LMX2594 Minimum High Order Capacitor for VCO

Dean Banerjee 9/7/2018

Conclusion

In summary, if the magnitude of the loop filter impedance as seen looking out from the Vtune pin is greater than what a 10 nF capacitor would be for the offset of interest, then phase noise degradation is possible. A general rule of thumb that has been used is 3.3 nF, but this could still cost 1-2 dB degradation. This phase noise degradation can be observed in the 50 kHz to 20 MHz range, but is most severe around 1-2 MHz. This was observed for only one device and at a fixed frequency of 14 GHz and at room temperature.

For the LMX2594, the loop bandwidths tend to be wider because the PLL noise is so good. So if the VCO noise is suppressed or dominated by the PLL noise, then some degradation can be tolerated. That being said, there are limits. For instance, if one puts 120 pF next to the VCO and R3 is 1 kohm, this is 20 dB degradation at 1 MHz, so this is getting sort of hard to suppress.

Setup

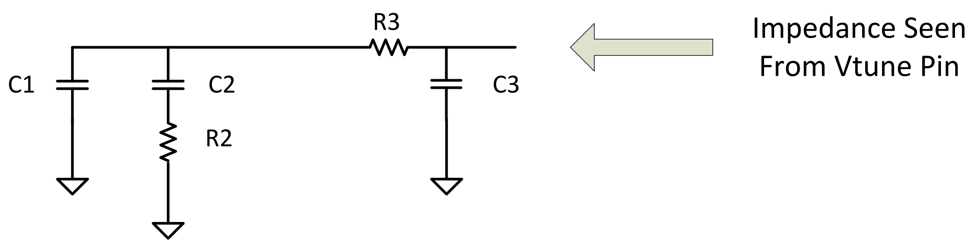
Parameter	Value	Unit
Fout	7000	MHz
Fvco	14000	MHz
Fpd	10	MHz
Kpd	3	mA
C1_LF	200	nF
C2_LF	10000	nF
R2_LF	68	ohm
R3_LF	Varies	ohm
R4_LF	0	ohm
C3 (C4_LF)	Varies	ohm

With the setup conditions above, the 2^{nd} order part of the loop filter has a very low impedance to ground so we can consider it an AC short. The R3 and C3 parameters were varied to understand the impact of the impedance looking out of the Vtune on the VCO phase noise.

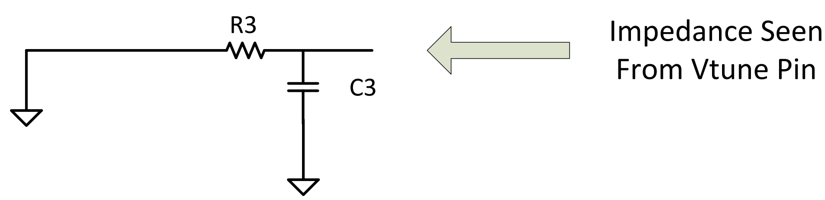
Note that C3_LF was left open all the time and the C4_LF footprint was used as this is closer to the VCO.

High Order Capacitor and Loop Filter Impedance

The high order capacitor is the capacitor closest to the Vtune Pin.



This is isolated by the R3_LF resistor. For THIS loop filter (not every loop filter), the rest of the loop filter is to ground, but because C1_LF=200 nF, which is very large, we can consider this to be an AC short and approximate this as follows:

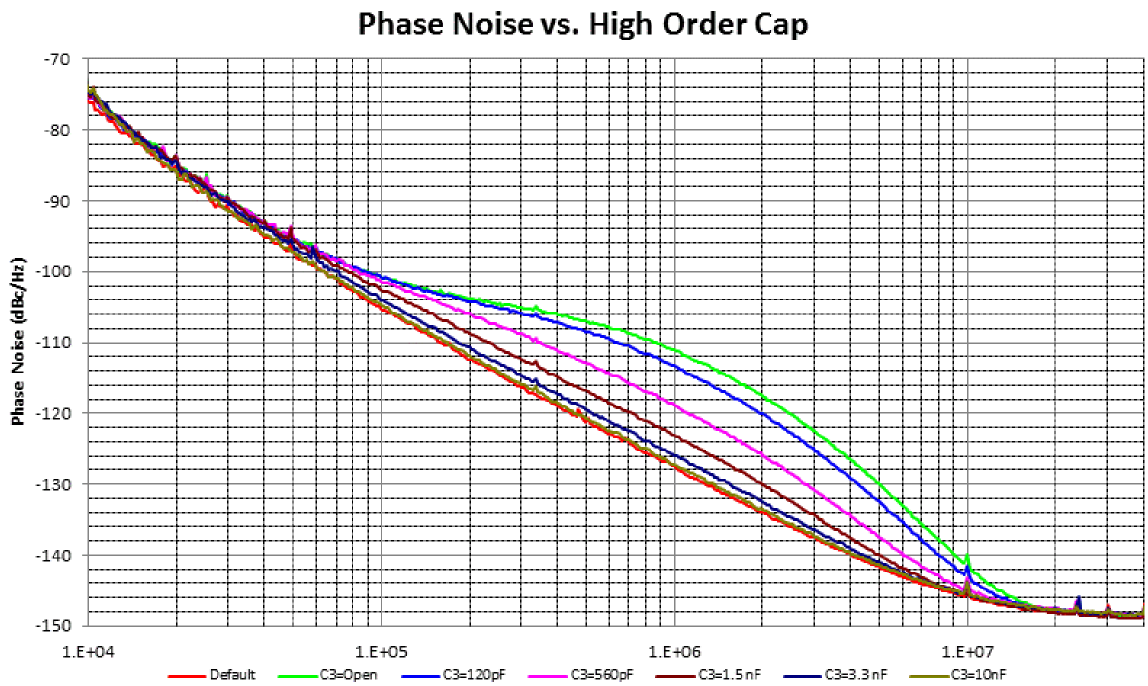


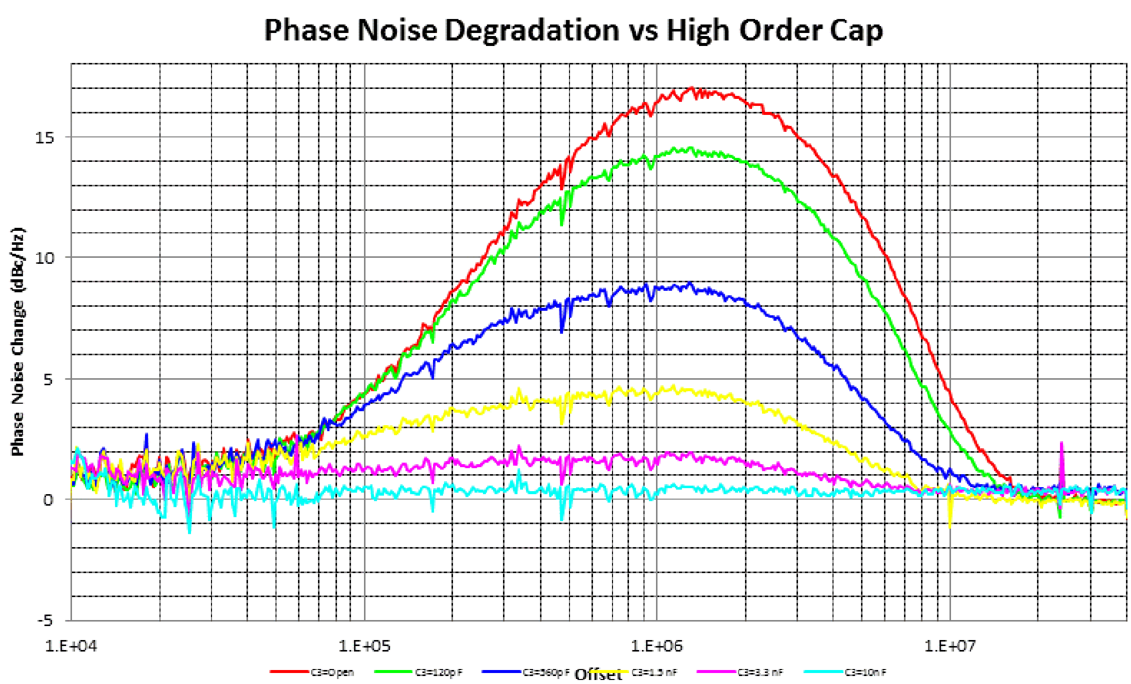
The impedance as seen from the Vtune pin can therefore be approximated as:

$$\|Z(s)\| = \left\|\frac{\mathrm{R3}}{1+s\cdot R3\cdot C3}\right\|$$

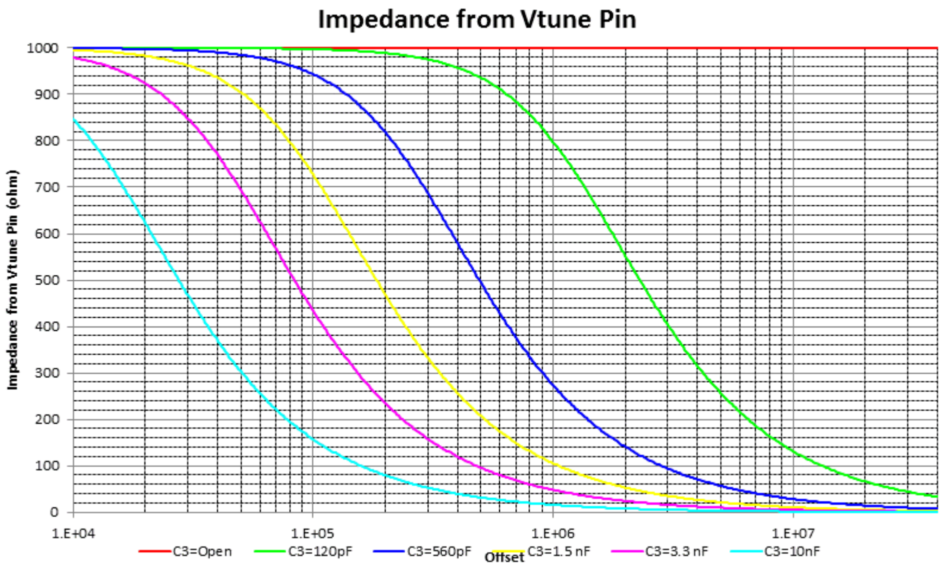
Impact of changing C3 when R3_LF was Fixed at 1 kohm

For this device, the Vtune pin cares about the impedance as seen looking out from the device. A simplified rule that the capacitor next to this pin should be 3.3 nF or greater to avoid VCO phase noise. A more conservative rule might be that the magnitude of the loop filter impedance in the 50 kHz to 20 MHz range should be less than it would be for a 10 nF capacitor to ensure the degradation is on the order of 0.5 dB or less.





Now this impedance can be calculated. The interesting region is from 20k – 20 MHz.

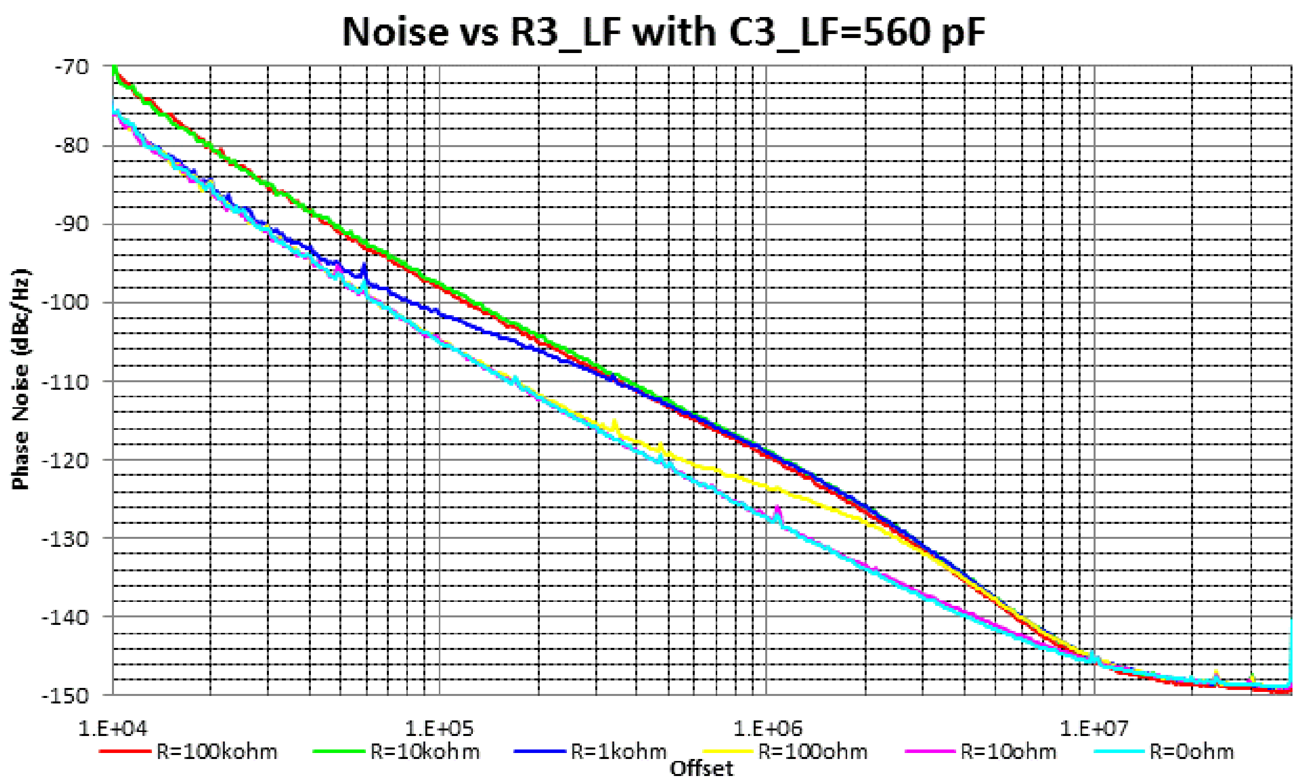


If we match the impedance graph with phase noise degradation, we can get an idea of what impedance is required to not have much degradation. It seems that the impedance requirement for phase noise changes, but the 3.3 nF gets you between 1-2 dB degradation and 10 nF gets you on the order of 0.5 dB degradation.

C3_LF	Open	120 pF	560 pF	1.5 nF	3.3 nF	10 nF
100 kHz Offset						
Impedance (ohm)	1000	997	943	728	434	157
Degradation (dB)	4.4	4.4	3.9	2.6	1.2	0.5
200 kHz Offset						
Impedance (ohm)	1000	989	817	468	234	79
Degradation (dB)	8.6	8.3	6.5	3.7	1.7	0.6
500 kHz Offset						
Impedance (ohm)	1000	936	495	208	96	32
Degradation (dB)	14.2	12.7	8.3	4.4	1.8	0.6
1 MHz Offset						
Impedance (ohm)	1000	798	273	106	48	16
Degradation (dB)	16.4	14.2	8.7	4.4	1.5	0.2
2 MHz Offset						
Impedance (ohm)	1000	558	143	54	24	8
Degradation (dB)	16.5	14.0	8.3	4.1	1.6	0.5
5 MHz Offset						
Impedance (ohm)	1000	257	57	21	10	3
Degradation (dB)	11.7	9.2	4.1	1.6	0.6	0.2
10 MHz Offset						
Impedance (ohm)	1000	131	28	11	5	2
Degradation (dB)	4.5	2.9	1.3	-1.2	0.6	0.6

Changing the R3_LF as a Sanity Check

As a crosscheck, C3_LF was held constant at 560 pF and then R3_LF was varied.



The above result makes sense. Note that for R=100 Kohm and 10 kohm, phase noise below 200 kHz is constant and worse than the others. This is because the impedance of 560 pF is lower and dominating. 560 pF at 10 kHz is 28 kHz. Now look at 200 kHz where 560 pF is 1.4 kohm. Here we see that R=1kohm is slightly better, but the R=10k and 100k are about the same because 1.4k is dominating. At 1 MHz, 560pF is 284 ohm. So you have to go down to 100 ohms for R3_LF for this do dominate the parallel combination.