
Basic Total Harmonic Distortion (THD) Measurement

Microsemi products achieve high levels of performance in part due to a carefully designed interface between external connectors and internal components. As a result, specific handling precautions must be observed for device reliability and optimum performance.

Purpose

This document covers the basic harmonic test measurement setup for an amplifier and the calculation of the total harmonic distortion.

Introduction

One method to characterize the linearity of an amplifier is to measure its total harmonic distortion (THD). Harmonic distortion is measured by applying a spectrally pure sine wave to the amplifier in a defined circuit configuration (i.e., bias conditions, output amplitude or output power level, frequency, etc.) and observing the output spectrum. The amount of distortion present at the output of the amplifier depends on several parameters, such as:

- Small and large signal nonlinearity of the amplifier being tested
- Amplifier's output amplitude or power level
- Frequency response of the amplifier
- Load applied to the output of the amplifier
- Amplifier's power supply voltage
- Circuit board layout
- Grounding
- Thermal management, etc.

Measurements based on amplitudes (e.g., voltage), must be converted to power to make the addition of harmonic distortion meaningful. For example, for a voltage signal, the ratio of the square of the RMS voltages is equivalent to the ratio of the power.

Harmonic distortion may be measured by applying a spectrally clean sine wave voltage signal to the input of the amplifier under test (may require a band pass or low pass filter if the excitation RF source has high harmonic output content). Next, adjust the input power level to the amplifier for a desired output power level and then looking at the output harmonic spectrums (second, third, and fourth harmonics, etc.) of the amplifier on a spectrum analyzer relative to the amplitude of the output fundamental signal, see [Figure 1](#) example. Another method is to measure the output waveform signal (as example shown in [Figure 3](#)) of the amplifier using a high speed/bandwidth oscilloscope (i.e., has BW greater than six to ten times of the fundamental frequency). Detrend the data if needed (i.e., remove offset; normally not required for a CW signal), and then perform a FFT to get the amplifier output's harmonic content. The power levels of the individual measurement harmonic values (second, third, and fourth, etc.) are usually expressed in decibel format, (dBc is relative to the fundamental carrier power level, or dBm is in absolute power). The simplest measurement unit to use for the harmonic measurement is dBm. This allows the tester to not have to keep track of the amplitude signal level of the fundamental frequency. For example, if measured in dBc, before calculating the THD, one needs to convert the dBc value to dBm value for each of the harmonic values before calculating their individual power level in watts.

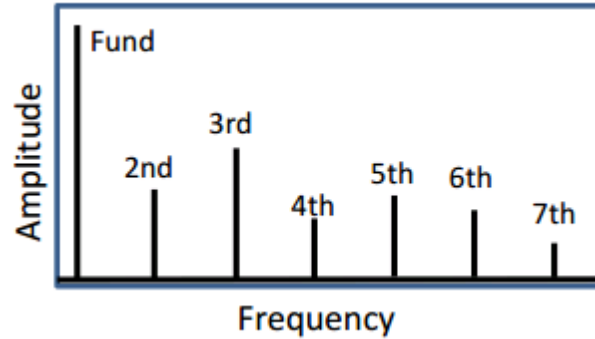


Figure 1. **Typical Harmonic Content of an Amplifier's Output**

Total Harmonic Distortion (THD) is expressed in Root-Sum-Square (RSS) in percentage. The THD is usually calculated by taking the root sum of the squares of the first five or six harmonics of the fundamental. In many practical situations, there is negligible error when only the second and third harmonics are included, as long as the higher harmonics are three to five times smaller than the largest harmonic. For example, 0.10 is one harmonic value and 0.03 is another higher harmonic value but three times smaller in amplitude:

$$\sqrt{0.10^2 + 0.03^2} = \sqrt{0.0109} = 0.104 \approx 0.1$$

An example of THD calculation will be provided at end of this application note.

Equations for THD Calculation

If the measurement data is in power,

$$\text{THD (\%)} = 100 \times \sqrt{\frac{P_2 + P_3 + P_4 + \dots + P_n}{P_1}}, \text{ Where } P_n \text{ is in watts (Eq. 1)}$$

If the measurement data is in volt,

$$\text{THD (\%)} = 100 \times \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots + V_n^2}}{V_1}, \text{ where } V_n \text{ is the RMS voltage (Eq. 2)}$$

Note:

1. P_n or V_n , where n = harmonic number, $n = 1$ is the fundamental frequency of the test signal applied to the amplifier under test.
2. Converting the power in dBm to watts: $P \text{ (W)} = 0.001 \times 10^{P/10}$, Where P is in dBm., (Eq. 3)
3. Converting V_{pk} (peak voltage) to V_{RMS} (RMS voltage): $V_{RMS} = V_{pk}/\sqrt{2}$, (Eq. 4)

Typical THD Test Measurement Setup

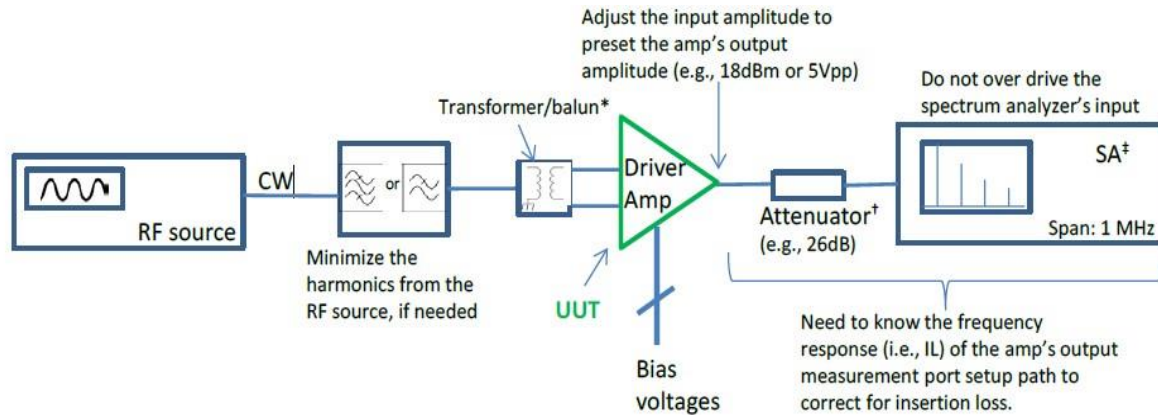


Figure 2. Typical THD Test Measurement Setup Diagram

Note:

- *A balun is optional only if the input to the amplifier under test has differential input ports. It is recommended to use a balun for the best THD result if the amplifier under test has differential input ports.
- †Attenuator value will depend on the amplifier's output amplitude/gain. The attenuator is used to protect the spectrum analyzer or oscilloscope's input. The frequency response of the attenuator, cables, and test measurement instrument are needed for insertion loss correction. May need a DC block on the input of the spectrum analyzer if the amplifier under test is not AC coupled.
- ‡ An alternative method is to measure the amplifier's output signal on a high speed/BW oscilloscope, and then apply FFT to get the amplifier's harmonic content.

Example of THD Calculation

Figure 3 below is the output waveform from the amplifier under test. The fundamental frequency is at 2.5 GHz and the output amplitude level is at 3.6 Vpp (driven into saturation). We will use this captured signal in our THD calculation example. One method is to use a spectrum analyzer to measure the amplifier's harmonic output and the other method is to use a high speed/bandwidth oscilloscope/DCA to capture the amplifier's output signal waveform (as shown in Figure 3) and then perform FFT to get its harmonic content. (This application note assumes the user knows how to perform FFT.)

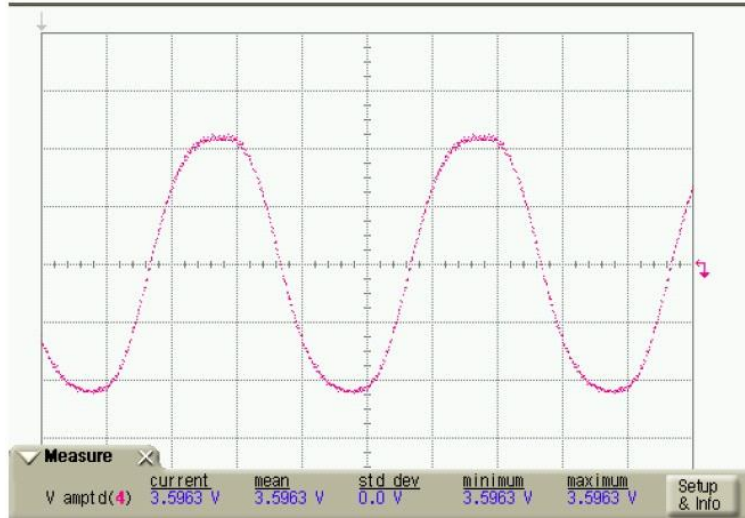


Figure 3. Example of the Amplifier's Output Signal at 2.5 GHz, 3.6 Vpp

Method1 used a spectrum analyzer to measure the output harmonics of the amplifier (up to the seventh harmonic in the below example), see [Figure 2](#) for the test setup. The following readings were collected from the spectrum analyzer, see [Table 1](#).

Freq (GHz)	Harmonic #	Pout (dBm)	Pout (μW), apply Eq. 3
2.5	1	16.17	41400
5	2	-35.3	0.2951
7.5	3	-6.83	207.5
10	4	-40.6	0.0871
12.5	5	-35.1	0.309
15	6	-37.5	0.1778
17.5	7	-54	0.003981

Table 1 - Spectrum Analyzer Measurement Readings

Using equation one above to calculate the THD, (measured at 2.5 GHz and the output voltage is at 3.6 Vpp):

$$\text{THD (\%)} = 100 \times \sqrt{\frac{0.2951\text{E}-06 + 207.5\text{E}-06 + 0.0871\text{E}-06 + 0.309\text{E}-06 + 0.1778\text{E}-06 + 0.003981\text{E}-06}{0.0414}} = \boxed{7.1 \%}$$

Method 2 used a high speed/BW oscilloscope to capture the amplifier output waveform signal ([Figure 3](#)), in a 50 Ω environment, then applied FFT to get its harmonic contents (up to the seventh harmonic in this example). We used the same bias voltages on the amplifier at output voltage of 3.6 Vpp, and at 2.5 GHz as in [Method 1](#), we achieved the following FFT results, see [Table 2](#) .

Freq (GHz)	Harmonic #	Pout (dBc)	Pout (dBm)	Pout (μW), apply Eq. 3
2.5	1	Ref	15.75	37584
5	2	-42	-26.25	2.37
7.5	3	-22.1	-6.35	232
10	4	-56.6	-40.85	0.0822
12.5	5	-47.3	-31.55	0.7
15	6	-51.7	-35.95	0.254
17.5	7	-66.8	-51.05	0.00785

Table 2 · Scope Measurement and Then Applied FFT to the Measurement Data

Using equation one above to calculate the THD (measured at 2.5 GHz and the output voltage is at 3.6 Vpp):

$$\text{THD (\%)} = 100 \times \sqrt{\frac{2.37\text{E}-06 + 232\text{E}-06 + 0.0822\text{E}-06 + 0.7\text{E}-06 + 0.254\text{E}-06 + 0.00785\text{E}-06}{0.037584}} = \boxed{7.9 \%}$$

Figure 4 below shows the graphic spectrum representation of these two measurement results.

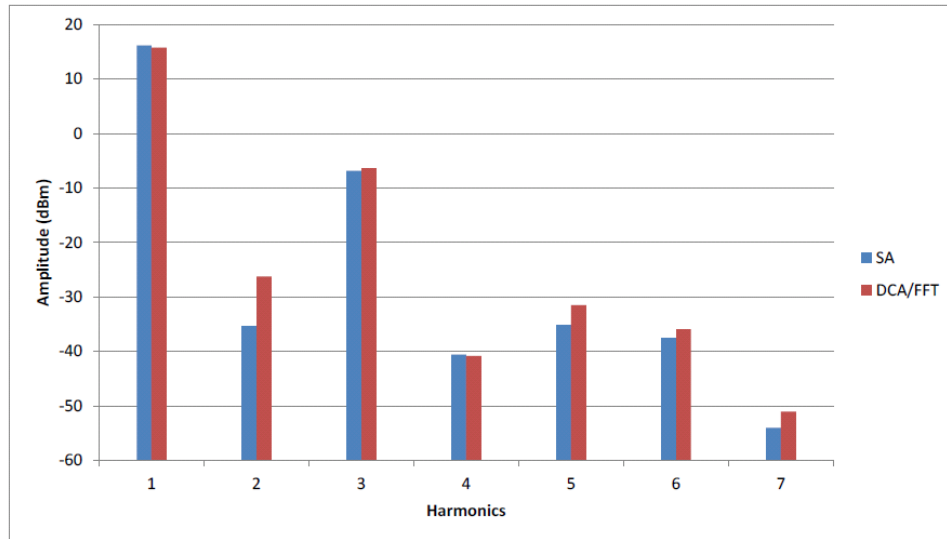


Figure 4. **Example of the amplifier's output harmonic signals at 2.5 GHz, 3.6 Vpp output, measured on a spectrum analyzer and FFT of the waveform measured on an oscilloscope/DCA.**

The comparison result shows there is about 0.8 % difference in the THD calculated results between the two test methods (spectrum analyzer vs. oscilloscope). This difference can be caused by the measurement uncertainty, measurement repeatability, frequency response error, and the oscilloscope's amplitude sensitive of measuring a small harmonic signal in the presence of a large fundamental signal. Based on the results, both THD test methods will work.



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