The Bessel-Thomson & other oscilloscope responses

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In the good old days of analog scopes, you pretty much had only one choice for frequency response—Gaussian. That came about because of the natural way in which the behavior of multiple components with similar responses (even if they are not individually Gaussian) aggregates up. There didn’t seem to be a strong reason to tamper with that response shape by deliberately inserting a filter somewhere.

The world of DSP has brought with it, among other things, the ability to easily tailor a response to a specific shape that may not necessarily be Gaussian. One obvious choice that has emerged is the flat response—something that is a better approximation to the textbook “brickwall” and that was hard to get to using analog circuitry. A flat response oscilloscope gives you better results when you want to accurately measure a signal’s rise time. However, more generally speaking, a flat response may not necessarily be an optimal choice.

Many textbooks actually refer to the brickwall as the “ideal” filter response, but that's more than a bit misleading. If your primary object of interest is not the rise time, a flat response or even a brickwall is actually not a good thing. For example, certain measurements require there to be minimal or no overshoot; never mind if the oscilloscope's agility does not quite match up to the signal rise time.

A case in point is the use of the Eye Diagram, especially to measure a transmitter's extinction ratio. The lines in an ideal eye diagram would be sharp, but in the real world they are fuzzy. Technically, they are statistical histograms—little bell-shaped distributions in their own right. A measurement
procedure needs to find the center of each of these histograms to determine, for example, the extinction ratio. Reducing the fuzziness of the lines—i.e., sharpening the histogram—is crucial to getting a good measurement.

Eye diagrams are insensitive to small variations of the 3dB bandwidth, but sensitive to small variations in the shape of the frequency response of the receiver. A response that allows some overshoot or ringing will immediately broaden the histogram. Enter the Bessel filter, also called a Bessel-Thomson filter. These filters are pretty far removed from the brickwall shape -- in fact, as the diagram below shows, they exhibit the most offensively gentle rolloff compared to Butterworth, Chebyshev, and so on, and you can quite gently slide off the passband without hurting your rear.

Adding insult to injury is the fact that the droop starts well before the specified cutoff frequency, so it loses the flatness battle with the Butterworth filter.

![The gentle rolloff of the Bessel lowpass filter. (Source: Maxim Integrated)](image)

What sets the Bessel-Thomson filters apart is their almost constant group delay (almost linear phase), which means no overshoot. So the use of a fourth-order Bessel-Thomson response, unlike a flat response, keeps the histogram sharp. This allows better determination of the true mean of the histogram.

That's why the key standards for optical transmitter testing typically specify that the measurement receiver should have a fourth-order Bessel-Thomson response with a corner frequency of 0.75x the bit rate. This allows for more meaningful and accurate measurement of the extinction ratio. Some oscilloscope manufacturers (e.g., Teledyne LeCroy) incorporate DSP-based group delay compensation to equalize pre-shoot and overshoot, maintaining the symmetry of the histogram so its all-important center (technically the mean or median) does not drift.

The effect of reducing bandwidth and applying the correct filter using a reference receiver, as opposed to using a wide bandwidth oscilloscope, is brought out quite nicely in Figure 1 of Tracking Transmitter Compliance Testing.

The usefulness of the Bessel-Thomson filter is not limited to eye diagrams. This filter's response actually closely approximates a Gaussian response, so it is also used to enable a scope to behave almost like it would have in the good old pre-DSP days. The almost constant group delay also has another beneficial effect—pulse waveforms are distorted symmetrically rather than asymmetrically.
as with other filter types (in addition to being less distorted due to no overshoot). This makes the Bessel-Thomson response good for many pulse measurement applications.

This is why some oscilloscope manufacturers in fact have this as their default response for pulse and eye diagram measurements. Note, however, that we said its response is “almost” linear phase. With the advent of DSP, we can tweak the traditional Bessel response for exact linear phase. This is what Tektronix does for its Bandwidth Enhancement filters, which then become general-purpose enough for Tek to recommend that you leave it on by default unless you need other response types (e.g., a flat response) for very specific measurements.

Have you been exposed to oscilloscopes with selectable response shapes? How did you react?