Collapse Phenomenon in Phase Noise Curve of E5052B

Xianhe Huang, Wei Fu

School of Automation Engineering, University of Electronic Science and Technology of China, Chengdu, China

Email: xianhehuang@uestc.edu.cn

Phenomenon: To improve the close-to-carrier phase noise of a crystal oscillator, the main technical is to increase the loaded Q_L. In our experiment, we first used an AT-cut 10 MHz overtone crystal resonator, whose unloaded Q was above 1000K. We planned to use this AT-cut crystal to test the circuit state first, and then replace it with an SC-cut high-precision crystal resonator.

The circuit prototype used a Pierce oscillator circuit with good frequency stability. Larger C_1 was selected to obtain a larger loaded Q_L [1]. The phase noise curve tested by Agilent E5052B is shown in Fig.1. Due to the lack of anti-interference measures such as shielding in the experimental circuit board, the interference in the curve is relatively large. However, the key issue is that a segment of the noise curve offset from the carrier frequency at around 1 Hz to 10 Hz directly collapsed, which is a strange phenomenon.

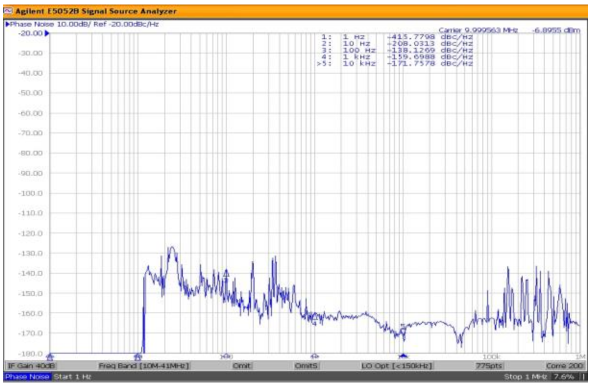

Fig. 1. The collapsed phase noise curve.

Explanation: A) First, due to the use of an AT-cut crystal, the excitation power cannot be too strong. At the same time, in order to improve the near-carrier noise, it is often necessary to further reduce the excitation power [2]. Therefore, the output power in the experiment was only about -7 dBm, so $(F * K * T)/(2 * P)$ is not less than -170 dBc/Hz. Therefore, it is impossible for the noise curve to be lower than -170 dBc/Hz.

B) Why did the curve collapse? We consulted the technical manual of Agilent E5052B[3], and its correct testing capability under specific conditions is shown in Table 1. From Table 1, it can be seen that under the given conditions in the table, the typical values of the sensitivity of a 10 MHz signal at 1 Hz and 10 Hz offset from the carrier are -74 dBc/Hz and -114 dBc/Hz, respectively, which are caused by the background noise of the testing system.

Table 1. SSB Phase Noise Sensitivity (Standard, < 150 kHz optim., Measurement quality = Normal, correlation = l, +5 dBm input, start frequency = l Hz, measurement time = 17.7 sec)

Input Frequency		Offset from carrier (Hz)								
		1	10	100	1k	10k	100k	1M	10M	40M
10 MHz	Spec.				-148.5	-156.5	-166.5	-168.5	-	-
	typ.	-74.0	-114.0	-144.5	-152.5	-160.5	-170.5	-172.5	-	-

However, the E5052B (and other similar phase noise testing systems) uses a correlation algorithm, and the true sensitivity after using the correlation algorithm can be estimated using eq. (1):

$$Noise_{meas} = Noise_{DUT} + \frac{Noise_{Ins}}{\sqrt{M}} \tag{1}$$

where M is the number of calibration times. It can be seen that when M = 10000 (the maximum number of calibrations for the E5052B), the instrument noise can be optimized by 20 dB, which means that the typical value of the sensitivity at this time can reach -134 dBc/Hz@10Hz.

The testing time with M=10000 is difficult to tolerate for experiments. As shown in Fig .1, the value of M used in this experiment is 200, which can optimize the instrument noise by 13 dB, and the typical value of the sensitivity can reach -127 dBc/Hz@10Hz. In fact, the typical value provided by the instrument has a margin. In this experiment, we were able to measure above -130 dBc/Hz@10Hz with M=200. It can be seen from Fig. 1 that the noise level is approximately -135dBc/Hz@10Hz, which is much lower than the calibrated instrument noise, resulting in a collapse.

Suggestion:

A) If the extremely long testing time can be tolerated, M can be appropriately increased.

B) A better solution is to use an extremely low-noise 10 MHz crystal oscillator as an external standard for the instrument.

References

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[2] J. R. Vig, Quartz Crystal Resonators and Oscillators for Frequency Control and Timing Applications—A Tutorial, 2016, [online] Available: https://ieee-uffc.org/download/quartz-crystal-resonators-and-oscillators-for-frequency-control-and-timing-applications-a-tutorial-2/

[3] Agilent E5052B Signal Source Analyzer User’s Guide. https://www.keysight.com/us/en/assets/7018-01528/data-sheets/5989-6388.pdf