RATIONAL SYNCHRONIZATION OF MICROWAVE OSCILLATORS FOR PHASE-NOISE IMPROVEMENT

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Abstract

A new technique for phase-noise reduction in microwave oscillators is presented, based on the synchronization with an external generator at a rational ratio. A design of a synchronized oscillator at the ratio 2/5 is presented, with the simulations and measurements of the synchronization bands. A good improvement of the free-running oscillator phase noise has been achieved.

1. Introduction

Signal generators are one of the most needed elements in modern communication systems. For the implementation of signal generators which generate a time-periodical signal, free-running oscillator circuits are generally an interesting choice. Oscillators used in communication systems generally have very strict phase-noise specifications, which not always can be satisfied by simple configurations of these circuits. In order to reduce the phase-noise generally the oscillator circuit is incorporated in a phase-locked loop or is synchronized by an external generator with very low phase-noise content. In communication systems where a large number of time-periodical carrier signals are required at different frequencies, it is expensive to obtain low phase-noise production in all the carrier signals.

If synchronization by an external generator is used for the phase-noise improvement in a multi-carrier system, it is possible to reduce the number of low phase-noise external reference generators when there exist for multiple carrier signals a different rational ratio between their free-running frequencies and the reference frequency. Then, with a lower number of the required external low phase-noise generators the total cost of the multi-carrier system is reduced.

In this work, a new technique is presented for the phase-noise reduction in microwave oscillators, based on the synchronization with an external generator at a rational ratio, and is illustrated through the design of a 2.9 GHz oscillator synchronized at the ratio 2/5, with the purpose to reduce the number of external low phase-noise generators in a transmitter-receiver system.

2. Rational Synchronization of Oscillators

When an external generator at frequency ω_s is connected to a free-running oscillator at frequency ω_0, a synchronized behaviour is obtained for rational values of the rotation number *r*:

$$r = \frac{\omega_s}{\omega_0}$$

For an arbitrary (non rational) value of *r*, the circuit is working in a quasi-periodic regime at the two fundamental frequencies ω_s and ω_0, with ω_0 the self-oscillation frequency, slightly modified under the influence of the synchronization generator. The resulting steady-state solution represented in the state space fills a torus surface [1]. Tuning the frequency of the input generator, for rational ratios r = m/n (m, n integer values), the mth harmonic component of ω_0 synchronizes with the nth harmonic component of ω_S. The synchronized solution forms a single closed trajectory in the state space, attracting all the former trajectories of the torus. The synchronization range is delimited by two saddle-node bifurcations [1], and increases with increasing synchronization power P_s. The synchronization range reduces strongly for higher values of m and n [2], and the synchronization phenomenon is difficult to observe experimentally.

3. Circuit Design

Due to the expected narrowness of the m/n synchronization bands, the free-running oscillator must be controllable in frequency. The circuit topology of the rationally synchronized voltage controlled oscillator (VCO) is presented in Fig. 1. The transistor is an ATF36077. The oscillation start-up conditions are satisfied at the drain port through series feedback (including a varactor diode) at the source port. The synchronization generator is connected to the circuit through an input-filter at ω_S. Also an output filter at ω_0 is used in order to reject the synchronization frequency. The circuit parameters have been optimized in order to obtain a 2.9 GHz self-oscillating frequency, employing an auxiliary generator (AG) at the frequentcy $\omega_{AG} = \omega_0$, and with voltage V_{AG} and phase Φ_{AG} [3].

4. Nonlinear analysis of the rationally synchronized oscillator

For the analysis of the synchronized circuit at the ratio r = 2/5, the synchronization generator is connected to the circuit with frequency ω_S and constant power P_s and phase Φ_s. The synchronization ranges of the 2.9 GHz VCO are analyzed by tracing the synchronization loci for different values of the synchronization power P_s. For this, a harmonic balance simulation is used with a Fourier-series expansion at the fundamental frequency $\omega_f = \omega_0/5$. With this selection of ω_f, the self-oscillation frequency is $\omega_0 = \omega_{AG} = 5\omega_f$ and the synchronization frequency is $\omega_S = 2\omega_f$. The synchronization loci are obtained, carrying out a sweep in $\Delta\Phi = \Phi_{AG} - 5/2\ \Phi_s = \Phi_{AG}$ ($\Phi_s = 0$) between 0 and π, calculating for each point of the sweep, the two variables V_{AG} and the self-oscillation frequency $\omega_0 = \omega_{AG}$, in order to satisfy the condition $Y_{AG} = 0$, with Y_{AG} the admittance represented by the AG [3]. Note, that for this sweep in $\Delta\Phi$, a 2π phase variation of the harmonic component at $2\omega_0 = 5\omega_S$ is obtained. The resulting synchronization loci for different values of P_s are shown in Fig. 2.

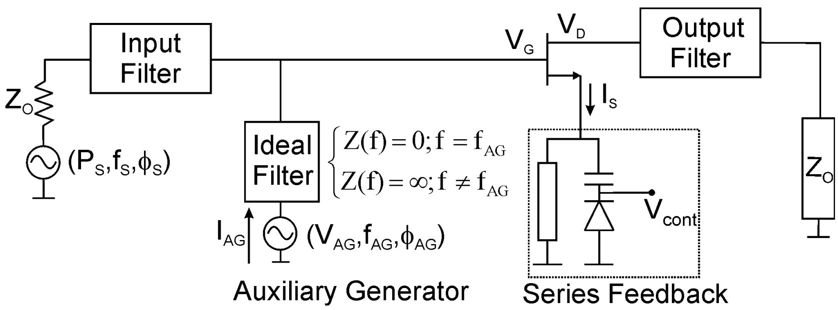

Figure 1. Circuit topology of the rationally synchronized voltage controlled oscillator

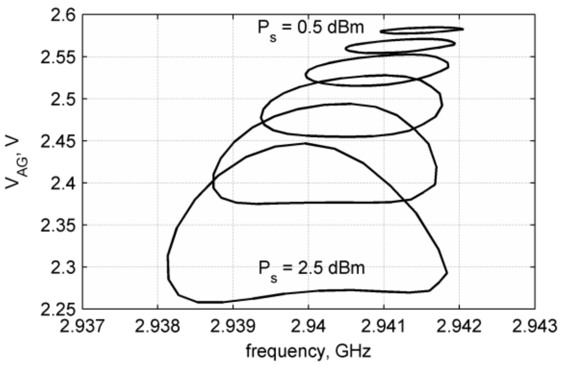

Figure 2. Synchronization loci for different values of the synchronization power P_s

For higher values of the synchronization power P_S, wider synchronization ranges have been found. In Fig. 2, also a small shift of the self-oscillating frequency can be observed for different values of P_S, which indicates that the varactor voltage should be modified in order to obtain a synchronization loci centred at 2.9 GHz. The synchronized and unsynchronized solutions in time domain are represented in a state-space in Fig. 3. The variables employed in the representation are the drain voltage V_D, the gate voltage V_G and the source current I_S. In the state-space, the quasi-periodic state that corresponds with the unsynchronized solution fills a torus surface (grey lines). When the system approaches the synchronized state, certain region on the torus becomes more attractive than the rest of the surface, and the orbit spends more time around it. In the synchronized state (black orbit in Fig. 3), both frequencies are harmonically related, and there is a closed orbit that attracts all the trajectories on the former torus. This orbit closes over itself after one period of the fundamental frequency $T_f = 1/f_f = 5/f_0 = 2/f_S$, which corresponds with five periods of the self-oscillating component and two periods of the component at the synchronization frequency.

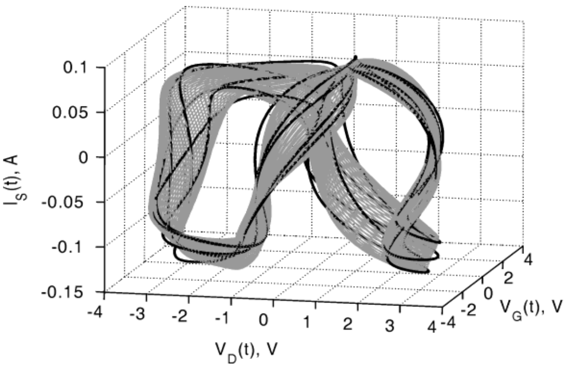

Figure 3. Representation of the synchronized (black line) and unsynchronized (grey line) solutions in a state-space

5. Experimental results

The synchronized circuit has been manufactured and measured. Fig. 4 shows the comparison between the simulated and the measured synchronization range versus the synchronization power. Fig. 5 shows the comparison between the output spectrum of the free-running and the synchronized oscillator, in a reduced span of 1 MHz. An important reduction of the phase noise is observed when the oscillator is synchronized. The circuit did not unlock in long term measurements of two days and was stable in the temperature range of 0-45ºC.

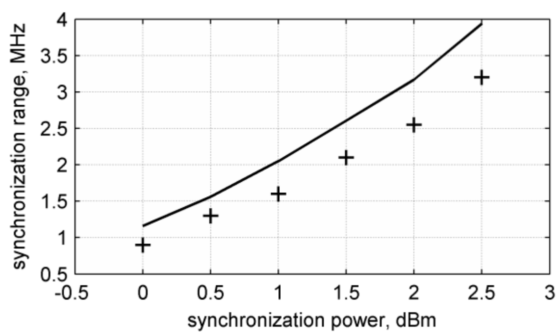

Figure 4. Synchronization range versus the synchronization power ——— simulated
\+ + + + measured

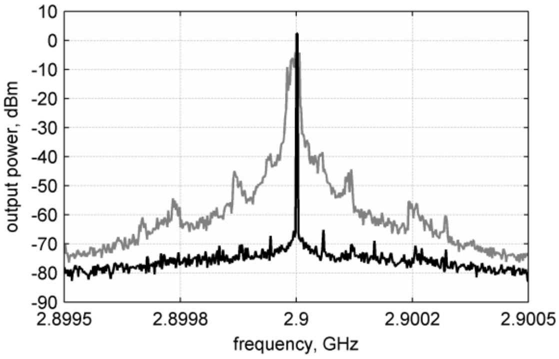

Figure 5. Output spectrum of the free-running and the synchronized oscillator. Grey line: free-running oscillator. Black line: synchronized oscillator

6. Conclusion

A new technique for the phase-noise reduction of a microwave oscillator, based on the rational synchronization with an external generator, has been illustrated through the synchronization of a 2.9 GHz voltage controlled oscillator at the ratio 2/5. The synchronization range has been obtained through a harmonic balance simulation of the circuit and experimentally verified by measurements. An important phase-noise improvement has been observed in synchronized operation.

Acknowledgments

This work was supported by the "Ministerio de Educación y Ciencia" of Spain, under Grant TEC2005-03563, and by the "Gobierno del Principado de Asturias" under Grant No. PC04-49.

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