Keysight Technologies
Bandwidth and Rise Time Requirements for Making Accurate Oscilloscope Measurements

Application Note

KEYSIGHT TECHNOLOGIES

Introduction

How much oscilloscope bandwidth do you need and how fast does the rise time need to be to measure your signals accurately? Oscilloscope users ask this question regularly, but getting a good answer is typically difficult. The answer depends on the frequency response roll-off characteristics of the signal under test (SUT); it must be down about 15 db or more at the scope bandwidth. Most users don't know the roll-off characteristics of their signals, so this answer isn't likely to be useful.

The roll-off characteristics will largely determine the amount of overshoot present in the step response of the SUT, so it may be more useful to have some "rules of thumb" for the bandwidth and rise time margin you need, based on the amount of overshoot.

To that end, we ran simulations in ADS (Keysight Technologies, Inc. Advanced Design System) for two different cases: a step with no significant overshoot (a fifth-order Bessel response) and a step with about 10% overshoot (a fourth-order Butterworth response). The oscilloscope frequency response used for these simulations is the flat phase and magnitude response used in Keysight high performance oscilloscopes. These simulations were normalized to a 1-GHz bandwidth, but the results apply for any bandwidth.

Signal under test with little or no overshoot in the step response

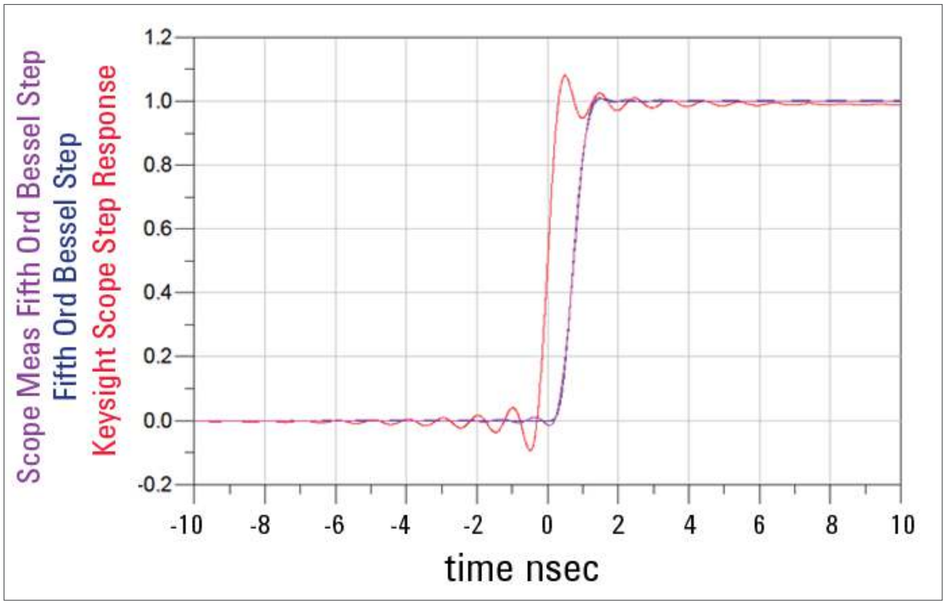

Figure 1. 1-GHz scope step response and scope measuring a step with little overshoot

In Figure 1, the red trace is the step response of a 1-GHz scope channel, the blue trace is the step response of a fifth-order Bessel filter, and the magenta trace is the step response of the scope measuring the fifth-order Bessel filter step. The bandwidth of the fifth-order Bessel filter was adjusted as high as possible until the rise time of the scope measurement of the Bessel step (magenta) was within 3% of the Bessel step rise time (blue).

Measurement results	
Scope rise time	434.7 pS
Fifth-order Bessel rise time	678.0 pS
Scope rise time measurement of fifth-order Bessel step	697.8 pS
Error in scope measurement	2.911%
Fifth-order Bessel rise time/scope rise time	1.560

The bandwidth of the Bessel filter that limited the rise time error to 3% or less turned out to be 520 MHz. The frequency response of the Bessel filter and the scope are shown in Figure 2. Note that the Bessel filter is down -14.3 db at the scope bandwidth.

Signal under test with little or no overshoot in the step response

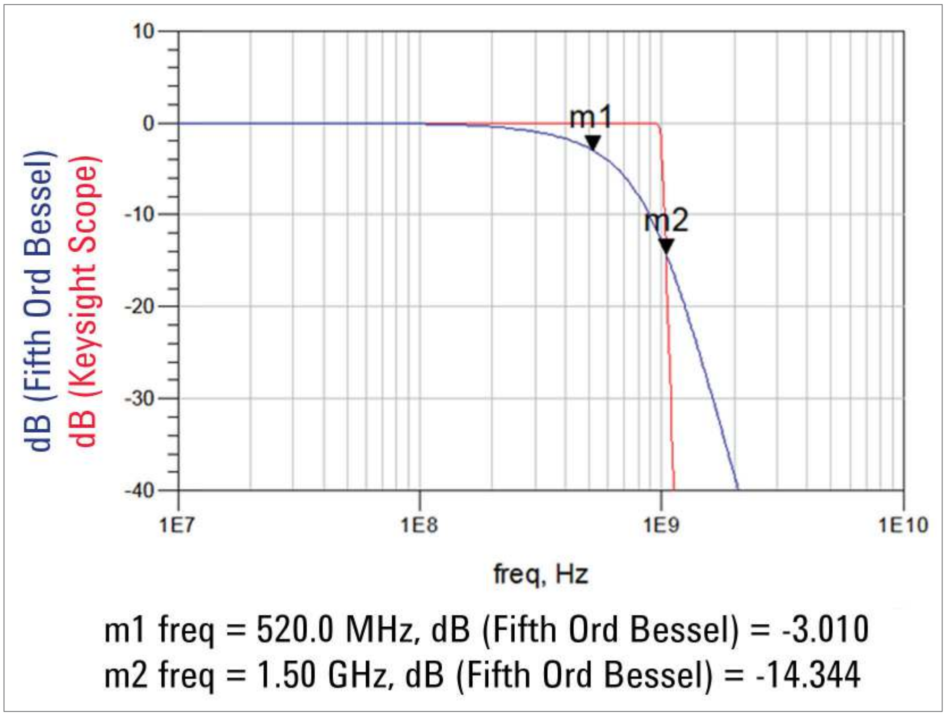

Figure 2. Frequency response of 1-GHz scope channel and fifth-order Bessel filter

Signal under test with ~10% overshoot in the step response

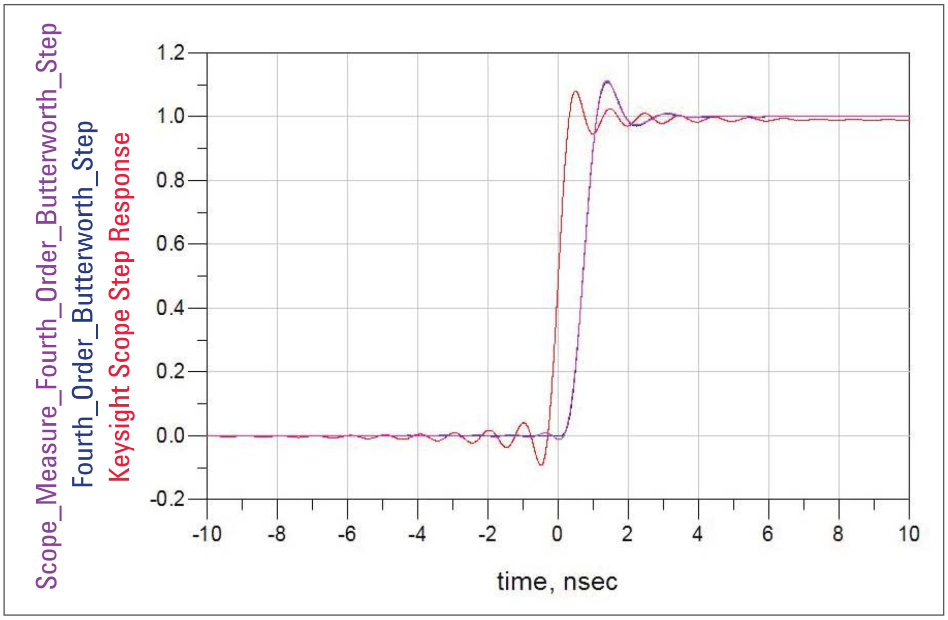

Figure 3. 1-GHz scope step response and scope measuring a step with 10% overshoot

In Figure 3, the red trace is the step response of a 1-GHz scope channel, the blue trace is the step response of a fourth-order Butterworth filter, and the magenta trace is the step response of the scope measuring the fourth-order Butterworth filter step. The bandwidth of the fourth-order Butterworth filter was adjusted as high as possible until the rise time of the scope measurement of the Butterworth step (magenta) was within 3% of the Butterworth step rise time (blue). Tabular results of measurements on these steps are:

Measurement results	
Scope rise time	434.7 pS
Fifth-order Bessel rise time	608.2 pS
Scope rise time measurement of fifth-order Bessel step	697.8 pS
Error in scope measurement	2.819%
Fifth-order Bessel rise time/scope rise time	1.399

The bandwidth of the Bessel filter that limited the rise time error to 3% or less turned out to be 640 MHz. The frequency response of the Butterworth filter and the scope are shown in Figure 4. Note that the Butterworth filter is down -17.3 db at the scope bandwidth.

Signal under test with ~10% overshoot in the step response

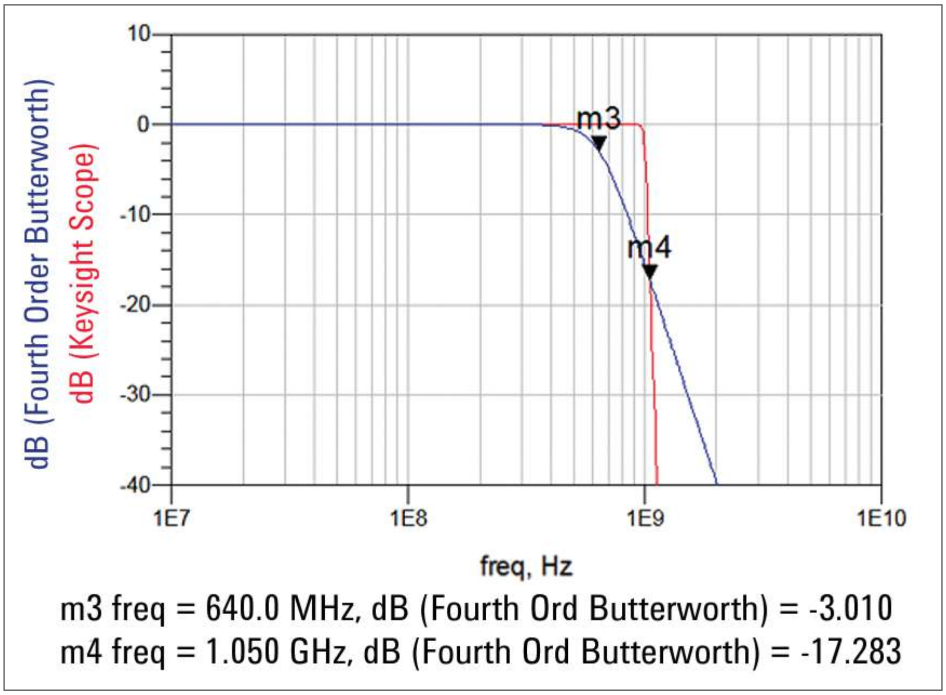

Figure 4. Frequency response of 1 GHz scope channel and fourth order Butterworth filter

Conclusions

- No great surprise: the faster the signal frequency response rolls off, the closer the 3 db bandwidth of the signal can get to the bandwidth of the scope.
- Because the rise time*bandwidth products are different for the scope versus the signal, you can't simply say that if the signal needs to be less than or equal to X times the scope bandwidth, then the signal rise time needs to be greater or equal to 1/X times the scope rise time.

Rules of thumb for determining adequate oscilloscope bandwidth/risetime

Signal under test has little overshoot in its step response

For less than 3% error in the rise time measurement:
- Signal bandwidth <~ .52 x scope bandwidth (about half)
- Signal rise time >~ 1.56 x scope rise time

Signal under test has around 10% overshoot in its step response

For less than 3% error in the rise time measurement:
- Signal bandwidth <~ .64 x scope bandwidth (more than half)
- Signal rise time >~ 1.4 x scope rise time

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