

Practical integrator using operational amplifier

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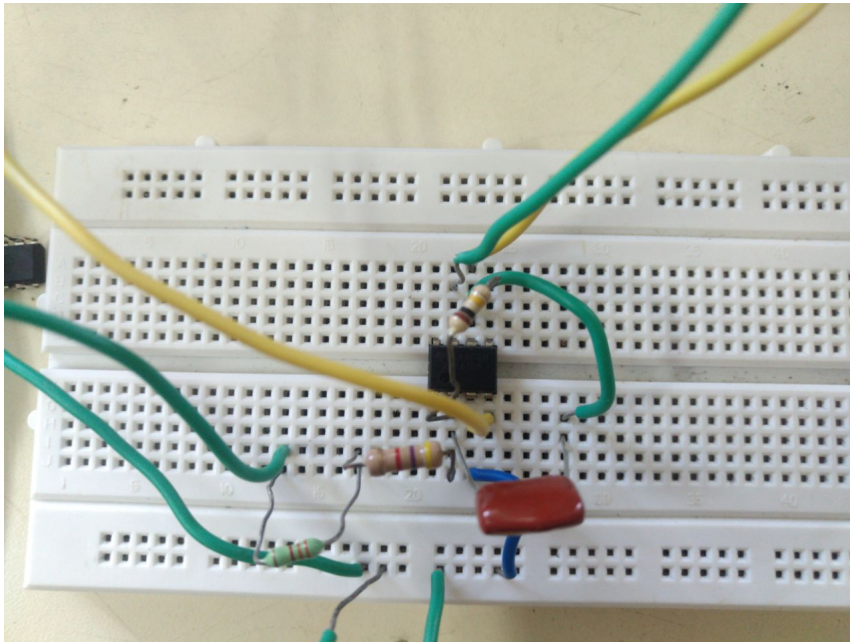
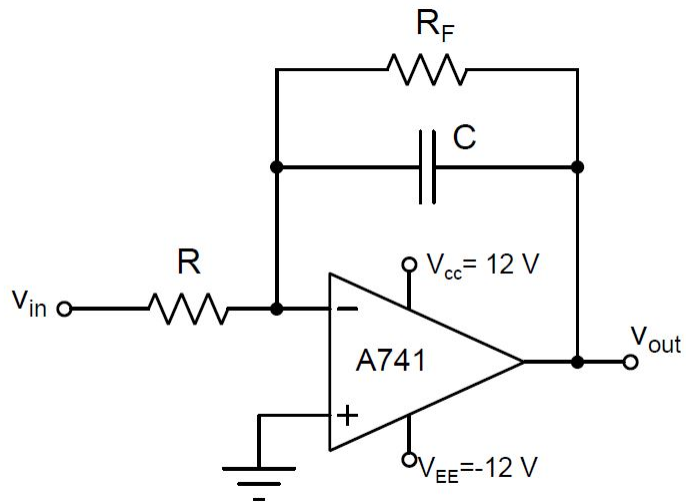
1 Aim

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

Components required

- μA741 OpAmp
- Resistors $R = 120\text{k}\Omega, 3.3\text{k}\Omega, 4.7\text{k}\Omega$
- Capacitor $C = 0.01 \mu\text{F}$
- 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,

$$H(s) = \frac{-R_F || \frac{1}{Cs}}{R}$$
$$H(j\omega) = \frac{-R_F}{R} \left[\frac{1}{1 + R_F C j\omega} \right]$$

The magnitude and phase response are given by,

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

3 Design

Q. Design a $\mu A741$ based voltage integrator with unity gain and $f_{-3dB} = f_{in}/15$ for a sinusoidal input $v_{in} = 2\sin(4000\pi t)$, keeping the phase error below 5%.

$$\text{Let } C = 0.01\mu F,$$

$$f_{in} = 2000Hz$$

$$f_{-3dB} = \frac{f_{in}}{15} = 133.33Hz$$

$$\frac{1}{2\pi R_F C} = 133.33$$

$$\frac{1}{2\pi RC} = 2000$$

$$R = 7.96k\Omega$$

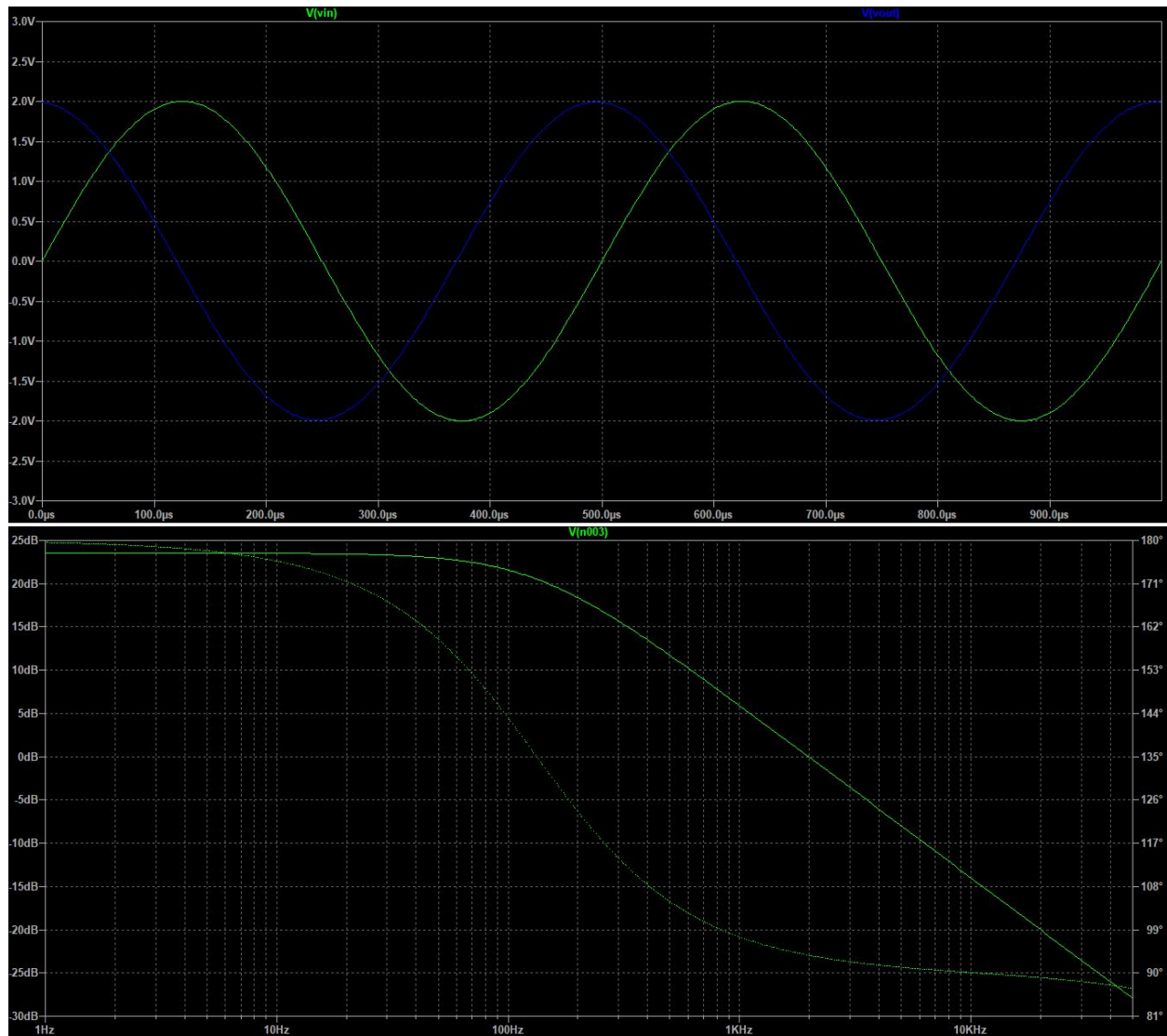
$$R_F = 119.37k\Omega$$

4 Calculations

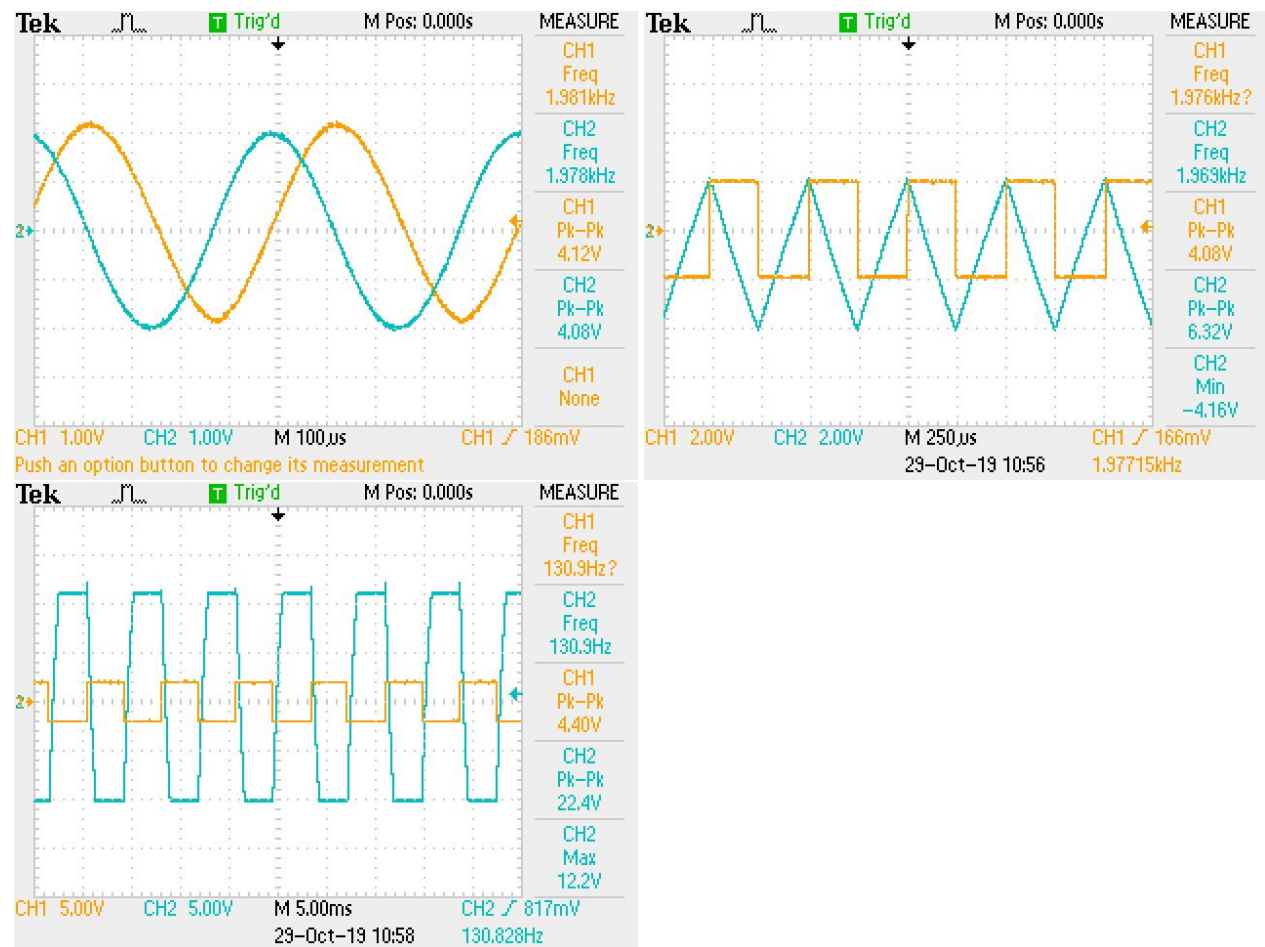
$$\text{Expected DC gain} = \frac{R_f}{R} = 15.25$$

$$\text{Expected phase shift} = \frac{\pi}{2} = 1.57rad$$

5 Simulation



6 Waveforms



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 or 92.13°, 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 configuration.

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

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

$$C\Delta V = I\Delta t$$

Substituting $C = 0.01\mu F$, $I = \frac{2}{8k}$, $\Delta t = \frac{0.5}{2000}$,

$$\Delta V = 6.25V$$

The output triangular waveform has a peak to peak voltage of around 6.25 V.

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

$$C\Delta V = I\Delta t$$

Substituting $C = 0.01\mu F$, $I = \frac{2}{8k}$, $\Delta t = \frac{0.5}{130}$,

$$\Delta V = 96.15V$$

Since $\Delta V > 2V_{sat}$, V_{out} gets clipped.

8 Results & Conclusions

The μ A741 based voltage integrator was designed and implemented successfully.