MUSIC VOICING SYSTEM*

DESCRIPTION

The SSM 2045 is a flexible high performance building block which offers the designer a maximum of options in the engineering of musical systems. Provided on-chip is a voltage controlled filter with both 2 pole as well as 4 pole low pass outputs and an uncommitted mixer/VCA combination.

The filter section has exceptionally low noise, offset and control feedthrough which delivers professional quality performance even in systems where the filter is not followed by a VCA. A voltage controlled feedback amplifier gives built-in electronic Q control with a minimum of in-band loss at the oscillation point.

The mixer/VCA section can either be connected to the filter input for waveform mixing or to the outputs for mixing between the 2 pole and 4 pole responses. The two linear and the exponential cross fade controls allow this circuit to be used both as a mixer and a VCA. This section also has excellent offset, signal to noise, and control feedthrough specs. A.C. coupling between the filter and mixer/VCA is not required.

Finally, the system as a whole delivers a "fat" open loop sound and additional features such as a series voltage controlled high pass filter can be added when used with the SSM 2024.

FEATURES

- 2 Pole and 4 Pole Low Pass Filter Outputs
- On-Chip Q Control
- Very Low Offset
- Exceptionally Low Control Feedthrough
- Low Noise (80db below nominal signal level)
- Low Volume Loss with Increasing Q

- On-chip Mixer/VCA
- Mixer can be connected either to input or outputs
- Mixer has both separate linear and exponential cross fade controls
- Minimum External Components Required
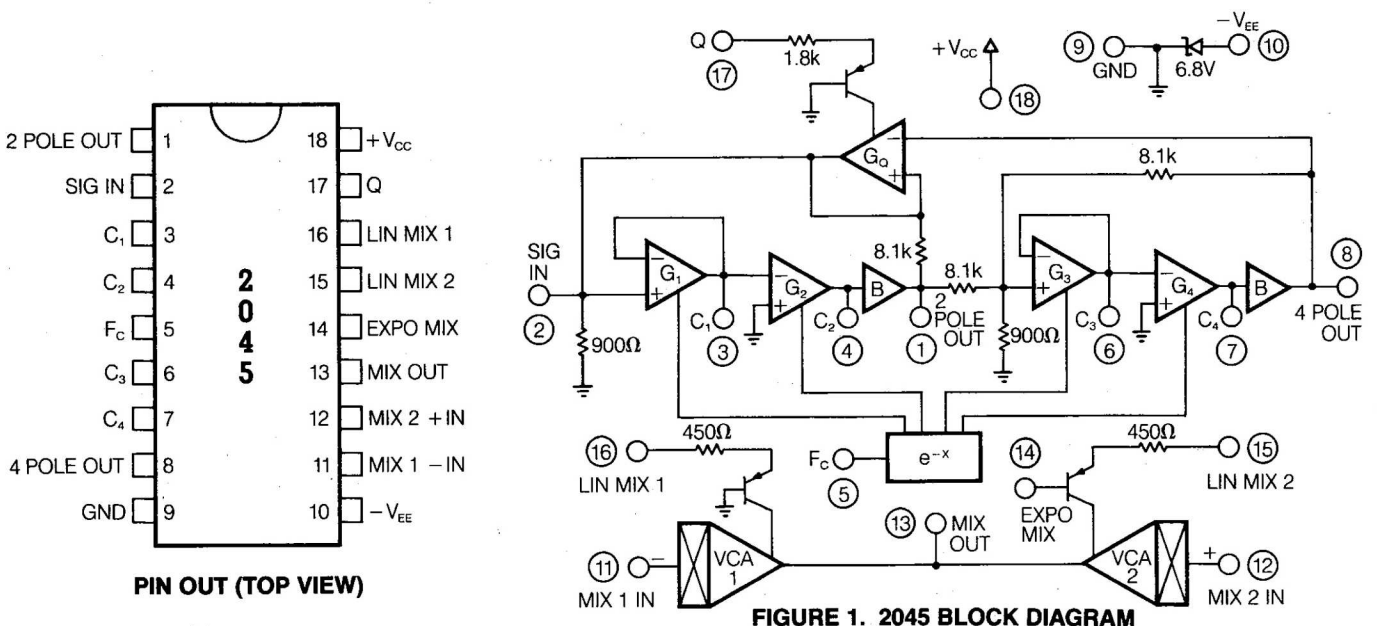- Rich "Open Loop" Sound
- $+/-$ 15 Volt operation

PIN OUT (TOP VIEW)

FIGURE 1. 2045 BLOCK DIAGRAM

The following specifications apply for $V_S = \pm 15V$ and $T_A = 25°C$.

PARAMETER	MIN	TYP	MAX	UNITS	CONDITIONS
FILTER SECTION					
Positive Supply Range	+5	+15	+18	V	
Negative Supply Range (Note 1)	−18	−15	−5	V	
Positive Supply Current	3.7	5.0	7.0	mA	
Negative Supply Current	5.8	6.5	7.1	mA	$V_{PIN 5} = GND, I_{PIN 15-17} = 0$
Output Offset (Pin 1)	−50		+50	mV	$V_{PIN 5} = GND$
Output Offset (Pin 8)	−50		+50	mV	$V_{PIN 5} = GND$
Change in Output Offset (Pin 1)	−40		+40	mV	$-90mV \leq V_{PIN 5} \leq +90mV$
Change in Output Offset (Pin 8)	−40		+40	mV	$-90mV \leq V_{PIN 5} \leq +90mV$
Signal Input Level (Pin 2)		150	3 00	mV_{pp}	
Signal Output Level (Pins 1, 8)		1	3.00	V_{pp}	
Output Source Current (Pins 1, 8)	5	10	15	mA	
Output Sink Current (Pins 1, 8)	600	750	900	μA	
Frequency Control Range	1000:1	5000:1			
F_C Input Bias Current (Pin 5)		1.0	2.5	μA	
F_C Control Sensitivity (Pin 5)	−20	−19.3	−18.7	mV/Octave	
Q Current Required for Oscillation (Pin 17)	120	150	185	μA	
Dynamic Range[2] (Clipping to Noise Floor)		92		dB	$V_{PIN 5} = -90mV$ (Filter Wide Open)
In Band Distortion[2] (THD) $4F_{IN} \leq F_C$		0.1		%	@ $150mV_{pp}$ IN
Max Distortion[2] (THD) $F_{IN} = F_C$		1.0		%	@ $150mV_{PP}$ IN
MIXER/VCA SECTION					
Output Offset Current	−12.5		+12.5	μA	$V_{PIN 11} = V_{PIN 12} = V_{PIN 14} = GND$ $I_{PIN 15} = 500μA, I_{PIN 16} = 0$ or $I_{PIN 16} = 500μA, I_{PIN 15} = 0$
Output Leakage	−1		+1	nA	$I_{PIN 15} = I_{PIN 16} = 0$
VCA Gain	3842	4085	4330	μmohs	$I_{PIN 15} = I_{PIN 16} = 500μA, V_{PIN 14} = GND$
VCA Gain Matching	−0.5		+0.5	dB	$I_{PIN 15} = I_{PIN 16} = 500μA, V_{PIN 14} = GND$
Mix Expo Input Bias Current (Pin 14)	−50		−5	μA	$I_{PIN 15} = 500μA, V_{PIN 14} = GND$
Control Rejection (untrimmed)		41.5	30	dB	RE $40mV_{pp}$ (PIN 11 or 12)
Signal to Noise		82		dB	RE $40mV_{pp}$ (PIN 11 or 12)
Distortion[2] (THD)		0.3		%	@ $40mV_{pp}$ (PIN 11 or 12)

Note 1: Resistor in series with pin 10 required for negative supply voltage $< -6.8V$.

Note 2: Due to automatic testing limitations these specs are guaranteed by bench Q.A. testing, 99.5% of the units are guaranteed to meet typical specification +50%.

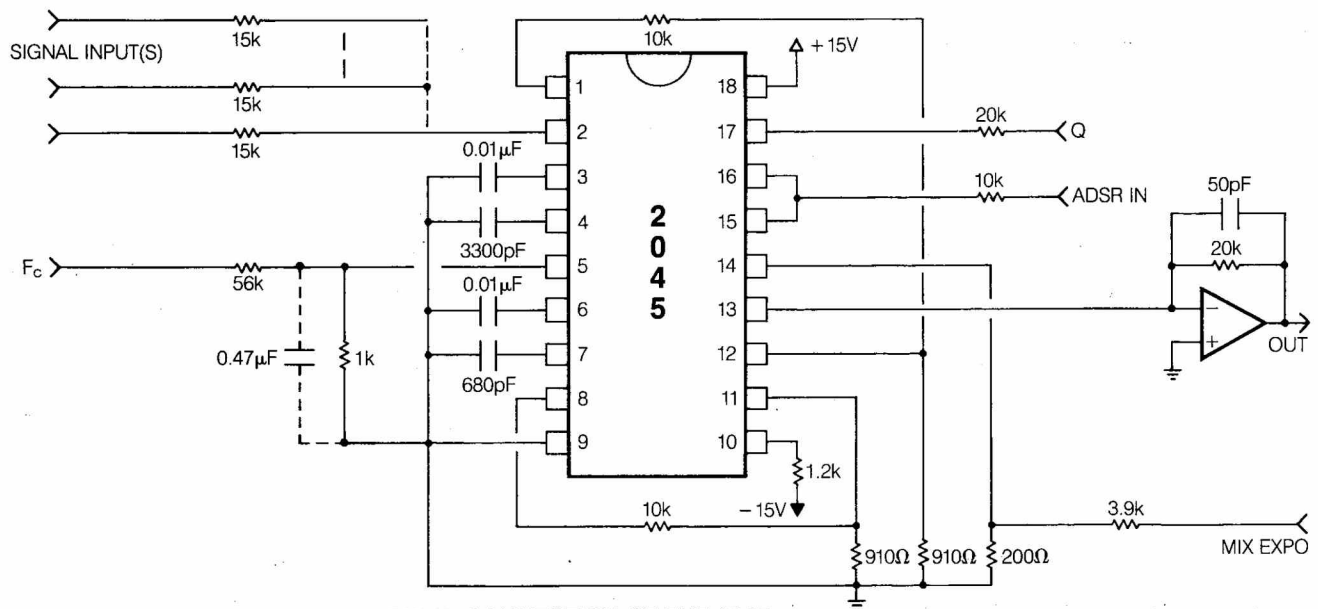*Final specifications may be subject to change.

FIGURE 2. A TYPICAL CONNECTION OF THE 2045

Power Supplies

The 2045 is designed to give best overall performance when operated from a +15 volt supply. Supply voltages down to +5V can be accommodated with increasing degradation of some of the specifications, notably VCA offset and control feedthrough. The negative supply can be any value below −5V with no change in performance. A −5 volt supply can be connected directly to pin 10. For a negative supply voltage below −6.8 volts, a series resistor is used whose value is determined by the equation below:

$$R_{limit} = (V_{ee} - 6.8)/7.1mA \text{ for } V_{ee} < -6.8V$$

A Typical Connection

Figure 2 above shows a typical connection of the 2045. The inputs of the VCA/mixer are connected to the two and four pole outputs of the filter section. This allows the relative amount of the two low pass responses to be placed under program control via the expo mix control. The envelope is applied to the two linear mix controls. This determines the overall volume at the final output.

Filter Section

The signal input has an input impedance of 900Ω and accepts a nominal input signal level of 150mV peak to peak. Somewhat higher levels can be used if the increased distortion is compatible with the desired sound. Signals can be summed at the input using a resistor network, the on-chip VCA/mixer section, or a multiple VCA I.C. such as the SSM 2024.

The frequency control input (pin 5) can vary the cutoff frequency over a 5000 to 1 range. Usually the sweep is restricted to 1000 to 1 which corresponds to +/−90mV at the pin. With the input attenuator shown above, the F_G control sensitivity is about −1 octave per volt. For best control rejection, a time constant of about 500μ seconds should be established to rapid control voltage changes either at the input pin itself or in the control summer preceding it.

The capacitor values shown in Figure 2 will give a cutoff frequency sweep range of about 20Hz to 20kHz when the voltage on pin 5 is varied between +/−90mV. the rolloff characteristic approximates a Butterworth response with the Q current at zero. The designer might try experimenting with different capacitor values (see last page for design equations).

The Q current input accepts current from a source above +600mV. The 1.8K resistor added in series with the emitter of a grounded base pnp transistor provides short circuit protection The circuit shown in Figure 2 will begin to oscillate with a pure sine wave when the Q current is in the range of 120 to 185 μA. Due to the way the Q feedback amplifier is connected, the in band loss at the oscillation point is only 6db instead of the usual 12db. This slight loss allows for enough headroom for complex signals when the device is in oscillation.

The outputs can source more than 10mA but will sink only about 750μA. If more output sink capability is required, resistors can be added from the outputs to the negative supply. The two pole output is inverted with respect to the four pole output.

The signal to noise ratio of the filter section is 84db for 150mV peak to peak at the signal input pin which allows for more than 6db of headroom. The worst case control feedthrough referred to this signal level is −32db, 12db better than conventional designs.
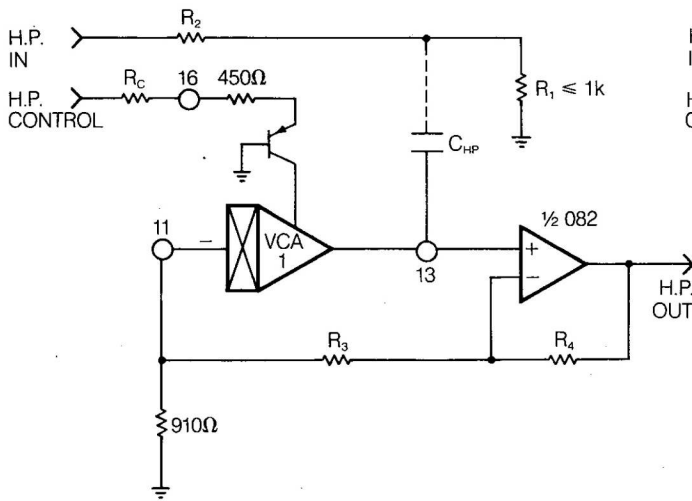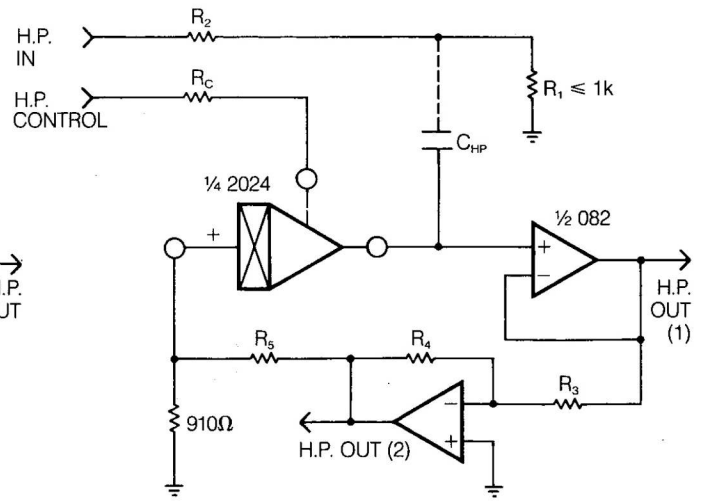
FIGURE 3a. **FIGURE 3b**

(NOTE: VCA 2 IS OFF, PINS 12, 14 AND 15 ARE GND)

VCA/Mixer Section

The impedance from the signal inputs of the VCAs to ground should be about 910Ω for the best offset and control rejection performance. The overall performance of the VCAs with respect to signal to noise, control rejection and distortion vs input signal level is identical to the SSM 2024.

This section is completely independent of the filter circuit allowing it to be used in several ways depending on systems requirements. First, it can be used as both the VCA and as a cross fade control between the two and four pole filter outputs. It can also be used in a similar manner as a volume contour VCA and to mix tone sources to the filter input. With most filters, placing the volume VCA before the filter instead of after would be unacceptable since the following VCA is used to mask the filter background noise and control feedthrough. However, the filter section specifications for the 2045 are good enough to allow this configuration. If one has more two tone sources, a third oscillator or a noise generator for example, the additional signals can be mixed or switched to the filter input using simple resistor summing, CMOS transmission gates or the SSM 2024.

A series voltage controlled high pass filter can also be made with this section (Figure 3a). Figure 3b shows a similar circuit using one section of the SSM 2024. The input signal level to these two circuits must be no more than 500mV$_{pp}$ unless padded as shown. The output level can be set by scaling R_3–R_5.

The controls of the VCA/mixer section are designed for maximum flexibility. Several control configurations and response characteristics are possible.

Figure 4 shows both VCA control inputs connected for linear control. A VCA will be completely off when the corresponding input control voltage is within about 500mV of ground. The series resistor to a linear control input should be chosen to give 250µA or less when the control voltage is at maximum.
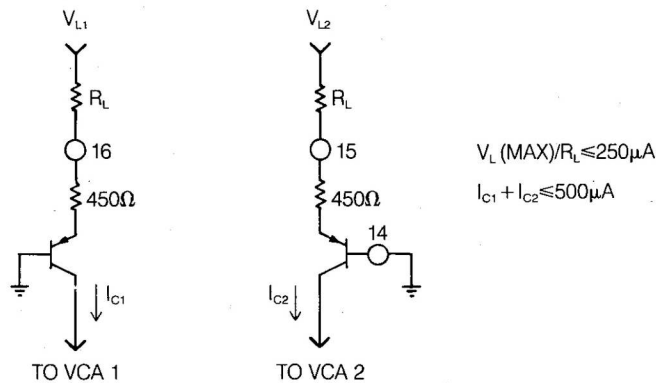

$V_L (MAX)/R_L \leqslant 250\mu A$

$I_{C1} + I_{C2} \leqslant 500\mu A$

FIGURE 4

V_{AT}

R_1

R_2

R_3

↓ TO PIN(S) 15 AND/OR 16

$$\frac{R_3 \, V_{AT} \, (MAX)}{2 \, (R_2 + R_3)} = V_{be}$$

$$R_2 + R_3 = 10R_1$$

$$\frac{V_{AT} \, (MAX)}{2R_1} \leqslant 500\mu A$$

FIGURE 5a

CONTROL CURRENT

I_C (MAX)

.75

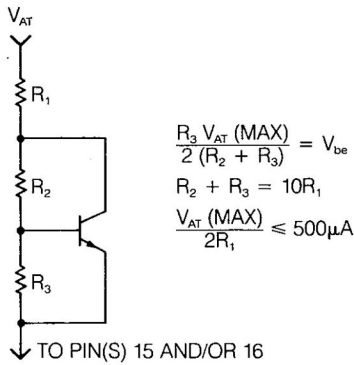.5

.25

0

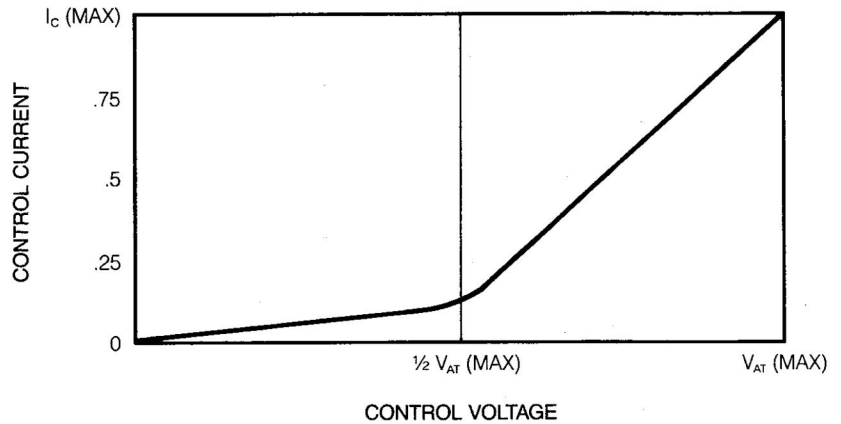½ V_{AT} (MAX) V_{AT} (MAX)

CONTROL VOLTAGE

FIGURE 5b

Figure 5a shows a circuit that can be added in series with a linear control input to give an audio taper control response. The network around the transistor is designed so that the impedance seen by the control voltage decreases by a factor of ten when the control voltage exceeds half of its maximum value. At this point the transistor turns on and almost all additional control current passes through the transistor. Figure 5b shows the approximate control characteristic of this circuit.

The connection for combined linear and exponential cross fade control is given in Figure 6a. This circuit splits a common linear control current between the two VCA's according to the transfer characteristic of a differential input pair. A transient generator can be applied to the common linear input to control the overall volume contour while the relative amount of the two signals at the inputs to the VCA's in the mix is determined by the voltage on pin 14. The characteristic of this control is shown in Figure 6b.

If just crossfade control is desired, a resistor can be connected to the common linear control from the positive supply to give a current of 500μA or less.
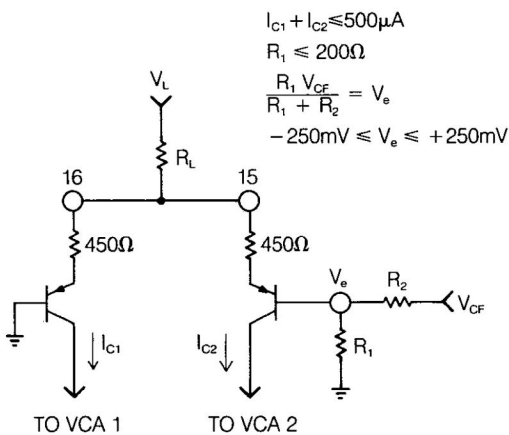
$I_{C1} + I_{C2} \leqslant 500\mu A$

$R_1 \leqslant 200\Omega$

$$\frac{R_1 \, V_{CF}}{R_1 + R_2} = V_e$$

$-250mV \leqslant V_e \leqslant +250mV$

V_L

R_L

16   15

450Ω   450Ω

V_e R_2

V_{CF}

I_{C1} I_{C2} R_1

TO VCA 1   TO VCA 2

VCA GAIN

0dB
−6dB
−12dB
−18dB
−24dB
−30dB
−36dB
−42dB
−48dB
−54dB
−60dB

VCA 1   VCA 2

−250mV   −125mV   0   +125mV   +250mV
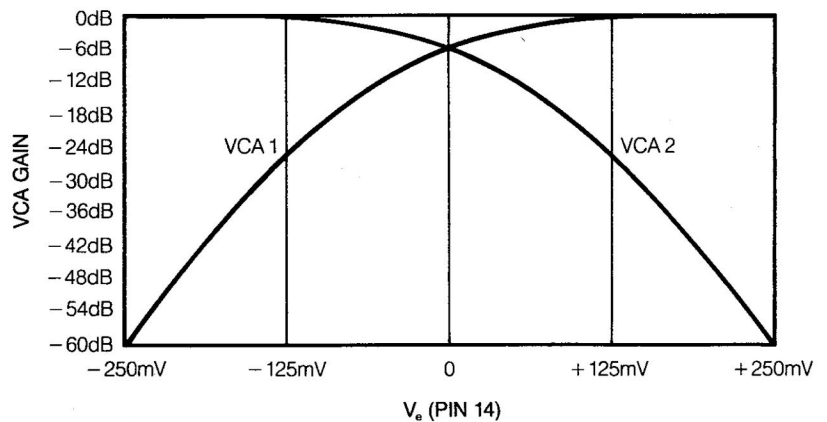
V_e (PIN 14)

FIGURE 6a

FIGURE 6b

CALCULATING THE 2045 RESPONSE CHARACTERISTIC

Each two pole section in the 2045 obeys the generalized two pole low pass transfer function;

$$\frac{Vout}{Vin} = H(s) = \frac{H_0\omega_0^2}{s^2 + \alpha\omega_0 s + \omega_0^2} \text{ where } \omega_0\, 2\pi = f_{cutoff} \text{ and } \alpha \equiv 1/Q$$

When one derives this function for the 2045 one gets;

$$\frac{Vout}{Vin} = \frac{-g_m^2/(C_1\,10\,C_2)}{S^2 + s\,g_m/C_1 + g_m^2/(C_1\,10\,C_2)}$$

Comparing the generalized equation with the one for the 2045 we have;

$$H_0 = -1, \quad \omega_0 = \frac{g_m}{\sqrt{C_1 10 C_2}} \text{ and } \alpha \equiv \frac{1}{Q} = \frac{\sqrt{C_1 10 C_2}}{C_1}$$

These last two equations enable one to calculate the capacitor values for a given desired transfer characteristic. Note the C_2 behaves as if it were ten times it's actual value. This is due to the gain of 10 in the second filter stage.

As a design example, let's take the principal application of the 2045: a lowpass filter with two and four pole outputs. If we wanted the final four pole output to have a Butterworth (maximally flat) rolloff characteristic with no feedback ($I_Q = \emptyset$), we would find from filter design tables that:

$$\omega_{01} = \omega_{02}, \quad \alpha_1 = 1.85 \text{ and } \alpha_2 = 0.765.$$

So the first two pole section would be overdamped and the second would be underdamped. Choosing $C_1 = 0.01\mu F$ we find:

$$C_1 = 0.01\mu F, C_2 \cong 3300pF, C_3 \cong 0.024\mu F, C_4 \cong 1500pF$$

This does produce a system with the correct response, however, performance under feedback is poor because of the high feedback gain required for oscillation. If we increase ω_{02} by about an octave and recalculate;

$$C_1 = 0.01\mu F, C_2 \cong 3300pF, C_3 \cong 0.01\mu F, C_4 \cong 680pF$$

This yields a system with excellent sonic quality. The onset of oscillation with increasing feedback is smooth and well controlled. Also the oscillation amplitude with a given feedback is nearly constant over the audio band as the frequency control is swept.

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