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THE MEASUREMENT OF AM NOISE OF OSCILLATORS

Enrico Rubiola[1]

[1]FEMTO-ST Institute, UMR 6174, CNRS and Université de Franche Comté, Besançon, France
rubiola@femto-st.fr

Abstract

This article describes the design of a measurement system for the AM noise of RF/microwave sources, explains the calibration procedures, and provides a set of practical measurements in terms of $S_\alpha(f)$, i.e., the power spectral density of the fractional amplitude fluctuation α. The cross-spectrum measurements provide information on the noise of the internal detector-amplifier pair.

Introduction

After a significant progress in the measurement of PM noise [1], it is necessary to improve the methods for the measurement of AM noise. The AM noise is relevant in feedback oscillators because of AM/FM conversion in resonators; in frequency multipliers, because of AM/PM conversion; in optical systems, where it is known as the RIN (relative intensity noise); in the emerging domain of microwave photonics [2]; in experimental physics, as a tool of investigation on near-dc noise brought up by nonlinearity.

AM noise measurements refer to the quasi-perfect narrow-band sinusoidal signal

$$v(t) = V_0[1+\alpha(t)]\cos[2\pi\nu_0 t + \varphi(t)] \ , \qquad (1)$$

where $|\alpha| \ll 1$, $|\varphi| \ll 1$, $\mathbb{E}\{\alpha\} = 0$, $\mathbb{E}\{\dot{\varphi}\} = 0$; $\mathbb{E}\{\,\}$ is the expectation. The power dissipated by a resistor R is $P \simeq \frac{V_0^2}{2R}(1+2\alpha)$, thus $\alpha(t) = \frac{1}{2}\frac{P-P_0}{P_0}$, where $P_0 = \frac{V_0^2}{2R}$ is the nominal power. The AM noise spectral density is

$$S_\alpha(f) = \frac{1}{4} S_{\frac{P}{P_0}}(f) = \frac{1}{4P_0^2} S_P(f) \ , \qquad (2)$$

which is measured by means of a power detector.

In the past, large work on AM noise was done at NIST using as the power detector a double balanced mixer with the two inputs in parallel [3, 4]. More precisely, the two mixer inputs are driven in-phase by the input signal through a power splitter. Improved sensitivity was obtained with the bridge (interferometric) correlation method [1]. Unfortunately, the latter is useful only for the measurement of two-port devices because a reference signal (the device-under-test input) is needed to balance the bridge. This is not the case of oscillators and other sources, where only the output signal is available.

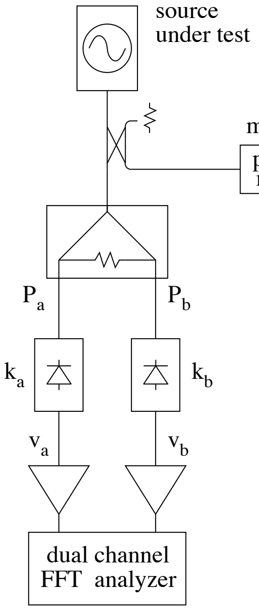

Figure 1: Scheme of the cross-spectrum system for the measurement of AM noise.

Proposed Method

The scheme of the AM noise measurement system is shown in Fig. 1. Employing commercial parts and instruments, this scheme is suitable to the frequency range from less than 1 MHz to at least 40 GHz. Only the dc amplifiers are home made. The power detector is of the Schottky or tunnel type, depending on power and frequency.

By inspection on Fig. 1, the AM noise of the source under test is

$$S_\alpha(f) = \frac{1}{4k_a k_b P_a P_b} S_{ab}(f) \ , \qquad (3)$$

where $S_{ab}(f)$ is the cross spectrum measured by the FFT analyzer; P_a and P_b the detector input power; k_a and k_b the detector gain. Practical values are 100–300 A^{-1} for the schottky diodes, and 300–1000 A^{-1} for the tunnel diodes. As the two channel are independent, the single-channel noise is attenuated by a factor $\frac{1}{\sqrt{2m}}$ in the cross spectrum averaged on m spectra.

Calibration. Calibration is performed by switching a small reference attenuation (0.1–0.5 dB) in the source-instrument path. This method exhibits high accuracy because

- It relies on the measurement of a reference attenuation, which is a power ratio.

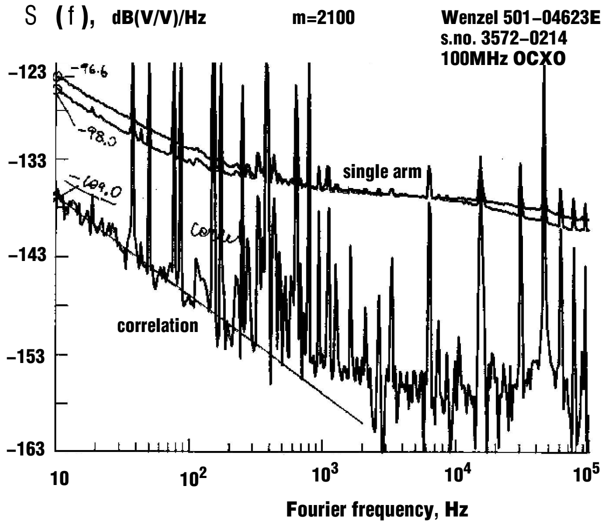

Figure 2: Example of AM noise measurement.

- It provides the *product kP* needed in Eq. (3) through a differential dc measurement.

Thus, no absolute measurement is needed.

Results

The proposed method allowed to measure numerous sources (quartz oscillators, DROs, RF/microwave sinthesizers, ...), available at the FEMTO-ST Institute and chosen as representative of their class. Figure 2 shows an example (high short-term stability OCXO). $S_\alpha(f)$ is converted into the Allan deviation $\sigma_\alpha(\tau)$, which is the amplitude stability as a function of the measurement time τ. Great attention was given to flicker noise, for which σ_α is constant. Most of the sources measured fall in the 10^{-6} range, with a minimum of 4.6×10^{-7}.

The lowest white noise observed on a source (microwave PLL) is of about -165 dB(V^2/V^2)/Hz. The background white noise could still not be measured. The estimated value is in the range of -170 dB(V^2/V^2)/Hz, which improves by 15 dB or more on the background noise given in [3, slide 38].

Looking at Fig. 2, the single-channel flicker noise coefficient is $h_{-1} = 2.9\times10^{-12}$ V^2/V^2/Hz (-115.4 dB), which means $\sigma_\alpha = 2\times10^{-6}$. As the oscillator noise is significantly lower, this is the background noise of the detector-amplifier pair. Further analysis shows that the main $1/f$ noise contribution is that of the dc amplifier, for the system can be significantly improved. With the present configuration, and averaging on $m = 2^{15}$ spectra (the memory size of our old FFT analyzer), the single-channel noise is rejected by 24 dB. In this condition, the dual-channel background $1/f$ noise coefficient is $h_{-1} = 1.15\times10^{-14}$ V^2/V^2/Hz (-139.4 dB), thus the instrument stability is $\sigma_\alpha = 1.3\times10^{-7}$.

Finally, a detailed report on the AM noise measurements at the FEMTO-ST Institute is available online [5].

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