Aspects of Low Distortion Sine Wave Generators Measurement

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Summary: This paper deals with testing of ultra-low distortion sine wave generators. Measurement of harmonic distortion based on lock-in amplifiers is described and practical results using fundamental-suppression method are presented.

Introduction

The total harmonic distortion (THD) is one of fundamental parameters describing spectral quality of harmonic signal. THD is defined as the ratio of *rss* (root-sum-of-squares) of all harmonic distortion components in the spectrum to the *rms* (root-mean-square) value of the fundamental component. It is calculated using a formula:

$$THD = 20\log\frac{\sqrt{\sum_{i=2}^{n} U_i^2}}{U_1}$$

where U_i is the rms value of i-th harmonic component in the spectrum.
THD can be measured using distortion meters, heterodyne spectrum analyzers, FFT analyzers or high precision digitizers (e.g. VXI modules as the Hewlett Packard HP E1437A or HP E1430A, see [4], [5], [6]). We have examined a modern test method using lock-in amplifiers for THD measurement.

Measurement using lock-in amplifier

While spectrum analyzers can measure a spectrum of signal in wide frequency range, the lock-in amplifiers enable to determine an amplitude and a phase of component of the signal at a specific reference frequency using phase-sensitive detection technique. Noise signals at frequencies other than reference one are rejected and do not affect the measurement.

Conventional lock-in amplifiers use an analog demodulator to mix an input signal with a reference signal. Dynamic reserve is limited to about 60 dB, and these instruments suffer from poor stability, output drift and excessive gain and phase error. Demodulation in modern DSP lock-in amplifiers (as the Stanford Research Systems SR830 [3]) is accomplished by sampling the input signal with a high precision A/D converter, and multiplying the digitized input by a synthesized reference signal. This digital demodulation technique results in more than 100 dB of true dynamic reserve (no pre-filtering) and is free of the errors associated with analog instruments. Dynamic reserve at specific frequency could be raised over 100 dB, filter slope up to 24 dB/oct according to [3].

The principle of higher harmonics measurement is shown in Fig. 1. The synchronization generator multiplies base frequency TTL signal by factor 2 to 5. Synchronization generator could be either another externally synchronized generator or special device based on phase-lock-loop (PLL) principle to generate the reference signal.

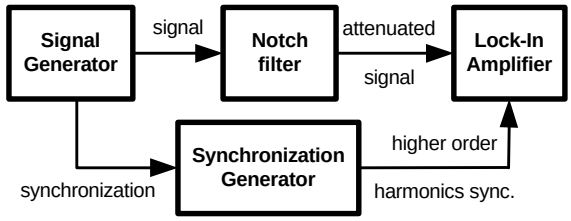

Figure 1: Principle of measurement using lock-in amplifier

Fundamental – Suppression Measurement

In case of low-distortion measurements (THD better than –80 dB) it is absolutely necessary to use notch filters (to suppress 1st harmonic and improve dynamic range of analyzers).

The distortion of notch filter must be lower than the lowest values to be measured. Since real filters attenuates not only fundamental but also higher harmonic components, true results are obtained using simple correction.

The amplitudes of higher harmonics must be corrected by values of filter attenuation at frequencies of harmonics.

Direct measurement (without notch filter) is influenced by distortion of the meter used. This problem is illustrated in Tables 1 and 2.

Following scheme shown in Fig. 2 was chosen mainly to avoid frequency stability problem of used generator, i.e. all devices (Spectral analyzer HP 35670A, VXI digitizer HP E 1430A and Lock-In amplifier SR 830) are examining signal with same parameters, at once. This problem was significant while using RC based generators.

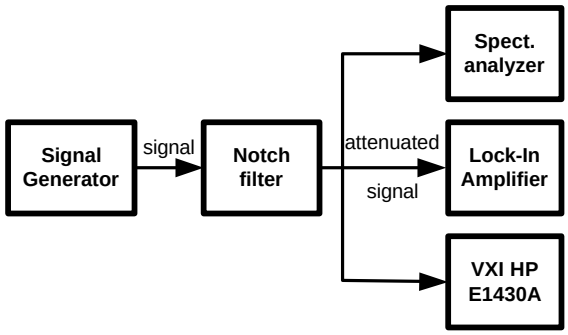

Figure 2: General scheme used for measurement of generator's parameter

All measurements were carried out using 50 Ω termination and passive notch filters. It's necessary to consider this fact when evaluating notch filter frequency charekteristic.

Spectrum calculated by Digester program developed at our department, from data gathered by VXI E1430A is shown in Fig. 3. This spectrum was already corrected with frequency characteristic of used notch

Table 1: Fundamental-suppression THD measurement (with notch filter) of DS360 generator

DS 360 Generator	frequency = 20.52 kHz, voltage = 1 V rms						**THD [dB]**
	1st harm		2nd harm		3rd harm		
	* [dBVrms]	** [dBc]	* [dBVrms]	** [dBc]	* [dBVrms]	** [dBc]	
SR 830DSP Lock in amplifier	-47.0	0	-118.8	-106.0	-118.9	-110.9	**-104.8**
HP 35670A Spectrum Analyzer	-47.0	0	-118.0	-105.2	-119.0	-111.0	**-104.2**
VXI & HP E1430A VXI Digitizer	-47.3	0	-120.0	-108.9	-119.1	-108.5	**-105.1**

* measured values in dBVrms

** values of harmonics in dBc (after correction)

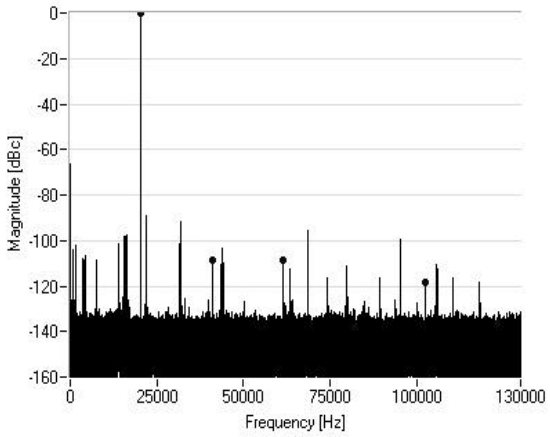

Figure 3: Spectrum of generator DS 360, U = 1 Vrms, f = 20.52 kHz, notch filter used, decimation level 5

filter. Harmonics are highlighted for better recognition. As reader could see, 4th harmonic is situated under noise level.

Conclusion

The experiences with measuring of low distortion sine wave signals had proven the necessity of using passive notch filters. The higher harmonics at levels under –80 dBc had called out the exigency of suppressing of first harmonic at least by –40 dB. The direct measurement is not usable because the distortion of the input circuitry of meters degrades measurement results. In case of fundamental-suppression THD measurement all three instruments provide practically same results. Since the lock-in amplifier is based on different principle than FFT spectrum analyzers (VXI digitizer with application software is in principle also FFT analyzer [6]), it can be successfully used for independent measurements of harmonic distortion in metrology laboratories. An automated version of the PC-controlled system with the SR830 or SR844 lock-in amplifiers is under development at present.

Table 2: Direct THD measurement (without notch filter) of DS360 generator

DS 360 Generator	frequency = 20.52 kHz, voltage = 1 V rms			**THD [dB]**
	1st harm [dBc]	2nd harm [dBc]	3rd harm [dBc]	
SR 830DSP	0.0	-73.4	-82.3	**-72.9**
HP 35670A	0.0	x	x	**x**
VXI & HP E1430A	0.0	-89.3	-108.7	**-89.2**

x – higher harmonics lie under noise floor of the spectrum analyzer

Acknowledgment

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