

Measure frequency response on an oscilloscope

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Oscilloscopes are time-domain instruments, but because they digitize waveforms, oscilloscopes can process time-domain signals into the frequency domain. The FFT (Fast Fourier Transform), spectrum analyzer options, and similar frequency domain tools, let you measure a circuit's frequency response with an oscilloscope. You can use several types of input excitation signals to measure frequency response: step functions, swept sines waves, white noise, and phase-modulated carriers.

The simplest type of frequency response measurement requires a signal source with a spectrally "flat" response in the frequency domain. This means that the signal spectrum is constant across all frequencies of interest. Swept sine waves, white random noise, and the Dirac impulse function all provide flat responses and all are available in arbitrary waveform generators. Keeping in mind that the impulse function is the derivative of a step function, it is also possible to use a fast edge or step signal from the oscilloscope to do frequency response testing. This later fact means that the oscilloscope can make self-contained frequency response measurements.

Step function

Our first example uses the step function to excite a digital filter, from which we measure frequency response. **Figure 1** shows all the steps involved in this measurement.

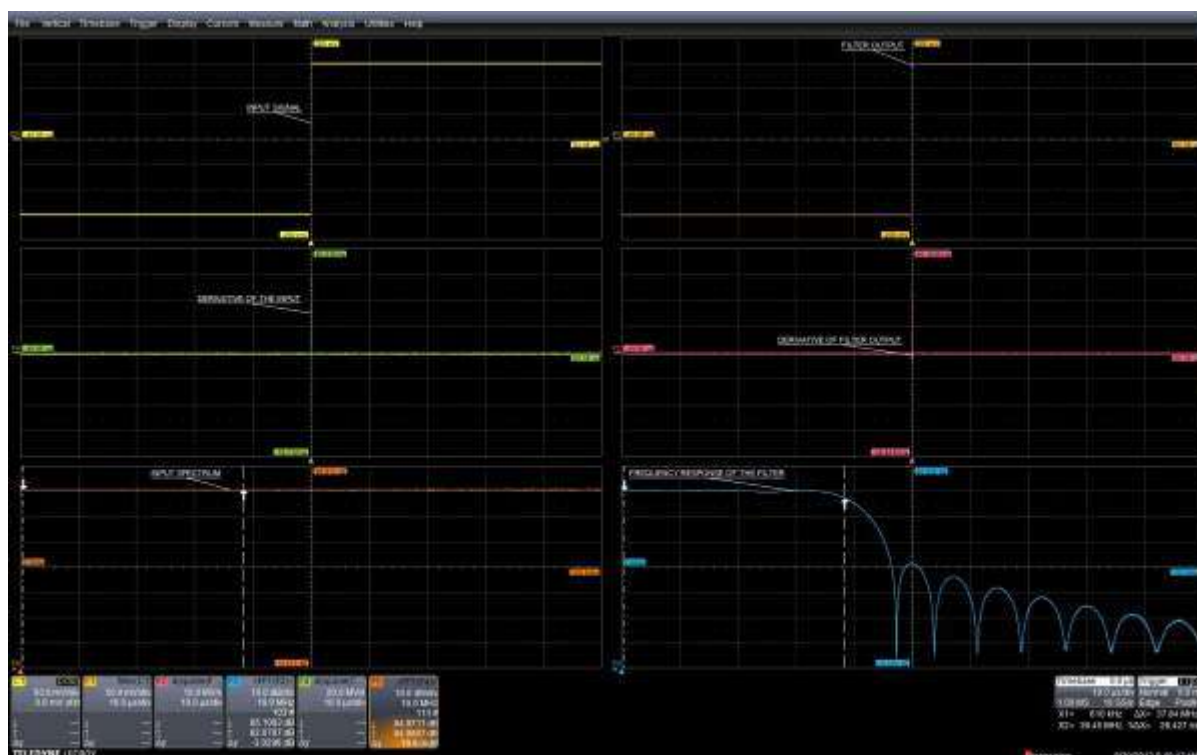


Figure 1. An FFT function lets you measure the frequency response of a digital filter that's excited by a step-signal source.

In Fig. 1, we use a step waveform as the input signal. The oscilloscopes "fast edge" or "cal" signal could be used depending on the desired measurement bandwidth. The signal's bandwidth is inversely proportional to the step's transition time. To make the measurement, apply the input signal to channel 1, shown in the upper left trace.

Math trace F4, just below the trace of the input signal, differentiates the step input. This is an impulse function. Note that the derivative math function is sensitive to baseline noise, which you can counter by decreasing the effective sample rate using the oscilloscope's sparse function. You can reduce the sample rate to a minimum of twice the desired measurement bandwidth and still satisfy the Nyquist Criteria.

The next lower trace is the FFT of the impulse. It shows a flat frequency spectrum over the 100 MHz band of interest. Cursor measurements show that the spectrum of the impulse function is flat to within 20 mdB over the bandwidth of the filter being tested. The step function is also applied to the input of the digital filter. The filter's output is shown in trace F1, in the upper right. This is differentiated in trace F2 (right center). The differentiated output is applied to the averaged FFT in trace F3 (right bottom), which shows the output signal's spectrum.

Technically, the frequency response is the complex ratio of the output spectrum to the input spectrum. Since we have assured that the input spectrum magnitude is flat, the output spectrum represents the correct shape of the frequency response. Cursors measure the -3 dB point as having a frequency of 38 MHz.

Swept sine

The example shown in **Figure 2** uses a swept-sine input from an arbitrary waveform generator. The sweep is set up to cover 10 kHz to 200 MHz.

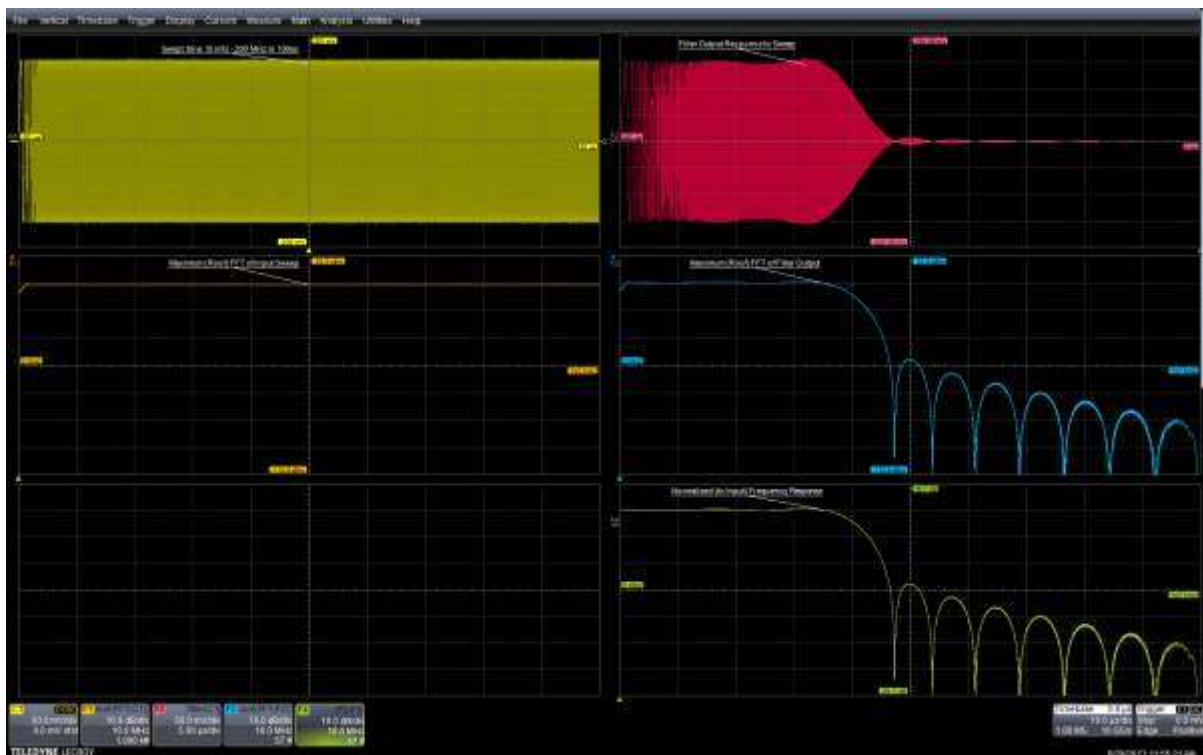


Figure 2. Using a swept sine to measure the frequency response of a digital filter results in a small "notch" as the input excitation signal starts (see center-right trace).

Because a swept sine wave steps through a range of frequencies, only one frequency excites the circuit under test at any given time. Thus, the peak of the FFT response must be captured and held. This is accomplished using the roof math function after the FFT. In other brands of oscilloscope this is called the maximum function. This is equivalent to the max hold function of an RF spectrum analyzer.

Again, the input is on trace C1 in the upper left. The FFT of the input appears in trace F1 (left center grid). The filter output time response is displayed in trace F2 (upper right) and shows the swept sine being attenuated as its frequency exceeds the low pass filter's cutoff frequency. The FFT of the filter output is contained in trace F3 (center right). The result of this measurement technique is very similar to the previous method. Note the small "notch" in both the filter input and output spectrum. This is a "startup" glitch in the swept sine.

If you divide the output spectral magnitude by the input magnitude, you'll normalize the measurement. Noting that the spectrum magnitude is displayed on a logarithmic scale, normalizing the output spectral response requires you to subtract the input power spectrum from the output power spectrum. See trace F4 (bottom right). The subtraction removes the notch at the low-frequency end of the spectrum. Again, this works because the input spectrum is basically flat. If that were not the case, then you'd need to calculate the complex ratio of the output-to-input spectrum.

White noise

White noise

The next example (**Figure 3**) uses white, random noise as the input source

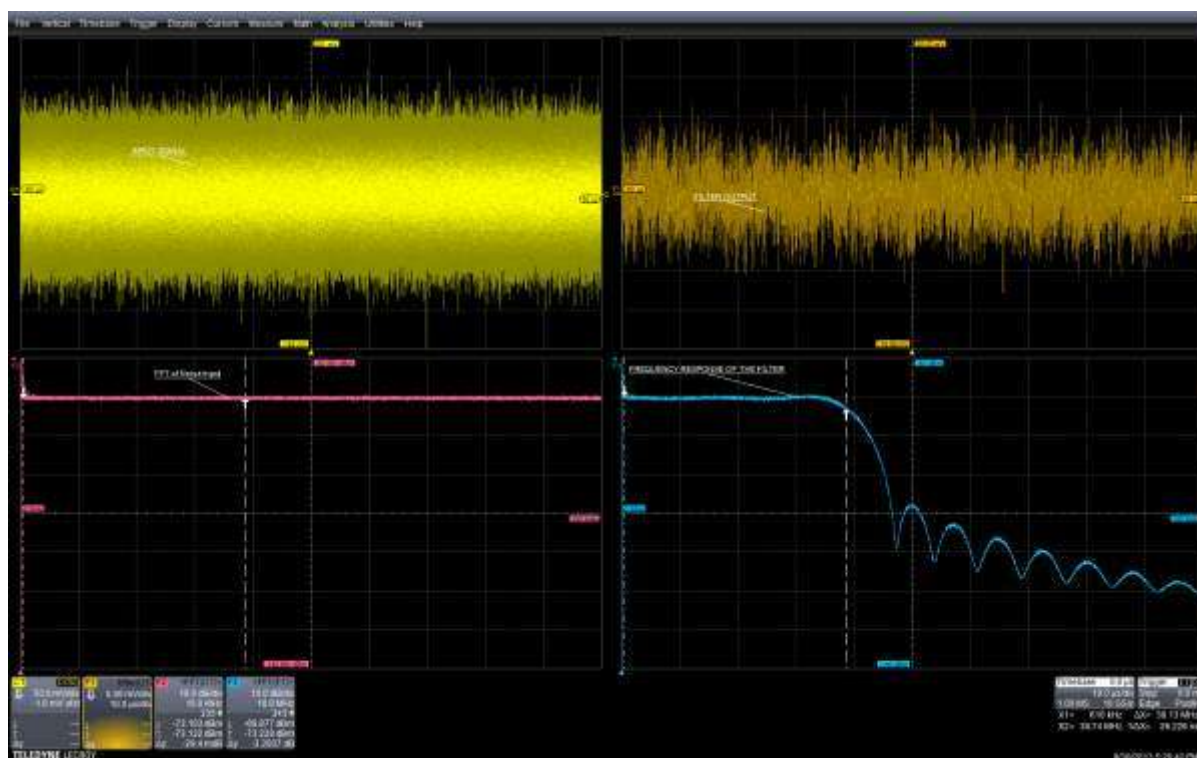


Figure 3. Measuring the frequency response of a filter using a white noise source requires using an averaged FFT.

The input signal, shown in the C1 trace (upper left), is white noise from an arbitrary waveform generator. The spectrum (averaged FFT) of the input signal is shown in trace F2 (lower left). Like all the other sources, this one also is spectrally flat. The same source is also applied to the filter and the filter output is shown in trace F1 (upper right). Trace F3 is the averaged FFT of the filter output and

shows the frequency response of the filter.

Note that the random noise source requires that we use the averaged FFT so we can see the mean response at each frequency. This is the only way to obtain statistically significant data from the white noise source.

Comparing the responses from all three methods, you can see that the swept sine technique produces the largest dynamic range as indicated by the depth of the notches in the spectrum. The noise source produced the poorest dynamic range because it has very high peak values but a relatively low standard deviation. This limits the maximum signal level that can be applied to the oscilloscopes digitizer. That limits dynamic range for this measurement, which could be improved by using a 12-bit instead of an 8-bit oscilloscope. The data from the step/impulse response is in the middle ground. The short duration of the impulse limits the total energy applied to the filter and causes a lesser dynamic range than the swept sine.

These measurements were made on a filter that responds to a voltage stimulus. You can apply similar techniques to devices which respond to other parameters. Take, for instance, a phase locked loop (PLL). It responds to a signal's phase. To find the frequency response of a PLL, use a PM (phase modulated) carrier as the input signal. The modulation source must be an impulse, swept sine, or spectrally flat noise. **Figure 4** shows a measurement of a PLL using a carrier modulated with a step function in phase.



Figure 4. Measuring the frequency response of a PLL using a phase modulated carrier lets you see changes in phase using the track function of the time-interval error parameter.

The input signal, from an arbitrary waveform generator, is a 66.7 MHz carrier phase modulated by a 2 radian step at the center of the trace. The arbitrary function generator produces a phase step with a transition time which is within a single sample clock period of the generator yielding a high modulation bandwidth. Normal signal generators have limited modulation bandwidth and may not provide sufficient bandwidth. The input signal is shown in trace C1 in the upper left corner. Trace Z4

is a zoomed view of the phase step in the upper right corner. The TIE or time interval error (instantaneous phase) of this signal is measured by parameters P1 and P2. Parameter P2 has its internal PLL turned on using a nominal bandwidth of 667 kHz (a cutoff factor of 100). It is the frequency response of this PLL that is being determined.

Math function F1, below C1, shows the track of the parameter P1. The track is a time-synchronous plot of the parameter value versus time. It shows the cycle-by-cycle change in the TIE measurement. It may be thought of as the instantaneous phase variation of the input signal. You can see the step function due to the phase modulation. The magnitude of the phase step is 4.958 ns, which at a carrier period of 15ns represents the 2 radian step amplitude.

The track of P1 is differentiated in trace F2 displayed below F1. The FFT of the differentiated step, in F3 (lower left) shows a flat frequency response out to 2 MHz. This is the spectrum of the input to the PLL.

The right side of the display, starting with the Track of P2 in math trace F4, follows the same steps for the PLL output. F5 is the impulse response and F6 is the spectrum of the output. The PLL within the TIE measurement exhibits a high pass characteristic with an upper -3dB point at approximately 667 kHz.

These examples show several methods and variants for measuring the frequency response of a device using an oscilloscope equipped with FFT, differentiation, sparse, averaging and extrema functions (roof/maximum). The step/impulse response method, requiring only the "fast edge" signal source on the scope, can be utilized without the need of an external signal source. The other techniques require an external generator. **Table 1** summarizes the characteristics of each method.

Table 1. Summary of input signals used to measure frequency response.

Method	Required Math Functions	Signal Source	Dynamic Range
Step/Impulse	FFT Average Derivative Sparse	Internal Step function such as 'fast edge'	Moderate (60 dB in the example)
Swept Sine	FFT Roof/Maximum	Sweep Generator or Arbitrary Waveform Generator	Excellent (70 dB in the example)
White Noise	FFT Average	White Noise Generator or Arbitrary Waveform Generator	Fair (50 dB in the example)

These techniques might save you a lot of time the next time you need to make a quick frequency response measurement.

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