

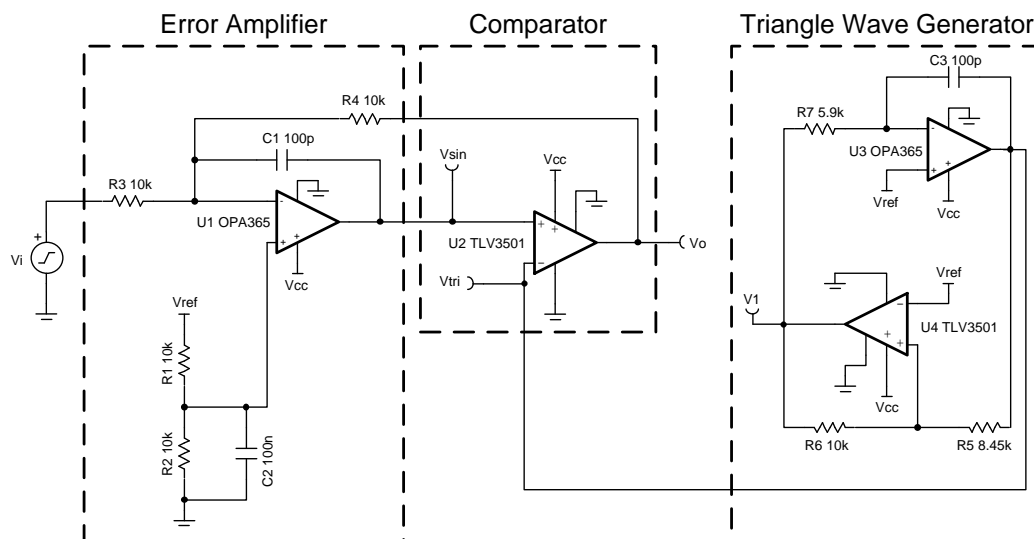
## PWM generator circuit

### Design Goals

Input		Output		Supply		
$V_{iMin}$	$V_{iMax}$	$V_{oMin}$	$V_{oMax}$	$V_{cc}$	$V_{ee}$	$V_{ref}$
-2.0V	2.0V	0V	5V	5V	0V	2.5V

### Design Description

This circuit utilizes a triangle wave generator and comparator to generate a 500 kHz pulse-width-modulated (PWM) waveform with a duty cycle that is inversely proportional to the input voltage. An op amp and comparator ( $U_3$  and  $U_4$ ) generate a triangle waveform which is applied to the inverting input of a second comparator ( $U_2$ ). The input voltage is applied to the non-inverting input of  $U_2$ . By comparing the input waveform to the triangle wave, a PWM waveform is produced.  $U_2$  is placed in the feedback loop of an error amplifier ( $U_1$ ) to improve the accuracy and linearity of the output waveform.



### Design Notes

1. Use a comparator with push-pull output and minimal propagation delay.
2. Use an op amp with sufficient slew rate, GBW, and voltage output swing.
3. Place the pole created by  $C_1$  below the switching frequency and well above the audio range.
4.  $V_{ref}$  must be low impedance (for example, output of an op amp).

## Design Steps

1. Set the error amplifier inverting signal gain.

$$\text{Gain} = -\frac{R_4}{R_3} = -1\frac{V}{V}$$

$$\text{Select } R_3 = R_4 = 10\text{k}\Omega$$

2. Determine  $R_1$  and  $R_2$  to divide  $V_{\text{ref}}$  to cancel the non-inverting gain.

$$V_{\text{o,dc}} = \left(1 + \frac{R_4}{R_3}\right) \left(\frac{R_2}{R_1 + R_2}\right) \times V_{\text{ref}}$$

$$R_1 = R_2 = R_3 = R_4 = 10\text{k}\Omega, V_{\text{o,dc}} = 2.5\text{V}$$

3. The amplitude of  $V_{\text{tri}}$  must be chosen such that it is greater than the maximum amplitude of  $V_i$  (2.0V) to avoid 0% or 100% duty cycle in the PWM output signal. Select  $V_{\text{tri}}$  to be 2.1V. The amplitude of  $V_1 = 2.5\text{V}$ .

$$V_{\text{tri}} (\text{Amplitude}) = \frac{R_5}{R_6} \times V_1 (\text{Amplitude})$$

Select  $R_6$  to be  $10\text{k}\Omega$ , then compute  $R_5$

$$R_5 = \frac{V_{\text{tri}} (\text{Amplitude}) \times R_6}{V_1 (\text{Amplitude})} = 8.4\text{k}\Omega \approx 8.45\text{k}\Omega (\text{Standard Value})$$

4. Set the oscillation frequency to  $500\text{kHz}$ .

$$f_t = \frac{R_6}{4 \times R_7 \times R_5 \times C_3}$$

Set  $C_3 = 100\text{pF}$ , then compute  $R_7$

$$R_7 = \frac{R_6}{4 \times f_t \times R_5 \times C_3} = 5.92\text{k}\Omega \approx 5.9\text{k}\Omega (\text{Standard Value})$$

5. Choose  $C_1$  to limit amplifier bandwidth to below switching frequency.

$$f_p = \frac{1}{2 \times \pi \times R_4 \times C_1}$$

$$C_1 = 100\text{pF} \rightarrow f_p = 159\text{kHz}$$

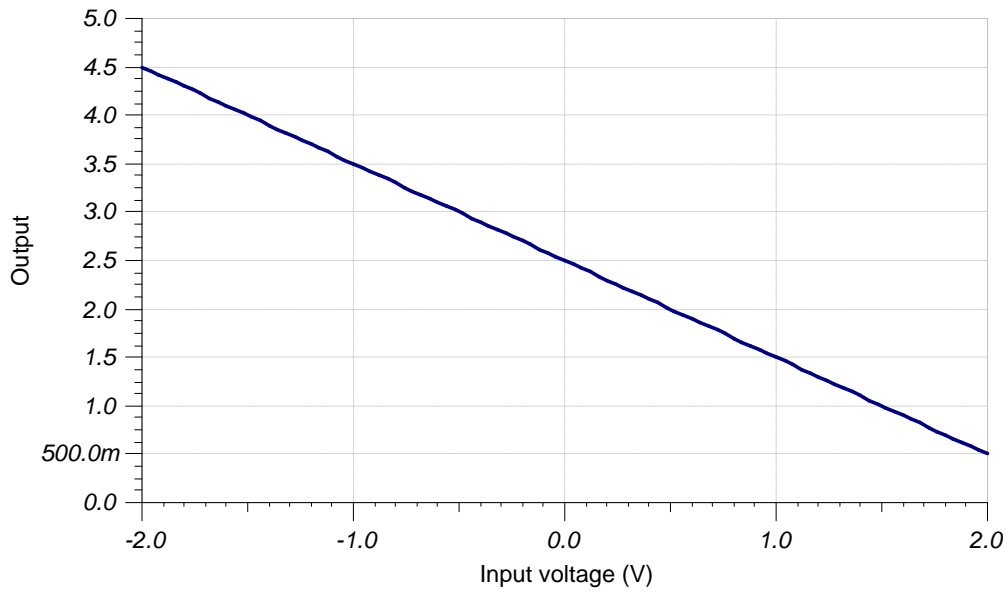
6. Select  $C_2$  to filter noise from  $V_{\text{ref}}$ .

$$C_2 = 100\text{nF} (\text{Standard Value})$$

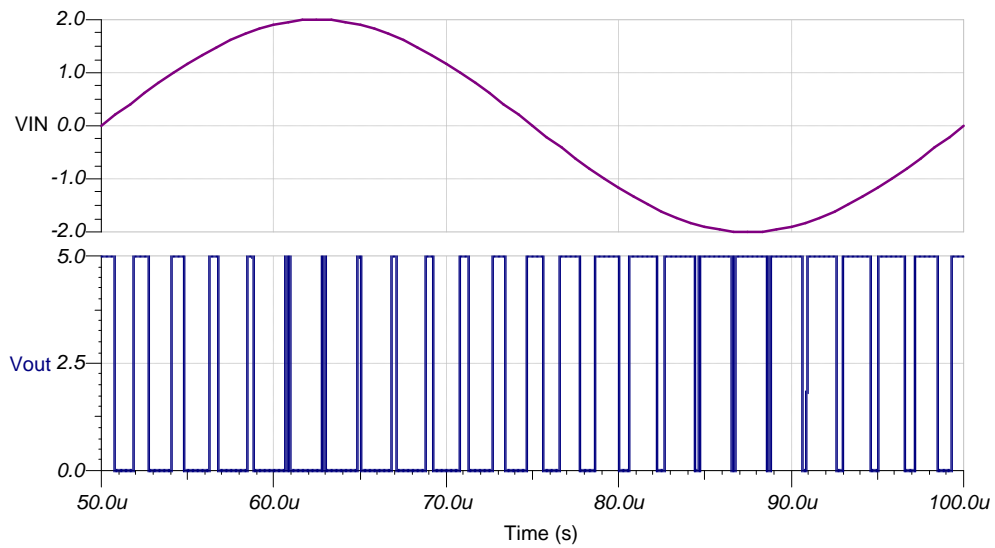
$$f_{\text{div}} = \frac{1}{2 \times \pi \times C_2 \times \frac{R_1 \times R_2}{R_1 + R_2}} = 320\text{Hz}$$

**Design Simulations**

**DC Simulation Results**



**Transient Simulation Results**



## Design References

See [Analog Engineer's Circuit Cookbooks](#) for TI's comprehensive circuit library.

See circuit SPICE simulation file [SBOC502](#).

See TIPD108, [www.ti.com/tool/tipd108](http://www.ti.com/tool/tipd108)

## Design Featured Op Amp

OPA2365	
$V_{SS}$	2.2V to 5.5V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	100 $\mu$ V
$I_q$	4.6mA
$I_b$	2pA
UGBW	50MHz
SR	25V/ $\mu$ s
#Channels	2
<a href="http://www.ti.com/product/opa2365">www.ti.com/product/opa2365</a>	

## Design Comparator

TLV3502	
$V_{SS}$	2.2V to 5.5V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	1mV
$I_q$	3.2mA
$I_b$	2pA
UGBW	-
SR	-
#Channels	2
<a href="http://www.ti.com/product/tlv3502">www.ti.com/product/tlv3502</a>	

## Design Alternate Op Amp

OPA2353	
$V_{SS}$	2.7V to 5.5V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	3mV
$I_q$	5.2mA
$I_b$	0.5pA
UGBW	44MHz
SR	22V/ $\mu$ s
#Channels	2
<a href="http://www.ti.com/product/opa2353">www.ti.com/product/opa2353</a>	

## Revision History

Revision	Date	Change
A	January 2019	Downscale the title and changed title role to 'Amplifiers'. Added link to circuit cookbook landing page.

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