Analog Engineer's Circuit
Differentiator Circuit
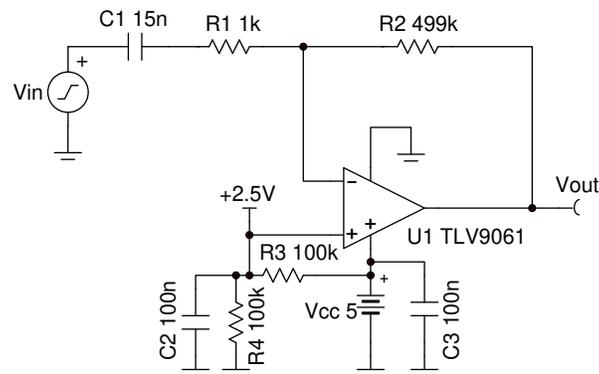
TEXAS INSTRUMENTS

Design Goals

Input		Output		Supply		
f_{Min}	f_{Max}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}	V_{ref}
100Hz	2.5kHz	0.1V	4.9V	5V	0V	2.5V

Design Description

The differentiator circuit outputs the derivative of the input signal over a frequency range based on the circuit time constant and the bandwidth of the amplifier. The input signal is applied to the inverting input so the output is inverted relative to the polarity of the input signal. The ideal differentiator circuit is fundamentally unstable and requires the addition of an input resistor, a feedback capacitor, or both, to be stable. The components required for stability limit the bandwidth over which the differentiator function is performed.

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Design Notes

1. Select a large resistance for R_2 to keep the value of C_1 reasonable.
2. A capacitor can be added in parallel with R_2 to filter the high-frequency noise of the circuit. The capacitor will limit the effectiveness of the differentiator function starting about half a decade (approximately 3.5 times) away from the filter cutoff frequency.
3. A reference voltage can be applied to the non-inverting input to set the DC output voltage which allows the circuit to work single-supply. The reference voltage can be derived from a voltage divider.
4. Operate within the linear output voltage swing (see Aol specification) to minimize non-linearity errors.

Design Steps

The ideal circuit transfer function is given below.

$$\text{Vout} \quad = \quad -R_2 \times C_1 \times \frac{d\,V_{in}(t)}{d\,t}$$

1. Set R_2 to a large standard value.

    $$R_2 = 499k\Omega$$

2. Set the minimum differentiation frequency at least half a decade below the minimum operating frequency.

    $$C_1 \geq \frac{3.5}{2 \times \pi \times R_2 \times f_{min}} \geq \frac{3.5}{2 \times \pi \times 499k\Omega \times 100Hz} \geq 11.1 \quad nF \approx 15nF \quad \left(\text{Standard} \quad \text{Value}\right)$$

3. Set the upper cutoff frequency at least half a decade above the maximum operating frequency.

    $$R_1 \leq \frac{1}{3.5 \times 2 \times \pi \times C_1 \times f_{Max}} \leq \frac{1}{7 \times \pi \times 15nF \times 2.5kHz} \leq 1.2k\Omega \approx 1 \quad k\Omega \quad \left(\text{Standard} \quad \text{Value}\right)$$

4. Calculate the necessary op amp gain bandwidth product (GBP) for the circuit to be stable.

    $$GBP > \frac{R_1 + R_2}{2 \times \pi \times R_1^2 \times C_1} > \frac{499k\Omega + 1 \quad k\Omega}{2 \times \pi \times 1 \quad k\Omega^2 \times 15nF} > 5.3MHz$$

    - The bandwidth of the TLV9061 is 10MHz, therefore this requirement is met.

5. If a feedback capacitor, C_F, is added in parallel with R_2, the equation to calculate the cutoff frequency follows.

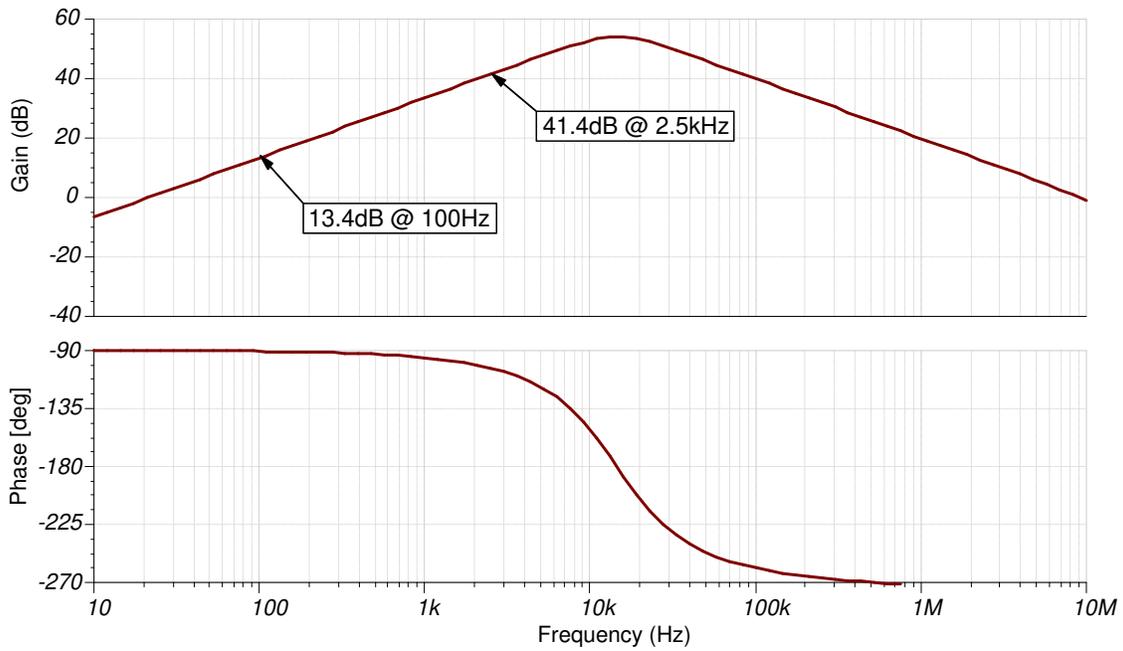 $$f_c = \frac{1}{2 \times \pi \times R_2 \times C_F}$$

6. Calculate the resistor divider values for a 2.5-V reference voltage.

    $$R_3 = \frac{V_{cc} - V_{ref}}{V_{ref}} \times R_4 = \frac{5V - 2.5V}{2.5V} \times R_4 = R_4$$

    $$R_3 = R_4 = 100k\Omega \quad \left(\text{Standard} \quad \text{Values}\right)$$
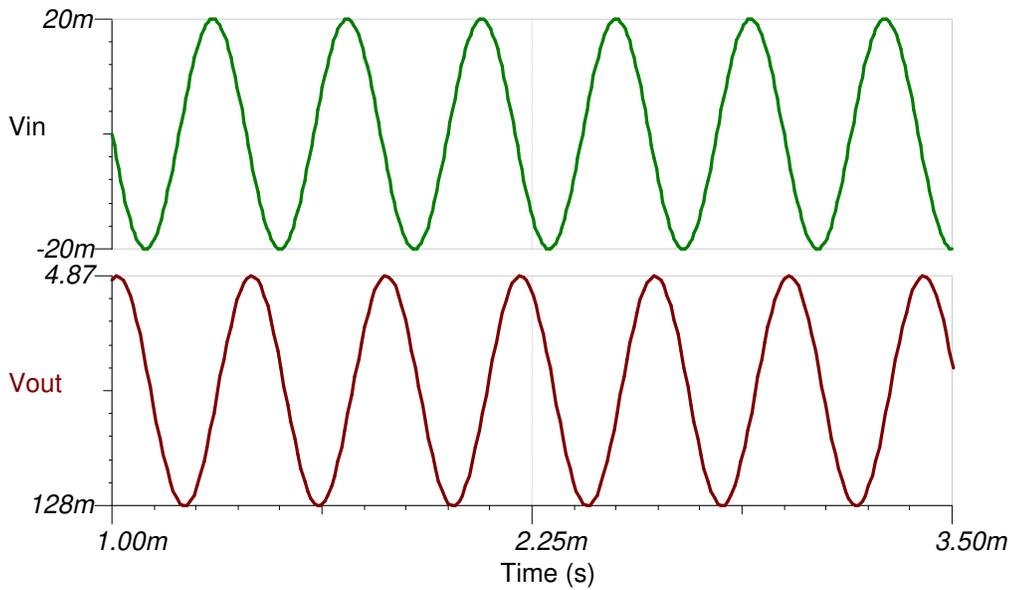
Design Simulations
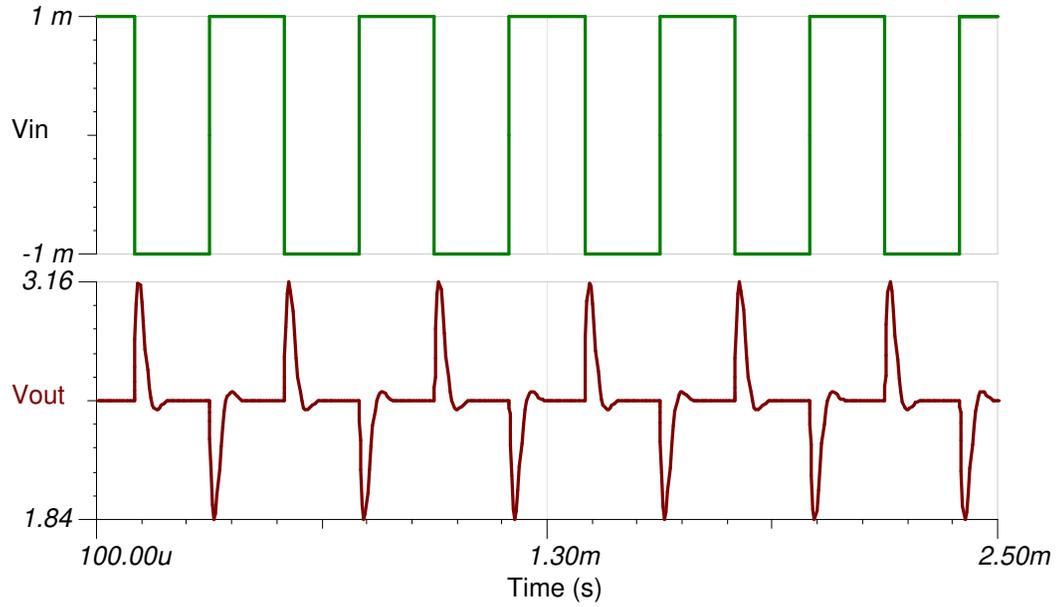
AC Simulation Results
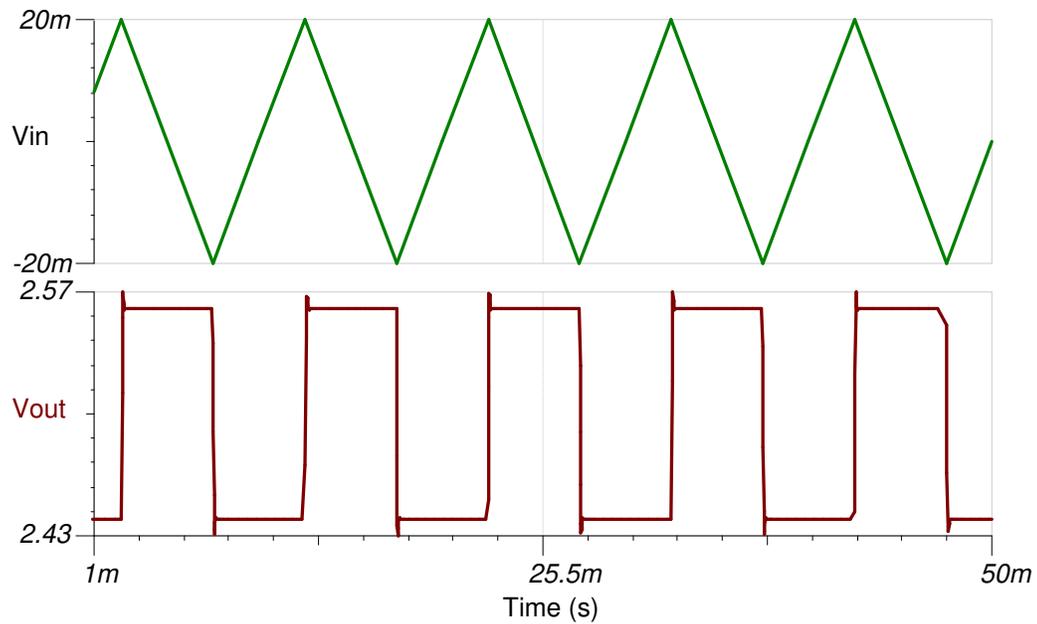

Transient Simulation Results

A 2.5-kHz sine wave input yields a 2.5-kHz cosine output.

A 2.5-kHz square wave input produces an impulse output.

A 100-Hz triangle wave input yields a square wave output.

Design Featured Op Amp

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

See circuit SPICE simulation file SBOC497.

TLV9061	
V_{cc}	1.8V to 5.5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	0.3mV
I_q	0.538mA
I_b	0.5pA
UGBW	10MHz
SR	6.5V/µs
#Channels	1, 2, 4
www.ti.com/product/tlv9061	

Design Alternate Op Amp

OPA374	
V_{cc}	2.3V to 5V
V_{inCM}	Rail-to-rail
V_{out}	Rail-to-rail
V_{os}	1mV
I_q	0.585mA
I_b	0.5pA
UGBW	6.5MHz
SR	0.4V/µs
#Channels	1, 2, 4
www.ti.com/product/opa374	

Revision History

Revision	Date	Change
A	January 2019	Downscale the title and changed title role to 'Amplifiers'. Added link to circuit cookbook landing page.
B	April 2020	Changed f_{MAX} in the Design Goals from 5kHz to 2.5kHz.
C	August 2021	Updated the numbering format for tables, figures and cross-references throughout the document.

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