Practice 4 - Bandpass filters detailed instructions

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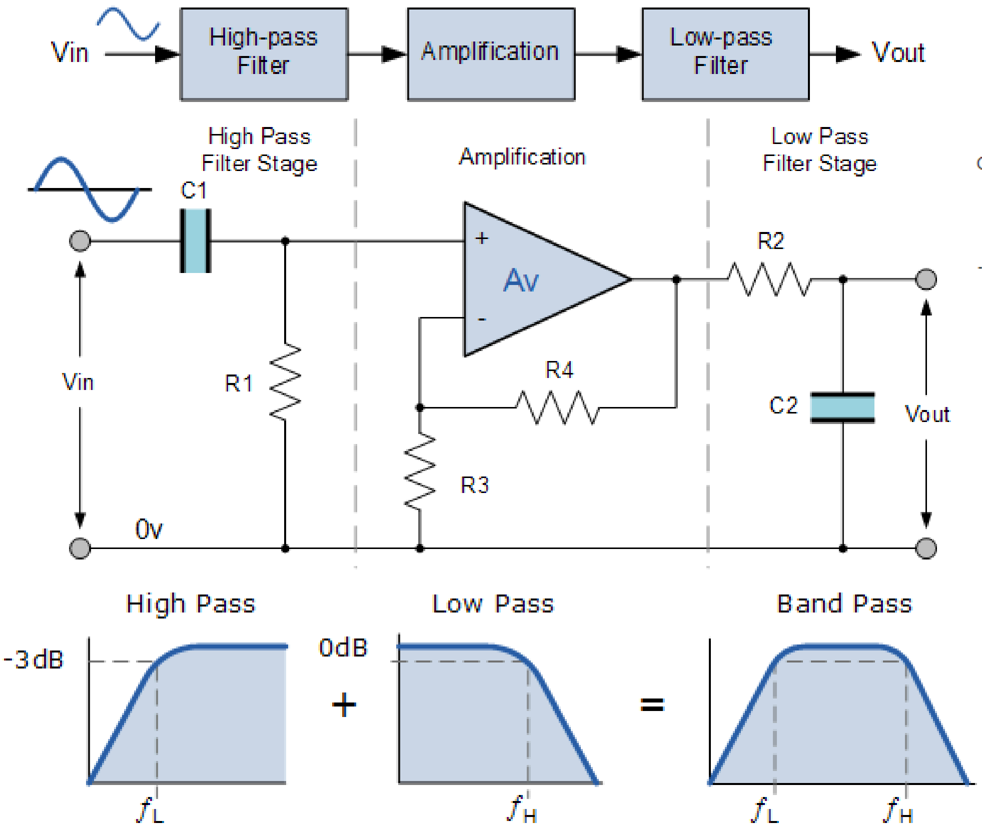
Practice 4

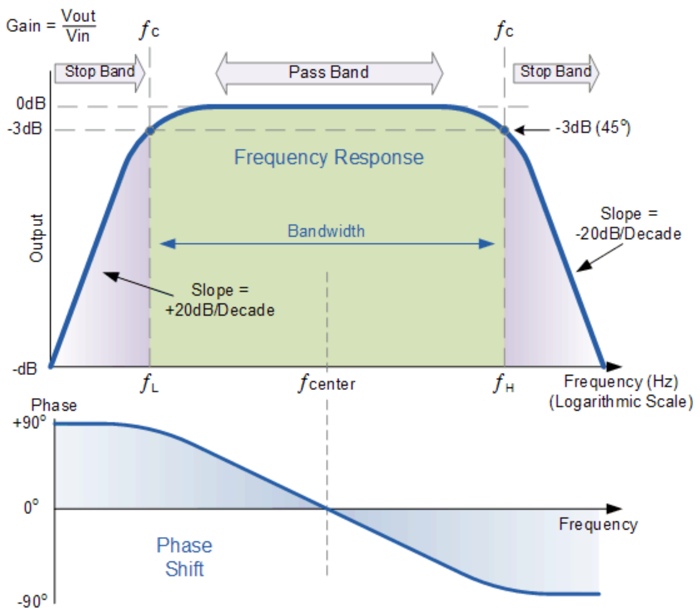
https://forms.yandex.com/cloud/637a6d72eb614687d53f9b86/

https://clck.ru/32jqdb

1st deadline: 02.12.2022 23:59 (GMT +8)

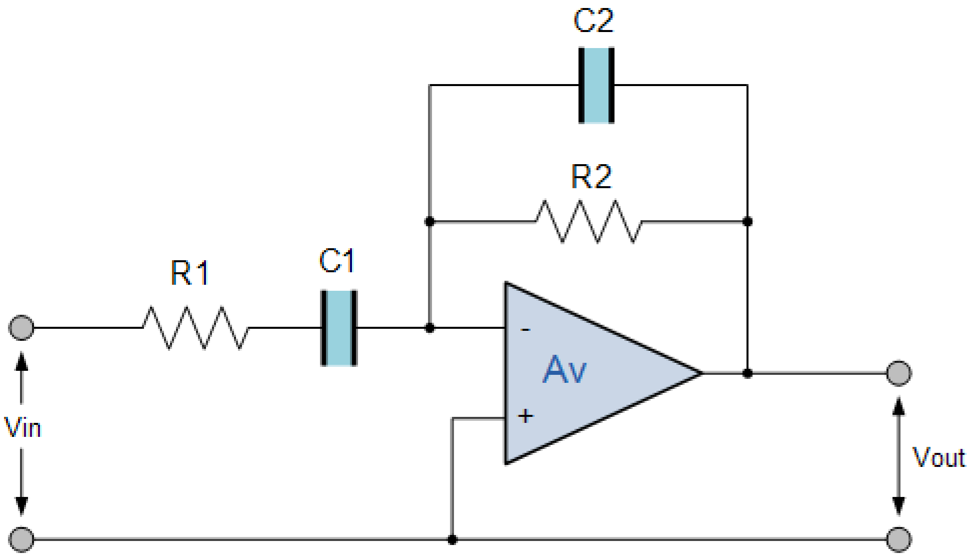
Active Band Pass Filter





Active Band Pass Filter

Inverting Band Pass Filter Circuit

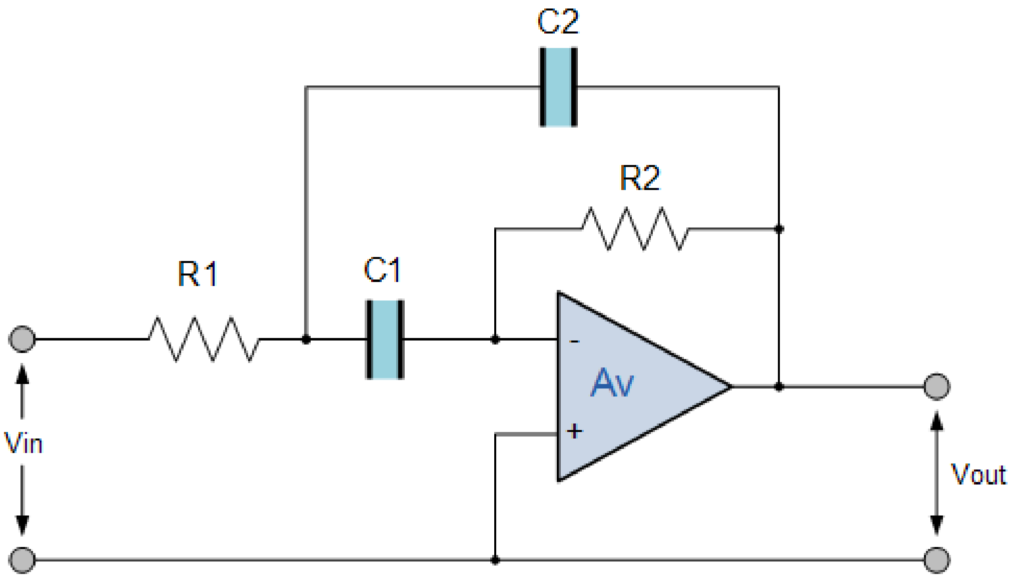


$$f_{C1} = \frac{1}{2\pi R_1 C_1}$$

$$f_{C2} = \frac{1}{2\pi R_2 C_2}$$

Active Band Pass Filter

Multiple Feedback Band Pass Active Filter



infinite-gain multiple-feedback (IGMF) band pass filter

the characteristics of the IGMF filter

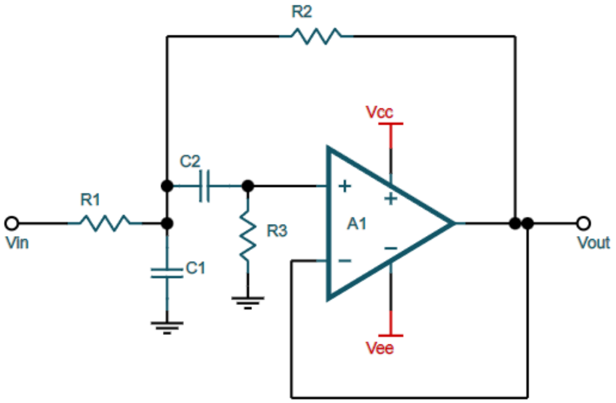
$$f_r = \frac{1}{2\pi\sqrt{R_1 C_1 R_2 C_2}}$$

$$Q = \frac{f_r}{BW_{-3dB}} = \frac{1}{2}\sqrt{\frac{R_2}{R_1}}$$

$$Max\ gain \sim -\frac{R_2}{2R_1} = 2Q^2$$

Active Band Pass Filter

Sallen-Key



the characteristics of the IGMF filter

$$\frac{U_{out}(p)}{U_{in}(p)} = \frac{KRC\omega_0 p}{R^2 C^2 \omega_0^{\,2} p^2 + RC(3-K)\omega_0 p + 1}$$

$$Max\ gain \sim K = 1 + \frac{R_2}{R_3}$$

$$C_1 = C_2 = C$$

$$R_1 = R_2 = \frac{1}{2} R_3$$

Middle frequency of bandpass: $\omega_0 = \frac{1}{RC}$

Bandwidth: $B = \omega_0(3-K)$

Frequency Transformation

Type of Transformation	Frequency transform
The Lowpass to Highpass (LP-HP) Frequency Transformation	$s \Leftrightarrow \frac{1}{s}$ $H_{HP}(s) = H_{LP}\left(\frac{1}{s}\right)$
The Lowpass to Bandpass (LP-BP) Frequency Transformation	$s \Leftrightarrow \frac{s^2 + \omega_0^2}{sBW}$ $H_{BP}(s) = H_{LP}\left(\frac{s^2 + \omega_0^2}{sBW}\right)$
The Lowpass to Band-Reject (LP-BR) Frequency Transformation	$s \Leftrightarrow \frac{sBW}{s^2 + \omega_0^2}$ $H_{BR}(s) = H_{LP}\left(\frac{sBW}{s^2 + \omega_0^2}\right)$

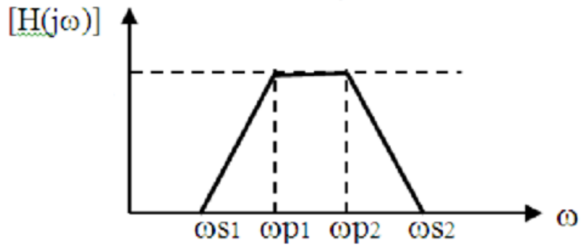
Typical values of Bandpass filter parameters

$$H_{BP2}(p) = \frac{K\frac{\omega_0}{Q}p}{p^2 + \frac{\omega_0}{Q}p + \omega_0^2} = \frac{K}{1 + Q(\frac{p}{\omega_0} + \frac{\omega_0}{p})}$$

$$\omega_0 = \sqrt{\omega_{P1}\omega_{P2}}$$

$$Q = \omega_0 / B$$

$$B = \omega_{p2} - \omega_{p1}$$



Butterworth

n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,4142	1,0000	1,000	0,71
3	1	1,0000	0,0000	1,000	–
	2	1,0000	1,0000	1,272	1,00
4	1	1,8478	1,0000	0,719	0,54
	2	0,7654	1,0000	1,390	1,31
5	1	1,0000	0,0000	1,000	–
	2	1,6180	1,0000	0,859	0,62
	3	0,6180	1,0000	1,448	1,62
6	1	1,9319	1,0000	0,676	0,52
	2	1,4142	1,0000	1,000	0,71
	3	0,5176	1,0000	1,479	1,93
7	1	1,0000	0,0000	1,000	–
	2	1,8019	1,0000	0,745	0,55
	3	1,2470	1,0000	1,117	0,80
	4	0,4450	1,0000	1,499	2,25
8	1	1,9616	1,0000	0,661	0,51
	2	1,6629	1,0000	0,829	0,60
	3	1,1111	1,0000	1,206	0,90
	4	0,3902	1,0000	1,512	2,56
9	1	1,0000	0,0000	1,000	–
	2	1,8794	1,0000	0,703	0,53
	3	1,5321	1,0000	0,917	0,65
	4	1,0000	1,0000	1,272	1,00
	5	0,3473	1,0000	1,521	2,88
10	1	1,9754	1,0000	0,655	0,51
	2	1,7820	1,0000	0,756	0,56
	3	1,4142	1,0000	1,000	0,71
	4	0,9080	1,0000	1,322	1,10
	5	0,3129	1,0000	1,527	3,20

Chebyshev

n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,0650	1,9305	1,000	1,30
3	1	3,3496	0,0000	0,299	–
	2	0,3559	1,1923	1,396	3,07
4	1	2,1853	5,5339	0,557	1,08
	2	0,1964	1,2009	1,410	5,58
5	1	5,6334	0,0000	0,178	–
	2	0,7620	2,6530	0,917	2,14
	3	0,1172	1,0686	1,500	8,82
6	1	3,2721	11,6773	0,379	1,04
	2	0,4077	1,9873	1,086	3,46
	3	0,0815	1,0861	1,489	12,78
7	1	7,9064	0,0000	0,126	–
	2	1,1159	4,8963	0,670	1,98
	3	0,2515	1,5944	1,222	5,02
	4	0,0582	1,0348	1,527	17,46
8	1	4,3583	20,2948	0,286	1,03
	2	0,5791	3,1808	0,855	3,08
	3	0,1765	1,4507	1,285	6,83
	4	0,0448	1,0478	1,517	22,87
9	1	10,1759	0,0000	0,098	–
	2	1,4585	7,8971	0,526	1,93
	3	0,3561	2,3651	1,001	4,32
	4	0,1294	1,3165	1,351	8,87
	5	0,0348	1,0210	1,537	29,00
10	1	5,4449	31,3788	0,230	1,03
	2	0,7414	4,7363	0,699	2,94
	3	0,2479	1,9952	1,094	5,70
	4	0,1008	1,2638	1,380	11,15
	5	0,0283	1,0304	1,530	35,85

Bessel

n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,3617	0,6180	1,000	0,58
3	1	0,7560	0,0000	1,323	–
	2	0,9996	0,4772	1,414	0,69
4	1	1,3397	0,4889	0,978	0,52
	2	0,7743	0,3890	1,797	0,81
5	1	0,6656	0,0000	1,502	–
	2	1,1402	0,4128	1,184	0,56
	3	0,6216	0,3245	2,138	0,92
6	1	1,2217	0,3887	1,063	0,51
	2	0,9686	0,3505	1,431	0,61
	3	0,5131	0,2756	2,447	1,02
7	1	0,5937	0,0000	1,684	–
	2	1,0944	0,3395	1,207	0,53
	3	0,8304	0,3011	1,695	0,66
	4	0,4332	0,2381	2,731	1,13
8	1	1,1112	0,3162	1,164	0,51
	2	0,9754	0,2979	1,381	0,56
	3	0,7202	0,2621	1,963	0,71
	4	0,3728	0,2087	2,992	1,23
9	1	0,5386	0,0000	1,857	–
	2	1,0244	0,2834	1,277	0,52
	3	0,8710	0,2636	1,574	0,59
	4	0,6320	0,2311	2,226	0,76
	5	0,3257	0,1854	3,237	1,32
10	1	1,0215	0,2650	1,264	0,50
	2	0,9393	0,2549	1,412	0,54
	3	0,7815	0,2351	1,780	0,62
	4	0,5604	0,2059	2,479	0,81
	5	0,2883	0,1665	3,466	1,42

Stage 1

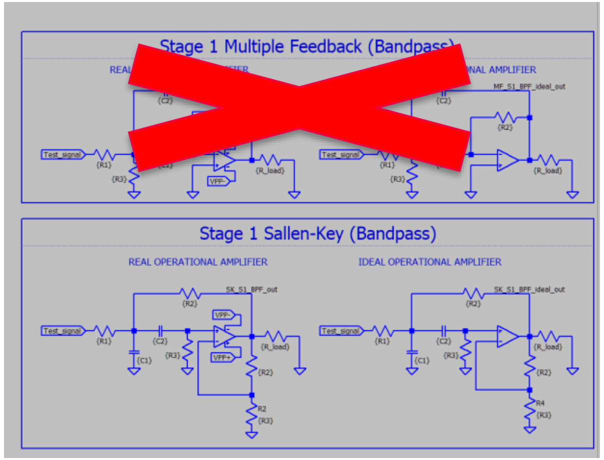
Model templates:

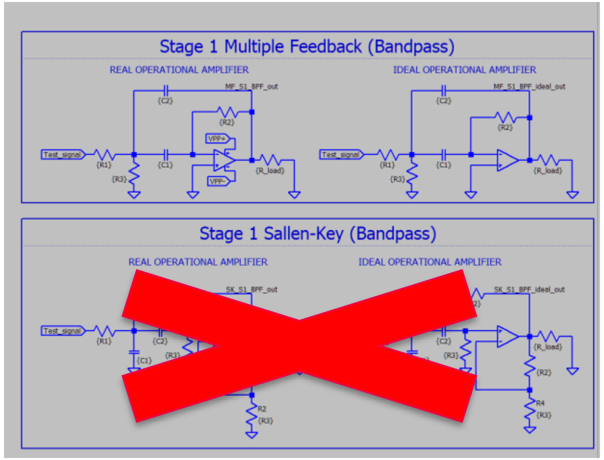
2021.11.02 - Practice - Bandpass filters.asc

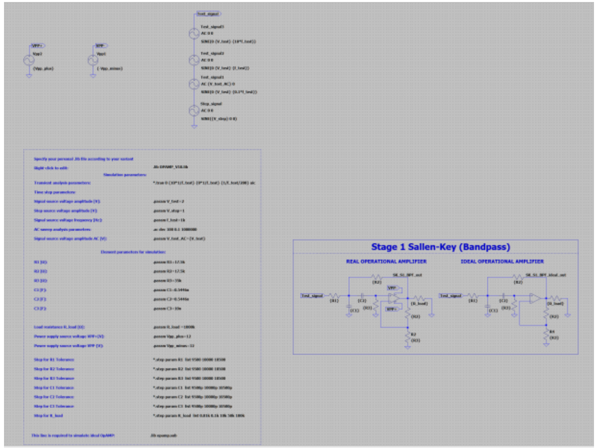
2021.11.02 - Practice - Bandpass filters.plt

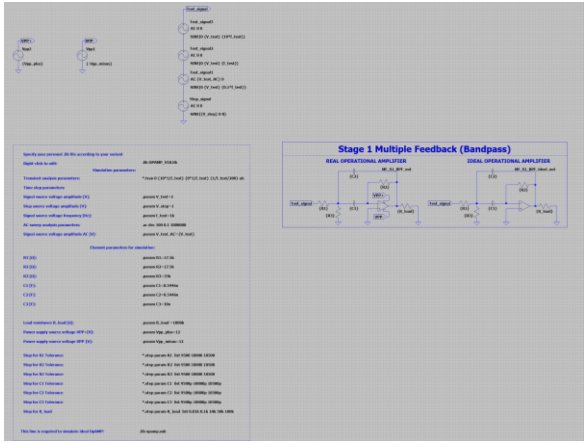
OPAMP_VXX.lib

Stage 2 -Delete all the schemes which doesn't correspond to your variant data





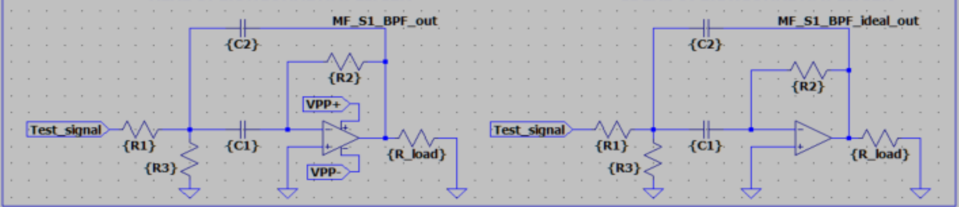




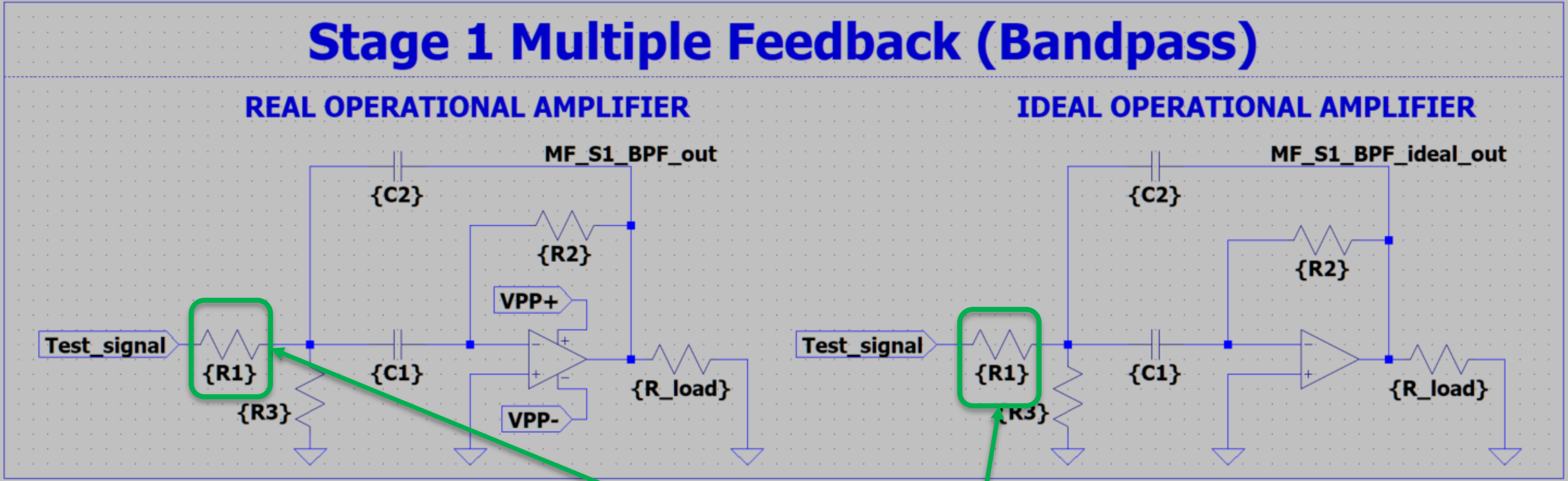
Stage 3 -Save a screenshot of your LTSPICE schematic

Specify your personal .lib file according to your variant	
Right-click to edit:	.lib OPAMP_V10.lib
Simulation parameters:	
Transient analysis parameters:	*.tran 0 {10*1/f_test} {0*1/f_test} {1/f_test/200} uic
Time step parameters:	
Signal source voltage amplitude [V]:	.param V_test=1
Step source voltage amplitude [V]:	.param V_step=0
Signal source voltage frequency [Hz]:	.param f_test=1k
AC sweep analysis parameters:	.ac dec 100 0.1 1000000
Signal source voltage amplitude AC [V]:	.param V_test_AC={V_test}
Element parameters for simulation:	
R1 [Ω]:	.param R1=10k
R2 [Ω]:	.param R2=50k
R3 [Ω]:	.param R3=10k
C1 [F]:	.param C1=10n
C2 [F]:	.param C2=10n
C3 [F]:	.param C3=10n
Load resistance R_load [Ω]:	.param R_load =1000k
Power supply source voltage VPP+[V]:	.param Vpp_plus=12
Power supply source voltage VPP-[V]:	.param Vpp_minus=12
Step for R1 Tolerance	*.step param R1 list 9500 10000 10500
Step for R2 Tolerance	*.step param R2 list 9500 10000 10500
Step for R3 Tolerance	*.step param R3 list 9500 10000 10500
Step for C1 Tolerance	.step param C1 list 9500p 10000p 10500p
Step for C2 Tolerance	.step param C2 list 9500p 10000p 10500p
Step for C3 Tolerance	.step param C3 list 9500p 10000p 10500p
Step for R_load	*.step param R_load list 0.01k 0.1k 10k 50k 100k
This line is required to simulate ideal OpAMP:	.lib opamp.sub

Stage 1 Multiple Feedback (Bandpass)



Stage 3 -Define R1 value in your model

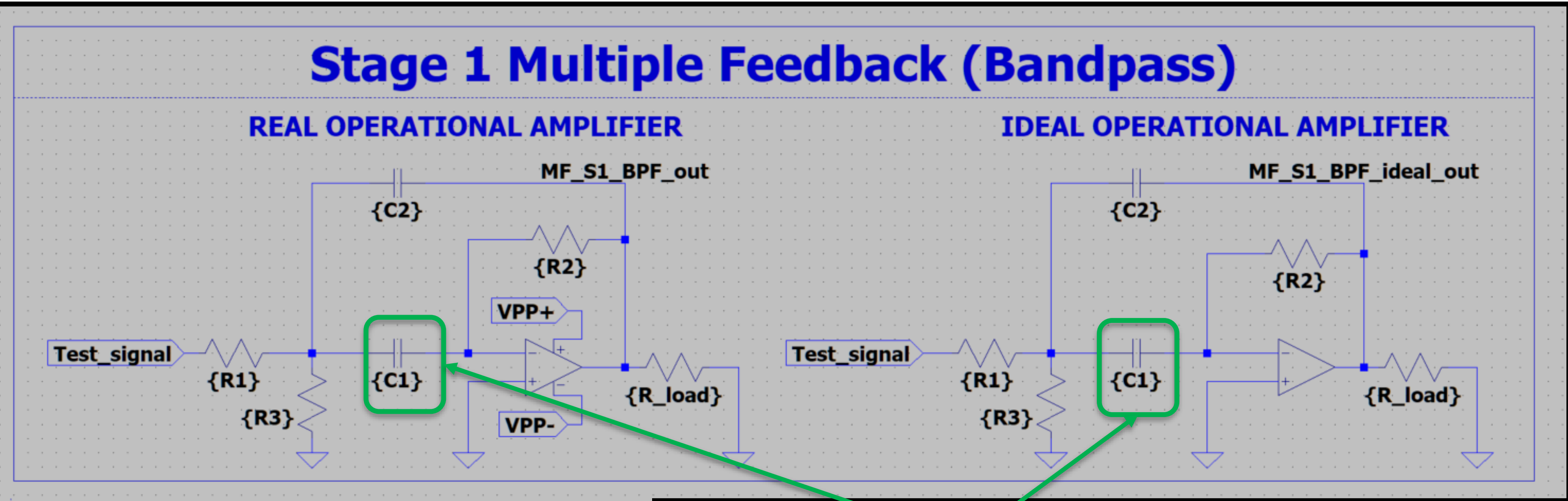


Element parameters for simulation:

R1 [Ω]:	.param R1=
R2 [Ω]:	.param R2=
R3 [Ω]:	.param R3=
C1 [F]:	.param C1=
C2 [F]:	.param C2=
C3 [F]:	.param C3=

R_1

You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant

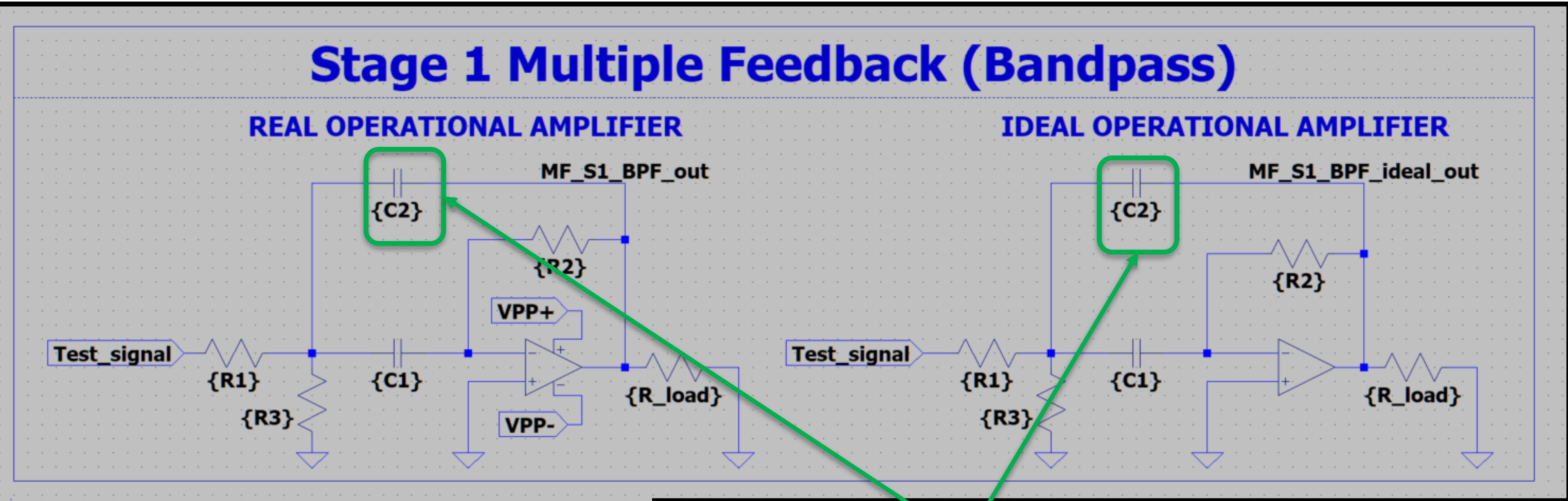


Element parameters for simulation:

R1 [Ω]:	.param R1=
R2 [Ω]:	.param R2=
R3 [Ω]:	.param R3=
C1 [F]:	.param C1=
C2 [F]:	.param C2=
C3 [F]:	.param C3=

C_1

You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant



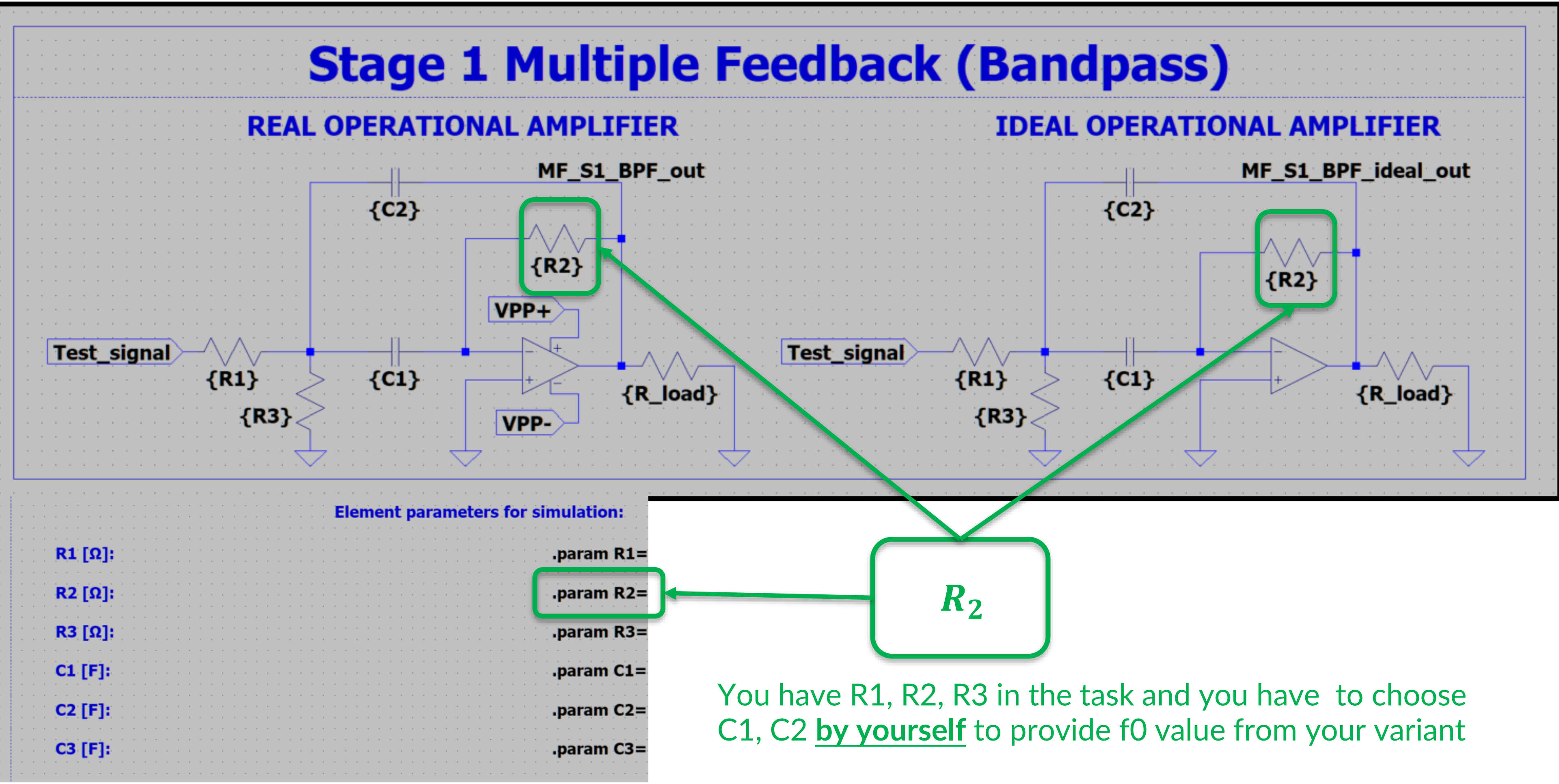
Element parameters for simulation:

R1 [Ω]:	.param R1=
R2 [Ω]:	.param R2=
R3 [Ω]:	.param R3=
C1 [F]:	.param C1=
C2 [F]:	.param C2=
C3 [F]:	.param C3=

C_2

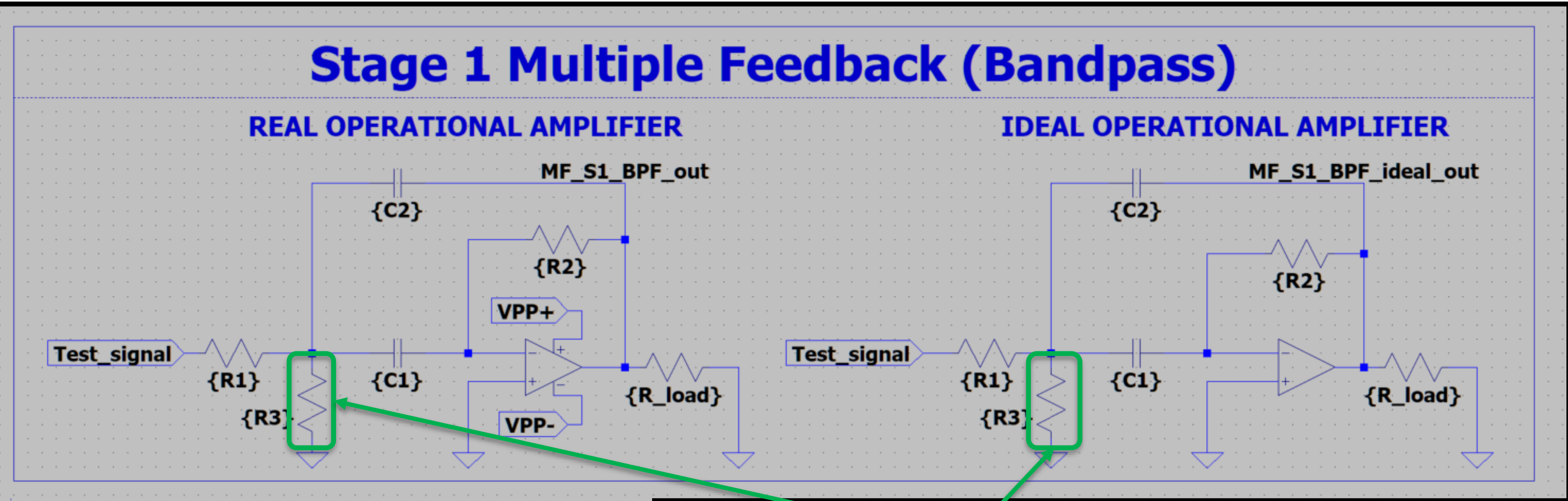
You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant

ITMO



You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant

Stage 3 -Define R1 value in your model

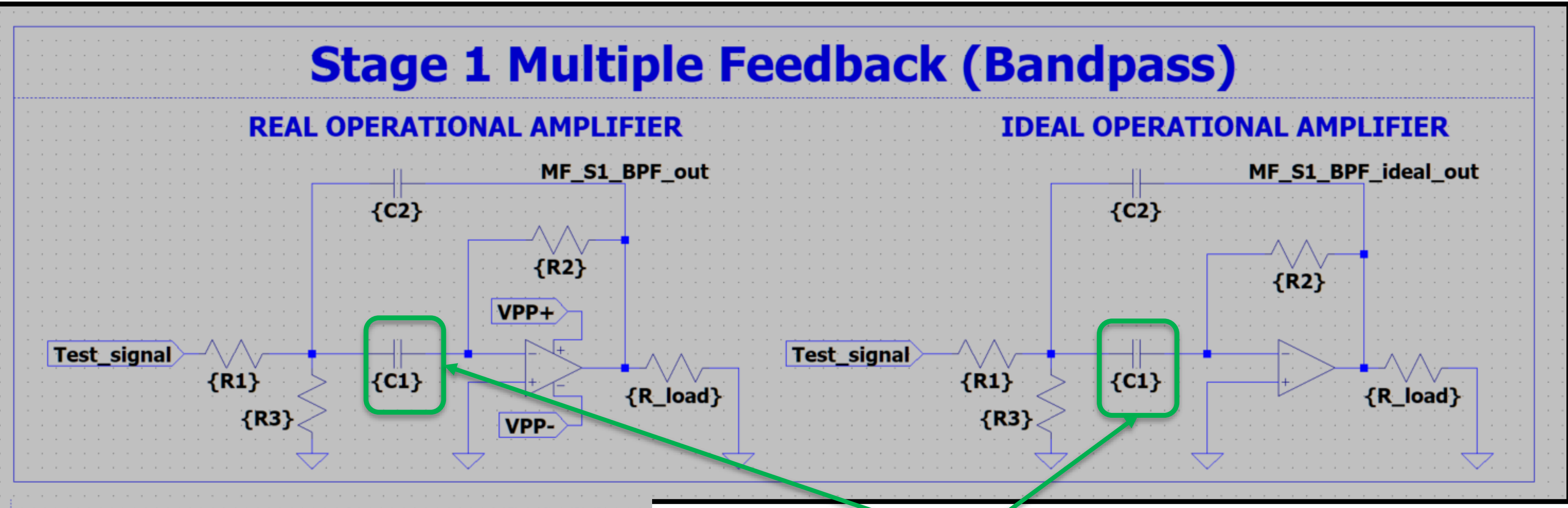


Element parameters for simulation:

R1 [Ω]:	.param R1=
R2 [Ω]:	.param R2=
R3 [Ω]:	.param R3=
C1 [F]:	.param C1=
C2 [F]:	.param C2=
C3 [F]:	.param C3=

R_3

You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant



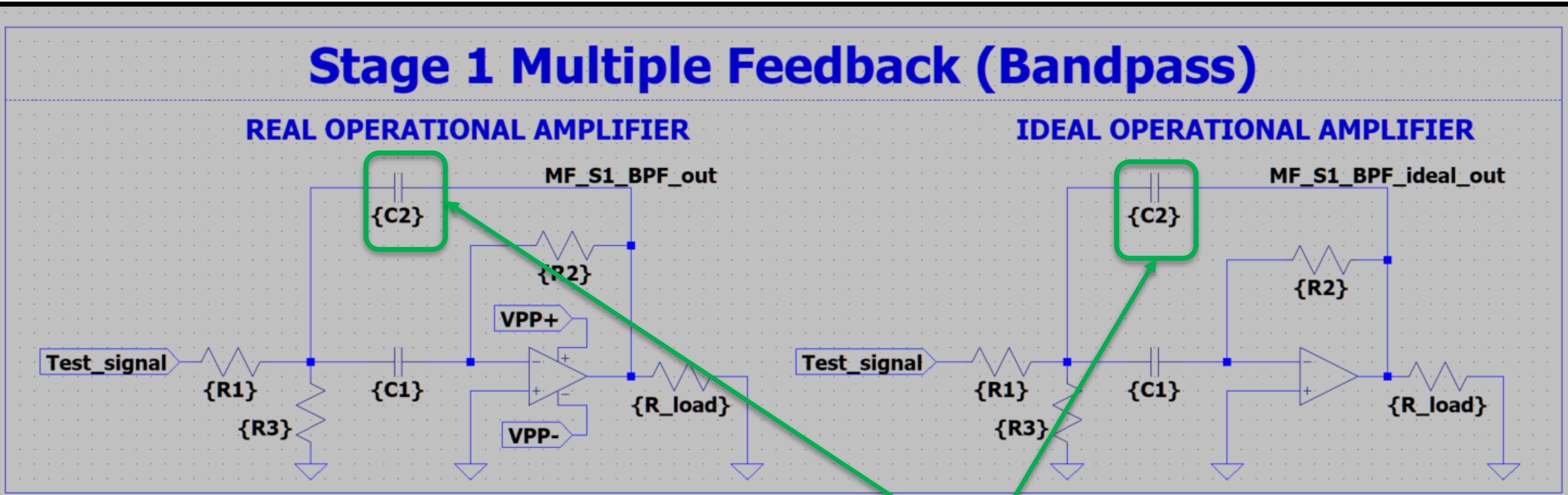
Element parameters for simulation:

R1 [Ω]:	.param R1=
R2 [Ω]:	.param R2=
R3 [Ω]:	.param R3=
C1 [F]:	.param C1=
C2 [F]:	.param C2=
C3 [F]:	.param C3=

C_1

You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant

Stage 3 -Define R1 value in your model



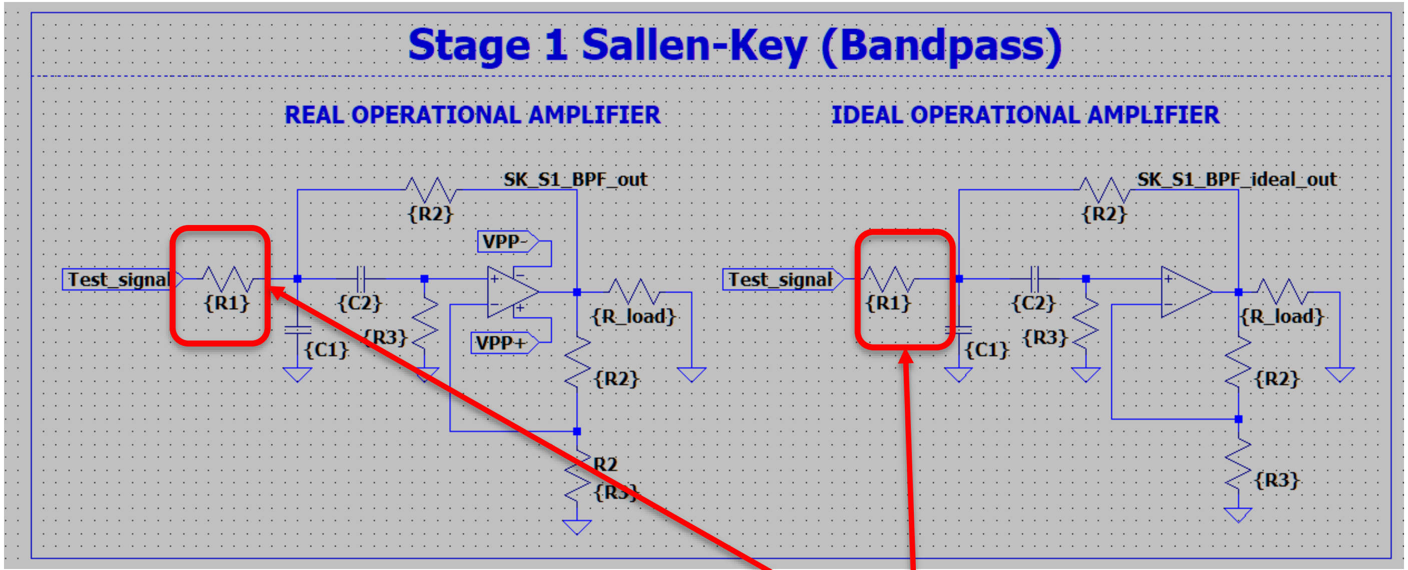
Element parameters for simulation:

R1 [Ω]:	.param R1=
R2 [Ω]:	.param R2=
R3 [Ω]:	.param R3=
C1 [F]:	.param C1=
C2 [F]:	.param C2=
C3 [F]:	.param C3=

C_2

You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant

Stage 3 -Define R1 value in your model



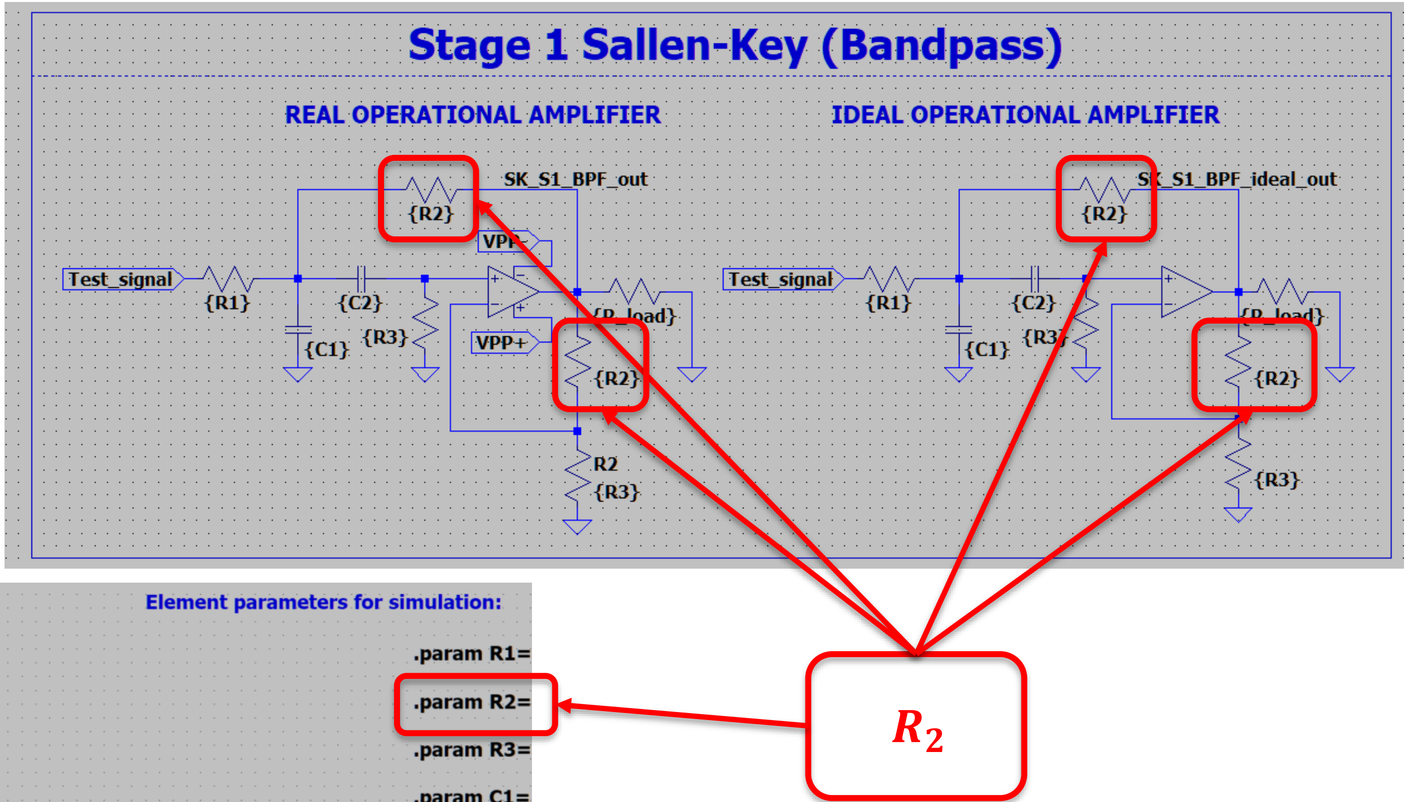
Element parameters for simulation:

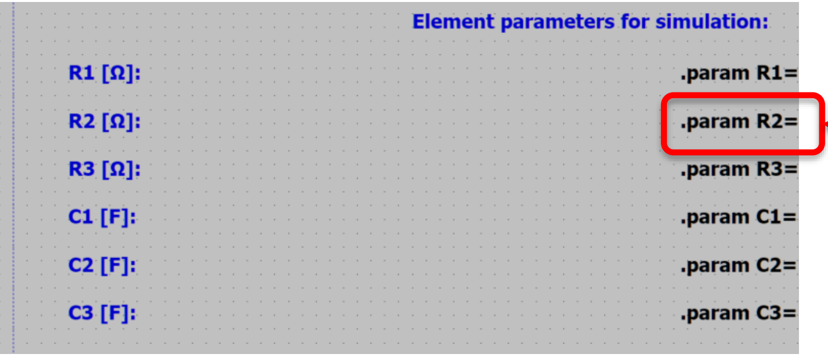
R1 [Ω]:	.param R1=
R2 [Ω]:	.param R2=
R3 [Ω]:	.param R3=
C1 [F]:	.param C1=
C2 [F]:	.param C2=
C3 [F]:	.param C3=

R_1

You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant

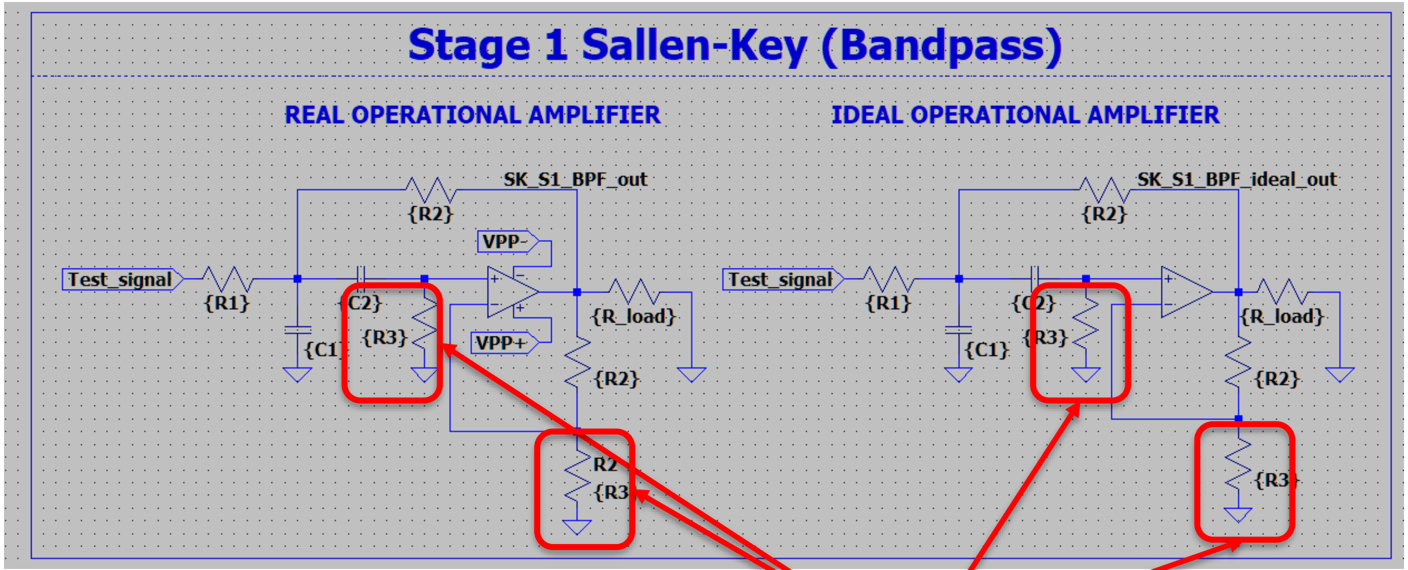
Stage 3 -Define R1 value in your model





You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant

Stage 3 -Define R1 value in your model



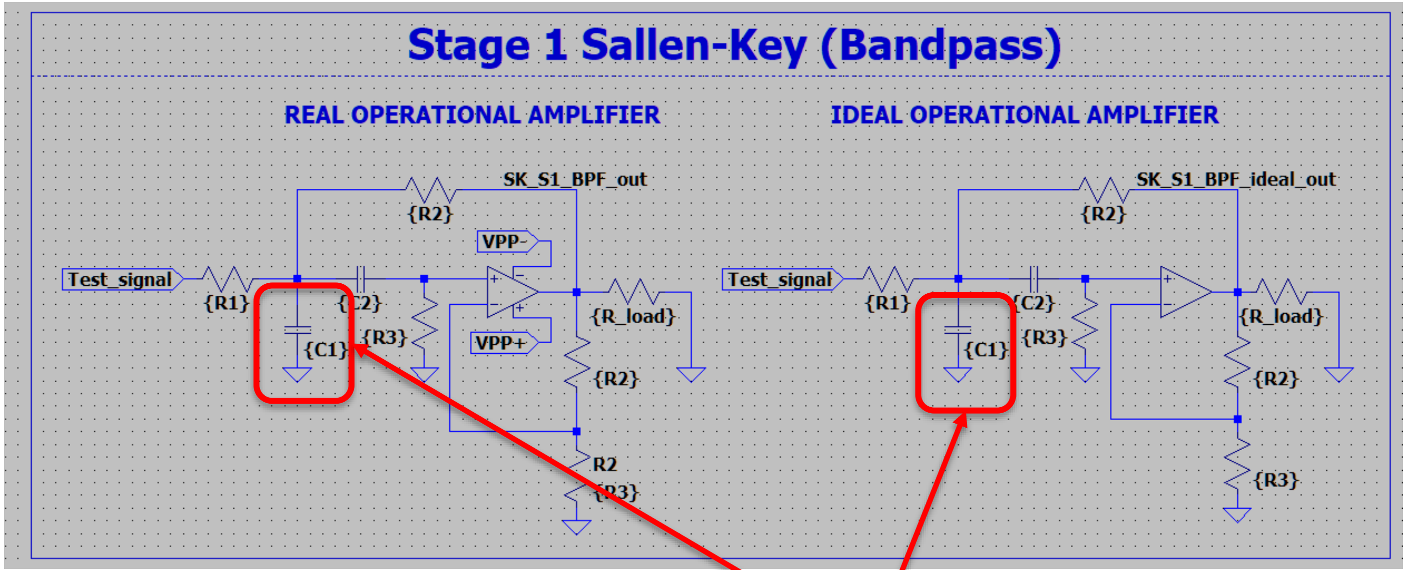
Element parameters for simulation:

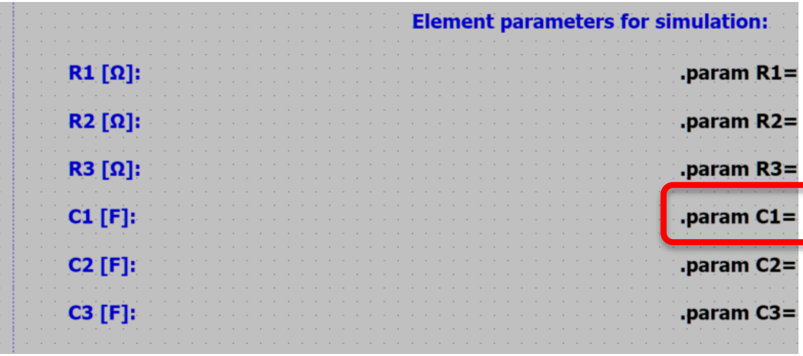
R1 [Ω]:	.param R1=
R2 [Ω]:	.param R2=
R3 [Ω]:	.param R3=
C1 [F]:	.param C1=
C2 [F]:	.param C2=
C3 [F]:	.param C3=

R_3

You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant

Stage 3 -Define R1 value in your model

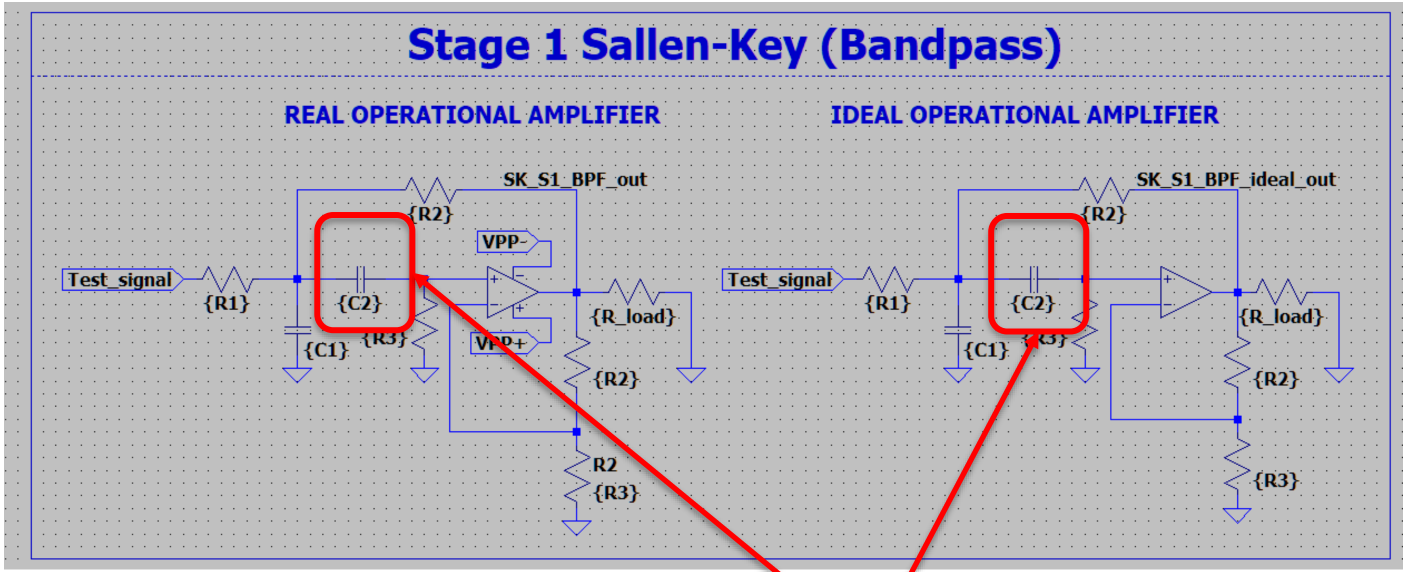


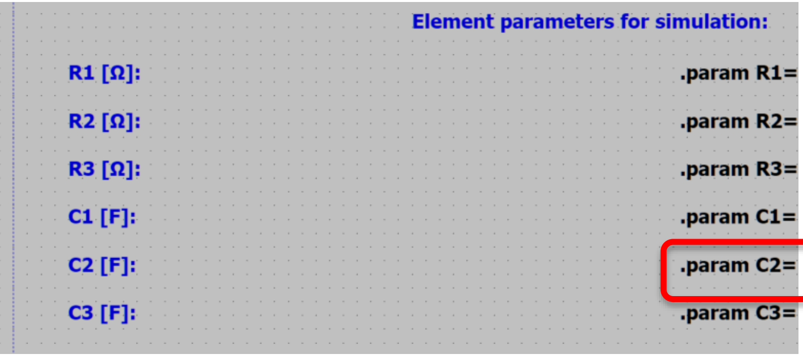


C_1

You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant

Stage 3 -Define R1 value in your model



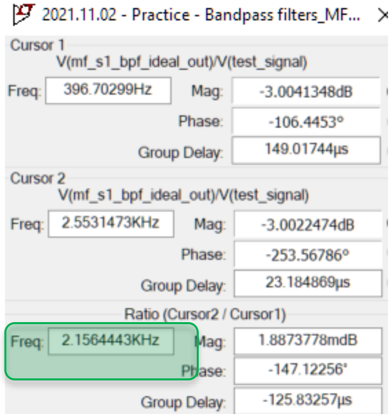


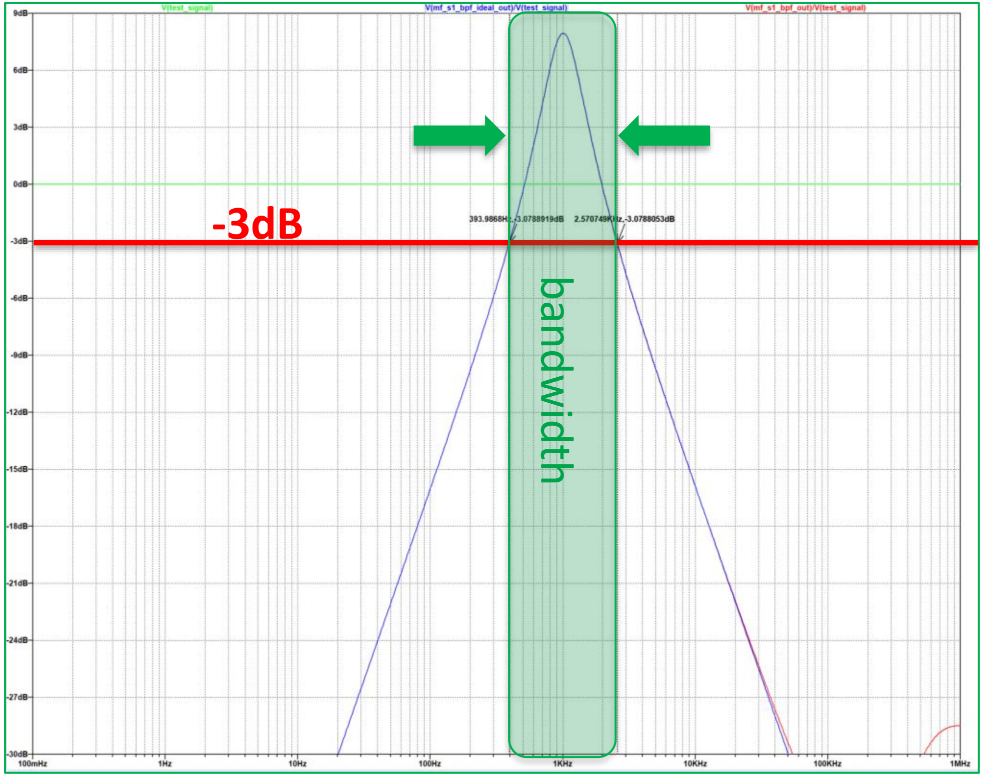
C_2

You have R1, R2, R3 in the task and you have to choose C1, C2 **by yourself** to provide f0 value from your variant

Define the bandwidth in **Hz** from simulation results of scheme with an **ideal** operational amplifier

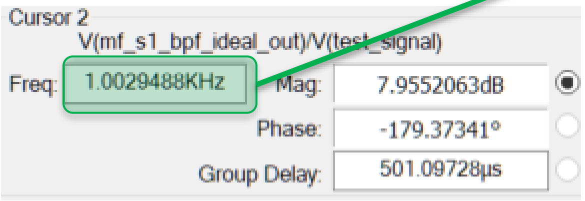
Define the bandwidth in **Hz** from simulation results of scheme with a **real** operational amplifier

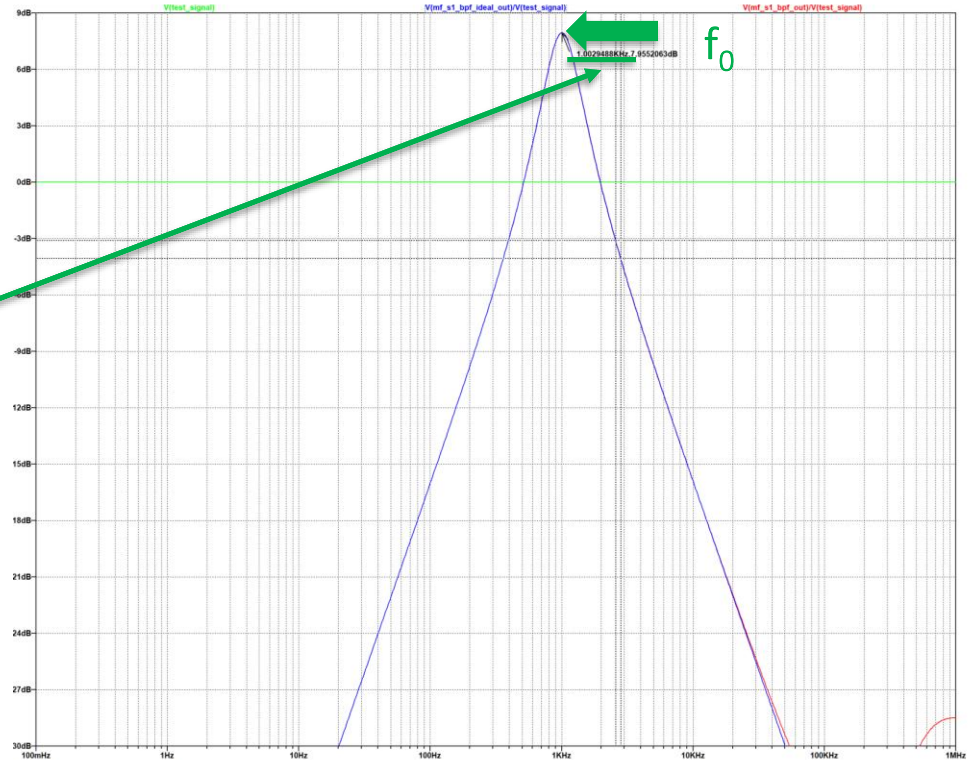




Define f0 as a middle of bandwidth from simulation results of scheme with an **<u>ideal</u>** operational amplifier

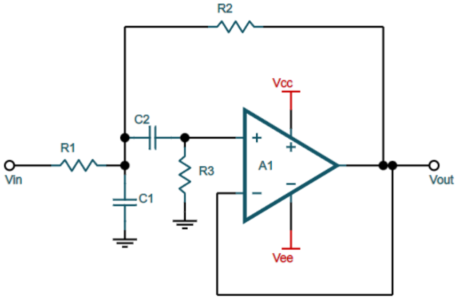
Define f0 as a middle of bandwidth from simulation results of scheme with a **<u>real</u>** operational amplifier



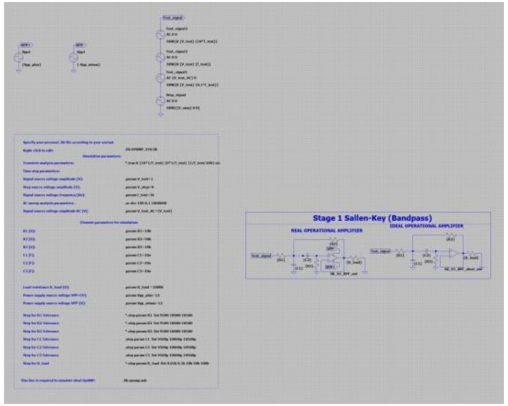


Stage 3 - Define f0 in Hz calculated from C1, C2, R1, R2, R3 real values

Sallen-Key Band Pass Active Filter



$$B = f_0(3 - K)\ [\text{Hz}]$$



$$C_1 = C_2 = C$$

$$R_1 = R_2 = \frac{1}{2} R_3 = R$$

$$R_3 = 2R$$

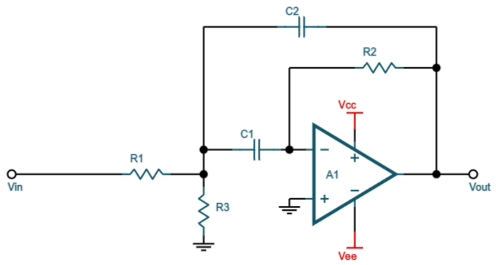
$$Max\ gain\ K = 1 + \frac{R_2}{R_3}$$

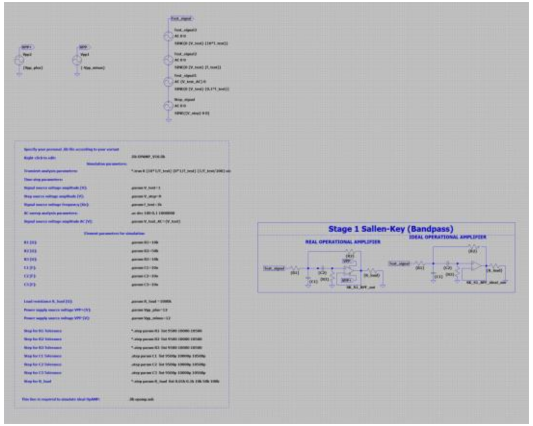
Middle frequency of bandpass: $\omega_0 = \dfrac{1}{RC}$ [rad/s] $f_0 = \dfrac{1}{2\pi \cdot RC}$ [Hz]

Bandwidth: $B = \omega_0(3 - K)$ [rad/s] $B = f_0(3 - K)$ [Hz]

Stage 3 - Define f0 in Hz calculated from C1, C2, R1, R2, R3 real values

Multiple Feedback Band Pass Active Filter





the characteristics of the IGMF filter

$$\frac{U_{out}(p)}{U_{in}(p)} = -\frac{\frac{R_2 R_3}{R_1 + R_3} C\omega_0 p}{\frac{R_1 R_2 R_3}{R_1 + R_3} C^2 \omega_0{}^2 p^2 + \frac{2 R_1 R_3}{R_1 + R_3} C\omega_0 p + 1}$$

$$Max\ gain \approx -\frac{R_2}{2R_1} = 2Q^2$$

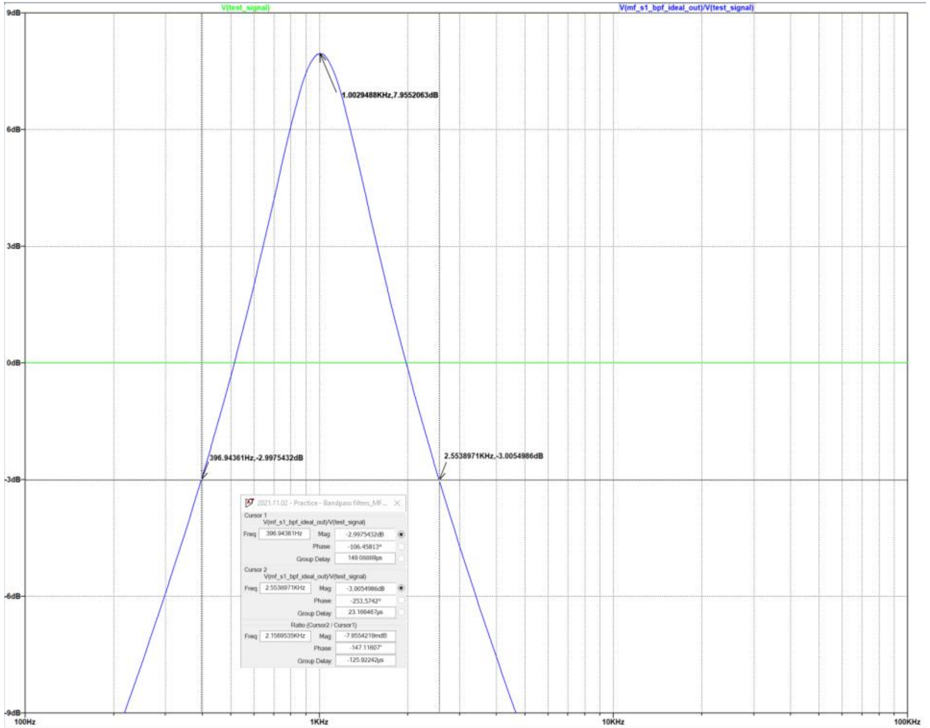
$$\boldsymbol{C_1 = C_2 = C}$$

Middle frequency of bandpass: $\omega_0 = \frac{1}{C}\sqrt{\frac{R_1 + R_3}{R_1 R_2 R_3}}$ [rad/s]

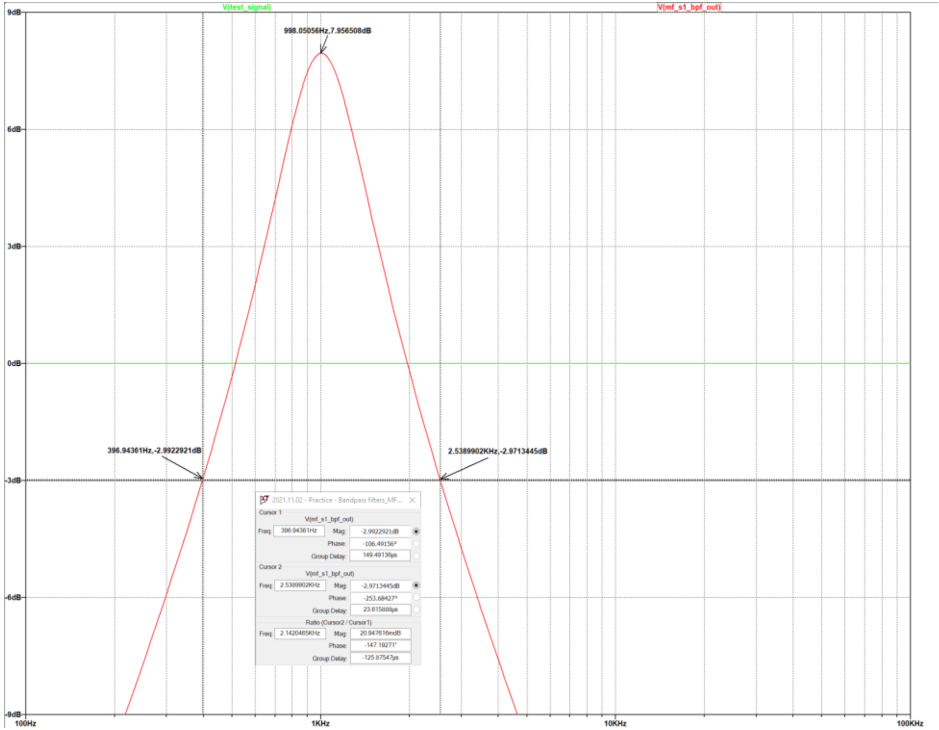
$$f_0 = \frac{1}{2\pi \cdot C}\sqrt{\frac{R_1 + R_3}{R_1 R_2 R_3}} \text{ [Hz]}$$

Bandwidth: $B = \frac{1}{\pi \cdot R_2 C}$

Stage 3 - Save a screenshot of your simulation results with frequency estimation

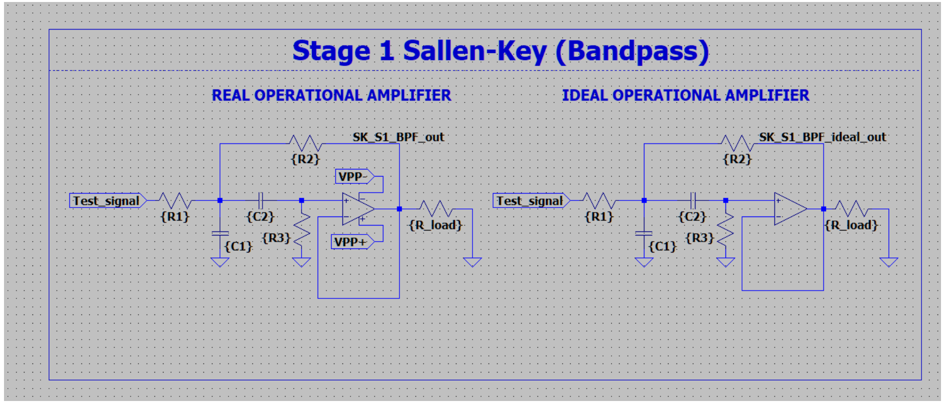


Ideal OpAMP



Real OpAMP

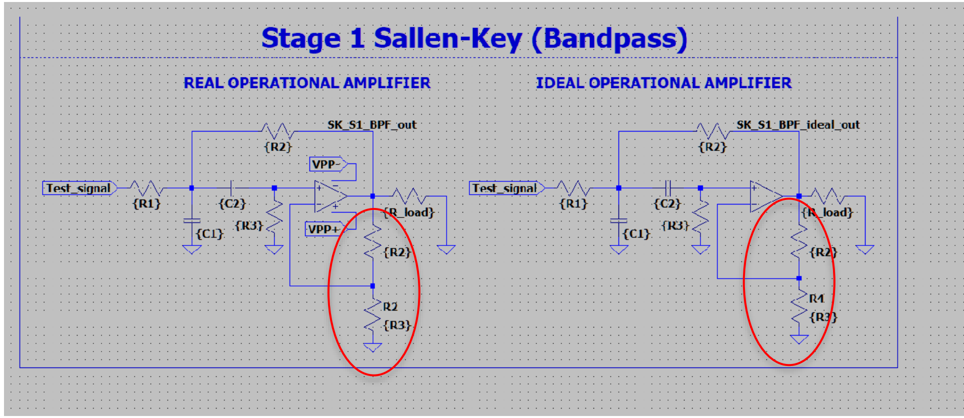
Fix Sallen-Key bandpass filter scheme issues



BEFORE

$$Max\ gain\ K = 1\ (\text{always})$$

$$K_{\omega 0} = \frac{\mathrm{K}}{3 - \mathrm{K}} = 0{,}5\ (-6\text{dB})$$



AFTER

$$Max\ gain\ K = 1 + \frac{R_2}{R_3} = 1{,}5\ (in\ the\ task)$$

$$K_{\omega 0} = \frac{\mathrm{K}}{3 - \mathrm{K}} = 1\ (0\ \text{dB})$$

Control test 3

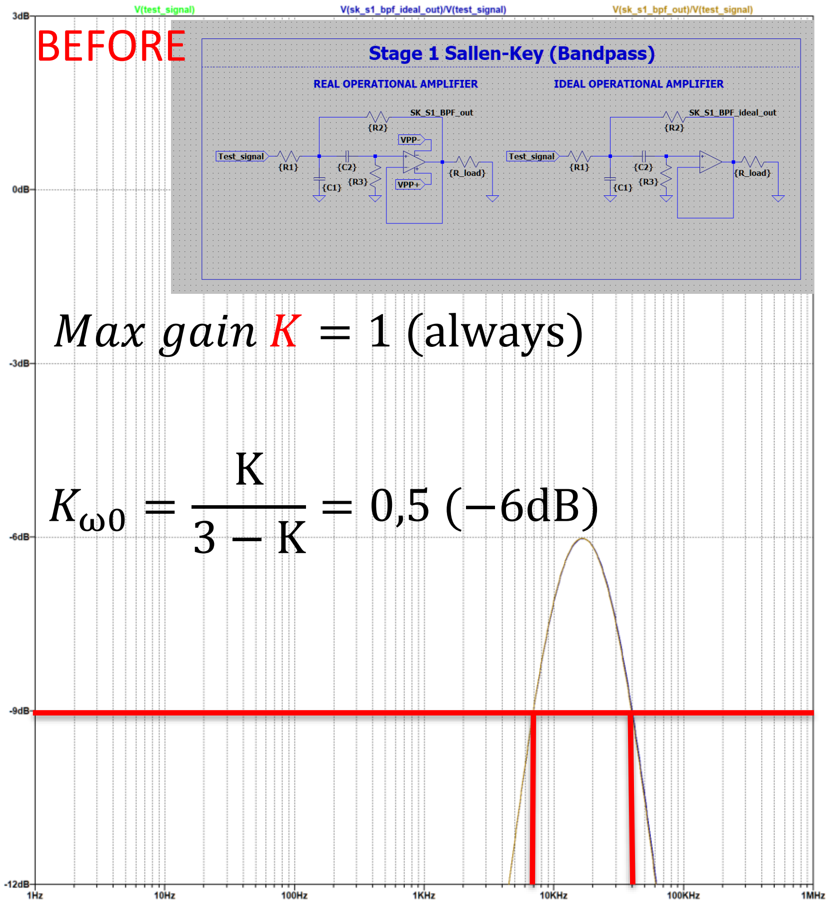
https://forms.yandex.com/cloud/6379029df47e7378d18aa0c4/

https://clck.ru/32kU7G

1st deadline: 23.11.2022 15:15 (GMT +8)

Fix Sallen-Key bandpass filter scheme issues

BEFORE



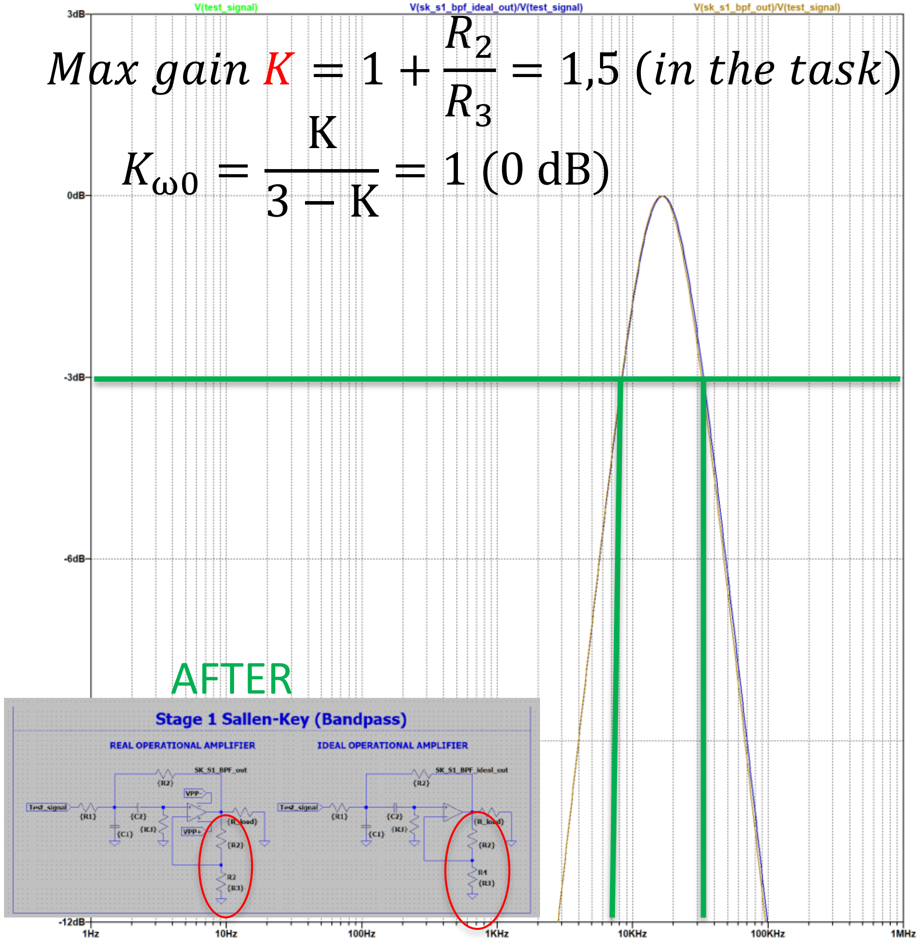
$$Max\ gain\ K = 1\ (\text{always})$$

$$K_{\omega 0} = \frac{\mathrm{K}}{3 - \mathrm{K}} = 0{,}5\ (-6\text{dB})$$

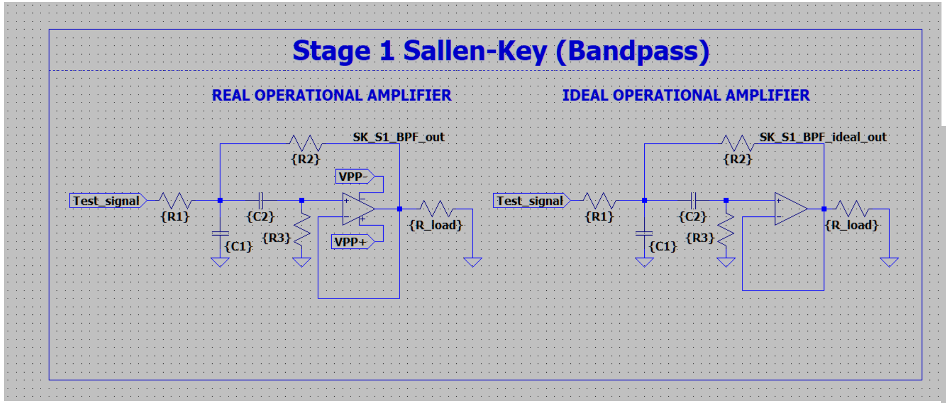
$$Max\ gain\ K = 1 + \frac{R_2}{R_3} = 1{,}5\ (in\ the\ task)$$

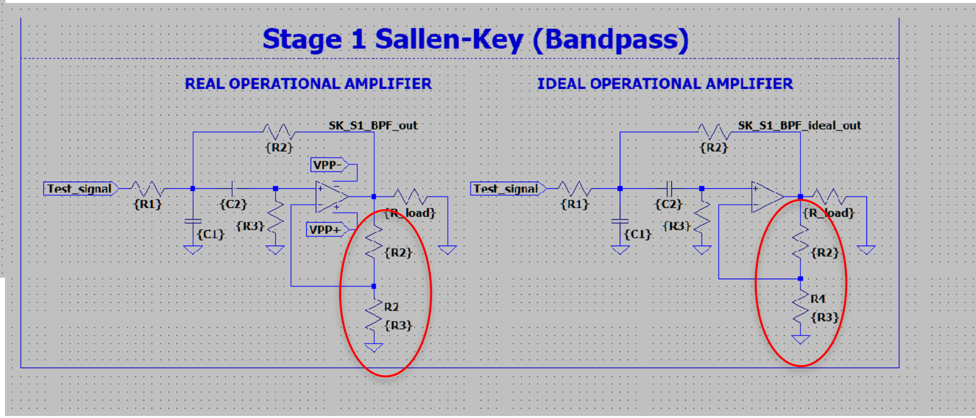
$$K_{\omega 0} = \frac{\mathrm{K}}{3 - \mathrm{K}} = 1\ (0\ \text{dB})$$

AFTER



Fix Sallen-Key bandpass filter scheme issues





<u>**Good news:**</u> all evaluations for C1/C2 are correct and the same for both cases

You may define the bandwidth at -9dB instead of -3dB or fix the scheme and makes new pictures with a new gain

AFTER

$$Max\ gain\ K = 1 + \frac{R_2}{R_3} = 1{,}5\ (in\ the\ task)$$

$$K_{\omega 0} = \frac{\mathrm{K}}{3 - \mathrm{K}} = 1\ (0\ \mathrm{dB})$$

Thanks for your attention!