

# A Co-design Study of Filters and Oscillator for Low Phase Noise and High Harmonic Rejection

Bing Zhang, Wenmei Zhang, Runbo Ma, Xiaowei Zhang, and Junfa Mao

**ABSTRACT**—In this paper, we present a novel oscillator (OSC) design. Bandpass filters, which can suppress harmonics, are incorporated into a co-design with an OSC to improve the OSC phase noise and harmonic rejection. The proposed OSC/bandpass filter co-design achieves a phase noise of  $-130.1$  dBc/Hz/600 kHz and harmonic rejection of 37.94 dB and 40.85 dB for the second and third harmonics, respectively, as compared to results achieved by the OSC before co-design of  $-101.6$  dBc/Hz/600 kHz and 21.28 dB and 19.68 dB. Good agreement between the measured and simulated results is achieved.

**Keywords**—Co-design, oscillator, bandpass filter, phase noise, harmonic rejection.

## I. Introduction

In modern RF transceiver design, the close-to-carrier noise performance and harmonics rejection of the local oscillator (OSC) are major consideration due to the narrow frequency spacing between communication channels. Some methods are now available to improve performance, such as adding an active feedback circuit [1], using the common-emitter configuration for the transistor [2], and employing transistors with low noise factor [3], [4].

With the development of RF integrated technology, co-designs between RF circuits or between circuits and antennas [5], [6] have proposed and used in RF end designs. Co-

designing essentially changes the structure of a circuit. It combines the function of the circuits and reduces the connection between the components. In this paper, an OSC and two bandpass filters are co-designed to improve the phase noise and harmonic rejection of the OSC. The measured results show that the relative harmonic rejections are 37.94 dB and 40.85 dB for the second and third harmonics, respectively, and the phase noise reaches up to  $-130.1$  dBc/Hz/600 kHz.

## II. Co-design and Simulation

Figure 1 shows the schematic diagram and layout of the OSC circuit and bandpass filters I and II. Filter I, which is used to replace the output match circuit and to suppress the harmonics of the output signal, is formed by  $C_1$ ,  $C_2$ ,  $C_3$ ,  $L_1$ ,  $L_2$ , and  $L_3$ . Bandpass filter II is composed of  $C_5$ ,  $C_6$ ,  $C_7$ ,  $L_8$ ,  $L_9$ , and  $L_{10}$  and is as a substitute for the OSC resonator and to suppress the harmonics in the feedback circuit. The  $S_{21}$  of filters I and II are shown in Fig. 2. The results show that the two filters with a center frequency of 1.2 GHz can suppress the second, third, and fourth harmonics.

A commercial software designer (SV) [7] is used to simulate the entire circuits, and the harmonic balance simulation results are shown in Figs. 3 and 4. Before co-design, the harmonic rejection for the second and third harmonics are 20 dB and 17 dB, and the phase noise is  $-119.0$  dBc/Hz/600 kHz. After co-design, the corresponding values for harmonic rejection are 48.5 dB and 38.6 dB, and a typical phase noise level of  $-137.5$  dBc at an offset frequency of 600 kHz is observed. Obviously, the co-design suppresses the harmonics and improves the phase noise significantly.

## III. Experiment Results

The measured output spectrum and phase noise are shown in

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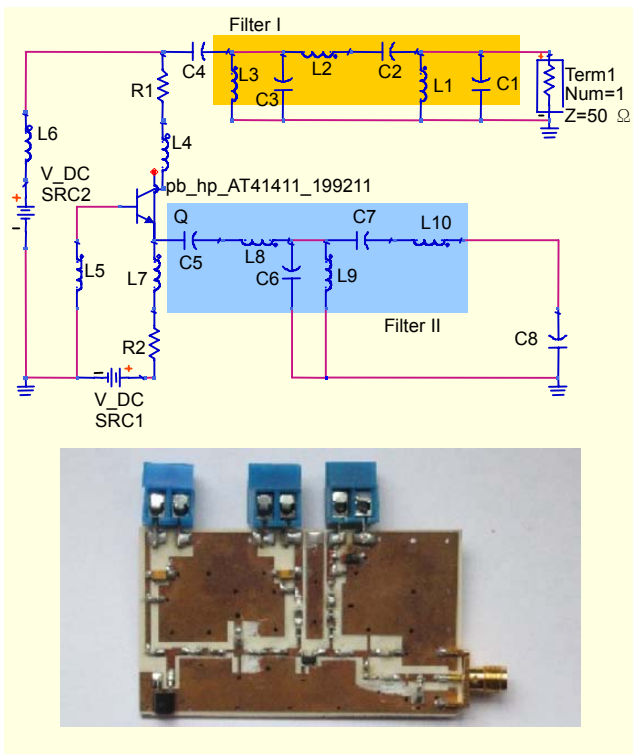


Fig. 1. Schematic diagram and layout of OSC/bandpass filter co-design.

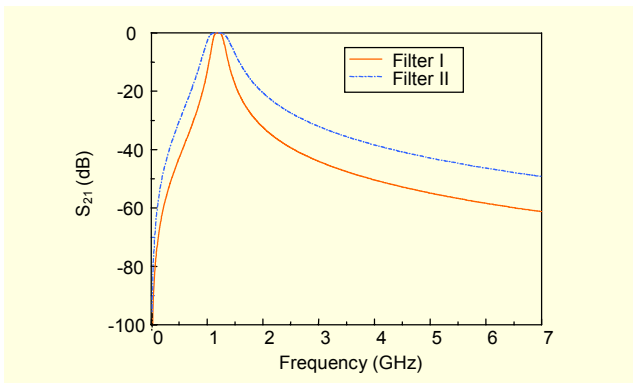


Fig. 2.  $S_{21}$  of the filters I and II.

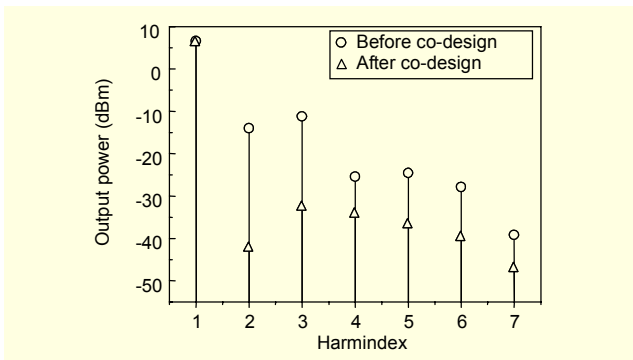


Fig. 3. Simulated output spectrum of the OSC before and after co-design.

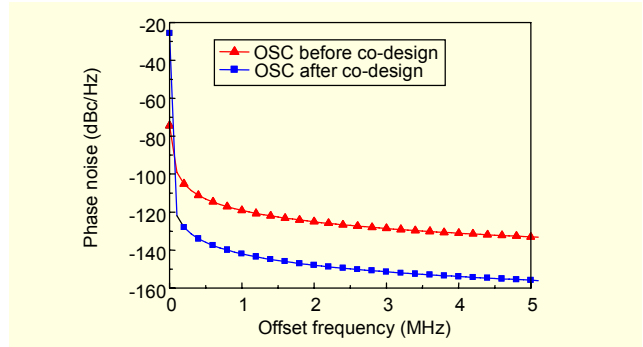


Fig. 4. Simulated phase noise of the OSC before and after co-design.



Fig. 5. Measured output spectra of the proposed OSC: (a) before co-design and (b) after co-design.

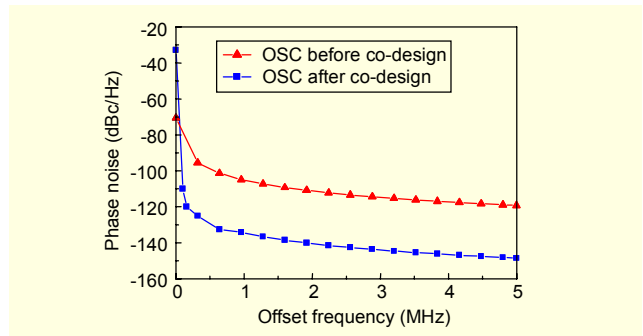


Fig. 6. Measured phase noise of the proposed OSC.

Table 1. Power of fundamental, second, and third harmonics. (dBm)

	Before co-design	After co-design
Fundamental power	6.18	7.13
2nd harmonic power	-15.1	-30.8
3rd harmonic power	-13.5	-33.7

Figs. 5 and 6, respectively. Good agreement between the measurement and simulation results has been achieved. For comparison, the fundamental, second harmonic, and third harmonic powers are listed in Table 1. After co-design, the OSC achieves rejection of 37.94 dB for the second harmonic

and 40.85 dB for the third harmonic, as compared to 21.28 dB and 19.68 dB before co-design. As shown in Fig. 6, phase noise levels of -101.6 dBc/Hz and -130.1 dBc/Hz at an offset frequency of 600 kHz are observed for the OSC before and after co-design respectively.

#### IV. Conclusion

In this paper, we presented an OSC/bandpass filter co-design, which improves the phase noise characteristic and harmonic rejection of the OCS. The output power of the realized OSC was 7.13 dBm at 1.2 GHz. The phase noise was -130.1 dBc/Hz/600 kHz, and the relative harmonic rejections were 37.94 dB and 40.85 dB for the second and third harmonics. Good agreement between the measured and simulated results was achieved. The results demonstrate that an OSC/bandpass filter co-design can significantly improve the phase noise and the quality of the output signal.

#### References

- [1] H.J. Kim and W.Y. Kim, "A Low Phase Noise LC VCO in 65 nm CMOS Process Using Rectangular Switching Technique," *IEEE Microw. and Wirel. Compon. Lett.*, vol. 17, no. 8, Oct. 2007, pp. 610-612.
- [2] M.Q. Bao et al, "A 25-GHz Ultra-Low Phase Noise InGaP/GaAs HBT VCO," *IEEE Microw. and Wirel. Compon. Lett.*, vol. 15, no.11, Nov. 2005, pp. 751-753.
- [3] Z.Q. Cheng and Y. Cai et al, "A Low Phase-Noise X-Band MMIC VCO Using High-Linearity and Low-Noise Composite-Channel Al<sub>0.3</sub>Ga<sub>0.7</sub>N/- Al<sub>0.05</sub> Ga<sub>0.95</sub>N/GaN HEMTs," *IEEE Trans. on Microw. Theory and Techn.*, vol. 55, no. 1, Nov. 2007, pp. 23-29.
- [4] S.H. Lee and W.H. Chuang et al, "Low-Phase Noise Hartley Differential CMOS Voltage Controlled Oscillator," *IEEE Microw. and Wirel. Compon. Lett.*, vol. 17, no. 2, Feb. 2007, pp. 145-147.
- [5] W. Wang and Y.P. Zhang, "0.18- $\mu$ m CMOS Push-Pull Power Amplifier with Antenna in IC Package," *IEEE Microw. and Wirel. Compon. Lett.*, vol. 14, no. 1, Jan. 2004, pp. 13-15.
- [6] S. Alalusi and R. Brodersen, "Antenna-Filter-CMOS LNA Co-design Strategy," *CPD2000 (Chip-Package Co-design)*, Zurich, Switzerland, Mar. 2000.
- [7] Ansoft Designer SV User Manual, Ansoft Ltd., available at <http://www.ansoft.com>.