Correlation of 10GBASE-T Linearity Measurements on the Oscilloscope and Spectrum Analyzer

Background

The 10GBASE-T standard defines a way of measuring the linearity of a transmitter by way of Spurious Free Dynamic Range*[1] (SFDR). This test is intended to measure the purity of the DAC used at the output.

The DUT*[2] is programmed to generate five different two-toned signals, each having a different combination of frequency tones. For each of these signals, the 10GBASE-T standard specifies a minimum allowed SFDR limit.

The linearity test sub modes are shown in Table 1. The DUT is set to operate in Test Mode 4 and submode corresponding to the required frequency tone.

1.132.12	1.132.11	1.132.10	Output Waveform Frequencies in MHz
			Two-tone Frequency Pairs
0	0	0	Reserved
0	1	1	Reserved
1	1	1	Reserved
0	0	1	(800/1024) x 47, (100/1024) x 53
0	1	0	(800/1024) x 101, (100/1024) x 103
1	0	0	(800/1024) x 179, (100/1024) x 181
1	0	1	(800/1024) x 277, (100/1024) x 281
1	1	0	(800/1024) x 397, (100/1024) x 401

Table 1. Linearity test modes.

*[1] SFDR is defined as the ratio of the RMS value of the carrier frequency (maximum signal component) at the input of the ADC or DAC to the RMS value of the next largest noise or harmonic distortion component (which is referred to as a “**spurious**” or a “**spur**”) at its output

*[2] Device under test

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The test mode frequency and limit values are shown in Table 2. Even though RBW is not defined for this measurement, we have considered RBW that is good enough to have noise floor such that these spurious frequencies can be measured.

The SFDR of a linearity signal should be according to the following equation:

$$\mathbf{SFDR \geq 2.5 + min\ (52,\ 58\ \tilde{-}\ 20 * log_{10}\ (\mathit{f}\ /\ 25))}$$

Where, '***f*** ' is the maximum frequency of the two test tones and SFDR is the ratio in dB of the minimum RMS value of either input tone to the RMS value of the worst intermodulation product in the frequency range of 1 MHz to 400 MHz. Using **Error! Reference source not found.**, the SFDR is computed for each of the linearity frequency tones as given in Table 2.

Tone #	Frequency Tones (f1, f2) in MHz	Minimum SFDR in dB
1	36.718, 41.406	54.5
2	78.906, 80.469	50.51
3	139.844,141.406	45.5
4	216.406, 219.531	41.75
5	310.156, 313.281	38.63

Table 2. Minimum SFDR for linearity tones.

Oscilloscope Dynamic Range

The objective of this section is to analyze the capability of the oscilloscope in distinguishing two frequencies that have a dynamic amplitude difference range of about 60 dB. This is done by feeding a known signal to the oscilloscope and evaluating the spurious frequencies.

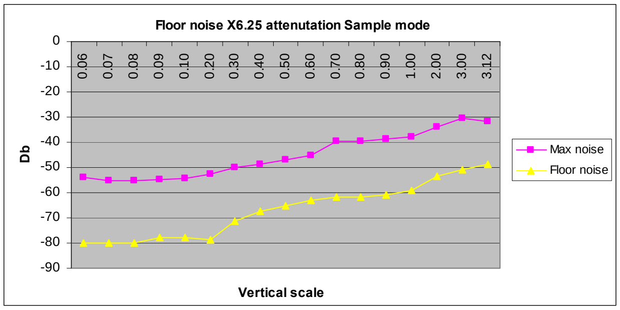


Figure 1. Oscilloscope noise floor at different vertical scales.

Figure 2. DPO oscilloscope set to 25GS/s . Channel two set to 400mV/div . Swept sine wave generator is used to generate 100 MHz signal with 10dBm level. Distortion means distortion occurs on the signal, spur means with no signal attached.

In Figure 1, the horizontal cursor ‘a’ is placed at the fundamental signal level and the second horizontal cursor ‘b’ is placed around the spurious signal level. Cursor ‘b’ is about 60 dB below cursor ‘a’ indicating that difference between the fundamental signal level and the spurious signal level is about 60 dB. Hence the measurement of linearity on oscilloscope seems feasible.

Oscilloscope Noise Floor

Error! Reference source not found. shows noise floor of the Oscilloscope measured at various vertical scales and input connected to ground.

The floor noise at 300 mV/div is about -75 dB and spurious frequencies are about -53 dB. However, spurious frequencies disappear when we feed the signal. If we do not consider the spurious spike, then the noise floor of -75dB will support this measurement.

Comparison with Spectrum Analyzer

Setup

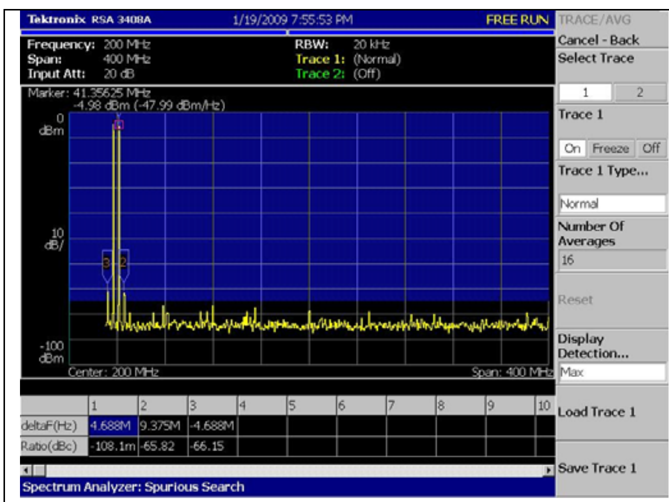
The signal was routed through the Balun to an oscilloscope which converts a differential signal into single-ended signal. But, the voltage level of the single-ended signal is not exactly half of the differential level due to built in 6dB attenuation. The linearity measurement is performed by feeding Balun output to the spectrum analyzer.

Table 3 shows a comparison of linearity measurements on the spectrum analyzer and oscilloscope. Signal from Lane A connected through Balun to the Spectrum Analyzer.

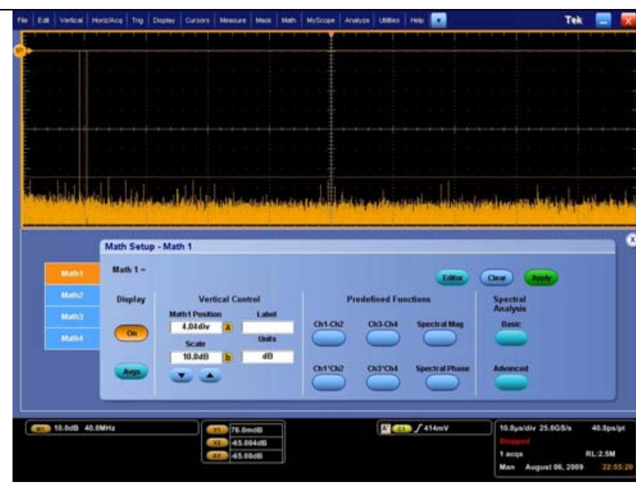
Tones	Spectrum Analyzer	Oscilloscope Setup 1	Oscilloscope Setup 2	Oscilloscope Setup 3
Setup	RF attenuation set to 20 dB, set Spurious measurement.	Lane A signal fed to DPO 70804 oscilloscope through Balun. Sample rate set to 25Gs/sec and RBW set to 20 kHz.	Lane A signal fed to DPO 70804 oscilloscope directly through probe. Sample rate set to 25Gs/sec, RBW set to 20 kHz.	Lane A signal fed to oscilloscope directly through SMA probe. Math 1 = Ch1- Ch2, Math2 = AVG(Spectralmagnitude(Math1))
Tone 1	6.51E+01	63.0	65.15	65.55
Tone 2	5.65E+01	60.0	63.80	62.54
Tone 3	5.92E+01	62.2	61.90	60.30
Tone 4	5.95E+01	60.0	61.42	60.93
Tone 5	5.58E+01	57.0	55.24	55.20

Table 3. Comparison on linearity measurement on spectrum analyzer and oscilloscope.

Figure 3 shows the screenshots of the spectrum analyzer and oscilloscope Setup 1 of linearity Tone 1 measurement.



Spectrum analyzer reading.



Oscilloscope screen shot, signal measured using P7350 probe.

Figure 3. Spectrum analyzer and oscilloscope screenshots of linearity Tone1 measurement.

Simulated Measurement

The oscilloscope Setups 2 and 3 were recommended for measuring linearity using oscilloscope without Balun. Their readings were similar to that of the spectrum analyzer. We also performed the simulation of two-tone signal and derived the linearity theoretically to ensure that the margin available on the oscilloscope is good for Linearity measurement. The following is a summary of these experiments.

Experiment 1:

The two-tone linearity signal was generated using Matlab (double precision). Linearity was then computed in Matlab for this signal as shown in Figure 4. It can be observed that the FFT does not have any spikes either due to intermodulation distortion or due to quantization noise. The linearity value in this case is more than 120 dB.

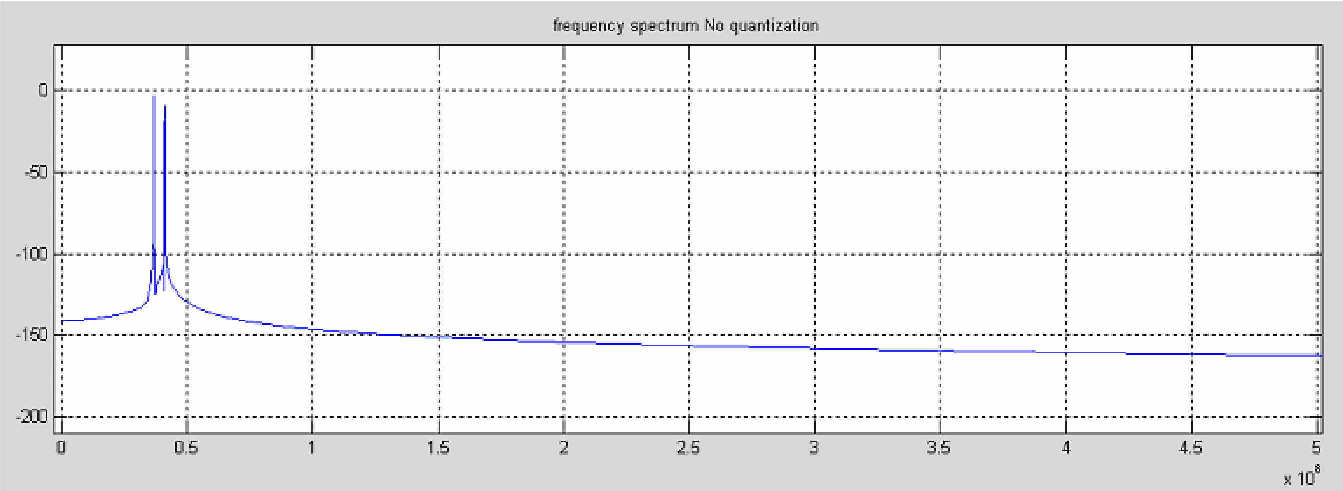


Figure 4. FFT of two-tone linearity signal with double precision.

Experiment 2:

The two-tone linearity signal was generated using Matlab (double precision) and quantized with 8 bit precision. Linearity was then computed in Matlab for this 8-bit precision signal as shown in Figure 5. Spikes are introduced due to the non-linearity of the DAC. The linearity value in this case is about 80 dB which is indeed sufficient to measure SFDR limit of 60dB.

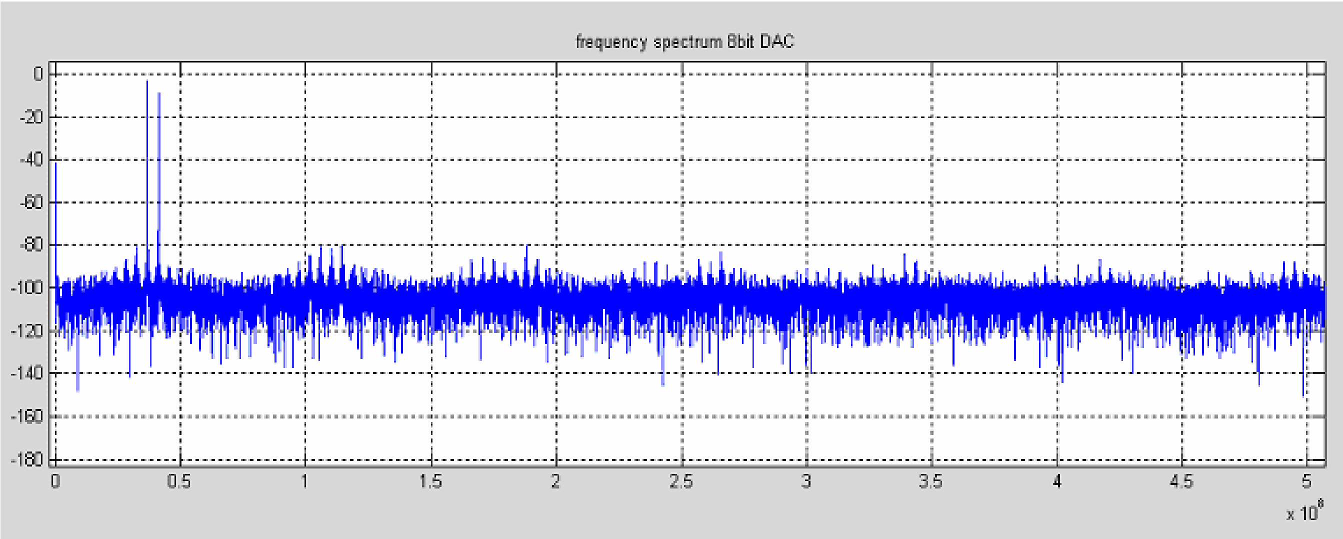


Figure 5. FFT of 8-bit quantized input signal.

Experiment 3:

The two-tone linearity signal was generated using Matlab (double precision) and quantized with 10-bit precision. Linearity was then computed in Matlab for this 10-bit precision signal as shown in Figure 6. The linearity value in this case is about 100dB. The FFT in this case resembles the FFT computed by the oscilloscope in Figure 3.

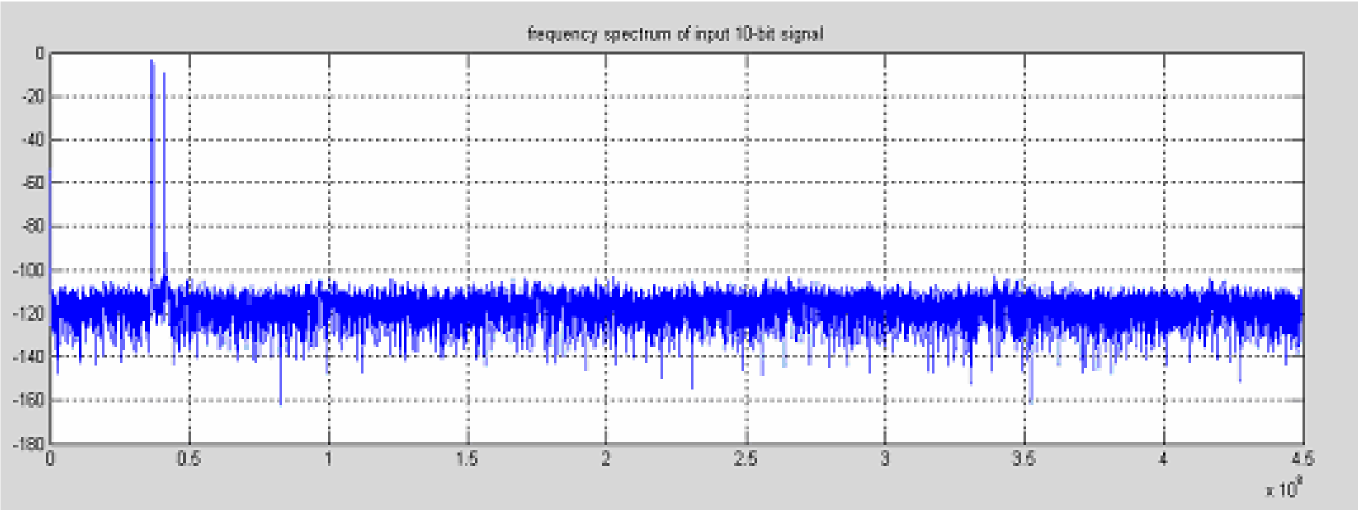


Figure 5. FFT of 10-bit quantized input signal.

Summary:

To ensure the feasibility, the test shown in Table 5 had been performed.

Test #	Test	Remarks
1	Measuring the noise floor (spurious noise)	The Floor noise is about -80db which is well below the minimum limit level, but the spurious noise without any signal is about -57 dB.
2	Measuring the dynamic range using known signal	The minimum distortion measured with known signal is about 62dB which is less than the allowed limit.
3	Comparison with spectrum analyzer	The measured oscilloscope results are close enough to spectrum analyzer results.

Table 4. Feasibility tests.

Conclusions

- We have a maximum margin of about 20dB and minimum of about 10dB from the limit value for the given DUT signal.
- The spectrum analyzer results were close enough to the oscilloscope based results. We have seen more harmonics with oscilloscope as compared to spectrum analyzer.
- With the above margin we can perform this measurement to indicate the pass or fail for 10GBASE-T signal on an oscilloscope.

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