Accurate Harmonics Measurement by Sampler
Part 2

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Abstract of Part 1

The Total Harmonic Distortion (THD) is one of the major frequency domain parameters for verifying dynamic linearity characteristics of devices like Analog to Digital Converter (ADC), Digital to Analog Converter (DAC), Amplifier and so on. Dynamic linearity characteristics of devices are varied by output frequency, and evaluated results at low frequency does not show the characteristics at high frequency. Therefore, THD must be measured at actual operating frequencies.

Measurement instrument to evaluate harmonic distortion needs to have low harmonic distortion and wide bandwidth characteristics. In general, it is difficult to realize both characteristics.

The part 1 introduced the basic measurement characteristics of Digitizer and Sampler. If Sampler has superior harmonic distortion performance, it is the best instrument to measure harmonic distortion. And then, it provided the best measurement condition of Sampler to measure correct harmonic distortion with experimental results. With attenuated measurement method described in this Part 2, these measurement conditions enable Sampler to measure correct harmonic distortion.

Attenuated Measured Results

As described in previous section, to increase harmonic distortion performance of Sampler, attenuated measurement method should be used. In this section, how much of attenuation should be applied to obtain good measurement result is discussed.

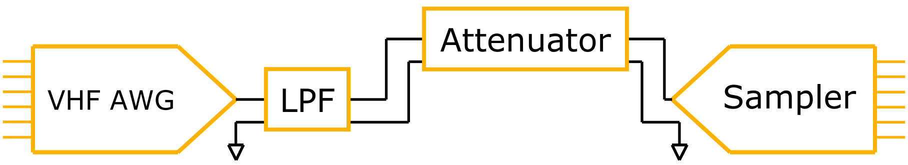


Figure 12: Configuration of the measurement

The Figure 12 shows the measurement configuration of attenuated measurement method. In this configuration, you never use the attenuator in AWG. This is because distortion characteristics of AWG may change when attenuator setting of AWG is changed. This means that distortion may occur after attenuation block of AWG.

Measurements were performed with 10dB, 13dB and 20dB attenuators. Averaging must be implemented to remove noise. The purpose of this measurement is harmonic distortion measurement and averaging does not affect harmonic distortion result. It used 100 times of averaging in these measurements.

10dB Attenuator

The Figure 13 shows data at 40MHz sampling frequency with 10dB attenuator. The condition of this graph is same as the Figure 11.

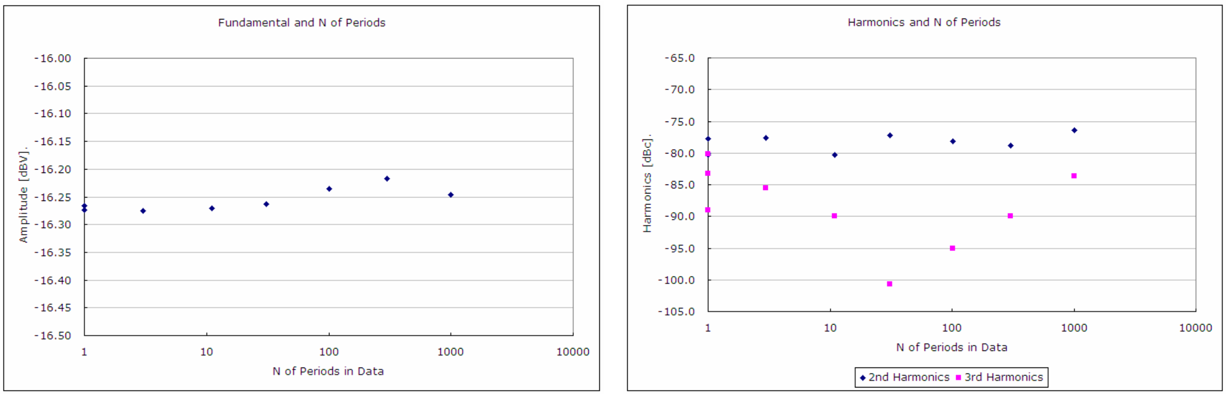


Figure 13: Measurement Results with 10dB Attenuator

From this result, 2nd harmonics distortion is about 7 to 10dB improved, and this means that attenuated measurement method is actually effective to improve harmonic distortion performance. The Figure 14 shows one of spectrums of above data. This spectrum shows that noise level of this measurement is -100dBV ~-110dBV. The fundamental amplitude of this measurement is about -16dBV, and measured harmonic distortions below 84dBc is under noise level and they are not reliable results. To lower noise level, it must increase number of average.

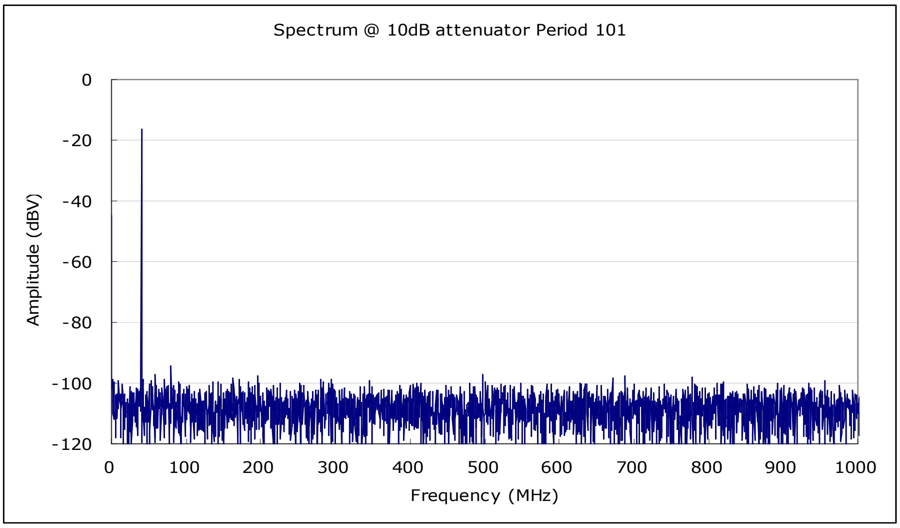


Figure 14: Spectrum at 10dB attenuator

13dB Attenuator

The Figure 15 shows data at 40MHz sampling frequency with 13dB attenuator. The 2nd harmonic distortion of this measurement is improved a few dB than the measured result with 10dB attenuator. But, harmonic distortions below 80dBc are not reliable results. Therefore, no reliable data will be taken if the attenuator values are increased more than 13dB.

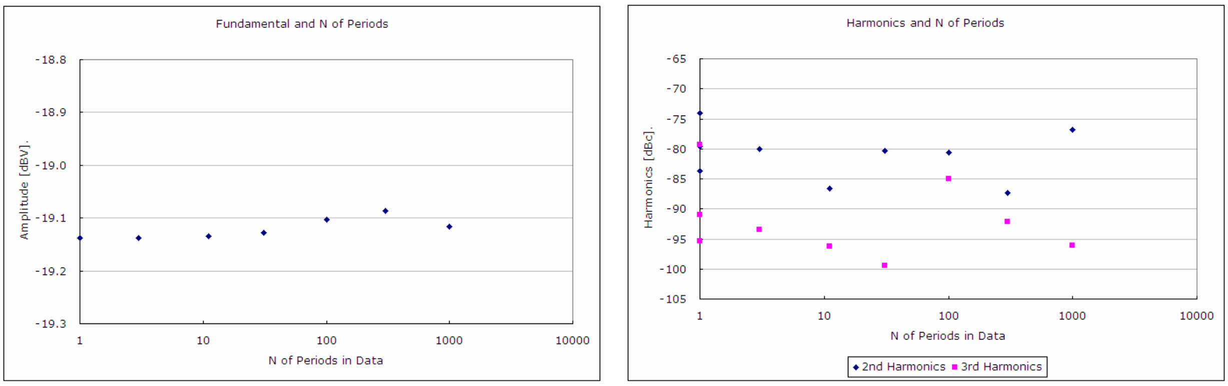


Figure 15: Measurement Results with 13dB Attenuator

Increase Number of Average

Now, number of average is increased from 100 to 1000. The Figure 16 shows the spectrum at this number of average. This graph shows that noise level at 1000 times of average is less than -110dBV.

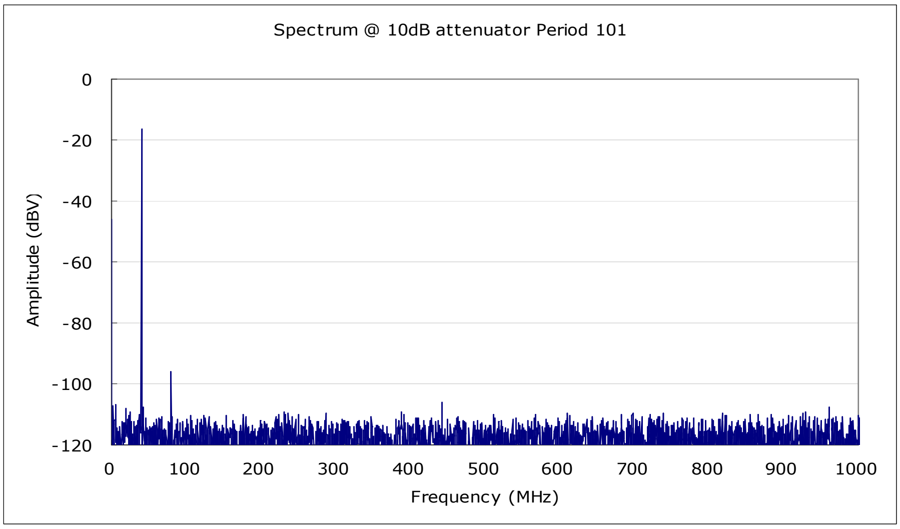


Figure 16: Spectrum at 1000 times average with 10dB attenuator

The Table 3 and the Figure 17 show measurement results while changing attenuation value from 0dB to 20dB. In these measurements, number of average is 1000 and number of periods in data is 101.

Table 3: Harmonic Distortions at several Attenuation values

Attenuator (dB)	Fundamental (dBV)	2nd Harmonics (dBc)	3rd harmonics (dBc)	2nd Harmonics (dBV)	3rd harmonics (dBV)
0	-6.23	-70.91	-107.42	-77.14	-113.64
3	-9.25	-73.30	-111.66	-82.56	-120.91
6	-12.21	-76.79	-107.68	-89.00	-119.89
10	-16.25	-79.73	-96.88	-95.98	-113.13
13	-19.15	-82.63	-86.19	-101.77	-105.34
16	-22.28	-81.78	-91.63	-104.06	-113.91
20	-26.17	-87.16	-88.76	-113.33	-114.93

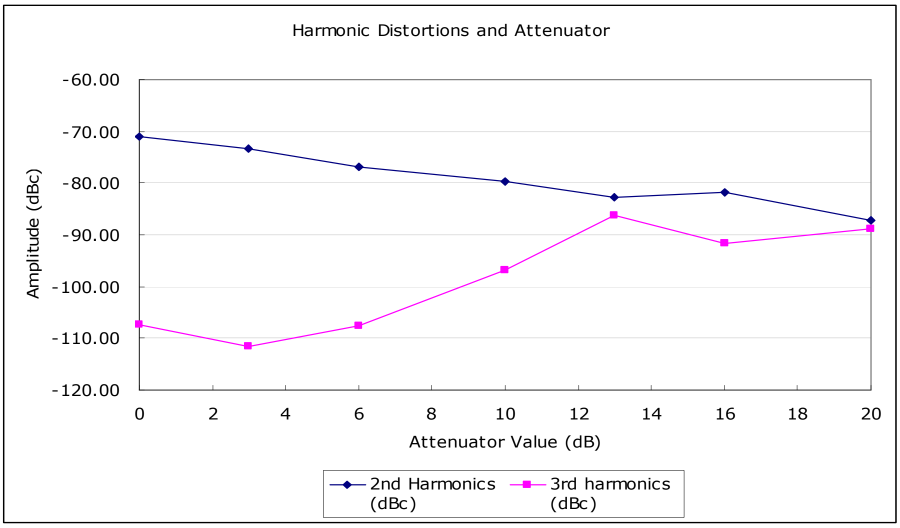


Figure 17: Harmonic Distortions at several Attenuator values

As shown in the Figure 16, noise level is about -110dBV, and all of 3rd harmonic distortion results and 2nd harmonic distortion result at 20dB attenuator are below noise level. 2nd harmonic distortion is decreased proportionally with attenuation values. After 13dB attenuation value, 2nd harmonic distortion is not changed proportionally with attenuation values. This means that these 2nd harmonic distortions are not caused by non-linearity of Sampler.

The Table 4 shows average and standard deviation of 20 times measurements when attenuation values are 13dB, 16dB and 20dB. Because the standard deviation of 2nd harmonic distortion result at 20dB is larger than the standard deviation at 13dB or 16dB, it is clear that 2nd harmonic distortion at 20dB is below noise level.

Table 4: Average and Standard Deviation at 13dB, 16dB and 20dB

Attenuator	13dB		16dB		20dB	
	Average	Stamdard Devisation	Average	Stamdard Devisation	Average	Stamdard Devisation
Fundamental (dBV)	-19.06	8.85E-04	-22.19	3.93E-04	-26.17	1.13E-03
2nd Harmonic Distortion (dBc)	-82.13	1.16	-82.64	1.10	-92.84	6.23
3rd Harmonic Distortion (dBc)	-93.07	3.66	-91.04	4.46	-87.80	4.58

The 2nd harmonic distortions at 13dB and 16dB attenuation values are almost same and the standard deviations of these conditions are small. This means that measurement results at these conditions are correct. The measured results -82.1dBc and -82.6dBc are very close to the measurement result by Spectrum Analyzer, that is -85.8dBc.

Summary

Input signal must be attenuated down to about -20dBV for correct measurement of harmonic distortions by the Sampler at 1.2V range. 16dB attenuator should be used. This increases the relative noise level and average must be performed to reduce this noise level.

Verification

Using obtained measurement conditions, several harmonic distortions of AWG output were measured. In this measurement, output frequencies were varied from 20MHz to 70MHz; and no LPF were used. First, AWG output signals were measured by Spectrum Analyzer. Then same AWG output signals were measured by Sampler. Measured results by Spectrum Analyzer and Sampler were compared.

In these measurements, 16dB attenuator was used and the number of average was 100. The Table 5 and the Figure 18 shows measurement and compared results.

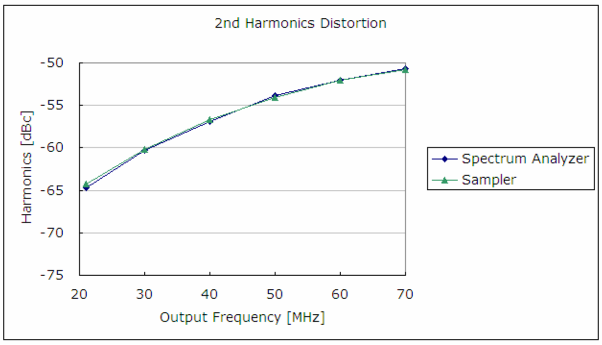
Table 5: AWG Output Measure Result without LPF

Spectrum Analyzer

Frequency (MHz)	Fundamental (dBm)	2nd Harmonic (dBm)	3rd harmonic (dBm)	2nd Harmonic (dBc)	3rd harmonic (dBc)
21	7.36	-57.37	-57.46	-64.73	-64.82
30	7.52	-52.79	-51.55	-60.31	-59.07
40	7.57	-49.35	-47.71	-56.92	-55.28
50	7.48	-46.34	-44.24	-53.82	-51.72
60	7.49	-44.57	-41.18	-52.06	-48.67
70	7.42	-43.29	-39.91	-50.71	-47.33

Sampler
Average: 100

Attenuation (dB)	Frequency (MHz)	Fundamental (dBV)	2nd Harmonic (dBV)	3rd harmonic (dBV)	2nd Harmonic (dBc)	3rd harmonic (dBc)
16	21	-18.85	-83.09	-85.11	-64.24	-66.26
	30	-18.91	-79.09	-78.68	-60.18	-59.77
	40	-18.98	-75.65	-74.74	-56.67	-55.75
	50	-19.11	-73.16	-71.28	-54.05	-52.16
	60	-19.19	-71.28	-68.09	-52.08	-48.90
	70	-19.30	-70.11	-67.09	-50.82	-47.80



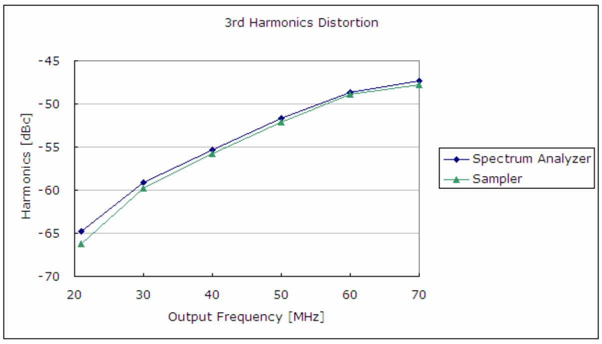


Figure 19: AWG Output Measure without LPF

The maximum delta of measured data by Sampler and Spectrum Analyzer is 1.5dB of 3rd harmonic distortion @20MHz. Overall, both of measured results by Sampler and Spectrum Analyzer are well matched, and it shows that obtained measurement conditions are correct.

Conclusion

The E9726A 6GHz Sampler can be used to measure harmonic distortions and measured harmonic distortion are well matched to the measurement result by Spectrum analyzer. The measurement conditions to measure correct harmonic distortion by Sampler are:

- Signal Amplitude is about -20dBV @ 1.2V input range (16dB attenuation)
- Sampling frequency is close to input signal frequency
- Number of periods in data is less than 5% of number of data