REVIEW OF PM AND AM NOISE MEASUREMENT SYSTEMS*

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Abstract - This paper reviews the measurement technologies of phase noise and amplitude noise. Definitions and the appropriate units of phase noise and amplitude noise are reviewed. Single channel, cross-correlation and carrier suppression techniques are compared and discussed. The use of the NIST PM/AM Noise Standard is also discussed.

I. Introduction

A carrier signal with a low amplitude modulation (AM) and phase modulation (PM) noise (Figure 1) can be mathematically represented by

$$V(t) = (V + \varepsilon(t))\cos(2\pi\nu_0 t + \phi(t)), \quad (1)$$

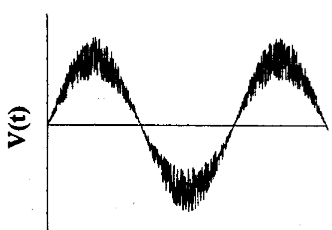
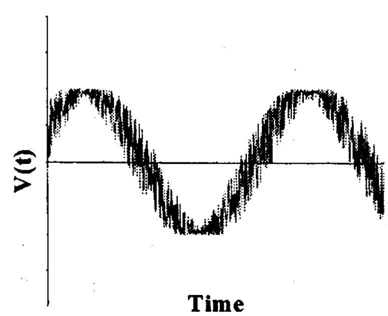


Figure 1 (a) Signal with AM noise



(b) Signal with PM noise

where the amplitude fluctuations about the nominal amplitude V are contained in $\varepsilon(t)$, and the phase fluctuations about the average frequency ν are given by $\phi(t)$. Figure 2 shows a vector representation of a carrier signal with AM and PM noise.

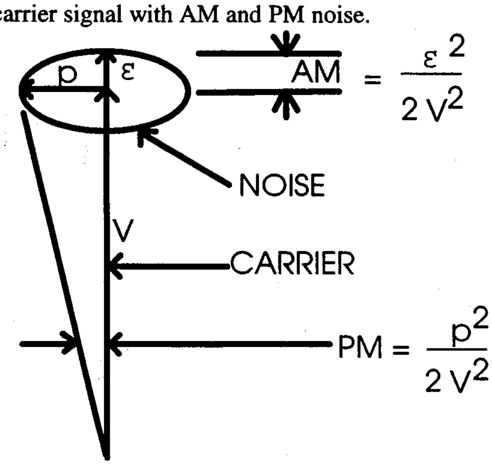


Figure 2. Vector representation of AM and PM noise on a carrier.

The IEEE recommended specifications for single side band PM and AM noise are given in the unit of dB below the carrier in a 1 Hz bandwidth (dBc/Hz):

$$L(f) = \frac{1}{2} S_{\varphi}(f) = \frac{\delta\phi^2(f)}{2BW}, \quad (2)$$

$$\frac{1}{2} S_a(f) = \frac{1}{2}\left(\frac{\varepsilon}{V_0}\right)^2 \frac{1}{BW}. \quad (3)$$

For frequency multiplication or division, AM noise may or may not change depending on the configuration. On the other hand, PM noise will always change. If $\nu_1 = N * \nu_2$, (4)

then $L_{\nu 1}(f) = N^2 * L_{\nu 2}(f)$. (5)

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Various PM/AM noise measurement systems will be discussed in the following sections.

II. PM Noise Measurements

II.1 Classic Single Channel

II.1.1 Basic Configuration for Two Oscillators:

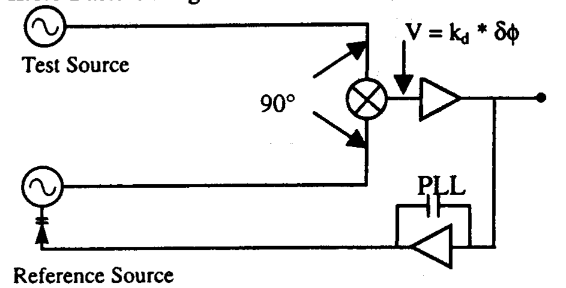

Figure 3. Basic Configuration for Two Oscillators

A phase-locked-loop (PLL) is used to lock the frequencies of the two oscillators 90° out of phase at the mixer. The noise can be measured at Fourier frequencies higher than the bandwidth of the PLL.

II.1.2 Basic Configuration for Devices

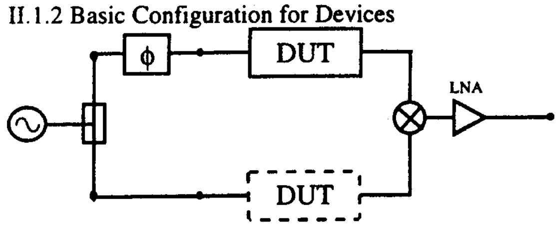

Figure 4. Basic Configuration for Devices

The devices under test (DUT) can be amplifiers, frequency multipliers, frequency dividers, etc. Two devices are used when the frequency changes.

II.2 Two-Channel Cross-Correlation

This technique uses two single-channel measurement systems. A two-channel fast Fourier transform (FFT) spectrum analyzer is used to measure the cross-correlation of the phase noises from each measurement system. Only the coherent noise present in both channels will average to a finite value. The time average of the incoherent noise [1] will approach zero as $N^{-1/2}$, where N is the number of averages.

II.2.1 Cross-Correlation Configuration for Two Oscillators

The measured PM noise of the system in Figure 5 is:

$$S_\phi(f)_{Cross_{1,2}} = S_\phi(f)_{DUT} + \frac{S_\phi(f)_{Ref_1} + S_\phi(f)_{Ref_2} + S_\phi(f)_{System_1} + S_\phi(f)_{System_2}}{\sqrt{N_{Averages}}} \quad (6)$$

The PM noise from an individual measurement system and the references decrease as the square root of the number of averages. The added noise source is for calibration purposes and will be discussed in more detail in Section II.4.

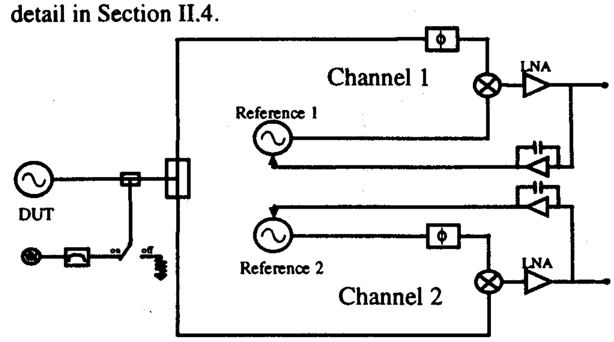

Figure 5. Cross-Correlation Configuration for Two Oscillators

II.2.2 Cross-Correlation Configuration for Devices

The measured PM noise of the system in Figure 6 is:

$$S_\phi(f)_{Cross_{1,2}} = S_\phi(f)_{DUT} + \frac{S_\phi(f)_{System_1} + S_\phi(f)_{System_2}}{\sqrt{N_{Averages}}} \quad (7).$$

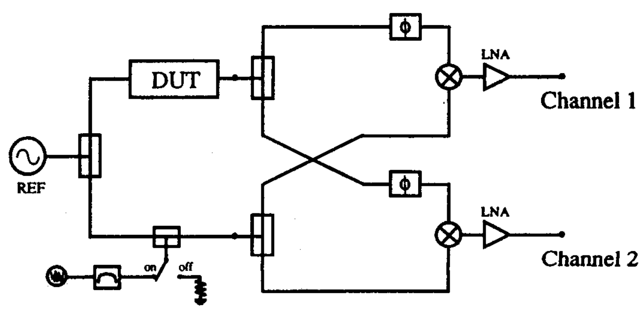

Figure 6. Cross-Correlation Configuration for Devices

II.3 Carrier Suppression

This technique is used to amplify the PM and AM noise to make it measurable by the other techniques mentioned above. It was introduced by Klaus H. Sann in 1968 [3]. As shown in Figure 7 the carrier signal in the DUT and arm A of the bridge are partially canceled by the carrier signal in arm B of the bridge when two signals are combined 180° out of phase in a hybrid. The noise about the carrier generated by the DUT is not changed when carrier suppression is applied, only the carrier and the noise originally associated with the carrier is reduced. Since PM noise and AM noise are measured and defined relative to the carrier power (see Figure 2), reducing the carrier has the effect of amplifying the PM and AM noise generated in the DUT.

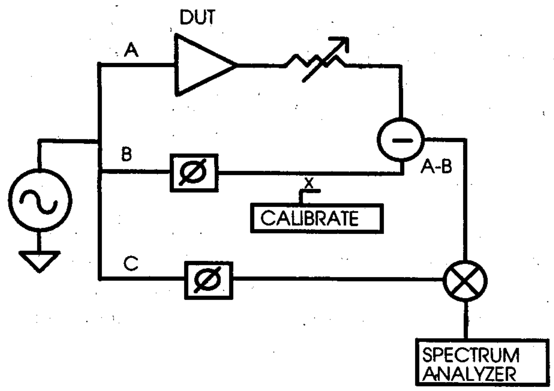

Figure 7. Carrier Suppression Configuration

This technique often allows us to attain noise floors comparable or lower than the cross- correlation technique, without the need for long averaging.[1] (See [3] for a discussion of the noise floor.)

II.4 Comparison of PM Noise Floors

The noise floors for the different measurement systems discussed above are compared in Figure 8.

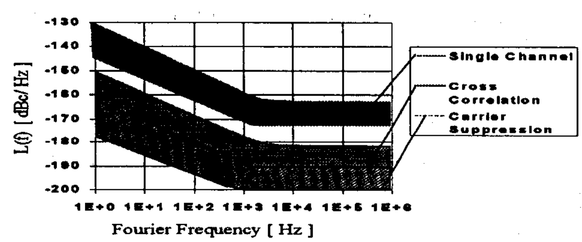

Figure 8. Noise Floors for Different PM Measurement Techniques

II.5 NIST PM/AM Noise Standard

The NIST PM/AM noise standard makes PM and AM calibrations much easier and faster than previous techniques [4]. With traditional calibration techniques, the phase-voltage-conversion coefficient (k_d) of the mixer and the gain (G) of the low noise amplifier (Figure 4) are measured using a substitution source. This yields the gain of the whole measurement system (= $G * k_d$) at only one Fourier frequency.

With the NIST PM/AM noise standard, this measurement is made as a function of Fourier frequency in situ. A white noise with known power is added to the carrier signal to create equal, known AM and PM noise.

[1] Some part of the system is patented, see [3].

The gain of the whole measurement system is calibrated by comparing the measured noise power and the known PM noise power. This calibration typically takes much less time than the substitution approach and is less prone to errors due to mismatches in the connections and components. This standard can also be used for AM noise measurements.

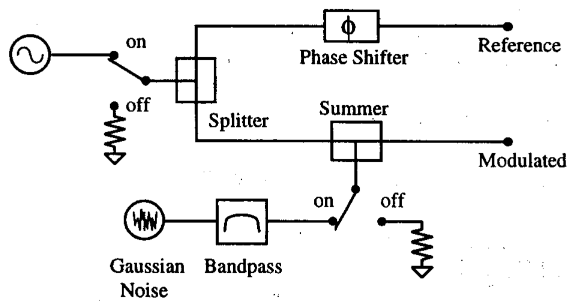

Figure 9. NIST PM/AM Noise Standard

As shown in Figure 9, Gaussian noise is added to one arm of the signal source. The added noise power is typically flat to 0.1 dB over a bandwidth of 10% of carrier frequency or a few hundred megahertz. The noise power is adjustable and pre-calibrated. NIST has made standards of this type from 5 MHz to 40 GHz. Using this standard the uncertainty of the calibration is less than 0.5 dB for Fourier frequency offsets out to 100 MHz from the carrier. The temperature coefficient of the standard is typically less than 0.02 dB/K.

The differential noise between the reference and modulated arm for a 10.6 GHz standard is shown in Figure 10. Also shown are the calibrated noise level and the PM noise for a typical dielectric resonator oscillator (DRO) source.

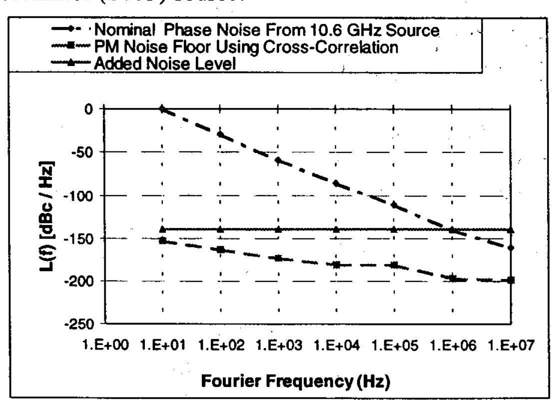

Figure 10. Comparison of PM Noise in NIST Standard

The standard can be used to measure the noise floor and the errors of PM or AM noise measurement systems, or to measure the noise added by various

DUTs. The noise source can also be added in series with the house frequency standard to calibrate various PM and AM noise measurements.

Using the cross-correlation technique discussed in Section II.2, we have measured PM noise floors for the measurement of DUTs of 140 dB below the PM noise of the source in the standard. (See Figure 10).

NIST has also developed systems for measuring the PM noise at Fourier frequencies up to 40% of the carrier. This system uses a wide band modulator for both PM and AM calibration [1,5].

III. AM Noise Measurement

III.1 Classic Single Channel

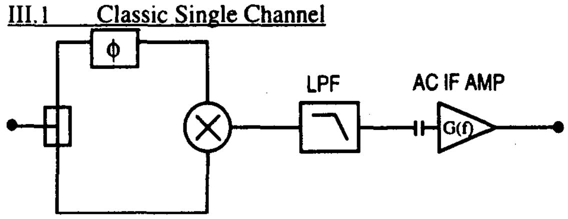

Figure 11. Basic Configuration for AM Noise Measurements

The signals entering the mixer should be in phase to measure AM noise. (The signals are 90° out of phase for PM noise measurement.)

III.2 Two-Channel Cross-Correlation

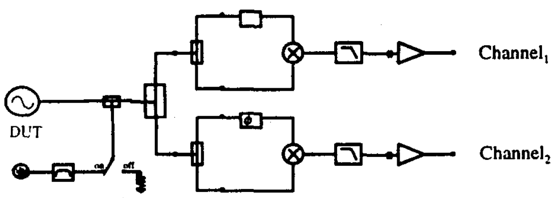

Figure 12. Cross-Correlation for Oscillators

In a cross-correlation AM noise measurement system for a source (Figure 12), the noise contributed by the individual measurement systems is reduced as

$$S_a(f)_{Cross_{1,2}} = S_a(f)_{DUT} + \frac{S_a(f)_{System_1} + S_a(f)_{System_2}}{\sqrt{N_{Averages}}} \quad (8)$$

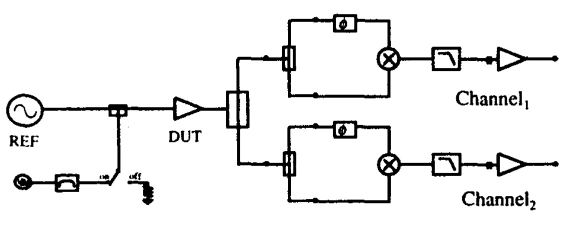

Figure 13. Cross-Correlation for Amplifiers

The measured PM noise of the system for amplifiers (shown in Figure 13) is:

$$S_a(f)_{Cross_{1,2}} = S_a(f)_{DUT} + S_a(f)_{REF} + \frac{S_a(f)_{System_1} + S_a(f)_{System_2}}{\sqrt{N_{Averages}}} \quad (9)$$

III.3 Carrier Suppression

The setup of the measurement system should be the same as discussed in section II.3. The signal going into the mixer should be at the same phase for AM noise measurement, instead of the 90° difference as usual for PM noise measurement.

Conclusion

We have shown three techniques for PM / AM noise measurement. Single channel systems have a simple setup and reach a modest noise floor. Cross-correlation systems achieve much lower noise floors than single channel systems but are more complex and require much longer times to make the measurements. Carrier suppression systems achieve noise floor comparable to the cross-correlation systems in real time, but are much more elaborate and require special care in calibration.

We have also discussed some of the advantages of using the NIST PM/AM noise standard to simplify the calibration procedure.

Acknowledgments

We thank Aimin Zhang for fruitful discussions.

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[5] F.L. Walls, "Frequency Calibration Standard Using a Wide Band Phase Modulator," United States Patent, No. 5,101,506, 1992.