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***Abstract*—This paper describes oscillator noise measurement techniques, challenges and associated measurement uncertainty. The cross-correlation method used in modern PN measurement equipments, can present erroneous result, depending upon phase-inversion, harmonics, o/p load mismatch, and cable length. This discussion is imperative for low phase noise signal sources, validated with 2.4 GHz SAW oscillator, and discussed steps for mitigating these issues by using filtering/phase-matching N/W**

Keywords—*Cross-Correlation, Oscillator, Phase Noise*

A. Oscillator Phase Noise Model

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B. Phase Noise Measurement Challenges And Uncertainty

	KTB	*f* *k ε N*	*f* *k ε N*
		q	

C. *Influence of Harmonics on Phase Noise Measurement*

$$\frac{c_{f_0}max}{c_{f_0}min}[dB] = 20log\left(\frac{1+3\frac{k_3H_3}{k_1H_1}}{1-3\frac{k_3H_3}{k_1H_1}}\right)$$

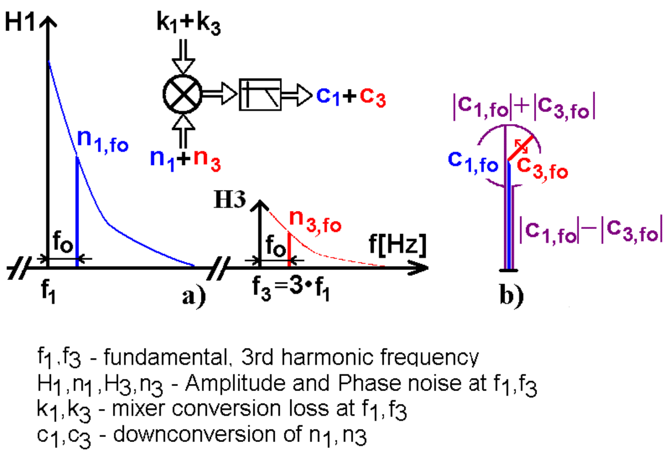

Fig. 1: (a) Spectral components of DUT signal, and b) down-conversion products

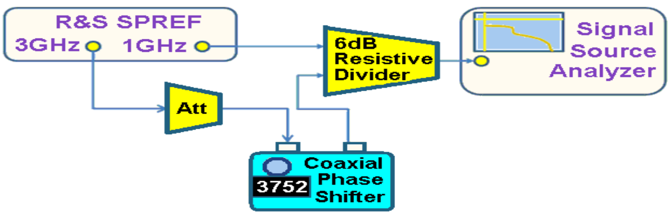

Fig. 2 Instrument setup for generating signals with harmonics and measuring the phase noise

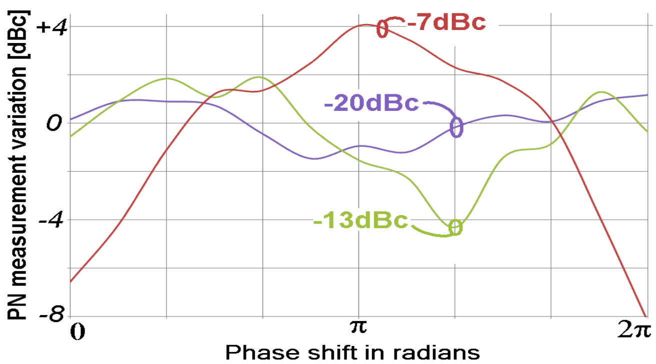

Figure (4) shows the relationship between phase noise and the conversion loss difference between the fundamental and third harmonic, for various levels of 3rd harmonic content in the signal presented at the input of the test equipment. The phase noise variations shown in Figure (4) are observed when fundamental is presented with high harmonic content at the input to the test equipment. These mixers (double balanced, image reject or triple balanced mixers) suppress the even order and as such show no significant variations in the case of even harmonics, while the 5th harmonic conversion loss is high enough and does not create measurement issues.

Analyzing Figure (4) if the mixer has a conversion loss difference between the fundamental and the 3rd harmonic of 7.5dB and the 3rd harmonic level is -7dBc (Red trace) we can expect a phase noise measurement variation of about 12dB (Red dot in Fig. 4, corresponding to the red trace in Fig. 3). For the same signal, if the conversion loss difference would be greater than 23dB, we could achieve a measurement variation smaller than +/-1dB. However, if the signal has a 3rd harmonic with a level of -20dBc (Green trace), and the conversion loss difference (between fundamental and 3rd) is higher than 10dB then the phase noise uncertainty will be less than +/- 1 dB.

All phase noise measurement methods that use mixers to down-convert the signal to baseband are subject to the effects described in Figure (4). The Phase Detector method and the Residual Phase Noise method will also demonstrate similar behavior. If the mixed signals have harmonics, the mechanism that converts the harmonics to baseband will degrade the measurement accuracy.

D. Estimation of Uncertainty

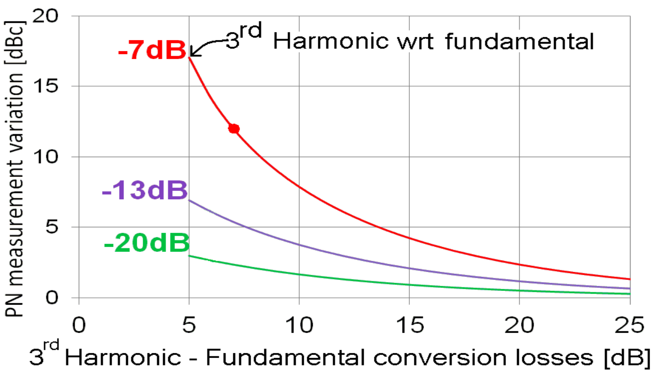

Fig. 4: Phase noise uncertainty estimate peak-to-peak (1) for different levels of 3rd harmonic with respect to fundamental.

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$S(f)$

$S_\alpha(f)$ $S_{\square}(f)$, f

$\mathcal{L} f$ $\mathcal{L} f$

$\mathcal{L} f$ $\mathcal{L} f$ $S_{\square}(f)$.

$S_{\square}(f)$

$\mathcal{L} f$

$\mathcal{L} f$ $S_{\square}(f)-$

Q

A. Phase Noise Measurement Techniques

$$x(t) = a(t) + c(t) \;\leftrightarrow\; X(f) = A(f) + C(f)$$

$$y(t) = b(t) + c(t) \;\leftrightarrow\; Y(f) = B(f) + C(f)$$

α b c α b

c

$\leftrightarrow$

T

$$S_{yx}^{1}(f) = \frac{2}{T} Y(f) X^{*}(f)$$

$*$

m' $\langle S_{yx} \rangle_m$

mT

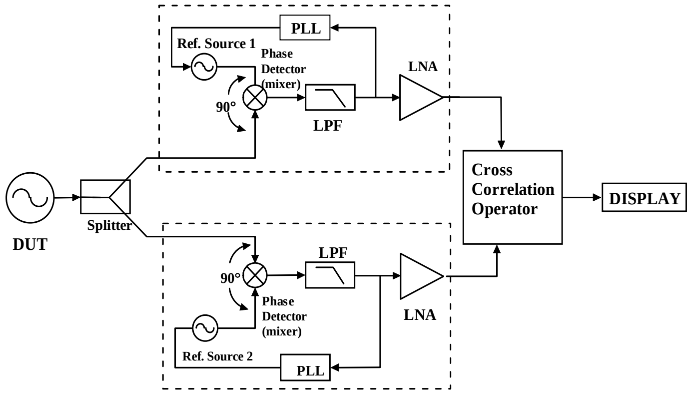
f

$$\langle S_{yx} \rangle_m = \frac{1}{m}\frac{2}{T}\sum_{i=1}^{m}(B_i A_i^*) + (B_i C_i^*) + (C_i A_i^*) + (C_i C_i^*)$$

$B_i A_i^*$ $B_i C_i^*$ $C_i A_i^*$

$C_i C_i^*$ α b

c



$B_i A_i^*$ $B_i C_i^*$ $C_i A_i^*$

$\frac{1}{\sqrt{m}}$ m $\langle S_{yx} \rangle_m$

S_{cc}

$\sqrt{M}$ M

$$[Noise]_{meas} = [Noise]_{DUT} + \frac{[Noise]_{chanel1} + [Noise]_{chanel2}}{\sqrt{M}}$$

$[Noise]_{meas}$

$[Noise]_{DUT}$ $[Noise]_{chanel1}$

$[Noise]_{chanel2}$

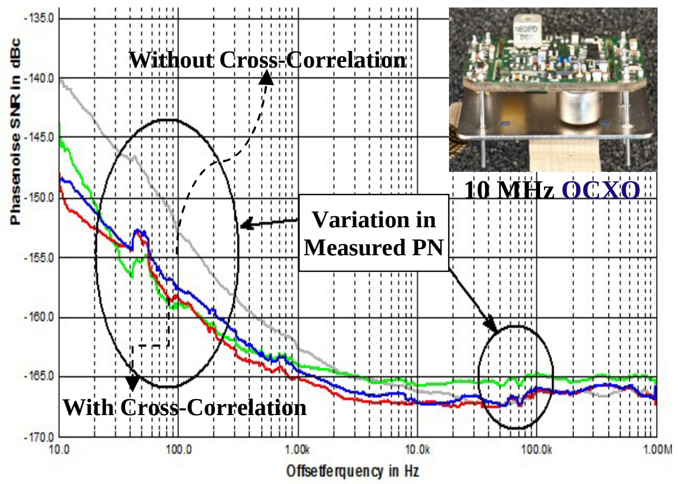
B. Cross-correlation: Uncertaintity in PN Measurement

x (t) *y (t)* *x*

y *d*

$$x = a + c + \varsigma_x d \leftrightarrow X = A + C + \varsigma_x D$$

$$y = b + c + \varsigma_y d \leftrightarrow Y = B + C + \varsigma_y D$$



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ς_x ς_y

d

ς_x ς_y $\varsigma = \varsigma_x \varsigma_y$

d a

b c

A. Resonator Operation in NonlinearityRegime

$$S_{yx} = S_{cc} + \varsigma S_{dd}$$

under-estimates the DUT noise

d S_{yx}

$\mathcal{L}\, f$

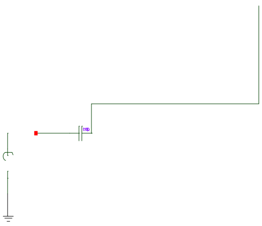
$*$ $* S_{yx}\ f$ d d d

d *C(f)*

D(f)

$\mathcal{L}\, f$

B. Collapse of Cross-Correlation Engine: Remedy !



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