Correlation Measurements between PM and AM Noise in Oscillators

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***Abstract*—We discuss techniques for measuring the correlation between phase-modulated (PM) and amplitude-modulated (AM) noise in an oscillator and report results of such correlation in a few selected oscillators of similar size, weight, power consumption and vibration sensitivity.**

Keywords—AM noise; correlation; modulation; PM noise

I. Introduction

The close-to-the-carrier phase-modulated (PM) and amplitude-modulated (AM) noise of an oscillator can show correlation. We discuss techniques for measuring the correlation between PM and AM noise in an oscillating signal. Past studies have focused on the relationship between PM and AM noise in high-performance quartz oscillators reported in [1, 2], but did not involve spectral-correlation measurements as in [3]. One model suggested that if the f^{-1} components in both PM and AM noise of a loop amplifier in an oscillator originate from the same source, and the amplifier is the dominant noise source in the oscillator, then the PM and AM noise of the oscillator may be correlated [2]. This correlation may exist even though the PM and AM noise have different power-law noise slopes. In this paper we revisit the work relating PM and AM noises described in [1, 2] by reporting the measured correlation between PM and AM noise of selected oscillators of similar size, weight, power consumption and vibration sensitivity.

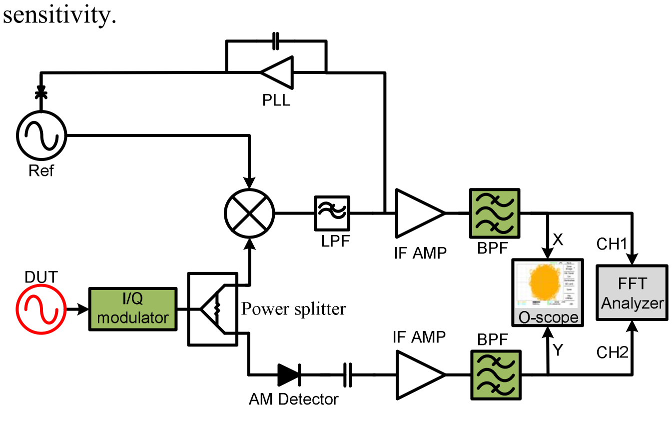
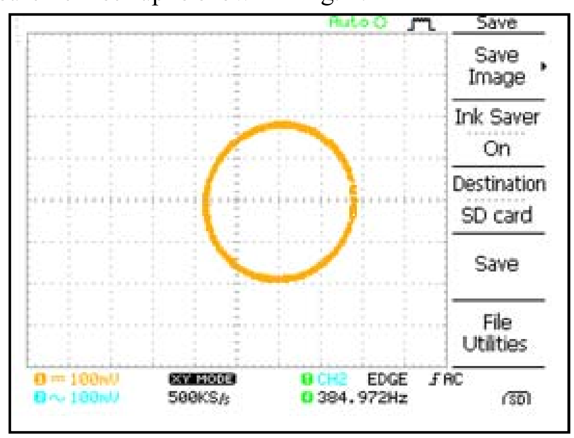


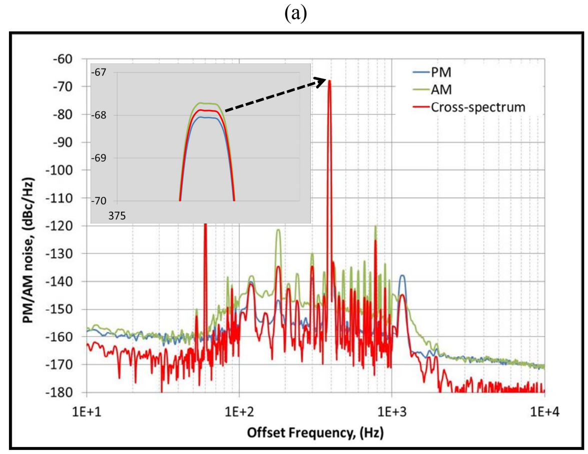
Fig. 1. Experimental set-up for PM-AM correlation test in an oscillator. DUT – Device Under Test, LPF – Low Pass Filter, BPF – Band Pass Filter, IF AMP – Intermediate Frequency Amplifier.

II. PM-AM Correlation Measurement Techniques

We study the correlation between PM and AM noise of two classes of low-noise oscillators, temperature-compensated quartz (TCXO) and quartz-MEMS. However, we first measure such a correlation in a 10 MHz signal obtained from a commercial signal generator, the device under test (DUT), by externally adding different types of modulation using an analog I-Q modulator [4]. A simplified block diagram of our measurement set-up is shown in Fig. 1.



(a)

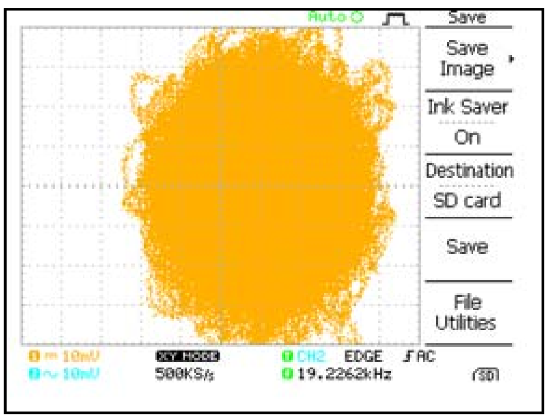


(b)

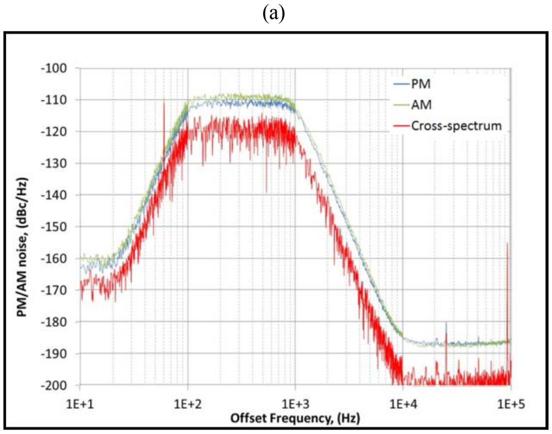
Fig. 2. A single sideband modulation at 400 Hz is added at the output of 10 MHz signal (DUT). (a) Scatter-plot of analog PM and AM noise measurement, 100% PM-AM noise correlation is found as expected shown by the circle. (b) Cross-spectrum between PM and AM tone at 400 Hz.

The DUT that is phase-locked with a reference oscillator is spilt into two paths: one connected to a PM detector and another to an AM detector. For assessing correlations of PM and AM noise on the carrier, we down-convert to baseband, measure and display the AM noise on the Y-axis and the PM noise on the X-axis of a 2-axis plot, as displayed by an O-scope (see Fig. 1). This so-called ‘scatter’ or ‘X-Y plot’ displays correlation in real-time by lines and ellipses, and lack of correlation by a random circular cloud pattern. The scatter plot does not conveniently provide a time average, so each signal is also fed to a 2-channel cross-spectrum analyzer that computes FFTs.

To confirm our concept, an I-Q modulator was used to add a single-sideband (SSB) modulation at 400Hz offset from a 10 MHz carrier (DUT). A small amount of SSB modulation produces equal amounts of correlated PM and AM [5]. This is shown in Fig. 2a as a XY-plot of PM vs AM. The circle indicates that PM and AM are 100 % correlated and a $\pi/2$ phase difference between them is verified for SSB modulation. The frequency-domain representation is shown in Fig. 2b. The power spectral density (PSD) of PM noise (blue curve), PSD of AM noise (green curve) as well as cross-spectrum between PM and AM (red curve) was measured with a 2-channel FFT analyzer. The cross-spectrum is exactly the expected geometric mean as shown.



(a)

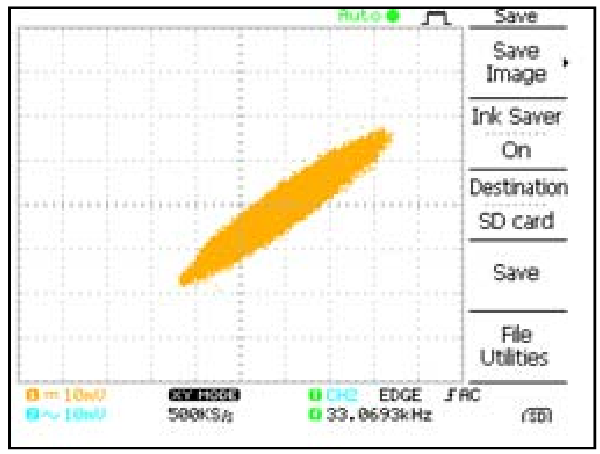


(b)

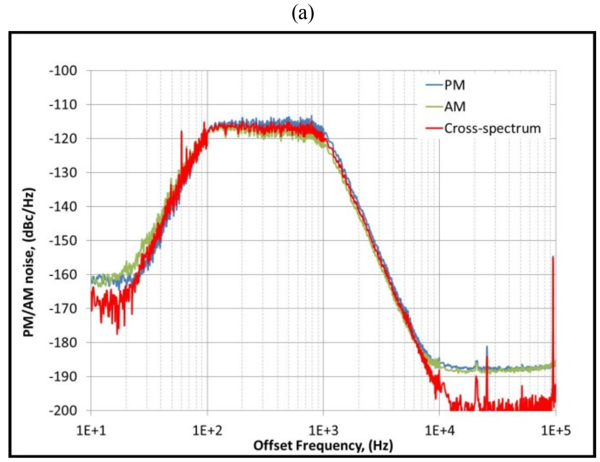
Fig. 3. A white-noise source with equal uncorrelated AM and PM noise is added to the DUT. (a) Scatter-plot of analog PM and AM noise. No PM-AM noise correlation is expected, nor found as shown by the cloudy pattern. (b) Cross-spectrum between PM and AM is the grassy bottom-most trace and PM and AM are the smooth traces. The cross-spectrum is entirely average-limited.

Next, an RF noise source is added to the DUT, producing equal levels of uncorrelated AM and PM noise. The signal’s PM and AM noise passes through bandpass filters (BPF) from 100 Hz < f < 1 kHz. These filters were used to observe the correlation effects only in the selected frequency range. No PM-AM noise correlation is expected, nor found as shown in Fig. 3a by the cloudy pattern. Fig. 3b is the frequency-domain representation, cross spectrum is the grassy bottom-most trace and PM and AM are the smooth traces. The cross-spectrum is not the geometric mean and reaches an average-limited threshold below the PM and AM spectra.

Finally, the amplitude and phase of the DUT was modulated with random noise to produce correlated PM and AM noise. Fig. 4a shows scatter-plot indicating that the amount of PM and AM is not exactly equal, but there is significant correlation between PM and AM noise. The same correlation effect can be seen in Fig. 4b, where the cross-spectrum is equal to the average of PM and AM noise at offset between 100Hz – 1 kHz.



(a)



(b)

Fig. 4. Correlated AM and PM noise is added to the DUT. (a) Scatter-plot of analog PM and AM noise. Significant correlation between PM-AM noise is found, as shown by the elliptical pattern (b) Cross-spectrum between PM and AM.

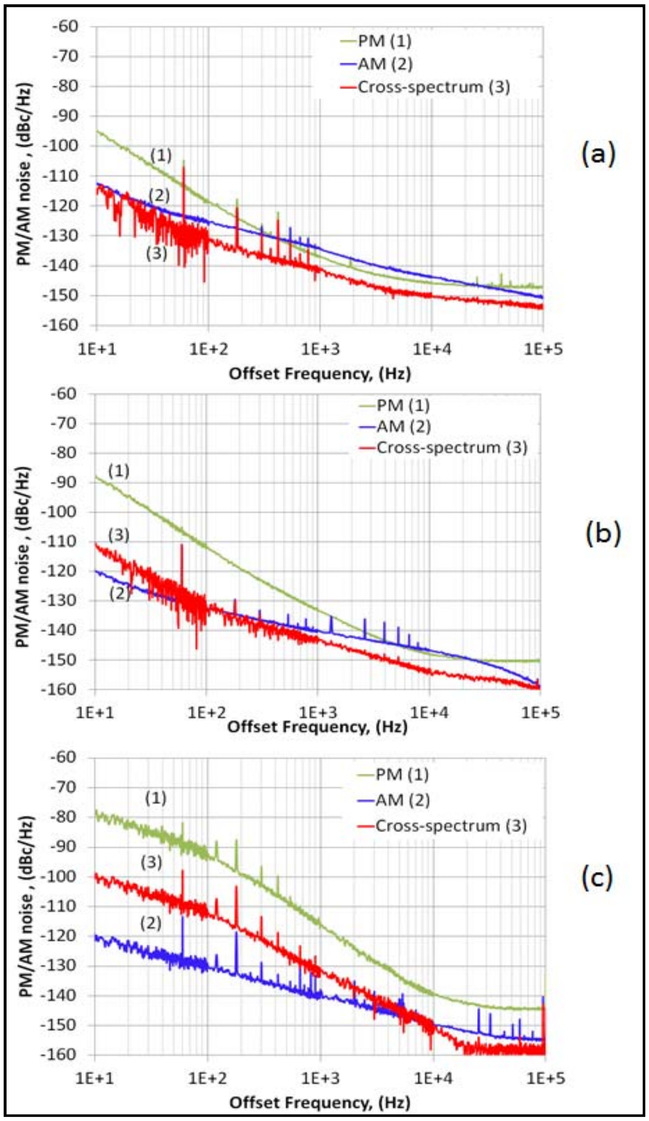


Fig. 5. Plot of PM noise, AM noise and correlation between them. (a) TCXO at 16.4 MHz, (b) TCXO at 11.2 MHz and (c) Quartz -MEMs oscillator at 663 MHz. These oscillators show correlation that varies from near zero (a) to almost 100% correlation (c) as the offset frequency gets closer to the carrier.

In order to measure the actual correlation between PM and AM noise of different oscillators, we removed the I-Q modulator as well as the BPFs from each channel. We chose as mentioned earlier three selected oscillators (DUT) of similar size, weight, power consumption and vibration sensitivity. The correlation results for three oscillators are shown in Fig. 5: two TCXOs and one quartz-MEMS oscillator. The plots show simultaneous amplitude and phase noise measurements along with the associated correlations between them. These oscillators show correlation that varies from near zero (a) to almost 100% correlation (c) as the offset frequency gets closer to zero (closer-to-the-carrier). These types of correlations may be useful in the analysis of oscillators as the loop is driven near the nonlinear regime.

III. Future Work

PM-AM correlations can be caused by several mechanisms, one being the non-linear deformations in the oscillator's resonator. We will extend this study to observe the correlation effect in oscillators under various vibration conditions. The vibration sensitivity establishes an oscillator's PM noise on many moving platforms such as ground and air vehicles. While low-frequency vibration noise close-to-carrier can be suppressed either by passive or active vibration-suppression schemes, mechanical vibration and acceleration in various operating environments can be the primary cause of mechanical deformations that increase the level of an oscillator's otherwise low PM noise. In the future, we plan to study and develop novel techniques for reducing the vibration sensitivity of an oscillator by use of PM-AM correlation measurements.

References

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