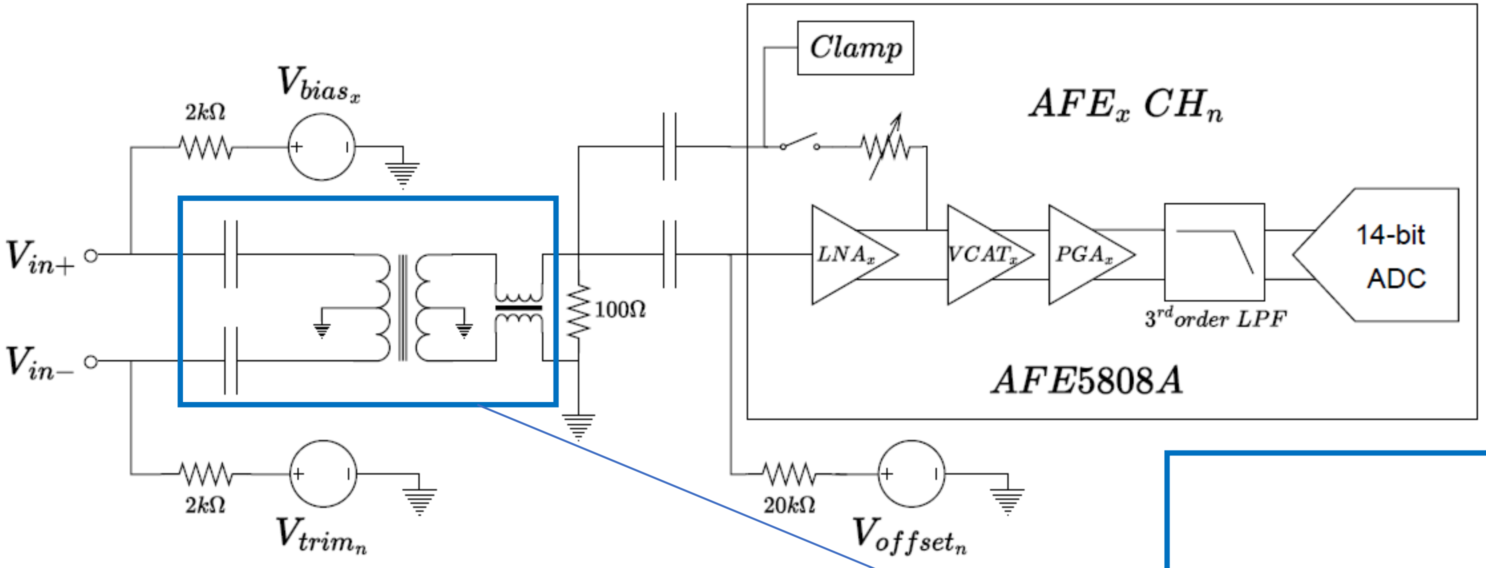
- Zero-pole cancellation can be tunned to improve the undershoot response.

$$H(z) = \frac{a_0 + a_1 z^{-1} + a_2 z^{-2}}{b_0 + b_1 z^{-1} + b_2 z^{-2}}$$

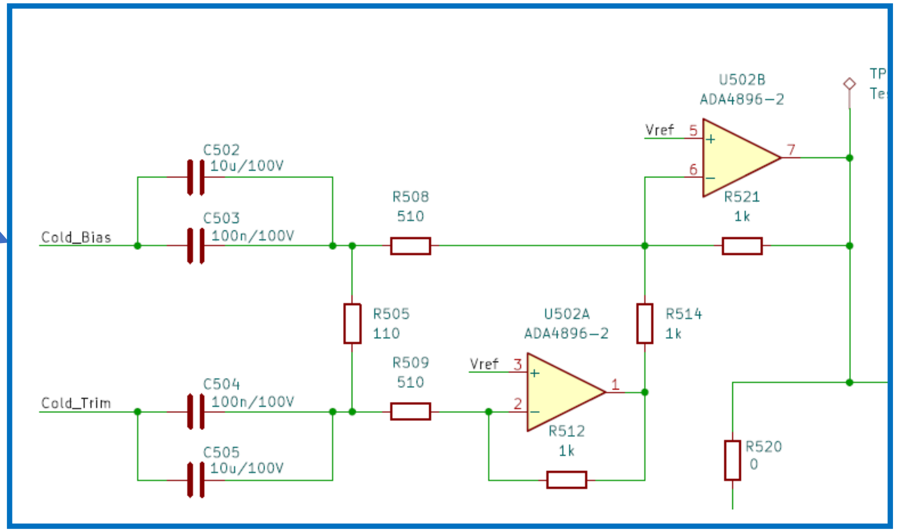
AFE compensator			
a_0	1	b_0	1
a_1	-1.926393964746584	b_1	-1.869256941624722
a_2	0.927193087221202	b_2	0.870178197223754

AFE compensator - tuned			
a_0	1	b_0	1
a_1	-1.926610659666155	b_1	-1.869533302398776
a_2	0.927255554491133	b_2	0.870178197223754

DAPHNE active receiver

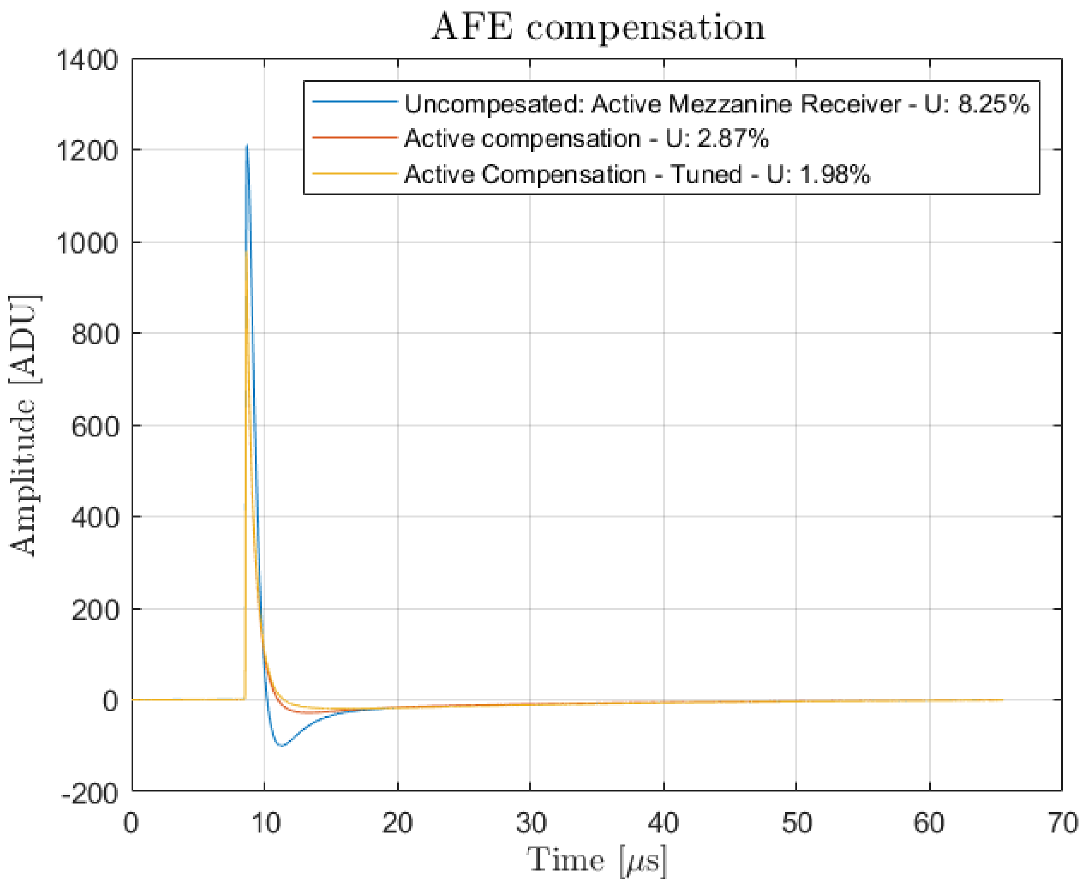


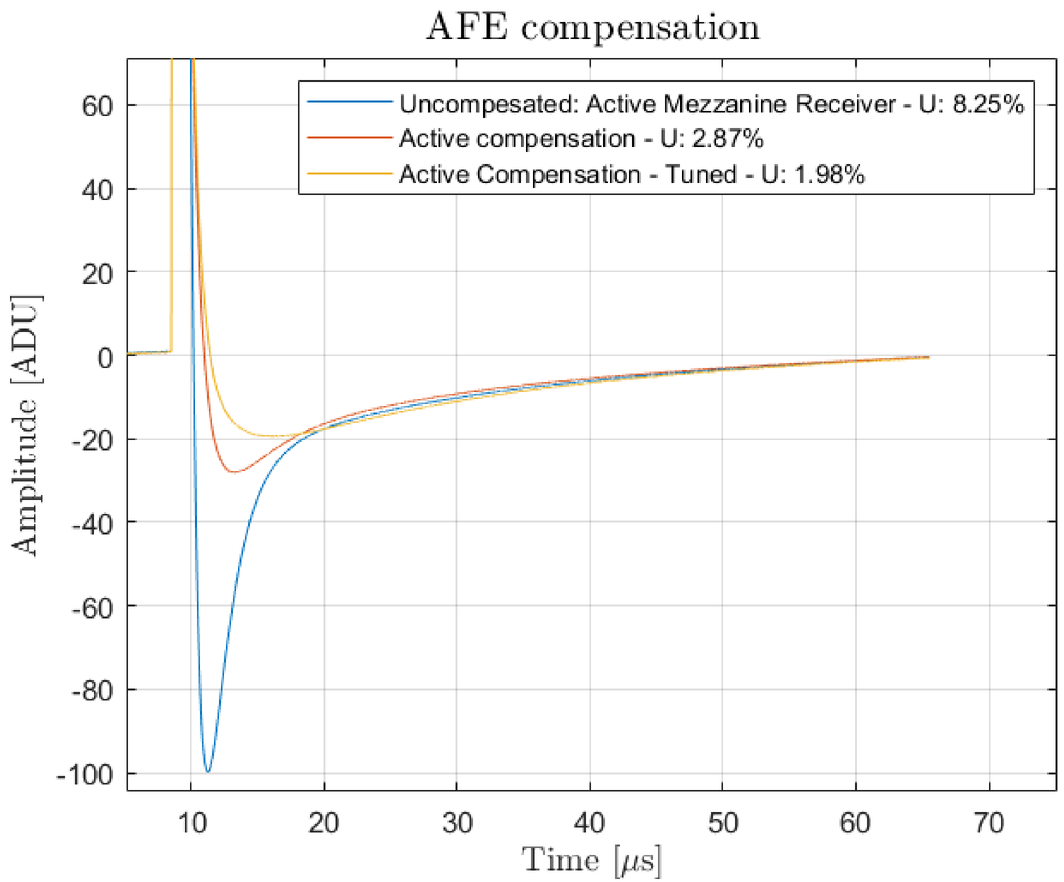
Active receiver



- With the opportunity of a mezzanine DAPHNE. An active receiver was developed at Milano-Bicocca to replace the transformer and eliminate the undershoot behavior introduced by it.

DAPHNE transfer function compensation – simulation on acquired data



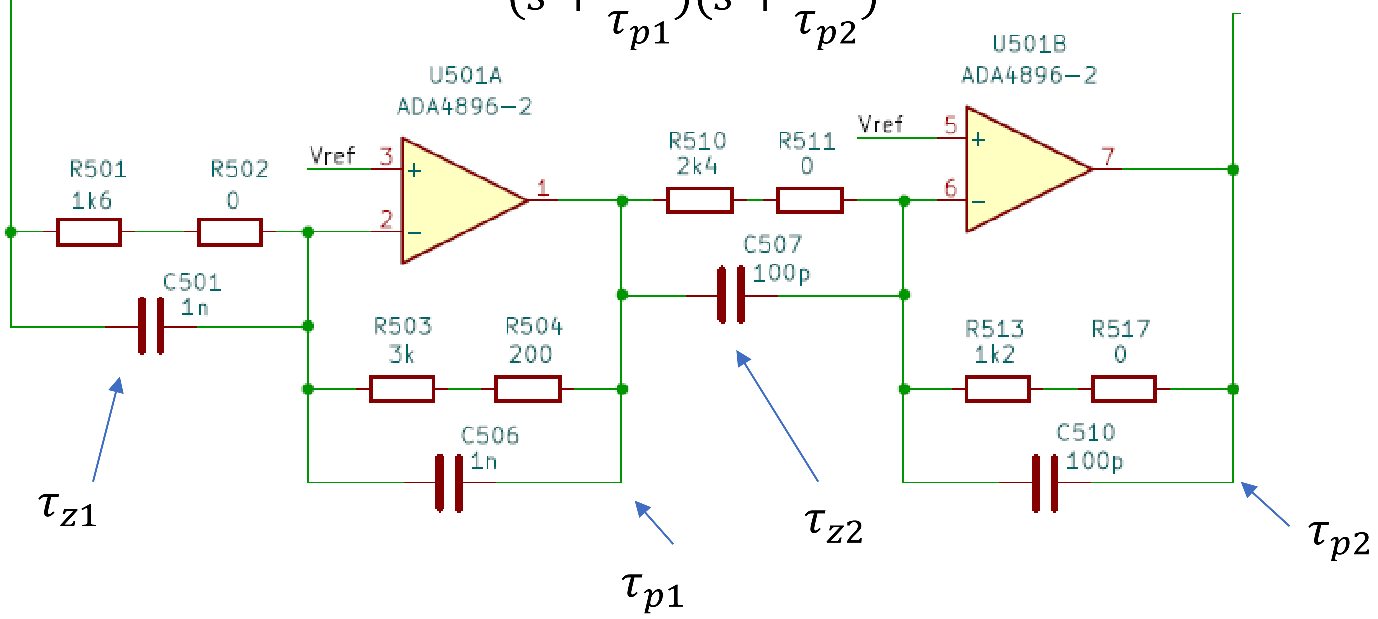


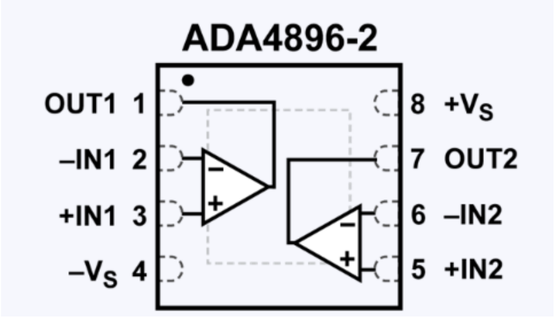
- The simulation shows the effect of the compensator on the acquired signal.
- The tuned compensator achieves a reduction of the undershoot to a level of 1,98%.

DAPHNE transfer function compensation circuit

Lead-Lag compensator

$$H(s) = \frac{(s + \frac{1}{\tau_{z1}})(s + \frac{1}{\tau_{z2}})}{(s + \frac{1}{\tau_{p1}})(s + \frac{1}{\tau_{p2}})}$$



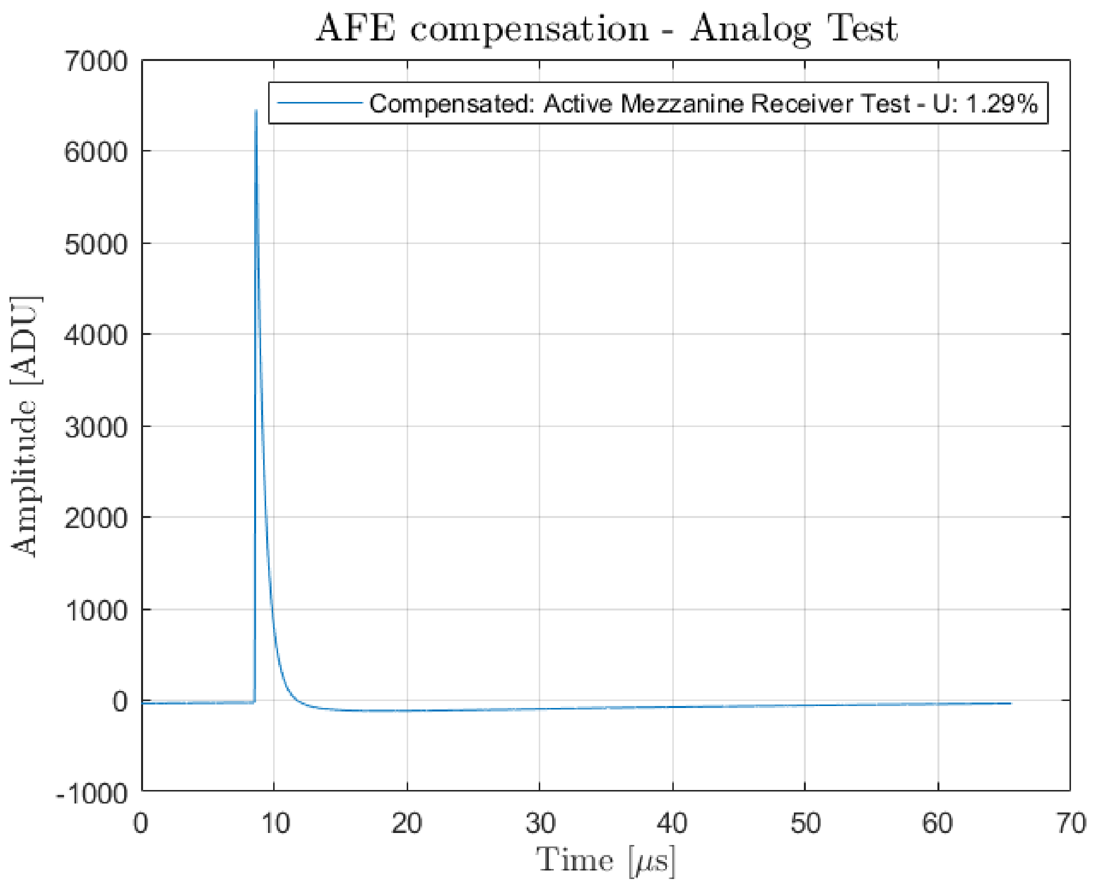


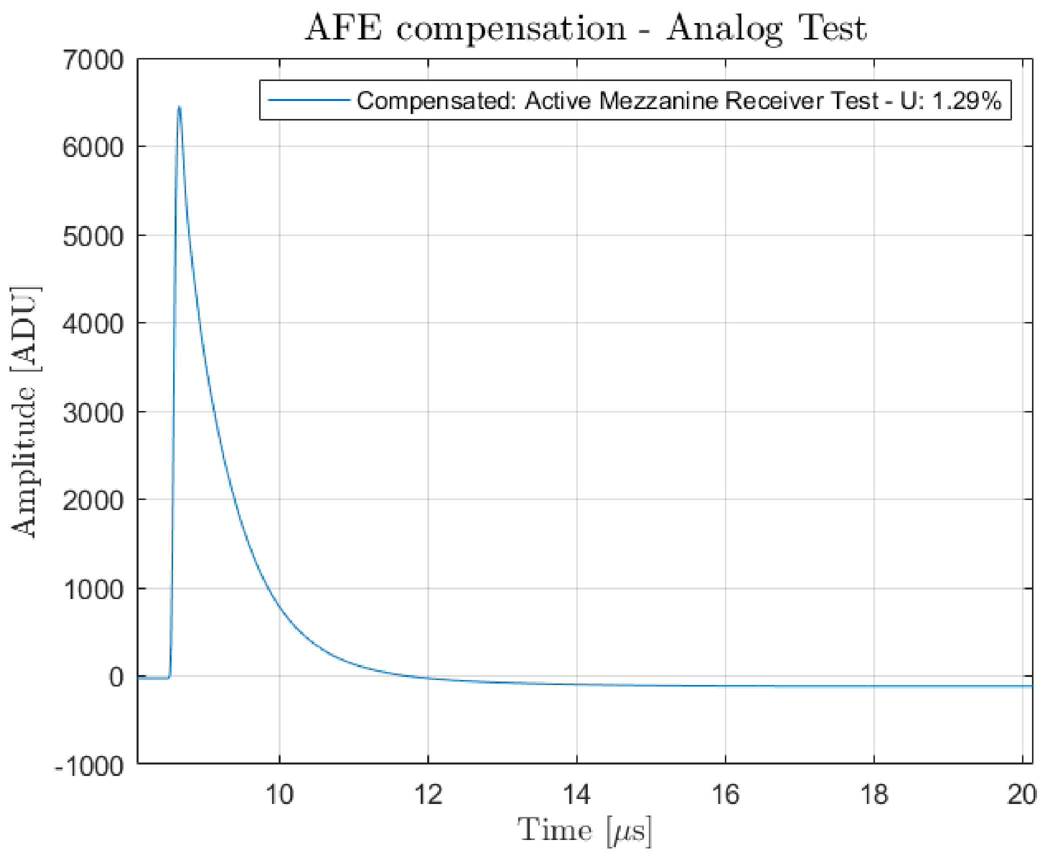
Features

- Low wideband noise
  - 1 nV/√Hz
  - 2.8 pA/√Hz
- Low 1/f noise
  - 2.4 nV/√Hz @ 10 Hz
- Low distortion: −115 dBc @ 100 kHz, VOUT = 2 V p-p
- Low power: 3 mA/amp
- Low input offset voltage: 0.5 mV maximum
- High speed
  - 230 MHz, −3 dB bandwidth (G = +1)
  - 120 V/µs slew rate
  - 45 ns settling time to 0.1%
- Rail-to-rail output
- Wide supply range: 3 V to 10 V
- Disable feature (ADA4897-1)

- To save precious FPGA resources, the filter can be implemented as an analog compensator in the mezzanine board using a lead-lag configuration.

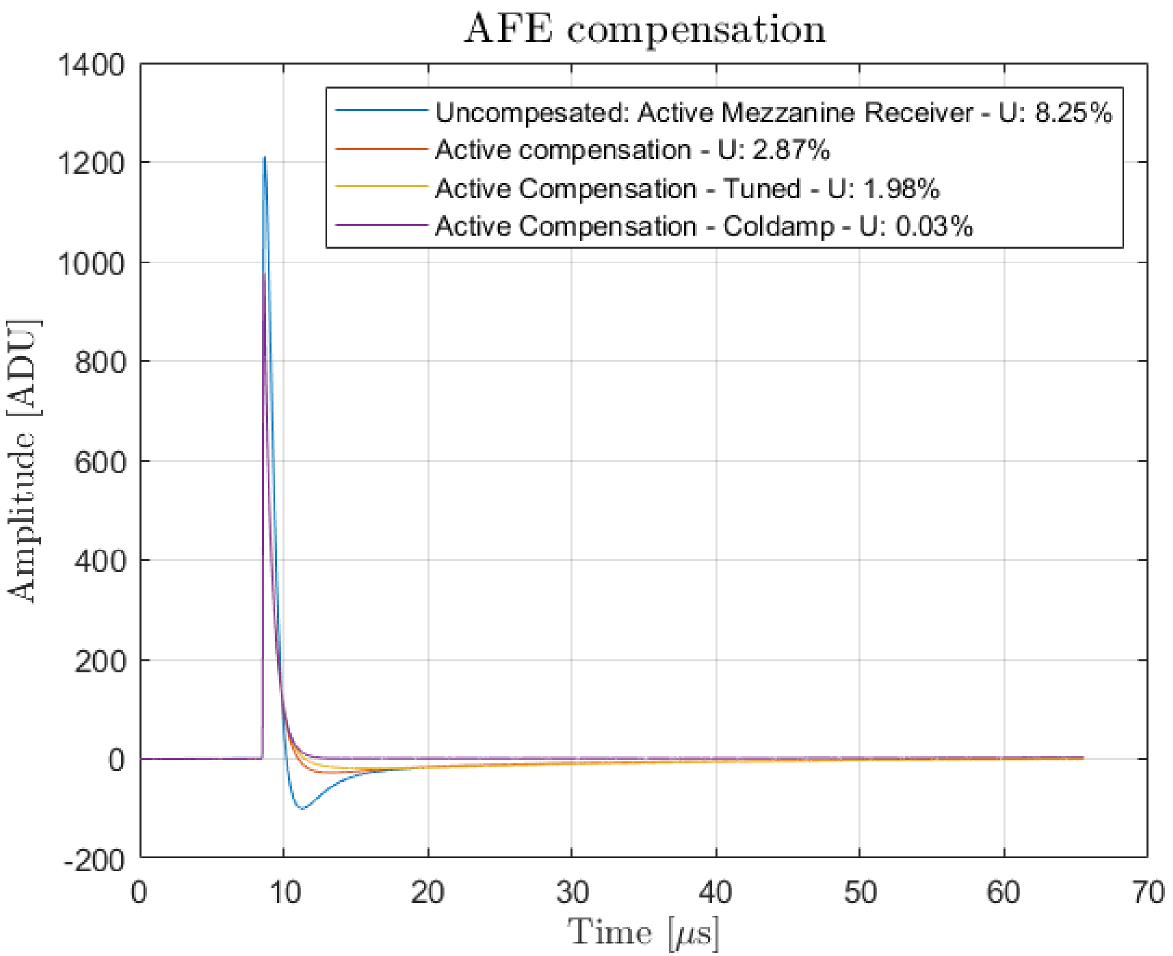
DAPHNE transfer function compensation - test

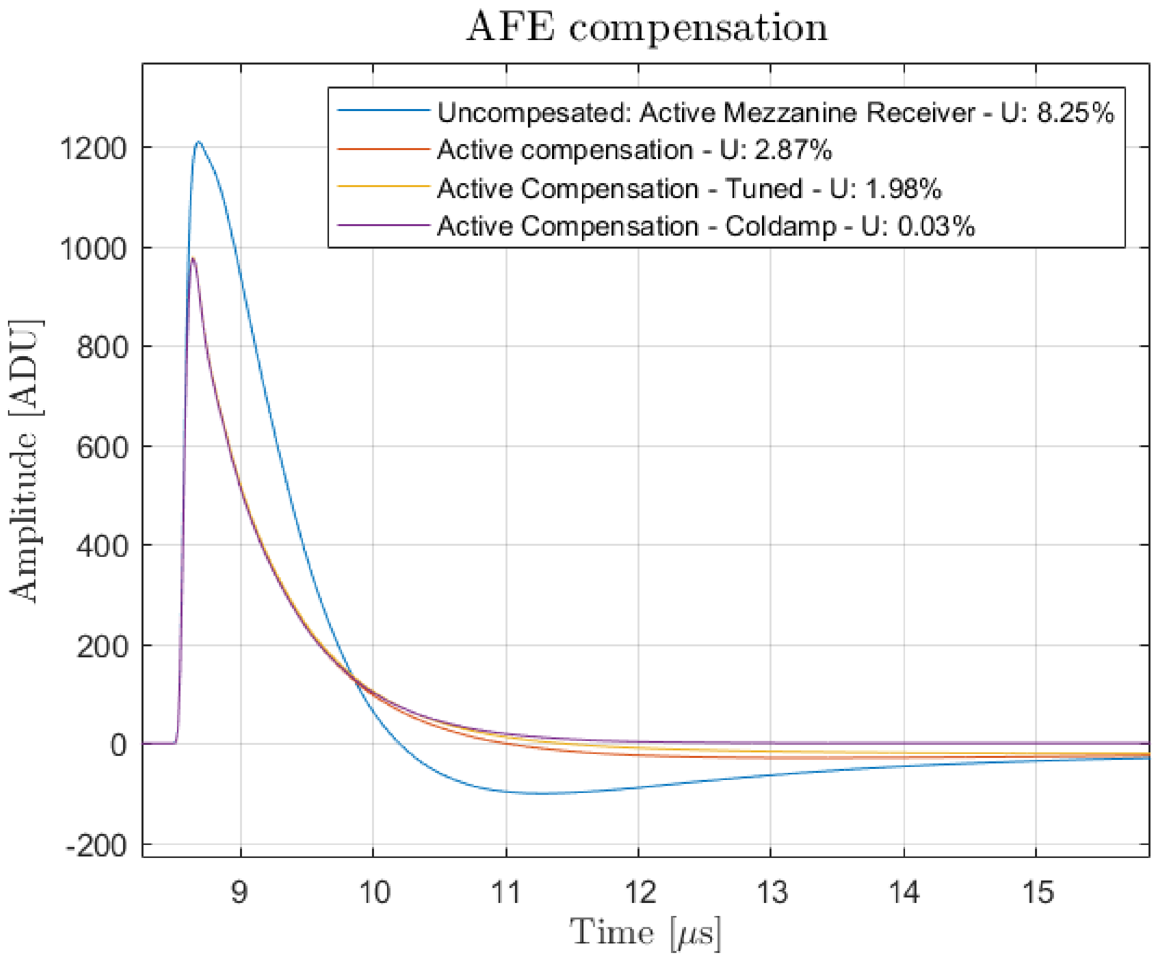




- The active receiver + the compensator was tested in Milano – Bicocca using the DMEM FBK system.
- The resulting undershoot level is at 1.29%.

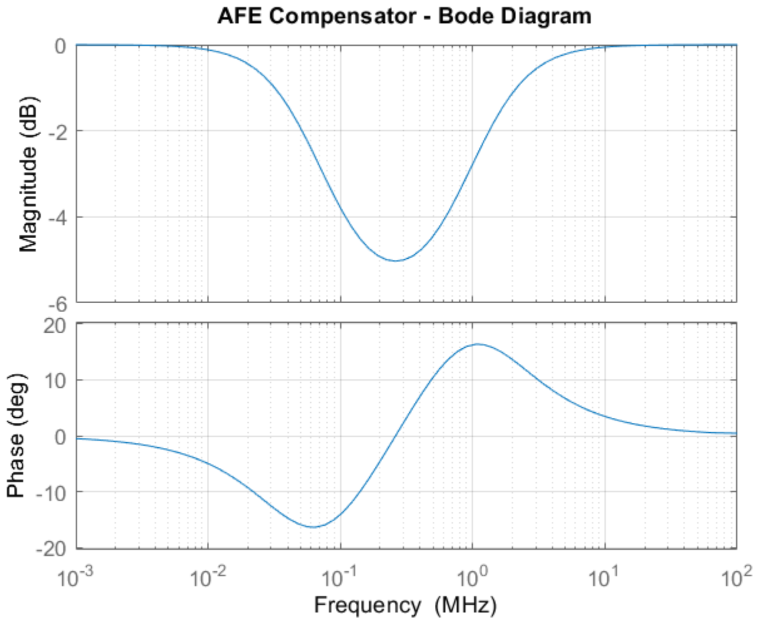
DAPHNE transfer function final compensation

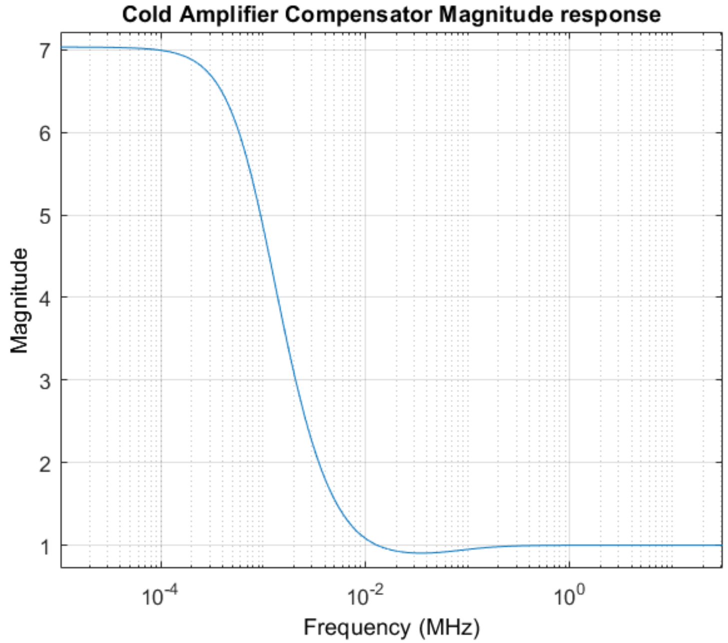


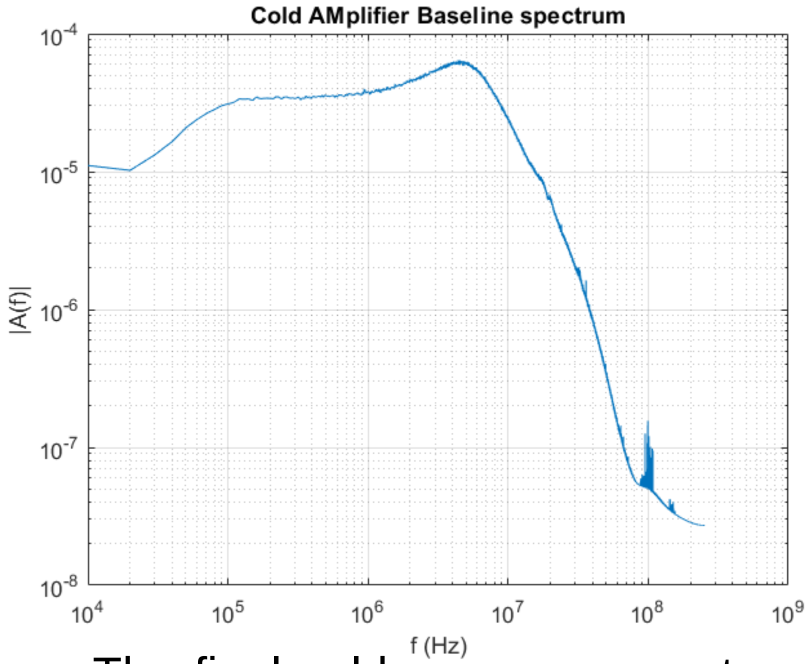


- The remaining undershoot is attributed to AC coupling in the system (cold amplifier).
- A similar procedure can was done to design a final compensator that can virtually eliminate the undershoot from the signal.

DAPHNE transfer function final compensation – Magnitude response

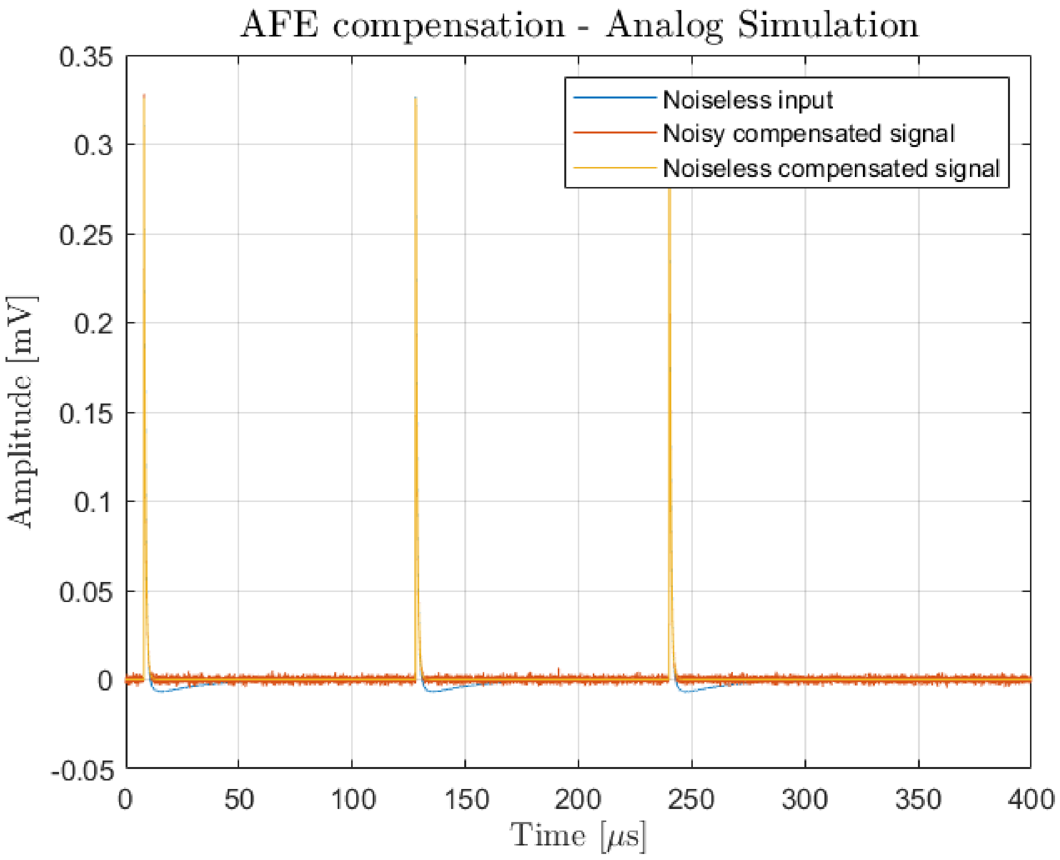


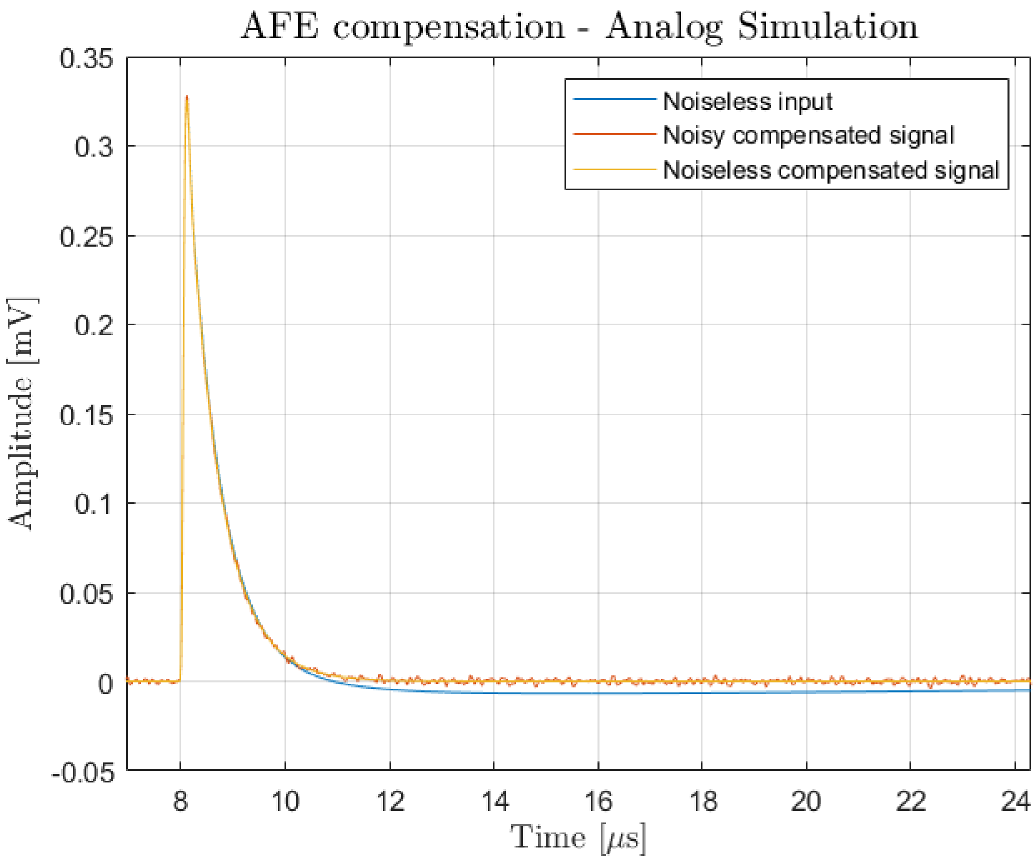




- The magnitude response of the AFE compensator does not amplify noise, therefore it can be implemented as a digital filter in DAPHNE's FPGA.
- The final coldamp compensator amplifies low-frequency noise, therefore it cannot be implemented in DAPHNE since it will amplify the 1/f noise injected by the AFE chip.
- The final coldamp compensator can be implemented as an analog filter, since the knee frequency is below the HPF cut-off of the cold amplifier.

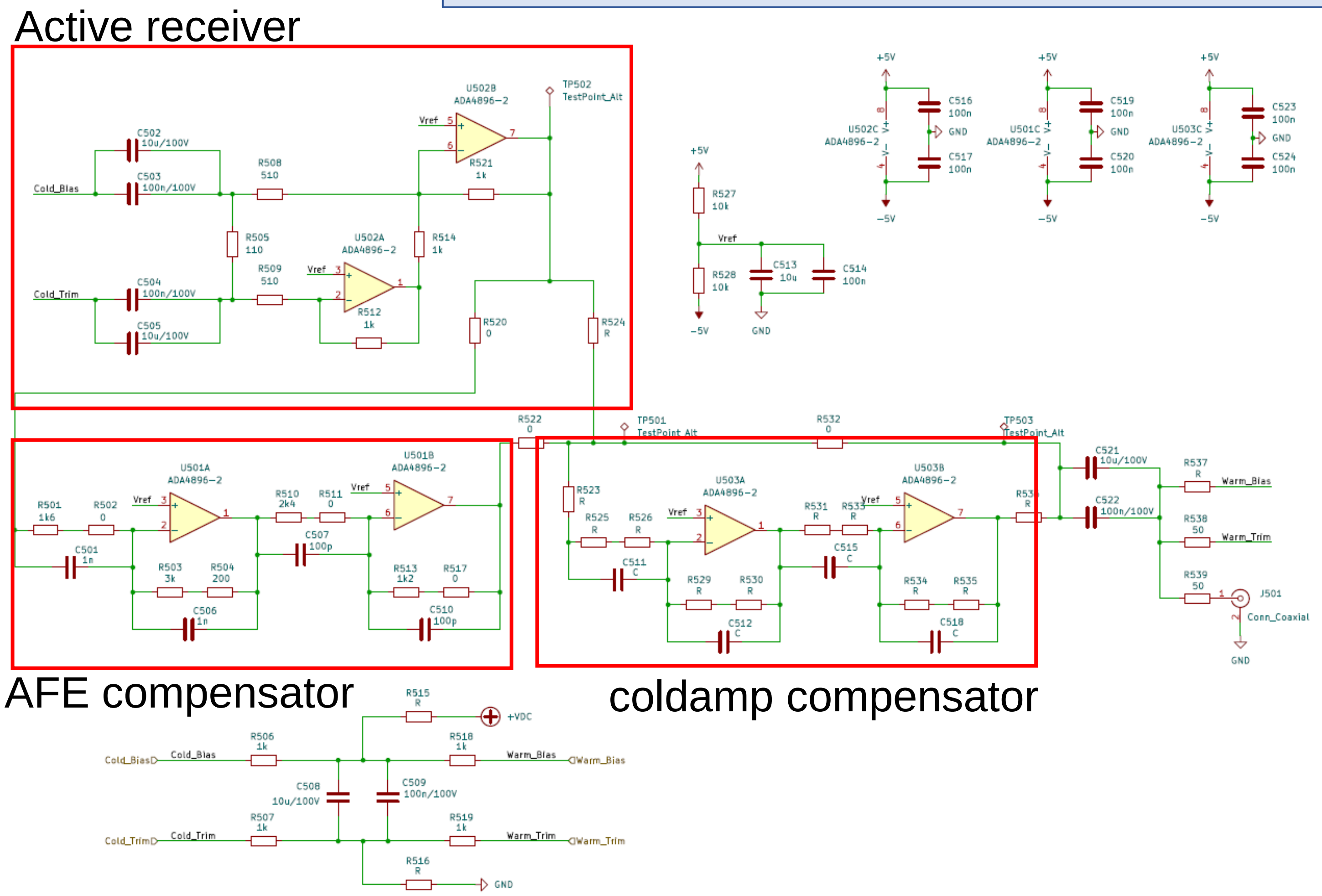
DAPHNE transfer function final compensation – Noisy simulation

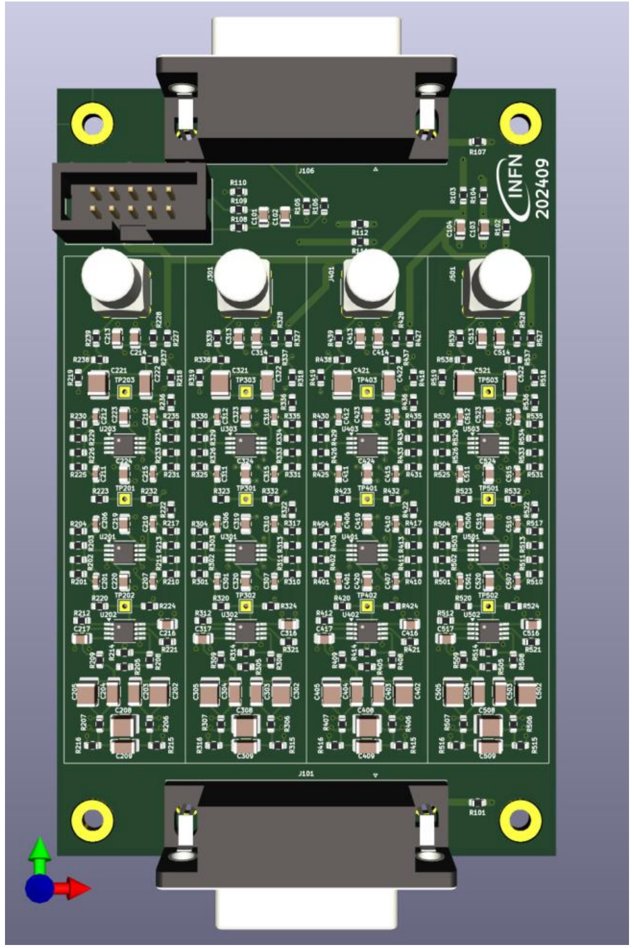




- The final coldamp compensator is simulated using noise data acquired at Milano-Bicocca.
- The simulation confirms that the filter has minimal impact on the noise and is stable in time.
- The actual noise performance and the final compensator was not yet to be tested.

DAPHNE transfer function final compensation – Noisy simulation





Conclusions

- The complete end-to-end simulation of DAPHNE developed at Milano-Bicocca allows to located the signal components causing the undesired signal undershoot.
- The active receiver allows to mitigate almost all the undershoot introduced by the transformer receiver.
- The AFE with integrators OFF does not have an all-pass transfer function. The resulting transfer function introduces around 8% undershoot in the signal.
- A digital AFE compensator was designed to nullify the effect of the poles identified to cause the excess undershoot. This compensator is stable and can be implemented as a digital or analog filter since it does not amplify any frequency spectrum.
- The AFE analog Lead-Lag compensator was tested as a second stage after the active receiver, producing a signal with 1,29% undershoot.
- A final analog Lead-Lag compensator can be implemented, removing almost entirely the undershoot of the signal. Although it amplifies low-frequency noise, the knee frequency of the compensator is below the high-pass cut-off of the cold-amplifier having almost no impact in noise behaviour, according to simulations.
- The active receiver and compensators board has been designed for 4 channels and we intend to test it at the coldbox in November.