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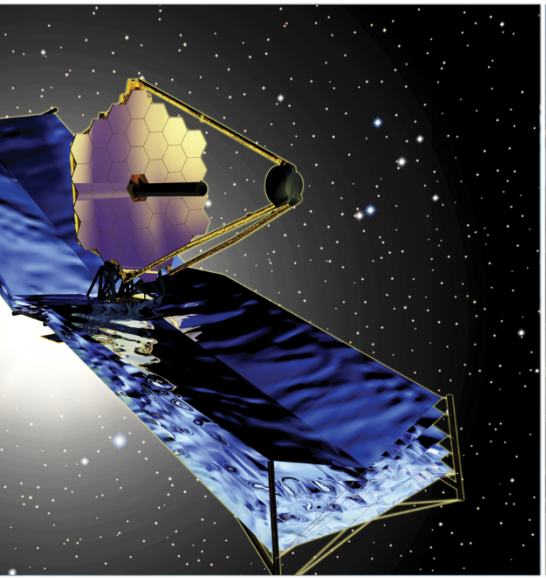

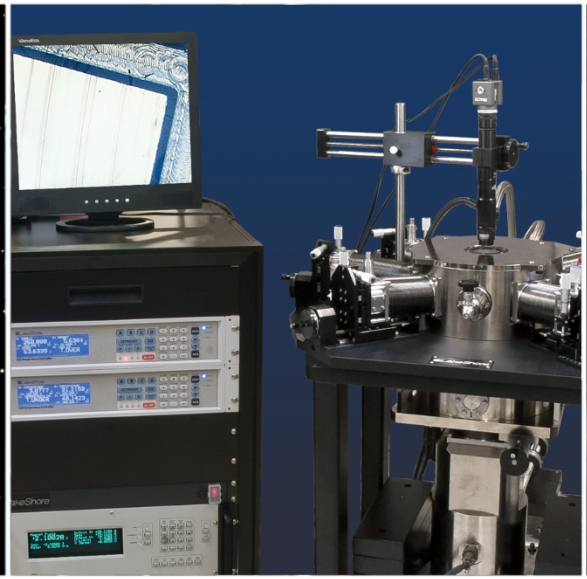

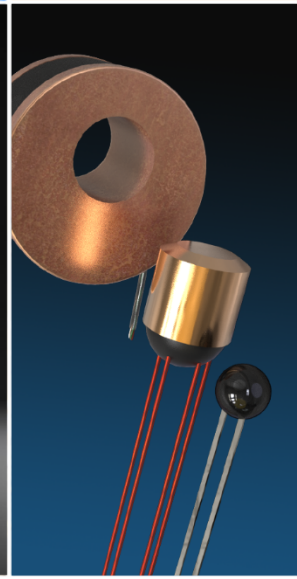

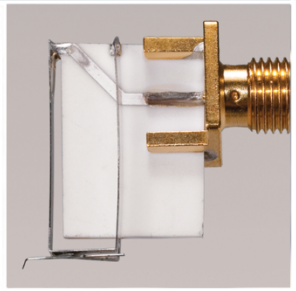

What do all of these Filters do?

Jeffrey Lindemuth

Outline

- Types of filters used in the M81
  - Demos using the M81, with up to 4 VM modules in lock-in mode
  - Sources are up to 2 VS modules
  - White Noise generator is a SRS DS360
- Why use filters
  - Input filters
  - Output filters
    - Infinite Impulse response (IIR) filter (low pass filter)
    - Finite Impulse response filter (FIR) (moving average filter)
    - Hybrid filter, a combination of IIR and FIR
- Which filters are best

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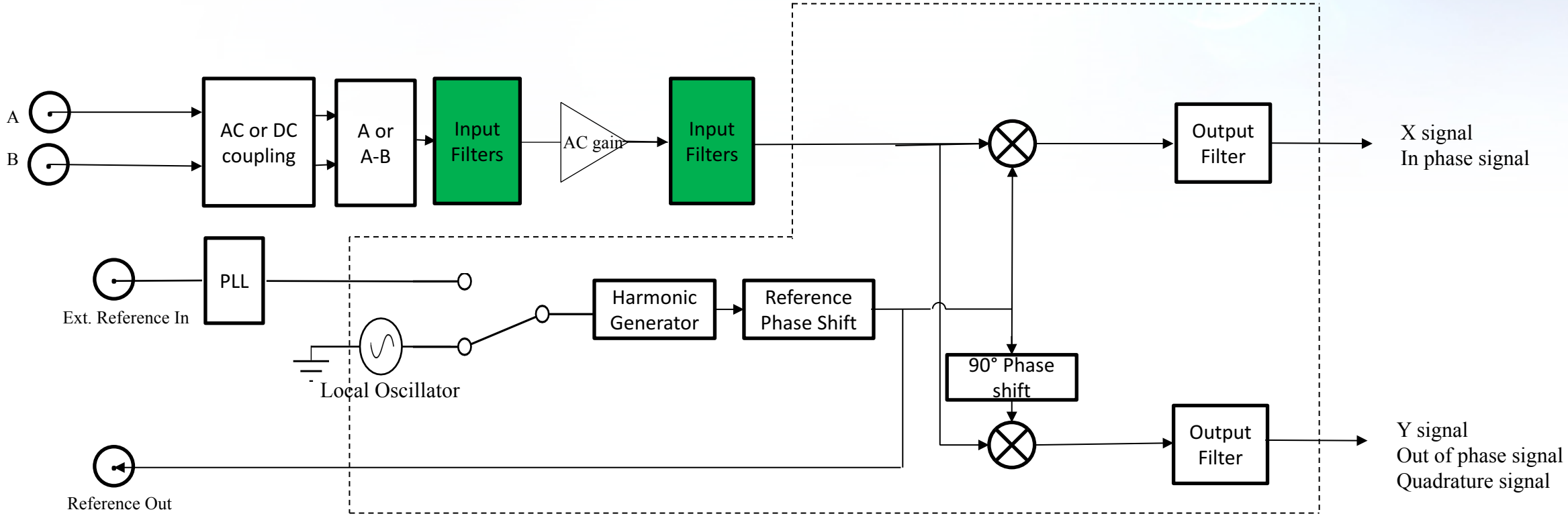
M81 Lock-in simplified block diagram

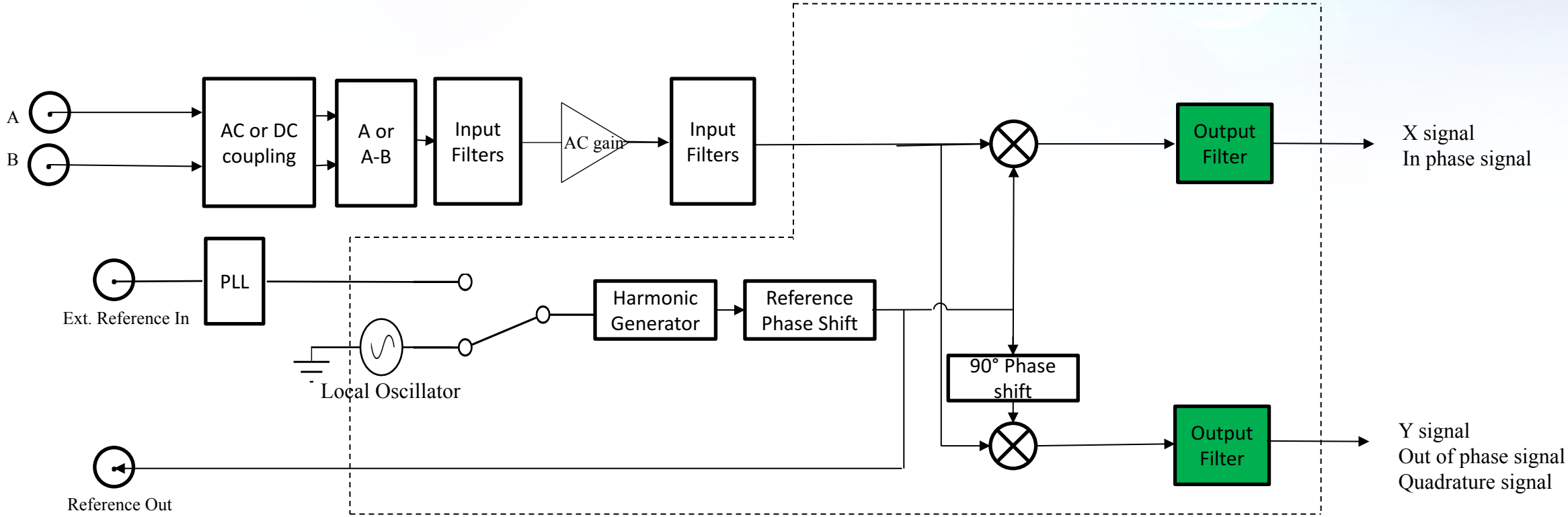


Input filters

- The input filters are used to reduce the amplitude of unwanted spurious signals
  - These signals can overload the amplifiers of the VM.
- The demo
  - Signal of interest is 100 Hz 1 mV
  - The spurious signal is 10 mV at 2000 Hz
  - Input filter is 300 Hz 12 dB slope

We can see the suppression of the 2000 Hz signal by a factor of 40.

M81 Lock-in simplified block diagram



Output filters

- Output filters are used to decrease the noise after the lock-in product detector.
- They also reduce any f and 2f in the output of the product detector

IIR step response

- IIR filter
  - Low pass filter with a time constant and slope
  - Higher time constant reduce the noise and increase the settle time

Roll-off	ENBW	1%	0.10%	10 ppm
dB	τ is time constant	Seconds	Seconds	Seconds
6	$\frac{1}{4}\ \tau$	4.61 τ	6.91 τ	11.51 τ
12	$\frac{1}{8}\ \tau$	6.64 τ	9.23 τ	14.24 τ
18	$\frac{3}{32}\ \tau$	8.41 τ	11.23 τ	16.55 τ
24	$\frac{5}{64}\ \tau$	9.98 τ	13.03 τ	18.65 τ

- Demo
  - 4 VM modules in lock-in mode, 83 Hz reference, each IIR filter is a 1 second time constant, but different slopes.
  - 10 volt PTP white noise added to to the 83 Hz signal.
- We notice:
- The 6 dB filter settles the fastest
- The 24 dB filter has the lowest noise

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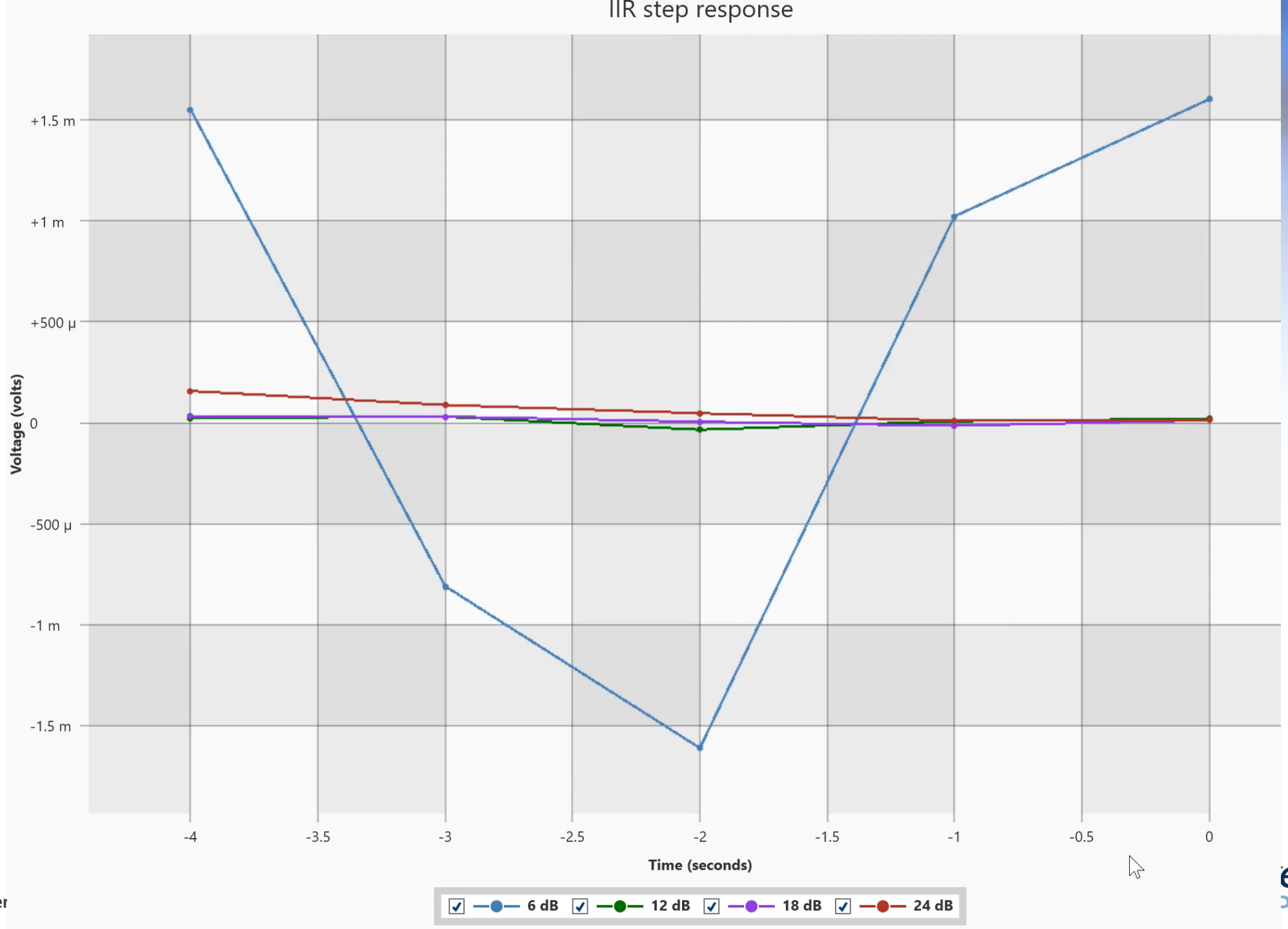
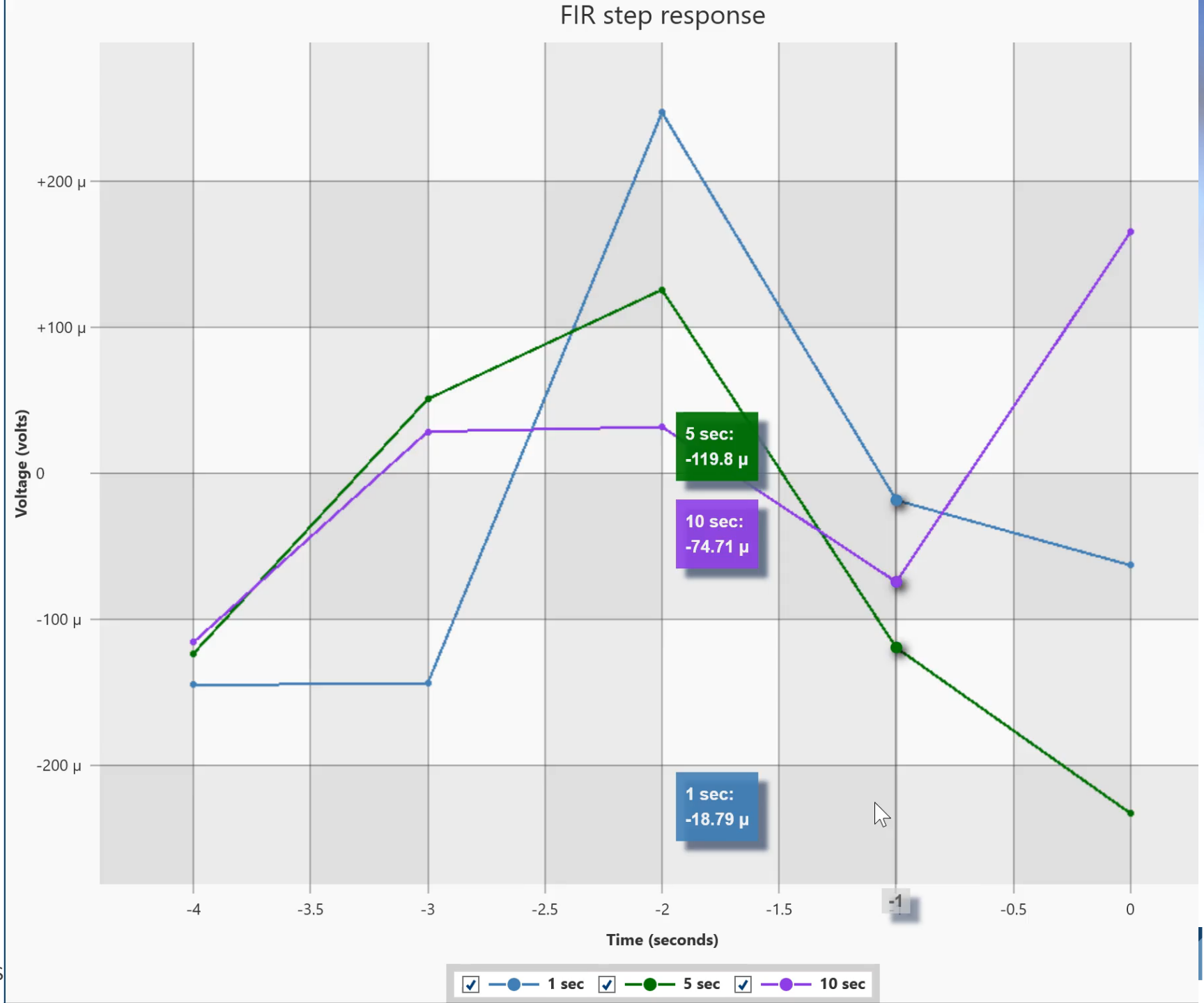

IIR step response
+1.5 m
+1 m
+500 µ
0
-500 µ
-1 m
-1.5 m
Voltage (volts)
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0
Time (seconds)
6 dB
12 dB
18 dB
24 dB

FIR step response

- FIR filter
  - Moving average filter with an averaging time
  - Longer average time reduces the noise.
- Demo
  - 3 VM modules in lock-in mode, 83 Hz reference
  - Each VM output filter is a FIR filter with average times of 1, 5, and 10 seconds
  - 1 volt PTP white noise added to to the 83 Hz signal.
- We notice:
- The filters settle, linearly, in one average time
- The 10 second filter has the lowest noise.



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Hybrid filters

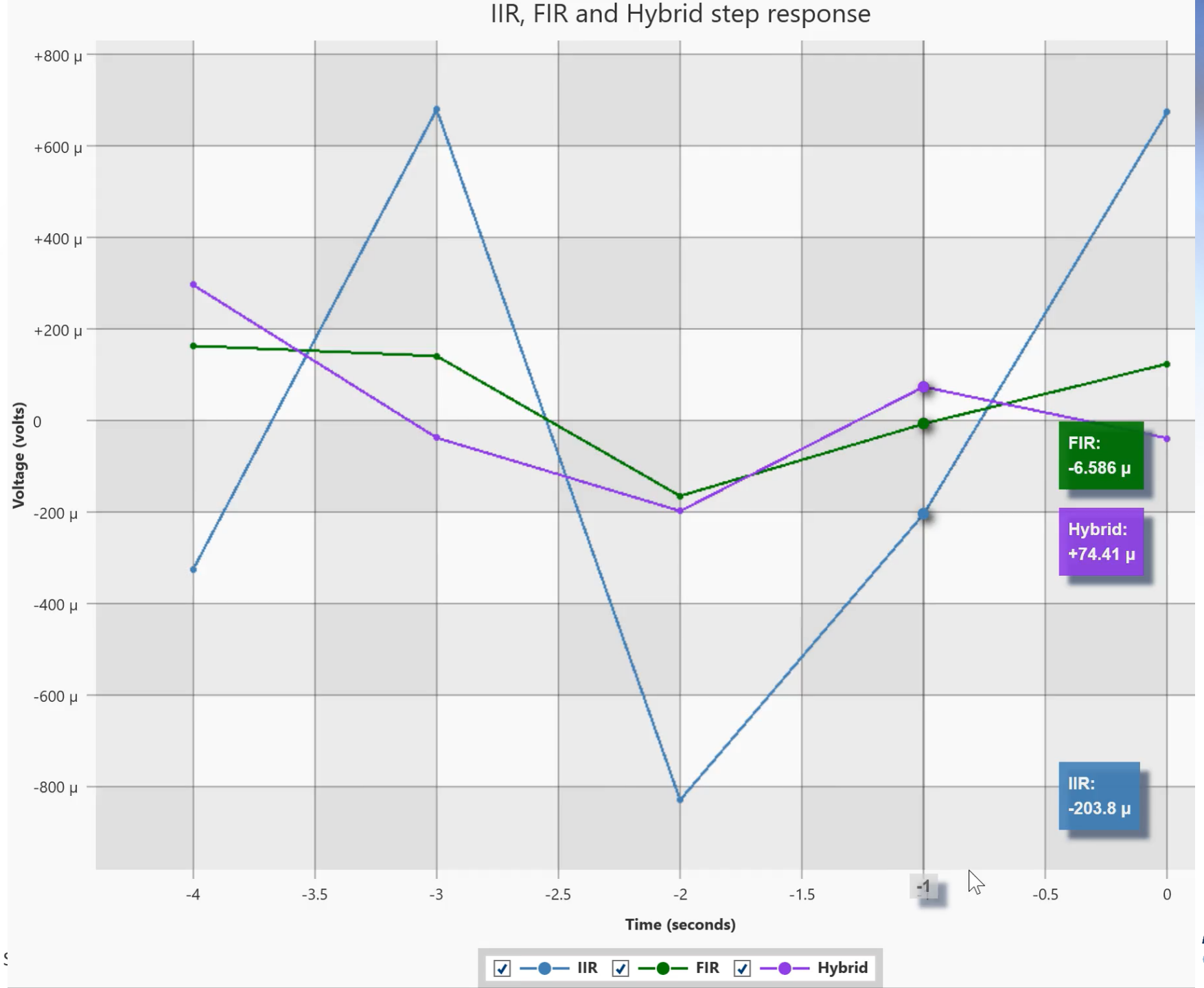
- The M81 can use both an IIR and FIR filter as the output filter.
- In general, the settle time depends on the ratio of time constant to the average time, and the slope of the IIR filter.
- We will consider the special case where the IIR is a 12 dB filter and the ratio of the time constant to the average time is 0.1:

$$t_{settle} = 1.6772\, t_{average}$$

$$t_c = 0.1 t_{average}$$

Hybrid filters

- In this demo three VM measure the same signal with noise. The signal is a 10 mV sine at 83 Hz. White noise of 10 volt PTP, crest factor 11 dB, is added to the signal and then measured in lock-in mode.
  - The first VM use an IIR filter, tc = 0.108 seconds, slope 12 db (1 second settle to 99.9%)
  - The second VM use a FIR filter average time 1 seoncd
  - The third VM is a hybrid filter tc = 0.0590; average time 0.590 (1 second settle to 99.9%)
- In this example there is not much difference between the FIR and hybrid filter. This is because the noise is perfect white noise, for which the FIR is very good filter.



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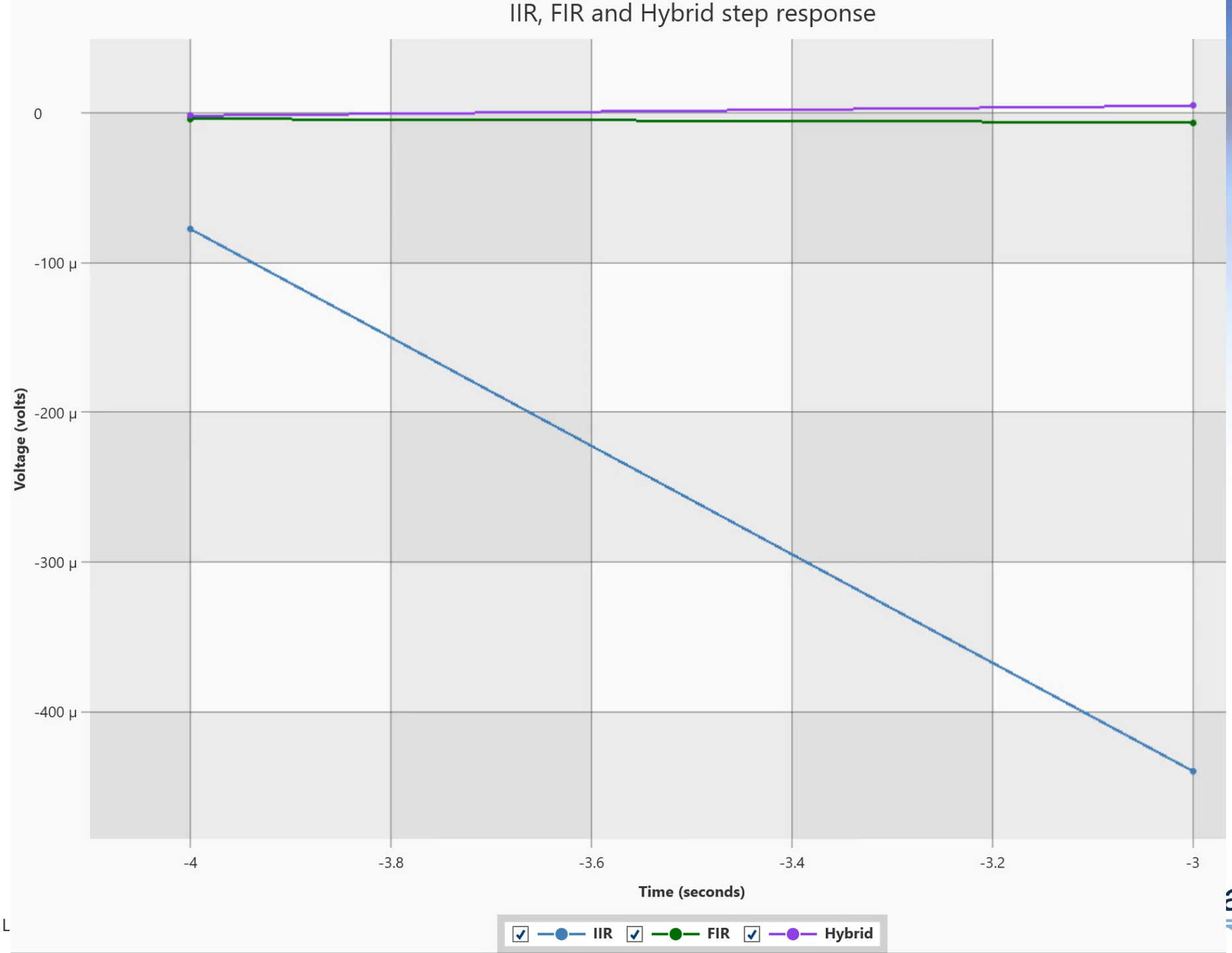
Hybrid filters

- When there are spurious signal present in the measurement the FIR filter does not provide the best noise reduction.
- In the second example the signal the M81 is set up as before, but there is no white noise. Instead, a signal at 124.5 Hz is added to the signal. The “noise” is actually the beating between the two signals.
- In this case the FIR has the most “noise” and the hybrid filter is better than the IIR filter.


IIR, FIR and Hybrid step response
0
-100 µ
-200 µ
-300 µ
-400 µ
Voltage (volts)
-4
-3.8
-3.6
-3.4
-3.2
-3
Time (seconds)
IIR
FIR
Hybrid