Practical integrator using operational amplifier

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Contents

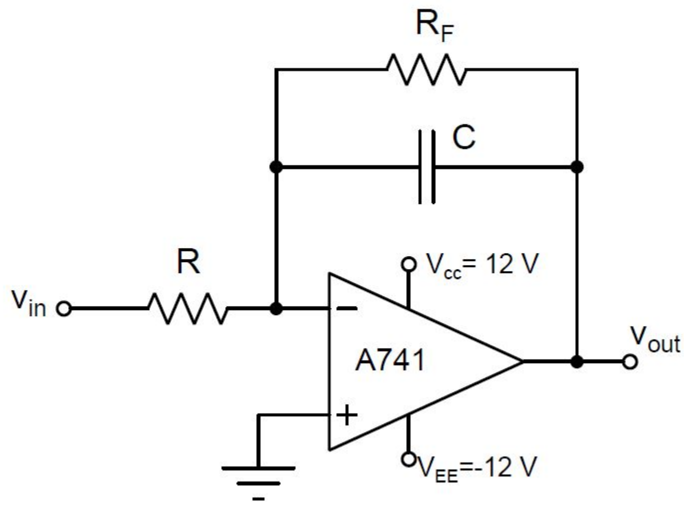
1 Aim

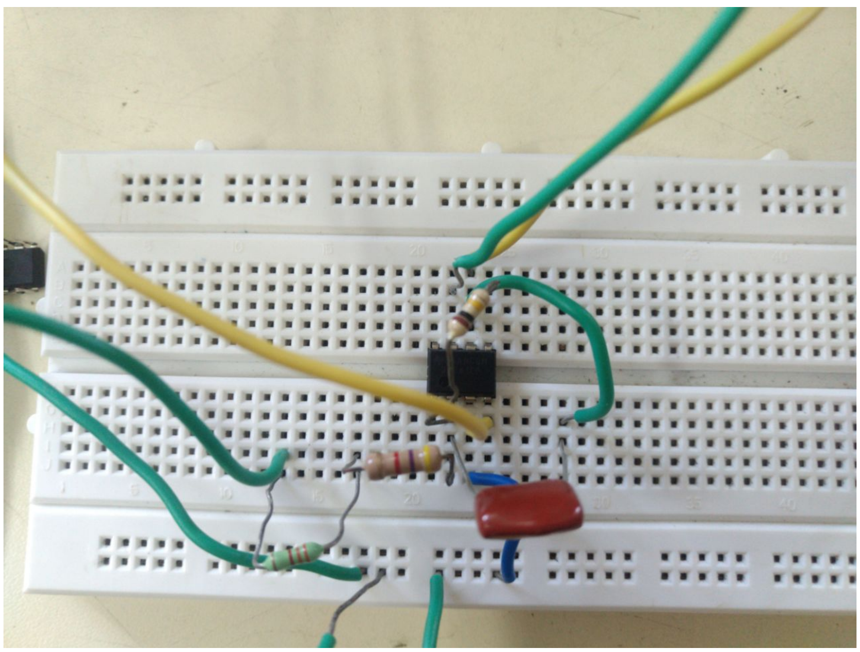
To design, implement and test a μA741-based voltage integrator.

Components required

- μA741 OpAmp
- Resistors R = 120kΩ, 3.3kΩ, 4.7kΩ
- Capacitor C= 0.01 μF
- Breadboard
- Digital Storage Oscilloscope
- Jumper wires
- Signal generator

Circuit diagram





2 Theory

In an integrator, the output voltage is proportional to the integral of the input. The response of an opamp circuit with feedback will reflect the characteristics of the feedback elements. In order to achieve integration, the feedback network is constructed using a capacitor.

In a practical integrator, one can overcome the limitations of an ideal integrator by adding resistor R_f in parallel with capacitor C. R_f prevents the opamp from going into open loop configuration at low frequencies.

Frequency response of a practical integrator is given by,

$$\begin{aligned} H(s) &= \frac{-R_F||\frac{1}{Cs}}{R} \\ H(j\omega) &= \frac{-R_F}{R}\left[\frac{1}{1+R_FCj\omega}\right] \end{aligned}$$

The magnitude and phase response are given by,

$$\begin{aligned} |H(j\omega)| &= \frac{R_F}{R}\frac{1}{\sqrt{1+\omega^2R_F^2C^2}} \\ \angle H(j\omega) &= \pi - tan^{-1}(\omega R_FC) \end{aligned}$$

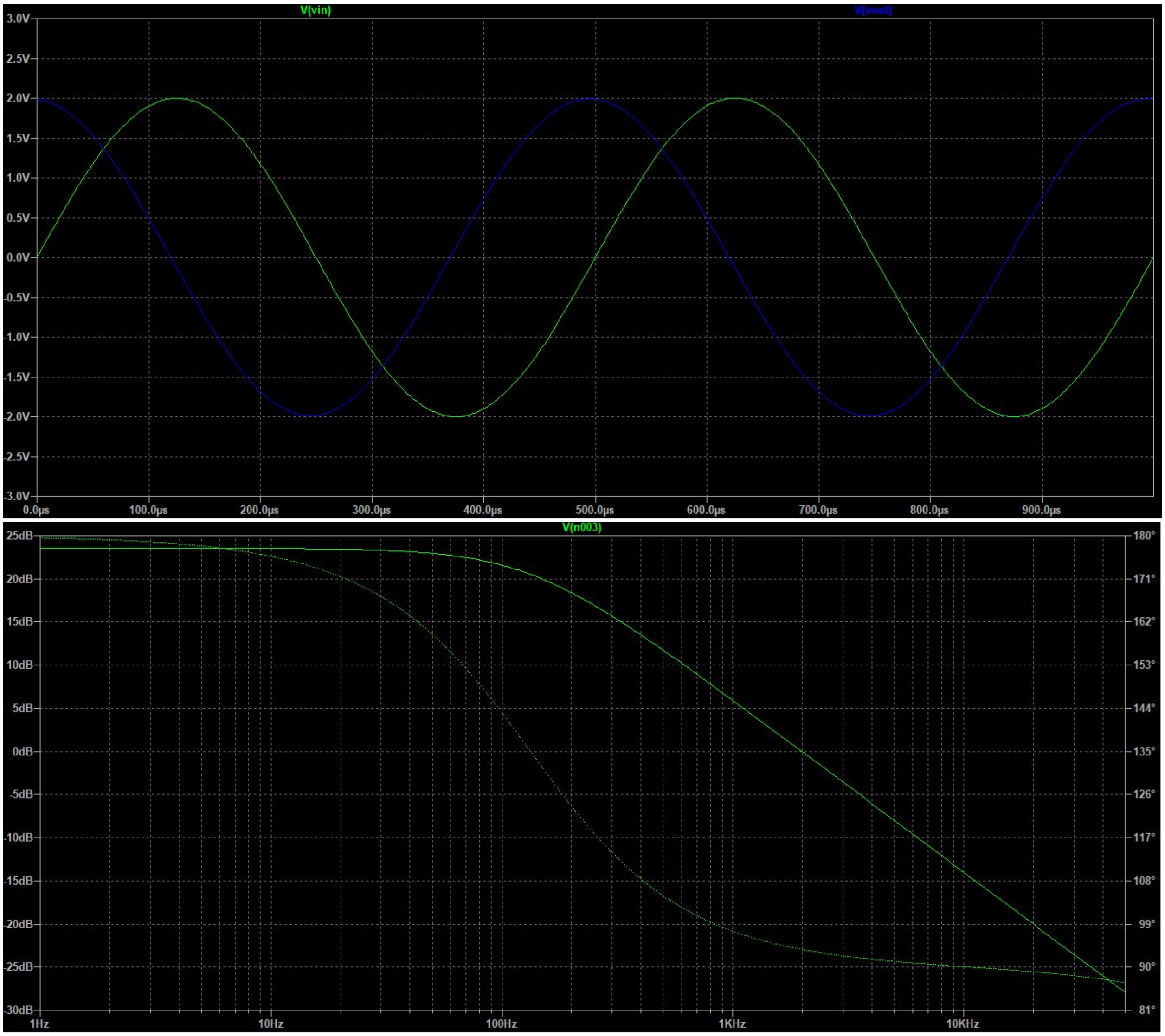
3 Design

Q. Design a μA741 based voltage integrator with unity gain and $f_{-3dB} = f_{in}/15$ for a sinusoidal input $v_{in} = 2sin(4000\pi t)$, keeping the phase error below 5%.

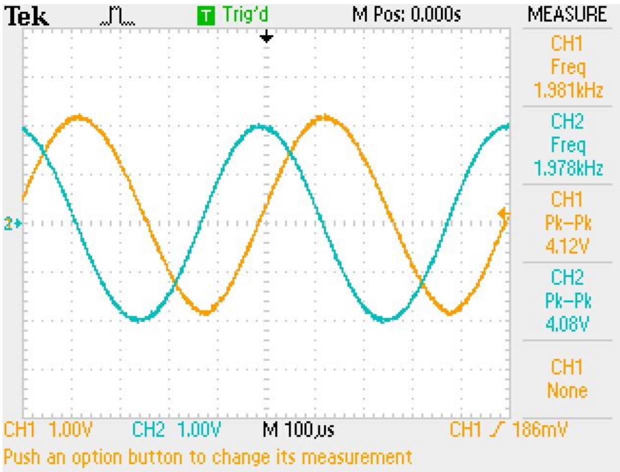
4 Calculations

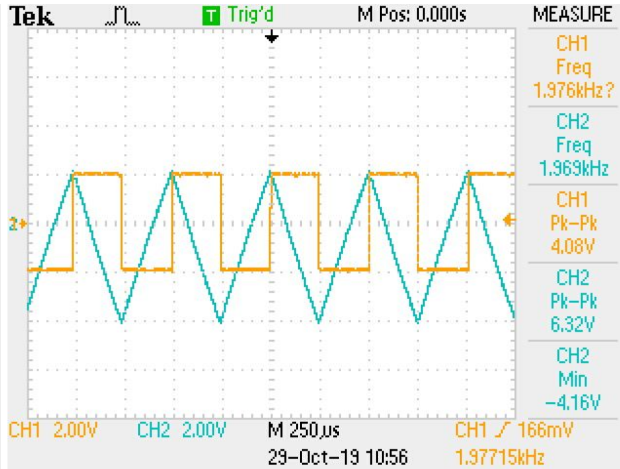
Let $C = 0.01\mu F$,
$f_{in} = 2000Hz$
$f_{-3dB} = \frac{f_{in}}{15} = 133.33Hz$
$\frac{1}{2\pi R_F C} = 133.33$
$\frac{1}{2\pi RC} = 2000$
$R = 7.96k\Omega, R_F = 119.37k\Omega$
Expected DC gain= $\frac{R_f}{R} = 15.25$
Expected phase shift= $\frac{\pi}{2} = 1.57rad$

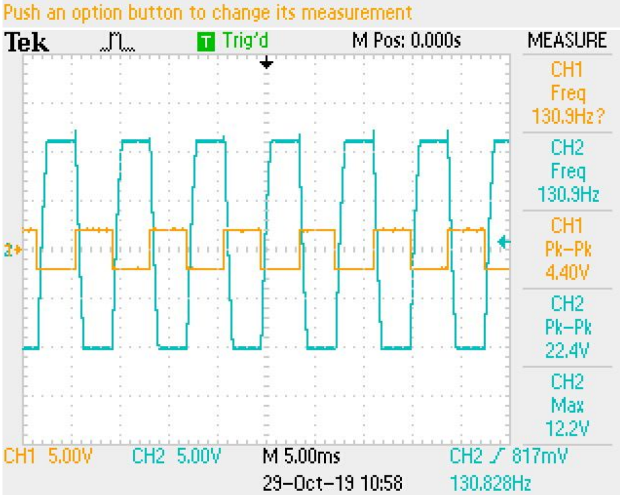
5 Simulation



6 Waveforms


Tek
Trig'd
M Pos: 0.000s
MEASURE
CH1
Freq
1.981kHz
CH2
Freq
1.978kHz
CH1
Pk-Pk
4.12V
CH2
Pk-Pk
4.08V
CH1
None
CH1 1.00V
CH2 1.00V
M 100μs
CH1 ⁄ 186mV
Push an option button to change its measurement


Tek
Trig'd
M Pos: 0.000s
MEASURE
CH1
Freq
1.976kHz?
CH2
Freq
1.969kHz
CH1
Pk-Pk
4.08V
CH2
Pk-Pk
6.32V
CH2
Min
−4.16V
CH1 2.00V
CH2 2.00V
M 250μs
CH1 ⁄ 166mV
29-Oct-19 10:56
1.97715kHz


Tek
Trig'd
M Pos: 0.000s
MEASURE
CH1
Freq
130.9Hz?
CH2
Freq
130.9Hz
CH1
Pk-Pk
4.40V
CH2
Pk-Pk
22.4V
CH2
Max
12.2V
CH1 5.00V
CH2 5.00V
M 5.00ms
CH2 ⁄ 817mV
29-Oct-19 10:58
130.828Hz

7 Observations

Q. Measure DC gain, -3dB frequency f_{3dB}, unity gain frequency f_u, roll-off rate and phase shift.

DC gain = 14.89

-3dB frequency = 132 Hz

Unity gain frequency = 2.07 kHz

Roll-off rate = -18.35 dB/decade

Phase shift = 1.608 rad, an error of 2.4%

Q. What happens if the feedback resistor R_F is removed from the circuit? Give reasons.

$V_{out} = \pm V_{sat}$ due to the capacitor acting as an open circuit at low frequencies. This sends the opamp into an open loop configuraton.

Q. Apply a square wave of 4V peak-to-peak and frequency 2 kHz. What to you see and why?

A triangular waveform is obtained as a result of the square wave being integrated.

Q. Change the frequency of the square wave input to 130 Hz. What do you observe and why?

The triangular waveform is now clipped at the $\pm V_{sat}$ levels. $C\Delta V = I\Delta V$ Substituting $C = 0.01\mu F$, $I = \frac{2}{8k}$, $t = \frac{0.5}{130}$, $\Delta V = 96.15V$ Since $\Delta V > 2V_{sat}$, V_{out} gets clipped.

8 Results & Conclusions

The μA741 based voltage integrator was designed and implemented successfully.