FilterWorkBench

FilterWorkBench is designed to calculate high- and low-pass practical active filters (Bessel, Butterworth, and Chebyshev) built according to the Sallen-Key scheme, with the gain factor of 1. The calculated frequencies range from **0.01 Hz** to **999.999 Hz**. The application supports calculations of filters from order N1 to order N8.

The Chebyshev filters can be calculated with five amplitude ripples of the frequency response in the passband:

PRN 0.1 dB	PRN 0.5 dB	PRN 1 dB	PRN 2 dB	PRN 3 dB

The major difference of **FilterWorkBench** from similar programs is the ability to calculate all practically realizable combinations of capacitor and resistor values for a particular solution, the range of resistor values being set by the designer.

The primary function of FilterWorkBench is to assist practically with building a preliminarily selected type of an active filter.

The application is mainly targeted at an experienced developer, thus it provides calculated data neither for amplitude, phase characteristics, nor for group delay time.

Resistors:

The used values range from 1 kOhms to 9999 kOhms. Each calculated value is rounded to the nearest value from the selected standard set of resistors. The following sets are used:

E24 (5%)	E48 (2.5%)	E96 (1%)	E192 (0.5%)

If necessary, the round-up can be canceled by selecting the following command:

Menu/Resistors/Compare-Off

Capacitors:

The values used start from 10pF. The upper value is restricted to the reasonable limit of 100uF. Values above the limit are also shown, but not in the standard format. For instance, 120uF will be presented as 1E2uF.

The following sets are:

E6 (20%)	E12 (10%)	E24 (5%)	E48 (2.5%)	E96 (1%)

Menu Description:

File.   **Print tab –** unfortunately, does not work yet in the current version of the program.
          Exit   **–** standard exit from the program.

Filter.   **Butterworth**
          Bessel
          Chebyshev / PRN=0.1
                        PRN=0.5
                        PRN=1,0
                        PRN=2.0
                        PRN=3.0

          Filter type selection. In case of Chebyshev filter,
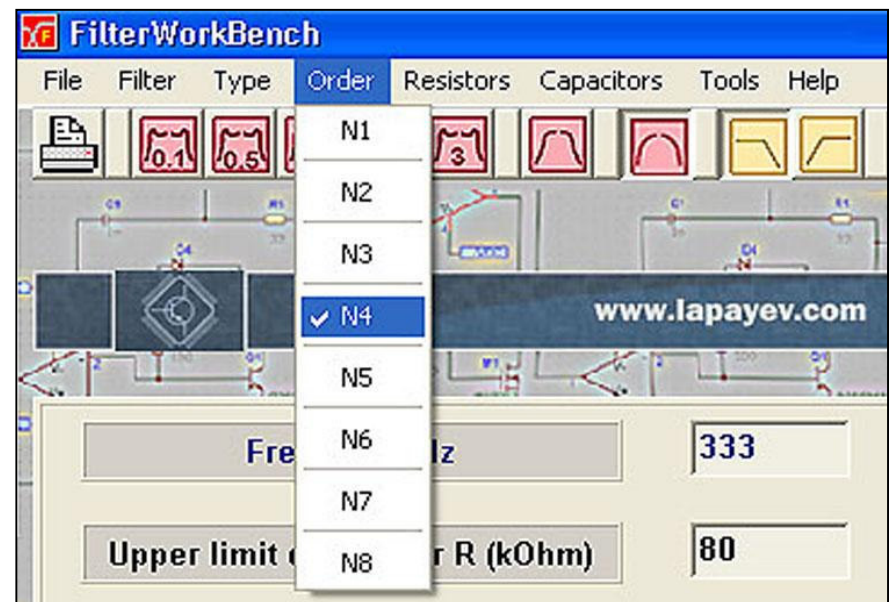   select amplitude ripples of the frequency response
          in the passband.
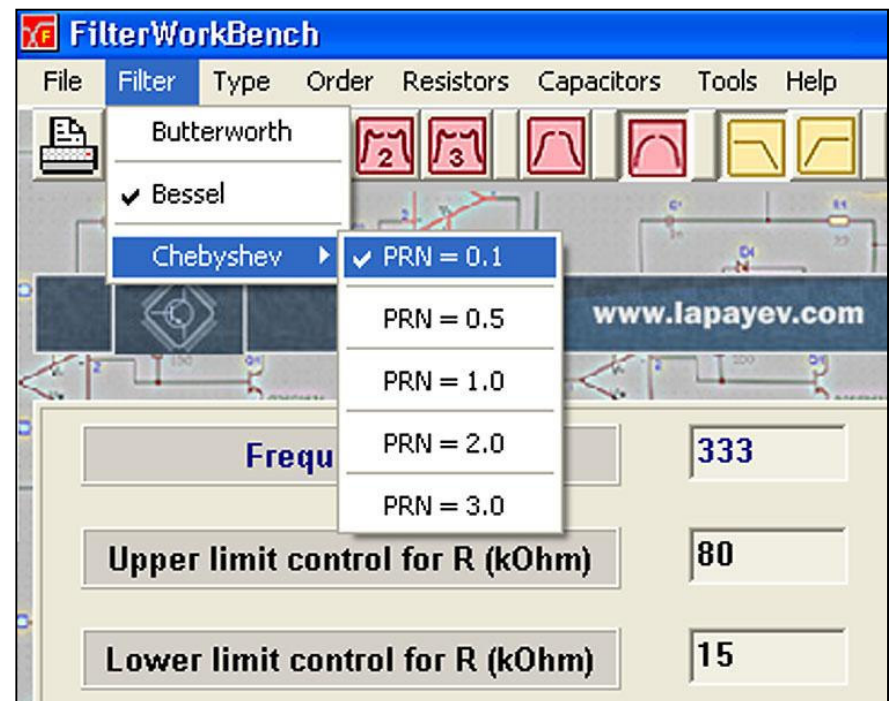
Type.   **Low - Pass**
            High - Pass

Filter class selection. Low–Pass or High–Pass.

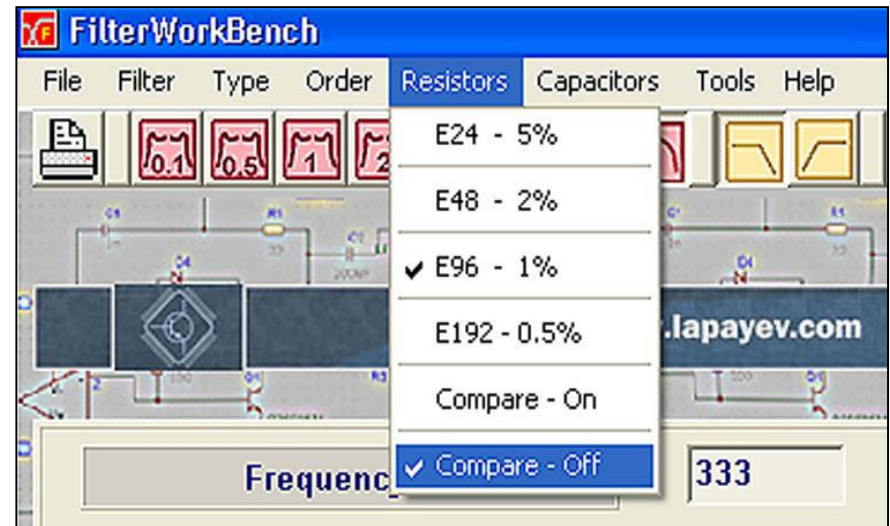**Order.**   Filter order selection. (N).

Resistors. **E24**
E48
E96
E192
Selection of a resistor standard value set.

Compare – On
Compare – Off

Turning on and off of the round-up option
for the received output of each resistor
to the nearest value in the selected set.

Capacitors **E6**
E12
E24
E48
E96
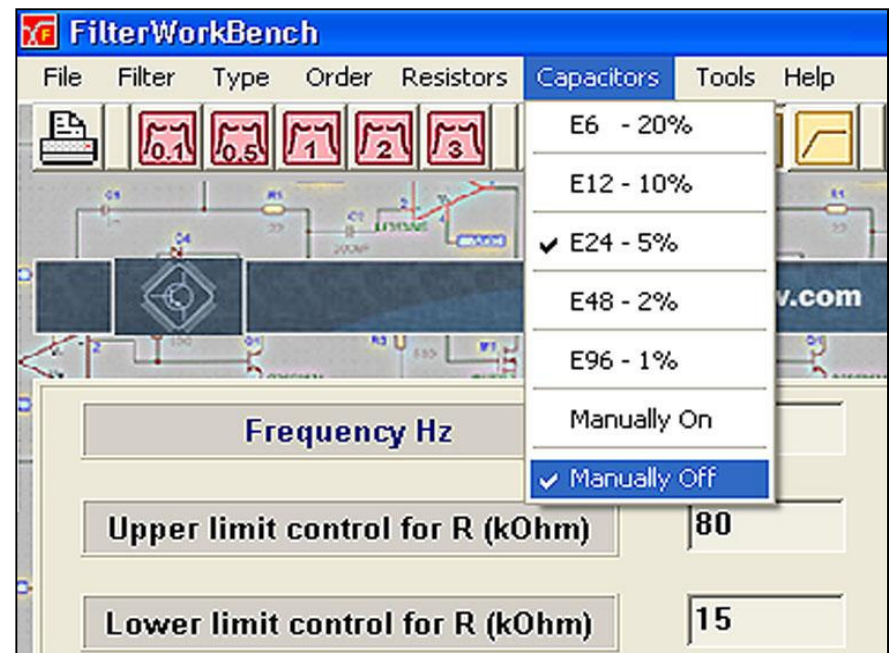Selection of a commonly used capacitor standard
value set.

Manually On
Manually Off

Selecting/deselecting of the manual value matching
option for capacitors.
By default, capacitance values are
picked from the selected standard set.
After the **Manually On** option is checked, there is
a possibility to use non-standard values.
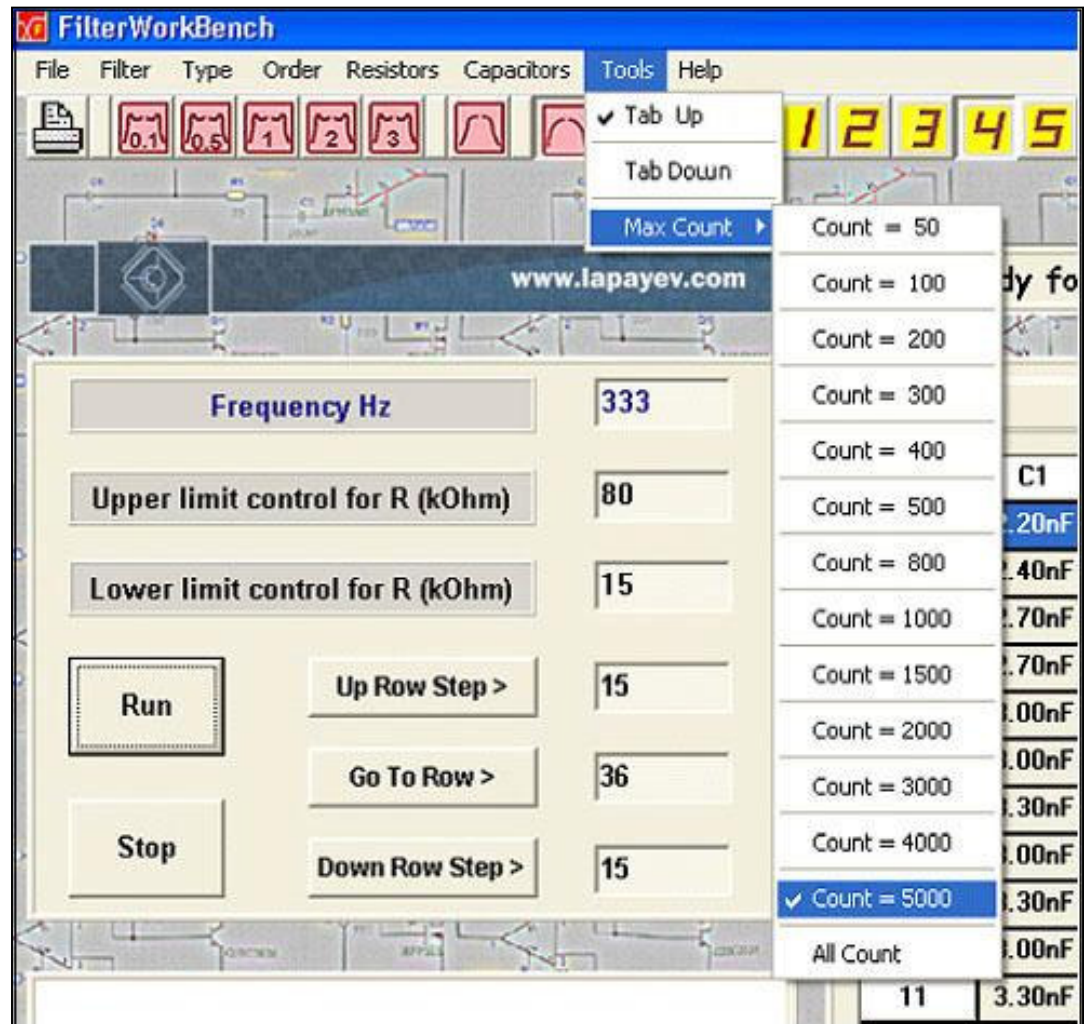Go to Page 9 for more detail.

4

Tools.   **Tab to Up**
                   Tab Down

                   Switching to the upper or lower part of the
                   output table.

.

                   Count = 50
                   Count = 100
                   - - - - - - -
                   Count = 4000
                   Count = 5000
                   All Count

                   A permitted limit on the number of
                   calculations.
                   By default, count = 5000.

Help.   Standard help.

Getting Started with FilterWorkBench. **Capacitors Manually Off –** default mode.

FilterWorkBench

File   Filter   Type   Order   Resistors   Capacitors   Tools   Help

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Ready for frequency = 333.000 Hz.   Total Count of decisions = 36

8

Frequency Hz   333 **1**

Upper limit control for R (kOhm)   80 **2**

Lower limit control for R (kOhm)   15 **3**

Run   Up Row Step >   15 **4**

Go To Row >   36 **5**

Stop   Down Row Step >   15 **6**

7   Bessel Low-pass filter. Fourth order N4. Gain=0dB.

number	C1	C2	R1	R2	unit 2	C3	C4	R3	R4
1	2.20nF	2.40nF	66.512k	71.165k	II	1.50nF	3.90nF	55.942k	60.761k
2	2.40nF	2.70nF	51.918k	74.285k	II	1.50nF	4.30nF	40.407k	76.296k
3	2.70nF	3.00nF	48.298k	63.884k	II	1.60nF	4.30nF	44.587k	64.822k
4	2.70nF	3.30nF	37.618k	74.563k	II	1.60nF	4.70nF	36.040k	73.368k
5	3.00nF	3.30nF	45.588k	55.375k	II	1.80nF	4.70nF	44.874k	52.378k
6	3.00nF	3.60nF	35.174k	65.789k	II	1.60nF	5.10nF	31.130k	78.278k
7	3.30nF	3.60nF	44.341k	47.443k	II	1.80nF	5.10nF	34.540k	62.712k
8	3.00nF	3.90nF	30.176k	70.787k	II	1.80nF	5.60nF	28.832k	68.421k
9	3.30nF	3.90nF	33.077k	58.707k	II	2.00nF	5.60nF	31.938k	55.589k
10	3.00nF	4.30nF	25.763k	75.200k	II	1.80nF	6.20nF	24.486k	72.766k
11	3.30nF	4.30nF	27.322k	64.463k	II	2.00nF	6.20nF	26.110k	61.417k
12	3.60nF	4.30nF	29.608k	54.528k	II	2.20nF	6.20nF	28.603k	50.967k
13	3.90nF	4.30nF	34.631k	43.032k	II	1.80nF	6.80nF	21.424k	75.828k
14	3.00nF	4.70nF	22.626k	78.337k	II	2.00nF	6.80nF	22.476k	65.051k
15	3.30nF	4.70nF	23.649k	68.135k	II	2.20nF	6.80nF	23.858k	55.712k
16	3.60nF	4.70nF	24.961k	59.175k	II	2.40nF	6.80nF	25.905k	47.034k

Low-pass filter, N4, 0dB.

C2   C1   OpAmpA   C4   C3   OpAmpB

R1   R2   R3   R4

Sallen-Key schematic

Sorting
- All
- Sort by min value C
- Sort by capacitors
- Sort by resistors

uF

nF

6

Select a filter class, type, and order. When using Chebyshev filter, remember to specify the PRN amplitude ripple. Also, select the required standard resistor and capacitor sets. If necessary, cancel resistor round-up to the nearest value in the selected set:

Menu/Resistors/Compare-Off

Point 1. Enter Fc value (Hz).

<u>Fc</u> value is distinguishing for different types of filters.

Butterworth Filters.

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Frequency cutoff (F cutoff) is normalized in the usual way by level of -3dB in the attenuation band.

Chebyshev Filters.

Frequency cutoff (F cutoff) is normalized by level of 0dB in the attenuation band, to be more exact, by the last, before the attenuation band, maximal local extremum of the amplitude ripple of the frequency response (PRN).

Bessel Filters.

Since Bessel filter is mostly used as a scheme with the constant Group Delay Time (GDT), the frequency cutoff (F cutoff) is normalized according to the following equation:

$$Fc = \frac{1}{2\pi} / GDT \approx 0.159155 / GDT;$$

The minimal value of the specified frequency is **0.01Hz**, maximal is **999999Hz**. Up to six digits are used, but not more than three decimal places, for instance **0.012 Hz, 12,345Hz, 465,333Hz, 8473,22Hz, 10000,5Hz, 900000Hz**.

Point 2.   Enter the **"Upper limit control" value for resistors.** Upper limit of resistor value.

Point 3.   Enter the **"Lower limit control" value for resistors.** Lower limit of resistor value.

Start – click the "Run" button.

Point 4.   **Up Row Step**. A custom value of row scroll upwards.

Point 5.   **Go To Row**. A custom scrolling to the specified row.
            By default, this is the number of the last row.

Point 6.   **Down Row Step**. A custom value of row scroll downwards.

Point 7.   The row contains information on class, type, and order of the current filter.

Point 8.   The number of obtained solutions for the current design for the specified parameters.

Table.

Depending on the order of the active filter, its scheme has from one to four units realized on operational amplifiers (OpAmp) according to the Sallen-Key scheme and described in the table as **UNIT1, 2, 3, 4.** Starting from the third order of the filter, units are calculated independently from each other. Thus, rather than using obtained values from a single row for all units, it is highly desirable to use different rows (e.g. where capacitance values match). In the example, this is row 8 for the first unit and row 1 for the second.

Getting Started with FilterWorkBench. **Capacitors Manually On –** Entering the capacitor values manually.

If you need to work with non-predetermined capacitance values, check the following option:

Menu/Capacitors / Manually On

A capacitance value field below the table becomes available for manual filling. By default, the value of **0.1uF** is used.
Fill in necessary fields depending on the filter order used. Ignore the remaining fields. Click the "**uF**"or "**nF**" button to the right to fill in corresponding capacitor values. The value is rounded to the second decimal place, with the smallest step of **1pF**.
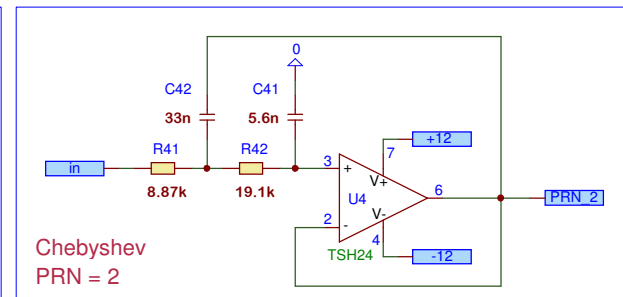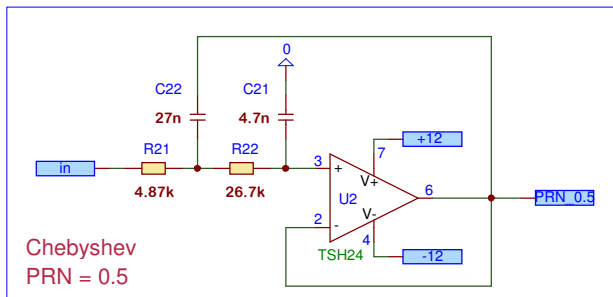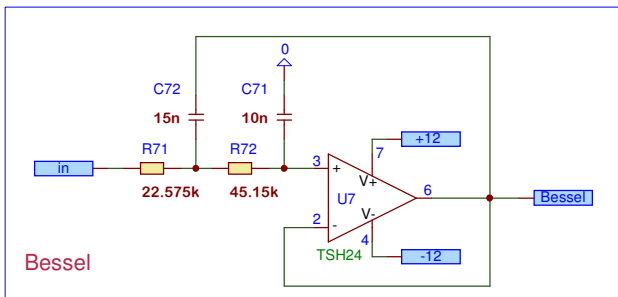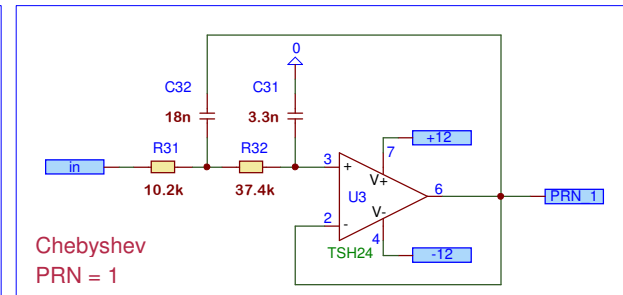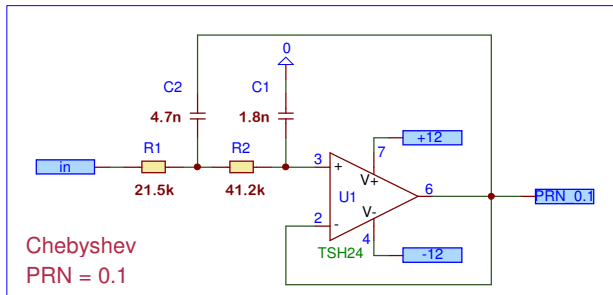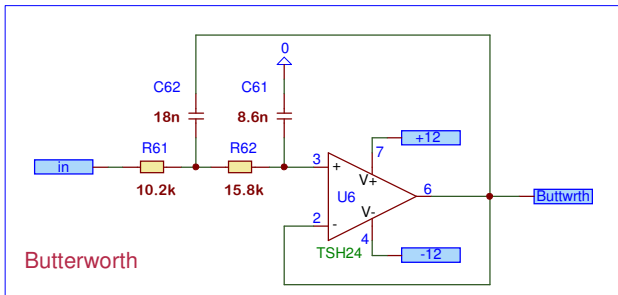
Please see further some examples of differentiation between the amplitude, phase characteristics, Group Delay Time, Chebyshev, Butterworth, and Bessel filters. Samples of practical schemes and their characteristics are also presented. At the end of the description, Sallen-Key schemes of filter design for each class and order are given.

As everything in our world, this application is not perfect, and I will be glad to hear any feedback from you. Please send your thoughts to:
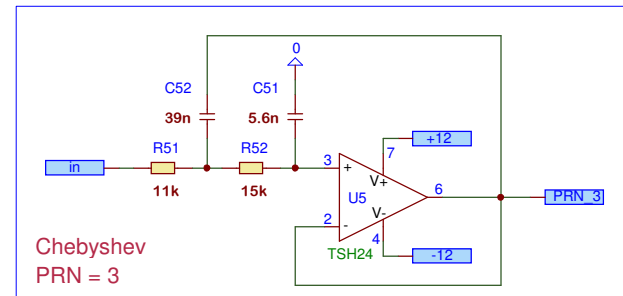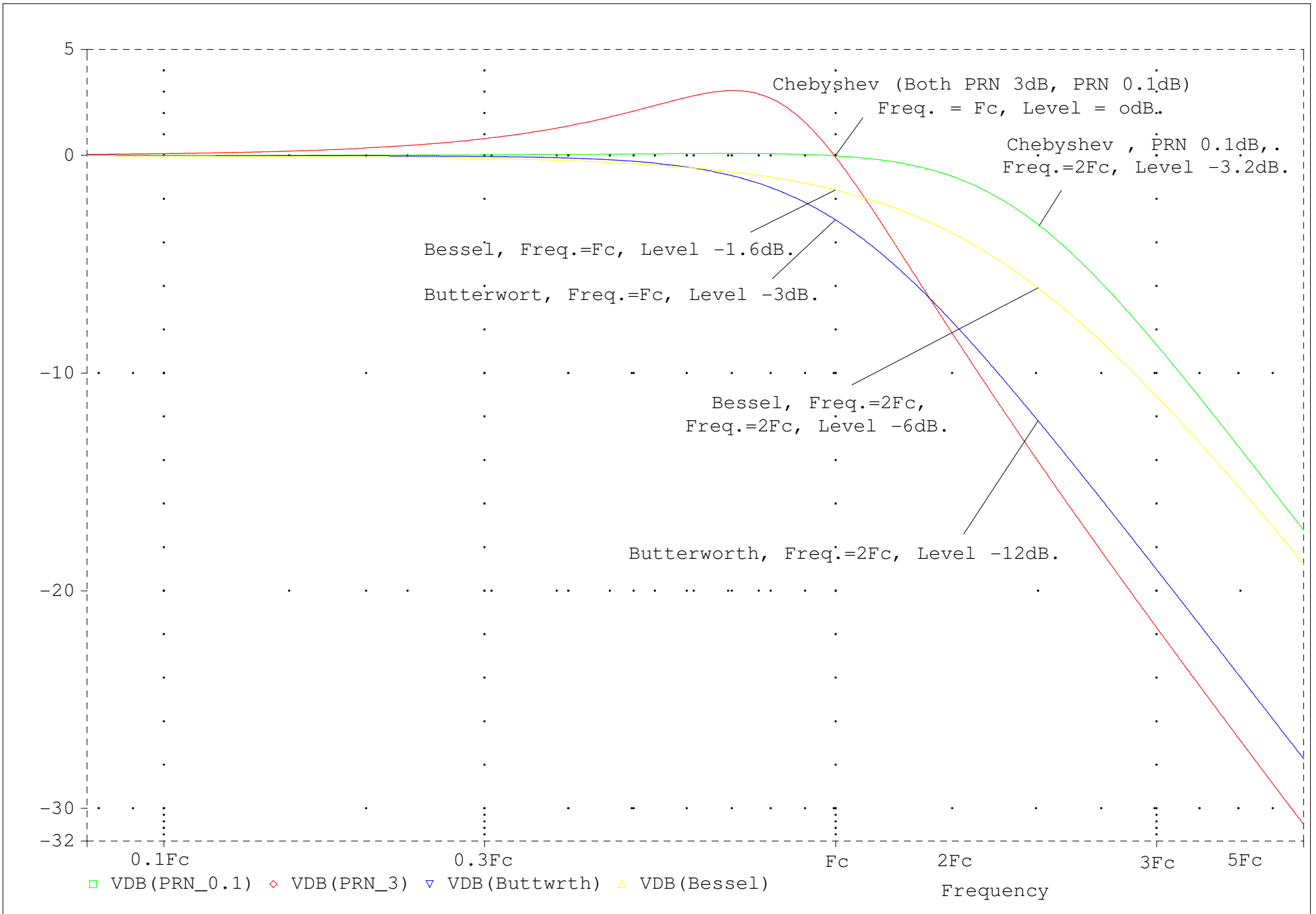
info@lapayev.com

Alex Lapayev

Butterworth

C62 18n — C61 8.6n
R61 10.2k — R62 15.8k
U6 TSH24
+12 / −12
Buttwrth

Chebyshev PRN = 0.1

C2 4.7n — C1 1.8n
R1 21.5k — R2 41.2k
U1 TSH24
+12 / −12
PRN 0.1

Chebyshev PRN = 1

C32 18n — C31 3.3n
R31 10.2k — R32 37.4k
U3 TSH24
+12 / −12
PRN 1

Bessel

C72 15n — C71 10n
R71 22.575k — R72 45.15k
U7 TSH24
+12 / −12
Bessel

Chebyshev PRN = 0.5

C22 27n — C21 4.7n
R21 4.87k — R22 26.7k
U2 TSH24
+12 / −12
PRN 0.5

Chebyshev PRN = 2

C42 33n — C41 5.6n
R41 8.87k — R42 19.1k
U4 TSH24
+12 / −12
PRN 2

Chebyshev PRN = 3

C52 39n — C51 5.6n
R51 11k — R52 15k
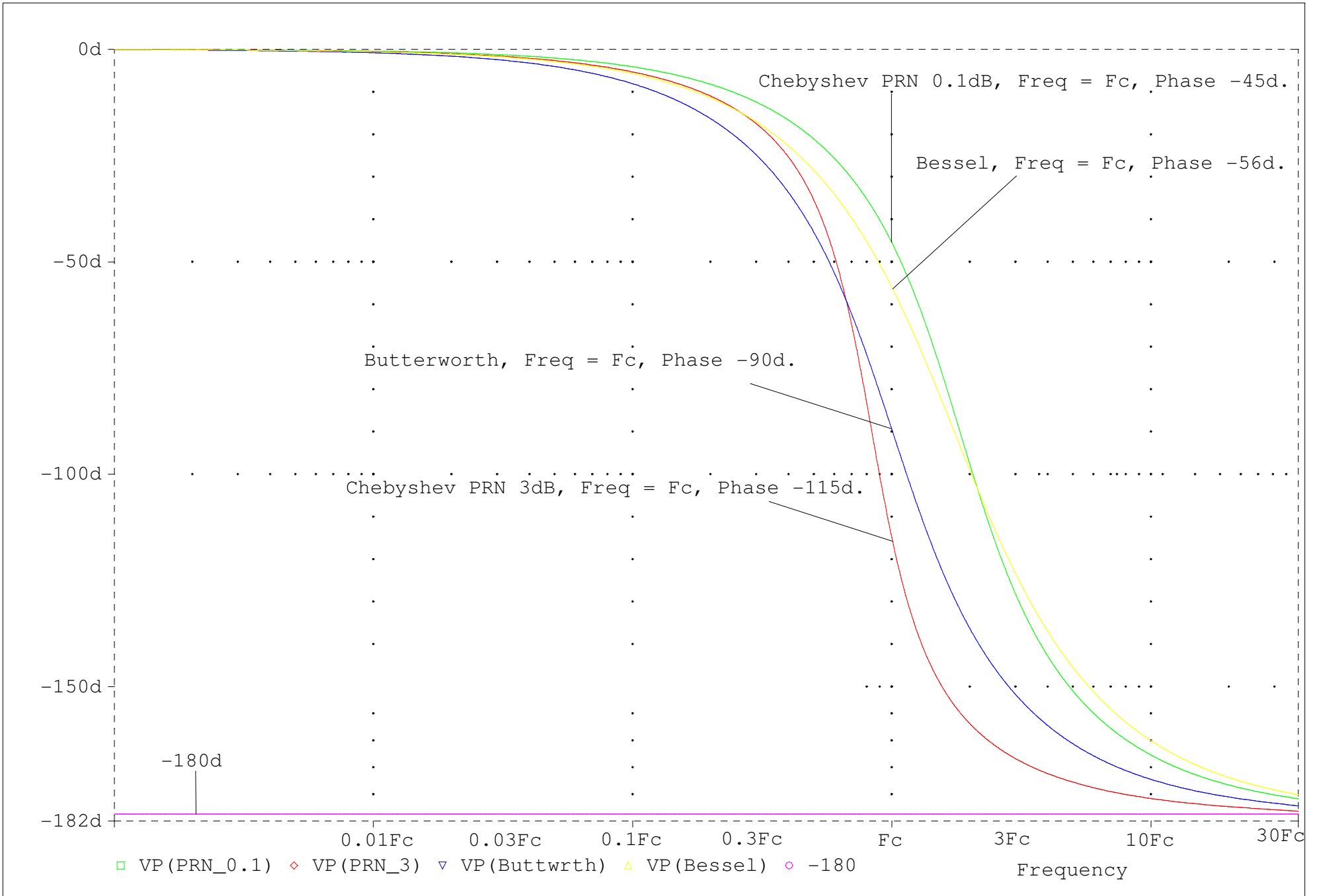U5 TSH24
+12 / −12
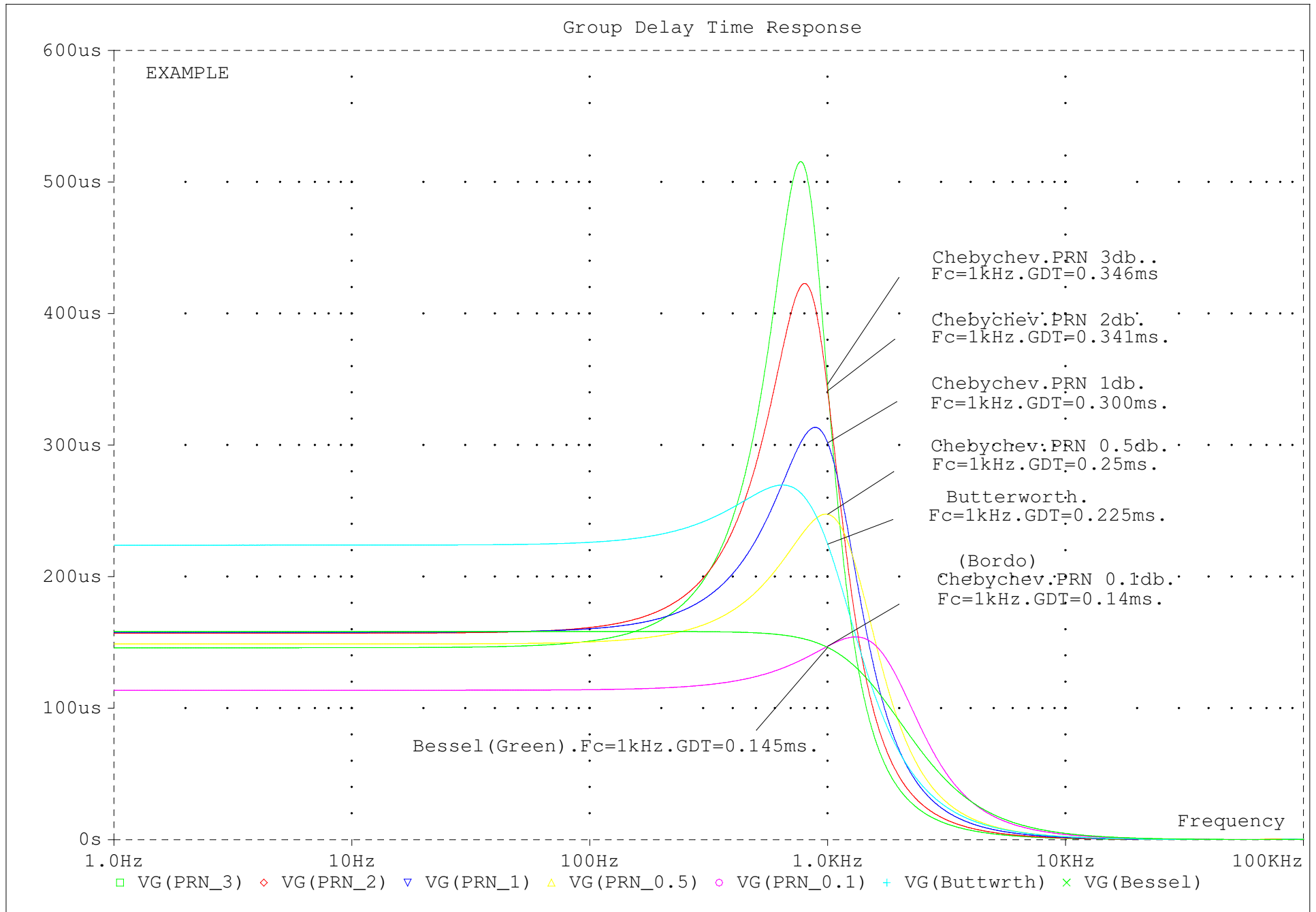PRN 3

Low-Pass Filtring. Fc = 1kHz, Order 2N, Gain 0dB.

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Low-Pass Filtering. Order N2, Gain 0dB, Frequency Response.

Chebyshev (Both PRN 3dB, PRN 0.1dB)
Freq. = Fc, Level = odB..

Chebyshev , PRN 0.1dB,.
Freq.=2Fc, Level -3.2dB.

Bessel, Freq.=Fc, Level -1.6dB.

Butterwort, Freq.=Fc, Level -3dB.

Bessel, Freq.=2Fc,
Freq.=2Fc, Level -6dB.

Butterworth, Freq.=2Fc, Level -12dB.

□ VDB(PRN_0.1)   ◇ VDB(PRN_3)   ▽ VDB(Buttwrth)   △ VDB(Bessel)

Frequency

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Low-Pass Filtering. Order 2N, Gain 0dB. Phase Response

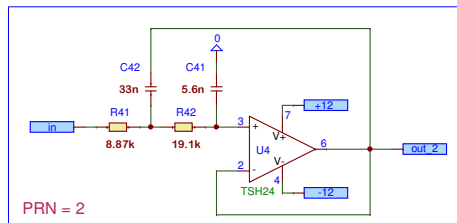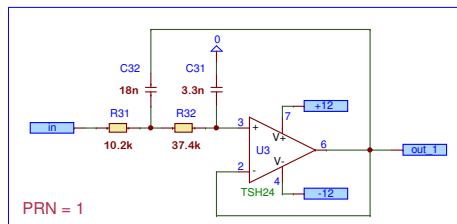Chebyshev PRN 0.1dB, Freq = Fc, Phase -45d.

Bessel, Freq = Fc, Phase -56d.

Butterworth, Freq = Fc, Phase -90d.

Chebyshev PRN 3dB, Freq = Fc, Phase -115d.

-180d

□ VP(PRN_0.1) ◇ VP(PRN_3) ▽ VP(Buttwrth) △ VP(Bessel) ○ -180

Frequency

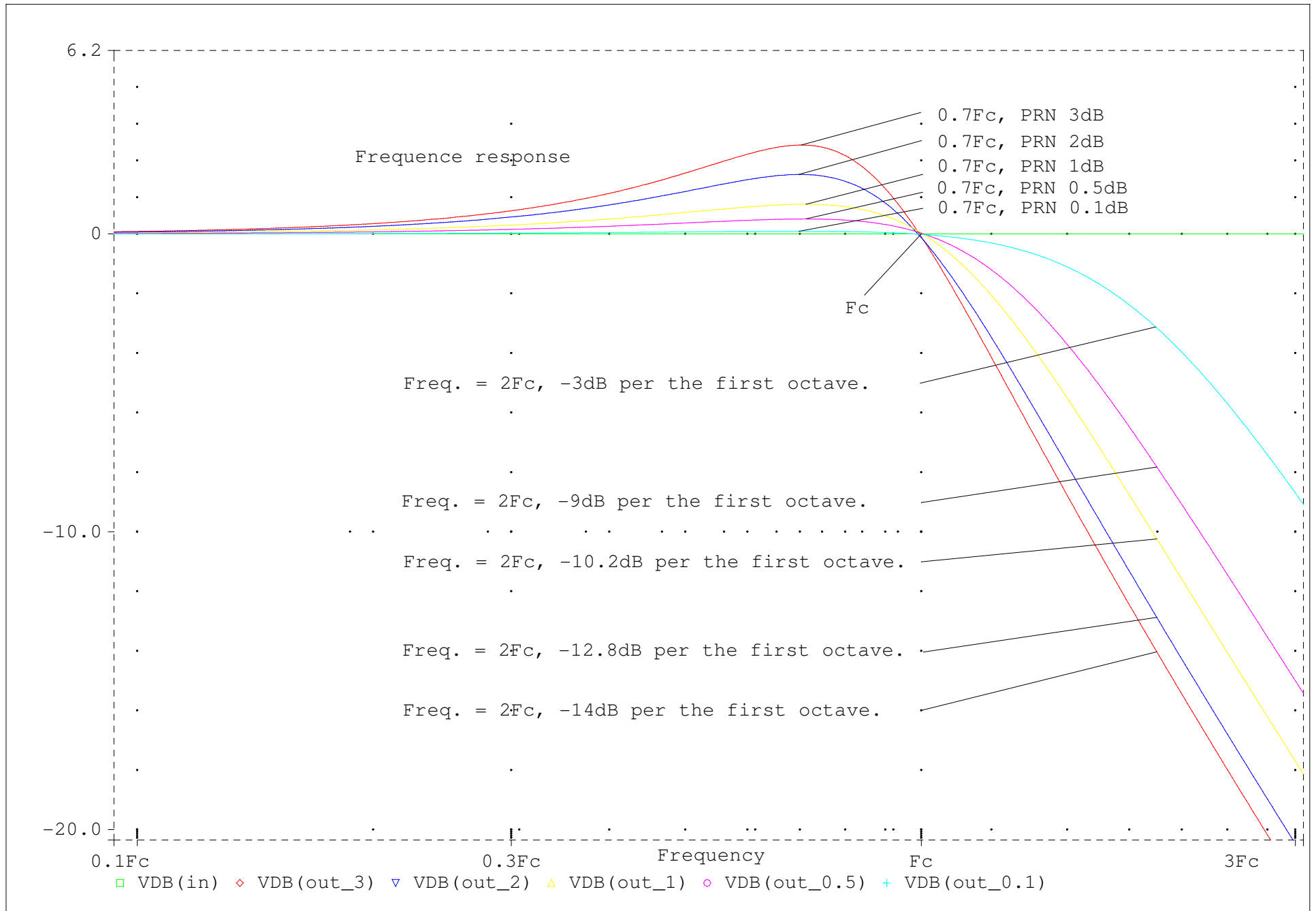WWW.LAPAYEV.COM

Low-Pass Filtring. Fc = 1kHz, Order 2N, Gain 0dB, Butterworth, Bessel and Chebyshev schematics.

Group Delay Time Response

EXAMPLE

Chebychev.PRN 3db..
Fc=1kHz.GDT=0.346ms

Chebychev.PRN 2db.
Fc=1kHz.GDT=0.341ms.

Chebychev.PRN 1db.
Fc=1kHz.GDT=0.300ms.

Chebychev.PRN 0.5db.
Fc=1kHz.GDT=0.25ms.

Butterworth.
Fc=1kHz.GDT=0.225ms.

(Bordo)
Chebychev.PRN 0.1db.
Fc=1kHz.GDT=0.14ms.

Bessel(Green).Fc=1kHz.GDT=0.145ms.

Frequency

600us
500us
400us
300us
200us
100us
0s

1.0Hz   10Hz   100Hz   1.0KHz   10KHz   100KHz

□ VG(PRN_3) ◇ VG(PRN_2) ▽ VG(PRN_1) △ VG(PRN_0.5) ○ VG(PRN_0.1) + VG(Buttwrth) × VG(Bessel)

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PRN = 0.1

C2 4.7n   C1 1.8n
R1 21.5k   R2 41.2k
in
U1 TSH24
+12
-12
out_0.1

PRN = 0.5

C22 27n   C21 4.7n
R21 4.87k   R22 26.7k
in
U2 TSH24
+12
-12
out_0.5

PRN = 1

C32 18n   C31 3.3n
R31 10.2k   R32 37.4k
in
U3 TSH24
+12
-12
out_1

PRN = 2

C42 33n   C41 5.6n
R41 8.87k   R42 19.1k
in
U4 TSH24
+12
-12
out_2

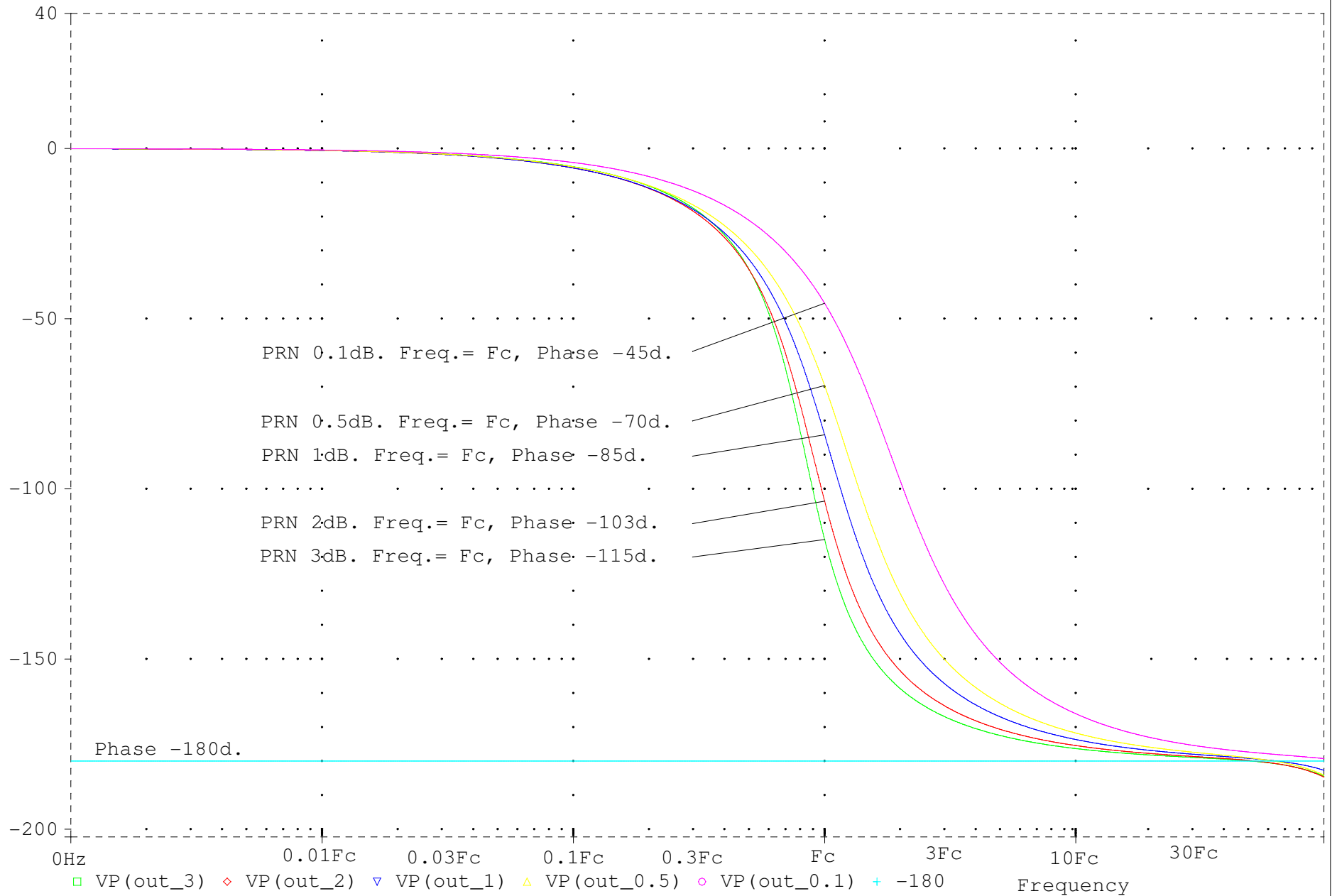PRN = 3

C52 39n   C51 5.6n
R51 11k   R52 15k
in
U5 TSH24
+12
-12
out_3

Chebyshev Low-Pass Filtring.Fc = 1kHz, Order 2N, Gain 0dB. PRN 0.1dB, 0.5dB, 1dB, 2dB,3dB.

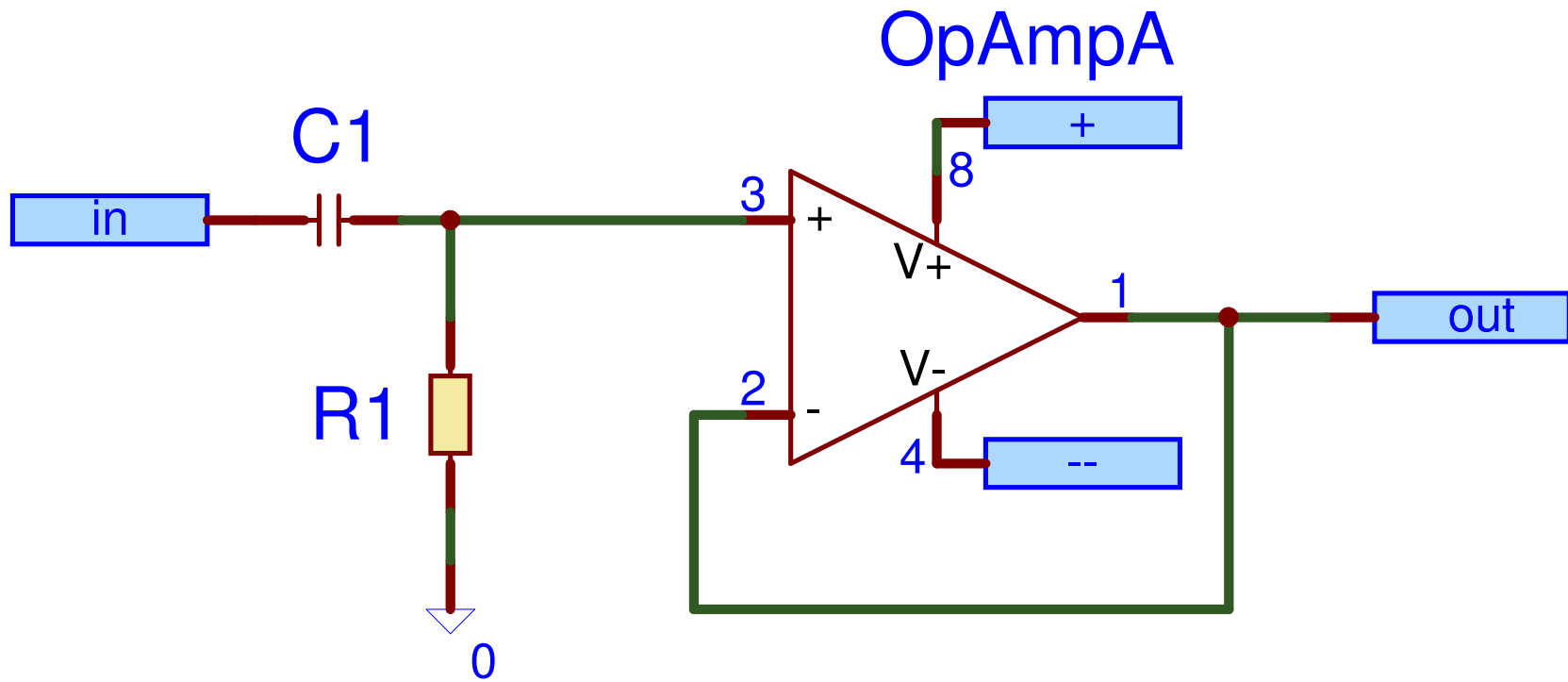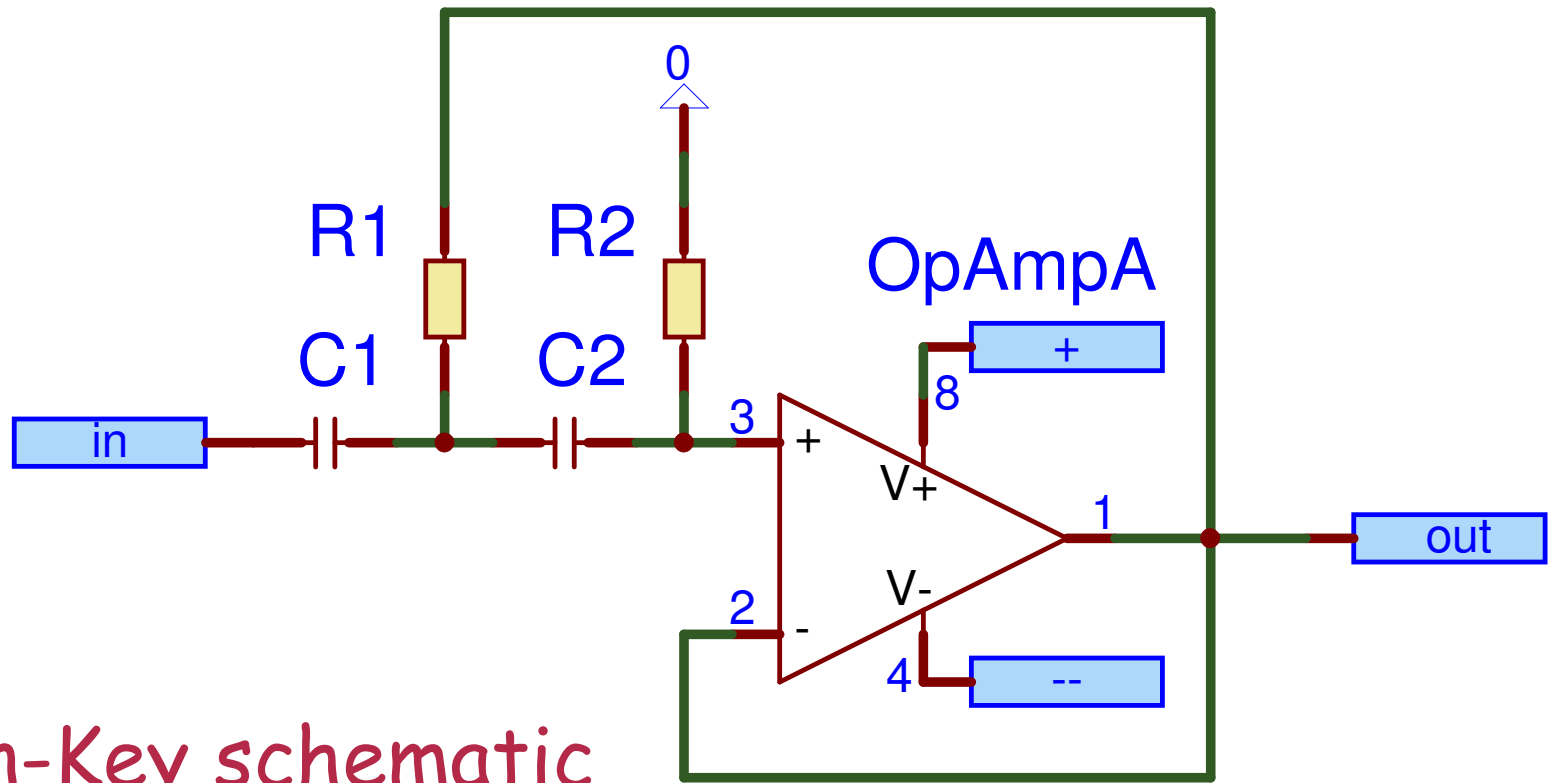Chebyshev Low-Pass Filter. Order 2N. Gain 0dB. PRN 0.1dB, 0.5dB, 1dB, 2dB, 3dB.

Frequence response

0.7Fc, PRN 3dB
0.7Fc, PRN 2dB
0.7Fc, PRN 1dB
0.7Fc, PRN 0.5dB
0.7Fc, PRN 0.1dB

Fc

Freq. = 2Fc, -3dB per the first octave.

Freq. = 2Fc, -9dB per the first octave.

Freq. = 2Fc, -10.2dB per the first octave.

Freq. = 2Fc, -12.8dB per the first octave.

Freq. = 2Fc, -14dB per the first octave.

6.2

0

-10.0

-20.0

0.1Fc   0.3Fc   Frequency   Fc   3Fc

□ VDB(in) ◇ VDB(out_3) ▽ VDB(out_2) △ VDB(out_1) ○ VDB(out_0.5) + VDB(out_0.1)

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Chebyshev Low-Pass Filter. Order 2N. Gain 0dB. PRN 0.1dB, 0.5dB, 1dB, 2dB, 3dB.

Phase response

PRN 0.1dB. Freq.= Fc, Phase −45d.

PRN 0.5dB. Freq.= Fc, Phase −70d.

PRN 1dB. Freq.= Fc, Phase −85d.

PRN 2dB. Freq.= Fc, Phase −103d.

PRN 3dB. Freq.= Fc, Phase −115d.

Phase −180d.

□ VP(out_3) ◇ VP(out_2) ▽ VP(out_1) △ VP(out_0.5) ○ VP(out_0.1) + −180

Frequency

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Chebyshev Low-Pass Filter. Fc = 1kHz. Order 2N. Gain 0dB. PRN 0.1dB, 0.5dB, 1dB, 2dB, 3dB.

Group Delay Time respomse

PRN 3dB, Fc = 1kHz, GDT=0.35ms.
PRN 2dB, Fc = 1kHz, GDT=0.34ms.
PRN 1dB, Fc = 1kHz, GDT=0.30ms.
PRN 0.5dB, Fc = 1kHz, GDT=0.25ms.
PRN 0.1dB, Fc = 1kHz, GDT=0.15ms.

EXAMPLE

600us
500us
400us
300us
200us
100us
0s

1.0Hz   10Hz   100Hz   1.0KHz   10KHz   100KHz

□ VG(out_3)   ◇ VG(out_2)   ▽ VG(out_1)   △ VG(out_0.5)   ○ VG(out_0.1)

Frequency

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High-pass filter, N1, 0dB.

OpAmpA

C1

in

R1

+

3

8

V+

2

V-

4

1

--

out

0

High-pass filter, N2, 0dB.

R1 R2

0

C1 C2

OpAmpA

in

3 +

+

8

V+

2 −

1

V−

out

4 −−

Sallen-Key schematic

High-pass filter, N3, 0dB.

OpAmpA

C1

R3   R4

OpAmpB

in   +   8   3   +   5   +   8   out

V+   1   V+   7

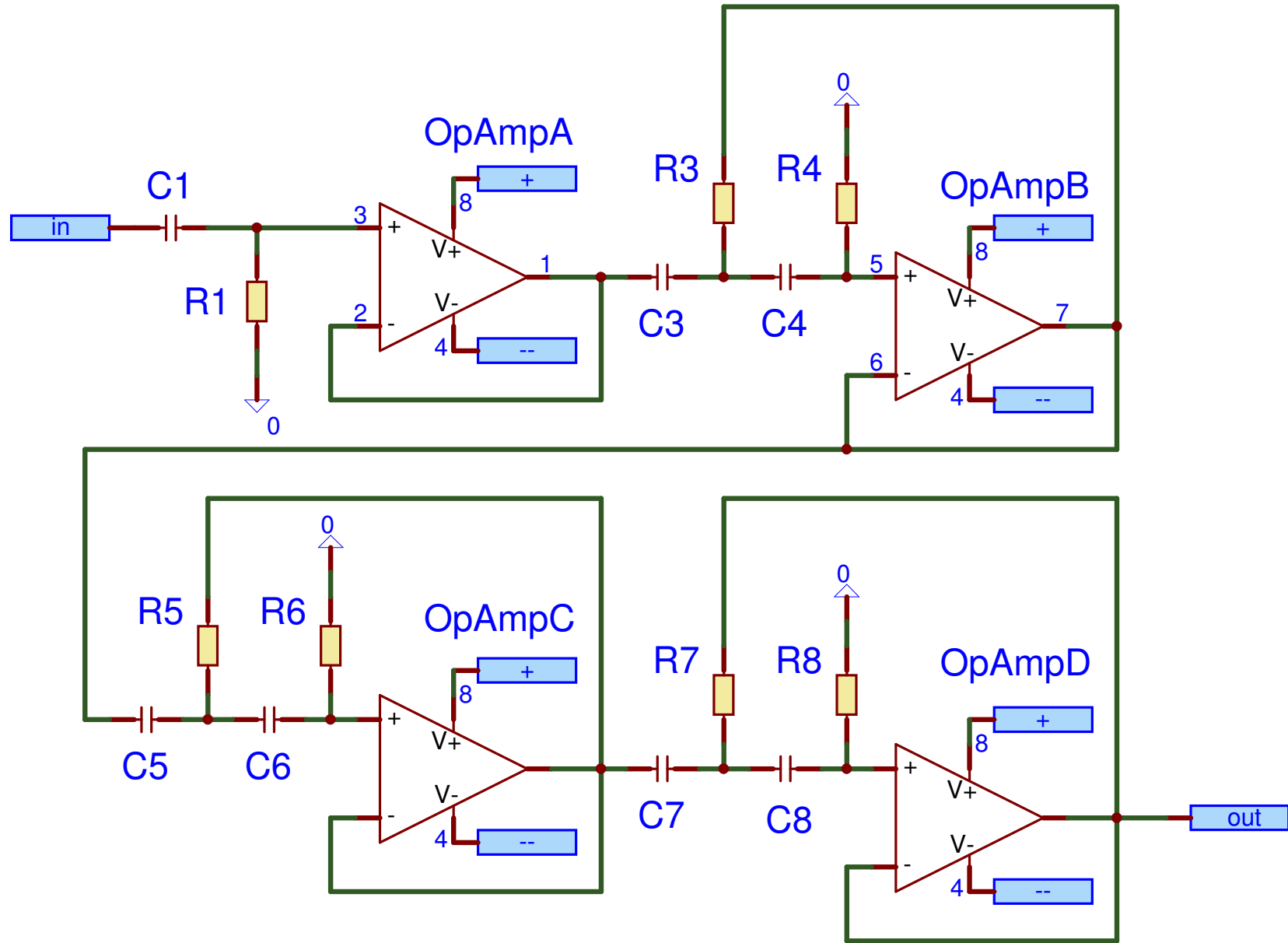R1   2   -   V-   C3   C4   6   -   V-

4   --   4   --

0
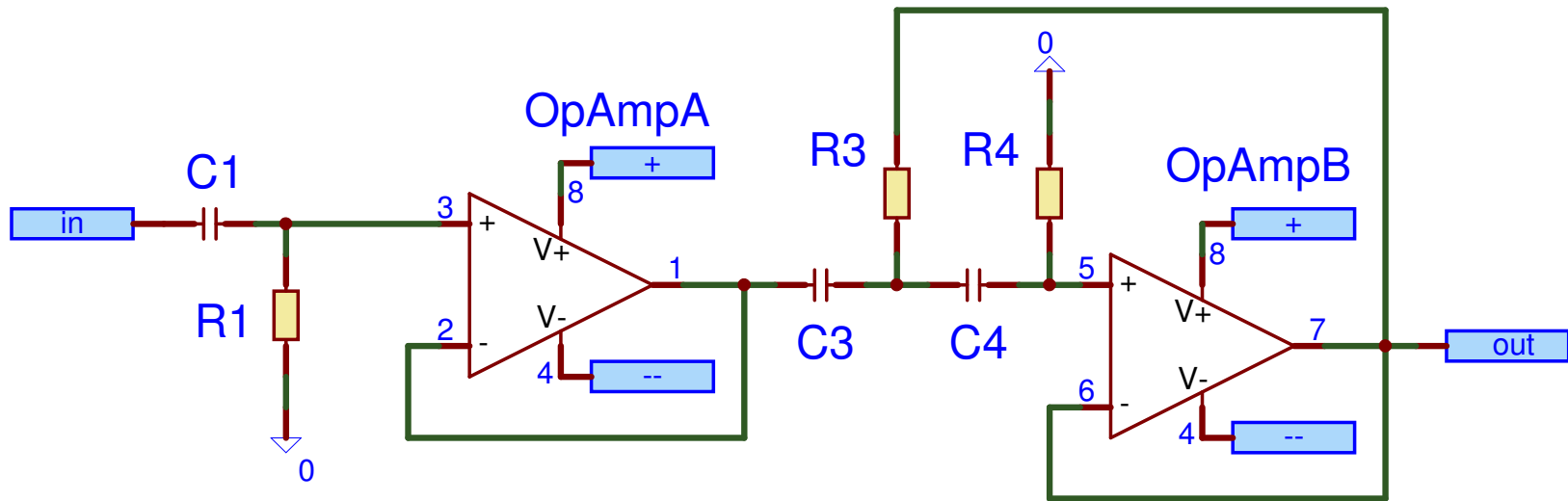
Sallen-Key schematic

High-pass filter, N4, 0dB.
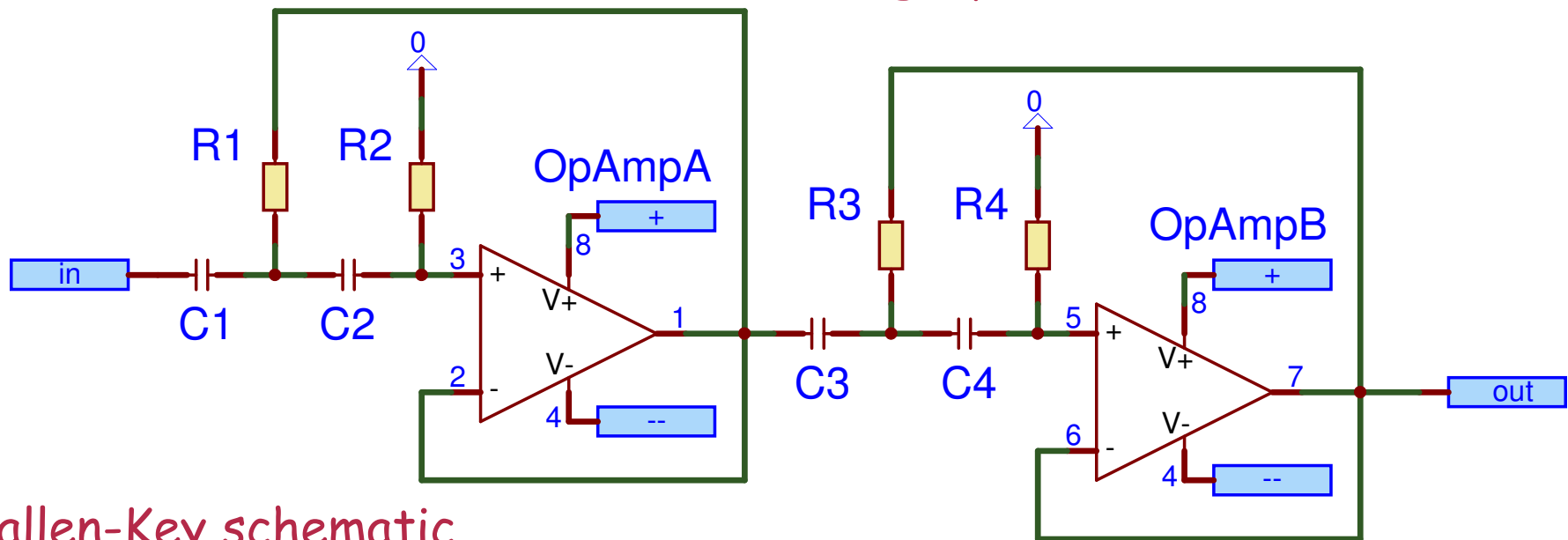
Sallen-Key schematic

High-pass filter, N5, 0dB.
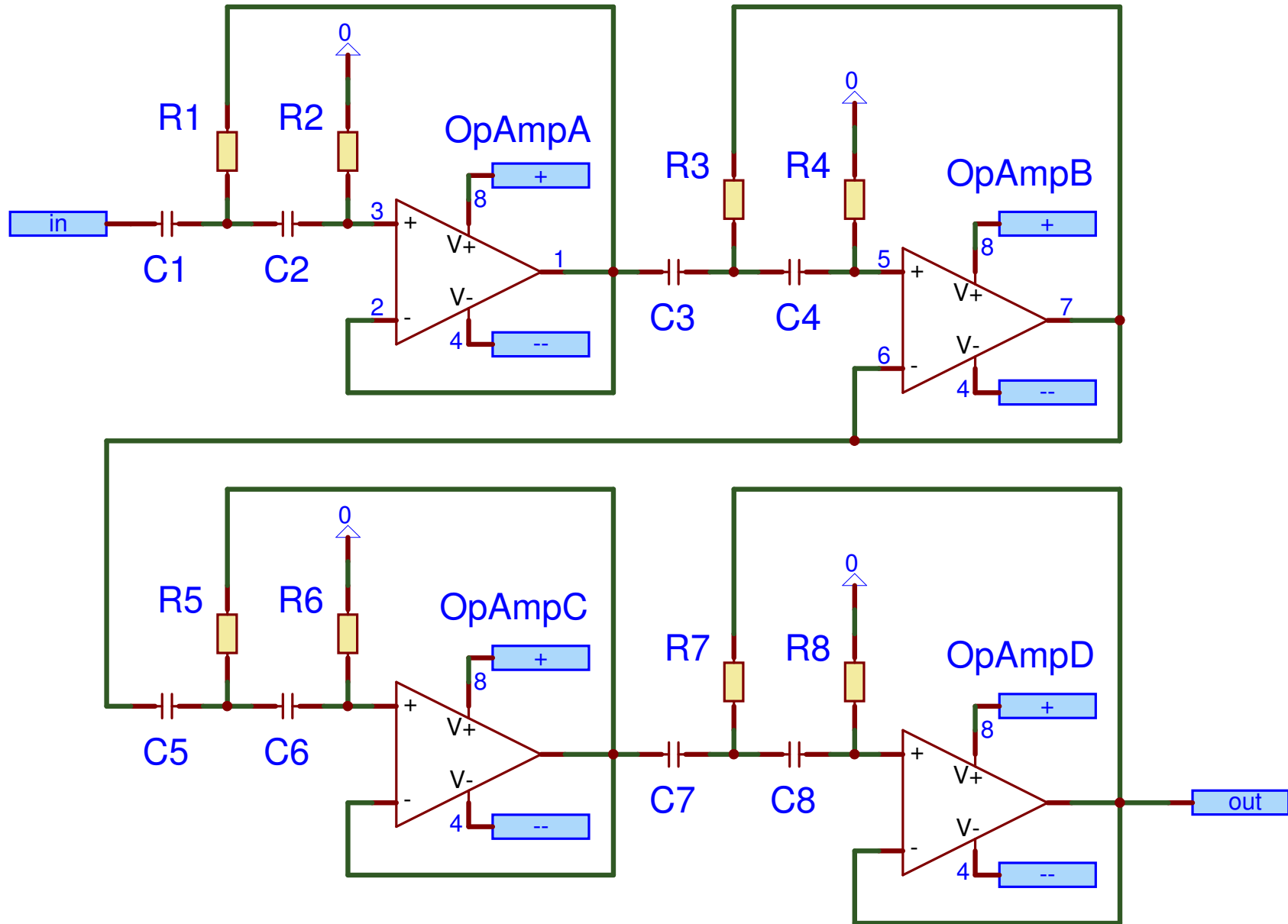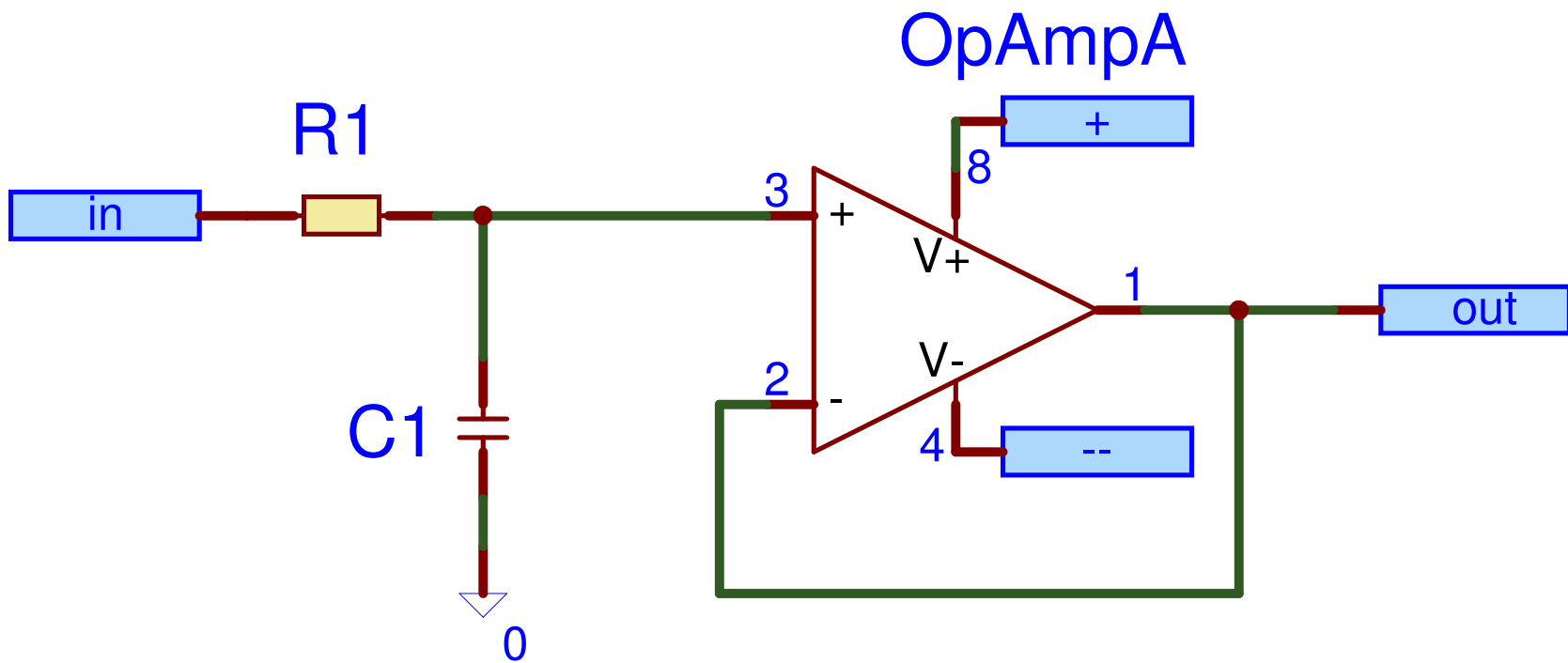

Sallen-Key schematic

High-pass filter, N6, 0dB.
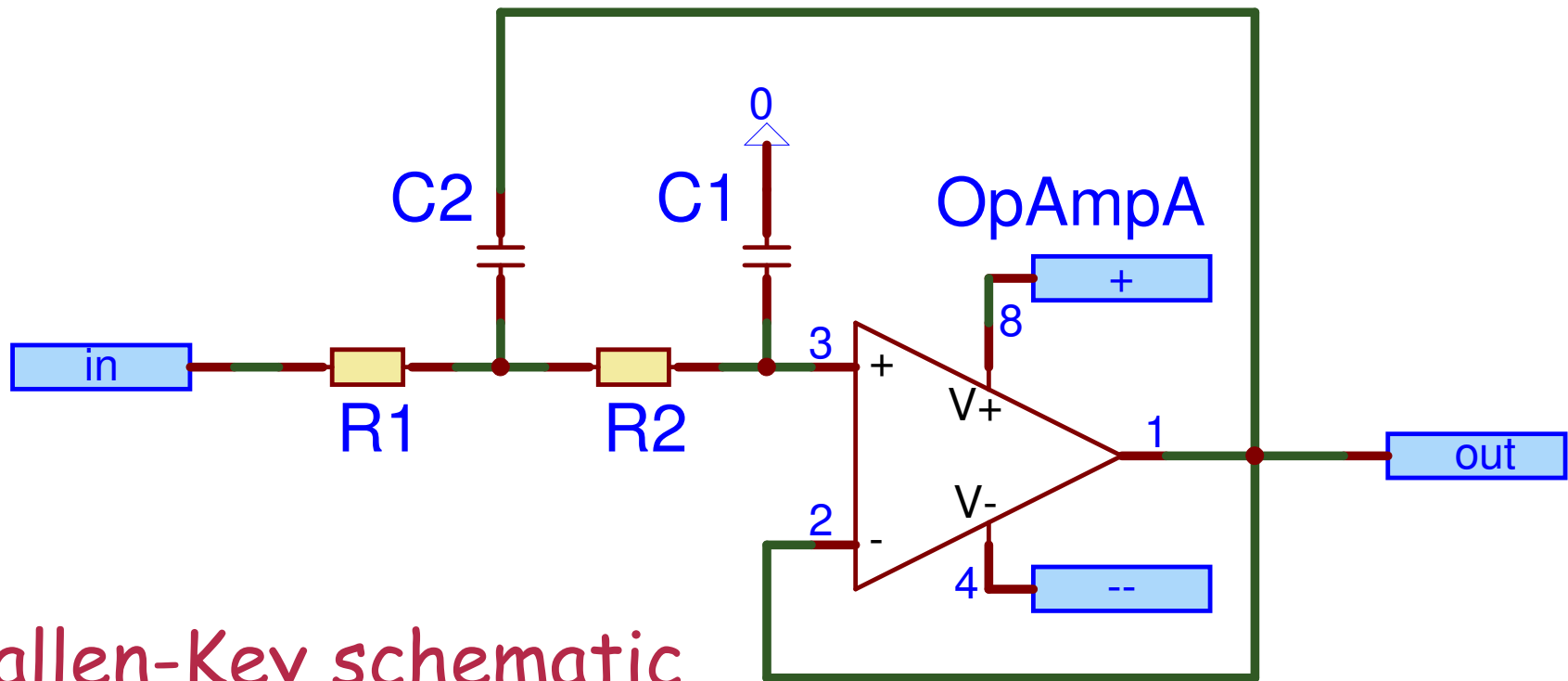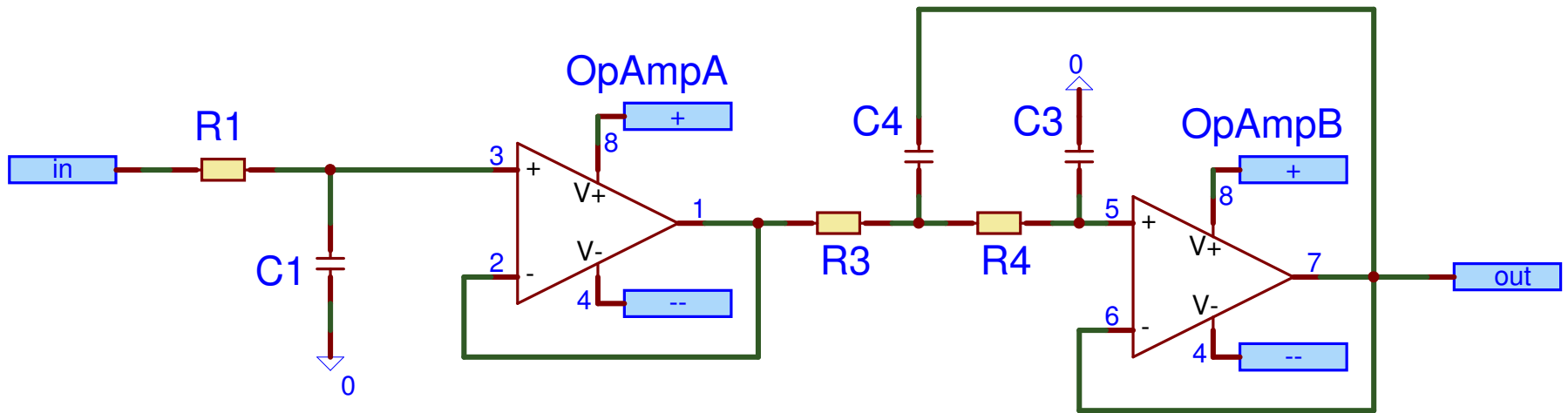
R1 R2 OpAmpA
in C1 C2 3 + 8 +
    V+
    1
    2 - V-
    4 --

R3 R4 OpAmpB
    5 + 8 +
    V+
    7
    6 - V-
    4 --
C3 C4

R5 R6 OpAmpC
    + 8 +
    V+
    out
    - V-
    4 --
C5 C6

Sallen-Key schematic

High-pass filter, N7, 0dB.

OpAmpA

C1

in

R1

R3 R4

OpAmpB

3 +
V+
8
+

2 −
V−
4
−−

1

C3 C4

5 +
V+

6 −
V−
4
−−

7

0

0

R5 R6

OpAmpC

0

R7 R8

OpAmpD

0

C5 C6

+
V+
8
+

−
V−
4
−−

C7 C8

+
V+
8
+

−
V−
4
−−

out

Sallen-Key schematic

High-pass filter, N8, 0dB.

R1 **R2** **OpAmpA**

R3 **R4** **OpAmpB**

+

8

in

3 +

V+

1

2 -

V-

4 --

C1 **C2**

+

+

8

5 +

V+

7

6 -

V-

4 --

C3 **C4**

R5 **R6** **OpAmpC**

R7 **R8** **OpAmpD**

+

8

+

V+

2 -

V-

4 --

C5 **C6**

+

+

8

+

V+

V-

-

4 --

C7 **C8**

out

Sallen-Key schematic

Low-pass filter, N1, 0dB.

OpAmpA

R1

in

out

3

+

V+

2

-

V-

8

+

1

4

--
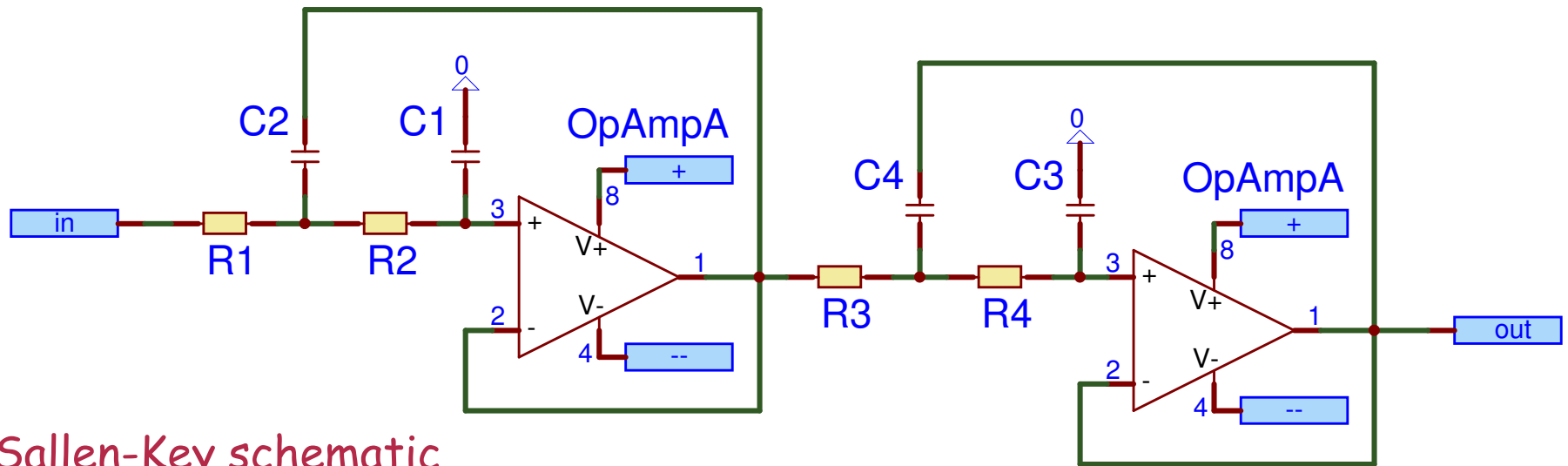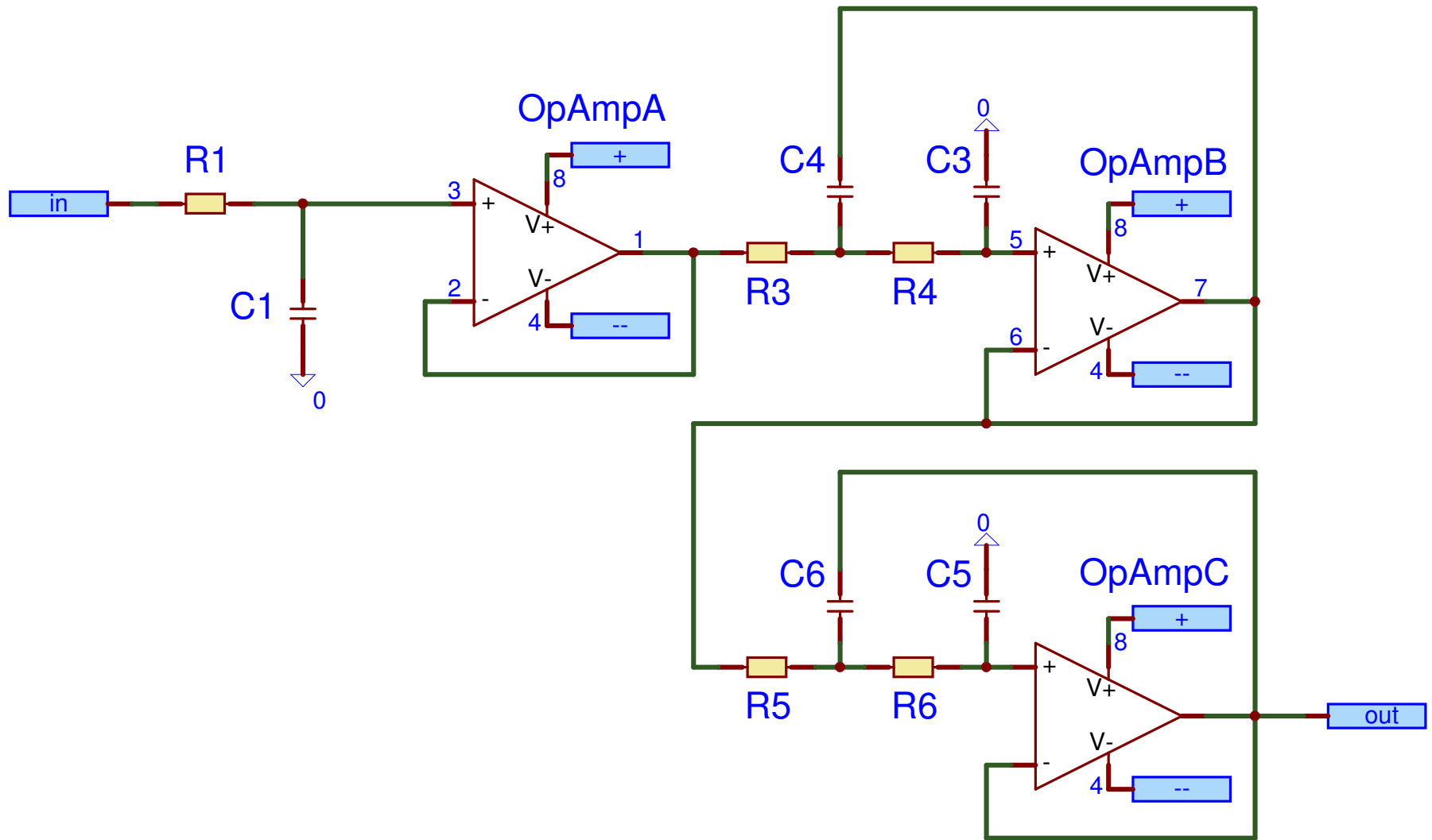
C1

0

Low-pass filter, N2, 0dB.

Sallen-Key schematic

Low-pass filter, N3, 0dB.

Sallen-Key schematic

Low-pass filter, N4, 0dB.

C2   C1   OpAmpA

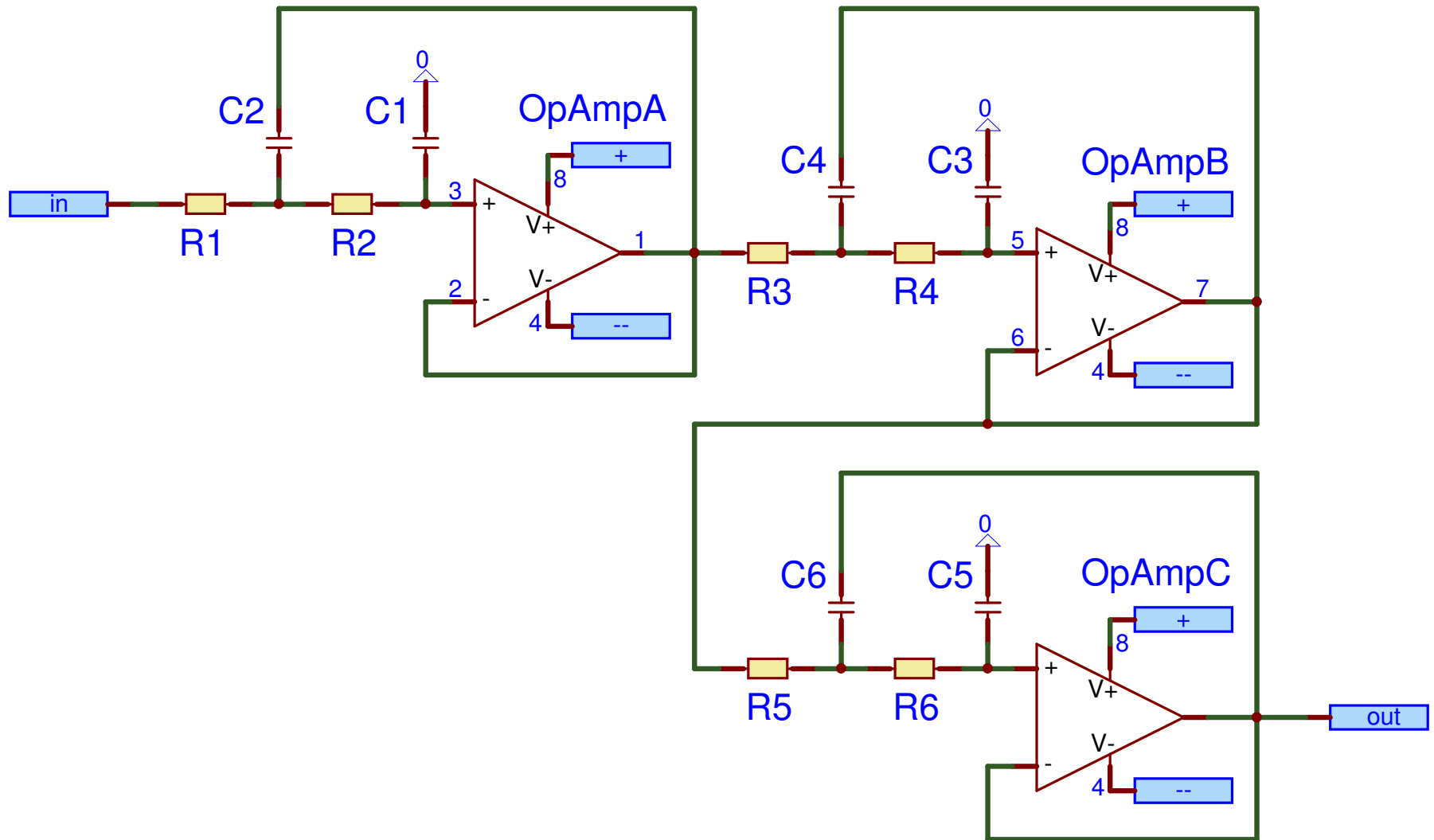in —[R1]—[R2]— 3 +
                        V+ 8 [+]
                        1
                     2 - V-
                        4 [--]

C4   C3   OpAmpA

[R3]—[R4]— 3 +
                    V+ 8 [+]
                    1 — out
                 2 - V-
                    4 [--]

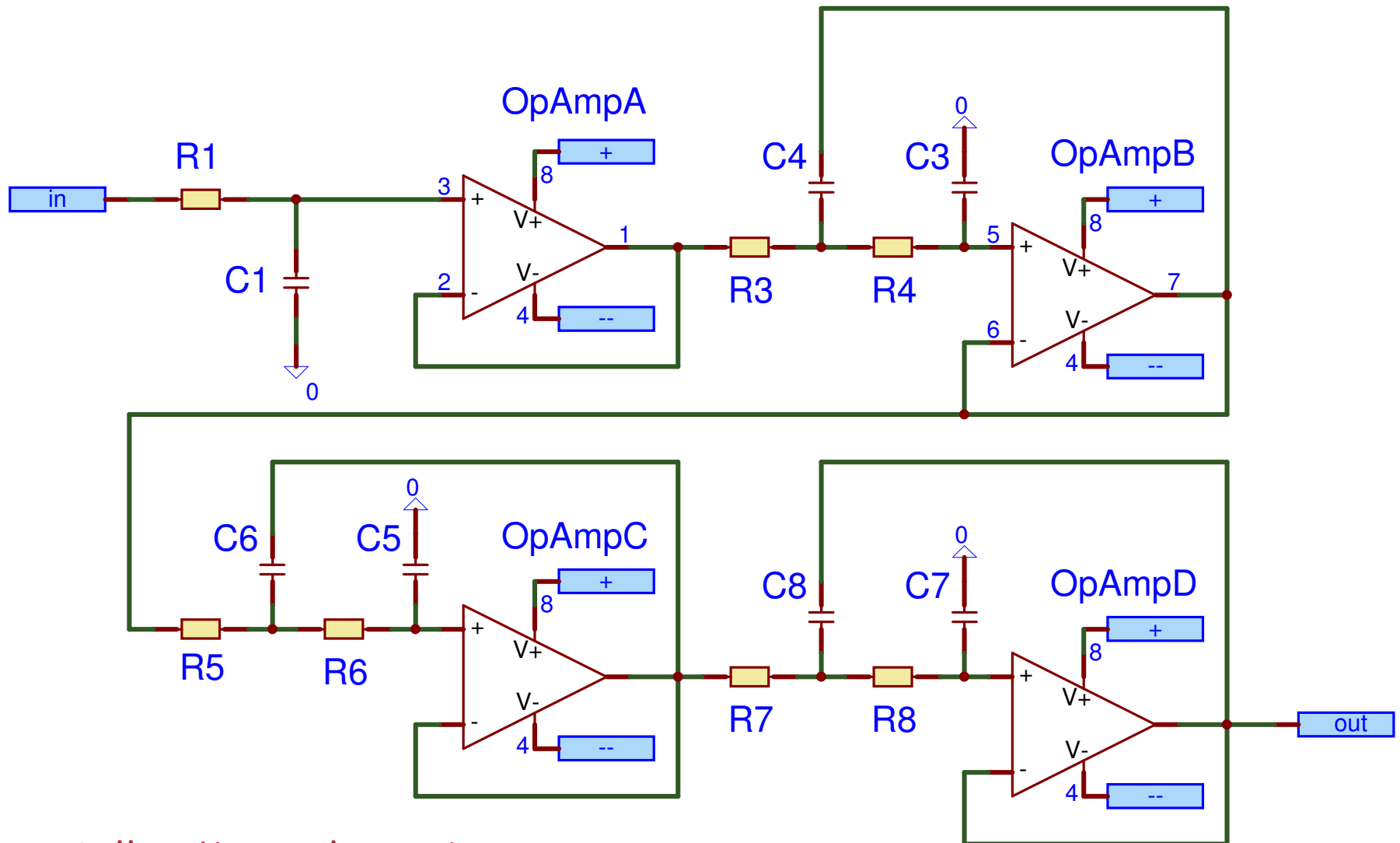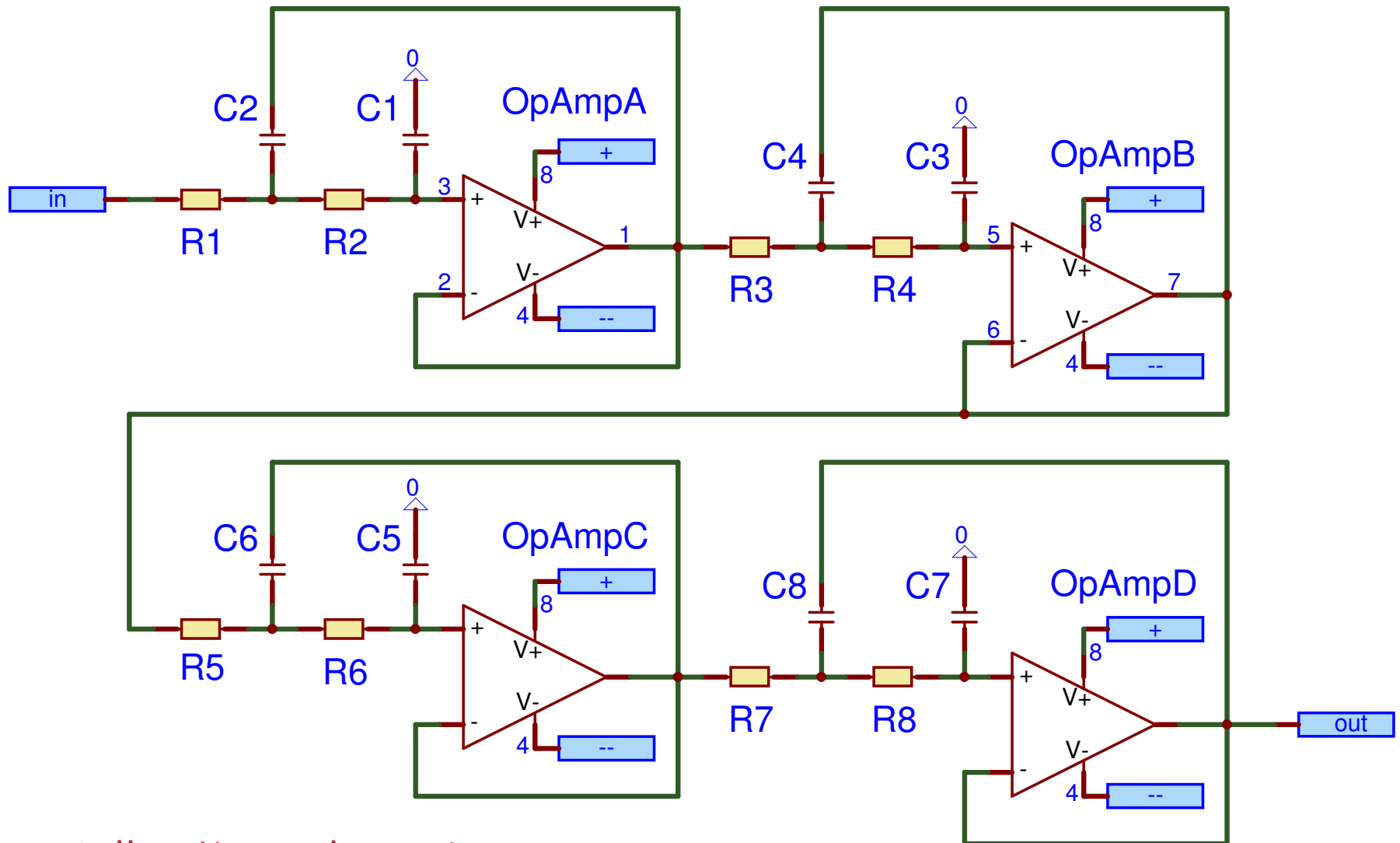Sallen-Key schematic

Low-pass filter, N5, 0dB.

Sallen-Key schematic

Low-pass filter, N6, 0dB.

Sallen-Key schematic

Low-pass filter, N7, 0dB.

Sallen-Key schematic

Low-pass filter, N8, 0dB.

Sallen-Key schematic