Unit 48 Active filters

- Active filters contain active devices such as transistors or op-amps so as to give gain as well as filtering action.
- The main advantage of active filters is that their performance can be made to be more independent of the signal source and load impedances.
- An iterative process is usually used to choose the best of the many possible designs for a particular application.

The passive filters examined in earlier units have the advantage of simplicity but their performance depends on the output impedance of the signal source and the input impedance of the load. This means that the corner frequencies can be changed when the passive filter is connected to different circuits.

More reliable performance is achieved by using active filters; that is, filters which include amplifiers such as op-amps to give some gain as well as filter action.

There are many hundreds of active filter designs which are well documented in specialist texts. We will examine one representative design which uses op-amps and which is suitable for use in the audio frequency region of the spectrum, that is for frequencies below about 10 kHz. These particular designs have been chosen for discussion because the author has used them in many applications and always found them to give consistent performance.

The three filters examined are low pass, high pass and band pass filters. The circuits for each type are given in Figures 48.1, 48.2 and 48.3. A useful feature of the design is that the shape of the circuit is the same in each case and that it is possible to use the same printed circuit board with different components to construct all three filters. This means that pcbs can be held ready in stock and used for different purposes, as needed.

A set of equations is given for each filter. In an RC filter there are many possible values for R and C which give a particular value of the RC product. Good design and also some experience will lead the user to avoid extreme values of R and C. In designing these filters you should try to use values of R within the range $100\,\Omega$ to $1\,\text{M}\Omega$ and values for C within the range 1 nF to $1\,\mu$F.

The design procedure is to make a guess at a reasonable value for some of the components, as indicated in each case, and then follow through the calculation to see if reasonable values of the other components are obtained from the calculations. The calculation is then repeated, using improved starting values until a satisfactory design is obtained. This iteration is best carried out by using a computer program or a programmable calculator. The writing of a suitable program is left as an exercise for the reader.

Besides the quantities, frequency, bandwidth and gain, which we have already met, we have the new parameter called peaking factor, α. The peaking factor describes the sharpness of the edge of a low or high pass filter. Some typical values for the increase in the gain at the band edge for high pass and low pass filters are shown in the table below.

α	0.1	0.3	1.0	1.4
dB peaking	20	10	3	0
Gain increase	10	3.16	1.4	1.0

Low pass filter

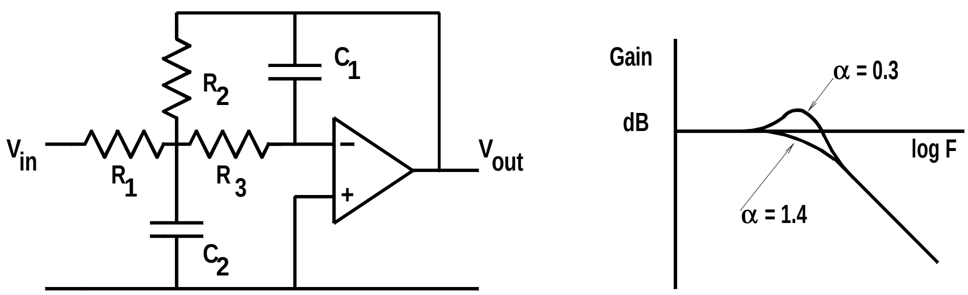

Figure 48.1: Low pass filter.

$$
\begin{aligned}
\text{Specified design quantities} \quad f &= \text{Cutoff frequency, Hz} \\
\alpha &= \text{Peaking factor} \\
A &= \text{Gain} \\
\text{Initial estimate} \quad C_1 &\ \text{in}\ \mu\text{F} \\
\text{Then} \quad C_2 &= \frac{4(1+A)C_1}{\alpha^2}\ \mu\text{F} \\
R_2 &= \frac{\alpha \times 10^6}{4\pi f C_1} \\
R_1 &= \frac{R_2}{A} \\
R_3 &= \frac{R_2}{1+A}
\end{aligned}
$$

High pass filter

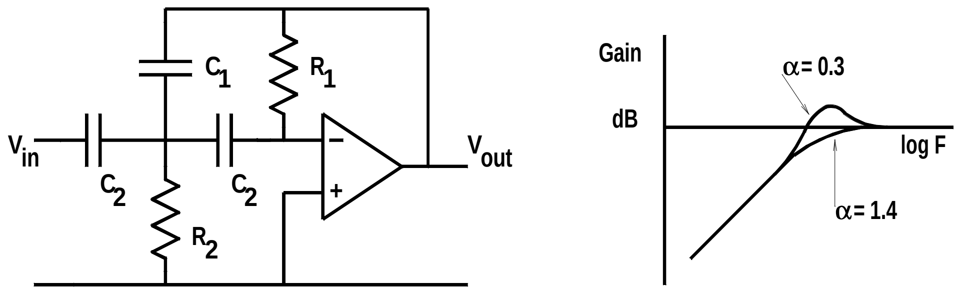

Figure 48.2: High pass filter.

$$
\begin{aligned}
\text{Specified design quantities}\quad f &= \text{Cutoff frequency, Hz} \\
\alpha &= \text{Peaking factor} \\
A &= \text{Gain} \\
\text{Initial estimate}\quad C_2 &\ \text{in}\ \ \mu\text{F} \\
\text{Then}\quad C_1 &= \frac{C_2}{A}\,\mu\text{F} \\
R_1 &= \frac{(2A+1)\times 10^6}{2\pi f \alpha C_2} \\
R_2 &= \frac{\alpha A \times 10^6}{2\pi f C_2 (2A+1)}
\end{aligned}
$$

Band bass filter

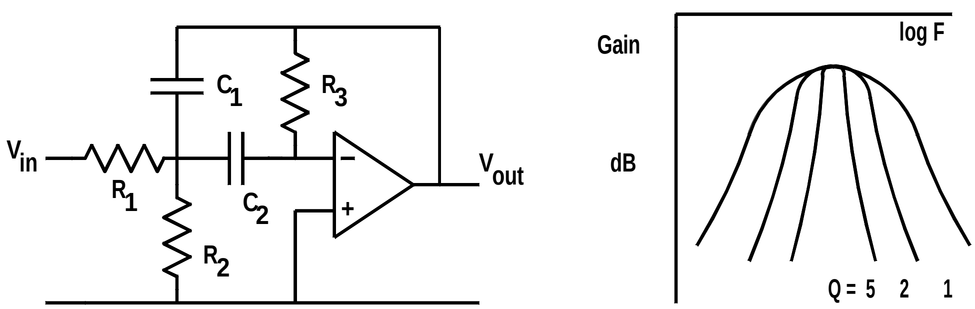

Figure 48.3: Band pass filter.

$$
\begin{aligned}
\text{Specified design quantities} \quad f &= \text{Centre frequency, Hz} \\
B &= \text{Bandwidth at 3dB down from peak} \\
A &= \text{Gain} \\
\text{Initial estimate} \quad C_1 &\ \text{in}\ \mu\text{F} \\
C_2 &\ \text{in}\ \mu F \\
\text{Then} \quad Q &= \frac{f}{B} \\
R_1 &= \frac{Q \times 10^6}{2\pi f A C_1} \\
R_2 &= \frac{1}{2\pi f Q (C_1 + C_2) \times 10^{-6} - \frac{1}{R_1}} \\
R_3 &= \frac{Q \times 10^6}{2\pi f} \left(\frac{1}{C_1} + \frac{1}{C_2} \right)
\end{aligned}
$$

48.1 Example

48.1 Design a low pass filter for a cutoff frequency of 1500 Hz, a gain of 12 and 3 dB of peaking at the band edge.

Use the circuit of Figure 48.1. A peaking of 3 dB at the band edge corresponds to a peaking factor of $\alpha = 1$, from the table. Make an initial estimate for C_1 and use the formulae for C_2, R_1, R_2 and R_3. The calculations can be presented as a table of successive iterations.

Iteration	1	2	3	4	5	6	Units
C_1	1.0	0.1	0.01	0.001	0.0005	0.0001	μF
C_2	52	5.2	0.52	0.052	0.026	0.005	μF
R_1	4.4	44	442	4.4k	8.8k	44k	Ω
R_2	53	530	5.3k	53k	106k	530 k	Ω
R_3	4.1	41	410	4.1k	8.2k	41k	Ω

In principle, all of these calculations give valid and correct filter design values.

In practice, iterations 1, 2 and 3 have such low resistances that the filter input impedances will be too low, typical op-amps will not be able to drive the large currents through the low resistances and the power consumption will be unnecessarily high.

Iteration 6 and any further iterations with smaller values of C_1 have overlarge values of R and the assumptions in the two rules for op-amps in Unit 39 begin to fail to be satisfied. Also high value resistors are unstable owing to current leakage in the thin moisture layer on the external surface of the resistors. If the capacitance of C_1 is too small, stray capacitances may come to dominate the operation of the circuit.

Therefore we reject otherwise valid designs when the resistances and capacitances are too small or too large. The circuit designer has to exercise judgment based on experience which is only sometimes codified in formal design rules. In this example, iteration 4 is a reasonable compromise.

The filter is fed with a signal from a signal source which itself has an output resistance. In principle, this source output resistance should be included in the value of R_1, otherwise the filter performance may be changed. However, we do not know the signal source resistance, so it is good practice to isolate the filter from the signal source by using a voltage follower stage in the input which has a high input impedance and low output impedance.

A suitable circuit, which includes this voltage follower input stage and which meets the stated requirements for frequency, peaking factor and gain, is shown in Figure 48.4. It should be noted that the calculated values for the resistors have been replaced by the nearest standard preferred value resistors.

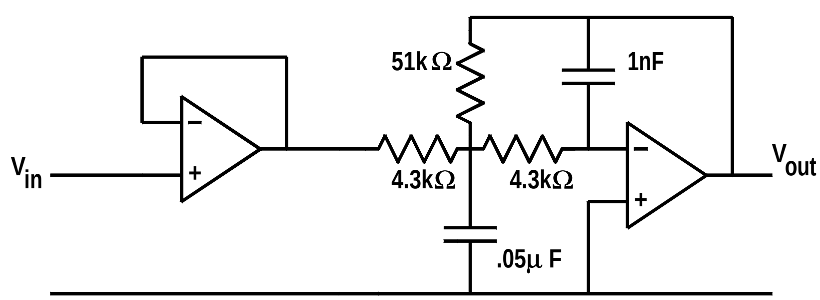

Figure 48.4: Example 48.1.

48.2 Problems

48.1 Design a low pass filter which has a cutoff frequency of 450 Hz, no peaking (0 dB) and a gain of 25. Draw your circuit design, showing the component values.

(These design values are given for reference purposes, to enable you to check your calculation method or program. They are not necessarily the best designs. $C_1 = 0.01\,\mu$F, $C_2 = 0.5\,\mu$F, $R_1 = 1\,$kΩ, $R_2 = 25\,$kΩ, $R_3 = 1\,$kΩ.)

48.2 Design a high pass filter which has a cutoff frequency of 80 Hz, a peaking of 10 dB and a gain of 6. Draw your circuit design, showing the component values.

(Reference design: $C_1 = 0.033\,\mu$F, $C_2 = 0.2\,\mu$F, $R_1 = 430\,$kΩ, $R_2 = 1377\,\Omega$.)

48.3 Design a band pass filter which has a centre frequency of 1.8 kHz, a bandwidth of 500 Hz and a gain of 15. Draw your circuit design, showing the component values.

(Reference design: $C_1 = 0.01\mu$F, $C_2 = 0.01\mu$F, $R_1 = 2122\,\Omega$, $R_2 = 2914\,\Omega$, $R_3 = 63.6\,$kΩ.)

48.4 Is it possible to design a band pass filter, using this design for a band pass filter, which has a centre frequency of 300 Hz, a gain of 17 and a bandwidth of 10 Hz?

48.5 A particular microphone has a frequency response which is flat to within 3 dB from 16 Hz to 16 kHz with a 20 dB per decade drop off outside this range. The microphone is connected to the input of a low pass filter having a corner frequency at 13 kHz and an $\alpha = 1$. Calculate and sketch the frequency response of the system.

48.6 Write a computer program which prompts the user to select the type of filter, the required filter parameters and initial estimates of C_1 and C_2. The program should then compute the resistor values and print the list of component values to the screen.