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# THE EVALUATION OF PHASE NOISE IN LOW NOISE OSCILLATORS


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## Abstract

A new measurement system for the characterisation of low noise oscillators is described. Injection locking rather than phase locking is used to achieve phase quadrature in the two oscillator phase detector method. This method is simpler to implement than conventional phase locked systems and by using a fixed rather than an electronically tuned reference, offers improved limiting sensitivity.


## Introduction

Recent advances in the design of low noise oscillators has placed increasing demands on the performance of noise measurement systems with improved frequency coverage and limiting sensitivity being necessary. The Ondria bridge [1] is capable of providing an excellent limiting sensitivity for measurements but has a small radio frequency bandwidth and requires a large amount of microwave hardware. Improved bandwidth performance may be achieved using the phase detector method [2] but it is necessary to provide a voltage tuneable reference source with better stability than the source under test and external phase locking circuitry.

This paper describes a new technique for realising the phase detector method without the requirement for a voltage tuneable reference source. The key to the new measurement system is the use of injection rather than phase locking to achieve phase quadrature between the reference source and the source under test. This has the following advantages over the conventional phase locked system:

i) The phase stability of the reference source which is the limiting factor for close to carrier measurements is easier to achieve using a fixed rather than an electronically tuneable source.

ii) The reference output is less susceptible to low frequency interference

iii) Injection locking is easier to implement

## The New Measurement System

Figure 1 shows the block diagram for the new measurement system. A small amount of the reference output power is directed through path 1 to provide the injection locking signal for the test source.

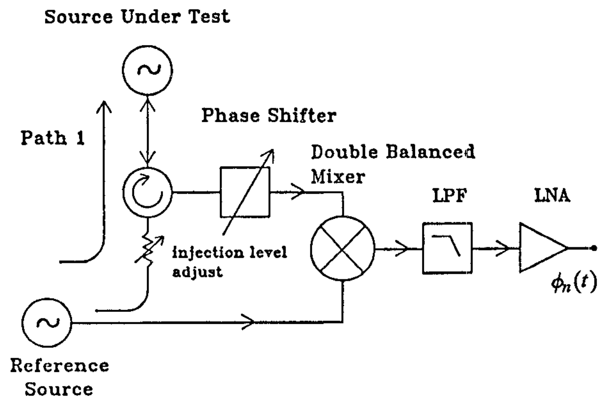


Figure 1. Block diagram for the injection locked phase noise measurement system.

Synchronisation of the oscillations occurs when the difference between their free-running frequencies is within the injection locking bandwidth for the system. For the case of low level injection this is defined by [3,4]:

$$B_L = \frac{f_0}{2Q}\left[\frac{P_{inj}}{P_o}\right]^{1/2} \quad (1)$$

where

$f_0$ is the unlocked frequency of the test source
$Q$ is loaded quality factor of the test source
$P_{inj}$ is the injected power level
and $P_o$ is the output power of the test source.

Where the load or device impedances in the oscillator are a function of amplitude or frequency this must be taken into account in determining the value for $Q$ [5].

The phase offset between the oscillations after locking is given by:



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$$\alpha = \sin^{-1}\left[\frac{\Delta f}{B_L}\right] \qquad (2)$$

where $\Delta f$ is the unlocked frequency difference between the oscillations This is shown graphically in Figure 2. It follows that a constant phase offset exists between the oscillations provided their frequencies remain constant.

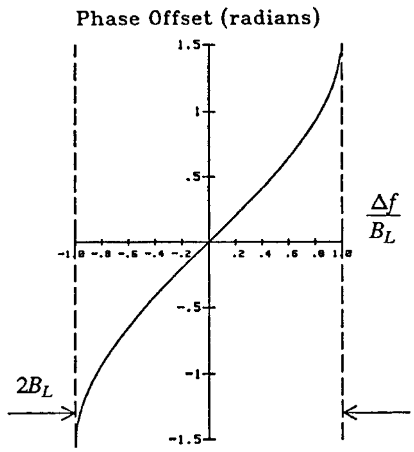


Figure 2. The phase-frequency characteristic for low level injection locking.

In practice it is unlikely that the phase characteristic will pass through the origin due to its dependence on the point at which the injected signal is introduced. To achieve the necessary phase quadrature condition at the mixer input ports, the relative phase of the oscillations is adjusted after locking using the phase shifting element shown in Figure 1.

With the signals in quadrature the mixer behaves as a phase detector and provides a baseband output voltage proportional to the phase variations of the test source.

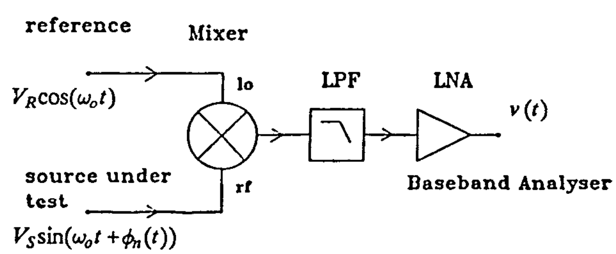


Figure 3. The operation of the mixer as a phase detector.

From Figure 3 the detected output voltage is given by,

$$v(t) = K_L A V_S \sin\phi_n(t) \qquad (3)$$

where

| | | |
|---|---|---|
| | $K_L$ | is the conversion efficiency of the mixer |
| | $A$ | is the gain of the amplifier |
| and | $\phi_n(t)$ | is the phase variation of the test source. |

For small $\phi_n(t)$,

$$v(t) \simeq K_\phi \phi_n(t) \qquad (4)$$

where $K_\phi = K_L A V_S$.

From (4) it follows that,

$$\phi_n(f_m)_{rms} = \frac{v(f_m)_{rms}}{K_\phi}$$

and the spectral density of the phase fluctuations is given by;

$$S_\phi(f_m) = \phi_n(f_m)^2_{rms} = \left[\frac{v(f_m)_{rms}}{K_\phi}\right]^2 \qquad (5)$$

where, $f_m$ is the video offset frequency and $v(f_m)_{rms}$ is measured in a 1 Hz bandwidth.

To callibrate the system it is necessary to determine the phase detector constant $K_\phi$. This may be achieved by measuring the magnitude of the beat signal occuring when the two sources are detuned slightly in the unlocked condition.

Assuming the reference noise to be negligible, and the unlocked frequencies of the sources to be nearly equal, the locked spectrum is given by [6,7];

$$\phi_m^2(f_m) = \frac{\frac{f_m^2}{f_o^2} Q^2 \frac{P_o}{P_{inj}}}{1 + \frac{f_m^2}{f_o^2} Q^2 \frac{P_o}{P_{inj}}} \cdot \phi_n^2(f_m) \qquad (6)$$

where $\phi_n(f_m)$ is the test source spectrum. It follows that inside the locking bandwidth the phase noise of the test source is suppressed but at larger offset frequencies is unaffected by the locking mechanism. This is illustrated in Figure 4 which shows the phase noise spectrum for an injection locked Gunn oscillator measured with different locking bandwidths.

To provide good close to carrier resolution for measurements it is necessary to minimise the locking bandwidth using low level injection.

To ensure the linear operation of the mixer and maintain a measurement error of less than 0.2dB the phase of the input signals must be held within 0.2 radians of phase quadrature [8]. For operation at the centre of the locking range this defines the minimum locking bandwidth that maybe used;

$$B_{L\min} = 5\delta\Delta f \qquad (7)$$

where $\delta\Delta f$ is the maximum differential frequency variation of the oscillations.

Infomation inside the locking bandwidth maybe obtained by characterising the phase noise suppression of the locking mechanism, and using this to correct the measured data. Where the locking parameters are not known and (6) cannot be evaluated the suppression characteristic maybe derived by measuring the attenuation of induced phase modulation side-

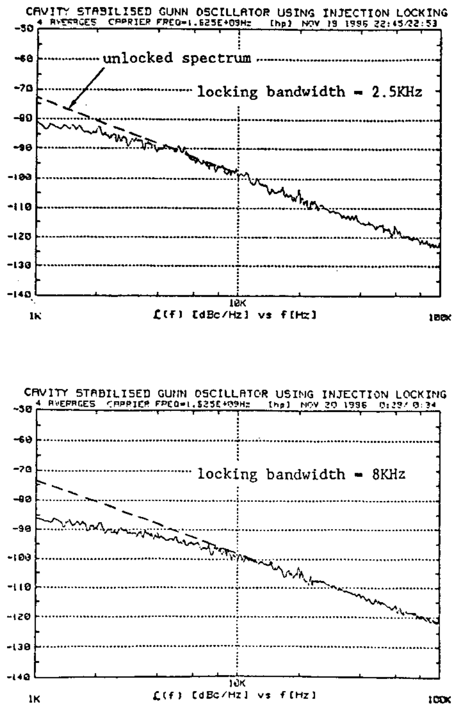


Figure 4. The effect of injection locking on the close to carrier noise spectrum

bands after locking. A range of offset frequencies must be considered to determine its frequency dependence.

Figure 5 shows the phase noise spectrum for a 125 MHz crystal oscillator measured using a 5 Hz locking bandwidth. A similar oscillator was used for the reference because of the low noise performance of the test source. Each oscillator then contributes an equal amount to the measured spectrum and 3dB must be subtracted from the results to provide the noise of the test source. The mixer, baseband amplifier, and two source calibration were all realised using the HP 11729C system. Also shown in Figure 5 are results measured using phase locking. These show excellent correspondence with the injection locked results at offset frequencies less than 1 kHz. At greater offsets the phase locked system is limited by the noise floor of the HP 8662A reference VCO. To allow a comparison of the results at offsets greater than 1 kHz results are also presented using the Ondria bridge. These predict a lower noise floor than the injection locked system because of phase detector noise in the locked system.

Results for a 10 GHz Gunn oscillator are shown in Figure 6 measured using both injection and phase locking. Good correspondence between the results is achieved at offsets outside the locking bandwidth.

## Conclusion

The new measurement system has been shown to provide results in excellent agreement with those of existing state of art techniques. It is simpler to implement than previous methods and is capable of good sensitivity performance by employing a fixed rather than an electronically tuneable source. The technique is particularly suitable for the evaluation of extremely low noise sources where a reference source is used with equivalent performance to the source under test and cannot be converted to a VCO. Other applications are in the measurement of microwave

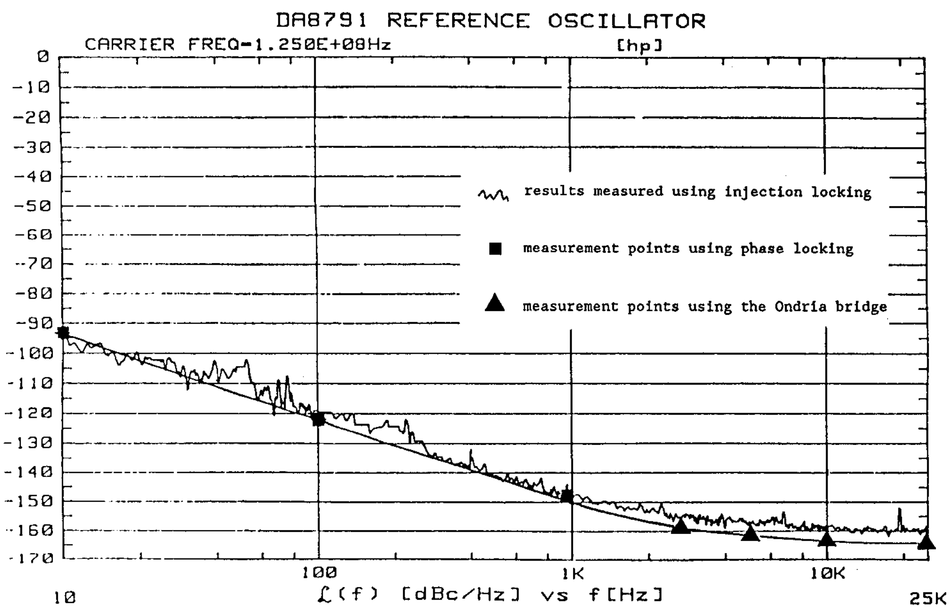


Figure 5. The phase noise spectrum of a 125 MHz ccrystal oscillator measured using, injection locking, phase locking and the Ondria bridge.

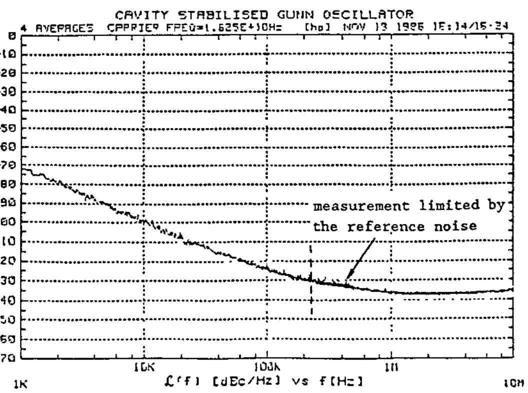


Figure 6a. The phase noise spectrum of a 16.25 GHz Gunn oscillator measured using injection locking.

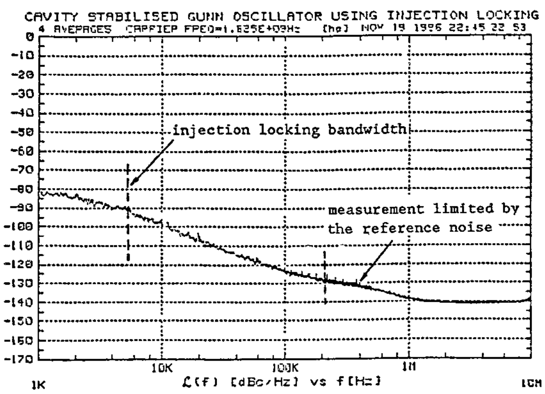


Figure 6b. The same oscillator measured using the HP 11729C/8662A phase noise test system.

sources which are already injection locked, to provide for example a desired combination of output power and noise performance. This new measurement technique may be implemented with minimum effort by utilising only the baseband hardware from an existing phase-lock equipment.

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