11.12: Summary

Filters are frequency-selective circuits. The basic forms are high-pass, low-pass, band-pass, and band-reject. Although filters may be constructed solely from resistors, capacitors, and inductors, active filters using op amps offer many advantages. These advantages include: modest component size, control over impedances and loading effects, elimination of inductors, and gain (if desired). The negative aspects include: frequency range limited by op amps used, power supply required, and the inability to handle large input/output powers. For many applications the advantages far outweigh the disadvantages, and therefore, active filters are used in a wide variety of modern products.

Filters are further defined by order and alignment. Order indicates the steepness of the attenuation slope. As a general rule, the eventual rolloff rate will equal 6 dB times the order, per octave. Order also indicates the minimum number of reactive elements needed to realize the filter. Alignment indicates the shape of the filter response in the frequency domain. Popular alignments include Bessel (constant time delay), Butterworth (maximally flat response in the pass band), and Chebyshev (ripples in the pass band, but with faster roll off rates). There is generally a trade-off between fast attenuation rates and smooth phase response. Alignment is indicated by the damping or $(\Omega)$ of the filter. $(\Omega)$ is the reciprocal of damping. Filters with low damping factors (i.e., high $(\Omega)$) tend to be “peaky” in the frequency domain and produce ringing on pulse-type inputs. (Chebyshevs are in this category.) The filter's critical frequency and 3 dB down frequency are not the same for alignments other than the Butterworth. The actual amount of “skew” depends on the alignment and order of the filter.

Once filter performance is specified, there are a number of ways in which the circuit can be physically realized. Common high- and low-pass realizations use the Sallen and Key VCVS approach. There are two variations on this theme: the unity-gain form and the equal-component form. Both forms use a second-order building block section. For higher orders, several second-order sections (and optionally, a first-order section) are combined to produce the final filter. It is important to remember that higher-order filters are not simple combinations of identical lower-order filters. For example, a fourth-order 1 kHz Butterworth filter is not made by cascading a pair of identical second-order 1 kHz Butterworth filters.
Rather, each section requires specific damping and frequency factors. A common design procedure utilizes lookup tables for these factors. The filters are designed by first scaling the general filter to the desired cutoff frequency, and then scaling the components for practical values.

For relatively low \(Q\) values (<1), band-pass filters are best realized as a cascade of high- and low-pass filters. For higher \(Q\) values, this technique is not satisfactory. Moderate \(Q\) values (up to 10) may be realized with the multiple-feedback filter. Very high \(Q\) applications (up to 100) may be realized with the state-variable filter. The state-variable is often known as the universal filter, as it produces high-, low-, and band-pass outputs. With the addition of a fourth amplifier, a band-reject filter may be formed. Fixed and adjustable gain versions of the state-variable may be utilized by the designer.

A somewhat more specialized group of filters are the equalizers commonly employed in audio recording and playback equipment. Unlike traditional filters, equalizers offer both boost and attenuation of frequencies. Generally, these circuits are based on parallel-parallel inverting amplifiers, utilizing an adjustable, frequency-selective feedback network.

Switched capacitor filter ICs offer the designer expedient solutions to general-purpose filter design. They are generally suited to the audio frequency range and require very few external components. The critical frequency is set by a clock input. The order and alignment may be either factory set or user adjustable (as in the universal state-variable types).

### 11.12.1: References


