Enhanced MESFET VCO Injection-Locking Bandwidth using Low Frequency Feedback Techniques

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ABSTRACT

A simple scheme for enhancing the locking range and capture range of MESFET VCOs is presented using a low frequency DC-coupled amplifier. This circuit is based on phase-locked loop (PLL) techniques; in the present case the MESFET VCO also provides the function of a mixer or phase detector. A 10 GHz prototype was constructed which demonstrated a locking range more than double that of the isolated VCO injection-locking range over the same range of injected signal power.

I. INTRODUCTION

Quasi-optical oscillator arrays show promise for power combining and novel beam scanning techniques [4]. These arrays depend on mutual synchronization of the oscillators, and therefore benefit greatly from having oscillators with very wide locking ranges under low power injection. Typically this requires a low Q-factor and hence a noisy oscillator. This paper presents a simple technique for increasing the locking range based on phase locked loop (PLL) concepts. A conventional PLL uses a phase detector, low-pass filter/amplifier, and VCO (Fig.1). The circuit presented in this paper makes use of the inherent nonlinearity of the VCO, which means that it can also serve as a mixer or phase detector. A simple PLL can then be constructed as shown in Figure 2. The advantage of a PLL is that the locking range (in this context we mean the "hold-in" range) is a function of the loop gain, which can then be easily controlled. The bandwidth of the loop also determines the "capture" range of the system; for most applications, this is a small fraction of the VCO center frequency, although it could be much large than the isolated VCO injection-locking range. Therefore, by simply adding a low-frequency DC-coupled amplifier to an existing MESFET VCO, we can create an oscillator with a potentially large locking range. In addition to quasi-optical oscillator arrays, there are several other communication applications that could benefit from such a device. In the following, we will present a theoretical justification, followed by an experimental verification of this idea.

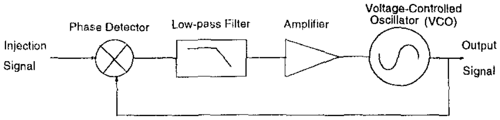

Figure 1– Simplified conventional Phase-Locked Loop diagram.

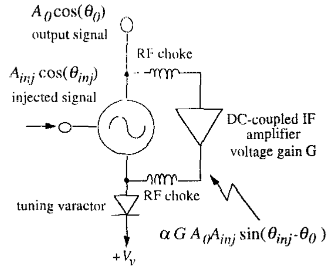

Figure 2– A novel PLL where the VCO also serves as a phase detector, due to the inherent nonlinearity of the constituent devices (such as a FET).

II. THEORY

When the oscillator is injected with an external low-level injection signal, the phase dynamics of the injection locked oscillator are described by

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[4]

$$\frac{\partial\theta}{\partial t} = \omega_o + \frac{\omega_o}{2Q}\mathrm{Im}\left\{\frac{V_{inj}}{V}\right\} \qquad (1)$$

where θ,ω_o,Q,and $V = Aexp(j\theta)$ are the instantaneous phase, free-running radian frequency, Q factor of the embedding network, and the output voltage (phasor) of the VCO,respectively. $V_{inj} = A_{inj}exp(j\theta_{inj})$ is the voltaghe (phasor) of the injection signal [1][4]. When the VCO is locked into the injection signal,

$$\frac{\partial\theta}{\partial t} = \omega_{inj} = \omega_o + \Delta\omega_{lock}\sin(\theta_{inj} - \theta) \qquad (2)$$

where $\Delta\omega_{lock} = \frac{\omega_o}{2Q}\frac{A_{inj}}{A}$ is called the locking range. A MESFET VCO has the I-V characteristics

$$I_{ds} = I_{dss}(1 - \frac{V_{gs}}{V_p})^2 \qquad (3)$$

where I_{dss} and V_p are the saturation current and pinch-off voltage of the MESFET, respectively [2]. If the external signal is injected at the gate, then the gate voltage includes a contribution from both the oscillator and the injected signal, written as

$$V_{gs} = A_{vco}'\cos(\theta') + A_{inj}cos(\theta_{inj}) \qquad (4)$$

where A_{vco}', θ' are the amplitude and phase of the free-running signal at the gate; A_{inj}, θ are the amplitude and phase of the injection signal. Substituting (4) into (3) gives a low frequency mixing product which can be extracted from the drain current (or voltage) through an RF choke, and expressed as a voltage $\epsilon\cos(\theta - \theta_{inj} + \alpha)$, where α is a possible phase shift through the device. This signal is then amplified and fed back to the varactor bias network, much like a phase locked loop. The output of the DC amplifier is expressed as $\beta\epsilon\cos(\theta - \theta_{inj} + \Phi)$, where β is the loop DC amplifier voltage gain, and Φ is the phase term including α and DC amplifier phase shift. The VCO output frequency will then be described by

$$\omega_o = \omega' \pm \beta\epsilon K\cos(\theta - \theta_{inj} + \Phi) \qquad (5)$$

,where ω' is the initial free-running VCO frequency without loop DC amplifier and K is the tunning sensitivity of the VCO. The +/- sign in (5) refers to whether the amplifier output is connected to the cathode or anode side of the varactor. Assuming the amplifier output is connected to the anode of the varactor, substituting (5) into (1) and making some approximations give a new phase equation

$$\frac{\partial\theta}{\partial t} = \omega_{inj} = \omega' + \Delta\omega_{lock}'\sin(\theta_{inj} - \theta + \Phi) \qquad (6)$$

where

$$\Delta\omega_{lock}' = \Big[(\beta\epsilon K)^2 + (\Delta\omega_{lock})^2 - 2\beta\epsilon K\Delta\omega_{lock}\sin\Phi\Big]^{1/2} \qquad (7)$$

and

$$\Phi = \arctan(\frac{-\beta\epsilon K\cos\Phi}{\Delta\omega_{lock} - \beta\epsilon K\sin\Phi}) \qquad (8)$$

$\Delta\omega_{lock}'$ is the new locking range of the system. If $2\beta\epsilon K\Delta\omega_{lock}\sin\Phi \leq 0$, $\Delta\omega_{lock}' > \Delta\omega_{lock}$,and therefore the locking range of the system is larger than that of the injection-locked VCO.

III. NOVEL PLL DESIGN AND MEASUREMENTS

This approach was verified using a 10GHz prototype. The VCO uses the common gate configuration in order to get a larger tuning range, and uses an NEC32184A GaAs MESFET and an M/A-COM 46580 beam-lead hyperabrupt varactor diode.(Fig. 3) The tuning range and power output versus the tuning voltage are shown in Figure 4. The external signal is injected at the gate by a 1 wavelength 50 Ω microstrip transmission line. The loop DC amplifier uses a two-stage BJT (NEC56708) broadband feedback amplifier in order to drive the varactor diode bias. [3] The power gain of the DC amplifier is shown in Figure 5 and the experimental results for both locking and capture ranges are shown in Figures 6 and 7.

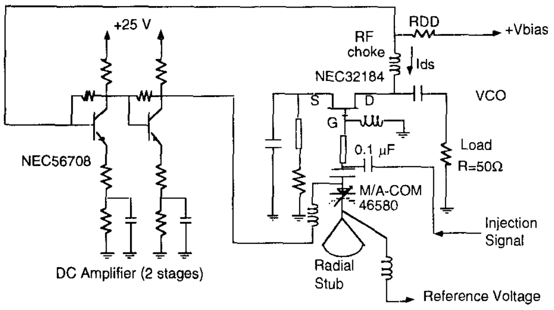

Figure 3– The prototype circuit used in this work. The VCO is a common gate circuit operating at 10 GHz. The feedback amplifier is a simple DC-coupled two-stage BJT design. The measured characteristics (Fig. 6-7) are critically dependent on the connection to the varactor (see text).

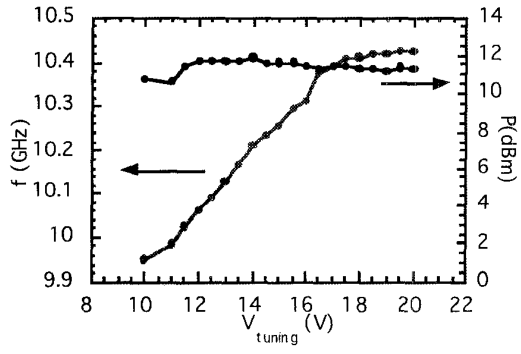

Figure 4– VCO characteristics.

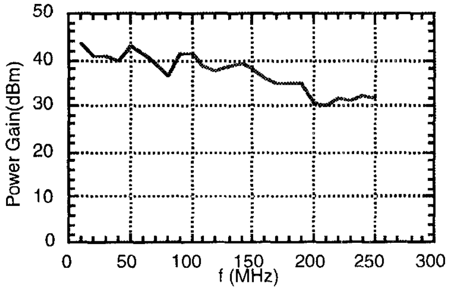

Figure 5– DC-coupled feedback amplifier gain.

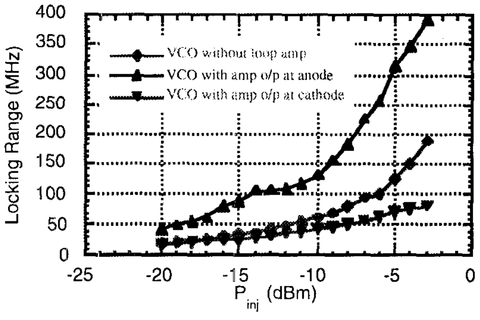

Figure 6– Measured hold-in range for the prototype circuit for both orientations of varactor bias, and comparison to the isolated VCO injection locking range.

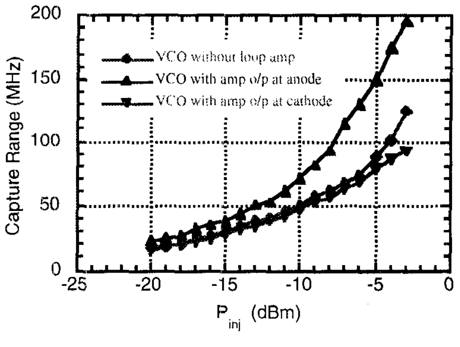

Figure 7– Measured capture range for the prototype circuit for both orientations of varactor bias, and comparison to the isolated VCO capture range.

In both figures, the locking and capture ranges are shown for both possible varactor configurations, and also compared with the measured result for the isolated VCO. The figures clearly show that the locking and capture ranges can be significantly improved by the feedback amplifier, and $\sin\Phi < 0$. The locking range is more than doubled over the range of injection power examined. This is a significant improvement for the coupled oscillator applications [4]. This is not simply a loading effect whereby the amplifier decreases the Q-factor of the VCO, which is verified by the decreases in the locking range when the amplifier is connected at the cathode of the varactor diode. In this case, the sign of $\sin\Phi$ term in (7) becames positive and the locking range decreases. The capture range could be increased further by increasing the bandwidth of the feedback amplifier.

V.CONCLUSIONS

We have presented a simple scheme for enhancing the hold-in and capture ranges of standard MESFET VCOs, using an inexpensive low-frequency DC-coupled feedback amplifier. Such circuits show promise for constructing high performance coupled-oscillator arrays, and can be applied in many applications of the communication electronics, such as the frequency synthesizer, FM demodulator, and so on.

VI. ACKNOWLEDGMENT

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VII. REFERENCES

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