

# **Filter Design in Thirty Seconds**

Bruce Carter

*High Performance Analog*

## ABSTRACT

Need a filter—fast? No theory, very little math—just working filter designs, and in a hurry? This is the right document.

## Contents

<b>1</b>	Introduction .....	<b>2</b>
<b>2</b>	Low Pass Filter .....	<b>4</b>
<b>3</b>	High Pass Filter .....	<b>5</b>
<b>4</b>	Narrow (Single Frequency) Band Pass Filter.....	<b>6</b>
<b>5</b>	Wide Band Pass Filter .....	<b>7</b>
<b>6</b>	Notch (Single Frequency Rejection) Filter.....	<b>8</b>
<b>7</b>	Band Reject Filter .....	<b>9</b>
	Appendix A—Standard Resistor and Capacitor Values.....	<b>12</b>
	Appendix B—Filter Notes (for the More Technically Minded).....	<b>13</b>

## Figures

Figure 1.	Low Pass Filter.....	2
Figure 2.	High Pass Filter.....	2
Figure 3.	Narrow (Single Frequency) Band Pass.....	3
Figure 4.	Wide Band Pass .....	3
Figure 5.	Notch Filter—Single Frequency Rejection .....	3
Figure 6.	Band Reject Filter .....	4
Figure 7.	Low Pass Filter for $\pm$ Supplies .....	4
Figure 8.	Low Pass Filter for a Single Supply.....	4
Figure 9.	High Pass Filter for $\pm$ Supplies .....	5
Figure 10.	High Pass Filter for a Single Supply.....	5
Figure 11.	Narrow Band Pass Filter for $\pm$ Supplies .....	6
Figure 12.	Narrow Band Pass Filter for a Single Supply.....	6
Figure 13.	Wide Band Pass Filter for $\pm$ Supplies .....	7
Figure 14.	Wide Band Pass Filter for a Single Supply.....	7
Figure 15.	Narrow Band Pass Filter for $\pm$ Supplies .....	8
Figure 16.	Narrow Band Pass Filter for a Single Supply.....	9
Figure 17.	Band Reject Filter for $\pm$ Supplies .....	10
Figure 18.	Band Reject Filter for a Single Supply.....	10

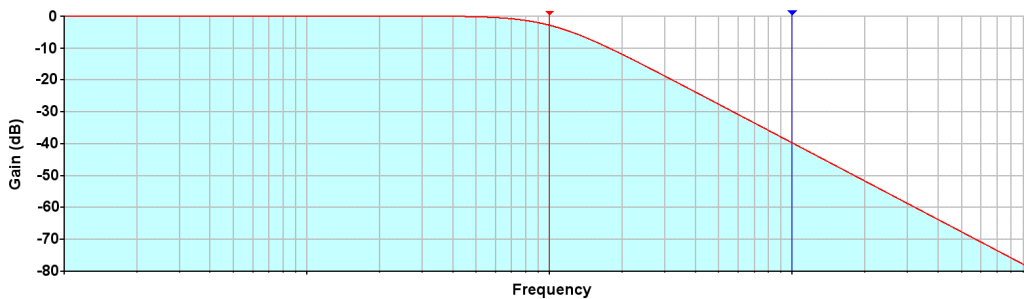
# 1 Introduction

This document is intended for designers that do not have the time to check filter theory in old college textbooks—and try to translate transfer equations into something that can be put into production. This is like looking at the back of the textbook for the answer. Speaking of the back of the book—Appendix B contains a brief introduction to the filter circuits given here, and the limitations of this *quickie* approach to design.

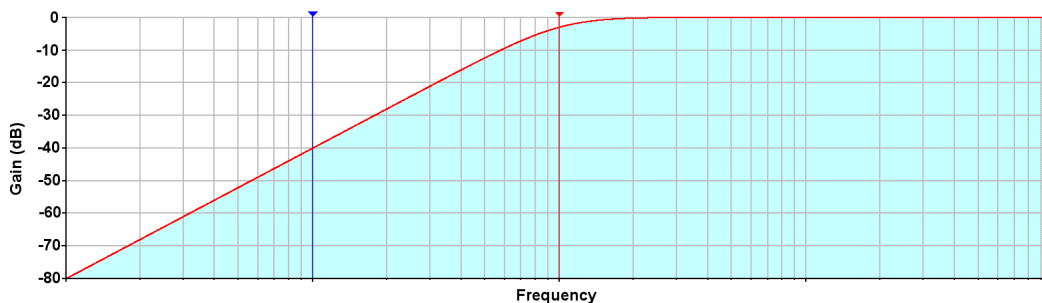
To design a filter, four things must be known in advance:

- The power supplies available: positive / negative—or only positive (single supply)
- The frequencies that need to be passed, and those that need to be rejected.
- A transition frequency, the point at which the filter starts to work—or—a center frequency around which the filter is symmetrical.
- An initial capacitor value—pick one somewhere from 100 pF for high frequencies to 0.1  $\mu\text{F}$  for low frequencies. If the resulting resistor values are too large or too small, pick another capacitor value.

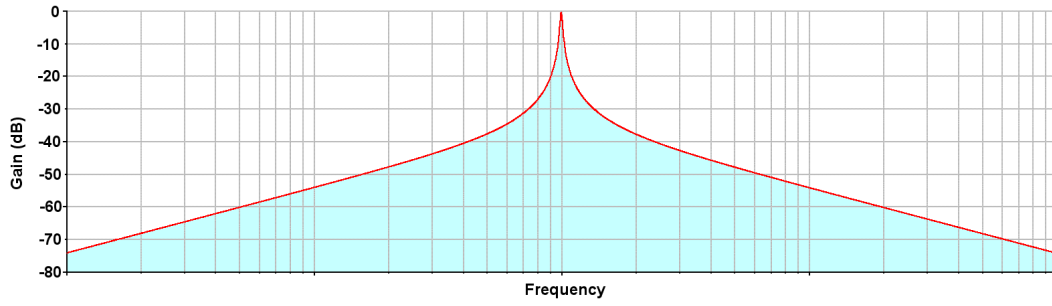
Ready? Let's design the filter. Pick the filter type from one of the following 6 options that represents the frequencies to be passed (shaded area):



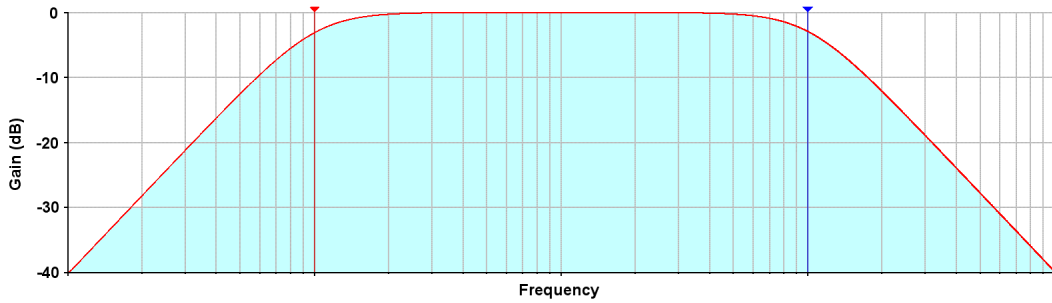
**Figure 1. Low Pass Filter—Go to Section 2**



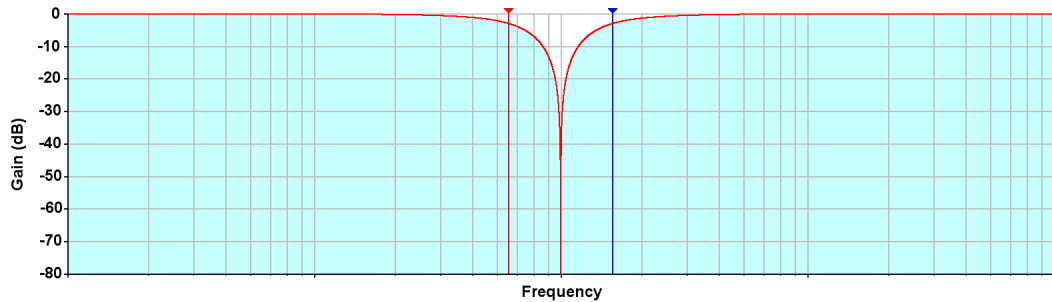
**Figure 2. High Pass Filter—Go to Section 3**



**Figure 3. Narrow (Single Frequency) Band Pass—Go to Section 4**



**Figure 4. Wide Band Pass —Go to Section 5**



**Figure 5. Notch Filter—Single Frequency Rejection**

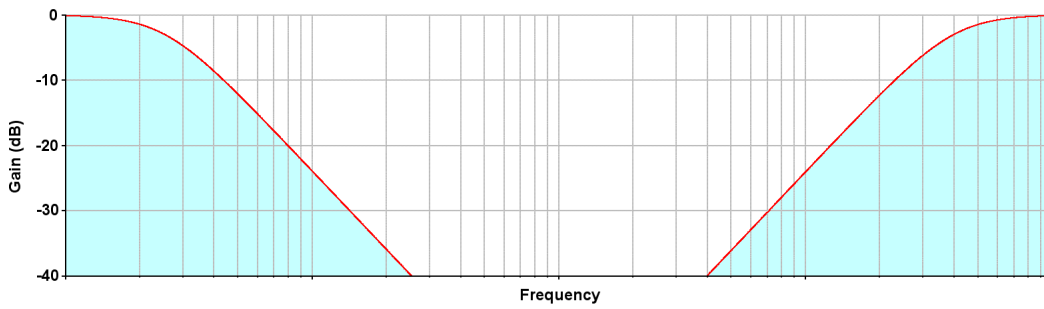


Figure 6. Band Reject Filter

## 2 Low Pass Filter

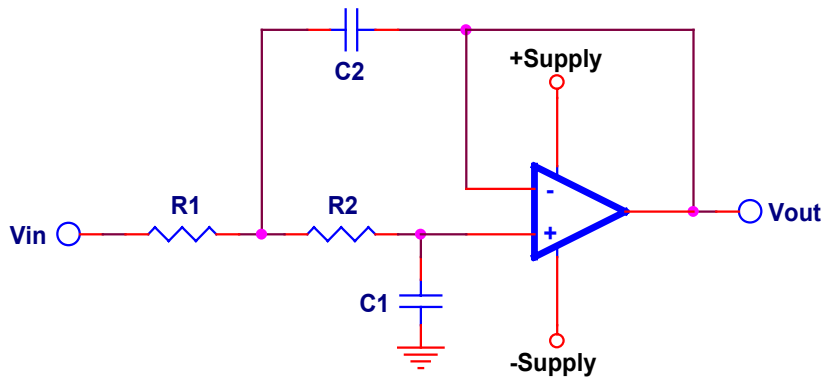


Figure 7. Low Pass Filter for ± Supplies

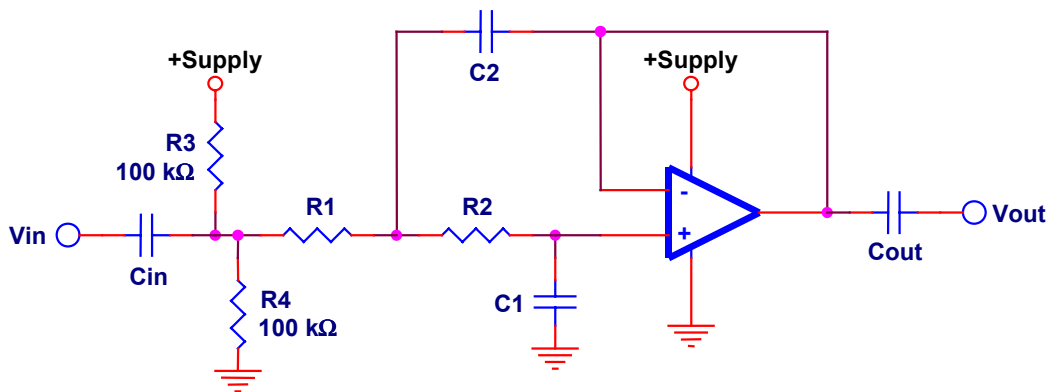


Figure 8. Low Pass Filter for a Single Supply

### Design Procedure:

- Pick C1: \_\_\_\_\_
- Calculate  $C2 = C1 * 2$ : \_\_\_\_\_

- Calculate R1 and R2 =  $\frac{1}{2\sqrt{2} * \pi * C1 * \text{Frequency}}$ : \_\_\_\_\_ (pick a standard value from Appendix A).

For the single supply case only:

- Calculate Cin = Cout = 100 to 1000 times C1 (not critical): \_\_\_\_\_

**DONE**

### 3 High Pass Filter

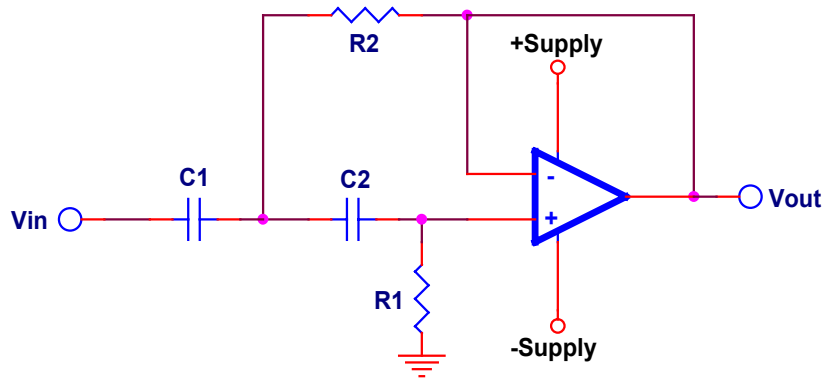


Figure 9. High Pass Filter for ± Supplies

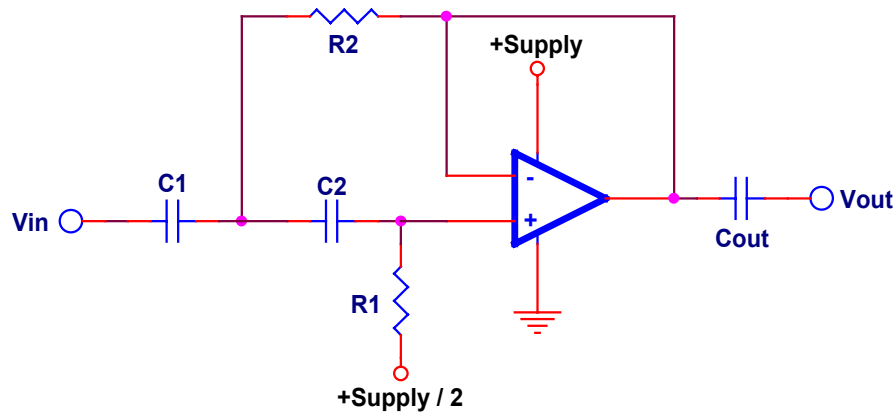


Figure 10. High Pass Filter for a Single Supply

**Design Procedure:**

- Pick C1 = C2: \_\_\_\_\_
- Calculate R1:  $\frac{1}{\sqrt{2} * \pi * C1 * \text{Frequency}}$ : \_\_\_\_\_ (pick a standard value from Appendix A).

- Calculate R2:  $\frac{1}{2\sqrt{2} * \pi * C1 * \text{Frequency}}$ : \_\_\_\_\_ (pick a standard value from Appendix A).

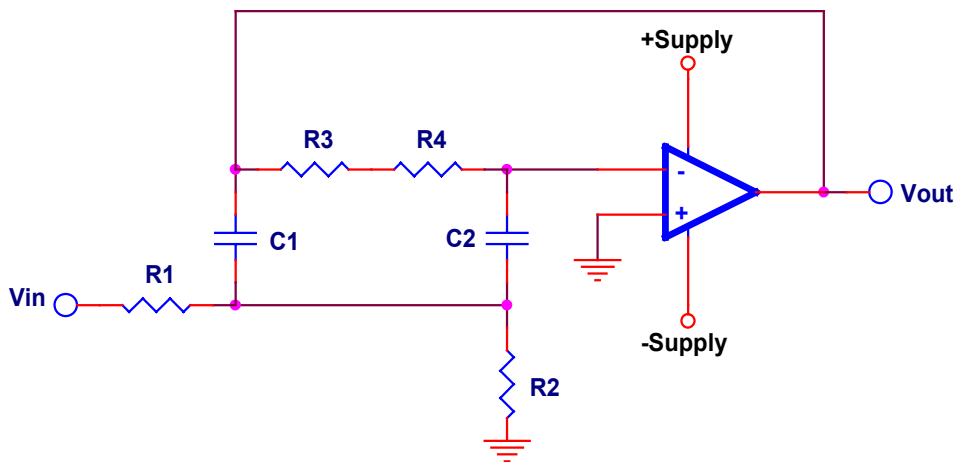
For the single supply case only:

- Calculate Cout = 100 to 1000 times C1 (not critical): \_\_\_\_\_

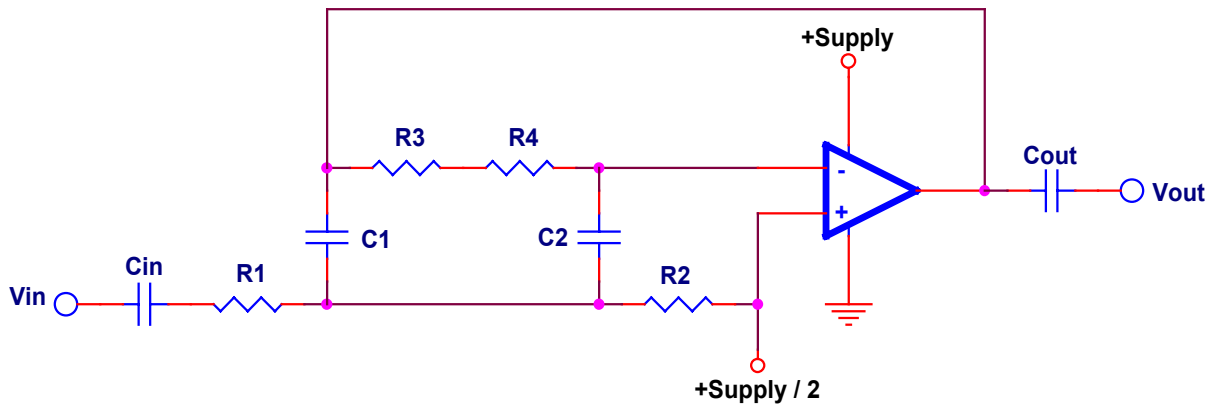
**DONE**

#### 4 Narrow (Single Frequency) Band Pass Filter

**NOTE:** These circuits include a gain of 10 (20 dB) at the center frequency.



**Figure 11. Narrow Band Pass Filter for ± Supplies**



**Figure 12. Narrow Band Pass Filter for a Single Supply**

**Design Procedure:**

- Pick C1 = C2: \_\_\_\_\_

- Calculate  $R1 = R4: \frac{1}{2 * \pi * C1 * \text{Frequency}}$  : \_\_\_\_\_ (pick a standard value from Appendix A).
- Calculate  $R3 = 19 * R1$
- Calculate  $R2 = \frac{R1}{19}$

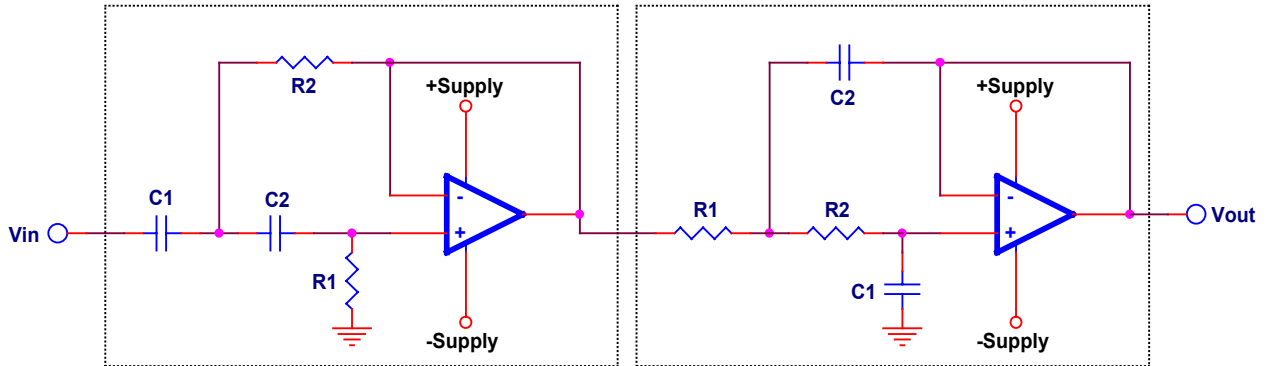
For the single supply case only:

- Calculate  $Cin = Cout = 100$  to  $1000$  times  $C1$  (not critical): \_\_\_\_\_

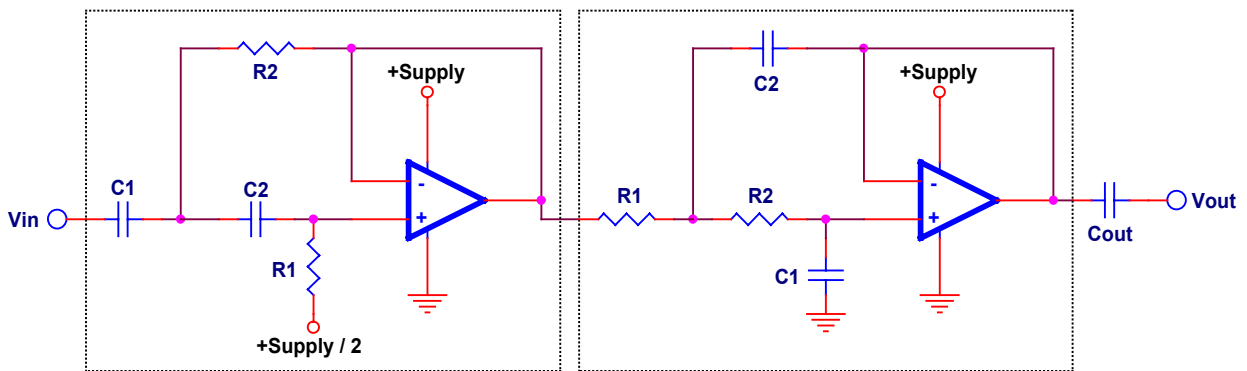
**DONE**

## 5 Wide Band Pass Filter

**NOTE:** The start and ending frequencies of the band should be at least five times different.



**Figure 13. Wide Band Pass Filter for ± Supplies**



**Figure 14. Wide Band Pass Filter for a Single Supply**

**Design Procedure:**

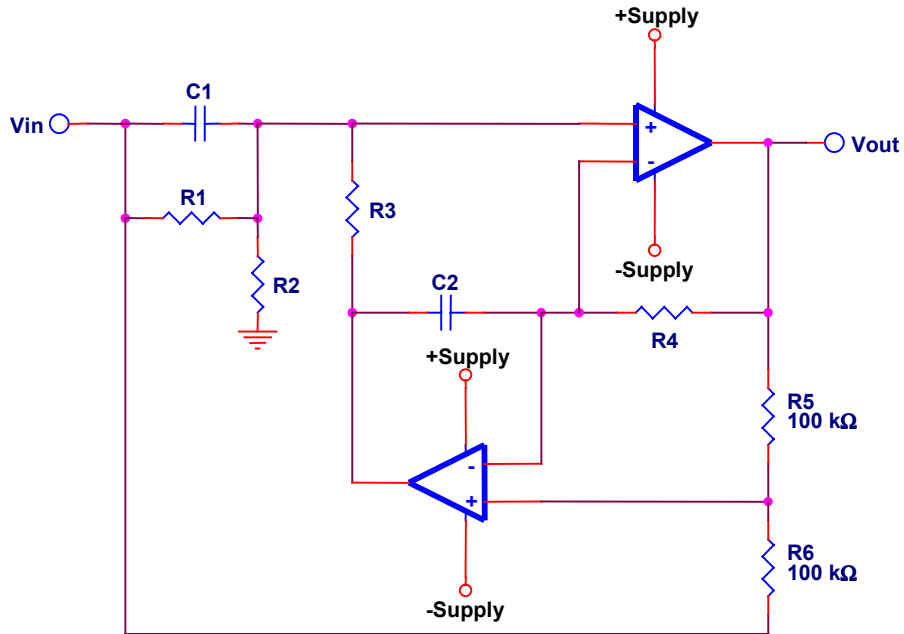
- Go to Section 3, and design a high pass filter for the low end of the band.

- Go to Section 2, and design a low pass filter for the high end of the band.
- For the single supply case only:
- Calculate  $C_{in} = C_{out} = 100$  to  $1000$  times  $C_1$  in the low pass filter section (not critical):

\_\_\_\_\_

**DONE**

## 6 Notch (Single Frequency Rejection) Filter



**Figure 15. Narrow Band Pass Filter for  $\pm$  Supplies**



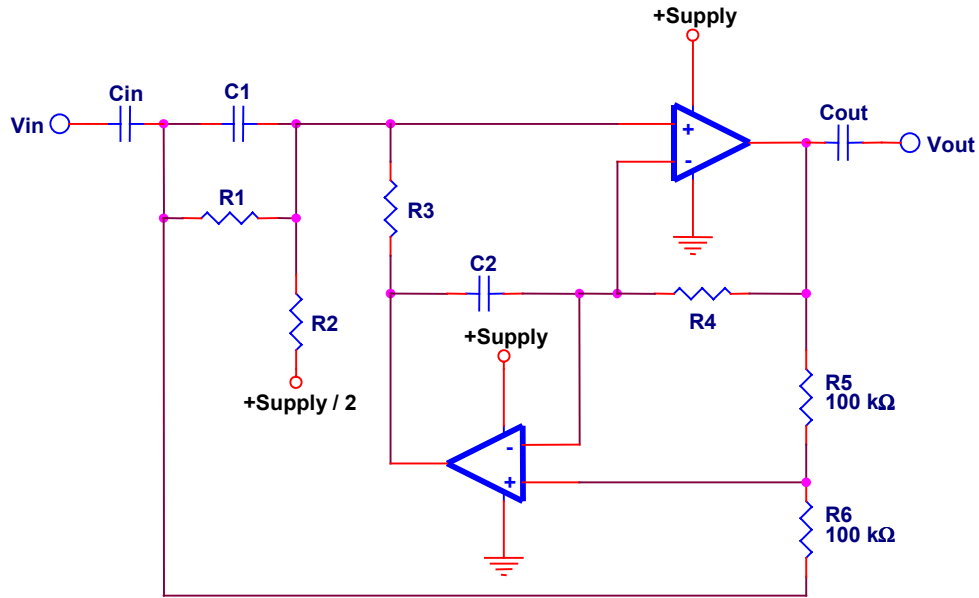


Figure 16. Narrow Band Pass Filter for a Single Supply

**Design Procedure:**

- Pick  $C1 = C2$ : \_\_\_\_\_
- Calculate  $R3 = R4$ :  $\frac{1}{2 * \pi * C1 * \text{Frequency}}$ : \_\_\_\_\_ (pick a standard value from Appendix A).
- Calculate  $R1 = R2 = 20 * R3$
- For the single supply case only:
- Calculate  $Cin = Cout = 100$  to  $1000$  times  $C1$  (not critical): \_\_\_\_\_

**DONE**

## 7 Band Reject Filter

**NOTE:** The start and ending frequencies of the band to be rejected should be at least fifty times different.

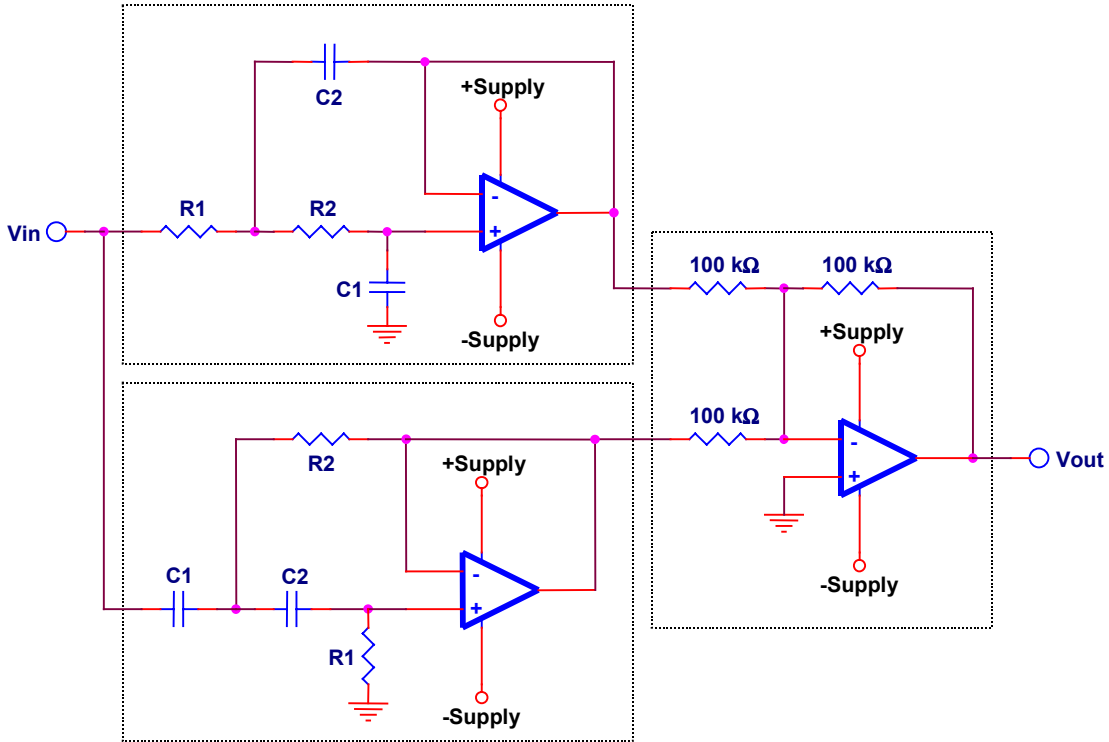


Figure 17. Band Reject Filter for  $\pm$  Supplies

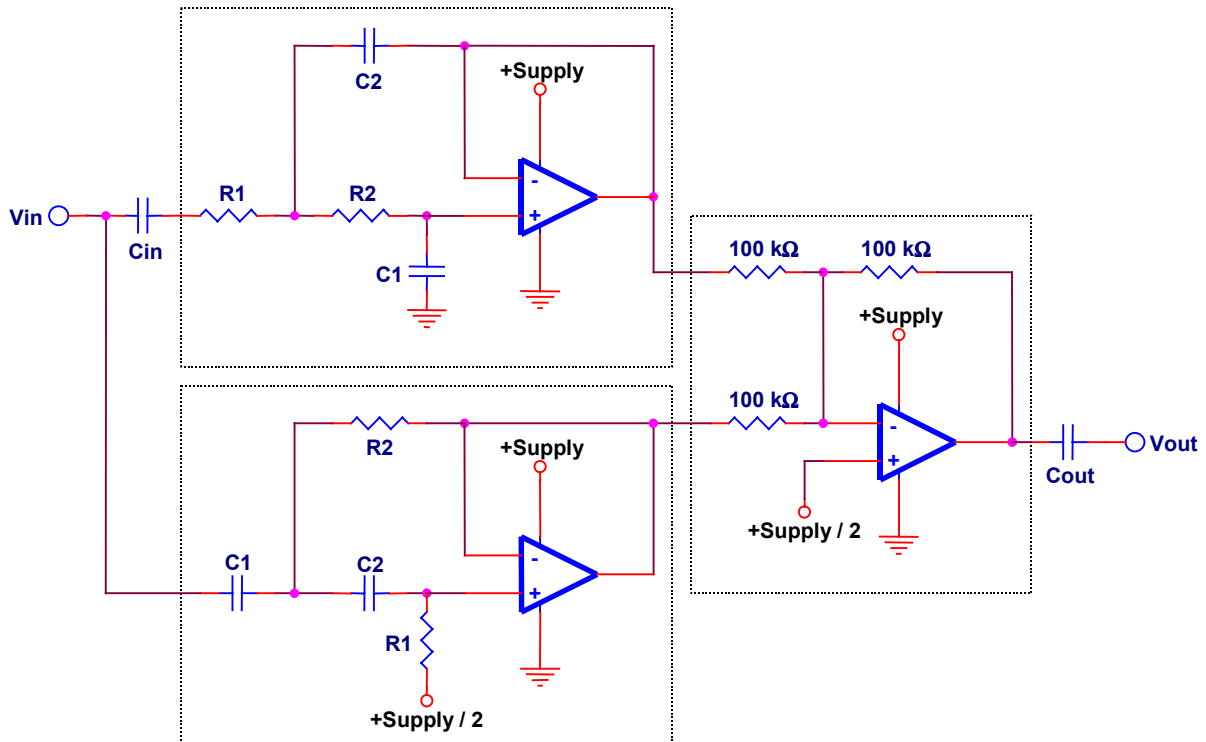


Figure 18. Band Reject Filter for a Single Supply

**Design Procedure:**

- Go to Section 3, and design a high pass filter for the low end of the upper band.
- Go to Section 2, and design a low pass filter for the high end of the lower band.
- For the single supply case only:
- Calculate  $C_{in} = C_{out} = 100$  to 1000 times  $C_1$  in the low pass filter section (not critical):  
\_\_\_\_\_

**DONE**

## Appendix A—Standard Resistor and Capacitor Values

### E-12 Resistor / Capacitor Values

1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, and 8.2; multiplied by the decade value.

### E-24 Resistor / Capacitor Values

1.0, 1.1, 1.2, 1.3, 1.5, 1.6, 1.8, 2.0, 2.2, 2.4, 2.7, 3.0, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.5, 8.2, and 9.1; multiplied by the decade value.

### E-96 Resistor Values

1.00, 1.02, 1.05, 1.07, 1.10, 1.13, 1.15, 1.18, 1.21, 1.24, 1.27, 1.30, 1.33, 1.37, 1.40, 1.43, 1.47, 1.50, 1.54, 1.58, 1.62, 1.65, 1.69, 1.74, 1.78, 1.82, 1.87, 1.91, 1.96, 2.00, 2.05, 2.10, 2.15, 2.21, 2.26, 2.32, 2.37, 2.43, 2.49, 2.55, 2.61, 2.67, 2.74, 2.80, 2.87, 2.94, 3.01, 3.09, 3.16, 3.24, 3.32, 3.40, 3.48, 3.57, 3.65, 3.74, 3.83, 3.92, 4.02, 4.12, 4.22, 4.32, 4.42, 4.53, 4.64, 4.75, 4.87, 4.99, 5.11, 5.23, 5.36, 5.49, 5.62, 5.76, 5.90, 6.04, 6.19, 6.34, 6.49, 6.65, 6.81, 6.98, 7.15, 7.32, 7.50, 7.68, 7.87, 8.06, 8.25, 8.45, 8.66, 8.87, 9.09, 9.31, 9.53, 9.76; multiplied by the decade value.

## Appendix B—Filter Notes (for the More Technically Minded)

### Low Pass Filter

The filter selected is a unity gain Sallen-Key filter, with a Butterworth response characteristic. Numerous articles and books describe this topology.

### High Pass Filter

The filter selected is a unity gain Sallen-Key filter, with a Butterworth response characteristic. Numerous articles and books describe this topology.

### Narrow Band Pass Filter

The filter selected is a modified Deliyannis filter. The Q is set at 10, which also locks the gain at 10, as the two are related by the expression:

$$\frac{R3 + R4}{2 \cdot R1} = Q = \text{Gain}$$

A higher Q was not selected, because the op amp gain bandwidth product can be easily reached, even with a gain of 20 dB. At least 40 dB of headroom should be allowed above the center frequency peak. The op amp slew rate should also be sufficient to allow the waveform at the center frequency to swing to the amplitude required.

### Wide Band Pass Filter

This is nothing more than cascaded Sallen-Key high pass and low pass filters. The high pass comes first, so energy from it that stretches to infinite frequency will be low passed.

### Notch Filter

This is the Fliege Filter topology, set to a Q of 10. The Q can be adjusted independently from the center frequency by changing R1 and R2. Q is related to the center frequency set resistor by the following:

$$R1 = R2 = 2 * Q * R3$$

The Fliege filter topology has a fixed gain of 1.

The only real possibility of a problem is the common mode range of the bottom amplifier in the single supply case.

### Band Reject Filter

This is nothing more than summed Sallen-Key high pass and low pass filters. They cannot be cascaded, because their responses do not overlap as in the wide band pass filter case.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

### Mailing Address:

Texas Instruments  
Post Office Box 655303  
Dallas, Texas 75265