

Analog Engineer's Circuit

PWM Generator Circuit



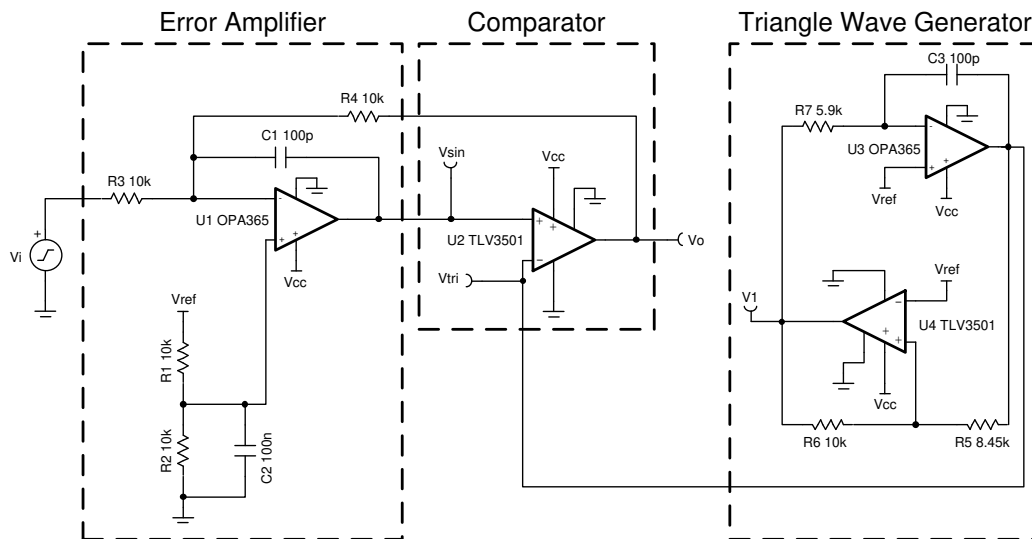
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Design Goals

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 500kHz 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_{ref} to cancel the non-inverting gain.

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

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

3. The amplitude of V_{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_{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 500kHz.

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

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

$$R_7 = \frac{R_6}{4 \times f_t \times R_5 \times C_3} = 5.92\text{k}\Omega \approx 5.90\text{k}\Omega (\text{Standard Value})$$

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

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

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

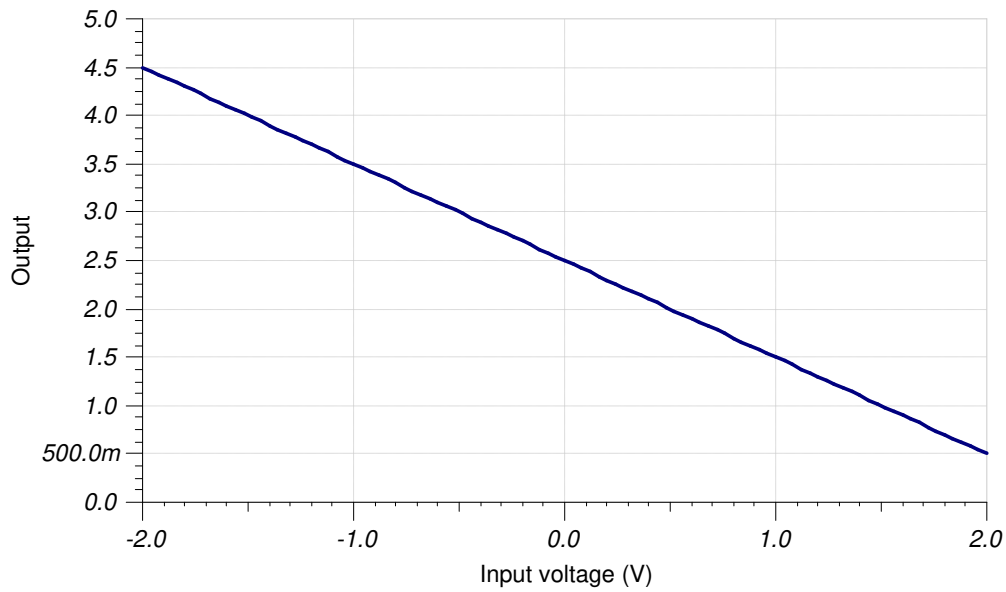
6. Select C_2 to filter noise from V_{ref} .

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

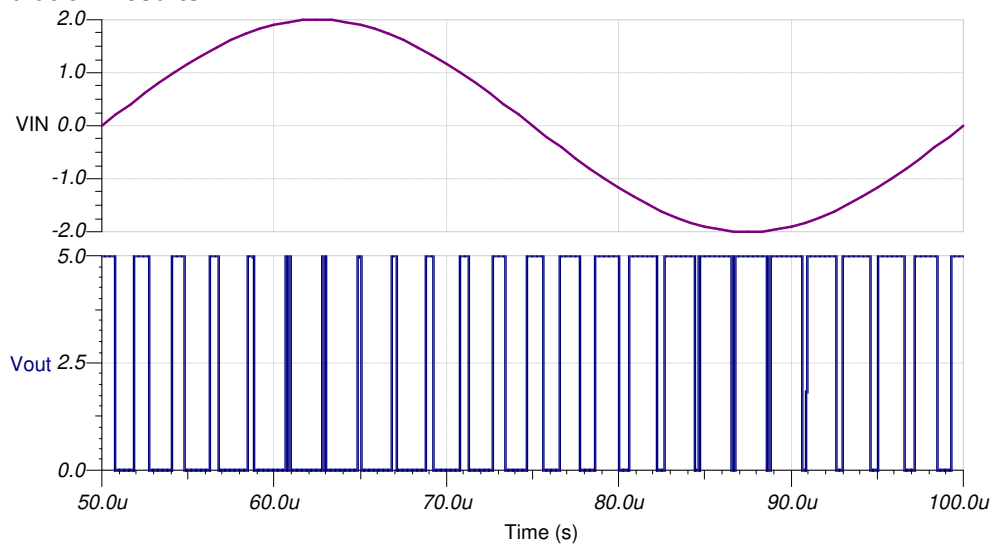
$$f_{\text{div}} = \frac{1}{2 \times \pi \times C_2 \times \frac{R_1 \times R_2}{R_1 + R_2}} = 320\text{Hz}$$

Design Simulations

DC Simulation Results



Transient Simulation Results



Design References

Texas Instruments, [Simulation for PWM Generator Circuit](#), circuit SPICE simulation file

Texas Instruments, [Analog PWM Generator 5V, 500kHz PWM Output](#), reference design

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 μ V
I_q	4.6mA
I_b	2pA
UGBW	50MHz
SR	25V/ μ s
#Channels	2
OPA2365	

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
TLV3502	

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/ μ s
#Channels	2
OPA2352	

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (February 2019) to Revision B (October 2024)	Page
• Updated the format for tables, figures, and cross-references throughout the document	1

Changes from Revision * (January 2018) to Revision A (February 2019)	Page
• Downscale the title and changed title role to 'Amplifiers'. Added link to circuit cookbook landing page.....	1

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