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IMPROVEMENT OF THE PULL-IN RANGE AND ACQUISITION TIME OF A MICROWAVE P.L.L. SYSTEM BY INJECTION LOCKING THE V.C.O.

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SUMMARY

The requirements of large pull-in range and short acquisition time in microwave and millimeter wave phase locked oscillators are of great importance since the free running VCO frequency may be some tens of MHz off the reference frequency. A substantial improvement can be obtained by injection-locking the V.C.O. to the reference signal; as a result, the V.C.O behaviour changes to a phase controlled fixed frequency oscillator, giving a reduction by one in the system order. Then, frequency acquisition is performed by the injection-locking process, and phase tracking is made by the P.L.L. system. We present experimental comparisons between a microwave P.L.L. system operating at 11 GHz, with an without injection-locking synchronization.

INTRODUCTION

The synthesis of microwave signals often requires, in addition to spectral purity and frequency stability, a large pull-in range and short acquisition time. This is due to the fact that in the microwave range, the free-running V.C.O. frequency can be some tens of MHz off the reference frequency, thus making acquisition by pull-in very long, if possible at all; note that in second order P.L.L.'s with active loop filters, practical considerations may result in a reduction of the D.C. gain of operational amplifiers well below their nominal values of about 100 dB, therefore reducing the P.L.L. pull-in range.

This paper describes how to improve the pull-in range and the acquisition time by injection locking the V.C.O. to the reference signal.

Alternatively this system can be viewed as an injection-locking process in which a phase control between oscillators has been added. This results in some interesting possibilities such as power combination of oscillators, and design of electronic phase shifters and phase modulators.

PLL BEHAVIOUR WITH INJECTION LOCKING

The standard simplified equivalent circuit for a P.L.L. system is sketched in the Figure 1. Part (a) shows the physical model, and (b) the linearized block diagram, were Kd is the phase detector constant in V/rad, F(s) is the loop filter transfer function, and Kf is the V.C.O. constant in rad/s/V. The pull-in range is given by /1/ :

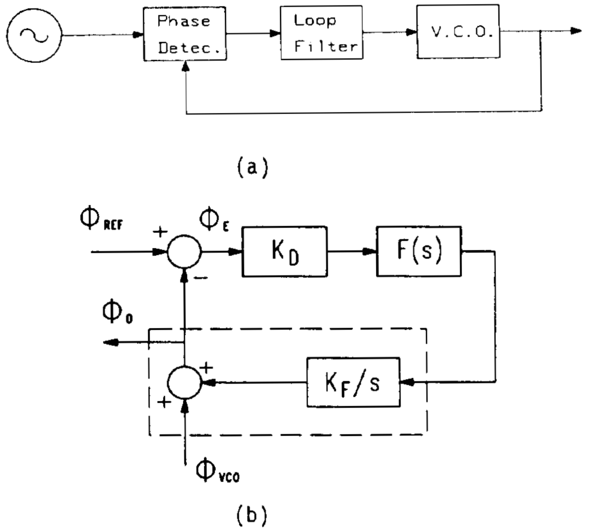

Figure 1.- Standard P.L.L. system. a) Physical model, b) linearized block diagram.

$$\Delta\omega_p = 2\sqrt{K_f\ K_d\ F(0)\ 2\ B \Big/ \left(1+\frac{1}{4\zeta^2}\right)}$$

and the approximated acquisition time for a second order P.L.L. with an imperfect integrator as loop filter is given by :

$$T_p \simeq 2.4\ \zeta^2 \left(1+\frac{1}{4\zeta^2}\right)^3 \frac{\Delta f^2}{B^3}$$

in terms of the loop bandwidth B, the damping coefficient ζ, the loop filter dc gain F(0), and the initial open loop offset frequency Δf.

The performance of this P.L.L. can be improved by fundamental or subharmonic injection locking of the V.C.O. to the reference signal. Figure 2a shows synchronization at the fundamental; in this case, use of a circulator is required. On the other hand, if the injection locking is subharmonic, the circulator is avoided, but the synchronization bandwidth is reduced.

The equivalent functional model is given in Figure 2b, which differs from Figure 1b in the V.C.O. behaviour, now a phase controlled fixed frequency oscillator, characterized by a constant Kp in rad/V. As a consequence, the system order is reduced by one.

The synchronization bandwidth is now fixed by the injection locking process, and it is given by /2/ :

$$\Delta\omega_m = 2\ \frac{\omega_o}{Q_{ext}}\sqrt{\frac{P_i}{P_o}}\ \ \frac{1}{\cos\ \theta}$$

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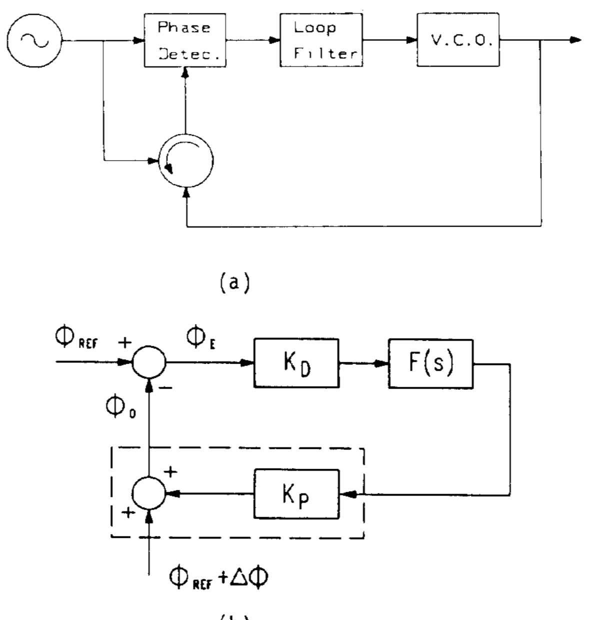


Figure 2.- P.L.L. system with a VCO injection locking synchronization at the fundamental. a) Physical model. b) Linearized block diagram.

in terms of the operating frequency ω_0, the external Q of the controlled oscillator, the injected power level Pi, the oscillator output power level Po, and the angle θ between the device line and the impedance locus of the controlled oscillator.

The acquisition time is also reduced, since it now depends only on the initial phase difference between the frequency synchronized signals. If an imperfect integrator with time constants $\tau 1, \tau 2$, is used as loop filter, the acquisition time is obtained from the step response of a first order system:

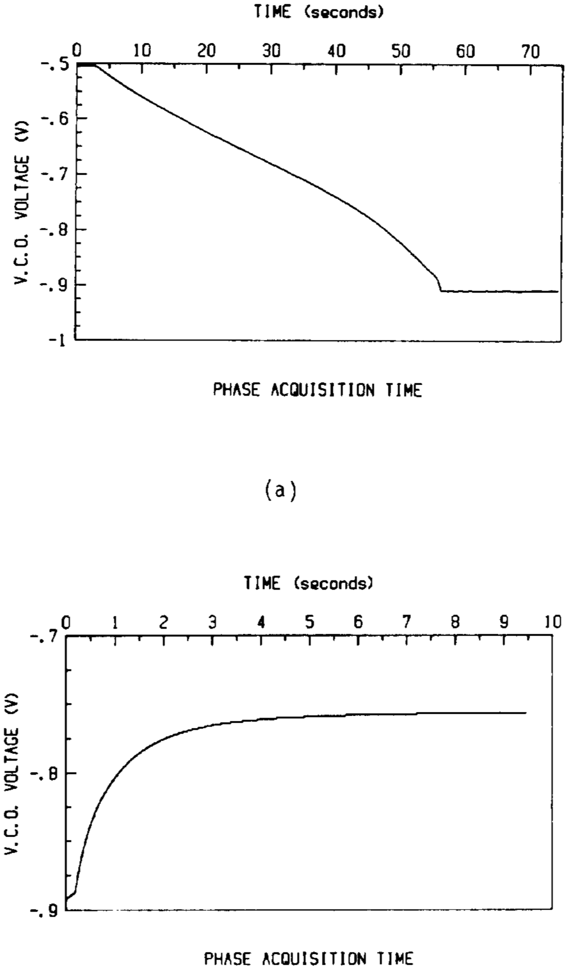
$$\phi_o(t) = \Delta\phi \frac{\tau_1}{\tau_1+K_d K_p \tau_2} e^{-t/\tau}+\phi_{ref}(t)$$

$$\tau = \tau_2 + \frac{\tau_1}{K_d K_p}$$

EXPERIMENTAL RESULTS

A comparison between a microwave P.L.L. system with and without injection locking was performed. The operating frequency was 11.43 GHz, the V.C.O. was a FET oscillator, its frequency controlled by the gate-source bias voltage with a value of Kf= 4.08E+6 rad/seg/V. As a phase detector a balanced microwave mixer using a microstrip hybrid ring was used, yielding a value of Kd= 0.381 V/rad.

In the P.L.L. circuit, a loop bandwidth of 10 KHz, and a damping factor ζ=1 were chosen. For practicals reasons, the loop filter dc gain was limited to 68 dB, giving a theoretical pull-in range of 21.8 MHz. The acquisition time for an initial offset of 20 MHz was 60 s (Figure 3a).



(a)

(b)

Figure 3.- Phase acquisition time. a) Second order P.L.L. b) with the injection locking synchronization.

If we include the injection locking process, with Pi= 3.5 dBm, Po= 14 dBm, Qext= 30, cos θ = 1 the synchronization bandwidth is 227 MHz. Figure 3b shows the measured values of the voltage applied to the V.C.O. with injection locking for an initial frequency offset of 20 MHz; the measured value of Kp is 20.7E+3 rad/V, and the loop filter parameters were τ1= 8.6E-3 and τ2= 1.5E-4. It is observed that locking is accomplished after 10 s, in good agreement with the theoretical time constant of τ = 1.08 s. The improvement is therefore a reduction by a factor 6.

The same comparison was made with another P.L.L. with loop bandwidth of 52 KHz, damping coefficient of 1.15, VCO constant 71.5E+6 rad/s/V, phase detector constant 0.1 V/rad and loop filter parameters τ1= 1.2E-3 and τ2=3E-5. The pull-in range obtained was 2 MHz using a D.C. loop filter gain of 38 dB. The acquisition time for a 300 KHz initial offset frequency was 2 s. (Figure 4a). If we include the injection locking process, with Pi=-12 dBm, Po=+14 dBm. Qext=14.5, cos θ = 1, the synchronization bandwidth measured is 78 MHz, with a Kp = 0.055 rad/V while the acquisition time is reduced around 0.5 s (Figure 4b).

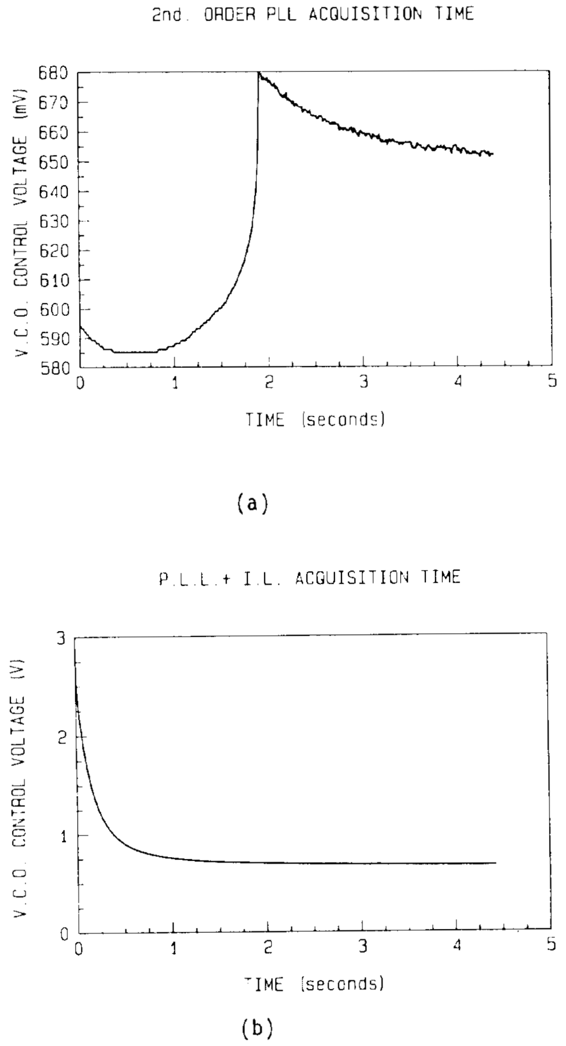


Figure 4.- Phase acquisition time. a) Second order P.L.L. b) with injection locking synchronization.

CONCLUSIONS

A substantial improvement of the pull-in range and the acquisition time in a second order microwave P.L.L. system can be obtained by the use of injection locking synchronization of the V.C.O. As a result the V.C.O. changes its behaviour, and becomes a phase controlled fixed frequency oscillator, thus reducing the system order by one.

It is also possible to use this technique in an Injection Locking Amplifier, in order to keep a given phase difference between the oscillators. This feature is of special interest for power combination of oscillators (area in which results will be soon reported) and also for the design of a class of ± 90° electronic phase shifters or phase modulators.

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