APPLICATION BRIEF

FIR vs. IIR filtering for faster lock-in measurements

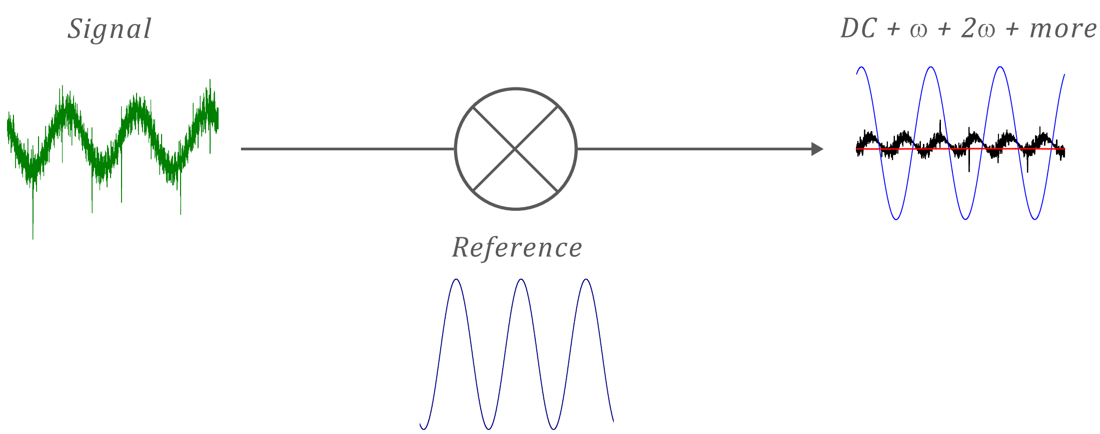

Figure 1: *Lock-in product detector. The input stage of a lock-in measures a voltage signal that contains an AC modulated signal (at frequency ω), a DC offset, noise, and AC signals at other frequencies. The DC component of the post-mixed signal contains information about the signal at frequency ω while other components need to be removed by the output filter.*

How do you measure AC signals when the noise is larger than the signal?

Lock-in amplifiers can measure AC signals in the presence of noise much larger in magnitude than the signal. Lock-ins achieve this high degree of sensitivity by mixing the measured signal with a single-tone AC reference signal (**Figure 1**). The output of the mixing results in a DC voltage of which the magnitude depends on the size of the signal at the reference frequency, but also includes other AC voltages (notably at the reference frequency) that need to be removed. To isolate the DC voltage (the desired signal), these higher-frequency components are removed with the so-called output stage filter.

Traditionally, a low-pass recursive filter (RC filter), also known as an infinite impulse response (IIR) filter, has been used as the output stage filter. For suitable rejection of these higher-frequency components, the IIR filters require long wait times for settled values. In this application brief, we will introduce an alternative filter, the moving average filter, or finite impulse response (FIR) filter, and demonstrate the measurement advantages of this filter over the traditional IIR filter.

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The IIR filter quandary and the FIR filter advantage

As the name implies, the output of an IIR filter approaches the final value exponentially, and like Achilles and the tortoise, never completely reaches the final value. For instance, a 12 dB roll-off filter with a 1 s time constant takes 6.6 s to settle to a value that is 99% of the final value. Higher-value roll-off filters and longer time constants are used in a lock-in measurement to improve rejection of the harmonics in the output stage and lower the noise of the measurement; however, this improvement in signal quality comes with a substantial increase in settle time and a slower lock-in acquisition (**Table 1**).

IIR filter roll-off	6 dB	12 dB	18 dB	24 dB
99% settle-time	4.6 τ	6.6 τ	8.4 τ	10.1 τ

Table 1: *Time for a IIR filter to settle to 99% of final value for a chosen time constant, τ.*

The FIR filter implementation uses a moving average with a user-selected averaging time. In the M81-SSM synchronous source measure system, the FIR filter time is set in reference frequency cycles; for example, with a 10 Hz reference frequency, a 1 s averaging time is 10 cycles while a 2 s averaging time is 20 cycles. The key advantage of the FIR filter is that the measurement settles to exactly 100% of the final value in the averaging time (**Figure 2**). For the same noise reduction of the output filter, the FIR filter will always settle faster than a IIR filter, which often results in significant reduction in overall measurement time.

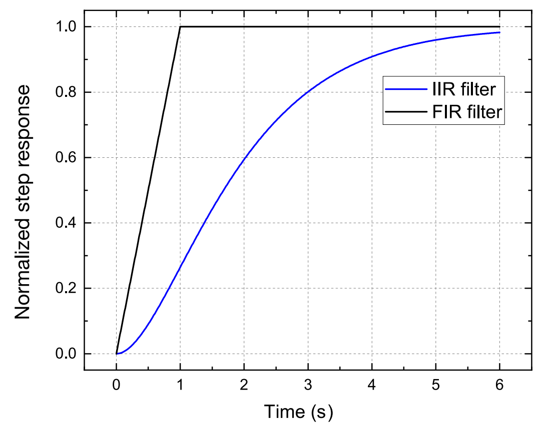

Figure 2: *Comparing the settle time of comparable IIR and FIR filters.*

Measurements with a 10 mΩ resistor

A current-dependent AC resistance measurement of a 10 mΩ resistor demonstrates the performance of the two filtering methods. An M81-SSM system was outfitted with a BCS-10 balanced current source module which varied the 83 Hz RMS current excitation of the resistor from 100 nA to 10 μA. At each excitation, a VM-10 voltage measure module acquired 75 data points at intervals determined by the filter settle time. The mean and standard deviation were calculated and divided by the excitation current to determine a measured resistance and uncertainty. In this measurement, the output filters were configured to produce a 0.05 Hz equivalent noise bandwidth, or ENBW. A 10 s filter time was used for the FIR filter, and the IIR filter used a 12 dB roll-off with a 2.5 s time constant. The measurement time per point for the FIR filter was 10 s while the measurement time per point for the IIR filter was 30 s or 3 times longer than the FIR. Both the average value and the error bars are similar for both filter configurations (**Figure 3**).

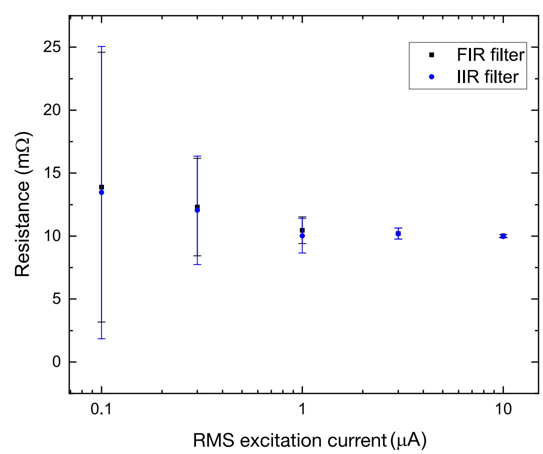

Figure 3: *Comparing FIR and IIR lock-in filtering with M81-SSM AC resistance measurements of a 0.01 mΩ resistor and varying current excitation.*

Conclusion

The output filter is a key component of lock-in detection. Using the M81-SSM FIR output filter feature often allows for faster measurements at the same signal to noise ratios compared to the IIR filter. In circumstances where the measured signal contains large interfering signals or signals in close proximity to the reference frequency, the IIR filter may show better noise rejection compared to the FIR filter. In these cases, the M81-SSM allows users to easily switch between FIR, IIR, and hybrid FIR/IIR output filtering. Hybrid filtering, including settling times, will be detailed in future application briefs.

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