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Concepts, Products, and Circuits for Audio • Analog / Digital

Analog Audio Tone Controls and Equalizers

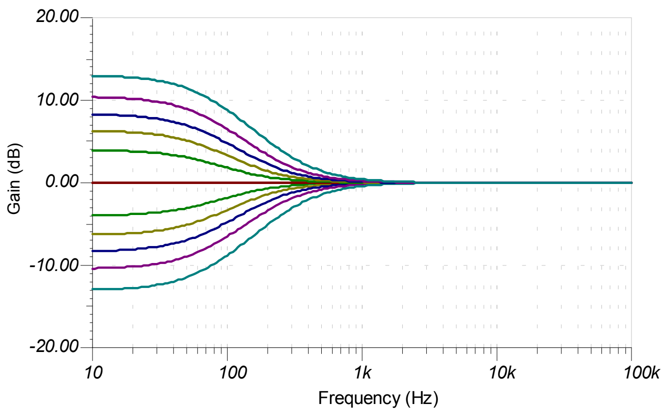
Application Note AN-12 **by Christopher Moore**

Introduction

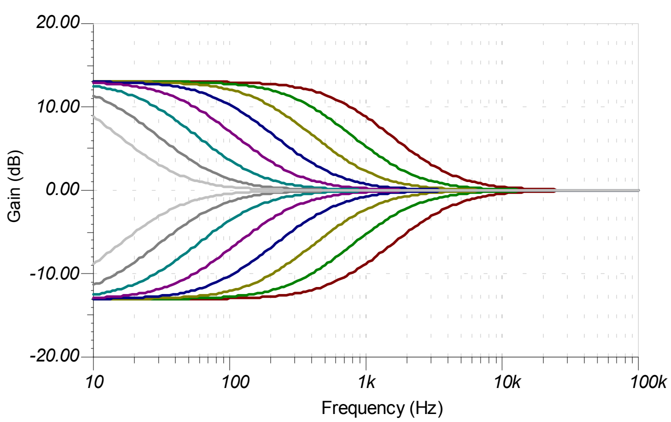
In this note I present a versatile topology for implementing high quality tone controls and equalizers. While this topology uses more op amps than the usual Baxandall bass and treble control and requires potentiometers with a fourth terminal (center tap to ground), it gives the designer far more options. This technique will be of interest to designers of high end audio and professional audio equipment.

Bass control

The curves below are from a bass control, with an upper corner frequency of 325Hz and a maximum boost/cut of 13dB. The bass control is swept in 11 steps with linear spacing, calling for a potentiometer with a linear taper.



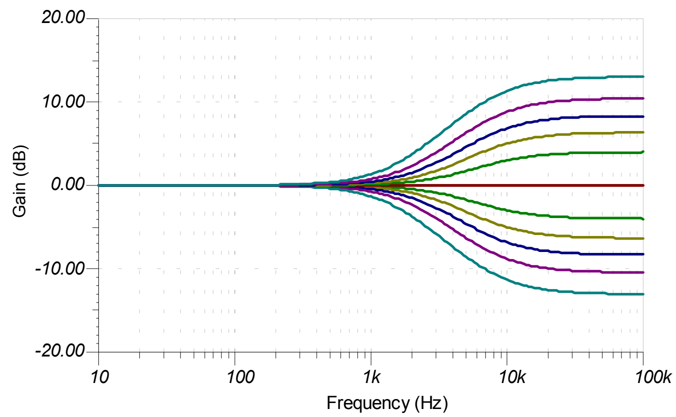
We can make a more versatile tone control if we replace R4 with another potentiometer wired as a variable resistor.



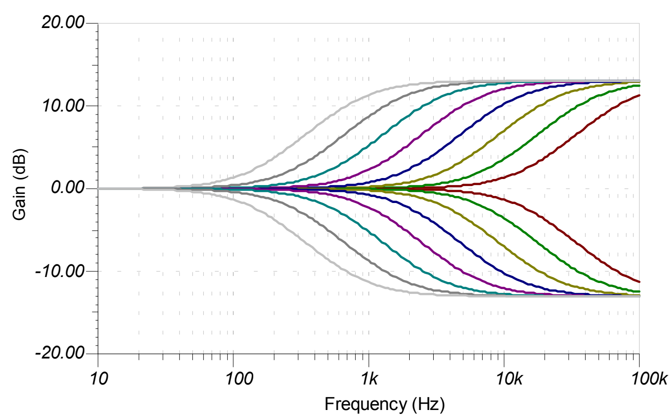
Sweeping this potentiometer from 1k to 100k in eight log steps will vary the corner frequencies while maintaining the maximum boost or cut.

Treble control

Simply interchanging C1 and R4 and choosing their values appropriately leads to a normal treble control. In this example, the lower corner frequency is 1.6kHz.

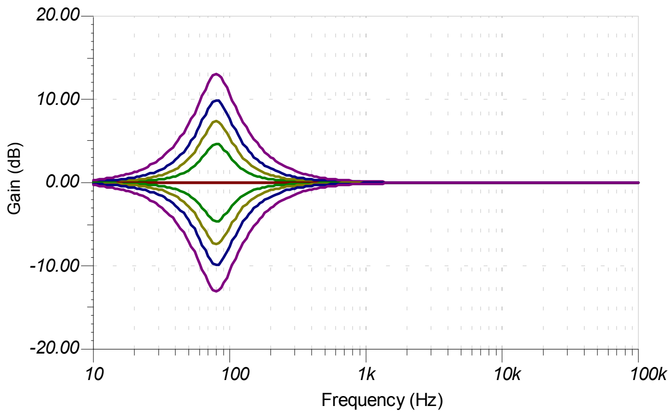


By varying R4 we can give the user control over the corner frequencies. In the next figure, the potentiometer is swept from 1k to 100k in eight log steps.



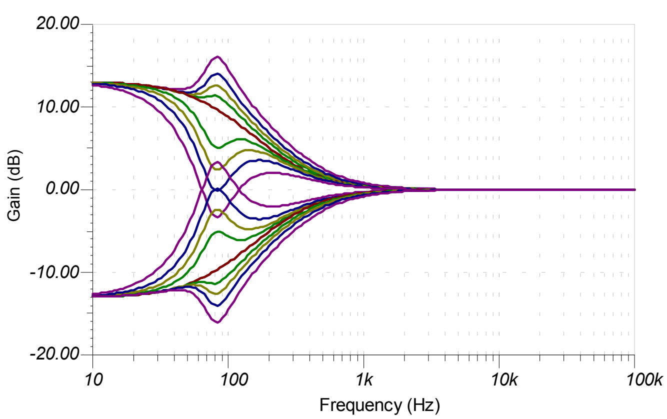
Peaking control

Moving beyond simple bass and treble controls, this versatile architecture allows us to create boost or cut bell curves. To realize these curves, we add a multiple-feedback second order bandpass filter with design criteria for center frequency, gain at the center frequency (set to 1 for our purposes), and Q (width of the skirts). Since the MFB bandpass is inverting, we precede it with a unity gain inverter (which can be shared by other peaking circuits). In the curves below, the center frequency is 80Hz and Q equals 2. Note that the family of curves is symmetrical and that the Q is constant as boost/cut is varied.



Interaction between bass and peaking control

In this topology, there is essentially no interaction between controls as long as their regions of influence are sufficiently removed from each other. But even when the controls overlap, the curves are still "reasonable" and remain monotonic. In the figure below, the boost and cut of the peaking control is varied while the bass control is held at maximum boost and cut. In the cases where the peaking control is bucking the bass control, the peak/notch depth is greater than the cases where the peaking control is aiding the bass control. Despite the asymmetry, the controls would still be useful.



Parametric equalizer

The parametric equalizer is arguably the most useful and versatile audio equalizer. This equalizer gives the user three controls– center frequency, boost/cut, and Q. When the equalizer has a number of parametric sections, the designer or user can construct complex EQ curves suitable for correcting loudspeaker or room deficiencies. Curves of a parametric section would resemble those shown above for the peaking control, except that two more figures would be needed to illustrate sweeping frequency with boost and Q fixed and varying Q while holding boost and frequency fixed.

A parametric section can be dropped right into this architecture in place of a peaking control. A preferred parametric realization would use the state variable technique (three op amps, a potentiometer for Q, and a dual potentiometer for center frequency).

Graphic equalizer

This architecture is also good for implementing a graphic equalizer. A graphic equalizer is a bank of from 5 to 31 peaking sections with frequencies evenly distributed on a log basis. Design the peaking filters for the required frequencies, all with the appropriate Q (all filters in a graphic equalizer have the same Q).

The overall structure

The overall structure consists of a cascaded pair of inverting op amp stages. The source is applied at the left side and the output is presented by the second op amp at the right side. The frequency sensitive stages are driven by the first op amp and have a maximum gain of one in their pass band:

- The high pass filter develops its maximum gain at higher frequencies and is used for the treble control.
- The low pass filter develops its maximum gain at lower frequencies and is used for the bass control.
- The bandpass filter develops its maximum gain at its center frequency and is used for the peaking control.

To provide boost, the filter output is passed through the potentiometer to the output op amp, where it combines in phase with the source signal coming through the input op amp and adds to the source level.

To provide cut, the filter output is passed through the potentiometer to the input op amp, where it combines out of phase with the source signal also coming into the input op amp and reduces the source level.

This structure delivers symmetrical boost and cut curves.

When a control is not in use (when it is defeated by setting its potentiometer to the center), it contributes no noise to the output.

For any value of boost or cut, the circuit can deliver its maximum output swing at any frequency: neither the input op amp nor the filter will overload before the output does so.

This is not the case if a state variable bandpass filter has been incorporated as a filter in this circuit to achieve a fully adjustable parametric section. For these filters, internal nodes operate at a gain greater than one, especially at the center frequency and for cases of higher values of Q. Careful design and gain scaling are required to minimize overload and noise issues when using the state variable filter in this structure.

Design flow for overall structure
Choose a value for R0 (feedback/feedforward resistors); 28.0K here.

Bass control

For the bass control, we design for the upper corner frequency, the frequency below which the bass control begins to boost or cut. The lower frequency (the frequency at which the shelf has essentially leveled off) tags along and is easily found by considering the boost amount in volts/volts. In the example here, the maximum boost is 13dB, or 4.5 volts/volt. The lower frequency is the upper frequency divided by 4.5.

Design flow for bass control
Choose Av, the maximum boost/cut. While all sections usually have the same maximum boost/ cut amount, each section can have its own value; 13dB here.
Solve for R3: R3 = R0 / (10 ^ (Av/20) -1); 8.06K here.
Pick f1, the upper corner frequency, the frequency below which the bass control begins to boost or cut; 325Hz here.
Pick a convenient value for R4; 10K here.
Solve for C1: C1 = 1 / 2*pi*f1*(R0 + R3) / (R3*R4); 220nF here.

Treble control

For the treble control, we design for the lower corner frequency, the frequency above which the treble control begins to boost or cut. The upper frequency (the frequency at which the shelf has essentially leveled off) tags along and is easily found by considering the boost amount in volts/volts. In the example here, the maximum boost is 13dB, or 4.5 volts/volt. The upper frequency is the lower frequency multiplied by 4.5.

Design flow for treble control
Choose Av, the maximum boost/cut. While all sections usually have the same maximum boost/ cut amount, each section can have its own value; 13dB here.
Solve for R3: R3 = R0 / (10 ^ (Av/20) -1); 8.06K here.
Pick f1, the lower corner frequency, the frequency above which the treble control begins to boost or cut; 1.6kHz here.
Pick a convenient value for R4; 10K here.
Solve for C1: C1 = 1 / 2*pi*f1*R4*(R0 + R3) / R3; 2.2nF here.

Peaking filter

The peaking sections use a multiple feedback inverting bandpass filter. The design flow below is appropriate for moderate to high Q filters (from 0.707 to any reasonable value). For lower Q's, a more complex procedure, one where the two capacitors assume different values, is available, but space doesn't permit including this procedure.

One advantage of this circuit is that each section can be tailored with respect to capacitor size and resistance values. Generally, we like to keep capacitor values small to keep their size down, but at low frequencies this leads to higher resistor values. Generally, we like to keep resistor values down to reduce noise, DC offset effects, and variation due to PCB contamination. Sections operating at low bass frequencies can use large resistors and more moderate capacitor values, while high frequency sections can use small to moderate capacitors and resistors.

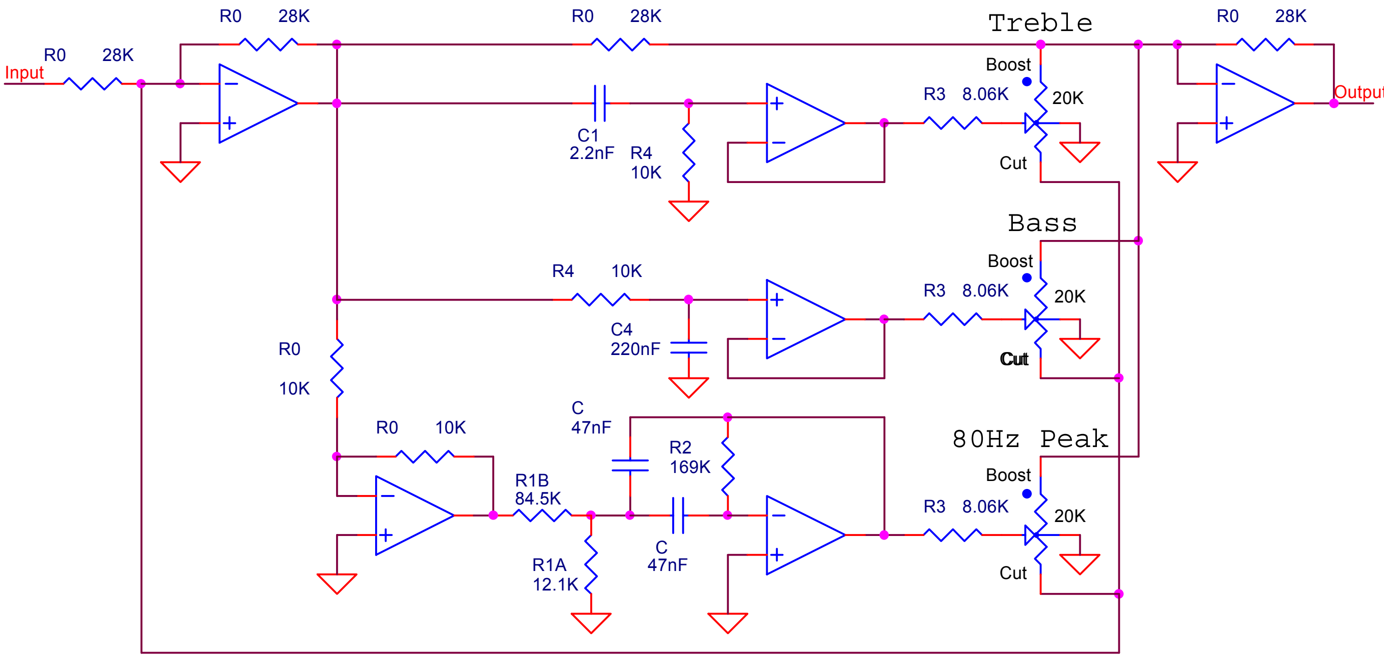
Design flow for peaking section with fixed center frequency and Q >0.707
Choose values for frequency (Fc, in Hz), Q (from 0.7 to 5 or so), maximum boost/cut (Av, in dB), and C (in farads). Fc = 80Hz; Q = 2; Av = 13dB, C = 47nF here.
Solve for:
K1 = 4*Q^2 – 2; 14 here.
R2 = 1 / 2*pi* Fc*C*(1 / (K1 + 2))^0.5; 169K here
R1A = R2 / K1; 12.1K here.
R1B = R2 / 2; 84.5K here.
R3 = R0 / (10 ^ (Av/20)-1); 8.06K here.

In conclusion

This topology gives you a lot of freedom. You can mix all types of equalizers, including user adjustable bass, treble, and parametric controls, and fixed peaking equalizers. The design process is straightforward and the performance is good.

Bibliography

Bohn, Dennis A., *Constant-Q Graphic Equalizers*, Audio Engineering Society Preprint 2265, 1985 October 12-16, Audio Engineering Society, NYC



Schematic showing bass, treble, and peaking tone controls

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