New Observations on Bias Current Variation of Op Amp Oscillators

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***Abstract*—A new phenomenon called Bias Current Hump in an injection locked op amp oscillator. This phenomenon has been used to design a tracking demodulator that does not require a phase locked nor does it require a discriminator for the demodulation of an FM signal. Experimental results have been presented in support of the theoretical conjecture.**

***Index Terms*—Injection locking, operational amplifier, Wien Bridge oscillator, pull-in characteristics, synchronization.**

1.0 Op Amp and Its Secret

An analogue front end of a modern wireless communication system is responsible for the interface between the antenna and digital part of the entire system. An Op Amp, famous for almost any kind of signal processing continues to be vital component for the analogue system design. The secret of its success is the notion that DC bias point of an Op Amp remains time and frequency invariants during its steady state. As such an Op Amp will continue to be a vital component for analog circuits design in the years to come as it is a digital world with analog environments.

2.0 The Departure

This paper reports the result that shows that there are situations where the bias point dos not remain invariant. It can be varied both in time and frequency in a controlled manner. This has led us to develop a tracking demodulator with extremely low distortion. This has come to our notice when performing experiments on an R-C Op Amp Oscillators (Fig.1).

3.0 OP Amp Oscillator

An Op Amp Oscillator, as a matter of fact any oscillators, is intentionally designed to remain in an unstable state in order to generate periodic waveform. The frequency of oscillation is set either by R-C or LC tank circuits. A self-excited oscillator is a nonlinear circuit, which builds up oscillation from any arbitrarily small excitation within the circuit. Higher the initial excitation, smaller is the buildup time. The principle of operation of an oscillator can be worked out either as a feedback circuit or as a negative resistance variety. To the authors the classification of oscillator into these two categories is mathematically meaningless. In the following we illustrate this idea with a simple R-C Oscillator, namely Wien Bridge Oscillator (WBO). Incidentally, it is worthwhile to note that during the build-up process, the bias point does change but in the steady it remains fixed.

$$i_a = i_b - i_S \qquad i_b = C\frac{dv}{dt} + \frac{v}{R} \tag{1}$$

$$i_b R + \frac{1}{C}\int i_b dt = v_0 - v + i_S R + \frac{1}{C}\int i_s dt \tag{2}$$

Assuming $i_s(t) = I_s \exp j\left(\omega_1 t + \theta\right)$ and we also can write

$$i_a R + \frac{1}{C}\int i_a dt = v_0 - v + E_S e^{j\omega t + v} \tag{3}$$

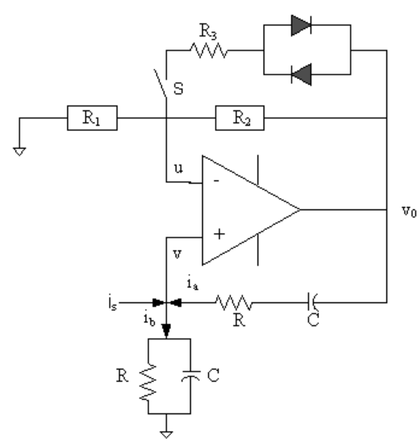

Figure 1: Op-amp based Wien Bridge Oscillator

Combining these equations one finds,

$$RC\frac{dv}{dt} + [3v - v_0(v)] + \frac{1}{RC}\int vdt = E_S \exp\left[j(\omega_1 t + \theta)\right] \tag{4}$$

where, $E_S = I_S R$

Assuming,

$$v(t) = A(t)\exp\left[j\omega_1 + j\psi(t)\right] \tag{5}$$

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Although the free running frequency of the oscillator is ω_0, the presence of the forcing signal changes the frequency to ω_1. Any discrepancy in this assumption is taken care of by incorporating in $\psi(t)$. Defining the complex frequency as,

$$j\omega = \frac{1}{v(t)}\frac{dv}{dt}$$

$$\text{or, } j\omega = \frac{1}{A}\frac{dA}{dt} + j\omega_1 + j\frac{d\psi}{dt} \tag{6a}$$

and using the relation (6a) and pulling $s = j\omega$, one can express (4) as

$$\frac{v}{v_s} = \frac{G(s)}{1 - G(s).G(A)} \tag{6b}$$

Where, $$\frac{1}{G(s)} = \frac{s}{\omega_0} + 3 + \frac{\omega_0}{s}$$

It is to be noted that in evaluating $G(A)$, we have invoked the quasi-static principle. That is, the entire time domain of observation has segmented into small interval where the value of the gain of the circuit is assumed to remain constants. $G(A)$ is the equivalent linearised gain between the output and input relation $[v_0(v)\, vs\, v]$. Incidentally, this is modified Barkhausen relation, which takes both the non-steady and non-linear nature of the problem. It appears to another that no-such relation has been reported in the literature. Incidentally, for our experimental data an empirical relation is written as

$$v_0(v) = 4.0188 - 3.6195v^2 - 10.38v^3 \tag{7}$$

That is, $$G(A) = 4.0188 - 7.785A^2 \tag{8}$$

From (4) one can be written as

$$j\omega + \omega_0\left[3 - \frac{v_0(v)}{v}\right] + \frac{\omega_0^2}{j\omega} = \frac{E}{ARC}e^{j\phi} \tag{9}$$

3.0 Synchronization

Injection of a periodic signal in to an oscillator leads to interesting locking phenomena. Studied by Adler [1], Kurukawa [2] and others [3]-[5], these effects have found increasingly greater importance for they manifest themselves in today's many transceivers and frequency synthesis techniques. In this paper we study the injection locked characteristics of an Op-Amp Wien Bridge Oscillator. A sinusoidal signal is used to synchronize the frequency and phase of the oscillator and using (7) it is easily shown

$$\frac{dA}{dt} = \frac{\omega_0}{2}[G(A) - 3] + \frac{\omega_0}{2}E\cos\phi \tag{10}$$

And $$\frac{d\varphi}{dt} = \frac{\omega_1^2 - \omega_0^2}{2\omega_1} - \frac{\omega_0}{2}\frac{E}{A}\sin\varphi + \frac{d\theta}{dt} \tag{11}$$

Where, $$\phi = \theta - \psi$$

$$(1 - a^2)^2 + F^2X^2 = \frac{F^2}{a^2}$$

$$a = \frac{A}{A_0}; X = \frac{\Omega}{K}; K = \frac{\omega_0}{2}\frac{E}{A_0} \tag{12}$$

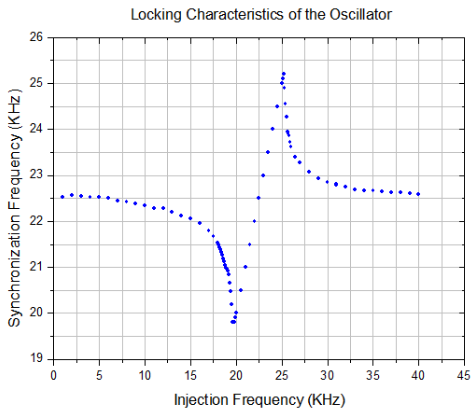

Figure 2 (a): Practical pull-In characteristics of an injection locked oscillator.

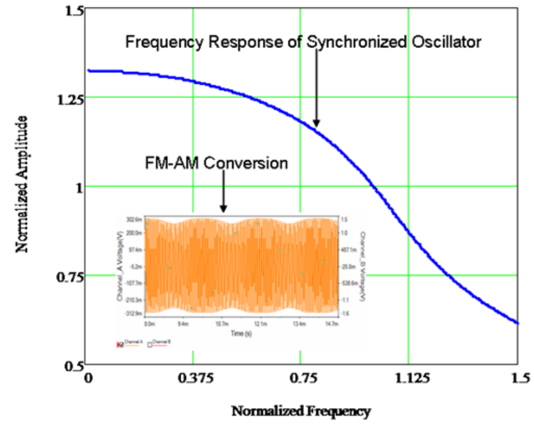

Figure 2(b): Frequency Response Characteristics of ILO.

Pull-in characteristics and frequency response characteristics of the injection locked oscillation (ILO) are shown in Fig. 2(a) and Fig. 2(b). It is seen that outside the locked range, the variation of the average frequency of the forcing signal are different on two sides of the locking boundary. The asymmetry appears due to two reasons, namely, (i) asymmetry tuning characteristics of the oscillator and (ii) amplitude modulation of the oscillator under forcing condition. This is corroborated by the observed on the unlocked spectra as shown in 3 (a) and 3(b). Fig. 2(b) clearly indicates the possibility of FM to AM conversion. A simulation results as inset in Fig. 2(b) confirms and as such one can write

$$v_0 = -0.0076v^2 + 3.111v \qquad (14)$$

Therefore at the output, FM signal will be demodulated. Only filtering is necessary to filter out the AF signal from the high frequency signal. Note that the detected waves are coherent i.e. the demodulation is tracking one.

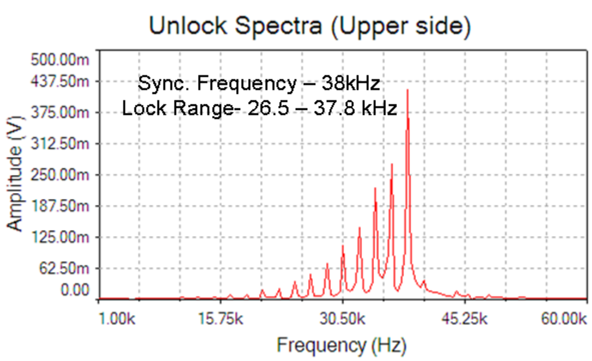

Figure 3 (a): Unlocked spectra of ILO at upper side.

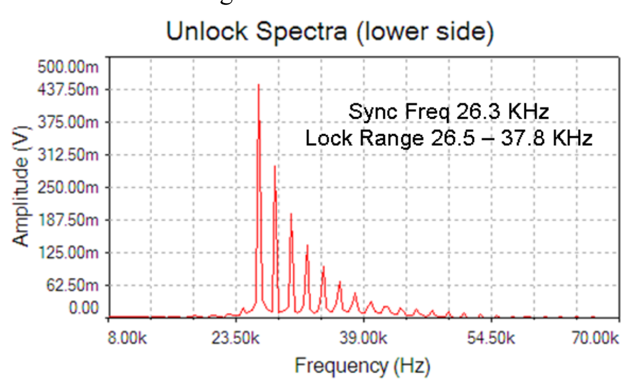

Figure 3 (b): Unlocked spectra of ILO at lower side.

3.0 Conversion and FM Signal Detection over the Locked Band

The bias current variation over the lock band, output voltage variation with the frequency are shown in Fig. 4(a), 4 (b) . Output voltage versus the input voltage have been observed in Fig. 5 Free running frequency of the Wien Bridge Oscillator is 22.3 KHz. Within the synchronization range the locked oscillator loses its identify and obeys command from the forcing signal. In this section the property of an ILO as an FM-AM converter has been looked into from a new perspective. FM-AM conversion is a phenomenon in which the frequency modulation of a given carrier gets converted into amplitude modulation of the same carrier. Thus an op-amp based Wien Bridge Oscillator can efficiently converts an FM signal to AM one and performs square law detection at the same time. Experimental results are shown in Fig. 6.

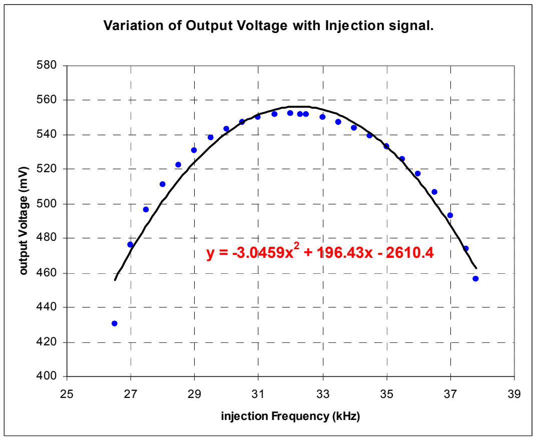

Figure 4 (a): Output voltage variation with injection frequency within lock range

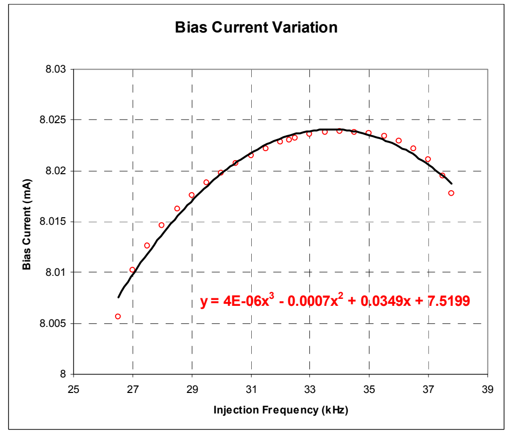

Figure 4(b): Bias current variation with injection frequency within lock range

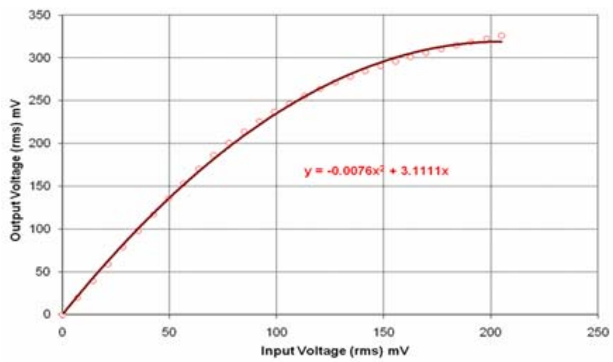

Figure 5: Output voltage versus input voltage.

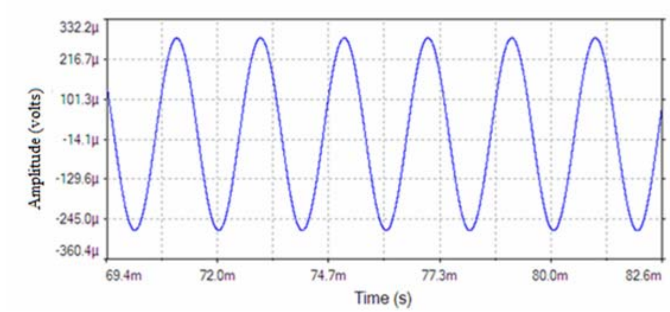

Figure 6: Detected Baseband (500 Hz) M detection in injection locked Wien Bridge Oscillator and measured distortion is 0.09%. Carrier frequency is set to be 30.5 KHz and injection level is 40 mV.

4. Interference Rejection

When the incoming FM signal is contaminated with an interfering tone the FM signal is converted into an AM signal, because the oscillator is tracking the incoming FM signal. But since the interfering signal lies outside the locking range the oscillator does not recognize and therefore on two grounds, viz. (1) FM-Am conversion of the FM signal (2) non tracking of the interference signal, the detected signal is almost free of interference as shown in Fig. 7.

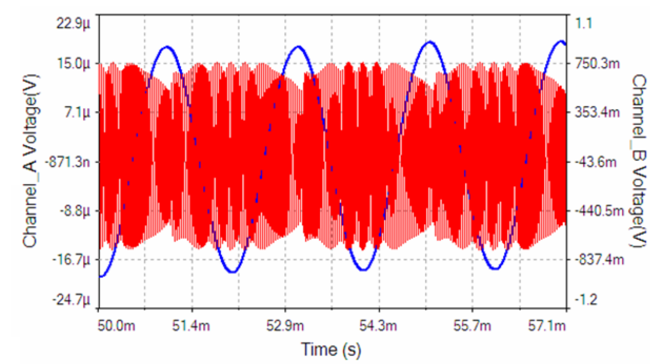

Figure 7: Detection across the output of op-amp based WBO (with Interference). Detected signal frequency is 500Hz with 0.75%. Strength of the FM signal is 50mV, Carrier Frequency – 30.5kHz, modulating index is 5 and base band signal is 500Hz. Interference Signal amplitude and frequency are 20mv and 28kHz respectively.

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