Periodic steady state analysis of a switched capacitor filter

For some circuits, such as switched capacitor circuits or oscillators, it is not possible to run the normal simulations (ac, stb etc) due to these simulations starting from dc operating point which in a periodic, switching system has little relevance. It is possible, however, (if the circuit is periodic) to run a pss analysis to establish a periodic operating point, followed by a “pac”, “pstb” etc. All the “p” simulations are for periodic analyses and all require the pss simulation to run first. The pss simulation basically runs a transient simulation until the circuit achieves a periodic steady state, ie for every period all the voltages and currents in the circuit follow the same paths. Then, from this periodic steady state, other simulations can be run.

For this example, the “pss” and “pac” analyses will be used to get the frequency response of a simple low pass filter. I will also cover some of the basics of switched cap circuits.

The specification of this filter will be as follows:

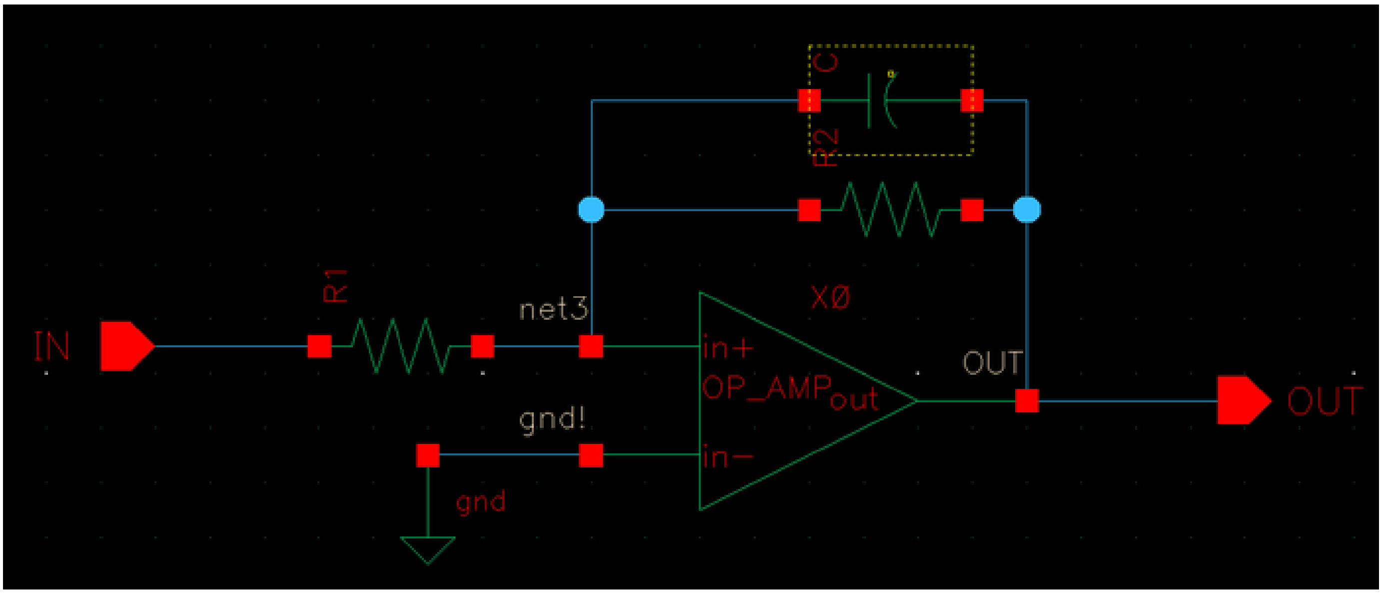
Gain = 0dB

-3dB frequency of 1kHz

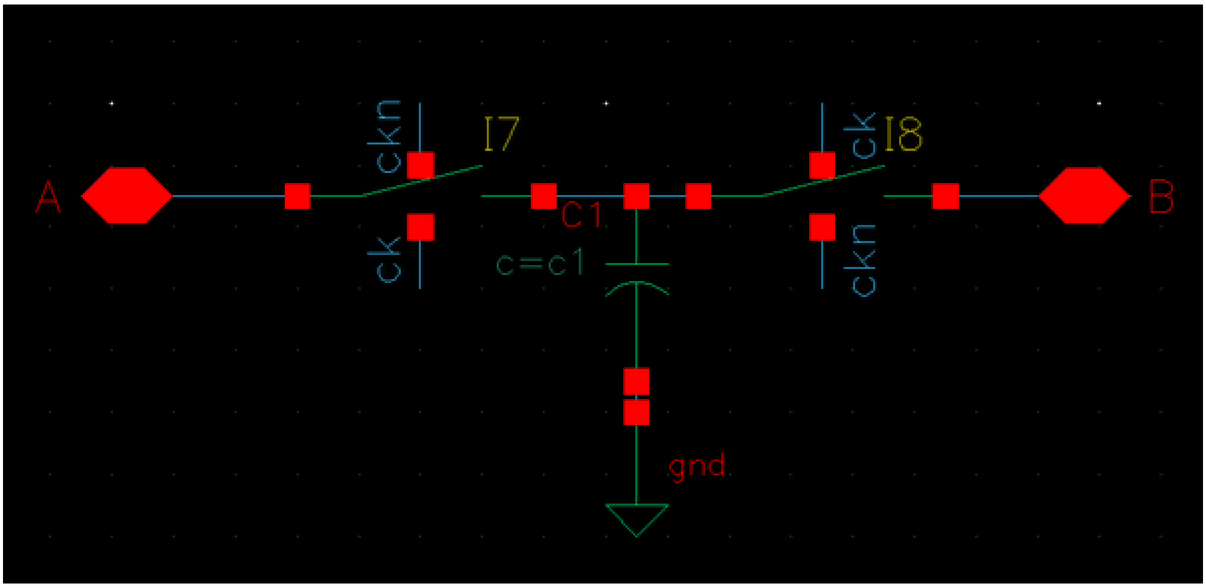
Roll off of 20dB/decade

Circuit design

200

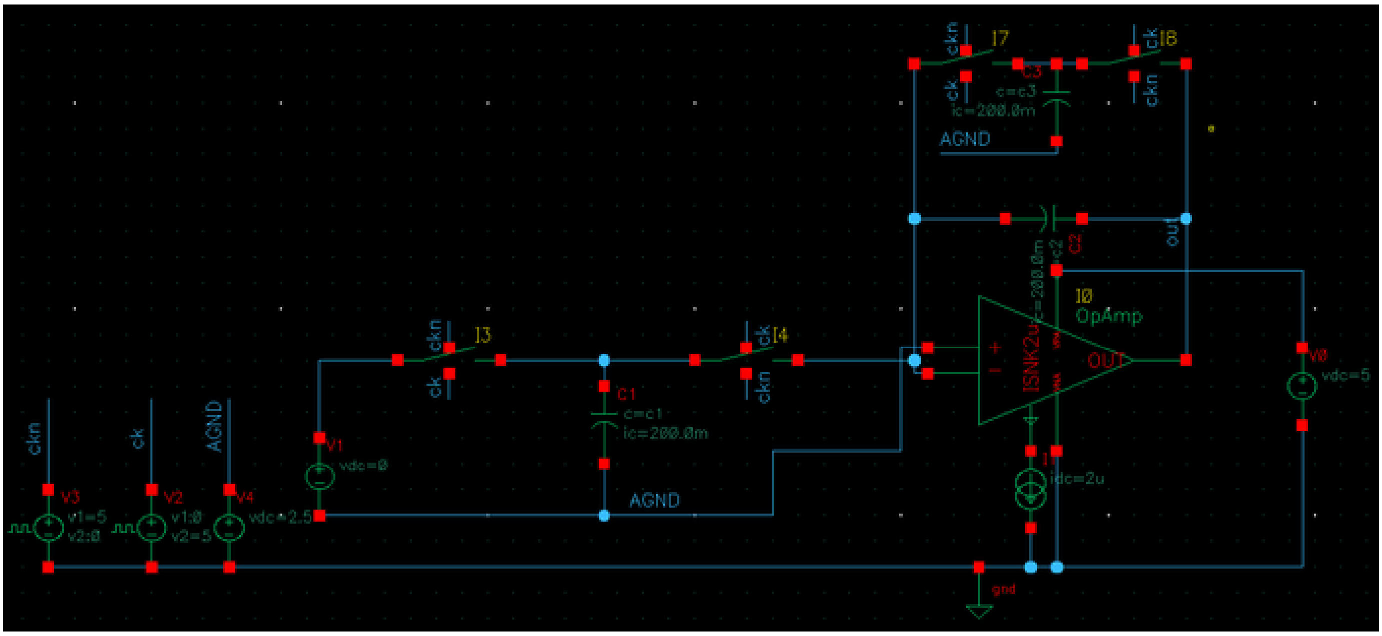


Above is shown a simple low pass filter. Its gain is R2/R1, so for 0dB gain, R2=R1. The -3dB frequency is 1/(2πR2C). Each resistor can be replaced with a switched capacitor like below.



Because the capacitor transfers a fixed charge on each clock cycle, it is effectively a lossless resistor with a resistance of 1/(Cf) where f is the switching frequency.

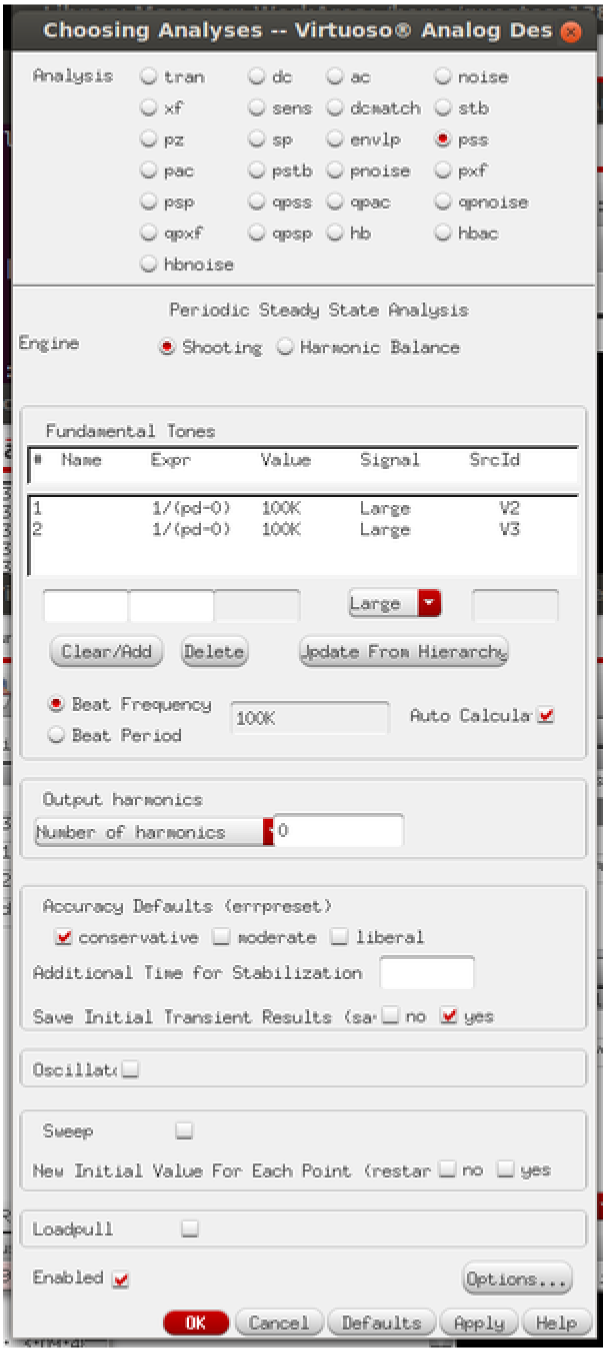
The filter then becomes the circuit shown below, where gain is c1/c3 and -3dB point is (c3*f)/(2π*c2)



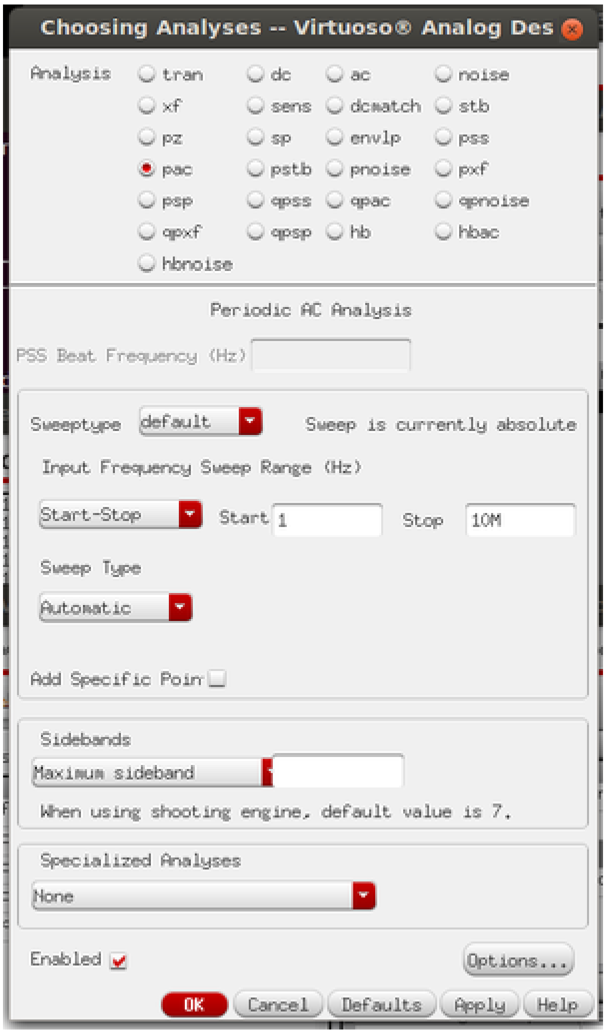
Setting c1=c3=1pF, f=100kHz (nb switching frequency needs to be considerably larger than the cut off frequency, say 10X or more) and c2=16pF should give the required filter.

Simulation

As stated before, the normal “ac” analysis will not work on this circuit, therefore a “pss” and “pac” simulations need to be run to determine the frequency response. The input source (V1) needs to have a PAC magnitude of 1 to set it as a PAC source, it also needs to be a DC source. The two Vpulse signals for ck and ckn are equal and opposite with a frequency of 100kHz.

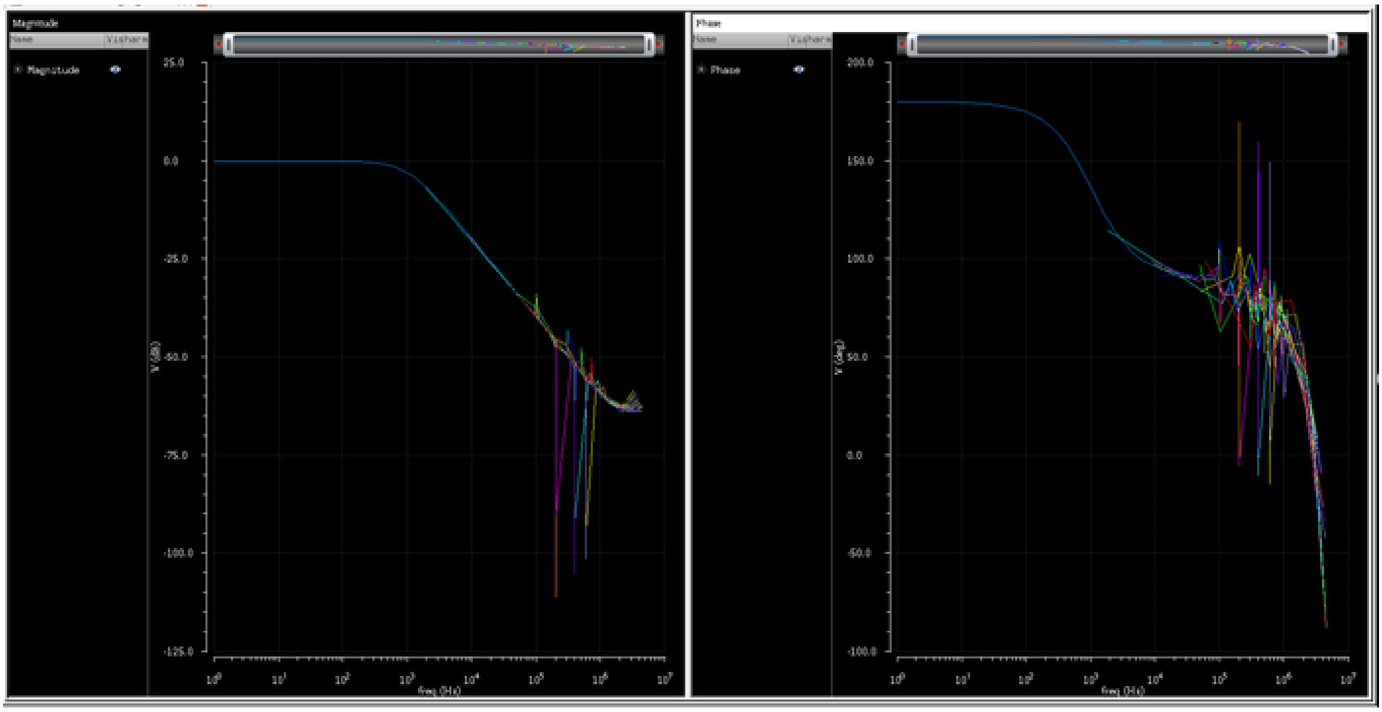


Above is shown how the PSS analysis should be set up. It automatically lists the periodic signals in the circuit under “Fundamental Tones”. In most cases it is ok to use the auto calculate for the beat frequency, which automatically takes the maximum frequency from the fundamental tones. In some cases, it might be necessary to set a beat frequency much higher than any of the fundamental tones as all fundamental tones need to be integer multiples of the beat frequency. It is also useful to save the initial transient start up results, as these are often useful for debugging. 200



The PAC analysis is set up as for the AC analysis, as shown above. To set up the outputs, I used the calculator to create these expressions: Magnitude: db20(v(”/out” ?result “pac”)) Phase: phase(v(”/out” ?result “pac”)) -3dB point: cross(db20(v(”/out” ?result “pac”)) -3 1 “either” nil nil)

My reults are as follows:



-3dB point is 978Hz, which is close to 1kHz, reducing C2 to 15.6pF brings the -3dB frequency to 1.001kHz. The discrepancy from calculation is probably due to non-ideal switches and parasitics.