RC Filters

Related topics

High-pass, low-pass, Wien-Robinson bridge, parallel-T filters, differentiating network, integrating network, step response, square wave, transfer function.

Principle and task

The frequency response of simple RC filters is recorded by point-by-point measurements and the sweep displayed on the oscilloscope.

Equipment

Plug-in board, 4mm plugs	06033.00	1
Resistor in plug-in box 500 Ohms	06057.50	1
PEK capacitor/case 1/10 nF/ 500 V	39105.14	4
PEK carbon resistor 1 W 5% 1 kOhm	39104.19	5
PEK connect.plug white 19 mm pitch	39170.00	5
Difference amplifier	11444.93	1
Wobble-functiongenerator 2 Hz-6 MHz	11765.93	1
Oscilloscope, 20 MHz, 2 channels	11454.93	1
Adapter, BNC-plug/socket 4 mm	07542.26	2
Connecting cord, 100 mm, yellow	07359.02	1
Connecting cord, 500 mm, red	07361.01	2
Connecting cord, 500 mm, blue	07361.04	3
Screened cable, BNC, l 300 mm	07542.10	1
Screened cable, BNC, l 1500 mm	07542.12	1

Problems

To record the frequency response of the output voltage of

1. a high-pass filter
2. a low-pass filter
3. a band-pass filter
4. a Wien-Robinson bridge
5. a parallel-T filter,

point by point and to display the sweep on the oscilloscope.

To investigate the step response of

6. a differentiating network
7. an integrating network

Set-up and procedure

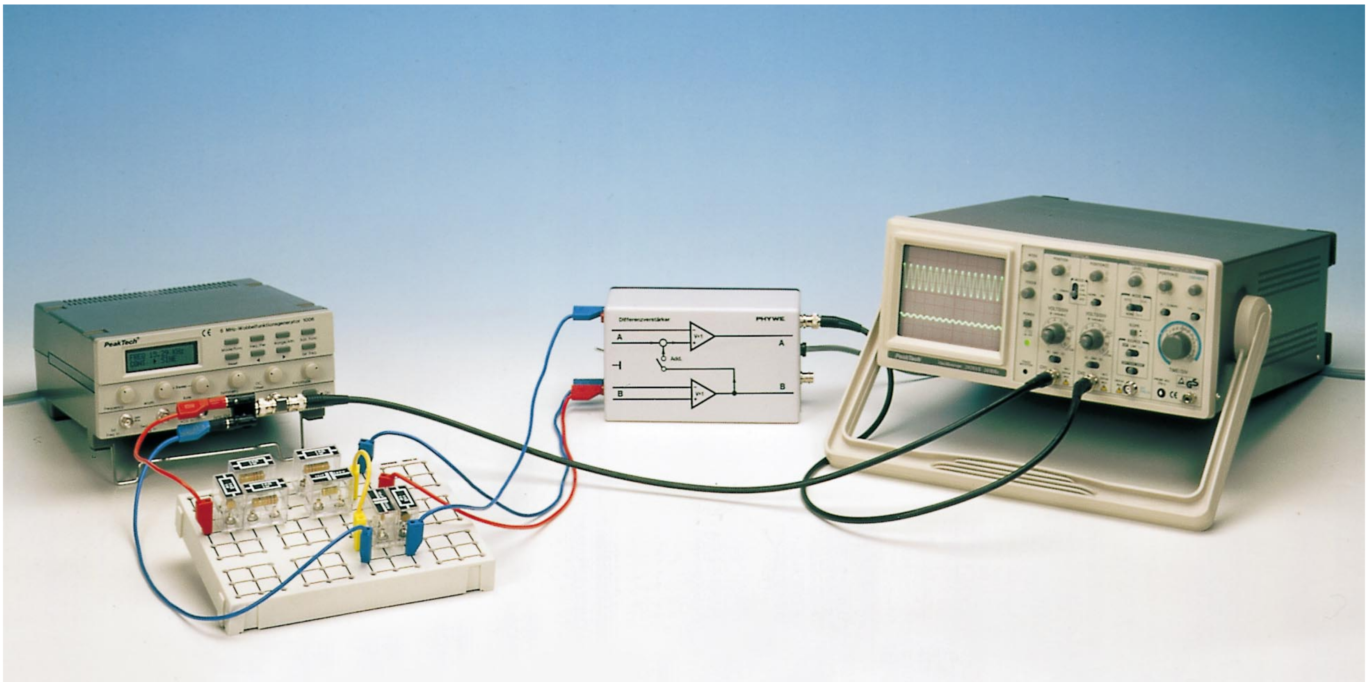
Set up the experiment in accordance with Fig. 1 or the circuit diagrams in Figs. 2 to 6. To measure the frequency response point by point, the input and output voltages U_i and U_O are measured with the oscilloscope. The frequency response can also be displayed on the oscilloscope by sweeping the generator frequency. In this case the H-output of the generator is connected to the X-input of the oscilloscope in X-Y operation. In the case of the Wien-Robinson bridge, the output voltage is not connected to earth although the generator and oscilloscope are and have the same earth potential, and we have to use the differential amplifier. It should be noted that the upper cut-off limit of the differential amplifier is 100 kHz when the input voltage is $U_i \leq 2\ V_{\rho\rho}$.

The 20 nF capacitor required in the parallel-T filter is made up from two 10 nF capacitors connected in parallel.

To investigate the square-wave behaviour of the differentiating network (high-pass) and the integrating network (low pass), square-wave frequencies of 0.1, 1 and 10 times the cut-off frequency f_c are fed to the input.

The output voltage is displayed on the oscillscope.

Fig.1: Experimental set-up: Wien-Robinson bridge.



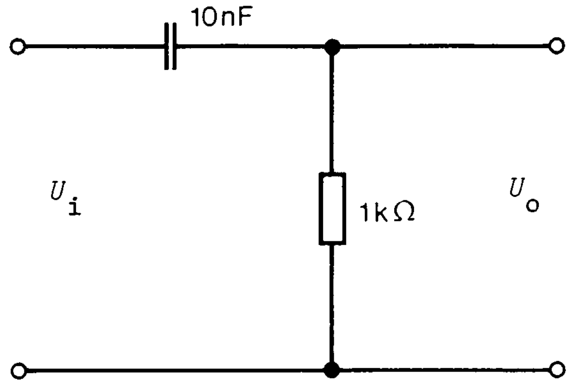


Fig. 2: High-pass filter.

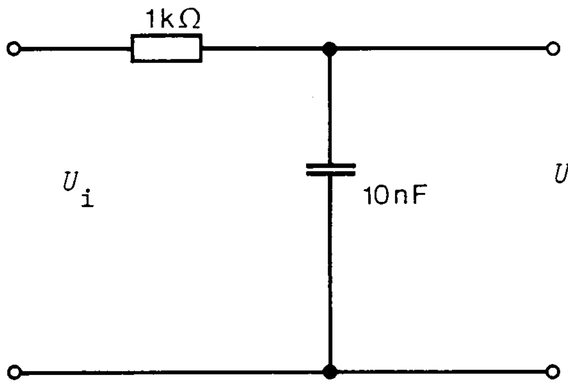


Fig. 3: Low-pass filter.

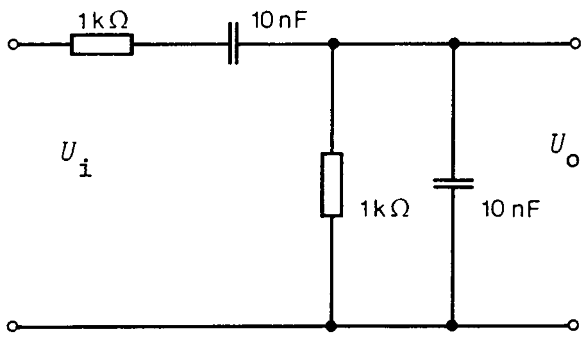


Fig. 4: Band-pass filter.

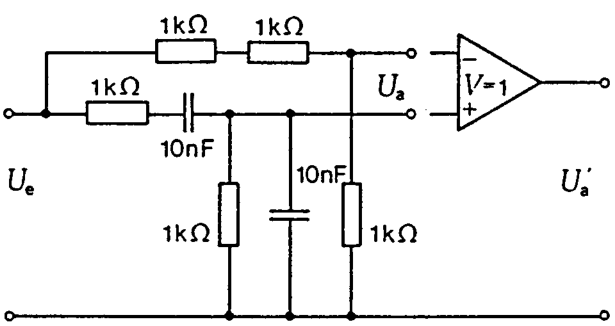
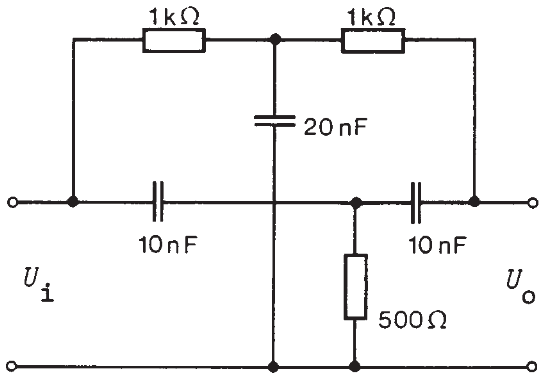


Fig. 5: Wien-Robinson bridge.

Fig. 6: Parallel-T filter.



Theory and evaluation

1. The high-pass filter is frequency-dependent voltage divider whose behaviour is described in complex terms by

$$\underline{A}\,(i\omega) = \frac{\underline{U}_O}{\underline{U}_i} = \frac{R}{R + \frac{1}{i\omega C}} = \frac{1}{1 + \frac{1}{i\omega RC}} \tag{1}$$

where ($i = \sqrt{-1}$). If we resolve for $\underline{A} = |\underline{A}| \cdot e^{i\phi}$ we obtain

$$|\underline{A}| = \frac{1}{\sqrt{1 + \frac{1}{\omega^2 R^2 C^2}}} \tag{2}$$

for the frequency response.

The 3 dB cut-off frequency f_c is the frequency at which

$$\left|\frac{\underline{U}_O}{\underline{U}_i}\right| = \frac{1}{\sqrt{2}}$$

applies. By substituting in (2) we obtain

$$f_c = \frac{\omega_c}{2\pi} = \frac{1}{2\pi\,RC}$$

2. From the voltage divider formula

$$\underline{A}\,(i\omega) = \frac{\frac{1}{i\omega C}}{R + \frac{1}{i\omega C}} = \frac{1}{1 + i\omega RC}$$

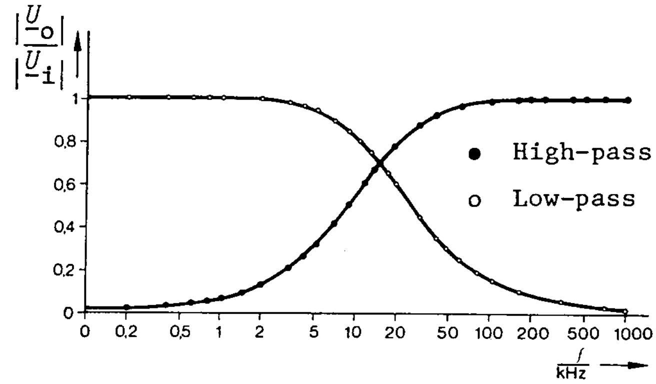
wehre $|\underline{A}| = \frac{1}{\sqrt{1 + \omega^2 R^2 C^2}}$

wie obtain the frequency response of the low-pass filter.

The 3 dB cut-off frequency is

$$f_c = \frac{1}{2\pi\,RC}$$

Fig. 7: Frequency response of high-pass and low pass filter.



3. If we connect a high-pass and a low-pass filter together we obtain a band-pass filter. The following equation, with the abbreviation $\omega RC = \Omega$, applies to the unloaded circuit:

$$\underline{A} = \frac{\frac{1}{\frac{1}{R} + i\omega C}}{\frac{1}{\frac{1}{R} + i\omega C} + R + \frac{1}{i\omega C}} = \frac{i\Omega}{1 + 3\,i\Omega - \Omega^2}$$

We thus obtain

$$|\underline{A}| = \frac{1}{\sqrt{(\frac{1}{\Omega} - \Omega)^2 + 9}}$$

The output voltage has its maximum value when

$$\Omega = 1.$$

The midband frequency f_m is thus

$$f_m = \frac{1}{2\pi RC}$$

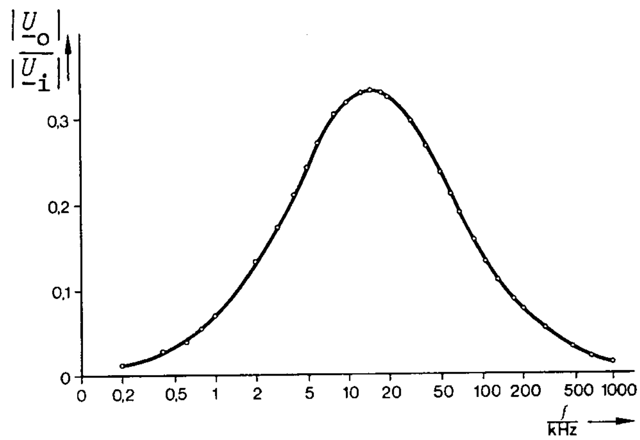
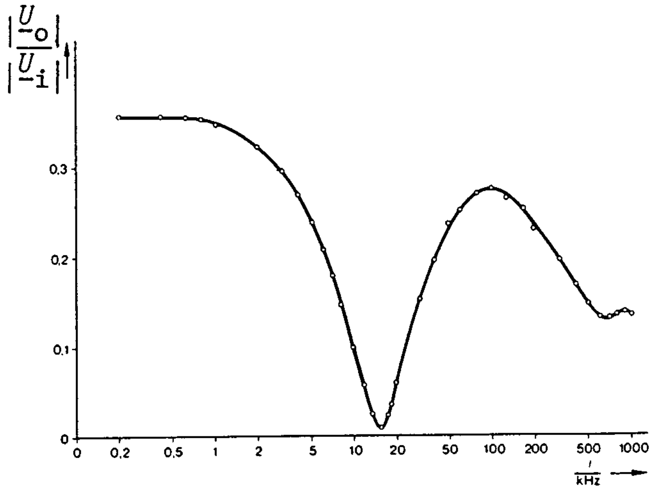


Fig. 8: Frequency response of the band-pass filter.

Fig. 9: Frequency response of the Wien-Robinson bridge. The drop beyond 100 kHz can be attributed to the differential amplifier.



4. If we add a parallel-connected voltage divider consisting of ohmic resistors in the ratio 2 : 1 to the band-pass, we obtain a Wien-Robinson bridge:

$$\underline{A} = \frac{1}{3} - \frac{i\Omega}{1+3\,i\Omega-\Omega^2}$$

$$|\underline{A}| = \frac{1 - \Omega^2}{3\sqrt{(1 - \Omega^2)^2 + 9\,\Omega^2}}$$

The output voltage has its minimum value at

$$f_m = \frac{1}{2\pi RC}$$

5. Unlike the Wien-Robinson bridge the parallel-T filter has the advantage that the output voltage is connected to earth. Using the nodal equation we obtain

$$\underline{A} = \frac{i\Omega}{1+4\,i\Omega-\Omega^2}$$

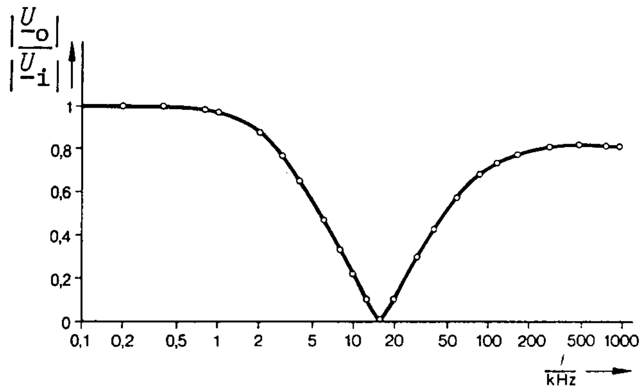
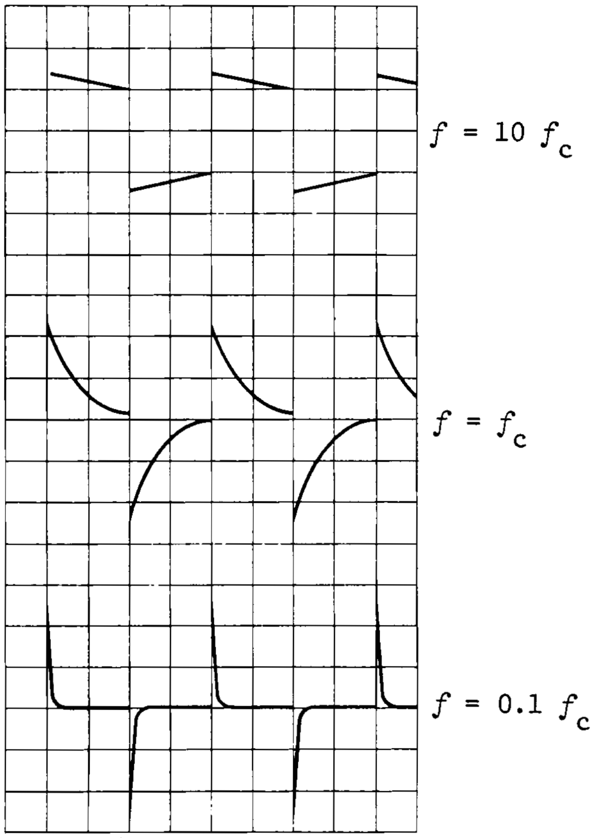


Fig. 10: Frequency response of the parallel-T filter.

Fig. 11: Square-wave behaviour of the high-pass filter at various frequencies.



$$|\underline{A}| = \frac{1 - \Omega^2}{\sqrt{(1 - \Omega^2)^2 + 16\,\Omega^2}}$$

The output voltage has its minimum value at

$$f_m = \frac{1}{2\pi\, RC}$$

6. The nodal equation

$$C \frac{d}{dt}(U_i - U_O) - \frac{U_O}{R} = 0 \qquad (3)$$

is applied to the unloaded output to calculate the step response of the differentiating network (high-pass).

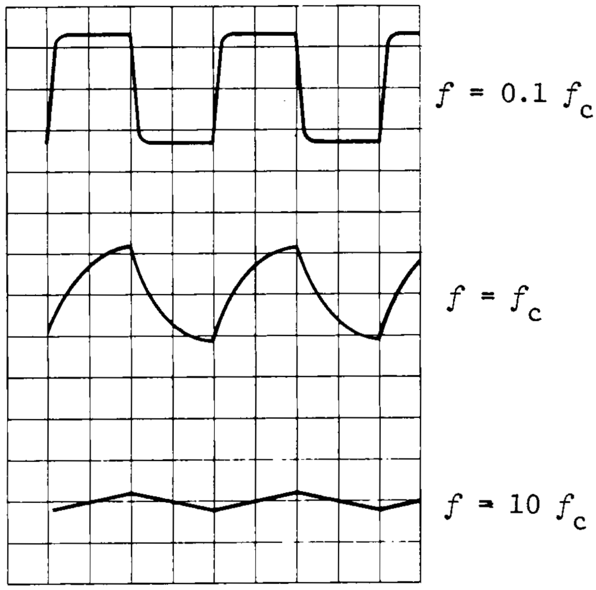
If input voltages U_i are used with frequencies $f << f_c$, then

$$U_O = R\,C \frac{d}{dt} U_i$$

follows from (3) because $U_O << U_i$.

Low-frequency input voltages are therefore differentiated.

Fig. 12: Square-wave behaviour of the low-pass filter at various frequencies.



7. Applying the nodal equation to the unloaded output of the low-pass filter gives

$$\frac{U_i - U_O}{R} - C\,\dot{U}_O = 0$$

If input voltages U_i are used with frequencies $f << f_c$, then

$$|U_O << U_i|$$

and we obtain from (4)

$$R\,C\,\dot{U}_O = U_i$$

or

$$U_O = \frac{1}{RC}\int U_i\, dt.$$

High frequency input voltages are therefore integrated.

Bibliography

U. Tietze & Ch. Schenk: Halbleiter-Schaltungstechnik (semiconductor circuits), Springer-Verlag, Berlin, Heidelberg and New York.