Study of the Effect of Noise on Output of Voltage Controlled Oscillator

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Abstract—*Phase Locked Loops act as basic building blocks in modern electronic system and noise has been one of the major concerns in the design of Phase Locked Loop. Noise affects the performances of Phase Locked Loop components such as loop filter, phase detector and voltage-controlled oscillator. Therefore, noise study of phase locked loop is very important. In this work, we report a study carried out to observe the effect of noise on performance of Voltage Controlled Oscillator. We perform the study by considering different values of Voltage Controlled Oscillator gain constant and different amplitudes of noise signal.*

1. INTRODUCTION

The phase locked loop (PLL) is a feedback control system which is used to maintain a constant output frequency and phase, according to the frequency and phase of the input signal. Fig. 1, shows the block diagram of a basic PLL consisting of a phase detector (PD), loop filter (LF), voltage controlled oscillator (VCO) and frequency divider. The PD generates an output proportional to the phase difference between its two inputs. The first input V_{in}, is usually generated by an external or reference oscillator, while the second input is directly related to the output of the VCO V_{out} [3]. The phase detector output pulse is smoothed by passing it through a loop filter. The resulting dc component is used as the input voltage for controlling the VCO. The output of the VCO is fed back to input of PD for comparison, which in turn controls the VCO oscillating frequency to minimize the phase and frequency difference with a the reference signal in order to achieve locked state.

The frequency divider in the feedback path is usually used to generate a low noise, high frequency digitally- programmable signal from a low-frequency low-noise crystal oscillator. The frequency division may be performed using an analog frequency divider or by a digital synchronous or asynchronous counter [1].

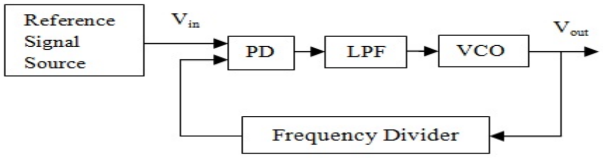

Fig. 1: Block diagram of Basic PLL

2. RELATED WORK

There are many reported works on PLL noise analysis in literature. In the year 2001, Ali Hajimiri presented the effects of different building blocks on the jitter and phase noise performance of PLLs [1].

Amit Mehrotra studied the problems of noise analysis of PLLs in the year 2002 [2].

Faisal Musa analyzed PLLs from the noise point of view and also he discussed different trade-offs in designing low noise PLLs [3].

A. Amornthipparat, A. Rangsiwatakapong, and D. Eungdamrong presented a mathematical model for PLL and studied the effect of the phase noise on PLL [4].

S. Limkumnerd and D. Eungdamrong investigated the roles of loop filters in phase noise contribution and presented a phase noise models that can be used for accurate phase noise prediction for PLL designs [6].

Muhammed A. Ibrahim and Jalil A. Hamadamin studied how different noise sources affect the noise performance of the output signal of PLL and they found out the trade-off between the suppression of noise at input and of VCO [7].

In the year 2007 Metha Jeeradit, Yohan Frans, Reza Navid, and Bruno Garlepp presented how the VCO phase noise obtained from HSPICE RF and from the Impulse-Sensitivity Function (ISF) method and how these phase noise estimates can be used to obtain a prediction of random jitter noise component in a PLL [8].

3. OBJECTIVE AND METHODOLOGY

The main objective of the proposed work is to analysis how different noise sources affect the performance of VCO at different VCO gain constant $K_{v.}$ The simulation of the VCO output with different noise sources is performed with MATLAB software.

4. VCO WITH DIFFERENT NOISE SOURCES

VCOs are the integral parts of all phase-locked loops. Noise and harmonics are critical parameter for VCO performance. Circuit and device noise can perturb both the amplitude and phase of an oscillator's output [9]. The essential features of the VCO are (a) phase stability, (b) large frequency deviation, (c) high modulation sensitivity, (d) linearity for frequency versus control voltage and (e) capability for accepting wide-band modulation. For PLL applications, it is treated as linear and time-invariant system. VCO is usually an oscillator, whose frequency is proportional to the control voltage V_c with a function given by

$$\omega_0 = \omega_c + K_v V_c \tag{1}$$

Where ω_0 = Output frequency of VCO, ω_c = Free running frequency of VCO, K_v = Gain constant of VCO, V_c = VCO input voltage i.e. the control voltage [5].

The sinusoidal output of a VCO can be expressed as

$$y(t) = A\cos(\omega_c t + K_v \int V_c \, dt) \tag{2}$$

So, the phase is the time integral of frequency.

If

$$V_c(t) = A_i * t \tag{3}$$

Where A_i = Amplitude of control voltage (in volts), t = time (in seconds).

Then equation (2) can be rewritten in the form of (4).

$$y(t) = A\cos(\omega_c t + K_v \int (A_i * t) \, dt) \tag{4}$$

Noise and harmonics are critical parameter for VCO performance. Circuit and device noise can perturb both the amplitude and phase of an oscillator's output [8]. Noise is any unwanted disturbances superimposed on a useful signal, which tends to obscure its information content. Noises are classified as internal noise and external noise. External noises are generated from outside sources and internal noise generated internally or within the communication system. Here we will discuss additive white Gaussian noise (AWGN), phase noise (PN) and amplitude noise (AN).

Additive White Gaussian Noise (AWGN) is the statistically random radio noise characterized by a wide frequency range with regards to a signal in a communications channel. The noise is additive because it is added to any noise to the information system. White means its power spectral density is flat and Gaussian because it has a Gaussian distribution in time domain. We generate AWGN using awgn() function in MATLAB. The agwn() function first measures the power of the given signal and then adds white Gaussian noise (WGN) to the signal for a given Signal to Noise Ratio (SNR) level in dB. This noise signal is added to control signal of VCO.

PN consists of small random perturbations in the phase of the signal, i.e. phase jitter. PN reduces the signal quality and increases the error rate of the communications link. If V_c is a ramp signal then PN can be expressed as

$$V_{PN}(t) = A_i * (t + \varphi(t)) \tag{5}$$

Where φ(t) is time varying phase instability that is the PN (in radians). This noise is also added to control signal of the VCO.

Finally, AN noise is the noise arising due to amplitude fluctuations in a signal. AN can be expressed as

$$V_{AN}(t) = (A_i + A_n) * t \tag{6}$$

Where A_n is the time varying amplitude instability (in volts). This AN noise is also added to control signal of the VCO.

5. THE ALGORITHM AND FLOWCHART OF SIMULATION PROGRAM

The algorithm of the simulation programme developed for the proposed work is given below.

Algorithm: Algorithm for VCO output signal.

Function awgn (V_c, SNR, 'measured');

randint (m, n, r)

Global float time t; time t1; time t2, time t3; V_c; pi; K_v; noise amplitude A_n ; integer SNR; free running frequency f_c; Ai; Amplitude of the VCO output signal A_v, phi.

```
1.  If AWGN then
2.   $V_c = A_i * t$
3.   AWGN = call awgn($V_c$, SNR, 'measured') // Generate additive white Gaussian noise
4.  If success step 3 then
5.   Go to step 8
6.  Else
7.   Go to step 1
8.   $VCO_{wn} = A_v*cos(2*pi*f_c*t + Kv * \int AWGN\ dt1)$ // Generate VCO output signal with AWGN noise
9.   Plot (t1,$VCO_{wn}$)
10.  If success step 9 then
11.  Go to step 14
12. Else
13.  Go to step 1
14. If AN then
15.  $A_n$ = call randint(m, n, r) //Generate a matrix of random integers of size m*n in a range [1,r]
16. AN = (Ai + An) * t // Generate amplitude noise
17. If success step 16 then
18.  Go to step 21
19. Else
20.  Go to step 14
21.  $VCO_{an} = A_v*cos(2*pi*f_c*t + Kv * \int AN\ dt2)$ // Generate VCO output signal with AN noise
22.  Plot (t2,$VCO_{an}$)
23. If success step 22 then
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24.   Go to step 27
25.  Else
26.   Go to step 14
27.  If PN then
28.   phi = call randint(m, n, r) *(pi/180) // phi in radians
29.   PN = Ai * (t + phi) // Generate PN noise
30.  If success step 29 then
31.   Go to step 34
32.  Else
33.   Go to step 27
34.   $VCO_{pn} = A_v*cos(2*pi*f_c*t + Kv * \int AN\ dt2)$ // Generate VCO output signal with PN noise
35.   Plot(t3,$VCO_{pn}$)
36.  If success step 35 then
37.   Go to step 40
38.  Else
39.   Go to step 27
40.  Stop
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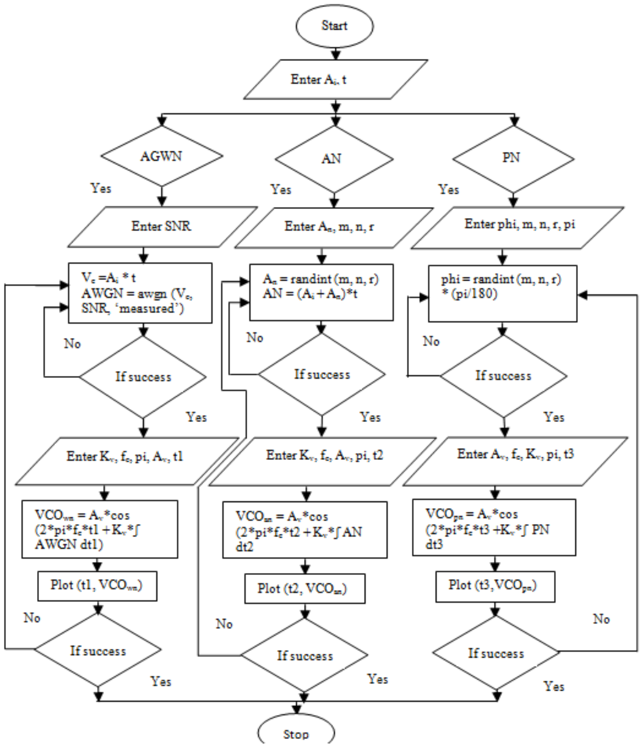

Fig. 2: Flowchart of the VCO simulation program

The flowchart of the simulation program is shown in Fig. 2.

6. RESULTS AND DISCUSSION

The objective of the proposed study is to observe the performance of VCO output with noise at different K_v value and it is simulated in time domain using MATLAB. The y-axis is the amplitude in volt and x- axis is the time in second. At first, amplitude of the noise signal is kept constant and varies the value of K_v (unit in radian per volt per second) from .001 to 100. In second, amplitude of the noise signal is varied, while K_v is kept constant. From the simulation result, it is seen that the VCO signal is less noisy for smaller values of *K*v, as shown in Fig. s 3-5. Fig. s 6-8 show the simulation result for VCO output at different values of amplitude of the noise signal. Here, we observe that the frequency of the VCO output signal is increased as amplitude of the noise signal increases.

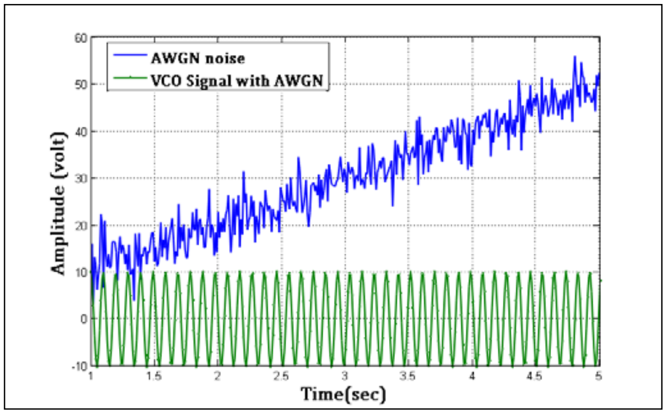

Fig. 3: VCO output with AWGN noise at K_v = .001

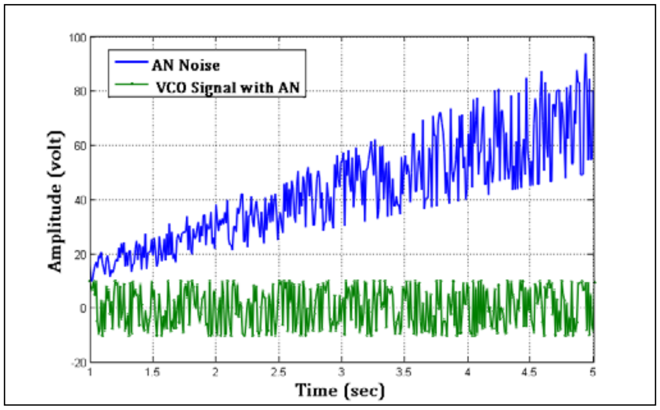

Fig. 4: VCO output with AN noise at K_v = 10

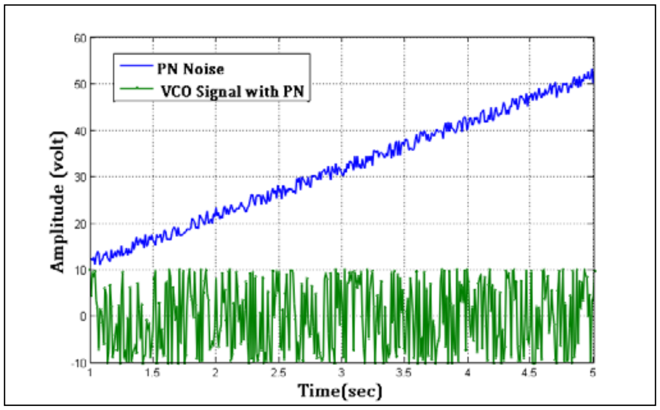

Fig. 5: VCO output with PN noise at K_v = 50

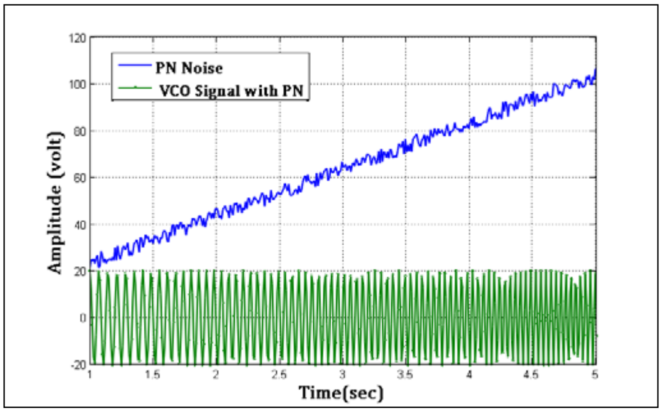

Fig. 6: VCO output with PN noise at amplitude = 20

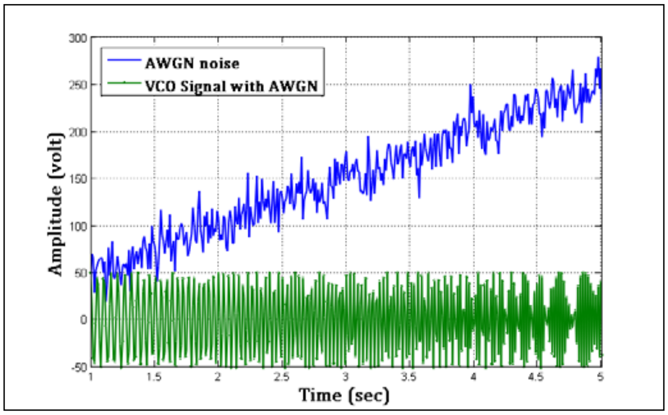

Fig. 7: VCO output with AWGN noise at amplitude = 50

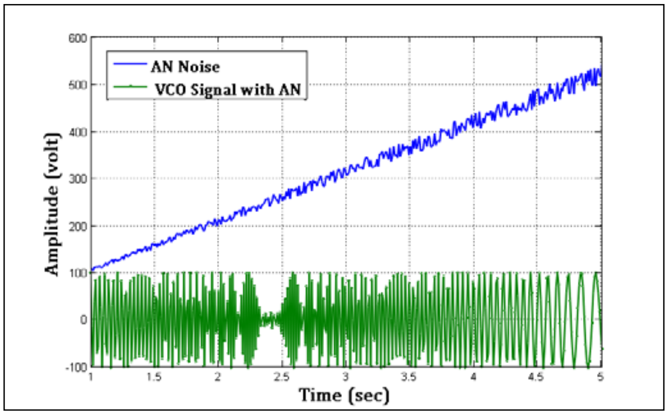

Fig. 8: VCO output with AN Noise at amplitude = 100

7. CONCLUSION

From the above study, we can conclude that the effect of noise on the performance of the VCO is small for lesser value of K_V. At the same time, we found that the frequency of the VCO signal increases with noise amplitude for a given value of $K_{V.}$

8. ACKNOWLEDGEMENTS

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