ACTIVE FILTERS

Active filters use amplifying elements — especially operational amplifiers — with resistors and capacitors to synthesize the desired filter characteristics.

- They are often easier to design than passive filters.
- They are usually smaller and less expensive because they do not comprise inductors. Thus, they are easily implemented on integrated circuits.
- Active filters can provide amplifier gain in addition to providing comparable frequency response as RLC filters.
- Active filters can be combined with buffer amplifiers to isolate each stage of the filter from source and load impedance effects.

Their limitations include:

- Active filters are less reliable and less stable.
- They have limited performance at high frequencies; they perform well below 100KHz. This is due to the gain-bandwidth product of the amplifying elements.
- Active filters generate noise due to amplifier circuitry.

This can be minimised by using low-noise amplifiers and careful circuit design.

Filters are usually categorised based on their order i.e. the number of poles, or their specific design types. There are the first-order, second-order, third-order etc. filters; we only briefly consider first- and second-order active filters.

First-Order Lowpass Filter

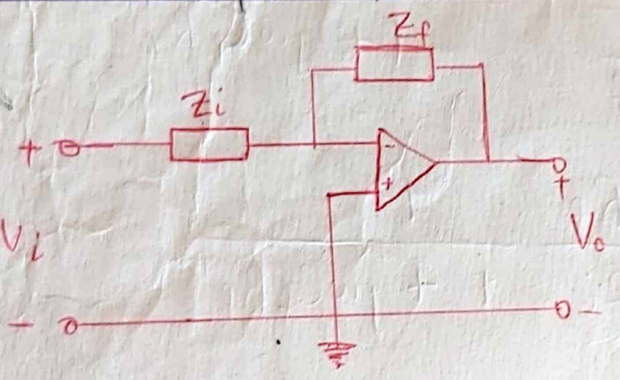

fig: A general first-Order Active filter

The general first-order filter could be a lowpass or highpass depending on the components chosen for Z_i and Z_f. In either case, one of these must be a reactive component.

The figure below shows a typical lowpass filter. The transfer function is:

$$H(\omega) = \frac{V_o}{V_i} = \frac{-Z_f}{Z_i}$$

where $Z_i = R_i$, and $Z_f = R_f \| \frac{1}{j\omega C_f}$

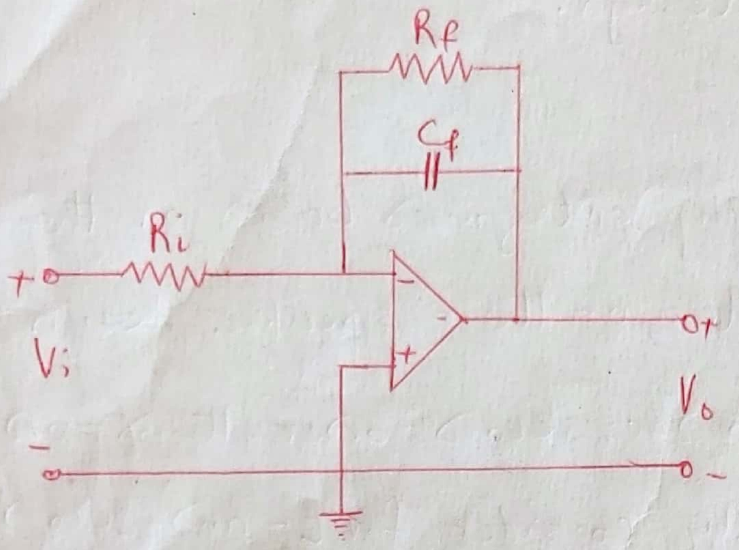

Figure: Active first-Order Lowpass filter

$$Z_f = \frac{R_f / j\omega C_f}{R_f + 1/j\omega C_f} = \frac{R_f}{1 + j\omega C_f R_f}$$

hence, $$H(\omega) = \frac{-R_f}{R_i} \frac{1}{1 + j\omega C_f R_f}$$

This is similar to $H(\omega) = \frac{1}{1 + j\omega RC}$ for the lowpass passive filter. The only difference is the low frequency or dc gain of $-R_f/R_i$ i.e. as $\omega \to 0$ (dc), $H(\omega) \Rightarrow -\frac{R_f}{R_i}$

The corner frequency is:

$$\omega_c = \frac{1}{R_f C_f}$$

ω_c is independent of R_i. This implies that even when several inputs with different R_i are required, the corner frequency is unchanged for each input.

First-Order Highpass Filter

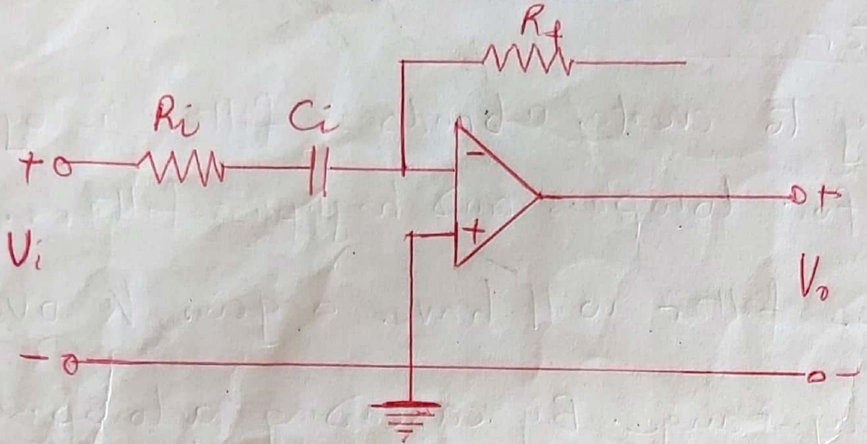

Fig: Active first-Order Highpass Filter

For the first-order highpass filter above,

$$H(\omega) = \frac{V_o}{V_i} = \frac{-Z_f}{Z_i}$$

where $Z_i = R_i + 1/j\omega C_i$, and $Z_f = R_f$.

Hence,

$$H(\omega) = \frac{-R_f}{R_i + \frac{1}{j\omega C_i}} = \frac{-j\omega C_i R_f}{1 + j\omega C_i R_i}$$

This is also similar to $H(\omega) = \frac{j\omega RC}{1 + j\omega RC}$ for the high pass passive filters ~~except for the high frequency gain~~ except that at high freq; ~~[illegible]~~ $(At\ \omega \to \infty,\ H(\omega) \to -R_f/R_i$

Its corner frequency is:

$$\omega_c = \frac{1}{R_i C_i}$$

Bandpass filter

An easy way to create a bandpass filter is by combining the circuits for lowpass and highpass filters. The resulting bandpass filter will have a gain, K over the required frequency range. By cascading a lowpass and a highpass filters with unity gains with an inverter with gain $-R_f/R_i$, a bandpass filter is obtained.

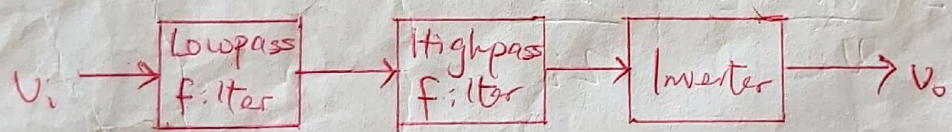

Fig: Block diagram of a Active Bandpass filter

The lowpass filter sets the upper cut-off frequency while the highpass filter sets the lower cut-off frequency. The inverter provides gain for the circuit.

The transfer function is obtained by multiplying the transfer functions of the lowpass and highpass filters with the gain of the inverter. i.e.

$$H(\omega) = \frac{V_o}{V_i} = \left(-\frac{1}{1+j\omega C_1 R}\right)\left(-\frac{j\omega C_2 R}{1+j\omega C_2 R}\right)\left(-\frac{R_f}{R_i}\right)$$

$$= \frac{-R_f}{R_i} \frac{1}{1+j\omega C_1 R} \frac{j\omega C_2 R}{1+j\omega C_2 R}$$

and $\omega_2 = \frac{1}{RC_1}$ is the upper corner frequency for the lowpass section, while

$\omega_1 = \frac{1}{RC_2}$ is the lower corner frequency for the highpass section.

where $C_i = C_1$, and $C_f = C_2$.

Also, $\omega_0 = \sqrt{\omega_1 \omega_2}$

$B = \omega_2 - \omega_1$

and $Q = \omega_0 / B$

} same as for passive filters (bandpass)

The passband gain, K is given by:

$$K = \frac{R_f}{R_i} \cdot \frac{\omega_2}{\omega_1 + \omega_2}$$

Bandreject (Notch) Filter

A simple construction of a bandreject filter involves a parallel combination of a lowpass filter and a highpass filter with a summing amplifier. The lower cut-off frequency, ω_1, is set by the lowpass filter while the upper cut-off frequency, ω_2 is set by the highpass filter. $\omega_2 - \omega_1$ is the filter bandwidth; the filter passes frequencies below ω_1 and above ω_2.

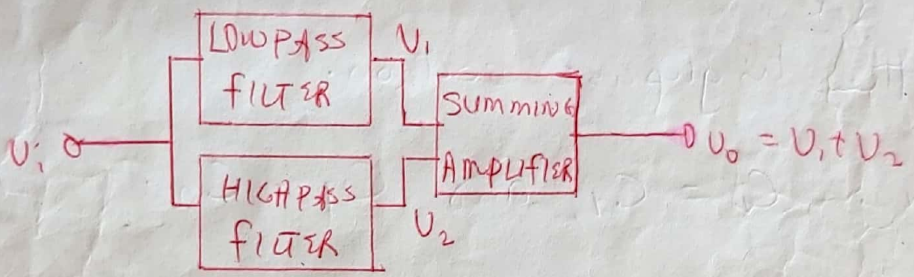

Fig: Block diagram of an Active Bandreject filter

The transfer function is obtained as:

$$H(\omega) = \frac{V_o}{V_i} = \frac{R_f}{R_i}\left(-\frac{1}{1+j\omega C_1 R} - \frac{j\omega C_2 R}{1+j\omega C_2 R}\right)$$

The equations for $\omega_1, \omega_2, \omega_c$, B and Q are the same as those for the bandpass filter.

The ~~ban~~ passband gain, K, however is obtained as:

$$K = \frac{R_f}{R_i}$$

The four filter types i.e. lowpass, highpass, bandpass and bandreject active filters are just typical examples; there exists several other complex active filters circuit designs.

Examples:

(1) Design a lowpass active filter with a dc gain of 4 and a corner frequency of 500Hz. Assume $C_f = 0.5\mu F$

Solution:

$$\omega_c = 2\pi f_c = 2\pi \cdot 500$$

and $\omega_c = 2\pi 500 = \frac{1}{R_f C_f}$ —— (1)

$$H(\omega) = \frac{-R_f}{R_i} \cdot \frac{1}{1 + j\omega C_f R_f}$$

DC gain = 4 i.e. $H(0) = 4$ i.e. {$\omega = 0$ at dc}

$\Rightarrow H(0) = \frac{-R_f}{R_i} = +4$ —— (2)

Assuming $C_f = 0.5\mu F$

$\Rightarrow$ in (1), $R_f = \frac{1}{2\pi \times 500 \times 0.5 \times 10^{-6}}$

$$R_f = \frac{1}{0.0015708} = 636.6197\ \Omega$$

$$R_f \simeq 636.62\ \Omega$$

and $R_i = \frac{R_f}{4} = \frac{636.62}{4} = 159.154$

$$R_i \simeq 159\ \Omega$$

Thus, a $640\ \Omega$ resistor for R_f and a $160\ \Omega$ resistor for R_i in the lowpass active filter design. Draw the circuit diagram.

(ii) Design a highpass filter with a high-frequency gain of 5 and a corner frequency of 2KHz. Use a 0.1μF capacitor for the design.

Ans: $R_i = 800\ \Omega$, $R_f = 4K\Omega$

Scanned with CamScanner

APPLICATIONS OF FILTERS & RESONANT CIRCUITS

Resonant circuits and filters find wide applications in electronics, power systems and communication systems.

Resonant circuits – series and parallel – are used in radio and TV receivers to tune in stations and to separate the audio signal from the radio frequency carrier wave. The antenna of an AM radio receiver receives several AM radio waves at different frequencies from different broadcast stations. A resonant circuit (bandpass filter) is required to select just one of the incoming waves, and filter out the rest.

Filtering circuits are used in the touch-tone telephone set. Lowpass, highpass and bandpass filters are used to separate and identify signals generated from different numbers on the touch-tone dialler at the telephone exchange office.

The crossover network is another typical application of filters. This couples an audio amplifier to woofer and tweeter speakers. It consists basically of a highpass RC filter and a lowpass RL filter. Frequencies higher than a prescribed crossover frequency, fc are routed to a high-frequency loudspeaker i.e. tweeter while frequencies below fc are routed to a low-frequency loudspeaker i.e. woofer. Tweeters are high-frequency loudspeakers designed to reproduce audio frequencies from ≃3KHz to ≃20KHz; while woofers are low-frequency loudspeakers designed to reproduce audio frequencies up to ≃3KHz. The two are combined to reproduce the entire audio range of interest with optimum frequency response.

The resonant circuit of a TV receiver also adopts the concepts of crossover networks to separate the video and audio bands of the RF carrier frequencies. The picture information, carried in the lower-frequency band (≃30Hz – 4MHz) is channeled into the receiver's video amplifier, while the sound information, [carried in the high-frequency band (around 4.5MHz)] is channeled to the receiver's sound amplifier.