A 5^{th} Order Butterworth Low-Pass Filter with TL081

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Date : December 24 2017 - April 24 2018 (updated)

Objective:

The objective of this project is to investigate behaviour of a 5^{th} order Butterworth low-pass filter with TL081 operational amplifier (op-amp) using Texas Instrument's *Filter Pro* software.

Filter Specifications:

- Cut-off frequency (f_C) : 10 kHz
- DC Gain : 100 (V/V)
- Filter Type : 5th Order,Butterworth,MFB,Single-ended

Filter Design:

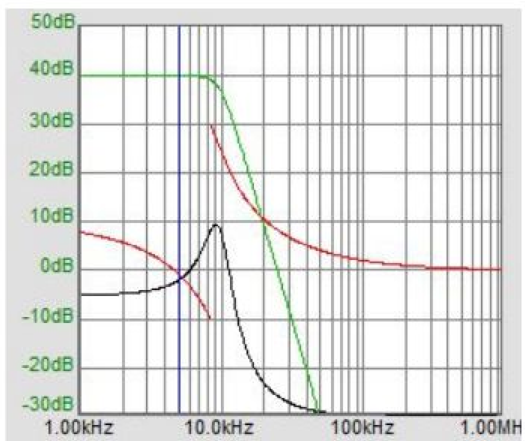

Figure 1 : Bode plot from Filter Pro

Note : The green line shows the response of the LPF.

	(Vout/Vin)	F	Q	Gain	Phase*	GBP
Real	1.0	10.000kHz		-3.05 dB	-45.2°	500kHz
A	10.0	10.000kHz	618.03m	15.89 dB	-89.7°	6.18MHz
B	10.0	10.000kHz	1.6180	24.08 dB	-90.5°	16.2MHz
	100.0	Totals	1.0000	36.91 dB	-225.4°	

Figure 2: Filter specs from Filter Pro

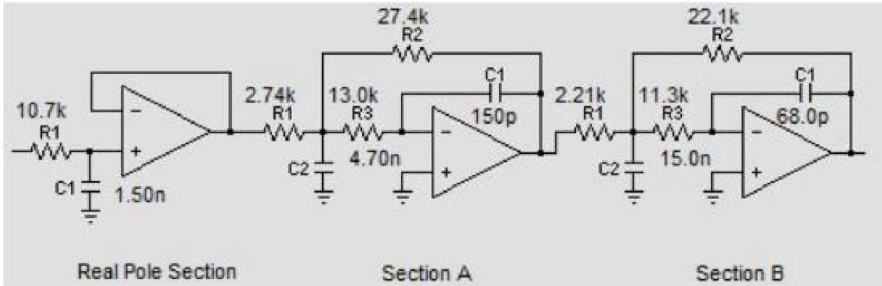

Figure 3 : Filter schematic from Filter Pro

Circuit Schematic in Pspice:

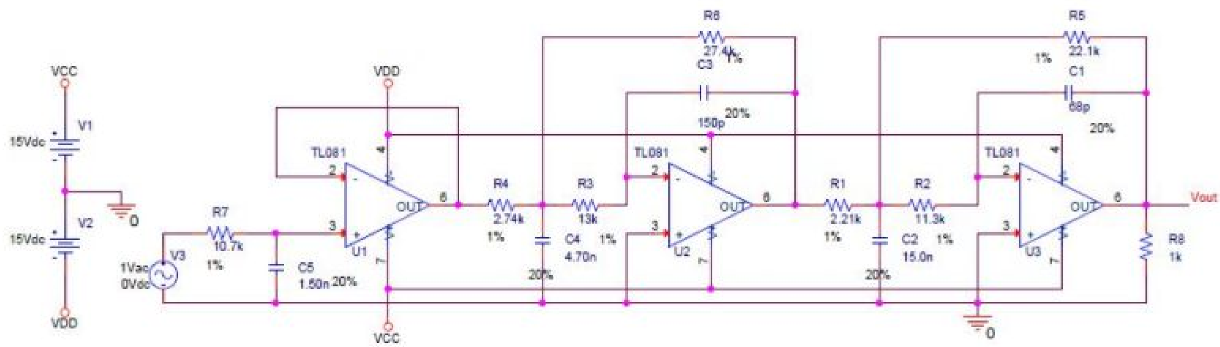

Figure 4 : 3rd order LPF on Pspice

Bode Plot in Pspice:

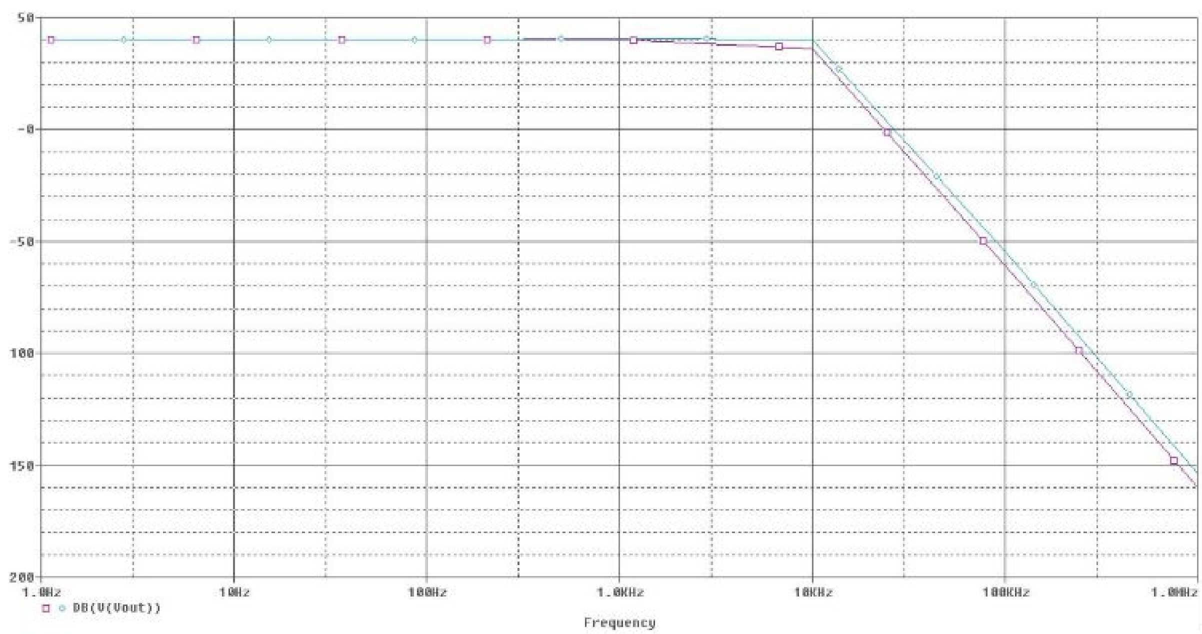

Figure 5: Bode Plot of the LPF on PSpice

Note : Blue trace shows the worst-case analysis (components with tolerance) of the LPF.The red trace shows the expected response of the LPF.

	Trace Color	Trace Name	Y1	Y2	Y1 - Y2
		X Values	10.000K	74.877	9.925K
	CURSOR 1,2	DB(V(Vout))	36.242	39.999	-3.7567
		DB(V(Vout))	39.941	40.346	-405.448m

Figure 6: Bode Plot data in Pspice

Conclusion:

A 5th order LPF with TL081 was designed in this project.In order to approximate the filter response and initialize the filter design,Texas Instruments Filter Pro software was used.The Bode diagram of the LPF can be seen in Figure 1.Below the cut-off frequency,10 kHz,since DC gain is chosen as 100 V/V (40dB),the filter gain is 40 dB.At the cut-off frequency,10 kHz,the filter gain is expected to be at the -3dB point which is about 37 dB numerically where there is no component tolerance.Let's look at the case when there's component tolerance,1% for resistors and 20% for the capacitors in the circuit.Below the cut-off frequency,the filter gain is 40.346 dB as shown in Figure 6 (red trace color indicates the bode plot with filter tolerance,the red one indicates the one without component tolerance).At 10 kHz,the gain when there's component tolerance is measured 39.941 dB.This is not theoretically acceptable because at the cut-off frequency the gain isn't -3dB below the highest DC gain.In practice,the higher LPF order gets,filter may be starting to decrease even below the cut-off frequency.The gain difference between the two cases due to the simulation and component tolerance as well as the op-amp TL081.The theoretical bode diagram with green trace is what's expected from the circuit.Beyond the cut-off frequency,when there is component tolerance added,the gain from 10 kHz to 100 kHz (1 decade) decreases 14.184dB.Similarly,when the theoretical Bode plot is examined,it can be seen that the there is 24.457 dB attenuation per decade.What can be done in this case to fix the filter characteristics difference between the Filter pro,and the design on Pspice with TL081,is of course using another op-amp with different specifications and re-designing the filter.

References:

[1] “TL081 op-amp datasheet.” [Online]. Available: http://www.ti.com/lit/ds/symlink/tl082.pdf.
[2] *Texas Instruments - Filter Pro*. [Online]. Available: http://www.ti.com/tool/filterpro&DCMP=hpa_amp_general&HQS=NotApplicable OT filterpro.