Electronics

029:128

Lecture Notes

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2007

First lecture begins w/ discussion
of syllabus, lab

Horowitz Hill Chap. 1 Foundations

First we review various ideas you've most likely seen already, and some terminology that might be new

Units	Q	charge		[Coulomb]
	V	voltage	= potential	[Volt]
	I	current	= flow of charge	[Coulomb/s] = [Ampere]
	P	power	= energy per unit time	[Watts]

Energy electrical QV = potential energy of chg Q

mechanical mgH = " " " mass M

concept: zero is arbitrary for potl. energy

mechanical, H referenced to sea level, floor, ...

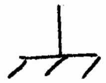
electrical, V referenced to what?

"Ground"

- as a convention, zero volts = "ground potl."
- it's a large body capable of accumulating or losing lots of electrons
- examples:
  - water pipe stuck into soil
  - metal enclosure of battery-powered circuit
- symbols:

or

or



"Voltage Drop" = difference in potential between two points

"Bias" = a voltage, usually DC

DC vs. AC

DC	$\lesssim 10$ Hz
audio freq.	$\lesssim 20$ kHz
RF (radio freq)	$\gtrsim 100$ kHz

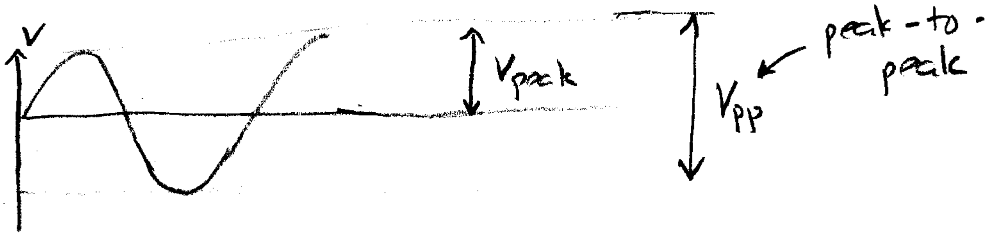
↑ for RF, potl varies along length of wire, due to short λ

DC, audio: potl is nearly constant along a wire

Electrical Power

60 Hz	N. America
50 Hz	Euro, Asia

Amplitudes for AC:



$$V_{rms} = \frac{1}{\sqrt{2}} V_{peak}$$

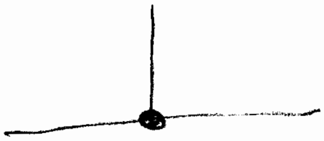
$$\uparrow V_{peak} = \frac{1}{2} V_{pp}$$

About schematic diagrams

an early goal of course: learn to read them

wire

assume elec potl
is uniform along
wire



node = connected

not connected

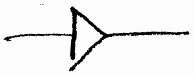
battery

or

resistor

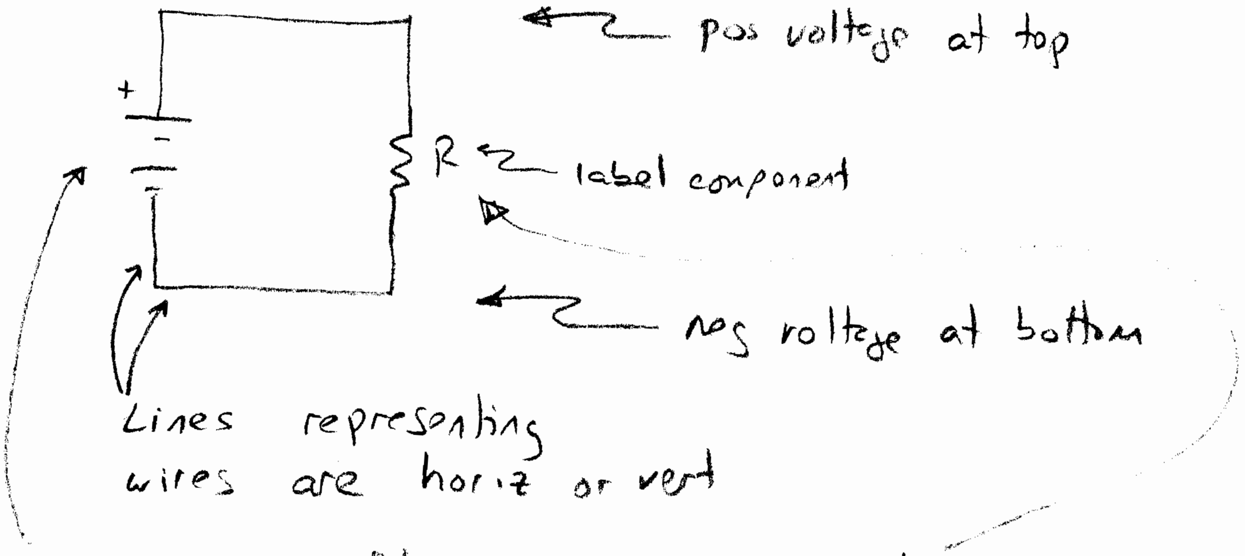
capacitor

diode



amplifier

Conventions for drawing schematics.



pos voltage at top

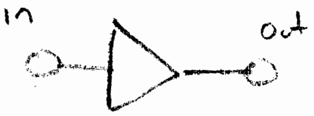
label component

neg voltage at bottom

Lines representing
wires are horiz or vert

Sources on left

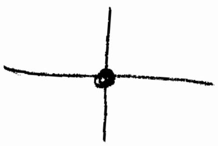
Loads on right



signals flow left to right

4 way nodes.

preferred style



not preferred

Statistical Treatment of Exptl. Data

here, we interrupt presentation of electronics fundamentals to review errors, so that you can do Lab 1

Terminology

- "measurement errors" are ± uncertainties
- two kinds:

  "systematic" - e.g. thermometer is not calibrated

  "random" - unpredictable variations in expt

  - if you repeat measurement 10 times, you get 10 different results
  - examples of causes:
    - unpredictable fluctuations in temperature, illumination
    - observer judgment in estimating tenths of smallest division

- small systematic errors → high "accuracy"
- " random " → " "precision"

Concepts for errors

- If you make only one measurement, it is sometimes hard to say whether errors are random or systematic
- here, "errors" does not refer to difference between theory & exptl. measurement
- in electronics, measurement errors typically occur in analog quantities (voltage, time, etc.) not in logic levels True & False

How to determine error

- usually, see mfg. specifications for instrument.

ex. multimeter, Hertz –
mfg spec 1.00% reading + 3 LSD
(cont.)

↑ "least signific. digit"

your reading 60.12 Hz

↑

LSD is 0.01 Hz

your uncertainty: $0.60 + 3 \times 0.01$

$= 0.63$

you report: 60.12 ± 0.63 Hz

- sometimes, with analog measurements, operator's opinion of how nearly he/she can read position of needle or waveform compared to scale

- seldom, jitter in indicated value of digital display

Propagation of Errors

← use in some labs, not all

↑ How you determine ± uncertainty of a calculated quantity

ex. you measure $V_{out} \pm \Delta V_{out}$, $V_{in} \pm \Delta V_{in}$

you calculate $A = \frac{V_{out}}{V_{in}}$

you find uncertainty ΔA using prop of errors:

$$(\Delta A)^2 = (\Delta V_{in})^2 + (\Delta V_{out})^2$$

generally if Q is calculated from a & b

then ΔQ uncertainty is calculated:

$$(\Delta Q)^2 = \left(\frac{\partial Q}{\partial a} \Delta a\right)^2 + \left(\frac{\partial Q}{\partial b} \Delta b\right)^2$$

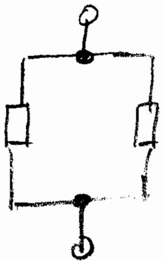
note that errors add thru their squares

back to Foundations

concepts:

series / parallel


series


parallel

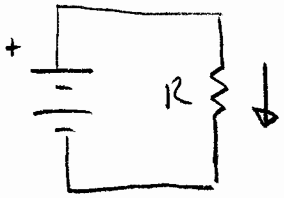

equivalent

for resistors:

series: $R_{equiv} = R_1 + R_2$

parallel: $'' = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$

direction of current flow



positive current flows from more pos. voltage to more neg. ''

Ohm's Law

$$\boxed{V = IR \qquad I = V/R}$$

where

V = voltage "drop" across resistor

I = current thru "

Ohms Law is empirical
↑ good for some materials not all

Resistors

- Three parameters:
  - resistance R
  - tolerance typ. ± 5%
  - power rating ← don't exceed this, or you burn it up; see Hw 1

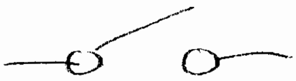
- Power dissipated

$$P = IV$$

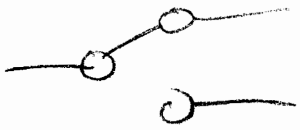
$$\boxed{P = I^2 R = V^2/R}$$ for a resistor

some schematic symbols

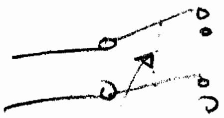
switches



SPST
single pole single throw
(use for on-off)



SPDT
(use to select A or B)

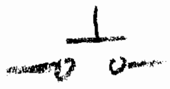


DPST

"ganged"

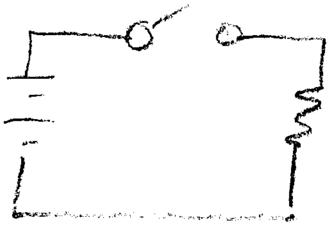
"open" 

"closed" 

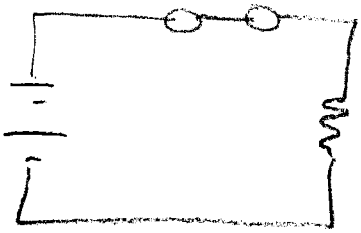
"normally open" bush button 

terminology

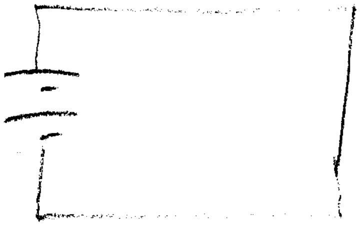
"open circuit"



"closed circuit"



"short circuit"



Kirchoff's Laws

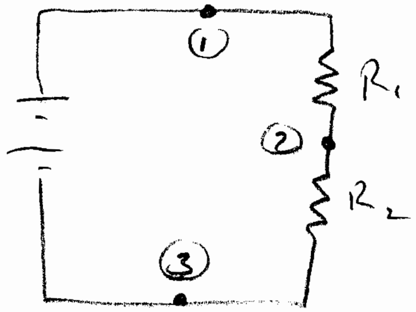
The physics behind circuit analysis

Voltage Law

(conservation of energy for an electron)

"Sum of Voltage Drops around a closed loop is zero"

ex.



$$\underbrace{(V_2 - V_1)}_{\text{voltage drop across } R_1} + \underbrace{(V_3 - V_2)}_{\text{drop across } R_2} + \underbrace{(V_1 - V_3)}_{\text{drop across battery}} = 0$$

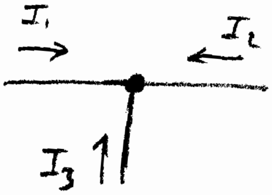
to use law, choose either cw or ccw, then go around complete loop

Current Law

(conservation of charge)

"Sum of currents into a node is zero"

ex.

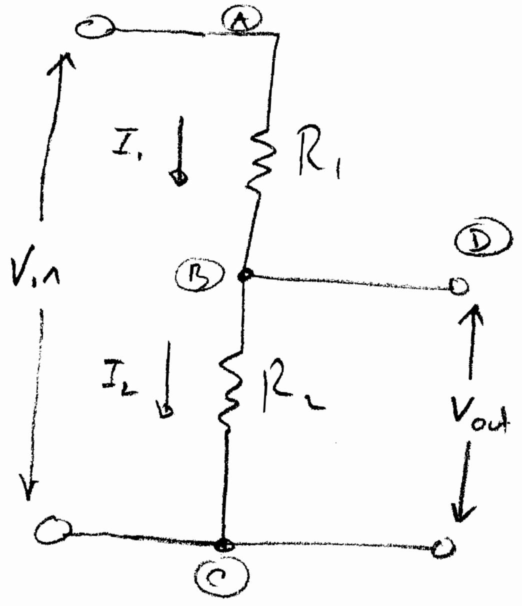


$$I_1 + I_2 + I_3 = 0$$

to use, first decide (arbitrarily) which direction represents positive current, arrows in example indicate choice of direction for pos. current flow

Voltage Dividers

two resistors in series



leave on board

Find $\frac{V_{out}}{V_{in}}$

★ Method of analysis (you'll see this repeated for many circuits)

1st identify components, nodes, loops

2nd write their rules, in algebraic form.

3rd combine, to eliminate variables, yielding desired quantity

1st components R_1, R_2

nodes Ⓑ, Ⓒ

loops none shown

2nd for R_1, Ohms Law $\frac{V_A - V_B}{R_1} = I_1$

for R_2, " " $\frac{V_B - V_C}{R_2} = I_2$

↑

note my convention:
positive current assumed
to flow from to bottom

for node Ⓑ: Kirch. Curr. Law
⇒ all current thru
R_1 must go out
either thru R_2 or
toward Ⓓ
However, Ⓓ is an open
circuit ⇒ no current
flows to Ⓓ

$$\Rightarrow I_1 = I_2$$

$\underline{3^{rd}}$

V_{out} / V_{in}

we must relate V_{out} & V_{in}
to other quantities in circuit

here, $V_{out} = V_D - V_C$

$= V_B - V_C$

↑ since Ⓑ & Ⓓ
are connected

$$V_{in} = V_A - V_C$$

combine to eliminate variables:

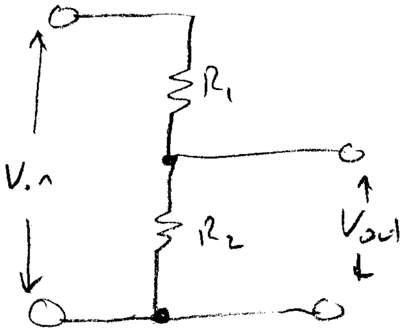
$$V_{out} = \underbrace{V_B - V_C}_{I_2 R_2} = I_1 R_2$$

$$\begin{aligned} V_{in} &= V_A - V_C \\ &= \underbrace{(V_A - V_B)}_{I_1 R_1} + \underbrace{(V_B - V_C)}_{I_2 R_2 = I_1 R_2} \\ &= I_1 (R_1 + R_2) \end{aligned}$$

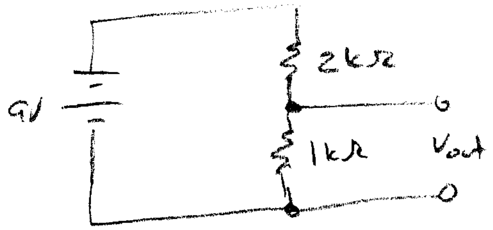
$$\frac{V_{out}}{V_{in}} = \frac{\cancel{I_1}\ R_2}{\cancel{I_1}\ (R_1 + R_2)}$$

$$\Rightarrow \boxed{\frac{V_{out}}{V_{in}} = \frac{R_2}{R_1+R_2}}$$

Voltage Divider



ex.



$$V_{out} = 9\,\text{Volt}\ \frac{1\,k\Omega}{3\,k\Omega}$$

$$= 3\,\text{Volt}$$

Terminology

"Voltage Source" provides fixed V_{out} regardless of current

"Current Source" " " I_{out} " " voltage

voltage source:

- more common
- almost every circuit has one
- battery or power supply

"sourcing & sinking current"

"Sourcing" if a circuit supplies positive current to a point

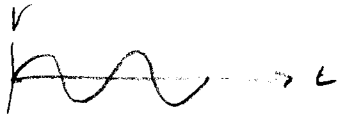
"sinking" vice versa

note: "sinking" ≠ resistive dissipation

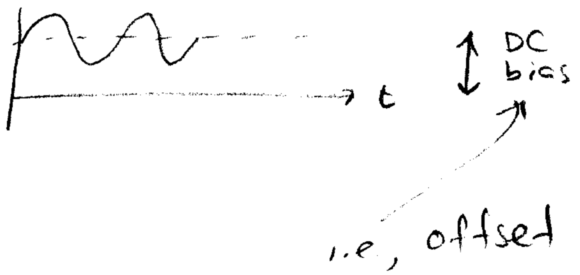
"offset" = "bias"

- a DC voltage,
- shifts an AC waveform up or down

AC signal



AC signal
with DC offset



"Gain"

$A_v = \frac{V_{out}}{V_{in}}$ voltage gain

$A_I = \frac{I_{out}}{I_{in}}$ current gain

"Unity Gain" $\Rightarrow$ $V_{out} = V_{in}$

"decibels"

- to compare ratio of two signals

$$\boxed{dB = 20 \log_{10} \frac{\text{amplitude } 2}{\text{amplitude } 1}}$$

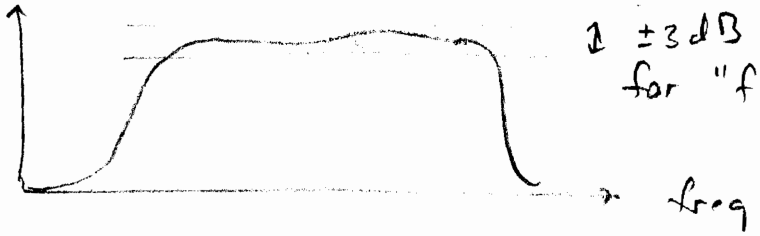
- often used for gain

  e.g. ratio is $1.4 \cong \sqrt{2}$

$$dB = 20 \log_{10} (1.4)$$

$$= 3 dB$$

"flatness"

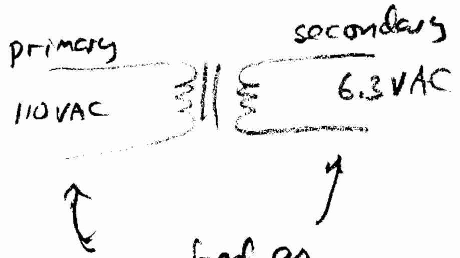


AC waveform concept

recall $V_{rms} = \frac{1}{\sqrt{2}} V_{peak} = \frac{1}{2\sqrt{2}} V_{pp}$

Two components for AC circuits

transformer



specified as rms

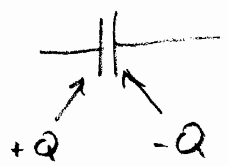
ex. 6.3 VAC transformer

input is 110 VRMS → 156 V peak

6.3 VRMS → 8.9 V peak

output

capacitor



charge stored on plates

$Q = C V$

↑ potential difference across plates

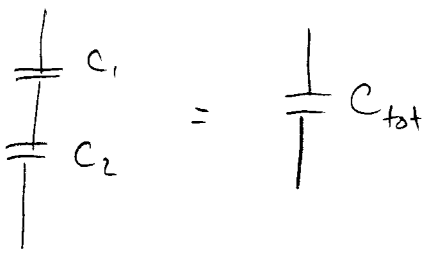
↑ capacitance in Farads

$$I = \frac{dQ}{dt}$$

$$\rightarrow \boxed{I = C\frac{dV}{dt}}$$

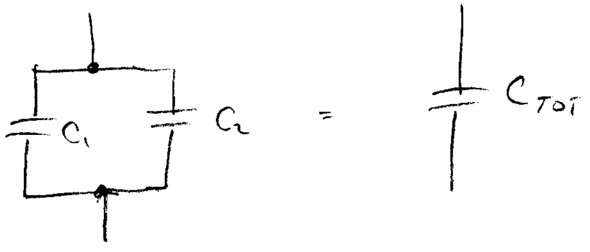
↑ the law for capacitors, analogous to $I = V/R$ for resistors

series



$$= \left[\sum_i C_i^{-1}\right]^{-1}$$

parallel

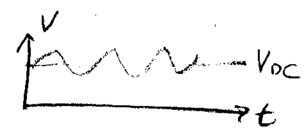


$$= \sum_i C_i$$

Lower case symbols

i = AC portion of current waveform

v = " " voltage waveform



$V(t) = V_{DC} + v$

Math: Complex Numbers

ref. Horowitz Hill Appendix B

$j^2 = -1$

$j = \sqrt{-1}$

complex no. $z = \underset{\text{real part}}{a} + \underset{\text{imaginary part}}{bj}$

complex conjugate $z^* = a - bj$

magnitude or modulus $|z| = \sqrt{z z^*}$

$= \sqrt{a^2 + b^2}$

notation $a = \underset{\uparrow \text{real part of}}{Re[z]}$ $b = Im[z]$

Recall Frequencies

$\underset{\text{units } s^{-1}}{\omega} = 2\pi \underset{\uparrow \text{units Hz}}{f}$

$f = \frac{1}{\text{period}}$

Math: Complex Exponential

$$e^{j\omega t} = \cos \omega t + j \sin \omega t$$

sinusoidal waveform:

$$v(t) = V_0 \cos \omega t$$

$$= \mathrm{Re}\left[V_0 e^{j\omega t} \right]$$

derivatives:

$$\frac{d}{dt} e^{j\omega t} = j\omega e^{j\omega t}$$

Impedance

- a generalized resistance
- allows rewriting law for capacitors so that it resembles Ohm's Law
- symbol Z
- a ratio of voltage / current

Impedance of Capacitor

recall law $I = C \frac{dV}{dt}$

AC signal with sinusoidal signal

$$V(t) = V_0 e^{j\omega t}$$

$$\frac{dV}{dt} = j\omega \, V(t)$$

$$\text{impedance} \quad Z = \frac{\text{voltage}}{\text{current}}$$

$$= \frac{\cancel{V_0} \cancel{e^{j\omega t}}}{j\omega C \cancel{V_0} \cancel{e^{j\omega t}}}$$

$$= \frac{1}{j\omega C}$$

Impedances

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

$$Z_R = R$$

$$Z_L = j\omega L$$

inductor

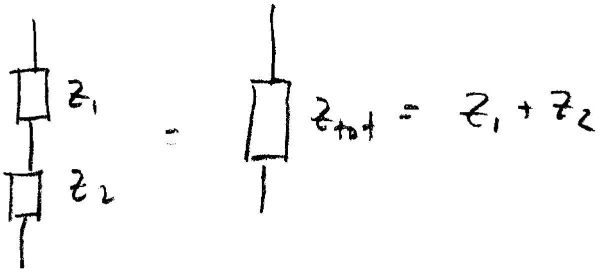
used mainly in RF circuits

Ohm's Law for Impedances

$$V(t) = I(t)\,Z$$

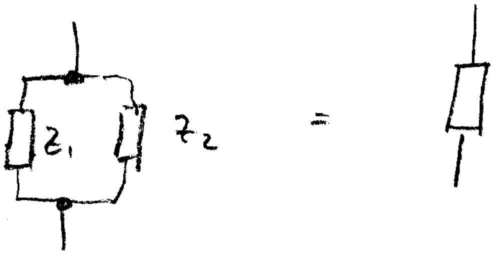
$$I(t) = \frac{V(t)}{Z}$$

series:



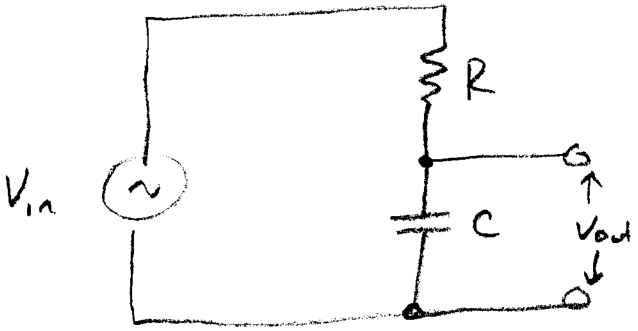
$Z_{tot} = Z_1 + Z_2$

parallel



$$Z_{tot} = \frac{1}{\frac{1}{Z_1} + \frac{1}{Z_2}}$$

Low Pass Filter



↑

looks like voltage divider

$$V_{out} = V_{in} \frac{Z_C}{Z_C + Z_R}$$

$$= V_{in} \frac{1/j\omega C}{1/j\omega C + R}$$

$$V_{out} = V_{in} \frac{1}{1 + j\omega RC}$$

↑ ↑

complex nos.

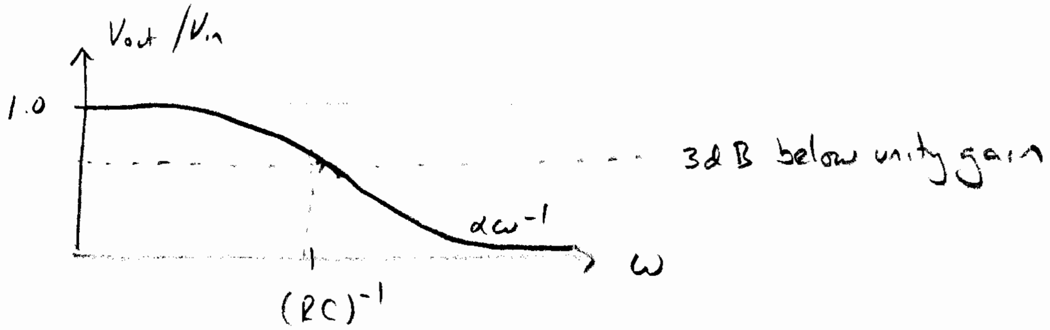
find amplitude, which is a real no.

$$V_{out}^{ampl} = \left(V_{out}^{*} \, V_{out}\right)^{1/2}$$

↑ real ↑ ↑ complex

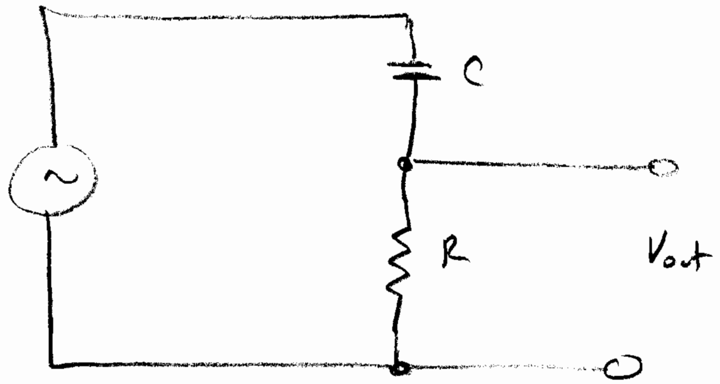
$$\boxed{V_{out} = V_{in} \frac{1}{(1 + \omega^2 R^2 C^2)^{1/2}}}$$

amplitudes (real nos.)



"frequency response curve" for Low Pass Filter

High Pass Filter



like a voltage divider

$$V_{out} = V_{in} \frac{Z_R}{Z_R + Z_C}$$

$$= V_{in} \frac{R}{R + 1/j\omega C}$$

$$V_{out} = V_{in} \frac{j\omega RC}{j\omega RC + 1}$$

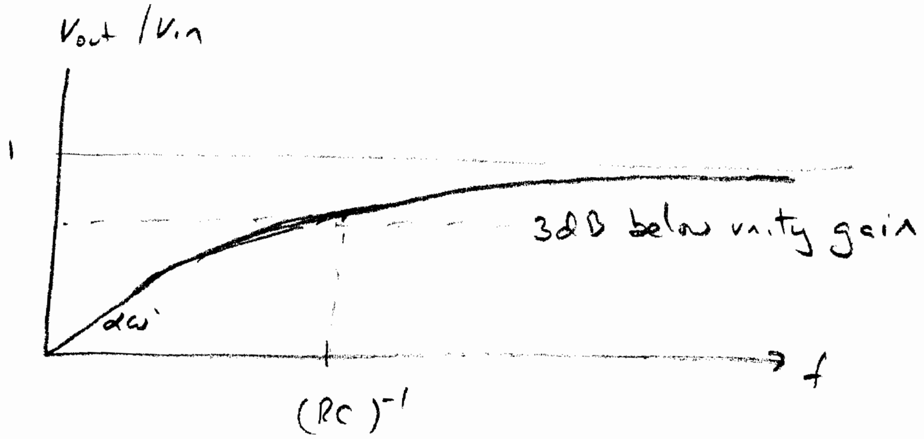
$\uparrow$ $\uparrow$

complex nos.

find amplitude

$$\boxed{V_{out} = V_{in} \frac{\omega RC}{(1+\omega^2R^2C^2)^{1/2}}}$$ amplitudes (real nos.)

freq response curve for high-pass



ex. filter applications

low pass filter: eliminate high freq. noise in a transmission of human voice w/ signal < 7 kHz

high pass filter: eliminate dc bias in an ac waveform

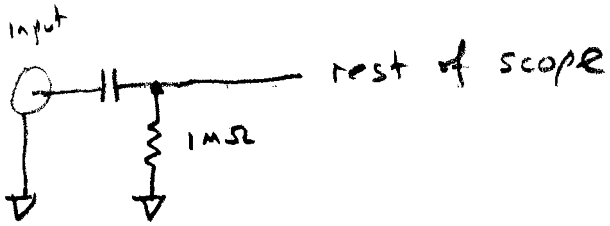
capacitor terminology

"roll-off frequency" of a filter = $(RC)^{-1}$

"time constant" " " = RC

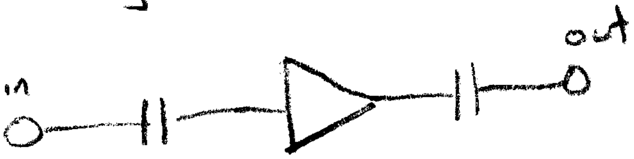
"dc-blocking capacitor"

- insert a capacitor to remove dc bias
- ex. "AC coupling" of scope:



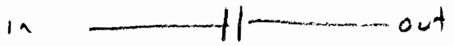
- also called "capacitive coupling" of a signal

- audio amps are often capacitively coupled

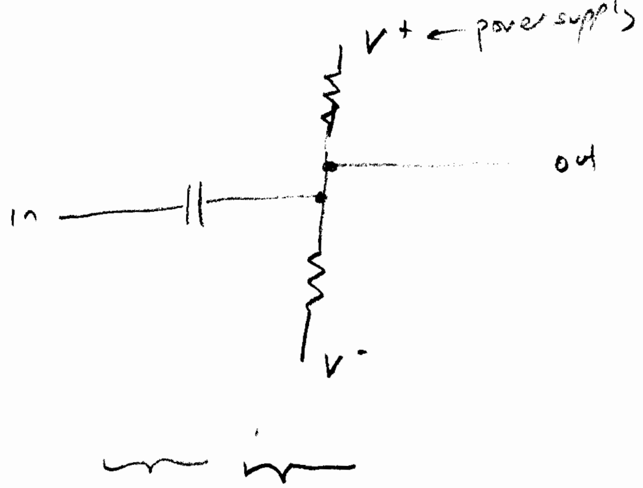


capacitors & dc bias

- use capacitive coupling to eliminate dc bias



- add a voltage divider to apply a desired dc bias



blocks any incoming dc bias

adds desired dc bias

terminology

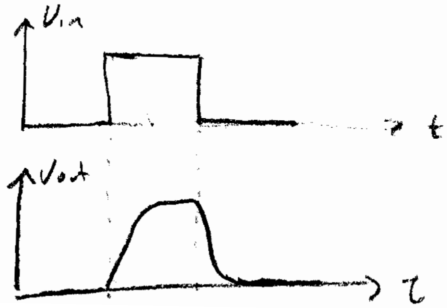
"time domain" , waveform $V(t)$

"frequency domain" dependence of amplitude on frequency

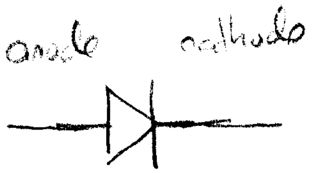
in lecture, we have considered filters in the "freq. domain"

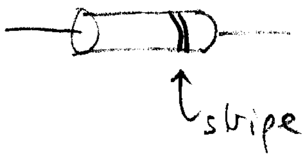
in lab, you will also measure filter performance in "time domain"

ex. time domain, applying a pulse input to a low pass filter



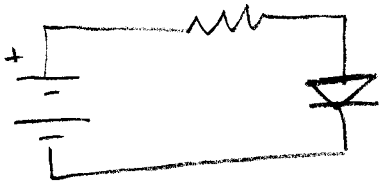
Diodes





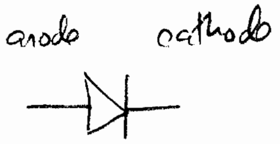
recall: positive current flows
from a more pos. voltage
toward a more neg. voltage

diode conduction



"forward biased" diode
conducts

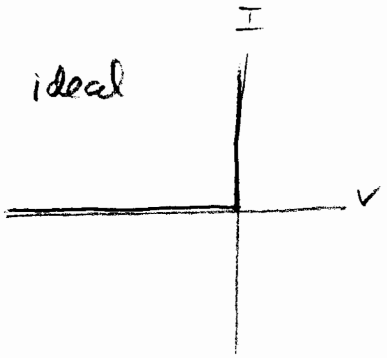
"reverse-biased" diode
doesn't conduct

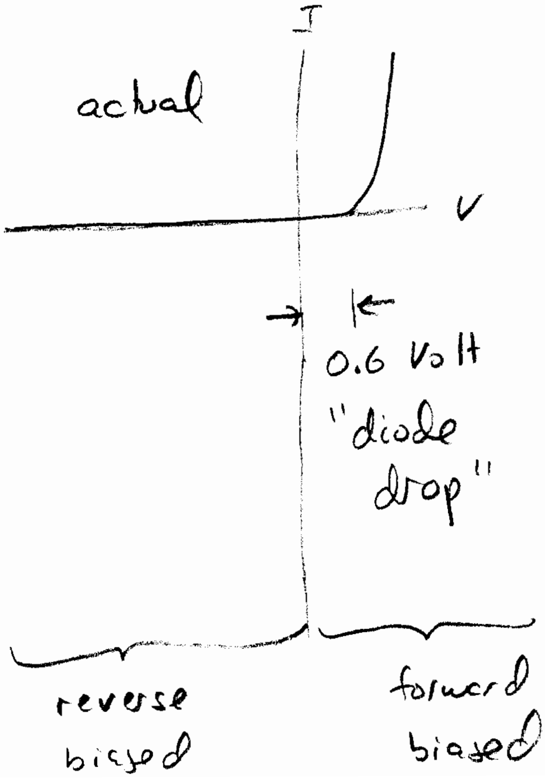


→ diode can conduct current in this direction

← diode blocks " " "

current-voltage characteristic of diode

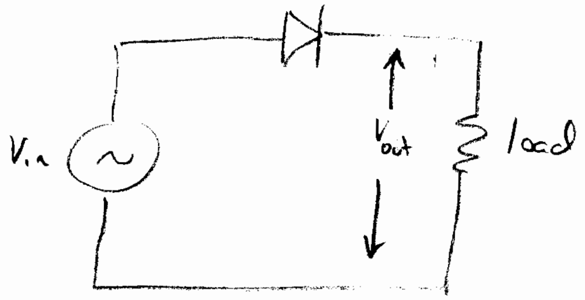


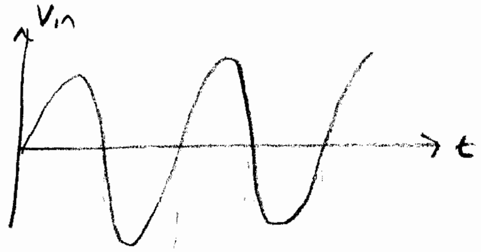


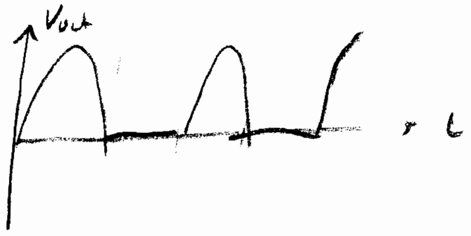
Diode Applications

- **Rectifier** (convert AC → DC)

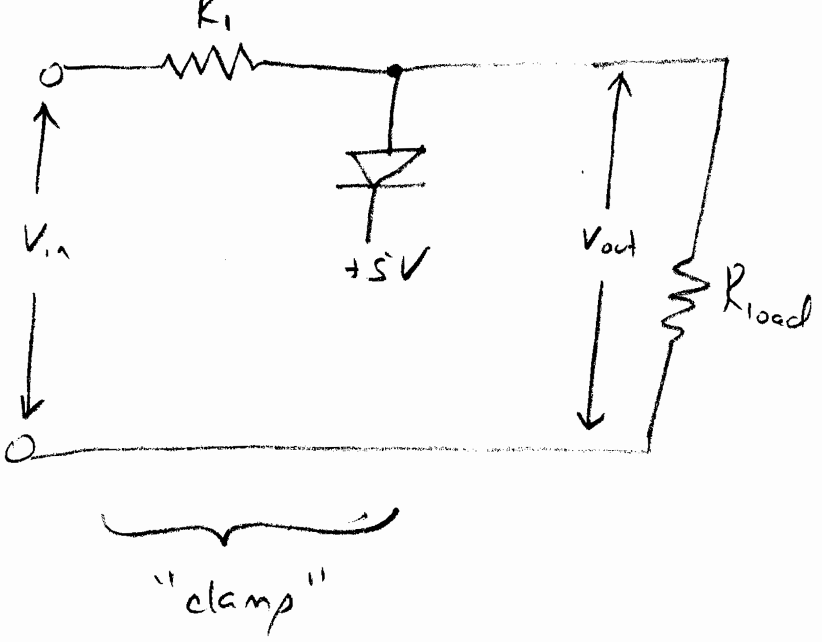
ex. "Half-Wave Rectifier"







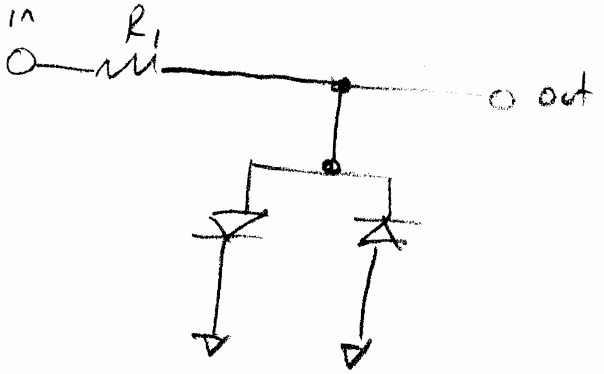
- "**Diode Clamp**" - prevent output from exceeding a certain positive voltage



- output voltage cannot exceed +5V + 0.6V = +5.6V because at higher voltages diode would conduct & act like a zero resistance in parallel w/ load

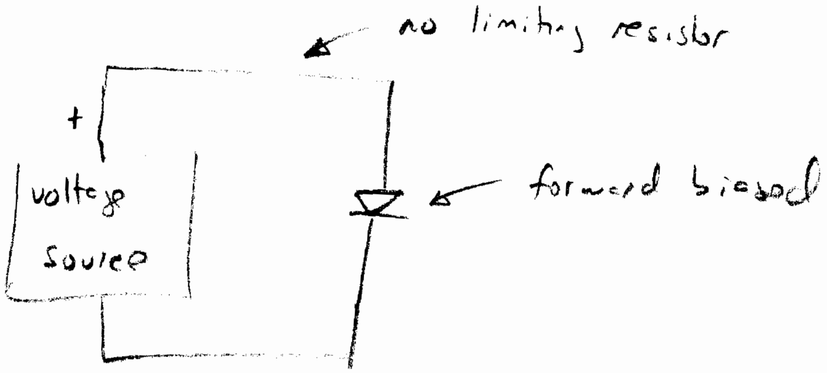
- R_1 is a "current limiting resistor" to avoid burning up diode, when diode conducts, typically 100 - 1kΩ

- "Diode Limiter" - prevent output from exceeding pos or neg voltage



prevents output from exceeding ±0.6 volt

- How to burn up a diode



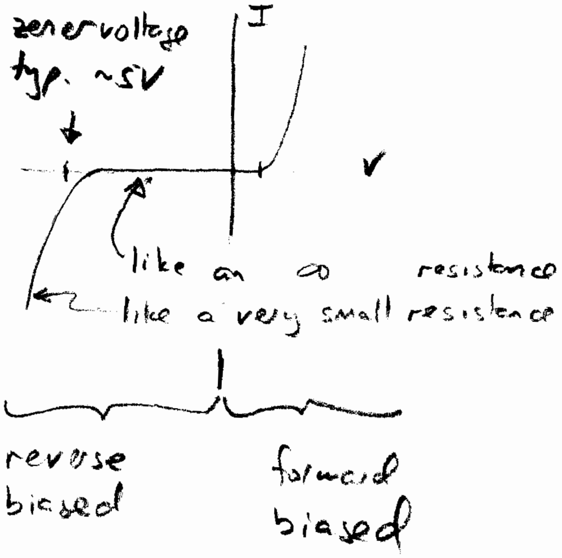
in forward conduction,

diodes resistance → 0

Power dissipated in diode $\frac{V^2}{0} \to \infty$

Types of diodes:

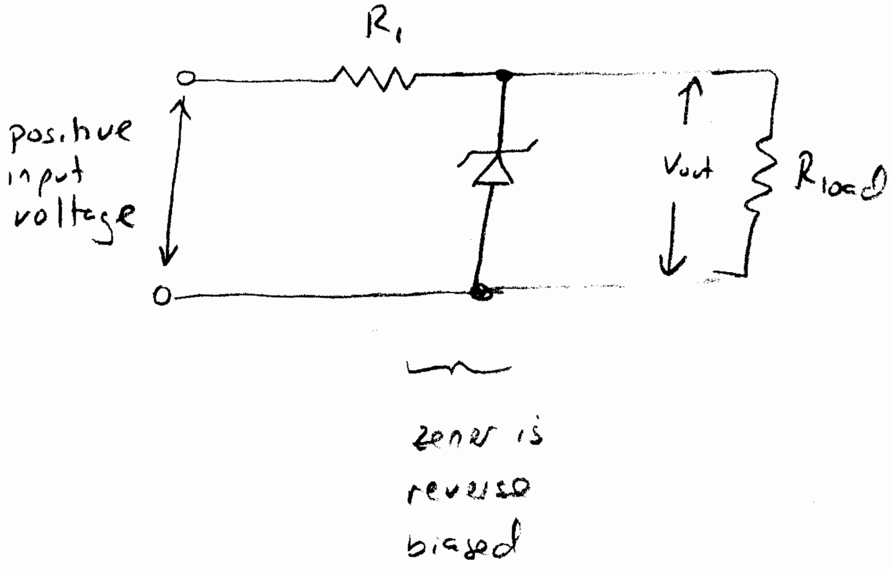
- signal e.g. 1N914 - for low power use
- power - for rectifiers, power supplies
- zener diode



a zener conducts when reverse-biased by more than the "zener voltage"

<u>zener application</u> : voltage regulator

↑ produces a steady output voltage, when you apply a larger (unsteady) input



zeners available for various small zener voltages, e.g. 5V