KEYSIGHT

Realtime oscilloscope bandwidth considerations for 25 Gbps PAM4 patterns

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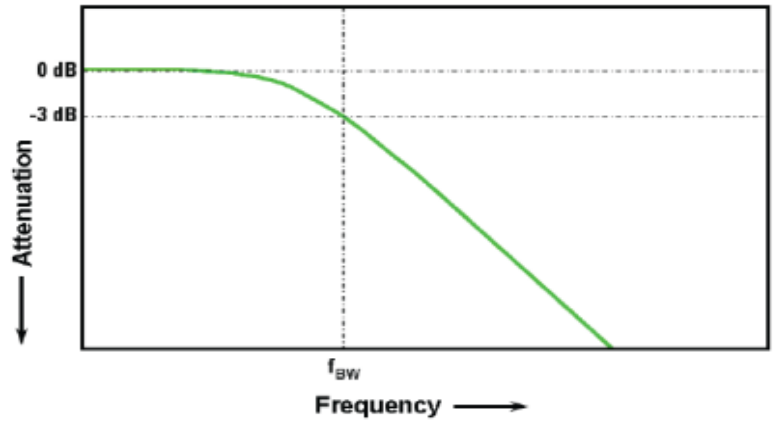
IEEE 802.3cy Task Force

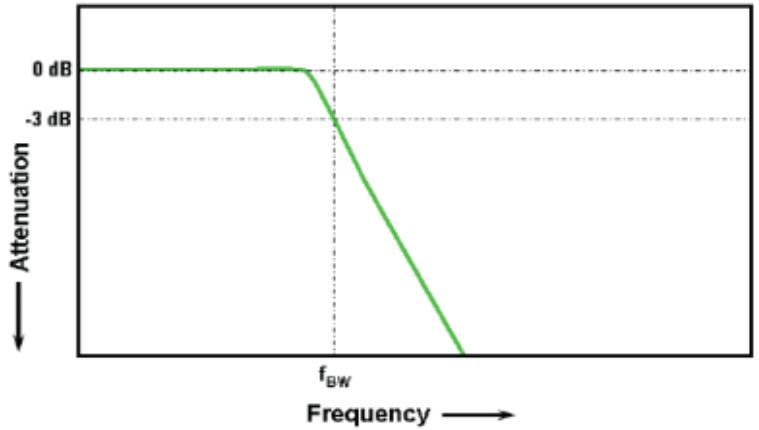
Backgrounds

- Back in the old days, we used to advise “fifth harmonics rule” just to encourage higher bandwidth oscilloscopes, but this is an outdated approach. It is an overkill in modern applications.
- Having too much bandwidth simply ends up integrating unwanted noise without any known benefits.
- As the bandwidth goes up, the relative cost of oscilloscope goes up.
- The 802.3cy 25GBASE-T1 is PAM4 single lane operating at 14.0625 Gbaud.
- There is no reference in 802.3cy as to the filter shape in the receiver that the oscilloscope must emulate. As the filter shape varies, so does the required measurement bandwidth.
- 4^{th} order Bessel-Thomson filter is used broadly as a choice of reference filter in the high speed datacom ethernet standards.

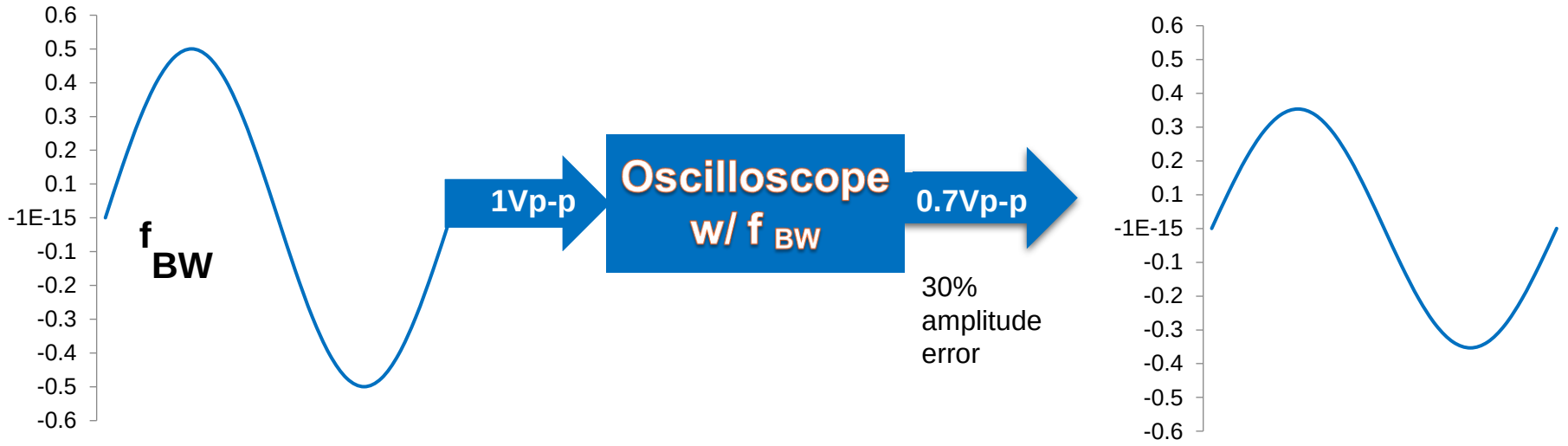
Definition of oscilloscope bandwidth



Gaussian frequency response (≤~1 GHz)



Maximally flat frequency response (>~1 GHz)



Oscilloscope bandwidth is specified at the frequency at which a sinusoidal input signal is attenuated by 3dB or to 70.7% of the signal's true amplitude.

Direct relationship between oscilloscope bandwidth and risetime

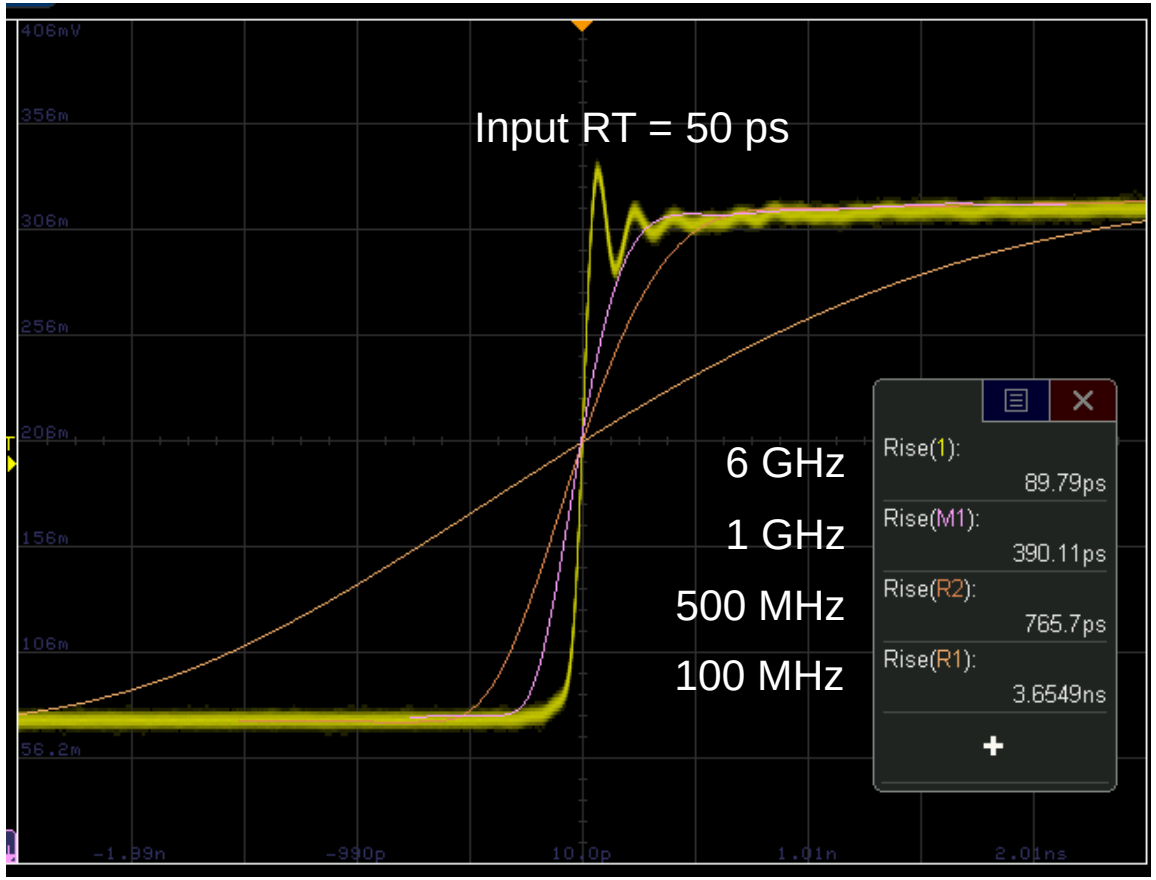
For a Gaussian response system,

Rise Time (10-90%) = 0.35/BW

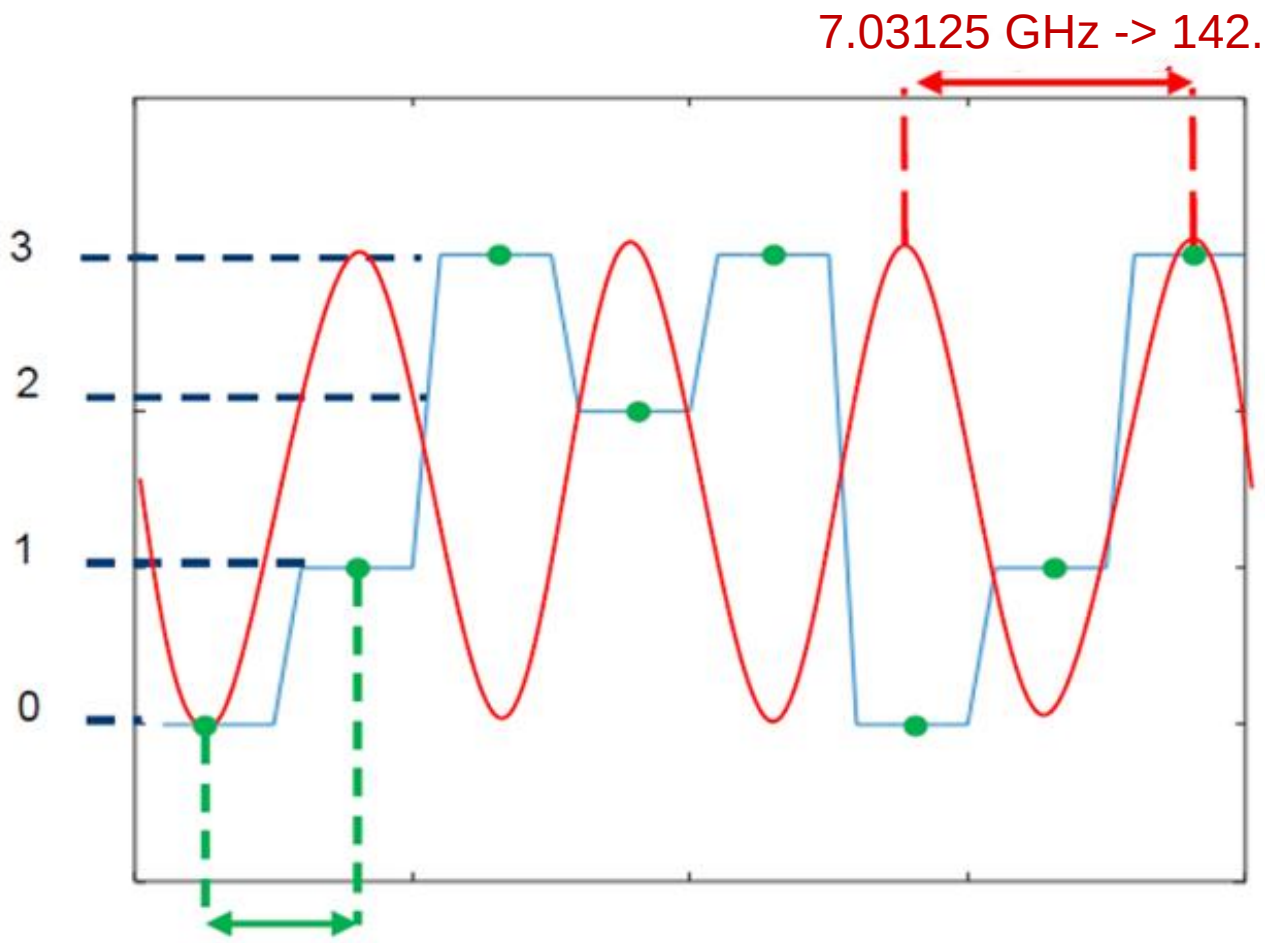
For a maximally-flat response system,

Rise Time (10-90%) = ~0.45/BW

As the scope input filter shape varies, so does the required measurement bandwidth.



25GBASE-T1 symbol rate and the 1st harmonic frequency



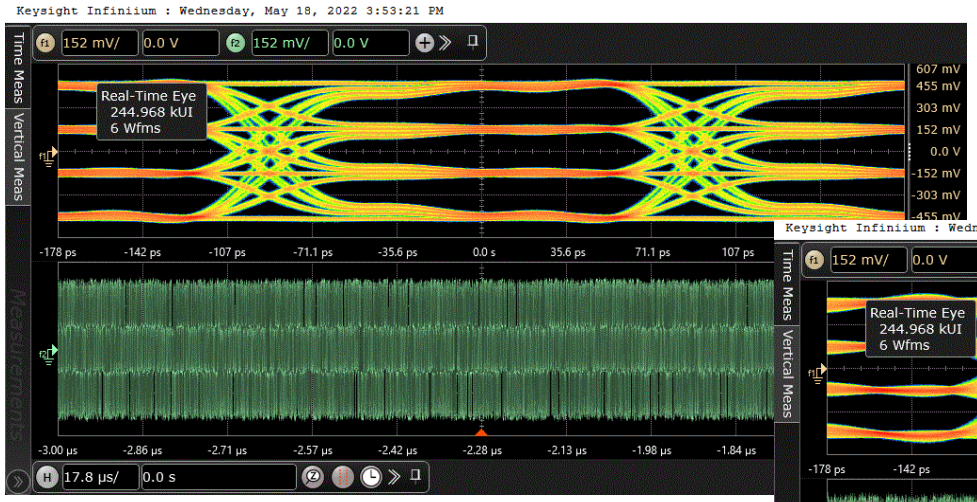
PAM4 signal

Symbol rate

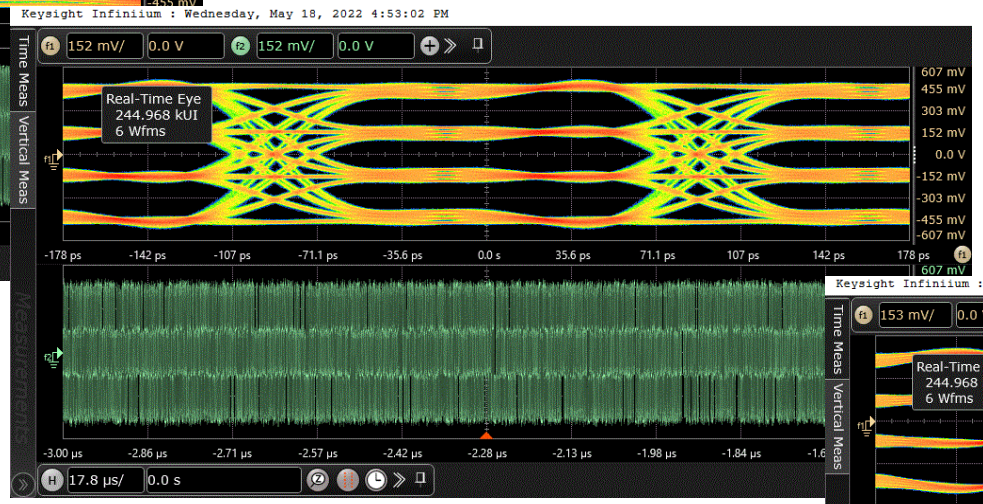
1st harmonic or fundamental

10GBASE-T1 SNDR test result in comparison

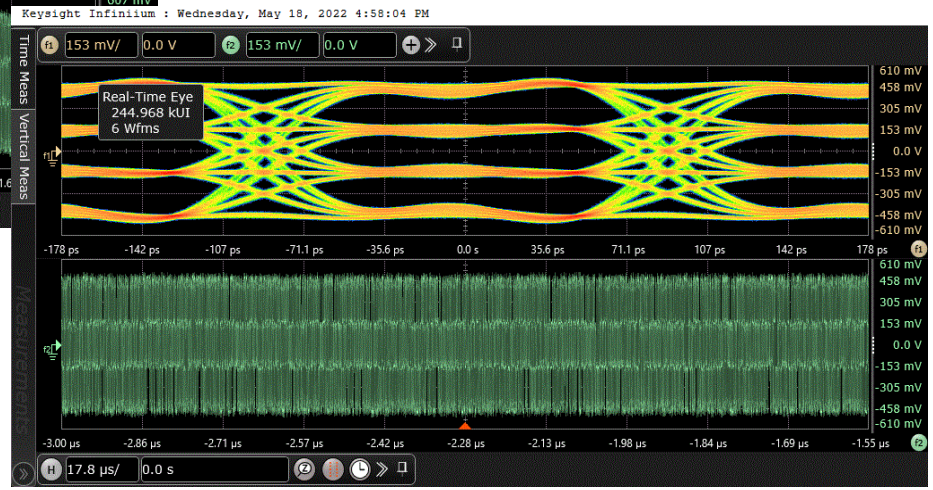
- TM4 5.625 Gbaud PRBS13Q test patterns used
- 16 GHz scope (with 5x the first harmonics, 14.0625 GHz = 2.8125 GHz *5) doesn't give any merit in SNDR measurement.
- Open Alliance TC15 PMA subgroup recommends minimum of 10 GHz scope to use for 10GBASE-T1 PMA test.



16 GHz (trial 1)



13 GHz (trial 2)

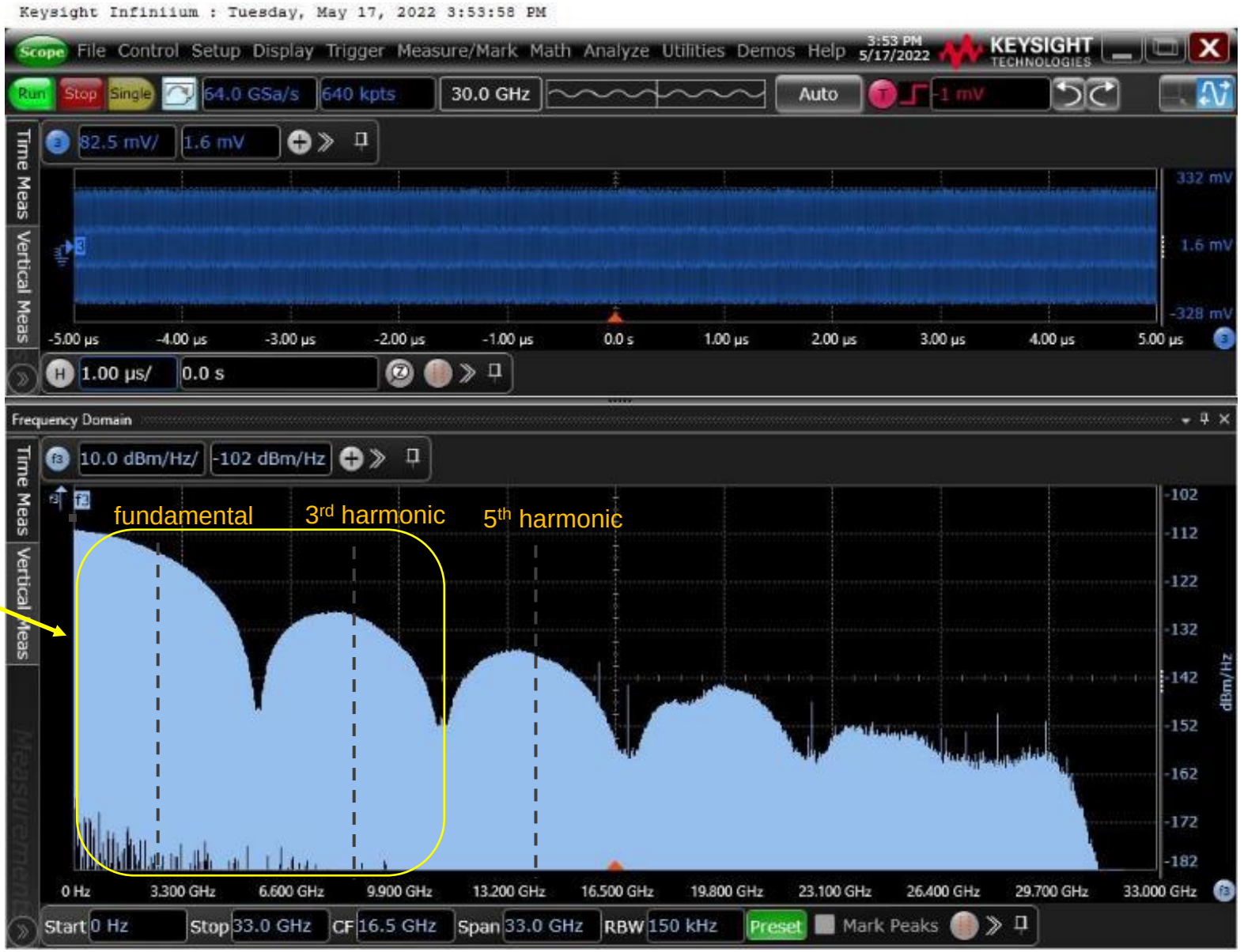


11 GHz (trial 3)

	SNDR (spec = >38dB) margin	Pmax	Sigma e	Sigma n
1 (Worst)	42.380 dB	11.5%	469.907 m	2.775 m	2.250 m
2	42.773 dB	12.6%	475.378 m	2.817 m	2.000 m
3	43.228 dB	13.8%	485.213 m	2.682 m	2.000 m

10GBASE-T1 PHY PSD test with 5.6 Gbd PRBS13Q patterns

- Most of energy is contained in the first two humps.
- 5th harmonic is an overkill.
- 4th harmonic should be enough.



4th order Bessel-Thomson filter response

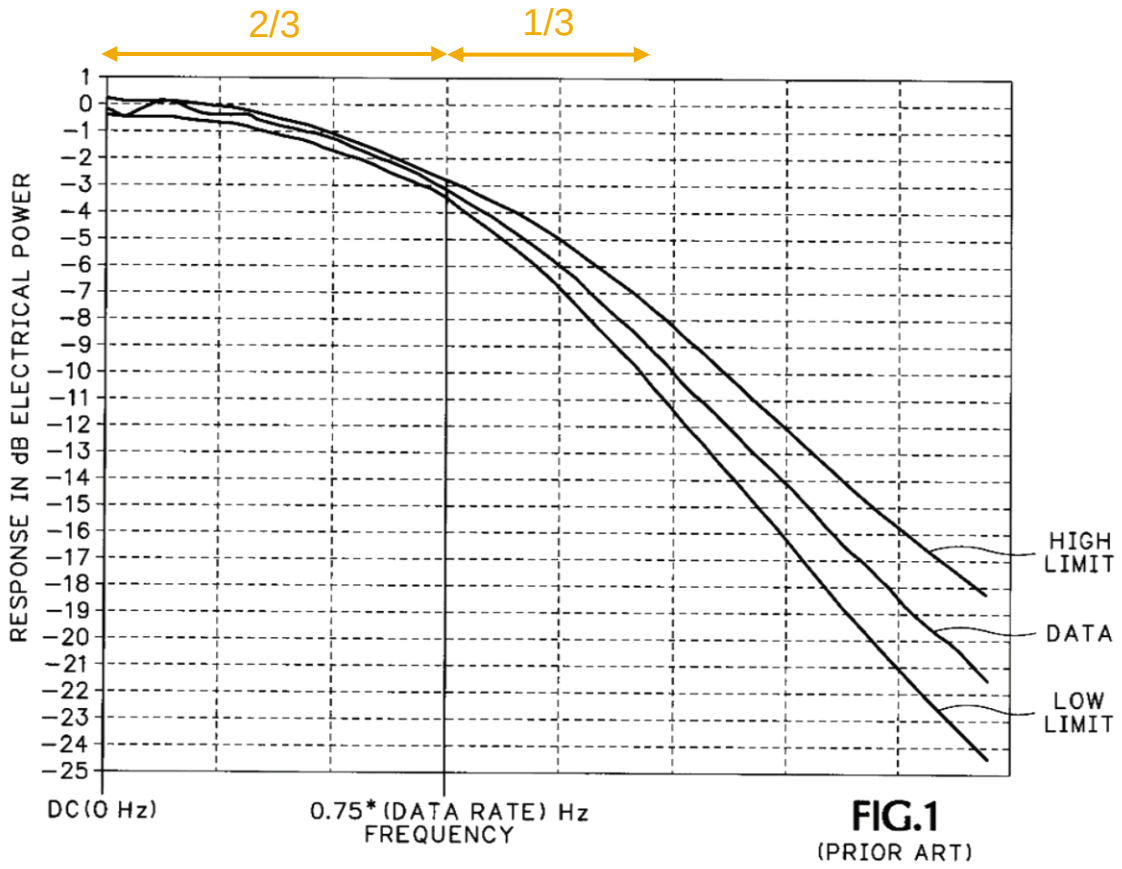
What if we adopt the 4th order Bessel-Thomson filter as a reference receiver filter?

- The Bessel-Thompson response rolls off past the -3dB point by roughly one third. (~2/3 to the left and ~1/3 to the right of the 3dB point).

- IEEE generally has adopted
  - Fbaud * 0.75 as the -3 dB point and
  - Fbaud * (3/2) for the channel response to -9 dB point

- -3 dB bandwidth typically is set to 75% of the symbol rate

- For 14.0625 Gbaud PAM4,
  - the -3 dB point would be 14.0625 GHz * 0.75 = **10.5468 GHz** and
  - the -9 dB would track to 10.5468 GHz * 3/2 = **15.8202 GHz** scope (or 16 GHz or higher)



Required realtime oscilloscope bandwidth

Scope BW >= Symbol rates in Gbaud *0.75 * 3/2

PAM4 data rate	Symbol rate	Reference Receiver BW (=0.75 * symbol rate)	Needed scope BW (=3/2 of reference receiver BW)	Recommended scope BW
25 Gbps	14.0625 Gbaud	10.5468 GHz	15.82 GHz	16 GHz or higher

Recommendations

- Stay away from the traditional “fifth harmonics rule”.
- 802.3cy adopts the 4th order Bessel-Thomson filter as a reference receiver filter.
- For 802.3cy 14 Gbaud PAM4 measurement, I would recommend to use a 16+ GHz bandwidth realtime oscilloscope.

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Thank you

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