Novel Open-Loop Phase Noise Measurement Technique for GHz Resonators

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***Summary* — GHz-resonator-based oscillators provide multiple advantages over conventional timing solutions relying on MHz or kHz resonators (e.g., quartz oscillators). With an emerging trend to adopt these clocking sources, it is important to study the frequency flicker of these GHz resonators, like those have been extensively investigated for quartz resonators. However, the loading effect at GHz range poses a serious limitation, hindering effective frequency flicker measurement of GHz resonators. To address such limitation, an improved open-loop phase noise measurement technique is presented. The technique is achieved by inserting an impedance tuning section between the resonator and testing fixture, to transform the impedance seen from the resonator. As a result, the loaded-Q of the resonator, and thus the noise floor of the measurement set up, is improved by more than 10 times, enabling an accurate characterization of the frequency flicker for resonators operating at GHz and above.**

Keywords—phase noise; AlN; Resonator; MEMS; Oscillator; Frequency noise

I. INTRODUCTION

Phase noise is one of the most important metrics for oscillators. One of the dominating factors for close-in noise is the frequency flicker of the passive resonator [1]. Therefore, it is essential to measure the frequency flicker of the resonators.

Assuming no other noise contributors, the oscillator output follows the resonance frequency the resonator. Therefore, the relationship between the oscillator phase noise and the resonator frequency flicker can be expressed by [1]

$$S_\varphi(f) = \frac{1}{f^2} S_f(f), \quad (1)$$

where $S_\varphi(f)$ is the oscillator's (close loop) phase noise induced by resonator frequency flicker, and $S_f(f)$ is the power spectrum of the resonator frequency flicker. The frequency flicker of a resonator can be calculated by measuring its open-loop phase noise: when fed with a clean sinusoidal signal, the frequency flicker of the resonator will induce phase noise to that signal, i.e.,

$$S_\emptyset(f) = (\frac{2Q_L}{f_0})^2 S_f(f), \quad (2)$$

where $S_\emptyset(f)$ is the induced phase noise (i.e., open-loop phase noise) of the resonator, Q_L is its loaded-Q, and f_0 is its resonance frequency.

Based on the theory above, the open-loop phase noise of MHz range resonators have been well studied before [3-5]. However, as further explained below, previously reported measurement technique cannot be directly implemented for GHz resonators, due to their invulnerability to the loading effect from the testing fixtures.

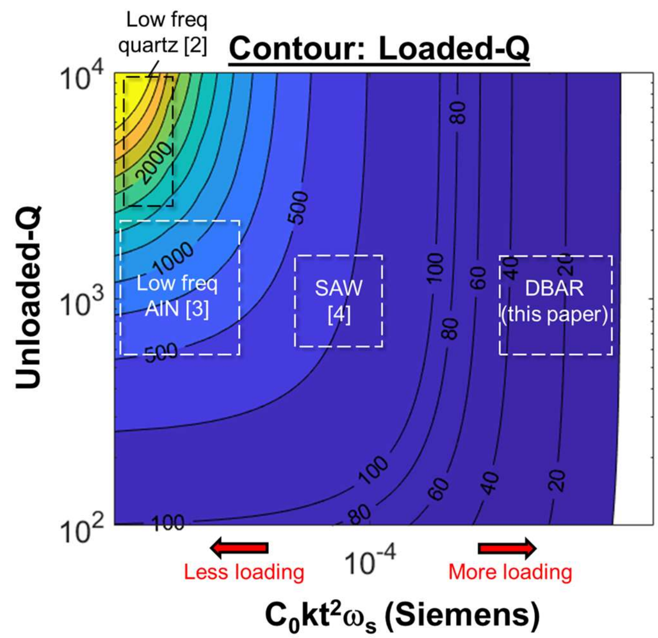

Fig. 1 Loaded-Q of different types of resonators

According to Eq. (2), open-loop phase noise is proportional to the loaded-Q of resonators. The loaded-Q of the resonators can be derived as

$$Q_L = \frac{Q_u Q_s}{Q_u + Q_s}, \quad (3)$$

where Q_u is the unloaded Q determined by the motional resistance R_m of the resonator (here ignoring the series routing resistance, since it is usually much less than 50 ohm), and Q_s is the Q determined by the series 50 ohm termination impedance from the testing fixture. From Eq. (3), the value of Q_s is essential. The expression of Q_s can be written by

$$Q_s = \frac{\pi^2}{8R_s\omega_0 C_0 kt^2}, \quad (4)$$

therefore, for resonators with large size (*i.e.,* high C_0), high frequency and high kt^2, the loading effect of the R_s will significantly impact the measurement.

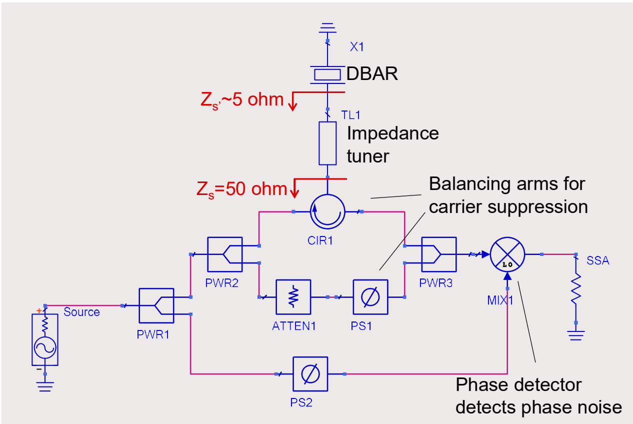

Fig. 2 The proposed measurement set up

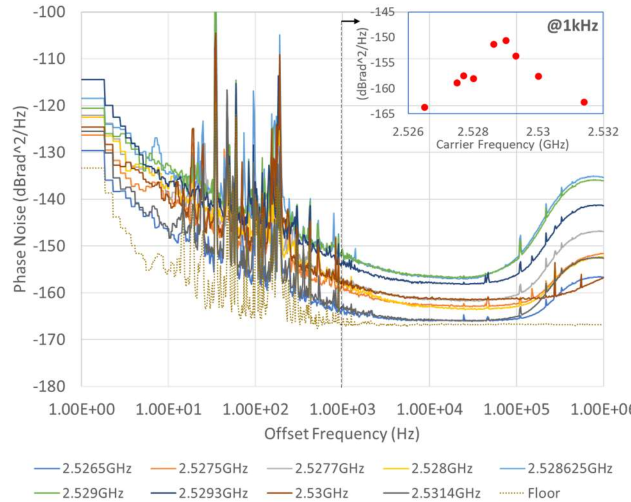

Fig. 3 The measured open-loop phase noise. Inset: phase noise magnitude at 1 kHz versus carrier frequency.

Fig. 1 further illustrates the loading effect. All the previous phase noise measurement of passive resonators have been focusing on the ones that are not easily loaded. For example, quartz resonators [3], low frequency contour-mode resonators [4], or higher frequency SAW resonators [5] with (at least for this specific work) relatively low coupling. On the other hand, for the DBAR [6], which is a new class of AlN-based BAW resonator developed at Texas Instruments that works at 2.5 GHz for timing applications, due to the relatively high frequency (main reason), large size, and high coupling, the loaded-Q is 50 times smaller than the unloaded-Q. In other words, due to the loading effect, the measurement noise floor (relative to the phase noise to be measured) is increased by $10 \times \log(1/50) = 17$ dB. It is therefore infeasible to measure GHz resonator phase noise with same measurement set up.

In this paper, this issue is solved by inserting an arbitrary impedance tuner in front of the resonator. The impedance tuner transforms the termination impedance seen from the DBAR from 50 ohm to a minimal value so that the loaded-Q of the DBAR is significantly improved. As a result, the noise floor of the measurement set up is decreased, and the open-loop phase noise of the DBAR is successfully measured.

II. METHODS/RESULTS

The schematic of the measurement set up is shown in Fig. 2. The DBAR is connected to an arbitrary impedance tuner, then to a circulator. The circulator is needed because the DBAR is a 1-port device, thus requiring a transformation to 2-port to be inserted into the measurement arm. Another arm with an adjustable attenuator and phase shifter is combined with the DUT arm by a power combiner. During the measurement, the two arms are tuned to be exactly the same in magnitude and opposite in phase, so that the common noise from signal source is cancelled, and only thing left is the phase noise coming from the DUT. Note that it has been verified that the open-loop phase noise of the circulator, impedance tuner, attenuator and phase shifter are significantly lower than the DUT noise. After the combination, the amplified phase noise is detected by a common phase detector set up (i.e. another branch of phase shifter that will be tuned to have a phase difference of 90^0 with respect to the DUT arm, which will be then fed into the LO input of an RF mixer), and measured by a baseband analyzer (E5052b signal source analyzer).

The measured results are shown in Fig. 3. The phase noise with different carrier frequencies are plotted. Thanks to the inserted impedance tuner that boosts the loaded-Q (increased by 10 times), the noise floor is well below the open-loop phase noise. Without the use of the impedance tuner, the phase noise cannot be detected. Inset shows the magnitude of the phase noise at 1 kHz offset, with different carrier frequencies. The DBAR used in this experiment has a resonance of 2.529 GHz (defined by the peak of the group delay), and the maximum phase noise also happens at the same frequency, thus validating the experiment results.

III. DISCUSSION/INTERPRETATION

The phase noise of the DBAR is successfully measured, confirming the validity of the proposed new technique.

IV. CONCLUSIONS

In conclusion, a novel measurement technique of measuring open-loop phase noise is proposed in this abstract. The new technique is especially useful for the measurement of GHz resonators with large size and high coupling. The new technique is experimentally verified, and successfully validated.

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