TPA2016D2 Passive Input Filter Design

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ABSTRACT

It is often necessary to filter audio signals to improve sound quality or limit output power. This can easily be done with a device like TPA2016D2. This paper explains how to design such a filter.

TPA2016D2 Input Filter Configuration

It is often necessary to filter audio signals in portable products to improve sound quality or selectively limit output power at different frequencies. This can easily be done with a device like TPA2016D2. This paper explains how to design such a filter in low-pass, high-pass or band-pass form. It also explains how to compensate for variation in amplifier input impedance as gain is adjusted. This variation, which is normal in TPA2016D2 and other variable-gain devices, can alter filter response. Generally this effect is small.

The following filter at TPA2016D2 input includes high-pass and low-pass sections to form a band-pass filter. Either section can be implemented without the other if only high-pass or low-pass is needed. The circuit includes the normal input capacitors that are required for DC isolation. Only one channel is shown.

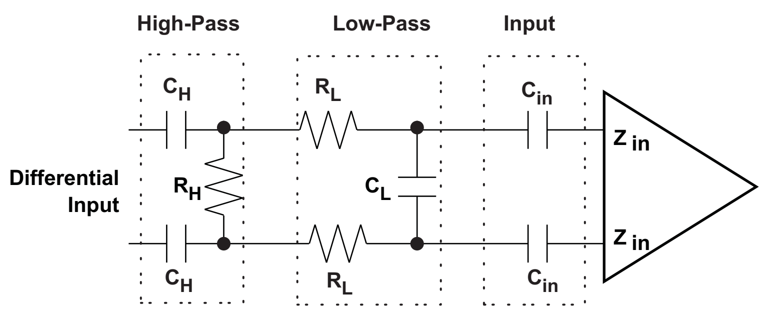

Figure 1. TPA2016D2 Bandpass Filter Configuration

Typically, the values for the filter components can be determined from the following rules and equations.

Input Capacitors for DC Isolation

- C_{in} is chosen to provide a low frequency rolloff with the minimum input impedance Z_{in} of TPA2016D2, which is 10kΩ per input pin. (Minimum Z_{in} occurs at maximum gain. See the Appendix for details.)
  – Typically C_{in} = 1µF, providing maximum rolloff frequency f_{in} of 16Hz (Equation 1).

$$f_{in} = \frac{1}{\left(2\pi \times Z_{in} \times C_{in}\right)} \tag{1}$$

This frequency falls as gain is reduced because Z_{in} increases.

High-Pass Filter

- R_H must be much smaller than minimum Z_{in} to prevent variation of the high-pass frequency as Z_{in} varies when gain is adjusted.
  – Typically R_H is around 1kΩ, providing maximum change in high-pass frequency of about 5%.
- C_H is chosen to provide the desired low-pass frequency f_H according to Equation 2. The equation assumes gain is below maximum, and it does not correct for the effect of loading by Z_{in}. Multiplying by a factor of 2 adjusts for the use of 2 capacitors, one on each side of the input, effectively in series.

$$C_H = \frac{2}{(2\pi \times R_H \times f_H)} = \frac{1}{(\pi \times R_H \times f_H)} \quad (2)$$

- C_H also must be much larger than C_L to prevent loss of gain through the voltage divider formed by these capacitors.

Low-Pass Filter

- R_L also must be much smaller than minimum Z_{in} to prevent loss of gain at the maximum gain setting.
  – Typically R_L is around 400Ω, providing maximum loss of about 0.4dB, a negligible change.
- C_L is chosen to provide the desired low-pass frequency f_L according to Equation 3. Multiplying R_L by a factor of 2 adjusts for the use of 2 resistors, one on each side of the differential input, effectively in series.

$$C_L = \frac{1}{(2\pi \times 2R_L \times f_L)} = \frac{1}{(4\pi \times R_L \times f_L)} \quad (3)$$

These equations are essentially correct as long as R_H and R_L are much smaller than Z_{in}, the high-pass and low-pass frequencies are widely separated and the high-pass frequency is well above the maximum rolloff frequency of C_{in} and Z_{in}. If these conditions are not true, it is best to design by modeling with a simulator. In any case it is good to confirm a design by simulation and adjust it if necessary before implementing the filter.

DESIGN EXAMPLE 1 – HIGH AND LOW PASS FREQUENCIES WIDELY SEPARATED

Consider a design for a filter including a 100Hz high pass section and a 12kHz low pass section. The notes and equations above lead to the following values.

- Select R_H = 1kΩ; then CH = 1 / (π × 1k × 100 Hz) = 3.18 µF. Use standard value 3.3µF
- Select R_L = 390Ω; then C_L = 1 / (4π × 390 × 12 kHz) = 17.0nF. Use standard value 16nF.

The filter response is shown in Figure 2 with responses for separate high pass and low pass sections. There is slight mid-band loss of less than 0.3dB caused by a loss of about 0.1dB in the low pass section and by small interactions between the high and low pass circuit elements.

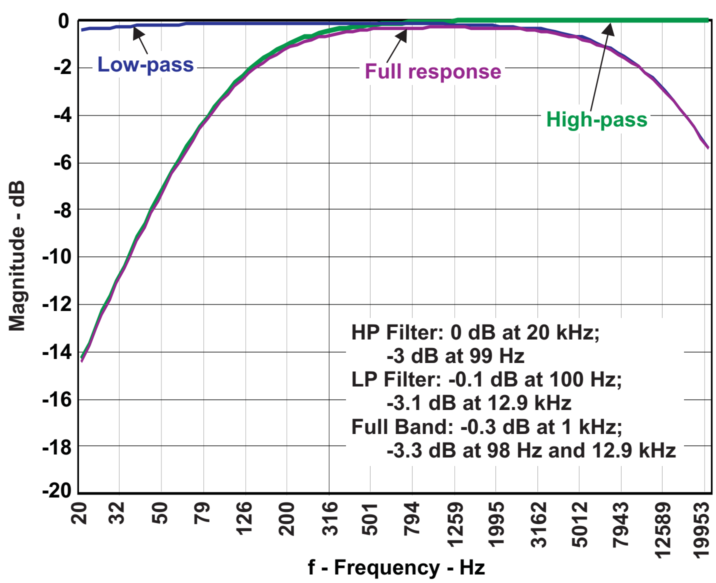

Figure 2. Input Filter Response, Widely Separated High and Low Pass Frequencies

High and low pass –3dB frequencies for the full band response are 98Hz and 12.9kHz. The error in the low pass response is caused by the large difference between the calculated value for C_L and the nearest available standard value, 16nF. If this error is acceptable the filter design is complete. If greater accuracy is necessary, R_L can be adjusted with a simulator like the one used here. RH of 953Ω and RL of 432Ω bring the high pass and low pass frequencies to 100Hz and 12.0kHz.

The circuit model in Figure 3 is used to simulate the response of this filter with a nominal Zin, 30kΩ. The feedback resistors are given the same value to show the net response of the filter without added gain or loss. The simulator used here is called TINA. It is available at no charge from the TI website, at http://focus.ti.com/docs/toolsw/folders/print/tina-ti.html.

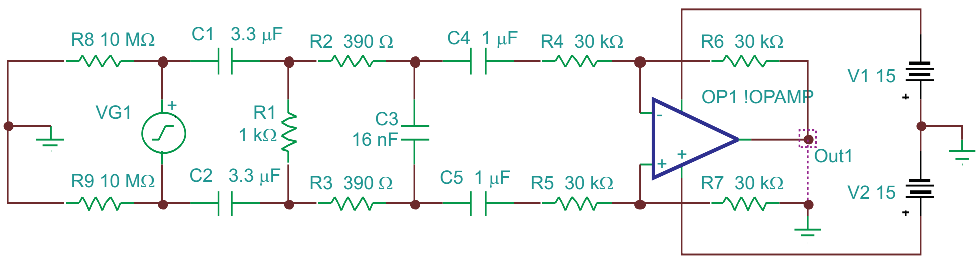

Figure 3. Circuit Model, Widely Separated High and Low Pass Frequencies

Varying gain in TPA2016D2 will change the response slightly because input impedance varies with gain. Filter response with maximum, nominal and minimum gain is shown in Figure 4.

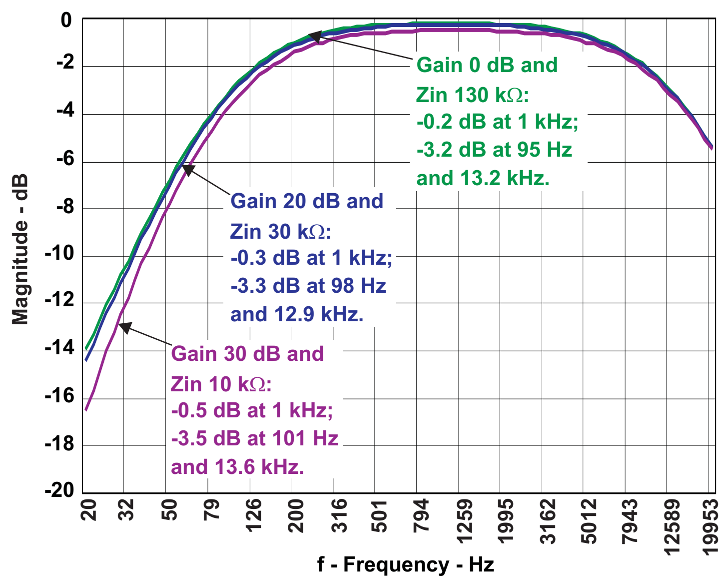

Figure 4. Input Filter Response Variation with Gain and Input Impedance

Variation is generally only a couple of tenths of a dB. The primary cause of differences is variation in the pole created by the input capacitors and input impedance. If it is necessary to keep frequency response more constant the value of the input capacitors can be increased to reduce the frequency of this pole. If it is necessary to keep filter gain more constant filter impedances must be reduced so amplifier input impedance produces less of a load on the filter output. Normally this is not a great issue, because loss of gain at minimum input impedance is generally small enough to ignore.

DESIGN EXAMPLE 2 – HIGH AND LOW PASS FREQUENCIES SPACED CLOSER TOGETHER.

Consider another design for a filter including an 800Hz high pass section and a 10kHz low pass section. The notes and equations above lead to the following values.

- Select R_H = 1kΩ; then $C_H = 1 / (\pi \times 1k \times 800Hz)$ = 398nF. Use standard value 390nF.
- Select R_L = 390Ω; then $C_L = 1 / (4\pi \times 390 \times 10kHz)$ = 20.4nF. Use standard value 22nF.

The filter response is shown in Figure 5 with separate responses for individual high pass and low pass sections. High and low pass –3dB frequencies for the full band response are 660Hz and 11.9kHz, so there is significant error in these frequencies. There is also a loss of nearly 2dB at the center of the pass band. Some of the frequency errors are caused by differences between calculated capacitances and actual capacitances, but most of the error is the result of interaction between the filter sections. It is possible to correct most of the frequency errors by adjusting component values, but clearly a simulator is required for an accurate response.

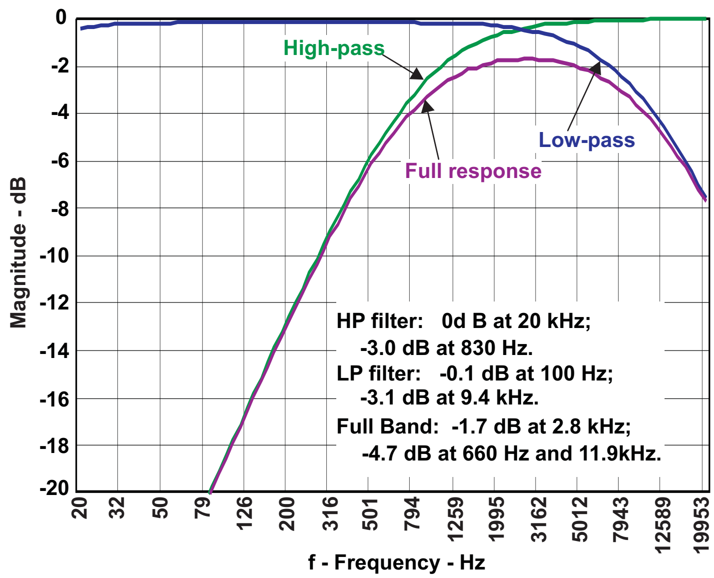

Figure 5. Input Filter Response, Closely Spaced High and Low Pass Frequencies

The circuit model shown in Figure 6 is used to simulate the response of this filter with a nominal Zin, 30kΩ. Again the feedback resistors are given the same value to show the net response of the filter without added gain or loss.

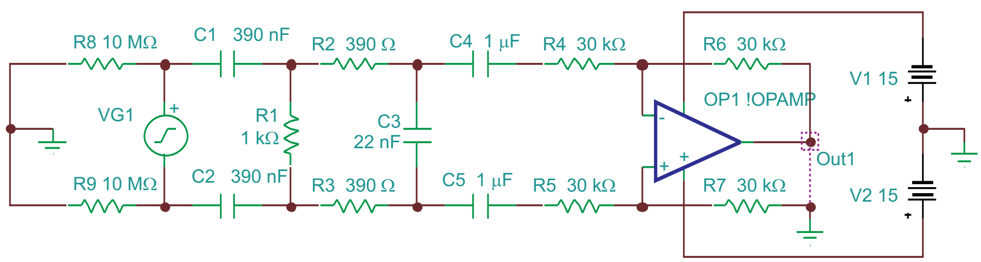

Figure 6. Circuit Model, Closely Spaced High and Low Pass Frequencies

Appendix A TPA2016D2 INPUT IMPEDANCE

Nominal input impedance of TPA2016D2 varies with gain as shown in Figure A-1, from 10kΩ per input pin at maximum gain to 125kΩ per input pin at minimum gain. The simplest high-pass filter configuration is a pair of capacitors in series with the inputs, but the frequency of such a filter would vary by a factor of 12.5 from minimum to maximum gain. If this variation is tolerable the circuit simplifies in this way.

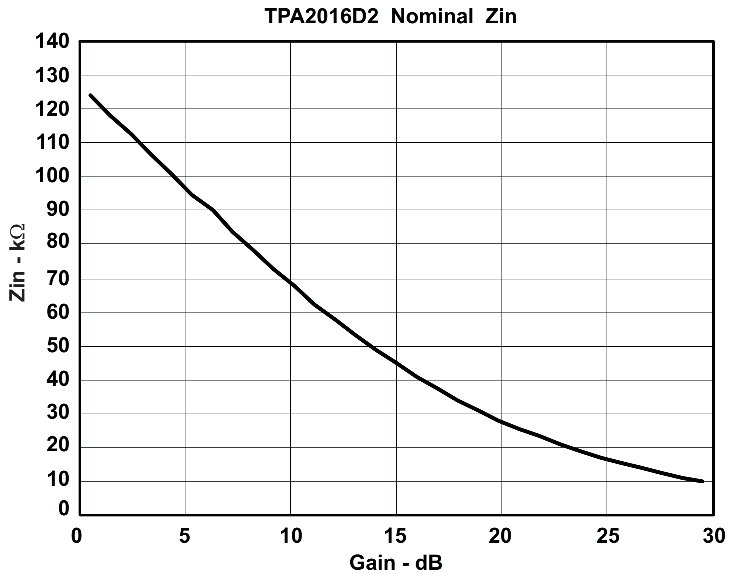

Figure A-1. TPA2016D2 Nominal Input Impedance