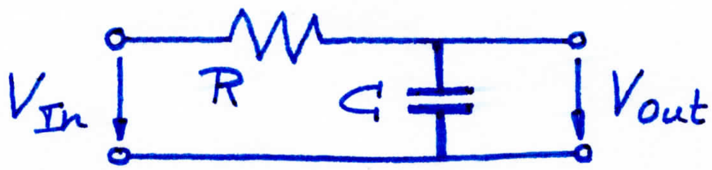
Gain-bandwidth product of op amp

Preliminary discussion: RC circuit



$$V_{out} = \frac{\frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} V_{In} = \frac{1}{1 + j\omega RC} V_{In}$$

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

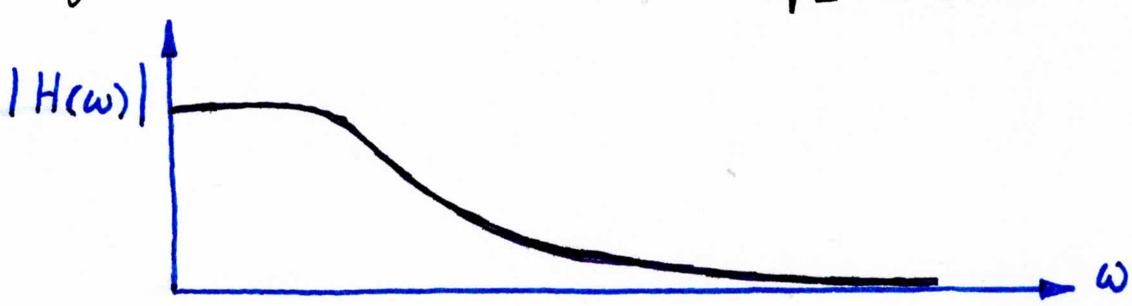
low $\omega \Rightarrow H(\omega) = 1$

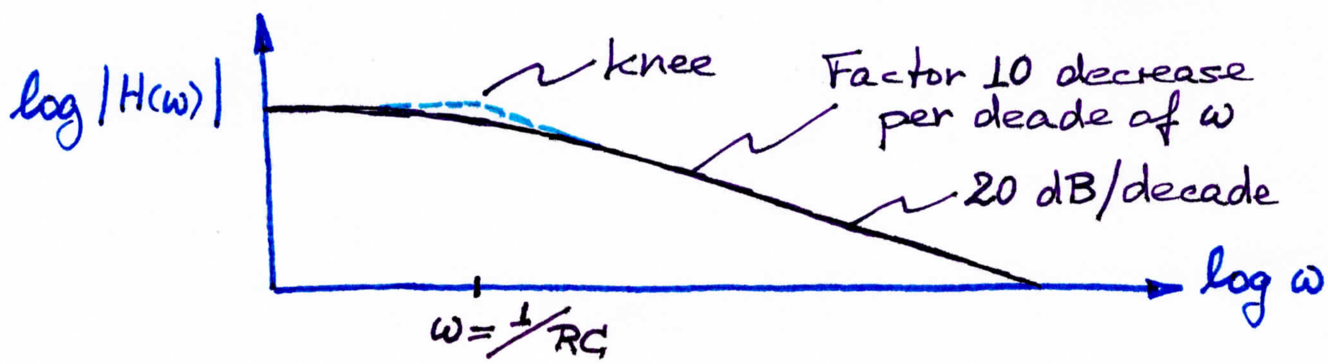
high $\omega \Rightarrow H(\omega) = -j\frac{1}{\omega RC}$

$\Rightarrow$ low $\omega \Rightarrow |H(\omega)| = 1$

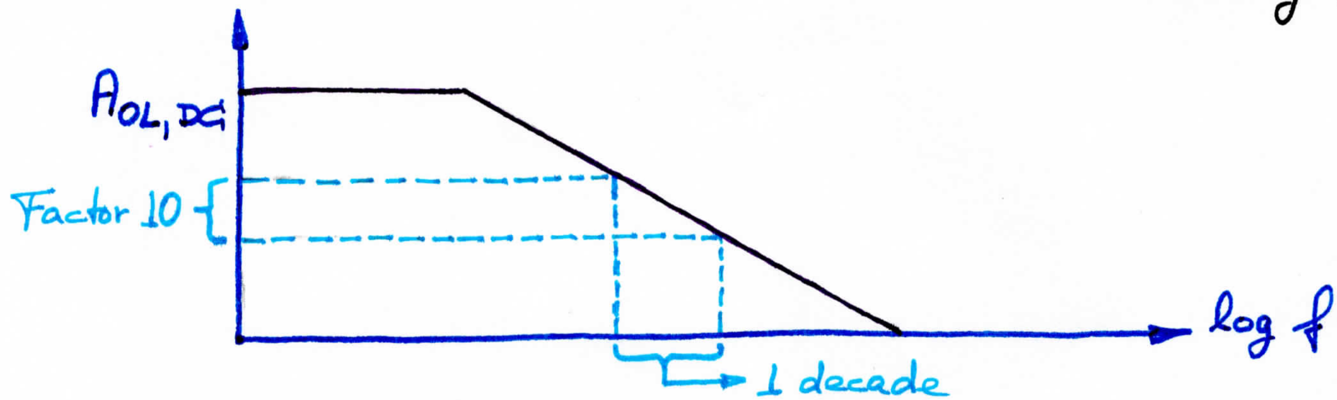
$\Rightarrow$ high $\omega \Rightarrow |H(\omega)| = \frac{1}{\omega RC}$

$\Rightarrow$ any $\omega \Rightarrow |H(\omega)| = \frac{1}{\sqrt{1 + \omega^2 R^2 C^2}}$





Op amps have the basically same transfer function.
(Why?)



What do we learn from this curve?

We see: $f \uparrow \Rightarrow A_{OL} \downarrow$

We also see: $\underbrace{A_{OL}}_{\text{Gain}=G} \times \underbrace{f}_{\text{Bandwidth}=B} = \text{constant}$

$\Rightarrow \boxed{G \times B = \text{constant}}$ → e.g. 10^7 Hz

Example:

Assume op amp with $G \times B = 10^7$ Hz

$\Rightarrow f = 1\,\text{Hz} \Rightarrow G = 10^7$ $(G = A_{OL})$

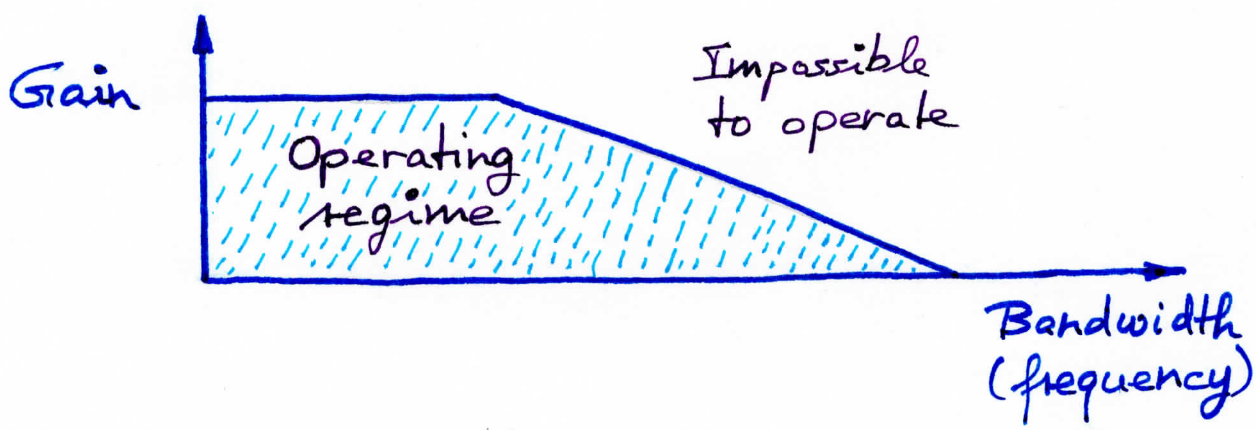
$f = 1\,\text{kHz} \Rightarrow G = 10^4$

$f = 1\,\text{MHz} \Rightarrow G = 10$

Consequences for op amp circuit design

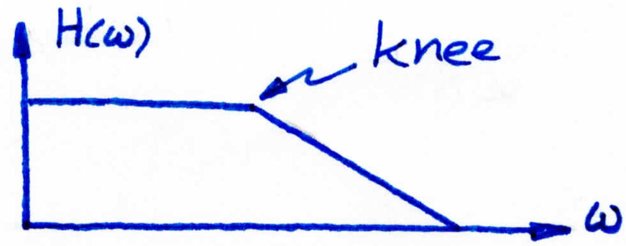
* We cannot exceed gain-bandwidth-product limitations. If $G \times B = 10^7$ Hz, then $G = 10^4$ ($= A_{OL}$) at 1 MHz is not possible.

* We need to stay within the gain-bandwidth limitations of the op amp.



Recall RC filter transfer function

$$|H(\omega)| = \frac{1}{\sqrt{1+\omega^2 R^2 C^2}}$$



$\omega = 0 \Rightarrow |H(\omega)| = 1$

$\omega = 1/RC \Rightarrow |H(\omega)| = 1/\sqrt{2}$ (knee)

$\omega = 2/RC \Rightarrow |H(\omega)| = 1/\sqrt{5} \approx 1/2$

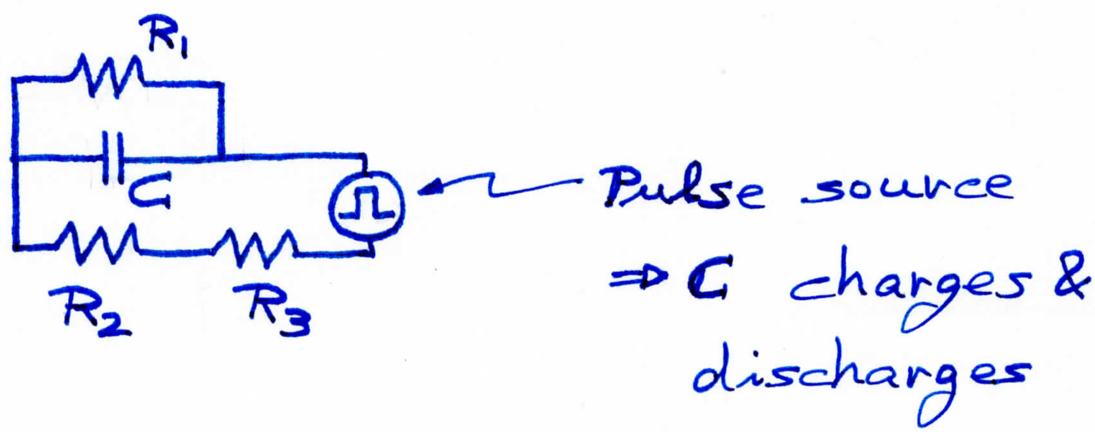
$\omega = 3/RC \Rightarrow |H(\omega)| = 1/\sqrt{10} \approx 1/3$

$\omega = 4/RC \Rightarrow |H(\omega)| \approx 1/4$

... and so on

$\Rightarrow$ To determine the frequency response of a circuit, we need to identify the RC time constant.

Q: What is the time constant of the following circuit?



$\tau = RC$ gives charging & discharging time constant. How will C discharge? C will discharge through all resistors. Circuit above: $R = R_1 \parallel (R_2 + R_3)$

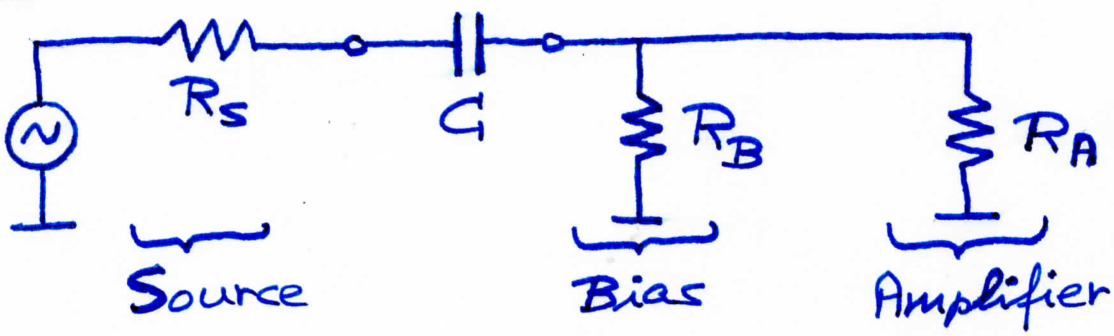
$\Rightarrow$ $\tau = RC$

Capacitance

Resistance "seen" by C

$\Rightarrow$ Knowing RC, we can calculate frequency response.

Example:

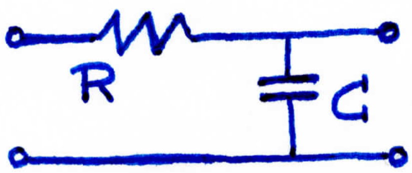


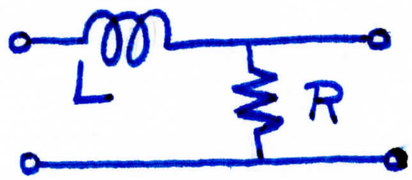
$RC = ?$

$R = R_S + (R_B \parallel R_A)$

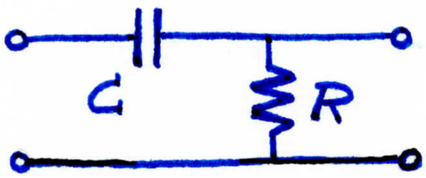
Relevant R

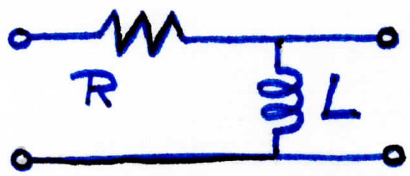
Low-pass filter





High-pass filter





Q: How many low-pass (or high-pass) filters?

Q: Are they mathematically equivalent?

Q: Time constants? $\Rightarrow$ $\tau = RC$ $\qquad \tau = L/R$

Q: Why do we have two filters (of each kind)?

Q: Which one is more common? $\Rightarrow$ RC?

Q: Why are RC filters more common?

Q: Do all filters have a knee frequency?

$\Rightarrow$ $\omega = 1/RC$ $\qquad \omega = R/L$

Summary of frequency response

Recall : RC filter

$$\left|\frac{V_{out}}{V_{In}}\right| = |H(\omega)| = \frac{1}{\sqrt{1+\omega^2R^2C^2}}$$

Knee frequency $\Rightarrow$ $\omega = \frac{1}{RC} = \frac{1}{\tau}$

↳ cutoff frequency $\Rightarrow$ $f = \frac{1}{2\pi RC} = \frac{1}{2\pi\tau}$

At knee frequency, voltage attenuation is

$$|H(\omega)| = 1/\sqrt{2}$$

At knee frequency, voltage attenuation in dB

$$20\log\frac{V_{out}}{V_{In}} = 20\log|H(\omega)| = -3\text{ dB}$$

At knee frequency, power attenuation in dB

$$10\log\frac{V_{out}^2}{V_{In}^2} = 10\log|H(\omega)|^2 = -3\text{ dB}$$

$\Rightarrow$ We see: Power attenuation in dB = Voltage attenuation in dB

Above knee frequency

$$|H(\omega)| = \frac{1}{\sqrt{1+\omega^2R^2C^2}} \approx \frac{1}{\sqrt{\omega^2R^2C^2}} = \frac{1}{\omega RC}$$

Inspection of eqn. reveals $|H(\omega)| \propto 1/\omega$

$\Rightarrow$ Attenuation $= -6$ dB / octave

$= -20$ dB / decade

Let us plot what we derived $\Rightarrow$ Bode plot