Analog Engineer's Circuit

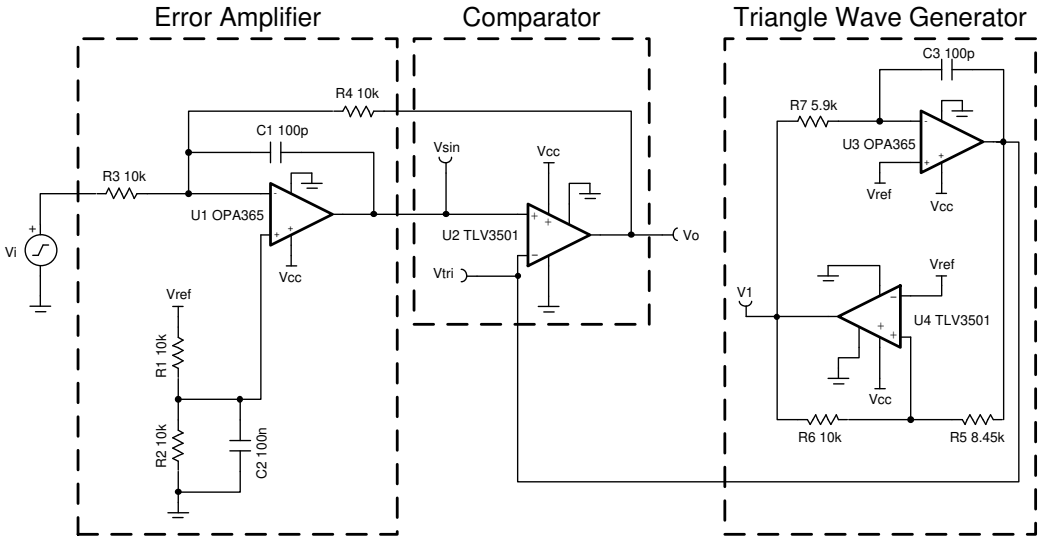
PWM Generator Circuit

Design Goals

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

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

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

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

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

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

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

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

4. Set the oscillation frequency to 500 kHz.

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

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

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

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

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

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

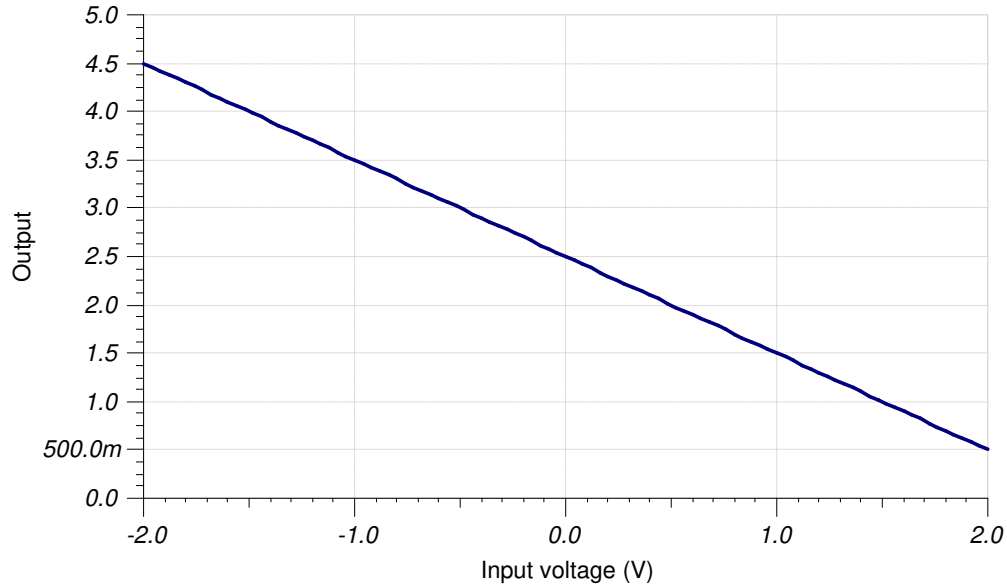
6. Select C_2 to filter noise from V_{ref}.

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

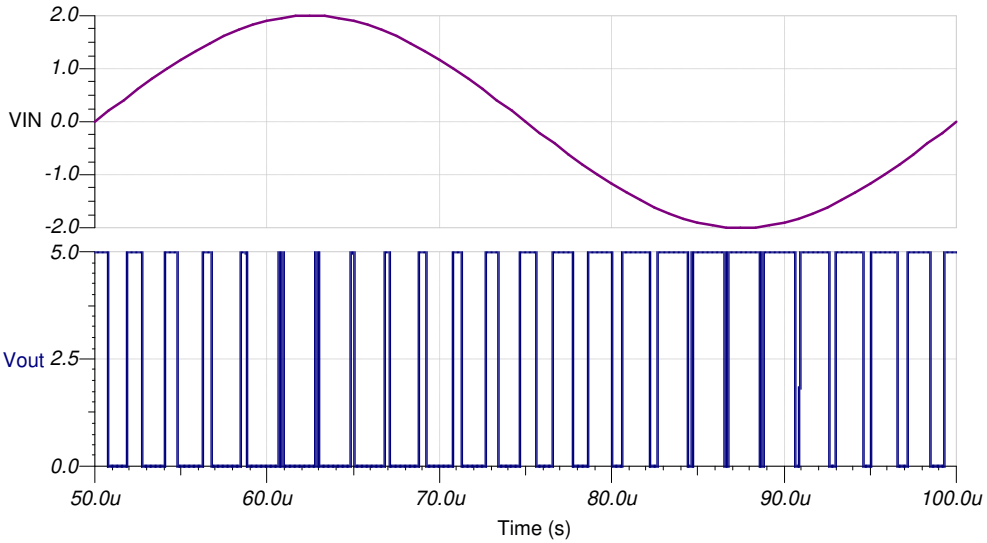
$$f_{div} = \frac{1}{2 \times \pi \times C_2 \times \frac{R_1 \times R_2}{R_1 + R_2}} = 320\text{Hz}$$

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, Analog PWM Generator 5V, 500 kHz PWM Output

Design Featured Op Amp

OPA2365	
V_{ss}	2.2 V to 5.5 V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	100 µV
I_q	4.6 mA
I_b	2 pA
UGBW	50 MHz
SR	25 V/µs
#Channels	2
OPA2365	

Design Comparator

TLV3502	
V_{ss}	2.2 V to 5.5 V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	1 mV
I_q	3.2 mA
I_b	2 pA
UGBW	—
SR	—
#Channels	2
TLV3502	

Design Alternate Op Amp

OPA2353	
V_{ss}	2.7 V to 5.5 V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	3 mV
I_q	5.2 mA
I_b	0.5 pA
UGBW	44 MHz
SR	22 V/µs
#Channels	2
OPA2352	

Revision History

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

Changes from January 19, 2018 to February 1, 2019	Page
• Downscale the title and changed title role to 'Amplifiers'. Added link to circuit cookbook landing page	1

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265