Selecting the Right Filter for Data Acquisition

In this article, we will define what a filter is and present different types of analog and digital filters. We will also address the use of filters and the issues with different types that should be considered when recording and analyzing data.
Lastly, this article shows the available types of filtering available in HBM data acquisition systems and how to choose and configure them to get accurate measurements.

But first, what is a filter?

Filters can be found in almost every electronic circuit. They're used in audio systems for pre-amplification, equalization, and tone control. In communications, filters are used for tuning in specific frequencies and eliminating others.
A filter determines the amount of attenuation that the amplifier provides and at what frequency that attenuation begins.

Why should we use filters?

In measurement applications, involving data acquisition and recording (*figure 1*), analog signals must be converted into digital**. Filters are used to remove noise or unwanted signal components in order to ensure proper A/D conversion.**

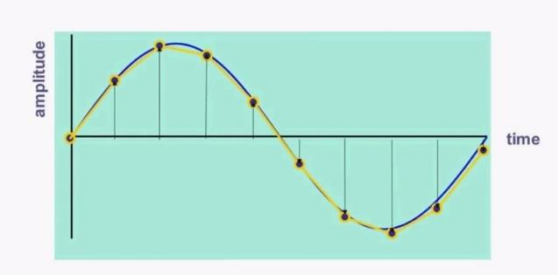

Figure 1: representation of the sine wave being acquired

In a basic circuit, an analog signal is sent into a signal amplifier.
Then, in the analog-in section of the amplifier, the gain and signal conditioning execute functions, such as conversion from current to voltage, voltage excitation amplitude gain, and voltage level shifts for connected sensors.
That's when the use of optional analog low-pass or anti-aliasing filters takes over. **These filters can be used to reduce out-of-band frequencies that can degrade the analog-to-digital conversion.**
Next, the signal is digitized. This digital conversion from the ADC transmits a digital representation of the gain filtered analog signal to a digital processor.
Finally, secondary digital filters are applied to the signal and then data is stored and analyzed.

Choosing the right filter

There's no such thing as a perfect filter as shown in *figure 2.* Thus, the pros and cons of each type of filter should be weighed before an educated decision is made. Measurement priorities will determine which method should be chosen and which filter mode works best in each case.

Picking the right filter depends on the type of signal we wish to record.

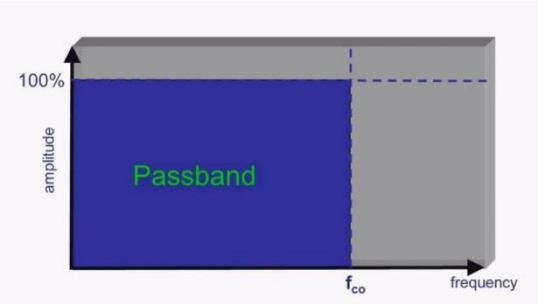

Figure 2: ideal filter

The analog filters

Analog filters are used to prevent aliasing and out-of-band noise, but also to protect signals from outside interference. They prepare the signal for acquisition and come in two forms:

- Anti-aliasing
- Signal

Anti-aliasing filters prevent signals faster than half of the system sample rate from being recorded or “under sampled”. Under sampling leads to spurious displays of nonexistent signals, i.e., "aliasing" (*figure 3*). Filters in the circuit that prevent such from happening are called "anti-aliasing filters."

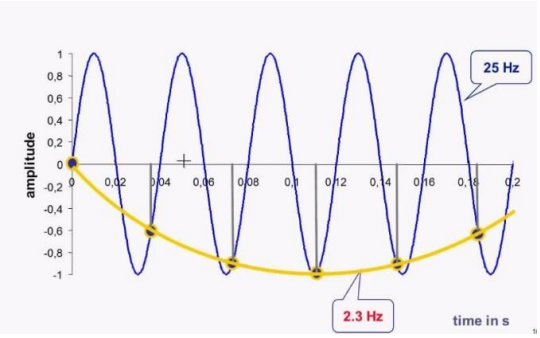

Figure 3: aliasing

Signal filters are typically used to:

- suppress unwanted frequencies
- eliminate noise
- prevent false triggers on spurious events. An example would be to suppress high frequency noise injected into lead wires and sensors.

The digital filters

A digital filter can be more precisely programmed. It uses an algorithm that simulates what the analog filter does. Digital filtering cannot eliminate noise peaks on the original signal like an analog. Such filters use oversampling and averaging techniques to reduce noise. Since the digital filtering occurs after the analog to digital converter, these can be far more flexible.

The side effects of filters

While useful, filters have drawbacks that should be taken into consideration, such as:

- amplitude errors near the cutoff frequency
- phase shifts in channels

In large-scale structural test with dozens of channels, for example, time alignment is crucial and even a small phase mismatch can cause issues in analyzing data properly.

However, phase shifts can be overcome in digital post process filtering by second filtering in reverse order. This is known as „phase less filtering“.

How does the filtering within HBM data acquisition systems work?

HBM offers a wide range of data acquisition systems, such as lab-based, and multiple small rugged multi-channel systems.
Typically, HBM has available three types of front-end analog filters: **Bessel, Butterworth**, and then a **wideband filter** set by default.

The Gen DAQ system

HBM Genesis HighSpeed – GEN DAQ – is a modular data acquisition system for fast measurements of electrical and mechanical parameters (*figure 4*).

Figure 4: image composition of Genesis HighSpeed data acquisition system

The GEN DAQ system offers a selection of front-end **analog filters** and an optional secondary **digital filter**.

- **Analog – Wideband:** in the absence of a filter, the limiting factor for the bandwidth is caused by input resistance and capacitance. Wideband means there are no extra filters in it. It provides the best signal fidelity and phase matching, but there's no aliasing protection or noise reduction.

- **Analog – Bessel**: usually used in time domain recordings. It has good high signal fidelity for transients and statistical inputs. It also features excellent impulse response, with almost no overshoot. However, the phase shift is significant. It's good for time domain, bad for frequency domain measurements. This allows the Bessel filter to be a good choice when taking transient measurements, as the shape of the waveform will be very well represented. This is the case of mechanical or ballistic applications or one-time event where accurate waveform shapes are a top concern.

- **Analog – Butterworth:** used for frequency domain analysis. It has great slope and phase matching, but there will be lots of overshoot and pre-shoot in transient or single-shot events, if the speed is too close to the selected sample rate. It should be considered for sinusoidal measurements in applications that involve FFTs, vibration analysis, shock response and harmonic measurements.

- **Digital:** a digital IIR – Infinite Impulse Response – filter is a mathematical method for filtering data. It allows the emulation of different analog filters, but mostly behaves as a Bessel style filter. A digital FIR filter is known as a Finite Impulse Response. It also emulates other filters, but mostly acts as the Butterworth type of filters. This type of filters cannot prevent aliasing and are applied to a filter after A/D conversion.

How do Gen DAQ products approach filtering?

Depending on the type of measurements needed, different input boards are available. To achieve proper filtering, input boards offer flexibility when it comes to choosing the filter type and cutoff frequency. The options include analog filters, digital filters, and digital data decimation.
In the end, the GEN DAQ systems allow the user to select between different types of filters:

- Wideband or bypass filters;
- The Bessel and Butterworth filters;
- Fixed frequency filters (with no switching);
- Digital filters and decimation (in the later filter stages);
- Automatic anti-aliasing filters. The filter frequency is switchable to give the best

fit for the application. Then selecting a ratio between the filter frequency and the sample rate allows the filter to be used as a noise reduction filter.

Analog filtering is more suitable for high speed systems, i.e. greater than 5 or 10 kilohertz. However, the possibility of anti-aliasing should be taken into account. Thus, the sample speed of the digitizer has to be considered.

Filtering and data acquisition final considerations

There are many things to consider when making measurements.
One consideration is that filters are part of the signal path when acquiring data. Knowing what filters are available and how they will affect data will ease the process of preparing measurements and acquire data.
Another key is to provide valid input to output data over the frequency range of interest. Anti-aliasing filters and signal filters are useful but there are pros and cons that need to be considered before using them.
Finally, when using filters during the acquisition, all channels should be set to the same settings to avoid any phase shift mismatches.
That's why choosing the right filter is fundamental.

Learn more on GEN HighSpeed DAQ at www.hbm.com/en/1448/genesis-high-speed-data-acquisition-system/

About HBM Test and Measurement

Founded in 1950, HBM Test and Measurement is today the technology and market leader in the field of test and measurement. HBM's product range comprises solutions for the entire measurement chain, from virtual to physical testing. The company has production facilities in Germany, USA, China and Portugal and is represented in over 80 countries worldwide.