

Further investigation into phase-noise uncertainties

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1. Abstract

The question of the uncertainty of a phase noise measurement is a vexed question which is difficult to answer well. This is partly because the measurement depends on so many parameters and some of these change with every measurement. A consequence of this is that the uncertainty of the measurement depends to a great extent on the device being measured.

The work reported here describes some investigations into the effect of variation of some of the parameters with the particular intention of investigating the uncertainty of noise measurements made close to the carrier. Throughout this paper the method of making the phase noise measurements discussed is the phase detector method using a phase locked loop. This means that measurements close to carrier are inside the phase locked loop and that it is necessary to correct the noise measurement for the effect of the phase locked loop. The uncertainty of performing this correction is the main uncertainty which is investigated here.

2. Introduction

The phase detector method using a phase locked loop is the most common phase noise measurement technique used and a block diagram is given in Figure 1 below.

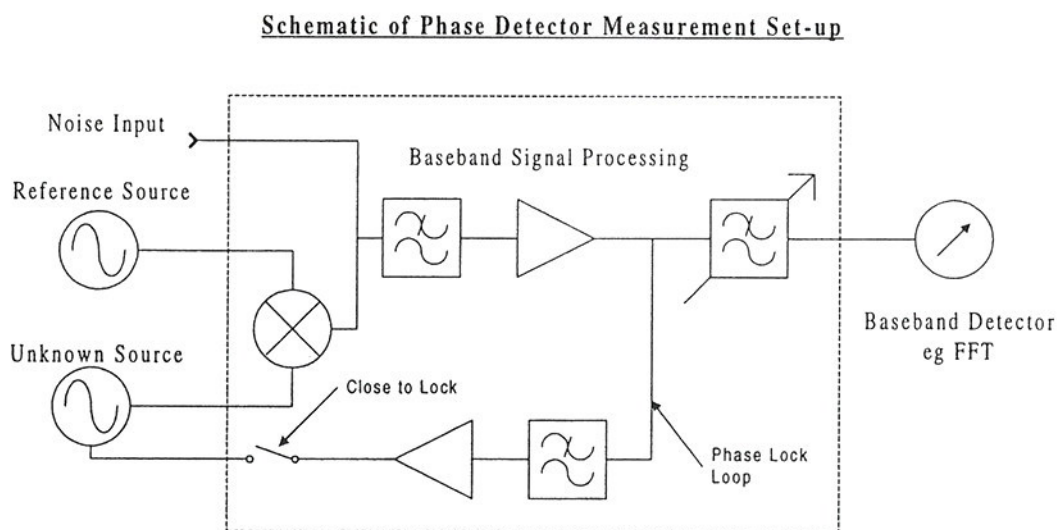


Figure 1 : Phase detector method block diagram

The use of a phase locked loop to establish quadrature suppresses the close in noise and the effect of this must be measured and a compensation applied. Establishing traceability for this correction has not previously been addressed. For close to carrier noise this correction will be very large and any errors in the correction could result in highly erroneous measurements

2.1. Previous work on traceability

Work on the traceability of this method has been presented previously [reference 1]. This work does not address any issues associated with the phase lock loop itself and so can only be considered to be valid outside the loop bandwidth at least until the treatment is extended. The discussion here draws heavily on that work and this discussion would not have been possible without it.

Several contributions to the overall uncertainty are considered and are given in the table below which is reproduced from reference 1:

Uncertainty Component	Contribution [dB]
Type A Contribution per Measurement	$\frac{10}{\ln 10} \cdot \frac{1}{\sqrt{N}}$ = 0.19 (N=500)
V_{rms}	
Type B Contributions per Measurement	
Linearity, G_{Lin}	0.07
Power Spectral Density, K_{PSD}	0.92
Frequency Response, $G(f)$	0.013
Phase Detector Constant, K_{ϕ}	0.08
Measurement Environment Contributions	
AM Noise Rejection	<i>measure level and rejection</i>
Noise Floor	<i>measure or calculate</i>
Reference Source	<i>measure or calculate</i>
Multiple Source Measurement	<i>combine uncertainties</i>
Total, as RSS [dB]	0.95

Table 1 : Uncertainty for phase detector method

There are several terms which must be considered, the dominant term being that due to the deviation from unity of the power spectral density response of the spectrum analyser. The uncertainty due to the phase detector constant is small and there is no term for the VCO tune constant. This is correct for measurements made outside the phase locked loop and for measurements made inside the phase locked loop where the loop suppression is measured. However, the loop suppression can also be predicted from the values of the phase detector constant and the VCO tune constant and it is this approach which is investigated here.

3. Correction for the phase locked loop

The method of correcting for the phase locked loop is based on that used in the HP 3048A phase noise measurement system. In this system a polynomial curve is derived which is used to correct the measured phase noise. The coefficients of this curve are derived by one of two methods, fitting to measured data or fitting to values calculated from the measured loop constants. In normal circumstances it would be reasonable to assume that one would use measured data when seeking the most accurate value but for the purposes of this investigation it is valid to use values calculated from the measured loop constants since this makes it straightforward to alter the correction coefficients in a realistic manner.

The response of the phase locked loop is described in terms of its poles and zeros, some of which are fixed by the interface and some of which are dependant on the oscillators under test. Two parameters vary depending on the phase locked loop configuration. One of these is an assumed pole which can be calculated from measured phase locked loop suppression data to allow for any peaking in the PLL or which can be derived from previously measured data. The other parameter is the open loop bandwidth, B_{op} defined by $B_{op} = |K_{\phi} \cdot K_{VCO} \cdot A_1 \cdot A_2 \cdot 10^{(G1+G2+6)/20}|$ where K_{ϕ} is the

phase detector constant, K_{VCO} is the VCO tune constant, A_1 and A_2 are attenuation values in the interface (in absolute terms) and $G1$ and $G2$ are gains in the interface (in dB). In the situation where the PLL suppression is not measured but is calculated from the measured loop constants, only K_ϕ and K_{VCO} can alter the PLL suppression correction. Here the effect of variation in K_ϕ and K_{VCO} on the calculated phase noise within the PLL is discussed.

The software actually calculates three sets of coefficients for three ranges of frequency. These ranges are:

$B_{cl}/100$ to $B_{cl}/10$

$B_{cl}/10$ to B_{cl}

B_{cl} to $10.B_{cl}$

where B_{cl} the closed PLL bandwidth is related to B_{op} by $B_{cl} = B_{op} \cdot P_f/Z$ where P_f and Z are a pole frequency and a zero which are inherent in the system interface. However, the calculation is simply a different curvefit to give improved fitting and no new variables are introduced.

In the measurements described here, the closed PLL bandwidth is of the order of 80 Hz and the measurements cover the range of 10 Hz offset frequency to 100 Hz offset frequency. The oscillators under test are the two 10 MHz oscillators built into the HP11848 interface unit.

4. The measurements

The variation of the phase detector constant and the VCO tune constant was evaluated using the statistical variability of several measured results. This does not, therefore, include Type B uncertainties in these values and is therefore an understatement. The table below gives the values used.

Item	Mean	Standard deviation (sample 4)
K_{VCO}	101.370	0.048 (0.05%)
K_ϕ	0.25399	0.00032 (0.13%)

Table 2 : Values of loop constants

The effect of these uncertainties was evaluated by varying each from its nominal value by one standard deviation and calculating the results. The same real phase noise raw data was used for each measurement.

The results are shown below using a log plot from 10 Hz to 100 Hz:

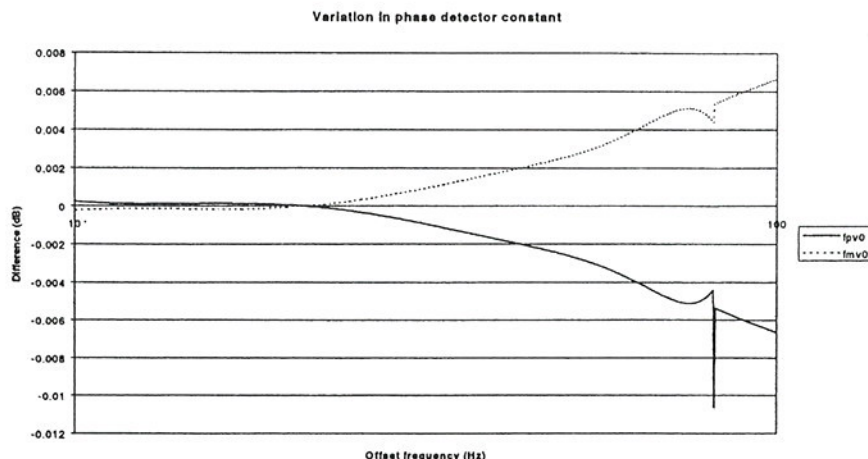


Figure 2 : Variation due to phase detector constant

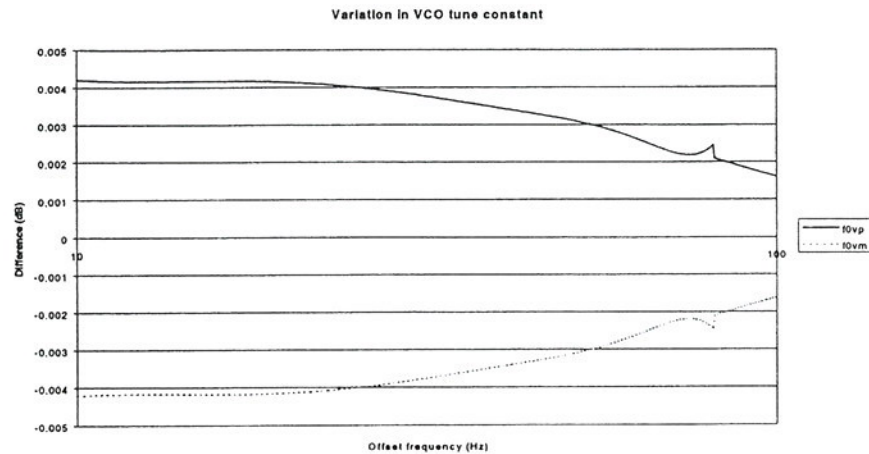


Figure 3 : Variation due to VCO constant

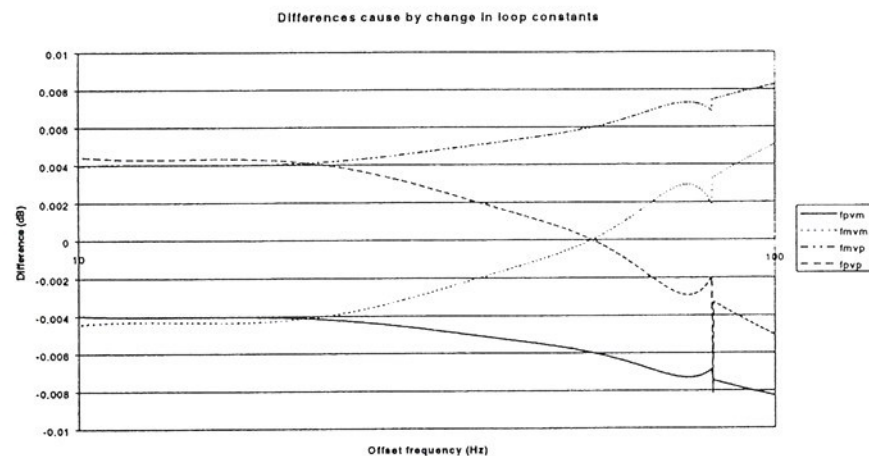


Figure 4 : Effect of combined variation

The effect of the phase detector constant is to introduce variation of 0.007 dB (an extreme value at the change in correction coefficients is more than 0.01 dB) and the effect of the VCO tune constant is to introduce an error of 0.004 dB. The combined uncertainty is dominated by the term due to the phase detector constant and is 0.008 dB to 2 significant figures. It is worth noting that $|1 - 10^{(0.008/10)}| = 0.18\%$ which is larger than the original error in K_{ϕ} which was 0.13% but it seems unlikely at this stage that significant uncertainties in phase noise measurements will result from the effects investigated thus far. However, in the situation where there is non-linear uncertainty propagation more careful investigation is required. This effect is insignificant when compared to the other errors given in Table 1 and can be neglected if they represent the uncertainty situation completely. It is not likely, however, that the very simple uncertainty contribution considered so far in this work represents the full uncertainty in phase noise measurements which will arise from uncertainty in the phase locked loop characterisation and so further work will be required and the contribution to the overall uncertainty is bound to increase.

5. Conclusion

The work reported here represents a preliminary study of the uncertainty of phase noise measurements inside the phase locked loop, an area not hitherto investigated. Since the response to the phase locked loop is non-linear it is clearly possible that a small error in the characterisation of the loop would result in a much larger error in the measurement. The work described here demonstrates the non-linear nature of this effect but has not, so far, shown any large increase in uncertainty which might become significant. This situation could change for results closer to carrier relative to the phase locked loop bandwidth - the results quoted here extend only to roughly $1/8^{\text{th}}$ of the closed loop bandwidth. As noted

above, the uncertainties used are only for the Type A component - the Type B components could be larger and could make a more significant difference. Further work is required in this area and the contribution to the overall uncertainty caused by uncertainty in the phase locked loop correction will be higher than reported here.

At present it is reassuring to see that the effects observed so far are small and that there would not appear to be a very large, unanticipated uncertainty source. However, the final conclusion can only be reached when further more detailed work is completed.

6. References

1. Traceable Phase Noise Measurements at NPL, Michael Leeson, 26th Automated RF and Microwave Measurement Society Conference Digest, 7th and 8th April 1997, Great Malvern