# Reducing oscillator PM noise from AM–PM noise correlation

A. Hati, C.W. Nelson and D.A. Howe

A new scheme for reducing the phase-modulated (PM) noise of an oscillator from correlation between amplitude-modulated (AM) and PM noise is presented. Experimental results of this correlation effect are also presented. An improvement of almost 10 dB in the PM noise is reported for frequency offsets with strong correlation.

*Introduction:* In most oscillators, the close-to-the-carrier amplitude modulation (AM) noise is usually lower than the phase modulation (PM) noise and does not pose serious problems. However, in high-performance systems where every decibel of PM noise is important, the AM noise cannot be neglected. Numerous applications consider AM noise effects on the overall performance of an oscillator or a system. However, very little is known about the relationship between AM and PM noise in an oscillator. Past studies have focused on the relationship between AM and PM noise in high-performance quartz oscillators, reported in [1, 2], but did not involve spectral-correlation measurements as in [3]. The close-to-the-carrier AM and PM noise of an oscillator can exhibit varying degrees of correlation [3, 4]. By measuring the PM noise of an oscillator in real time, the oscillator noise can be corrected for and reduced. However, it can be difficult to measure the PM noise without a higher-quality reference or a high-quality factor element to measure against. The AM noise is relatively easy to measure, requiring only a diode and a few capacitors. If the PM noise is correlated to the AM noise, the measurement of the AM noise can be utilised to improve the PM noise. In this Letter, we present a feed-forward scheme for reducing PM noise from AM–PM noise correlation.

*Description of system:* We designed a simple-loop oscillator at 635 MHz with a quartz-MEMS resonator [5] shown in Fig. 1 (inside the upper dashed box). The PM noise, AM noise and the correlation between them are measured with an I–Q demodulator shown in the lower dashed box. In an oscillator, the correlation between AM and PM noise can originate either from the loop amplifier or the resonator. In our oscillator, such correlation originates mainly from the nonlinear resonator. We observe more than 90% correlation from the cross-spectrum below the 200 Hz offset as shown in Fig. 2. When the cross-spectrum is equal to the geometric mean of the AM and PM noise, it represents 100% correlation [3].

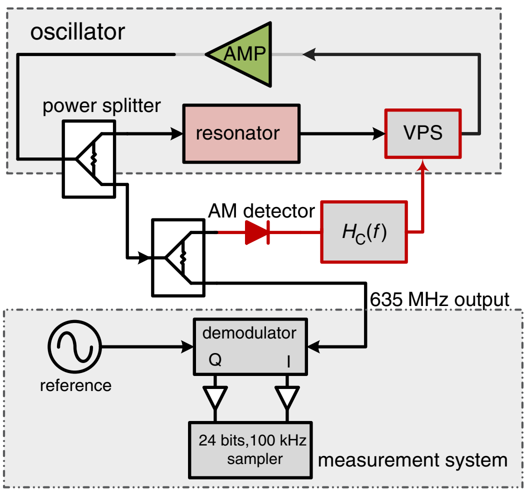


**Fig. 1** *Block diagram of quartz-MEMS resonator-based oscillator, feed-forward control circuit and measurement system*

VPS: voltage-variable phase shifter

If a control signal of equal magnitude, same noise slope but opposite phase as the PM noise is generated, then it can be utilised to improve the PM noise of the oscillator via a feed-forward correction. Two transfer functions are measured and used to calculate the required control function: $H_{AM-PM}(f)$ is measured from the output of the AM detector to the PM ($\tan^{-1}$ I/Q) of the I–Q demodulator and $H_{VPS}(f)$ is measured between the input of the voltage-variable phase shifter (VPS) and the PM output of the demodulator. The control transfer function $H_C(f)$ can then be calculated from

$$H_C(f) = -\frac{H_{AM-PM}(f)}{H_{VPS}(f)}$$

Close to the carrier, the PM noise and AM noise have a noise slope of $f^{-3}$ and $f^{-1}$, respectively. The integration of the AM noise that is required to match the PM noise can be achieved automatically via the Leeson effect [6] by applying the feed-forward signal to the VPS in the oscillator loop.

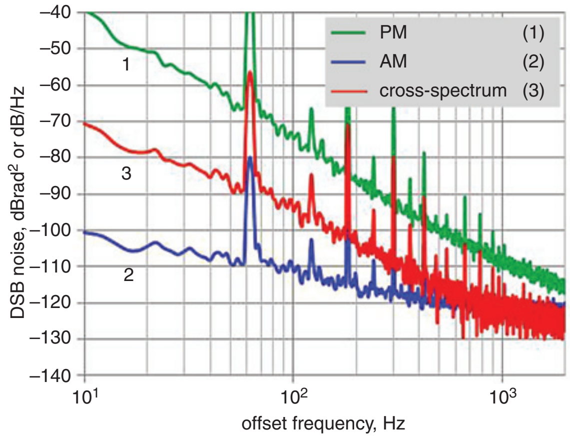


**Fig. 2** *Plot of double-sideband PM noise, AM noise and cross-spectrum between them for quartz-MEMS oscillator at 635 MHz*

Plot shows strong correlation as offset frequencies get closer to carrier

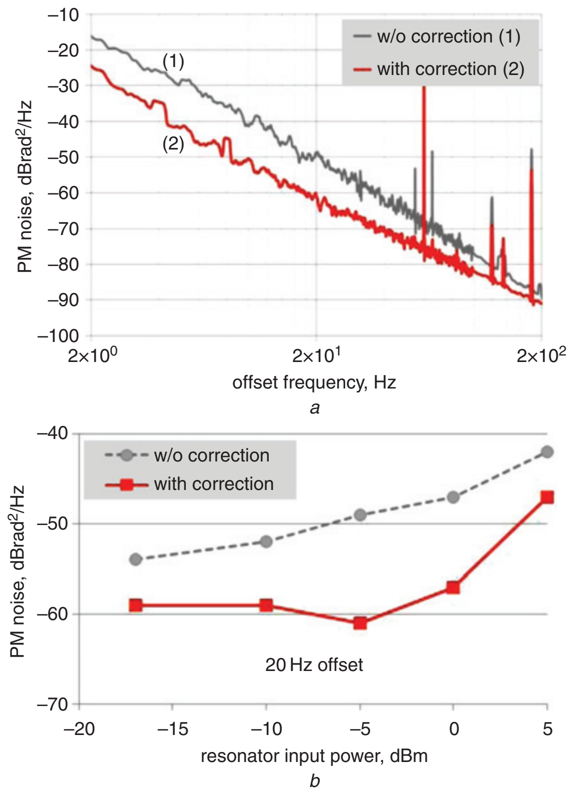


**Fig. 3** *Experimental results of (PM noise of oscillator with and without feed-forward correction resonator input power = −5 dBm), and PM noise at 20 Hz offset against resonator input power*

*a* PM noise of oscillator with and without feed-forward correction
*b* PM noise at 20 Hz offset against resonator input power

*Results:* The PM noise of the oscillator at 635 MHz with and without feed-forward correction is provided in Fig. 3*a*. Improvement in the PM noise is clearly visible for the offset frequencies below 100 Hz. The correlation was also measured for variable input power to the resonator and the feed-forward correction was applied. The PM noise against resonator input power at 20 Hz offset is depicted in Fig. 3*b*. It shows more than a 10 dB improvement at an input power of −5 dBm to the resonator.

*Conclusion:* We have demonstrated that the correlation between AM and PM noise can be used to reduce the steady-state PM noise of an oscillator. In the future, we plan to study such correlation effects in an oscillator when it is subjected to vibration, and utilise the same feed-forward scheme to lower the vibration sensitivity.


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One or more of the Figures in this Letter are available in colour online.

A. Hati, C.W. Nelson and D.A. Howe (*National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA*)

E-mail: archita.hati@nist.gov

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