IQ oscillators: Tracking AM and FM Demodulators

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Abstract

The behaviour of a quadrature oscillator when subjected to a synchronizing signal has been analysed and experimentally studied in depth. It has led to the development of a single shot tracking FM discriminator with excellent interference rejection capability. It can also be used as a phase locked demodulator exploiting tracking capability.

1. Introduction

In modern wireless communication system, efforts are continuously made to replace as many analogue blocks by digital blocks, because it is easier to process digital signals than analogue signals. But it has not yet been possible to realize a replacement of the analogue-front by a digital front end, where the use of an IQ oscillator plays an important role. The function of an IQ is to generate outputs which are in Quadrature and it is required the outputs remain in quadrate over a specified tuning range. This requires synchronization of the IQ oscillators over the frequency variation or the bandwidth of the incoming signal. It appears to the authors that although quite a large number of works on IQ or Quadrature Oscillators have been reported almost nothing has been published on the synchronization aspects of IQ oscillators especially on their capability to act as tacking demodulators. This paper focuses on these aspects.

2. Preliminary

The basic theory behind generation of quadrature signals can be explained by supposing that I and Q channel-outputs are

$$x = \cos \omega_0 t, \quad y - \sin \omega_0 t \tag{1}$$

Therefore:

$$\frac{dx}{dt} = -\omega_0 y; \ \frac{dy}{dt} = \omega_0 x \tag{2}$$

That is,

$$\frac{d^2 x}{dt^2} + \omega_0^2 x = 0 \ \ or \ \frac{d^2 y}{dt^2} + \omega_0^2 y = 0. \tag{3}$$

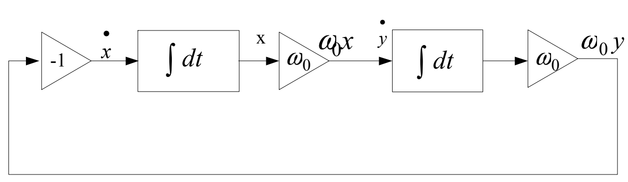

Fig.1a: Diagramatic Representation of Equations (1 - 3)

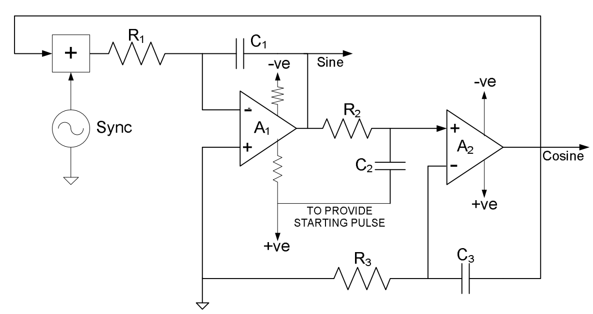

Fig.1b:Synchronization Scheme of an Quadrature Oscillator

This is the equation of an ideal harmonic oscillator. It is worthwhile to note that it oscillates with amplitude equal to that given as an excitation. Block diagrammatic representations of these two simple equations are shown in Fig.1a, the practical implementation of which is shown in Fig.1b. In this paper, we incorporate an extra arrangement that replace, the simple resistance R is replaced by a parallel combination of the 'R' and series combination of an appropriate resistance and two diodes, connected back-to-back.

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3. The System Equation

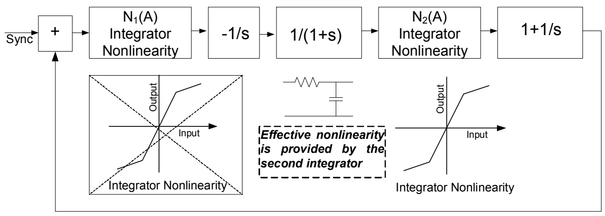


Fig.2a: Generic Model of Quadrature Oscillator

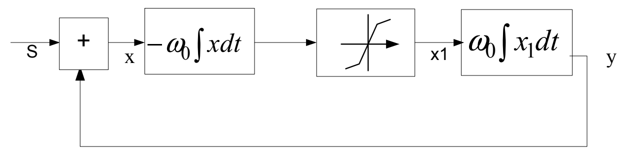


Fig.2a: Analytical Equivalent of Fig.2b

The generic model of quadrature oscillator is shown in Fig 2a and its analytical equivalent is shown in Fig. 2b. Refer to the Fig 2b we can write

Referring to the Fig. 2a and 2b it is easily shown that

$$s = x + y,\ x_1 = -\omega_0 N(\int xdt)$$
$$y = \omega_0 \int x_1 dt = -\omega_0^2 \int N(\int xdt)dt \qquad (4)$$

$$\frac{dy}{dt} = \frac{dx}{dt} - \frac{ds}{dt} = -\omega_0^2 N(\int xdt) \qquad (5)$$

That is
$$\frac{dx}{dt} + \omega_0^2 N(\int xdt) = \frac{ds}{dt} \qquad (6)$$

Again representing the nonlinearity as a sum of a linear term plus a nonlinearity the above equation can be approximated as

$$\frac{dx}{dt} + \omega_0^2 \int xdt + N_1(\int xdt) = \frac{ds}{dt} \qquad (7)$$

This is the governing equation of an IQ oscillator under the influence of an external signal, represented as $s(t) = ESin(\omega t + \theta)$

i.e.
$$\frac{ds}{dt} = E(\omega + \dot{\theta})\exp[\ j(\omega t + \theta) \qquad (8)$$

and
$$x = A(t)\exp(j\omega t + \psi) \qquad (9)$$

i.e.
$$j\omega = \frac{1}{x}\frac{dx}{dt} = \frac{\dot{A}}{A} + j(\omega + \dot{\theta}) \qquad (11)$$

$$\frac{1}{j\omega} \approx \frac{1}{j\omega} + \frac{1}{\omega^2}\left(\frac{\dot{A}}{A} + \dot{\theta}\right) \qquad (12)$$

Moreover it is easily shown that $\int xdt = \frac{2x}{j\omega} + \frac{1}{\omega^2}\frac{dx}{dt}$.

Now using the above equations it is easy to write this equation in terms of $A, \dot{A}, \omega, \dot{\theta}$

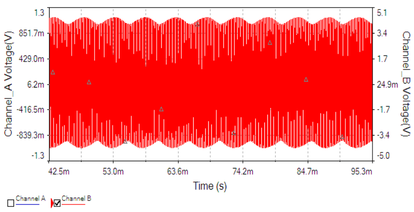


Figure 3: FM to AM conversion

$$\left(1+\frac{\omega_0^2}{\omega^2}\right)\frac{\dot{A}}{A}+N_1(A)=E(\omega+\dot{\theta})Cos\ \varphi \qquad (13)$$

$$\left(1+\frac{\omega_0^2}{\omega^2}\right)\frac{d\psi}{dt}+\omega^2-\frac{\omega_0^2}{\omega}=E(\omega+\dot{\theta})Sin\ \varphi \qquad (14)$$

When $\phi=\theta-\psi$ and $N_1(A)$ is the equivalent liberalised gain of the non-linearity. Now assuming that centre frequency of the oscillator is equal to the centre frequency of the incoming signal then $\phi\approx 0\ i.e.\ \psi=\theta$. That is oscillator output is faithfully frequency modulated. Again, it is seen that

$$\frac{dA}{dt}+N_1(A)A\cong E(\omega_0+\dot{\theta}) \qquad (15)$$

This equation clearly shows that the fluctuation of the amplitude is given by

$$\frac{\Delta A}{dt}\cong E\dot{\theta} \qquad (16)$$

This indicates that $x(t)$ is an AM- FM wave. And again $dy/dt=dx/dt-ds/dt$ therefore the input of the second integrator is an AM-FM wave. This is shown in Fig. 3. Now if we assume that the signal is CW signal then the phase equation is

$$\frac{d\phi}{dt}=\frac{\omega^2-\omega_0^2}{2\omega}-\frac{w_0E}{A}\sin\phi \qquad (17)$$

Which is typical locking equation of an injection locked oscillator.

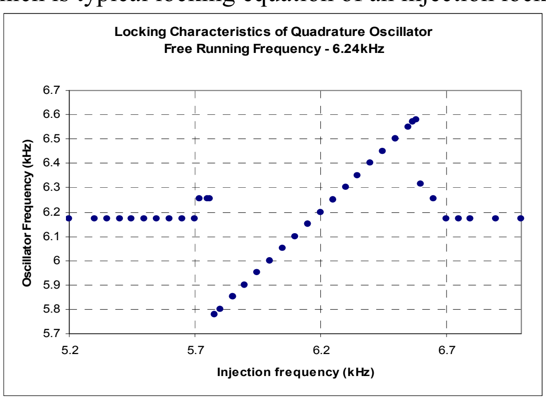


Figure 4: Locking Characteristics

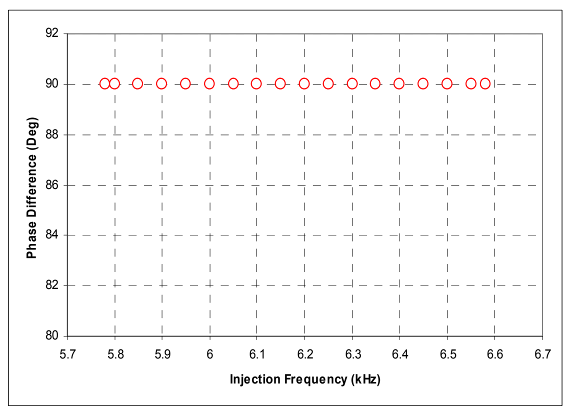


Figure 5: Phase difference over lock band.

4. Experimental Observation

A simulation experiment has been set up with Multisim11. The locking characteristic of the IQ oscillator is shown in Fig 4. Fig 5 shows the phase relationship between I- and Q- channels output over the lock-band which is in quadrature over the entire range. Figure 6 shows the variation of the output of the second integrator with input. It is found that the dependence is nearly square-law. Thus along the AM-FM signal at the input of the second integrator, it is easily appreciated that the output of the second integrator is square law detected version of the original FM synchronizing signal. The filtered output with distortion 0.45% (where frequency of the FM carrier signal is 6.0 kHz, Base band is 500Hz, Amplitude – 300mV and Modulating Index - 0.6) is shown in Fig. 7. Fig.7a shows the demodulated output using the FM-AM conversion where as Fig.7b displays the demodulated using phase tracking capability. Another interesting feature of the injection locked oscillator is its interference squelching aspect.

The experimental findings are shown in Fig 8. This astonishing property is easily explained by fact (1) a synchronised oscillator ignores any signal that lies outside the lock-band and (2) the detection principle involves FM to AM conversion (Fig.8a). Fig.8b shows higher distortion when phase tracking alone is used.

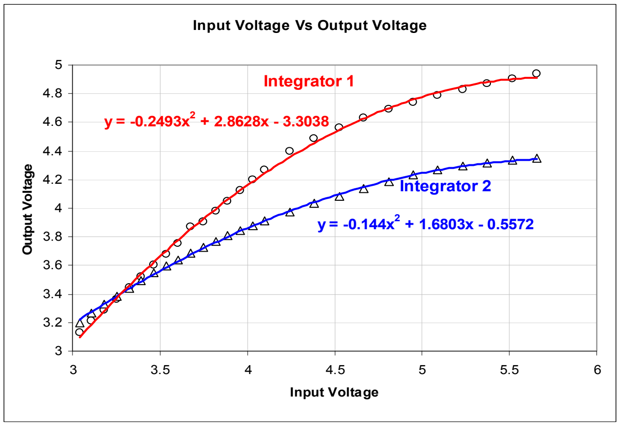


Figure 6: Variation of the output of the 2nd integrator.

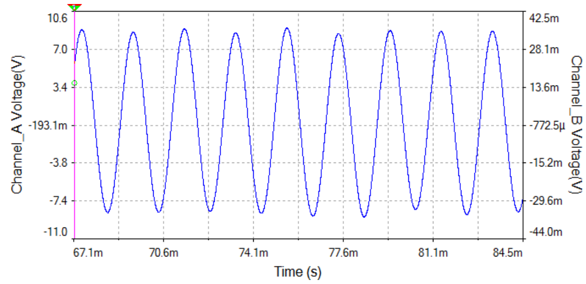


Figure 7(a): Filtered output of 2nd integrator

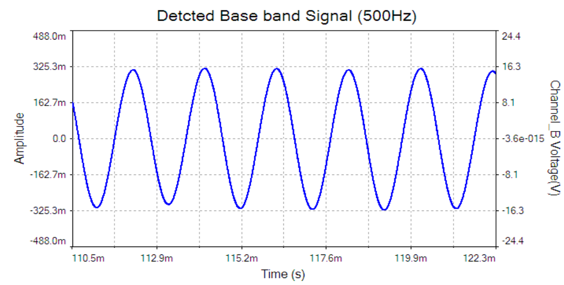
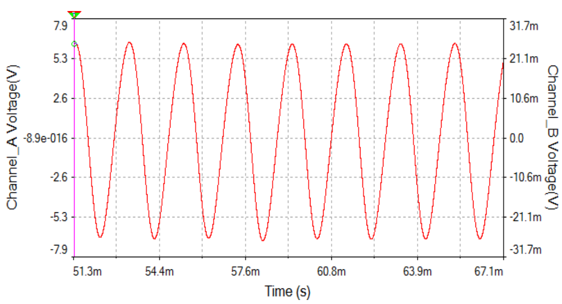


Figure 7(b): Filtered phase detector output



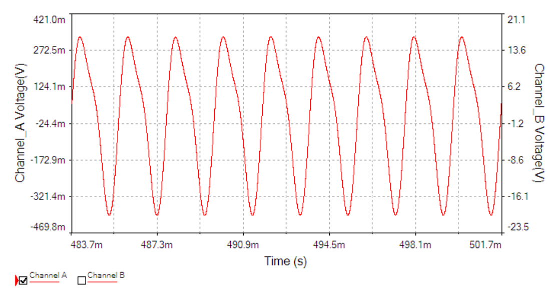


Figure 8(a & b) - FM detection at Output with Interference (a)Interference frequency – 6 kHz with amplitude – 300 mV then Distortion – 7.4% (b) Phase Detector Output Interference Freq –6 kHz with amplitude – 300 mV then Distortion – 25.4%

5. Conclusion

A non linear theory of the quadrature oscillator has been presented that explains its capability as an FM to AM conversion. More interestingly it has been proved both theoretically and experimentally that the IQ can be used as tracking AM and FM demodulators with a high noise squelching property. Theoretical and experimental results mutually support. Further over the entire locking range I- and Q- outputs are in quadrature.

6. Acknowledgment

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