ECE 100 - Electronic Systems Lab

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

Office hours: Tu. 2-4

Class builds on 35, 45, 65
Covers: Filters, feedback, oscillators, other related circuits
7 labs: 2 matlab, 5 hardware (Reports ≤ 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 life!
- 24/7 access to labs (EBU2 rm 329 + 333A)
  - must photograph your circuit (instead of signoff sheet)
  - TAs available M 7-10, T 7-10, W 4-10 pm (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 Sectra 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

![Graph showing signal strength vs frequency]

- Other phones, stations, etc will interfere unless filtered out
- Noise power is $kT \frac{B}{n}$<br>
  - $k$: Boltzmann constant $1.38 \times 10^{-23}$ J/K<br>
  - $T$: Noise temperature of receiver or antenna
  - $B$: Bandwidth

Reducing bandwidth lowers noise!

![Graphs showing filter gain and ideal low-pass vs frequency]

Passive Filter Building Blocks:

- $R$: $V = IR$
  - $Z = R$
- $C$: $I = C \frac{dV}{dt}$
  - $Z = j\omega C$
- $L$: $V = L \frac{dI}{dt}$
  - $Z = j\omega L$
Lab #1 RLC filters

Assume $V_{in}$ is sinusoidal voltage, find steady-state response. $R, L, C$ are in series.

$$i(w) = \frac{V_{in}(w)}{R + jwL + \frac{1}{jwC}} = \frac{V_{in}(w) \cdot jwC}{1 + jwRC - w^2LC}$$

$$V_{out}(w) = \frac{i(w)}{jwC} = \frac{V_{in}(w)}{1 + jwRC - w^2LC}$$

$$gain = \frac{V_{out}(w)}{V_{in}(w)} = \frac{1}{1 + jwRC - w^2LC}$$

Gain is complex. We typically want $|Gain|$

Remember $\sqrt{a^2 + b^2} = (a^2 + b^2)^{1/2}$

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

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

Our filter $|Gain| \rightarrow \frac{1}{\omega^2LC}$ for $\omega \rightarrow \infty$

Why? Power is $\sim V^2$ each pole adds 6dB per decade for each pole.
Other combinations of R, L, C:

![Circuit Diagrams](image)

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

**How to understand these intuitively:**

![Circuit Diagram](image)

Voltage divider: \( \frac{V_{out}}{V_n} = \frac{Z_2}{Z_1 + Z_2} \)

- **C** is high impedance at low frequencies
- **L** is high impedance at high frequencies
- \( L || C \) is low impedance only at resonance \( \omega = \frac{1}{\sqrt{LC}} \)
- \( C || L \) is high impedance only at resonance \( \omega = \frac{1}{\sqrt{LC}} \)
We define the transfer function $H(s), s = \sigma + j\omega$

e.g. $H(w) = \frac{V_{out}(w)}{V_{in}(w)}$

- 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 $\omega_o \rightarrow$ system will oscillate at $\omega_o$
- positive real part $\sigma \rightarrow$ oscillation grows with time
- negative real part $\sigma \rightarrow$ oscillation decays with time

\[
H(s) = \frac{1/sC}{R+sl+1/sC} = \frac{1}{1+sCR+1/sC} \quad \text{LPF}
\]

\[
H(s) = \frac{1/sL}{R+1/sL+sl} = \frac{1/sL}{1+sCL+1/sL} \quad \text{HPF}
\]

\[
H(s) = \frac{1}{sL+1/sC+R} = \frac{1}{1+sCR+1/sC} \quad \text{BPF}
\]

All of these have a form of \( \frac{1}{1+2Z \frac{\omega}{\omega_0} + \left( \frac{\omega}{\omega_0} \right)^2} \)

\( \omega_0 = \frac{1}{\sqrt{LC}} \) resonant frequency

\( Z = \frac{R\sqrt{C}}{2L} \) damping factor

\( Z = 1 \) : critically damped

\( Z = \frac{1}{2} \) : maximally flat

- more on this later.
Let's explore LPF:

\[ H(\omega) = \frac{1}{1 + j\omega RC - \omega^2 L} = \frac{1}{1 + 2j\omega R C - \omega^2 L} \]

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

\[ |H(\omega)|^2 = \frac{1}{(1-\omega^2)^2 + 4\omega^2 L^2} \]

where is the maximum?

\[ \frac{d}{d\omega} \left( \frac{1}{|H(\omega)|^2} \right) = 2(1-\omega^2)(2\omega) + 8\omega^2 L^2 = 0 \]

one solution at \( \omega = 0 \)

another solution at:

\[ 1-\omega^2 = 2L^2 \]

\[ \omega = \sqrt{1-2L^2} \rightarrow \text{scale to } \omega = \omega_0 \sqrt{1-2L^2} \]

Substitute to get \( |H(\text{peak})|^2 = \frac{1}{(1-(1-2L^2)^2 + 4\omega^2 L^2) (1-2L^2)} \)

\[ \omega = \frac{R}{2\sqrt{2}} \text{ what happens as } R \to 0? \]

\[ \omega = \frac{R}{2\sqrt{2}} \]

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

\[ |H(\omega)|^2 = \frac{4\omega^2 L^2}{(1-\omega^2)^2 + 4\omega^2 L^2} \]

\[ \leftrightarrow \text{ half-power (-3dB) BW is when } |H(\omega_0)| = \frac{1}{\sqrt{2}} \]

(Think voltage divider)

\( (1-\omega^2)^2 + 4\omega^2 L^2 \rightarrow 1-\omega^2 = \pm 2\sqrt{2}L \omega \)

\[ \omega^2 \pm 2\sqrt{2}L \omega - 1 = 0 \rightarrow \omega = \frac{\pm \sqrt{8L^2 + 4} - 2\sqrt{2}L}{2} \]

\[ \text{BW} = 2\sqrt{2}L (\omega_0) \]

\[ Q = \frac{\text{Frequency}}{\text{Bandwidth}} = \frac{1}{2\sqrt{2}} \]

\[ \omega = \frac{\sqrt{2\sqrt{2}L} - \sqrt{8 + 4}}{2} \]

Diagram:

- \( -\omega \)
- \( 0 \)
- \( \sqrt{8 + 4} \)
- \( \omega_0 \sqrt{1-2L^2} \)