How to Design

Single-supply, 2nd order, MFB high-pass filter circuit

General Purpose Amplifiers

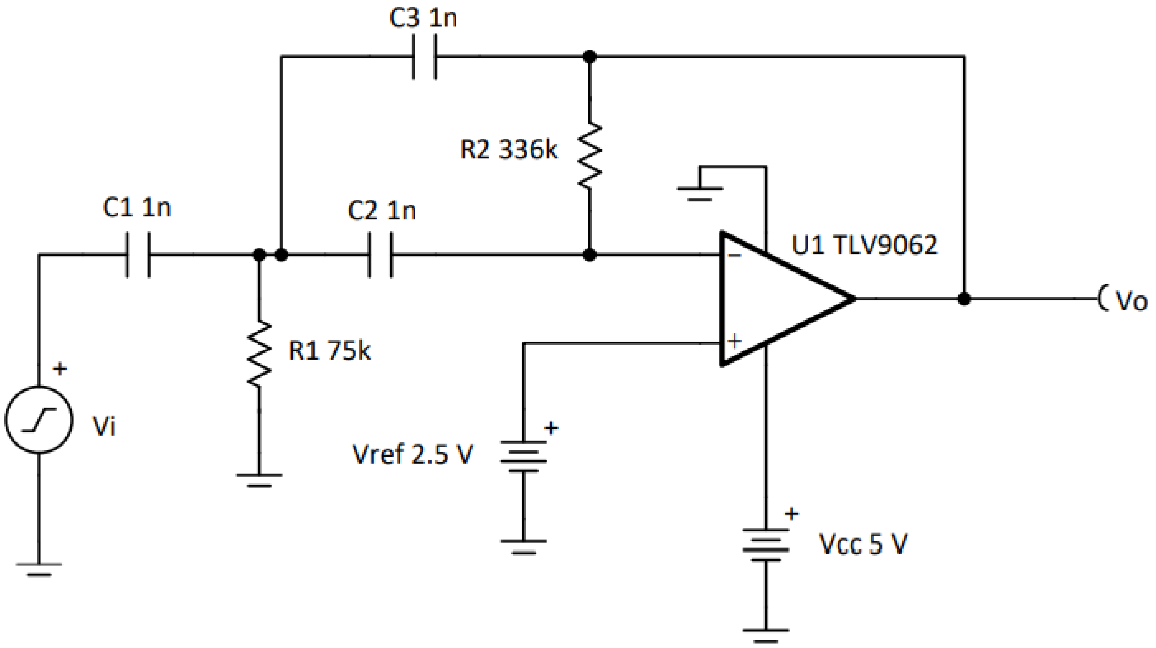
www.ti.com/general-amps

www.ti.com/circuitcookbooks

Analog Engineer's
Circuit Cookbook: Op Amps

Texas Instruments

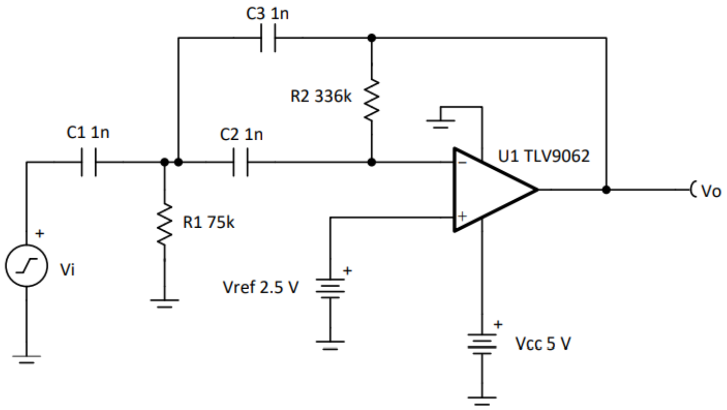
Circuit Description



Design Steps

Input		Output		Supply	
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}
-2.45 V	+2.45 V	0.05 V	4.95 V	5 V	0V

Gain	Cutoff Freq. (f_c)	Max Freq. (f_{max})	V_{ref}
-1 V/V	1 kHz	10 kHz	2.5 V



$$H(s) = \frac{-s^2\frac{C_1}{C_3}}{s^2 + s\frac{C_1 + C_2 + C_3}{R_2 \times C_2 \times C_3} + \frac{1}{R_1 \times R_2 \times C_2 \times C_3}}$$

$$H(s) = \frac{-s^2\frac{C_1}{C_3}}{s^2 + a_1 \times s + a_0}$$

$$\text{Here,}\ \ a_1 = \frac{C_1 + C_2 + C_3}{R_2 \times C_2 \times C_3},\ \ a_0 = \frac{1}{R_1 \times R_2 \times C_2 \times C_3}$$

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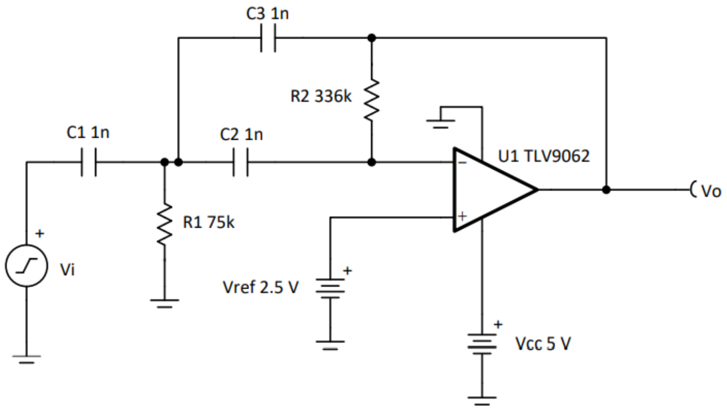

$$\omega_c = 1\frac{\text{radian}}{\text{second}} \rightarrow a_0 = 1,\ a_1 = \sqrt{2},\ \text{let } C_{1n} = C_{2n} = C_{3n} = 1\text{ F}$$

$$\text{Then } R_{1n} \times R_{2n} = 1 \text{ or } R_{2n} = \frac{1}{R_{1n}},\ a_1 = \frac{3}{R_{2n}} = \sqrt{2}$$

$$\therefore R_{2n} = 2.1213,\ \ R_{1n} = \frac{1}{R_{2n}} = 0.4714$$

a_0 and a_1 are found on TI.com in Table 1 of Active Low-Pass Filter Design (SLOA049).

Design Steps

Input		Output		Supply	
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}
-2.45 V	+2.45 V	0.05 V	4.95 V	5 V	0V

Gain	Cutoff Freq. (f_c)	Max Freq. (f_{max})	V_{ref}
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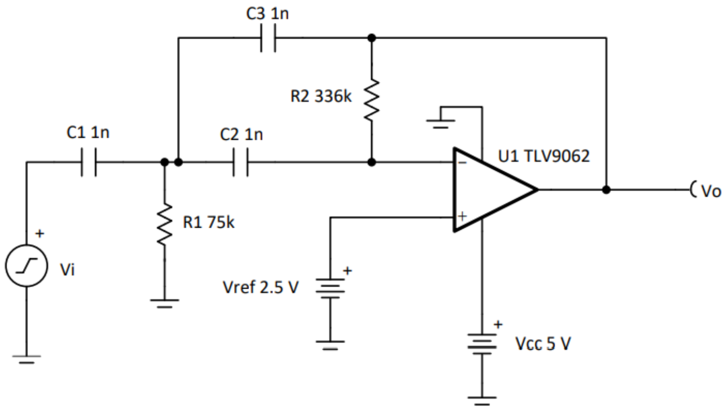

$$R_1 = R_{1n} \times m = (0.4714 \times m), \ \ R_2 = R_{2n} \times m = (2.1213 \times m)$$

$$C_1 = \frac{C_{1n}}{m \times \omega_0} = \frac{1}{m \times \omega_0} \text{F}$$

$$C_2 = \frac{C_{2n}}{m \times \omega_0} = \frac{1}{m \times \omega_0} \text{F}$$

$$C_3 = \frac{C_{3n}}{m \times \omega_0} = \frac{1}{m \times \omega_0} \text{F}$$

Design Steps

Input		Output		Supply	
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}
-2.45 V	+2.45 V	0.05 V	4.95 V	5 V	0V

Gain	Cutoff Freq. (f_c)	Max Freq. (f_{max})	V_{ref}
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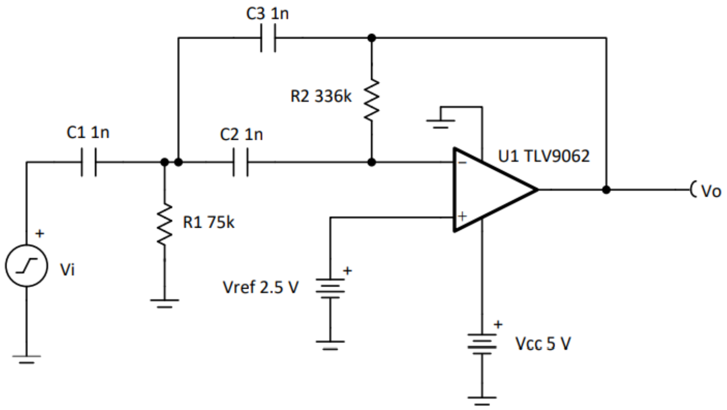

Set C_1, C_2, and C_3 to 1nF and calculate m.

Given $\omega_0 = 2 \times \pi \times f_c$, where $f_c = 1\text{kHz}$,

$$C_1 = C_2 = C_3 = \frac{1}{m \times \omega_0} F = \frac{1}{m \times 2 \times \pi \times 1\text{kHz}}$$

So, $m = 159155$

Calculate R_1 and R_2 based on *m*.

$$R_1 = R_{1n} \times m = 0.4714 \times 159155 \approx 75\text{k}\Omega \text{ (Standard Value)}$$

$$R_2 = R_{2n} \times m = 2.1213 \times 159155 \approx 336\text{k}\Omega \text{ (Standard Value)}$$

Design Steps

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V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}
-2.45 V	+2.45 V	0.05 V	4.95 V	5 V	0V

Gain	Cutoff Freq. (f_c)	Max Freq. (f_{max})	V_{ref}
-1 V/V	1 kHz	10 kHz	2.5 V

Calculate minimum required GBW and SR for f_{max}. Be sure to use the noise gain for GBW calculations. Do not use the signal gain of –1V/V.

$$\text{GBW} = 100 \times \text{Noise Gain} \times f_{max} = 100 \times 2 \times 10\text{kHz} = 2\text{MHz}$$

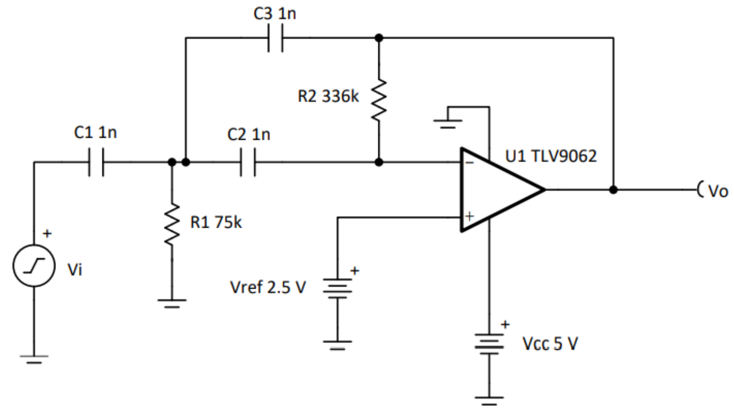
$$\text{SR} = 2 \times \pi \times f_{max} \times V_{iMax} = 2 \times \pi \times 10\text{kHz} \times 2.45\text{V} = 0.154\frac{\text{V}}{\mu\text{s}}$$

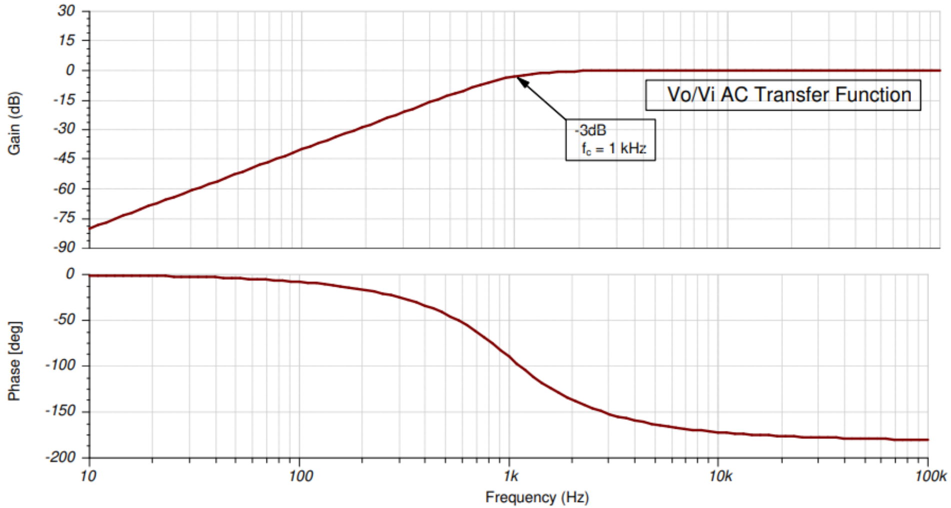
The TLV9062 device has GBW of 10MHz and SR of 6.5V/µs, so the requirements are met.

AC Results

Input		Output		Supply	
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}
-2.45 V	+2.45 V	0.05 V	4.95 V	5 V	0V

Gain	Cutoff Freq. (f_c)	Max Freq. (f_{max})	V_{ref}
-1 V/V	1 kHz	10 kHz	2.5 V





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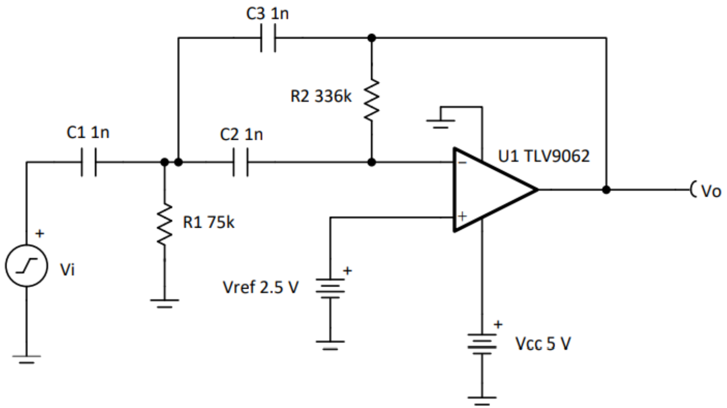
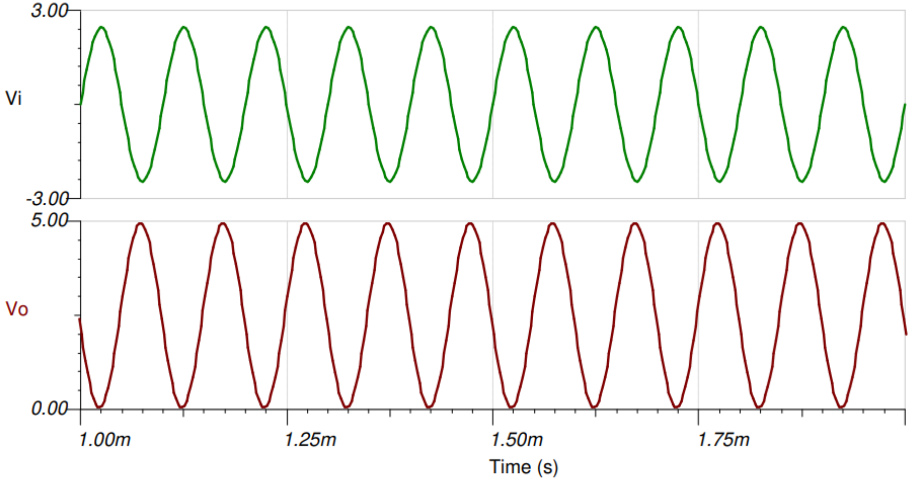
Transient Results

Input		Output		Supply	
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}
-2.45 V	+2.45 V	0.05 V	4.95 V	5 V	0V

Gain	Cutoff Freq. (f_c)	Max Freq. (f_{max})	V_{ref}
-1 V/V	1 kHz	10 kHz	2.5 V



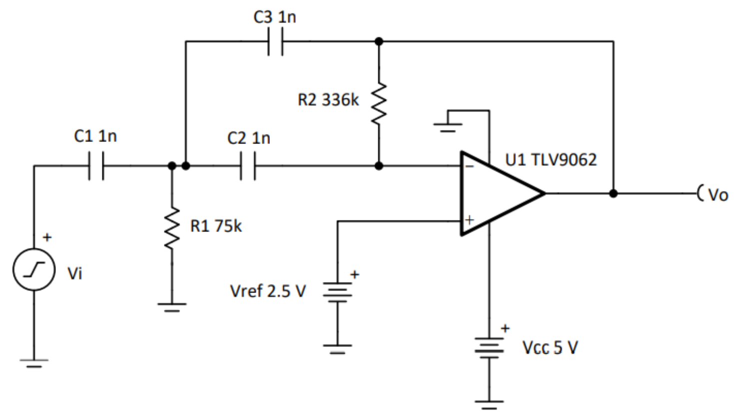


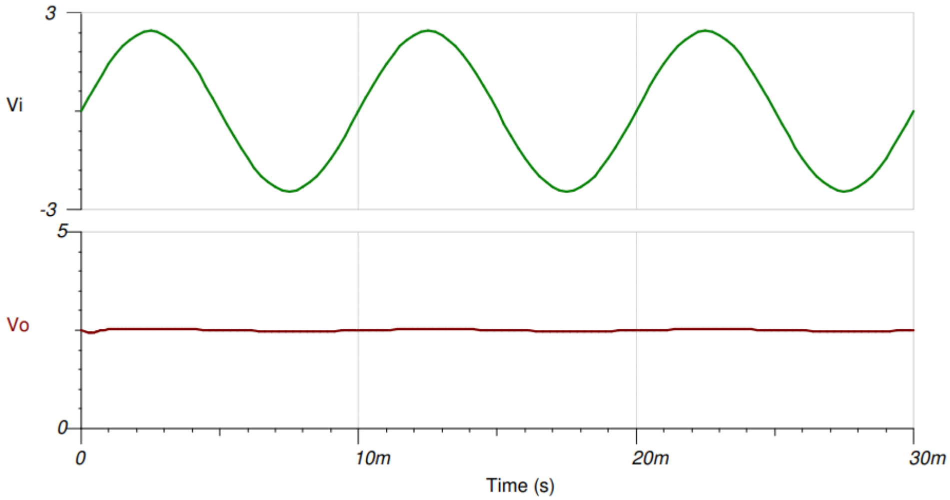
Filter Output in Response to a 5-V_{pp}, 10-kHz Input-Signal (Gain = –1V/V).

Transient Results

Input		Output		Supply	
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}
-2.45 V	+2.45 V	0.05 V	4.95 V	5 V	0V

Gain	Cutoff Freq. (f_c)	Max Freq. (f_{max})	V_{ref}
-1 V/V	1 kHz	10 kHz	2.5 V



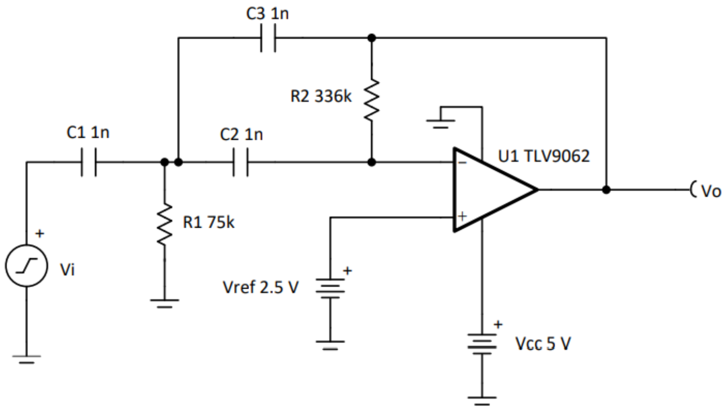


Filter Output in Response to a 5-V_{pp}, 100-Hz Input-Signal (Gain = –0.01V/V)

Design Notes

Input		Output		Supply	
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}
-2.45 V	+2.45 V	0.05 V	4.95 V	5 V	0V

Gain	Cutoff Freq. (f_c)	Max Freq. (f_{max})	V_{ref}
-1 V/V	1 kHz	10 kHz	2.5 V



Design Notes:

1. Check common mode range and output swing, and reference to bias the amplifier in single supply designs.
2. Use precision, low-drift passives to minimize errors.
3. Select op amp with sufficient bandwidth and slew rate.

Design Resources

EE Cookbook: Op Amp
www.ti.com/circuitcookbooks
Step-by-step circuit design of common op amp building block circuits.

TI Designs
www.TI.com/tidesigns
Ready-to-use reference designs with
theory, calculations, simulations
schematics, PCB files, bench test results

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offset voltage, input bias current, stability, noise and more

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