

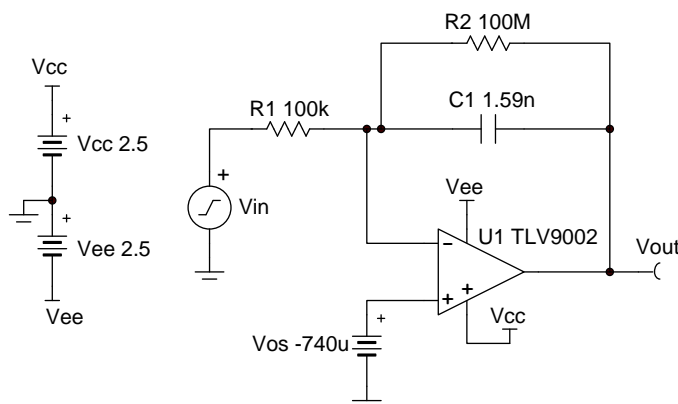
## Integrator Circuit

### Design Goals

Input			Output		Supply	
$f_{Min}$	$f_{0dB}$	$f_{Max}$	$V_{oMin}$	$V_{oMax}$	$V_{cc}$	$V_{ee}$
100Hz	1kHz	100kHz	–2.45V	2.45V	2.5V	–2.5V

### Design Description

The integrator circuit outputs the integral 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 integrator circuit will saturate to the supply rails depending on the polarity of the input offset voltage and requires the addition of a feedback resistor,  $R_2$ , to provide a stable DC operating point. The feedback resistor limits the lower frequency range over which the integration function is performed. This circuit is most commonly used as part of a larger feedback/servo loop which provides the DC feedback path, thus removing the requirement for a feedback resistor.



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### Design Notes

1. Use as large of a value as practical for the feedback resistor.
2. Select a CMOS op amp to minimize the errors from the input bias current.
3. The gain bandwidth product (GBP) of the amplifier will set the upper frequency range of the integrator function. The effectiveness of the integration function is usually reduced starting about one decade away from the amplifier bandwidth.
4. An adjustable reference needs to be connected to the non-inverting input of the op amp to cancel the input offset voltage or the large DC noise gain will cause the circuit to saturate. Op amps with very low offset voltage may not require this.

## Design Steps

The ideal circuit transfer function is given below.

$$V_{out} = -\frac{1}{R_1 \times C_1} \int_0^t V_{in}(t) dt$$

1. Set  $R_1$  to a standard value.

$$R_1 = 100k\Omega$$

2. Calculate  $C_1$  to set the unity-gain integration frequency.

$$C_1 = \frac{1}{2 \times \pi \times R_1 \times f_{0dB}} = \frac{1}{2 \times \pi \times 100k\Omega \times 1 \text{ kHz}} = 1.59nF$$

3. Calculate  $R_2$  to set the lower cutoff frequency a decade less than the minimum operating frequency.

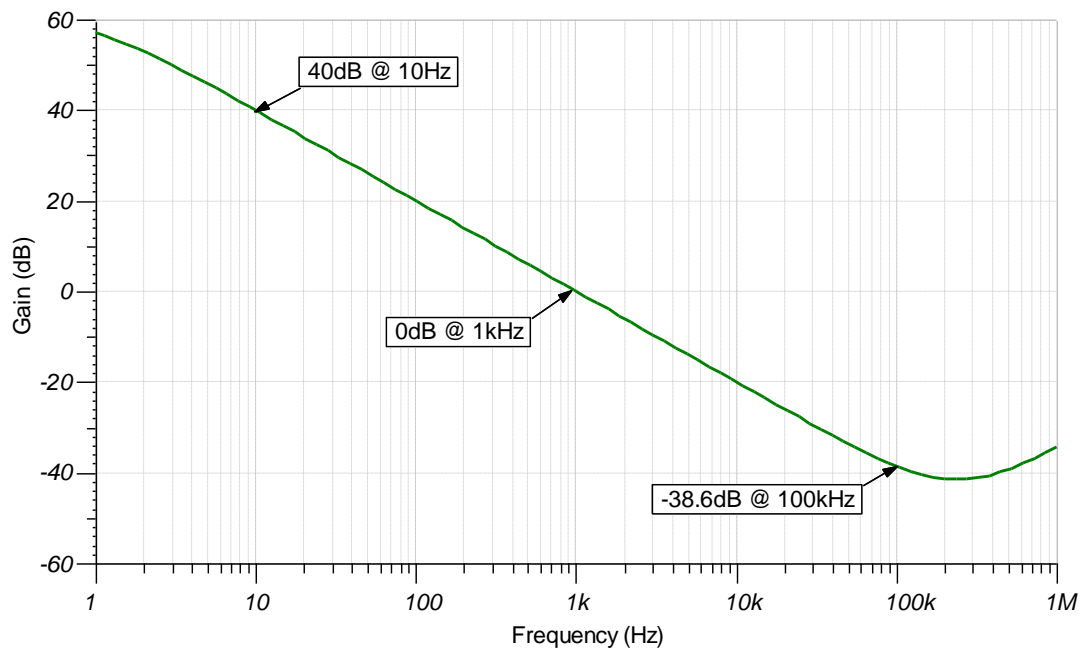
$$R_2 \geq \frac{10}{2 \times \pi \times C_1 \times f_{Min}} \geq \frac{10}{2 \times \pi \times 1.59nF \times 10Hz} \geq 100M\Omega$$

4. Select an amplifier with a gain bandwidth at least 10 times the desired maximum operating frequency.

$$GBP \geq 10 \times f_{Max} \geq 10 \times 100kHz \geq 1 \text{ MHz}$$

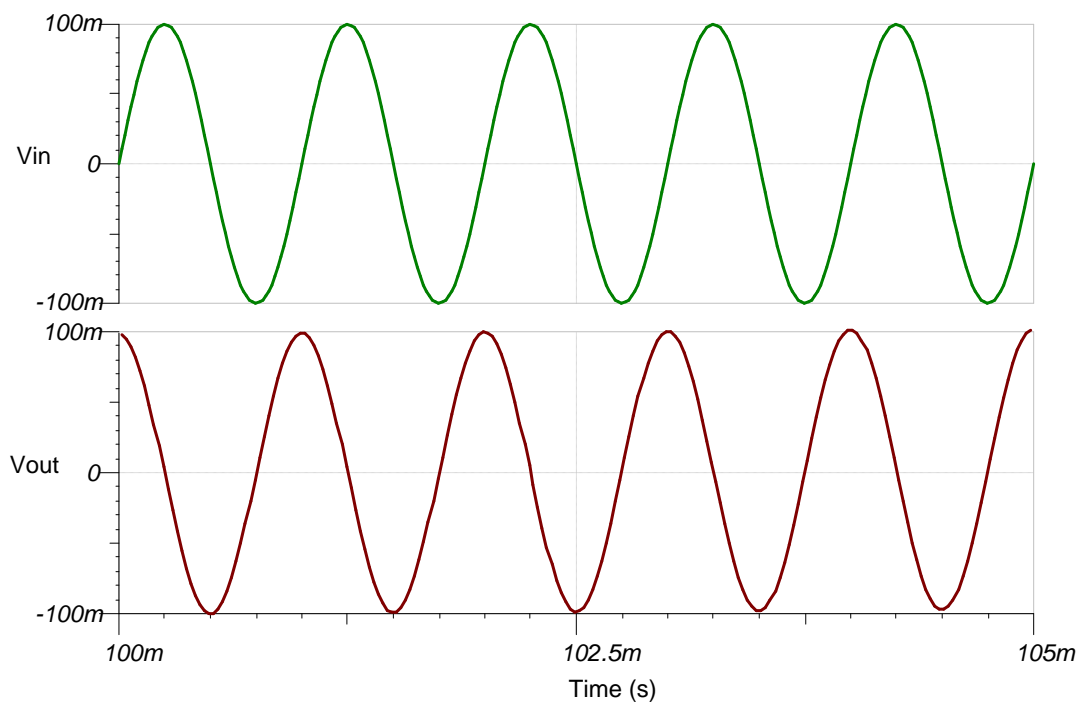
## Design Simulations

### AC Simulation Results

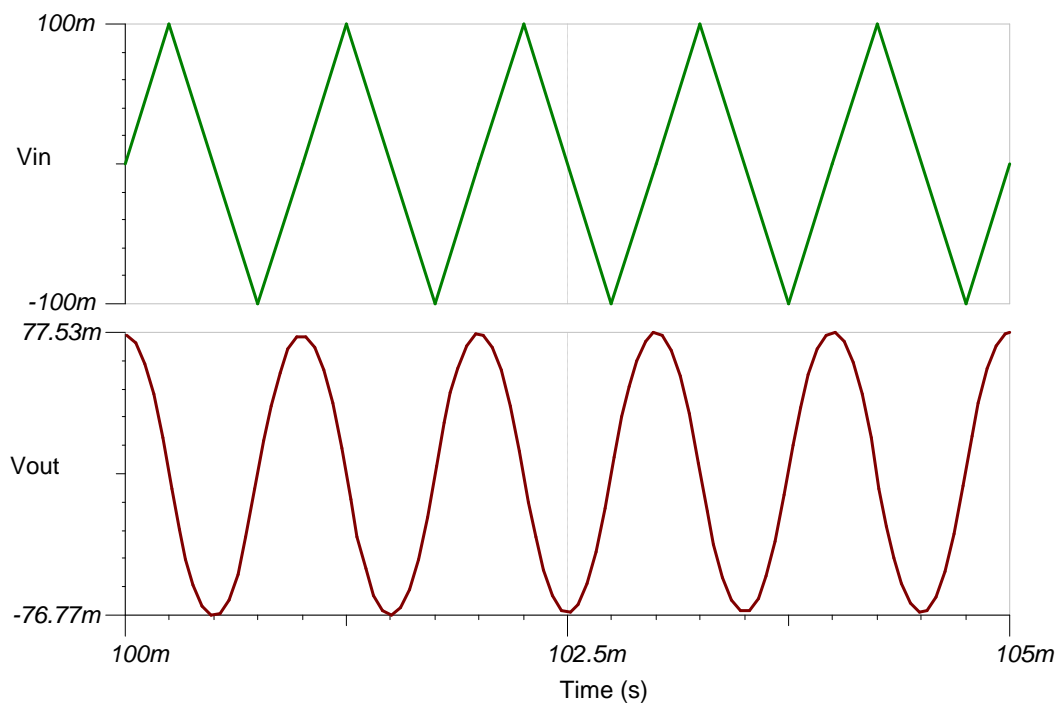


## Transient Simulation Results

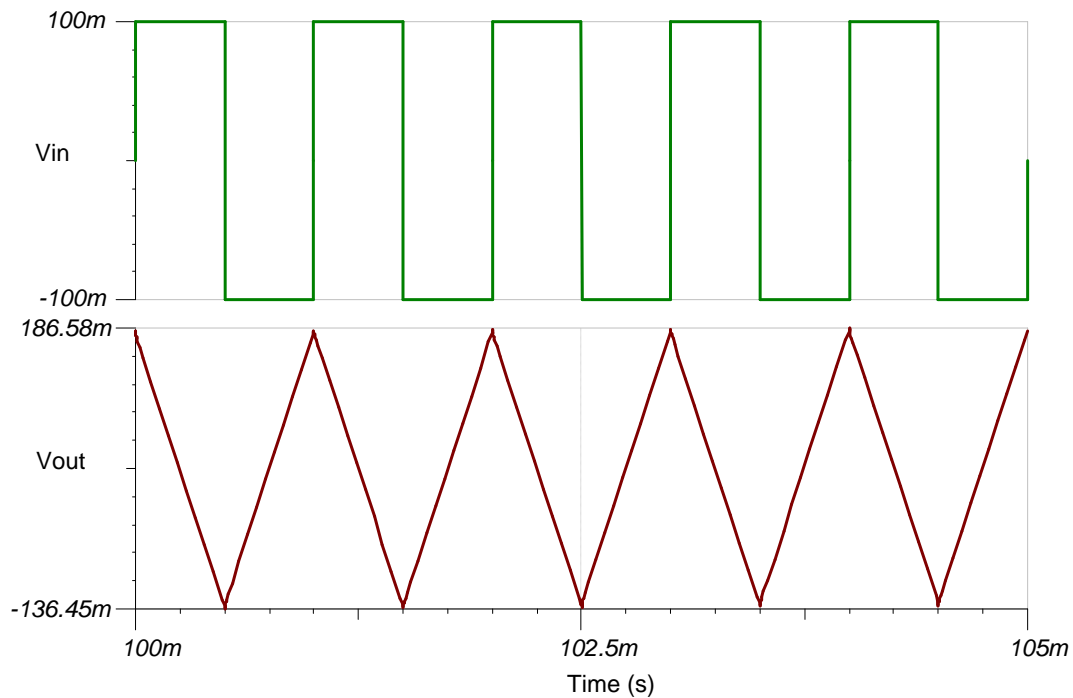
A 1-kHz sine wave input yields a 1-kHz cosine output.



A 1-kHz triangle wave input yields a 1-kHz sine wave output.



A 1-kHz square wave input yields a 1-kHz triangle wave output.



### Design References

See TIPD191, [www.ti.com/tool/tipd191](http://www.ti.com/tool/tipd191).

## Design Featured Op Amp

TLV9002	
$V_{CC}$	1.8V to 5.5V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{os}$	0.4mV
$I_q$	0.06mA
$I_b$	5pA
UGBW	1MHz
SR	2V/ $\mu$ s
#Channels	1, 2, 4
<a href="http://www.ti.com/product/tlv9002">www.ti.com/product/tlv9002</a>	

## Design Alternate Op Amp

OPA376	
$V_{CC}$	2.2V to 5.5V
$V_{inCM}$	( $V_{EE}$ -0.1V) to ( $V_{CC}$ -1.3V)
$V_{out}$	Rail-to-rail
$V_{os}$	0.005mV
$I_q$	0.76mA
$I_b$	0.2pA
UGBW	5.5MHz
SR	2V/ $\mu$ s
#Channels	1, 2, 4
<a href="http://www.ti.com/product/opa376">www.ti.com/product/opa376</a>	

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