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Impact of γ - optimization parameters and phase margin on closed loop gain of phase-locked loop

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Abstract

The γ-optimization parameter is one of the key parameters for designing loop filters of phase-locked loop and optimal choice of γ depends on phase margin of the system. Here, we propose to study the impact of γ-optimization parameter and phase margin on closed loop gain of phase-locked loop for frequency synthesizer. A model has been developed and simulated, considering two different filter sections in the loop, namely: (i) the active lag-lead filter and (ii) the filter with standard feedback approach to study the impact. The simulation of the model is performed on MATLAB platform. In this paper, we will discuss in details about the derivation of the model and study of its stability in terms of γ-optimization parameter and phase margin considering both filter configuration in the loop.

Key words: Phase margin, γ-optimization parameter, frequency synthesizer, PLL bandwidth.

1. INTRODUCTION

The loop bandwidth (BW) and phase margin (PM) are two most important properties of phase-locked loop (PLL) transfer function (TF). There is a third property, called γ, which also needs to be specified in order to design the loop filter (LF) of PLL. This parameter is based on the concept of maximizing the PM at the loop BW. It quantifies the property of maximizing the PM at the loop BW. The value $\gamma = 1$ is a pretty good rule of thumb for minimizing the switching speed of the PLL for a given PM and loop

BW. By allowing γ values other than one, the lock time can be decreased in the order of 30% based on the value of PM. A γ value slightly greater than one, corresponds to maximum value of PM at a frequency less than the loop BW. On the other hand, a γ value of less than one corresponds to maximum value of PM at a frequency greater than the loop BW [1].

There are very few studies related to γ - optimization parameters in literature. In 2006, Dean Banerjee had defined γ-optimization parameters to design LF in an optimal way. He studied the relationship between γ-optimization parameters and PM. Besides, he studied the effects of this parameter on peaking and flatness of closed loop gain [2]. In the year 2007, Lin Jia, Kiat Seng Yeo Jian Guo Ma, Manh Anh Do, and Xiao Peng Yu studied the system stability based on the value of γ and PM and had drawn a conclusion that the stability limit for γ is different with different PM for the system [3].

In view of the importance of the subject, we propose to study the impact of γ-optimization parameter and PM on closed loop gain of PLL for frequency synthesizers. A model has been developed and simulated to study the feasibility of the work.

2. THE MODEL

The PLL is a feedback control system consisting of a phase frequency detector (PFD), a low pass LF, a voltage controlled oscillator (VCO) and a frequency divider (FD) network as shown in Fig.1.

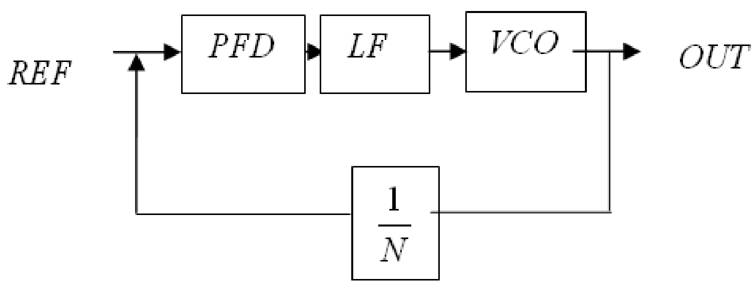


Fig. 1: Block diagram of a PLL

The closed loop TF of the system can be written as [4, 5]:

$$H(s) = \frac{K_d F(s) \frac{K_0}{s} A_d}{1 + \frac{A_d k_d F(s) K_0}{Ns}} \tag{1}$$

Where K_d = PFD gain in volts/radian; K_0/s = VCO gain in Hz/volt; N = Division ratio; A_d = Amplifier gain and F(s) = Loop filter TF.

The γ-optimization parameter can be defined in terms of loop BW and time constants of the LF of a PLL and may be derived as [1, 2]:

$$\gamma = \frac{1}{(2\pi BW)^2 T_1 T_2} \tag{2}$$

Where BW = Loop BW of the PLL; T_1, T_2 = Time constants of the LF used in PLL design.

The value of T_1 and T_2 depends on the type of LF used in the PLL. The circuit diagrams of active lag-lead filter (ALLF) and loop with standard feedback approach (SFA) for our proposed model are as shown in Fig.2.

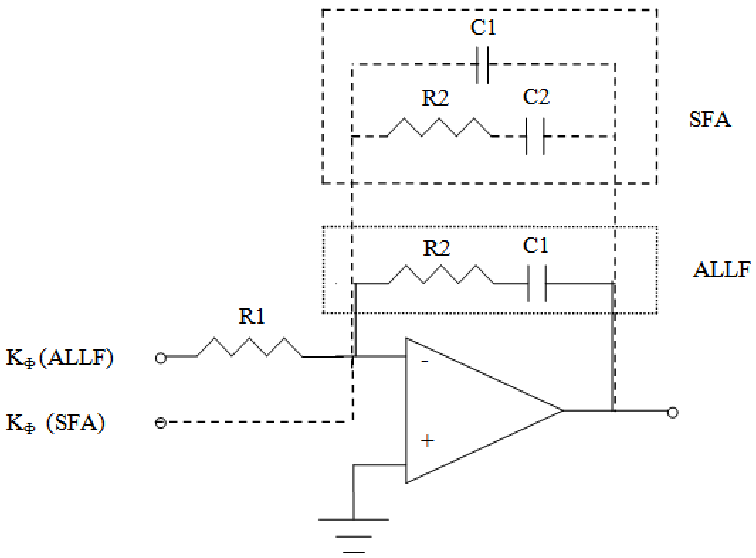


Fig. 2: Filter sections with ALLF (solid line) and SFA (dotted line)

Let us consider the loop with ALLF in Fig. 2. The TF of the system under this approach can be derived as:

$$F(s) = \frac{1 + sCR_2}{sCR_1} \tag{3}$$

Where $CR_1 = T_1$ and $CR_2 = T_2$

If we replace the filter section by considering SFA, which is also shown in Fig.2, the TF of the system can be derived as:

$$F(s) = \frac{1 + sT_2}{sA_0} \frac{A}{(1 + sT_1)} \tag{4}$$

Where the LF coefficients $A_0 = C_1 + C_2$, $T_1 = \dfrac{C_1 C_2 R_2}{C_1 + C_2}$ and $T_2 = C_2 R_2$

Thus, from equation (4) the TF for loop with SFA becomes,

$$F(s) = \frac{1 + sC_2R_2}{s^2 C_1 C_2 R_2 + s(C_1 + C_2)} \tag{5}$$

Putting the values of T_1 and T_2 for the loop with ALLF in equation (2) gives,

$$\gamma = \frac{1}{(2\pi BW)^2 CR_1 CR_2}$$

Similarly, putting the values of T_1 and T_2 for the loop using SFA into equation (2) and subsequently making little mathematical manipulation results,

$$\gamma = \frac{(C_1 + C_2)}{(2\pi BW)^2 C_1 (C_2 R_2)^2} \tag{6}$$

3. THE SIMULATON METHODS

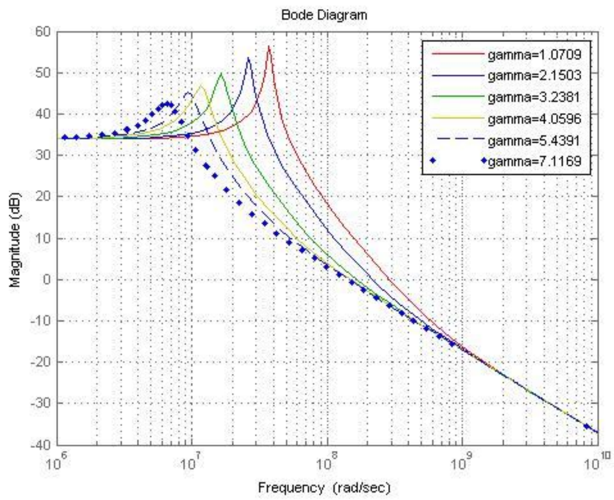
Considering the TF of the PLL model we simulate it to study the behavior of the model. Using Bode plot analysis the closed loop gain of the system is simulated for different values of γ-optimization parameter for analysis. The γ value is calculated in terms of system BW and time constants of the LF. The BW (-3dB) of the system is calculated from the Bode plot analysis by using “BANDWIDTH” function. It returns the BW of the SISO model T, defined as the first frequency where the gain drops below 70.79 percent (-3 dB) of its dc value. The frequency is expressed in radians per second. The algorithm of the program developed for simulating the PLL model is given below.

The Algorithm

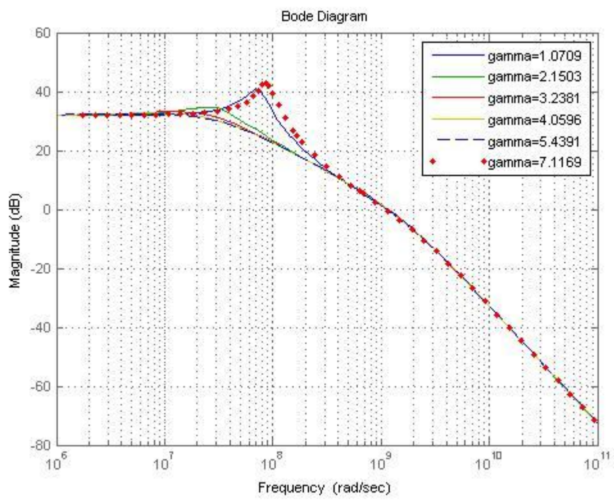
Steps	Instructions	Steps	Instructions
1	enter num, den	14	G= mineral (L*H5)
2	H= tf (num, den)	15	evaluate loop gain
3	evaluate H1	16	T= L/ (1+G)
4	repeat steps 1 & 2	17	evaluate the system transfer function
5	evaluate H2	18	BW = bandwidth (T)
6	repeat steps 1 & 2	19	evaluate the system bandwidth
7	evaluate H3	20	LT= 4/bw
8	repeat steps 1 & 2	21	evaluate the lock time
9	evaluate H4	22	T_1 = C*R_1 & T_2= C*R_2
10	repeat steps 1 & 2	23	evaluate loop filter time constants
11	evaluate H5	24	$\gamma = (2*\pi*BW)^2*T_1*T_2$
12	L=mineral (H1*H2*H3*H4)	25	evaluate the γ optimization parameter
13	evaluate forward loop gain L	26	end

4. SIMULATION RESULSTS & DISCUSSIONS

Fig.3 (a) show the responses of simulation for impact of γ - optimization parameter on closed loop gain for loop with ALLF for different test cases. It is observed that increasing γ slightly decreases peaking of the LF responses. However, increasing value of γ decreases the flatness. Fig.3 (b) show the responses of simulation for impact of γ-optimization parameter on closed loop gain for loop with SFA for different test cases. It is observed that higher peaks and less flatness occur on closed loop gain response for loop with ALLF as compared to the Loop with SFA.



(a) Impact of γ on closed loop gain using ALLF



(b) Impact of γ on closed loop gain using SFA

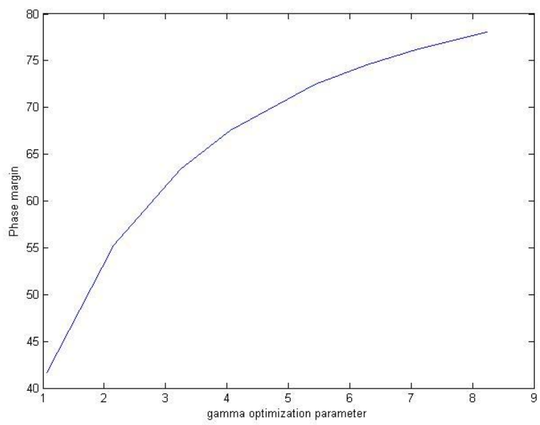
Fig 3: Impact of Gamma optimization factor on closed loop gain

The values of γ, PM and lock time observed from simulated responses for different test cases for loop with ALLF and SFA are given in Table 1.

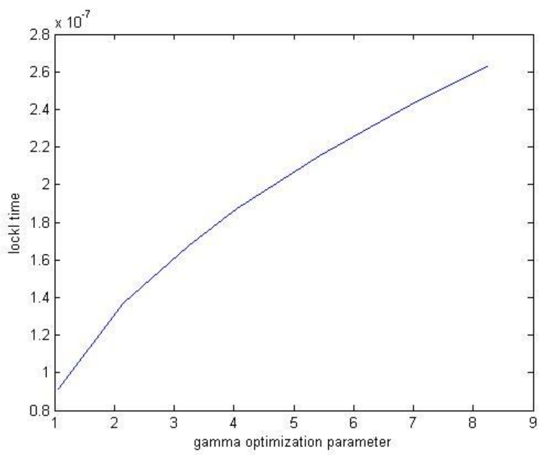
Table 1: Phase margin and lock time for different values of γ

Test cases	Values of γ	Phase margin (Degree)	Lock time (in μsec)
1	1.0709	41.7	0.091176
2	2.1503	55.3	0.13711
3	3.2381	63.4	0.16760
4	4.0596	67.6	0.18711
5	5.4391	72.5	0.21553
6	6.2793	74.6	0.23068
7	7.1169	76.3	0.24494
8	8.2415	78.1	0.26264

The observed data in Table 1 is plotted as shown in Fig. 4(a) and Fig. 4(b). From Fig. 4(a), it is observed that PM increases almost linearly with the value of γ. It is also observed from Fig. 4(b) that the lock time increases almost linearly with the value of γ.



(a) Phase margin versus γ- optimization parameter



(b) Lock time versus γ- optimization parameter

Fig.4: Simulation response for different value of γ, PM and Lock time

5. CONCLUSION

The impact of γ-optimization parameters and PM on closed loop gain of PLL has been presented here. From our simulation results, it is observed that increasing γ-optimization parameter slightly decreases peaking and the flatness of the LF responses of PLL. This phenomenon is more prominent in case of ALLF as observed from Fig. 3(a). In case of loop with SFA, as γ increases, the peaking increases, but the flatness almost remains the same throughout, which is obvious from the simulation responses of Fig. 3(b). So, we can conclude that for wide range of γ value we can achieved more system stability for loop with SFA then the loop with ALLF. The fastest lock time that we have achieved during our simulation experiment is 0.091176µsec with PM = 41.7 and γ =1.0709. Many LF design techniques assume a γ value as one, but from our investigations, it is obvious that there is further room for optimization. Since the lock time of the PLL system depends on the value of γ and PM, so it makes sense to choose the γ and PM value in such a way that lock time can be minimized [2].

These results will certainly provide PLL developers in research and industrial application to develop their own PLL, based on our results, with an indication of the performance tradeoffs associated with current technologies.

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