ECE 100 - Electronic Systems Lab

website: | Office hours: Tu. 2-4

web.eng.ucsd.edu/ece/groups/electromagnetics/
Classes/ECE100Fall2011/index.htm

Class builds on 35, 45, 65

Covers: Filters, feedback, oscillators, other related circuits

7 labs: 2 matlab, 5 hardware (Reports $\leq$ 5 pages)

Due at end of class each Thursday

2 midterms: October 20th, November 17th

Grades: 30% labs, 30% midterms, 40% final

Read Rules section of website

- No changes to midterm or final dates/times
- No late labs - after I leave the lecture hall, it's late!
- 24/7 access to labs (EBU2 rm 329 + 333A)
  - must photograph your circuit (instead of signoff sheet)
  - TAs available M 7-10 (Alex), T 7-10 (Ansun), W 4-10 pm (Henry, Mahdi) (not Friday)
- Note the section on integrity

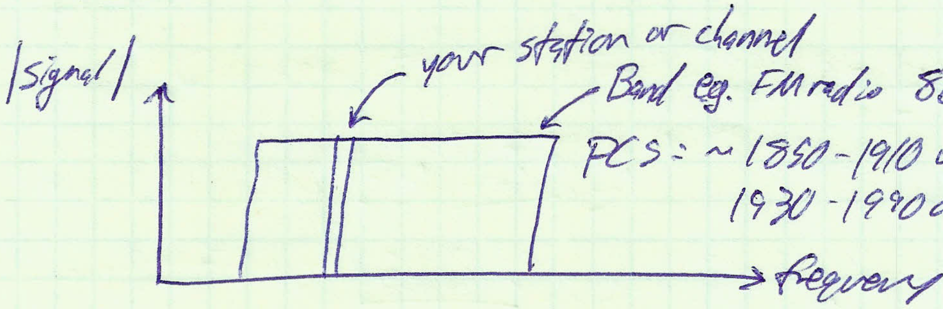
Find a lab partner. One of you email me your names/PID.

Lab access code:

No Book Required, but Sedra + Smith Ch 10, 16, 17 will be useful.

Filters:

- Reduce interference from signals not of interest
  - radio signals, mobile phones, transmit/receive channels, etc
- Reduce noise from outside the band of interest

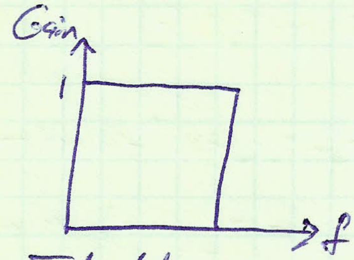


PCS: ~1850-1910 uplink, 1930-1990 downlink } divided among carriers, locations

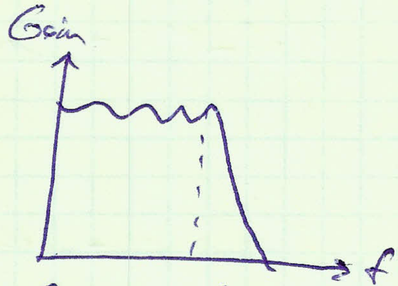
- Other phones, stations, etc will interfere unless filtered out
- Noise power is kTB ← Bandwidth
  - T: Noise temperature of receiver or antenna
  - k: Boltzmann Constant 1.38×10^{-23} J/K

Reducing bandwidth lowers noise!

$$Gain = \frac{Out}{In}$$
$(V, I, \ldots)$

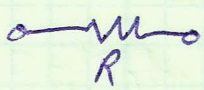


Ideal Low-Pass

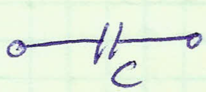


Realistic Low-pass

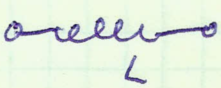
Passive Filter Building Blocks:



$V = IR$ $\qquad$ $Z = R$

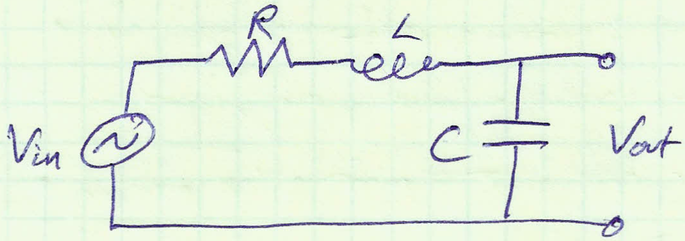


$I = C\frac{dV}{dt} \rightarrow i = Cj\omega v$ $\qquad$ $Z = \frac{1}{j\omega C}$



$V = L\frac{dI}{dt}$ $\qquad$ $v = Lj\omega i$ $\qquad$ $Z = j\omega L$

Lab #1 RLC filters



assume V_{in} is sinusoidal voltage, find steady-state response

R, L, C are in series

$$i(\omega) = \frac{V_{in}(\omega)}{R + j\omega L + 1/j\omega C} = \frac{V_{in}(\omega)\, j\omega C}{1 + j\omega RC - \omega^2 LC}$$

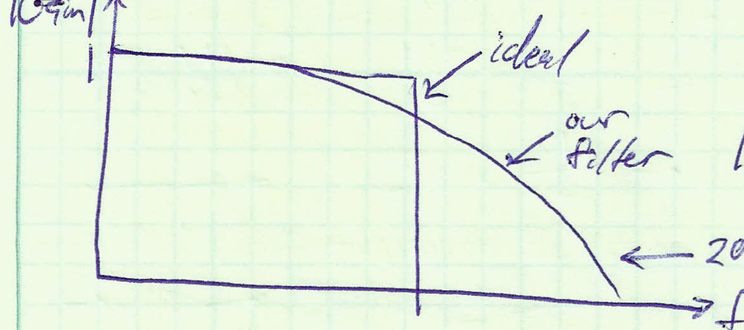
$$V_{out}(\omega) = \frac{i(\omega)}{j\omega C} = \frac{V_{in}(\omega)}{1 + j\omega RC - \omega^2 LC}$$

$$\text{gain} = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{1}{1 + j\omega RC - \omega^2 LC}$$

Gain is <u>complex</u>. We typically want $|Gain|$

remember $|a + jb| = (a^2 + b^2)^{1/2}$

$$|Gain| = \left[\frac{1}{(1-\omega^2 LC)^2 + (\omega RC)^2}\right]^{1/2}$$



$|Gain| \to 1$ for $\omega \to 0$

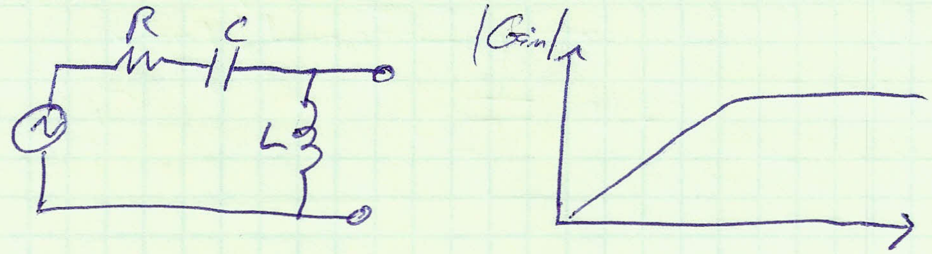
$|Gain| \to \frac{1}{\omega^2 LC}$ for $\omega \to \infty$

← 20 dB/decade for each pole

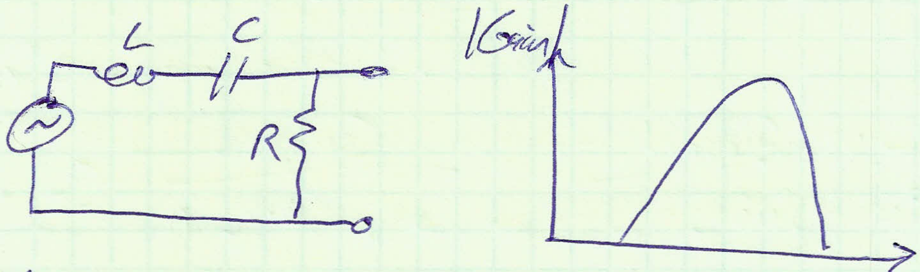
why? Power is $\sim V^2$

each pole adds $1/\omega$

Other combinations of R, L, C:



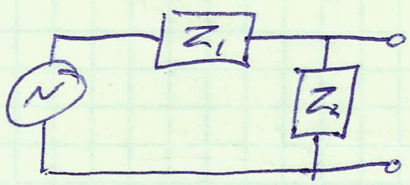
HPF



BPF

How can we make a band-reject or notch filter?

How to understand these intuitively:

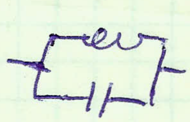


voltage divider: $\frac{V_{out}}{V_{in}} = \frac{Z_2}{Z_1 + Z_2}$

C is high impedance at low frequencies

L is high impedance at high frequencies

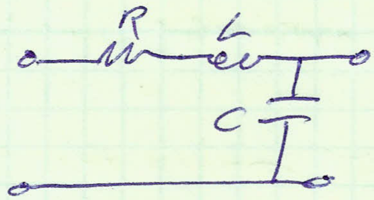
 is low impedance only at resonance $\omega = \frac{1}{\sqrt{LC}}$

 is high impedance only at resonance $\omega = \frac{1}{\sqrt{LC}}$

We define the transfer function $H(s)$, $s = \sigma + j\omega$

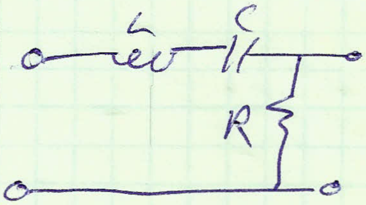
e.g. $H(\omega) = \dfrac{V_{out}(\omega)}{V_{in}(\omega)}$

- doesn't have to be voltage gain, but for us it typically is.
- we will talk more about complex variable s later
  - poles, e.g. $H(s) = \frac{1}{s-p}$ describe natural modes of system
  - pole at $\omega_0 \rightarrow$ system will oscillate at ω_0
  - positive real part $\sigma \rightarrow$ oscillation grows with time
  - negative real part $\sigma \rightarrow$ oscillation decays with time



$$H(s) = \frac{1/sC}{R + sL + 1/sC} = \frac{1}{1 + sCR + s^2LC} \quad \text{LPF}$$

$$H(s) = \frac{sL}{R + 1/sC + sL} = \frac{s^2LC}{1 + sCR + s^2LC} \quad \text{HPF}$$



$$H(s) = \frac{R}{sL + 1/sC + R} = \frac{sRC}{1 + sCR + s^2LC} \quad \text{BPF}$$

All of these have a form of $\dfrac{1}{1 + 2\zeta\left(s/\omega_0\right) + s^2/\omega_0^2}$

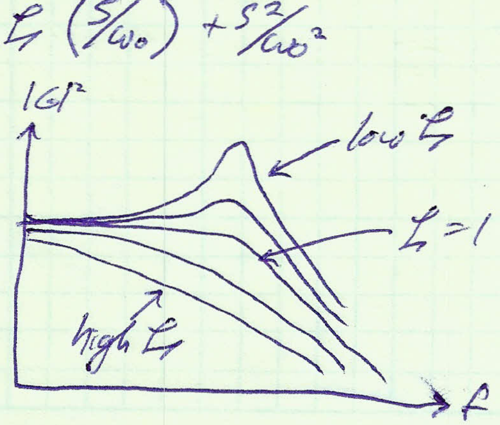
$\omega_0 = \dfrac{1}{\sqrt{LC}}$ resonant frequency

$\zeta = \dfrac{R}{2}\sqrt{\dfrac{C}{L}}$ damping factor

$\zeta = 1$: critically damped

$\zeta = \frac{1}{\sqrt{2}}$: maximally flat

— more on this later



Let's explore LPF:

$$H(\omega) = \frac{1}{1 + j\omega RC - \omega^2 LC} = \frac{1}{1 + 2j\zeta\frac{\omega}{\omega_0} - \frac{\omega^2}{\omega_0^2}}$$

set $\omega_0 = 1$ for simplicity (just scale it back in later)

$$|H(\omega)|^2 = \frac{1}{(1-\omega^2)^2 + 4\zeta^2\omega^2}$$ where is the maximum?

$$\frac{\partial}{\partial\omega}\left(\frac{1}{|H(\omega)|^2}\right) = 2(1-\omega^2)(-2\omega) + 8\zeta^2\omega = 0$$

one solution at $\omega = 0$

another solution at:

$$1 - \omega^2 = 2\zeta^2$$

$$\omega = \sqrt{1 - 2\zeta^2} \rightarrow \text{scale to } \omega_0\sqrt{1-2\zeta^2}$$

Substitute to get $$|H(\omega_{peak})|^2 = \frac{1}{(1-(1-2\zeta^2))^2 + 4\zeta^2(1-2\zeta^2)}$$

$\zeta = \frac{R}{2}\sqrt{\frac{C}{L}}$ what happens as $R \rightarrow 0$? $$= \frac{1}{4\zeta^2(1-\zeta^2)}$$

Let's explore BPF: $$H(\omega) = \frac{2j\zeta\,\omega/\omega_0}{1 + 2j\zeta\,\omega/\omega_0 - (\omega/\omega_0)^2}$$, set $\omega_0 = 1$

$$|H(\omega)|^2 = \frac{4\zeta^2\omega^2}{(1-\omega^2)^2 + 4\zeta^2\omega^2}$$

half-power (-3dB) BW is when these are equal

(think about voltage divider)

$$(1-\omega^2)^2 = 4\zeta^2\omega^2 \rightarrow 1 - \omega^2 = \pm 2\zeta\omega$$

$$\omega^2 \pm 2\zeta\omega - 1 = 0 \rightarrow \omega = \pm\zeta \pm \sqrt{\zeta^2+1}$$

$BW = 2\zeta\ (\times\omega_0)$

$$Q = \frac{\text{frequency}}{\text{FWHM}} = \frac{1}{2\zeta}$$