# *TEMP 101 Circuits and Signals*

# *Tutorial on RC Low Pass Filter*

# *&*

# *RC High Pass Filter*

*By*

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# *Low Pass RC Filter*

The cut off frequency is given as

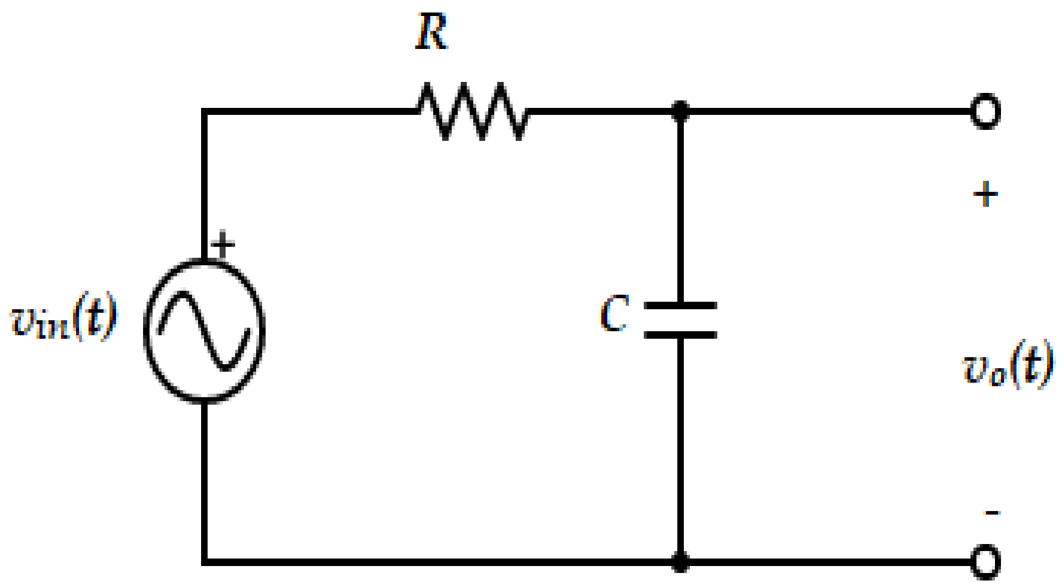
$$f_c = \frac{1}{2\pi RC}$$

The magnitude response is given as

$$M = \frac{1}{\sqrt{1 + \left(\frac{f}{f_c}\right)^2}}$$

The phase response is

$$\phi = -\tan^{-1}\left(\frac{f}{f_c}\right)$$



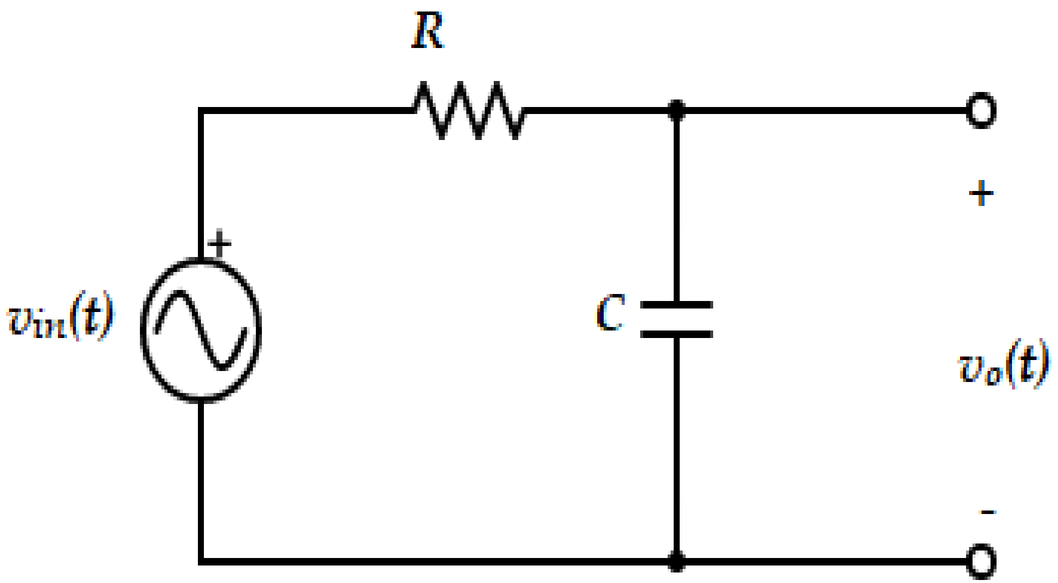
# *Question*

Design a first order low pass filter RC filter for a cut off frequency of 1000 Hz. Evaluate the gain in dB and phase at the following frequencies

| $f$ | $0.01f_c$ | $0.1f_c$ | $0.2f_c$ | $0.5f_c$ | $0.7f_c$ | $f_c$ | $2f_c$ | $5f_c$ | $7f_c$ | $10f_c$ | $20f_c$ | $100f_c$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

***Answer:***

The circuit diagram is shown




The cut off frequency is given as

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

The required cut off frequency is

$$f_c = 1000\ Hz$$

So

$$\frac{1}{2\pi RC} = 1000$$

# Question

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|---|---|---|---|---|---|---|---|---|---|---|---|---|

$$\frac{1}{2\pi RC} = 1000$$

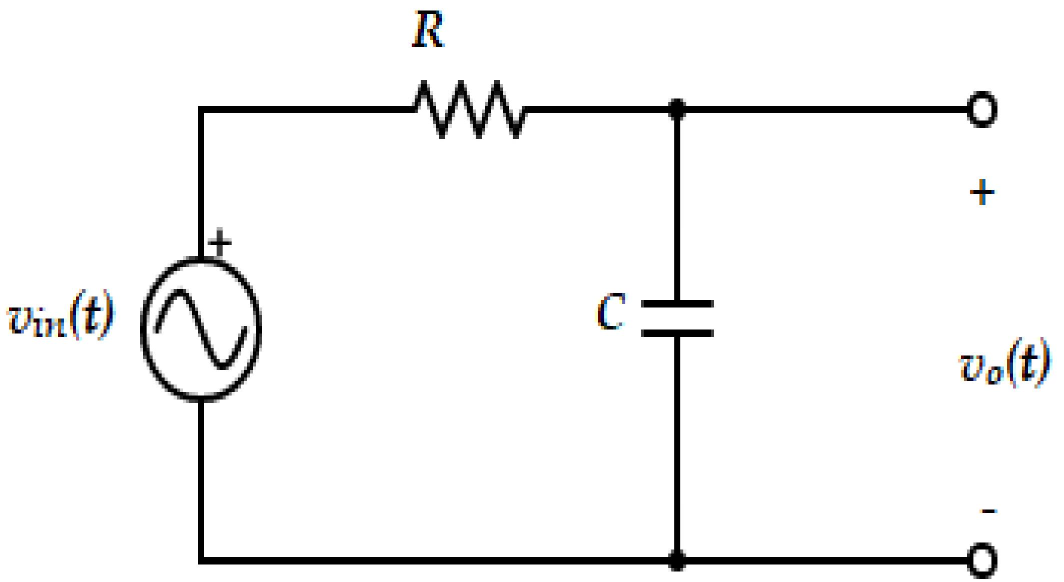
Let $C = 0.01\ \mu F$

$$R = \frac{1}{2\pi f_c C}$$

$$R = \frac{1}{2\pi \times 1000 \times 0.01 \times 10^{-6}}$$

$$R = 15915.49\Omega$$

$$R = 15.915\ k\Omega$$



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Gain is given as

$$M = \frac{1}{\sqrt{1 + \left(\frac{f}{f_c}\right)^2}}$$

| $f$ | $0.01f_c$ | $0.1f_c$ | $0.2f_c$ | $0.5f_c$ | $0.7f_c$ | $f_c$ | $2f_c$ | $5f_c$ | $7f_c$ | $10f_c$ | $20f_c$ | $100f_c$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $M$ | 1 | 0.995 | 0.9806 | 0.8944 | 0.8192 | 0.7071 | 0.4472 | 0.1961 | 0.1414 | 0.0995 | 0.0499 | 0.01 |

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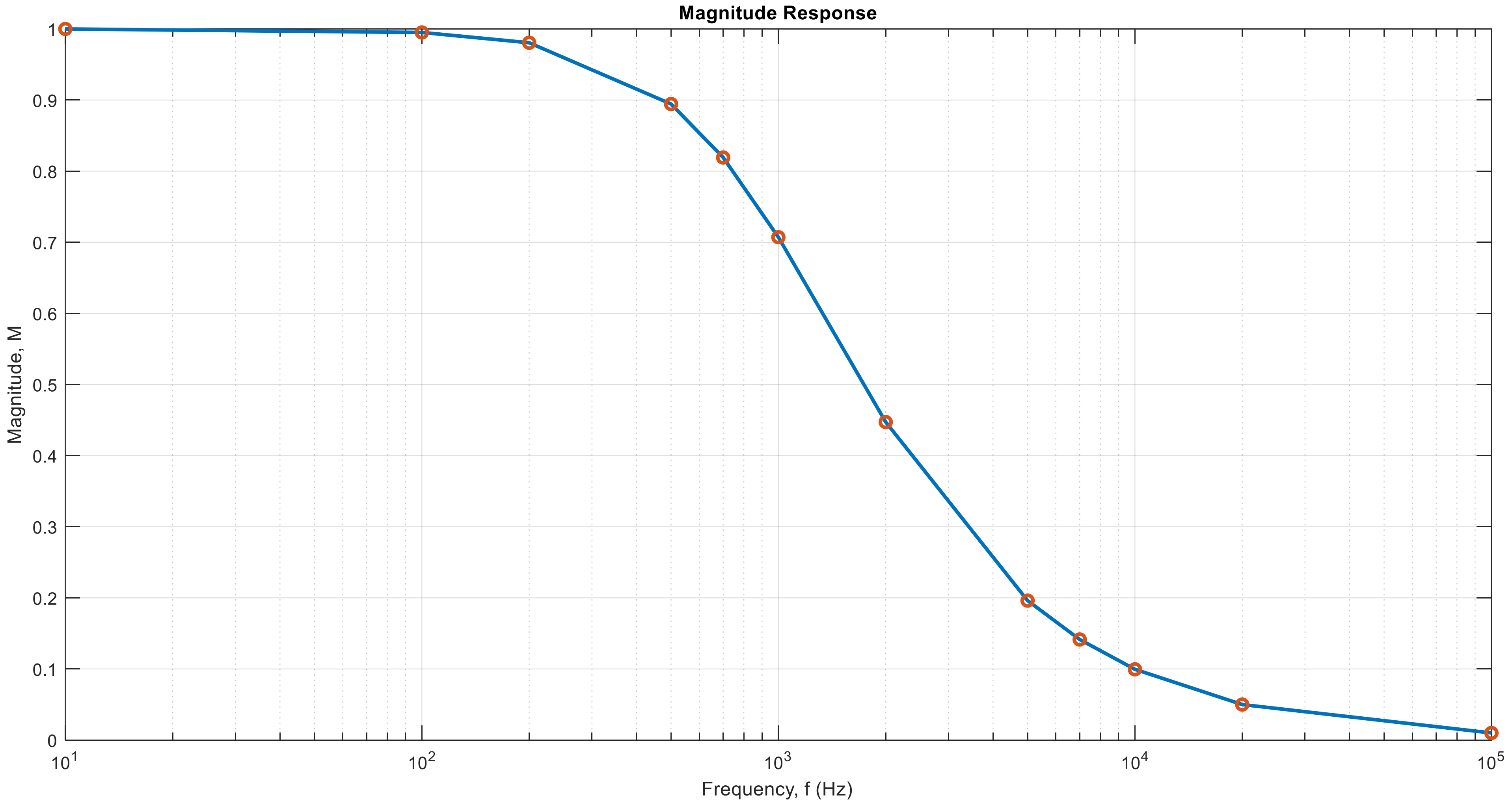
|---|---|---|---|---|---|---|---|---|---|---|---|---|

Gain is dB is given as

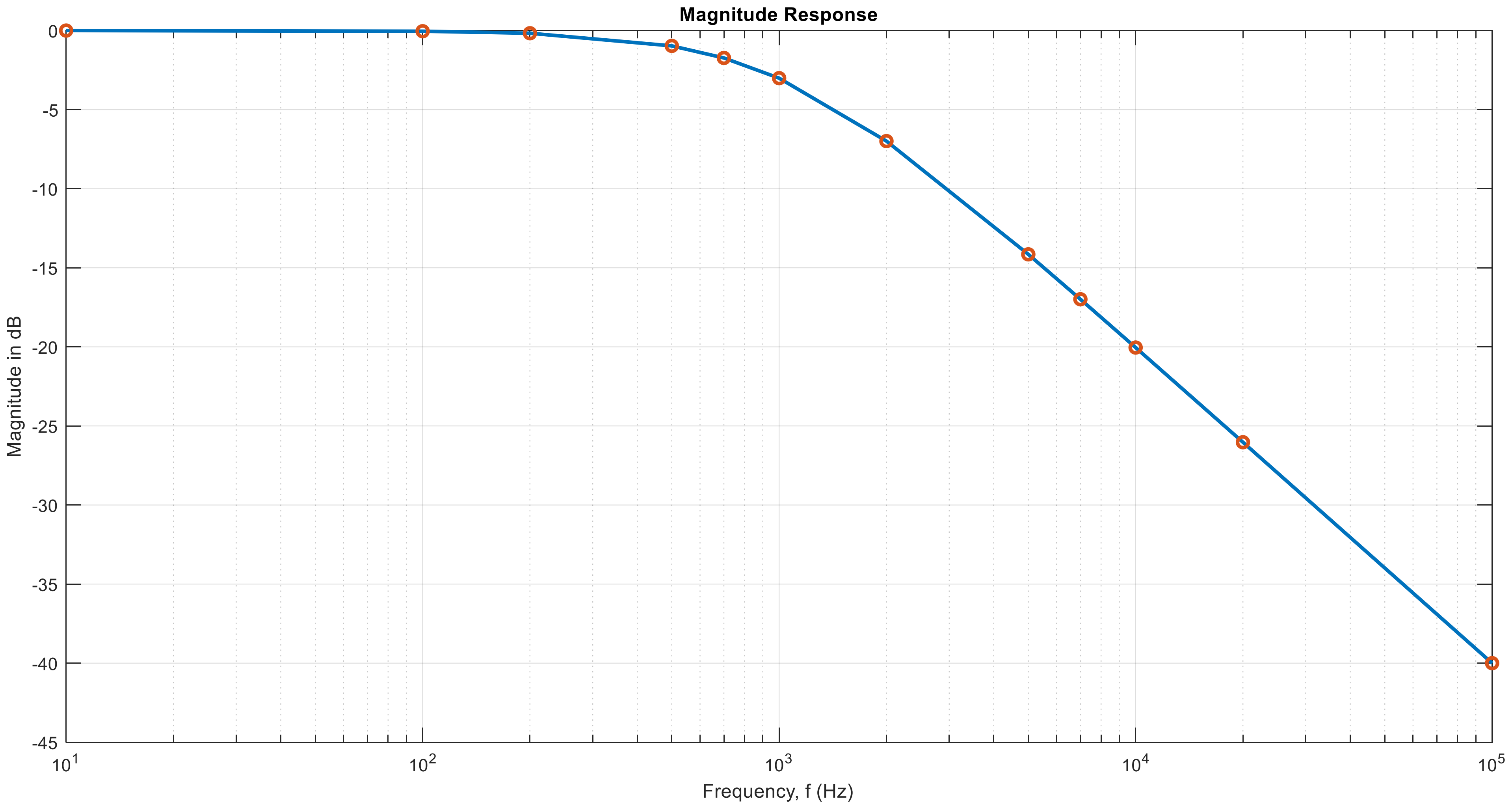
$$M_{dB} = 20.\log_{10}(M)$$

| $f$ | $0.01f_c$ | $0.1f_c$ | $0.2f_c$ | $0.5f_c$ | $0.7f_c$ | $f_c$ | $2f_c$ | $5f_c$ | $7f_c$ | $10f_c$ | $20f_c$ | $100f_c$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $M$ | 1 | 0.995 | 0.9806 | 0.8944 | 0.8192 | 0.7071 | 0.4472 | 0.1961 | 0.1414 | 0.0995 | 0.0499 | 0.01 |
| $M_{dB}$ | 0 | $-0.04$ | $-0.17$ | -0.97 | -1.73 | -3.01 | $-6.99$ | $-14.15$ | $-16.99$ | $-20.04$ | $-26.04$ | $-40$ |

# *Magnitude Response*

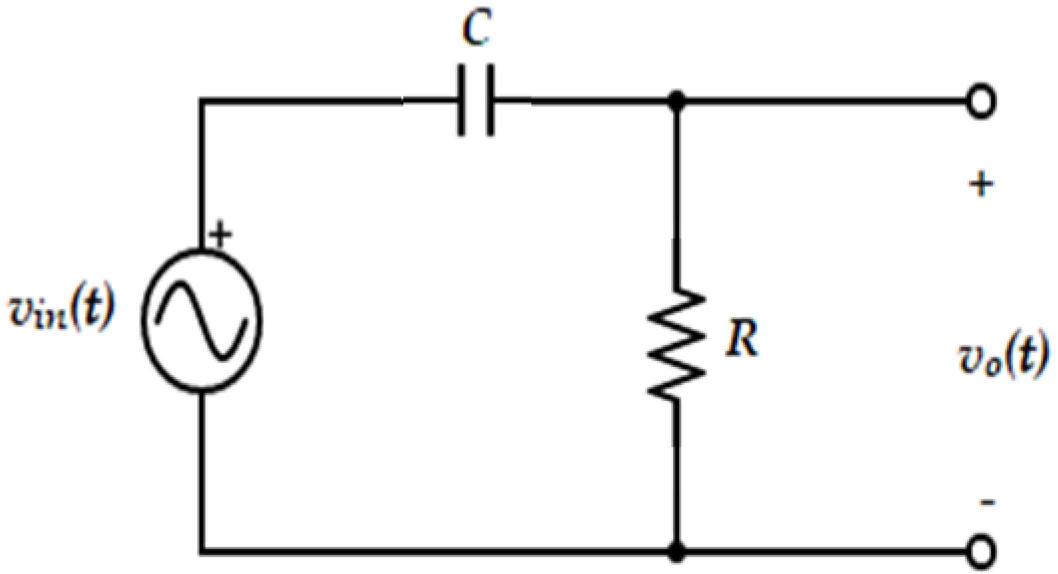


# *Magnitude Response*



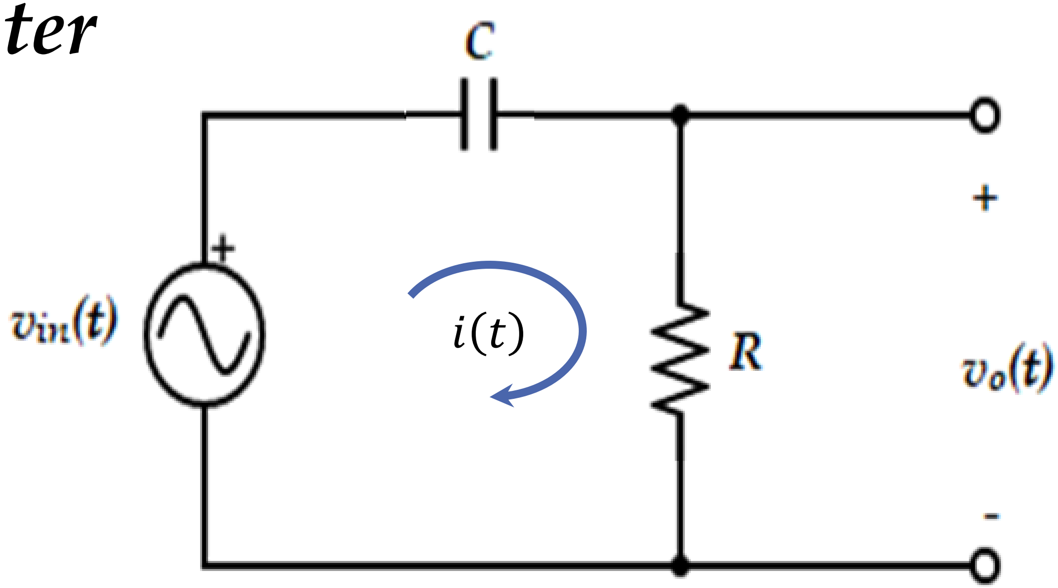
# *High Pass RC Filter*

The circuit diagram is shown



# *High Pass RC Filter*

The circuit diagram of a RC high pass filter is shown

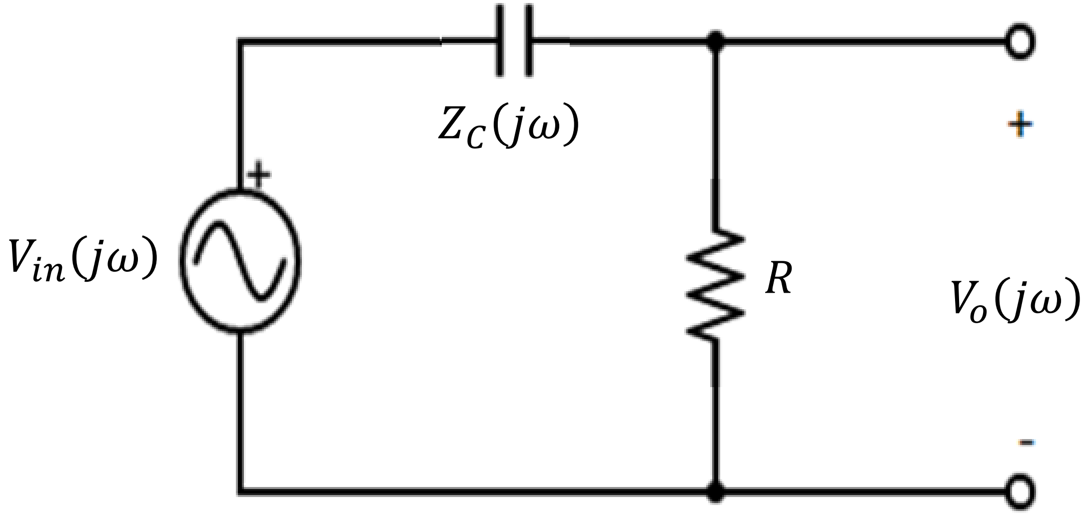



Let $i(t)$ be the current flowing through the circuit

Impedance of the capacitor is

$$Z_C(j\omega) = \frac{1}{j\omega C}$$

We can draw the circuit diagram in the frequency domain as follows




According to Voltage division rule, the voltage across the capacitor or the output voltage will be

$$V_o(j\omega) = \frac{R}{R + Z_C(j\omega)} \times V_{in}(j\omega)$$

# *High Pass RC Filter*

$$V_o(j\omega) = \frac{R}{R + Z_C(j\omega)} \times V_{in}(j\omega)$$

$$\frac{V_o(j\omega)}{V_{in}(j\omega)} = \frac{R}{R + Z_C(j\omega)}$$

Substituting for $Z_C(j\omega)$, we get

$$\frac{V_o(j\omega)}{V_{in}(j\omega)} = \frac{R}{R + \frac{1}{j\omega C}}$$

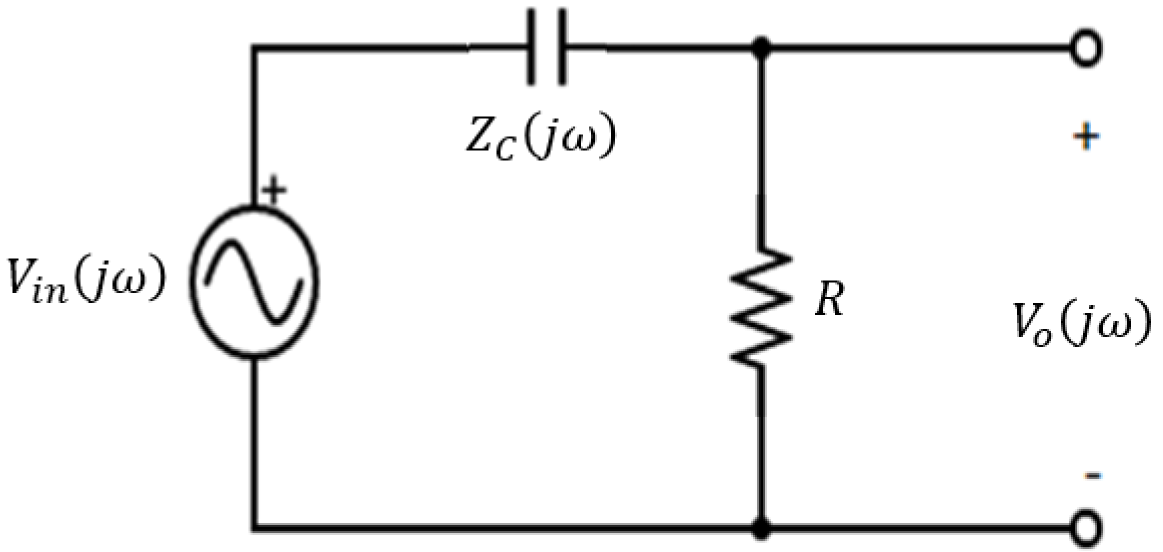
$$\frac{V_o(j\omega)}{V_{in}(j\omega)} = \frac{j\omega RC}{j\omega RC + 1}$$

What is $\frac{V_o(j\omega)}{V_{in}(j\omega)}$?

It is the frequency response. So

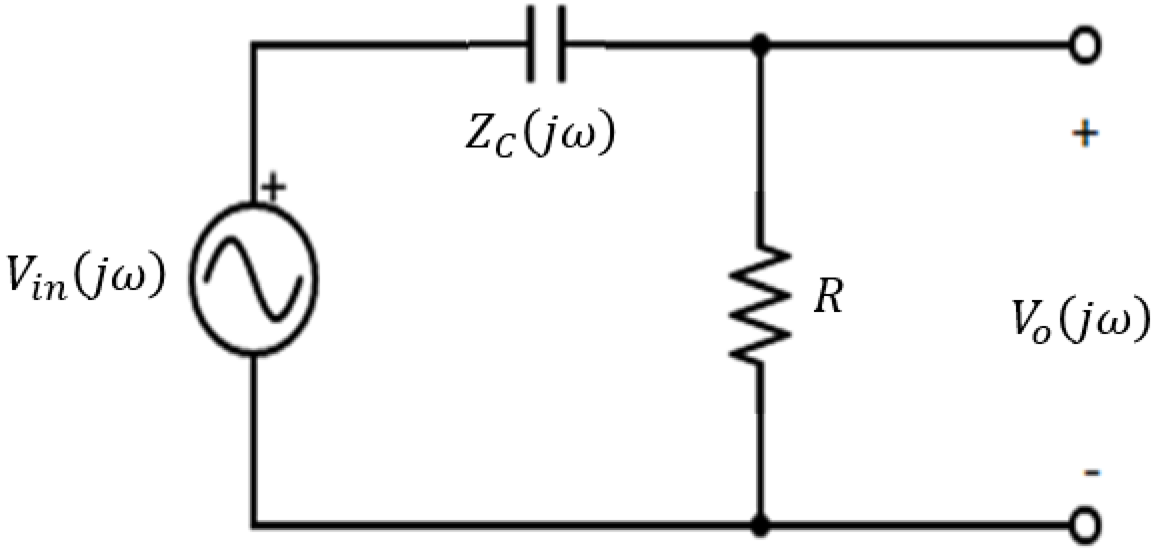
$$H(j\omega) = \frac{j\omega RC}{j\omega RC + 1}$$

Where $H(j\omega)$ is the frequency response



# *High Pass RC Filter*

$$H(j\omega) = \frac{j\omega RC}{1 + j\omega RC}$$




What is $\omega$?

$$\omega = 2\pi f$$

So

$$H(f) = \frac{j2\pi fRC}{1 + j2\pi fRC}$$

$$H(f) = \frac{1}{\frac{1}{j2\pi fRC} + 1}$$

$$H(f) = \frac{1}{1 - j\frac{1}{2\pi fRC}}$$

Let

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

Then

$$H(f) = \frac{1}{1 - j\frac{f_c}{f}}$$

# *High Pass RC Filter*

$$H(f) = \frac{1}{1 - j\frac{f_c}{f}}$$

The magnitude response is

$$M = |H(f)| = \left|\frac{1}{1 - j\frac{f_c}{f}}\right|$$

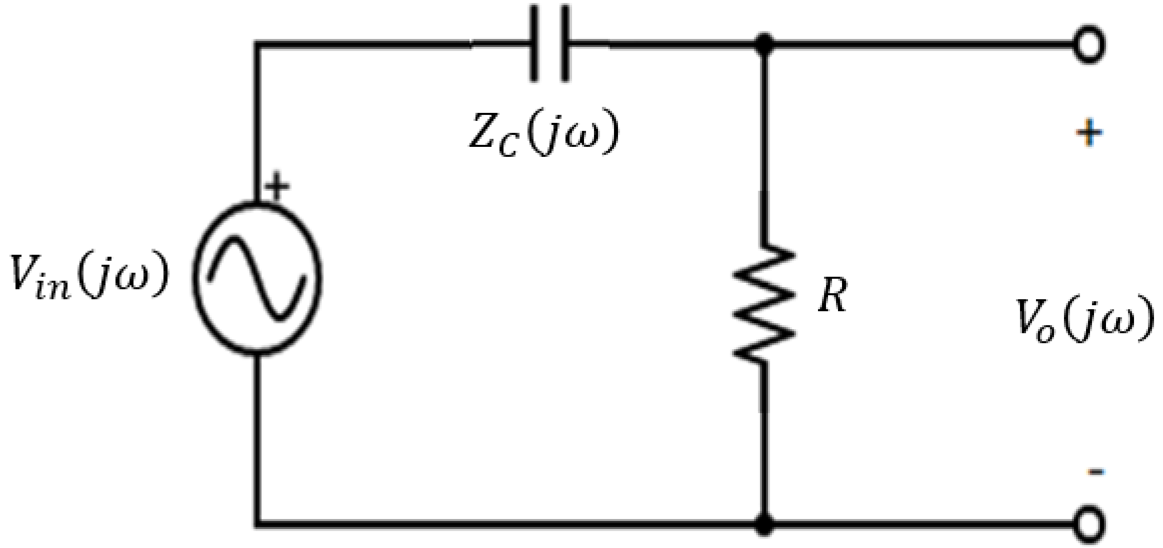
$$M = \frac{1}{\sqrt{1 + \left(\frac{f_c}{f}\right)^2}}$$

The phase response is

$$\phi = \angle H(f)$$

$$\phi = 0 \;- -\tan^{-1}\left(\frac{\frac{f_c}{f}}{1}\right)$$

$$\phi = \tan^{-1}\left(\frac{f_c}{f}\right)$$



# *Thank You*