PHY405-L04

Resonances and Diodes

Lab reminder

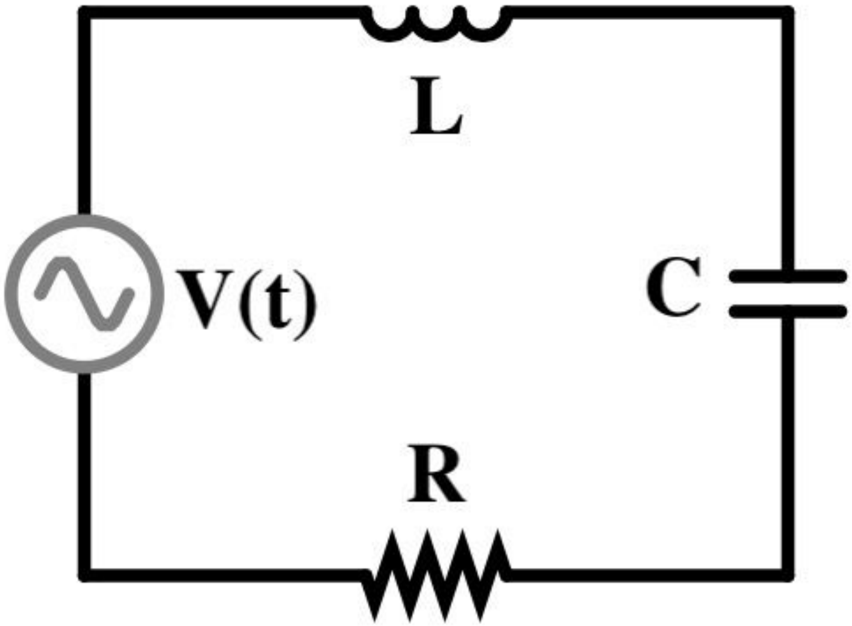
Please close the drawer/doors behind you…

Lab reminder 2

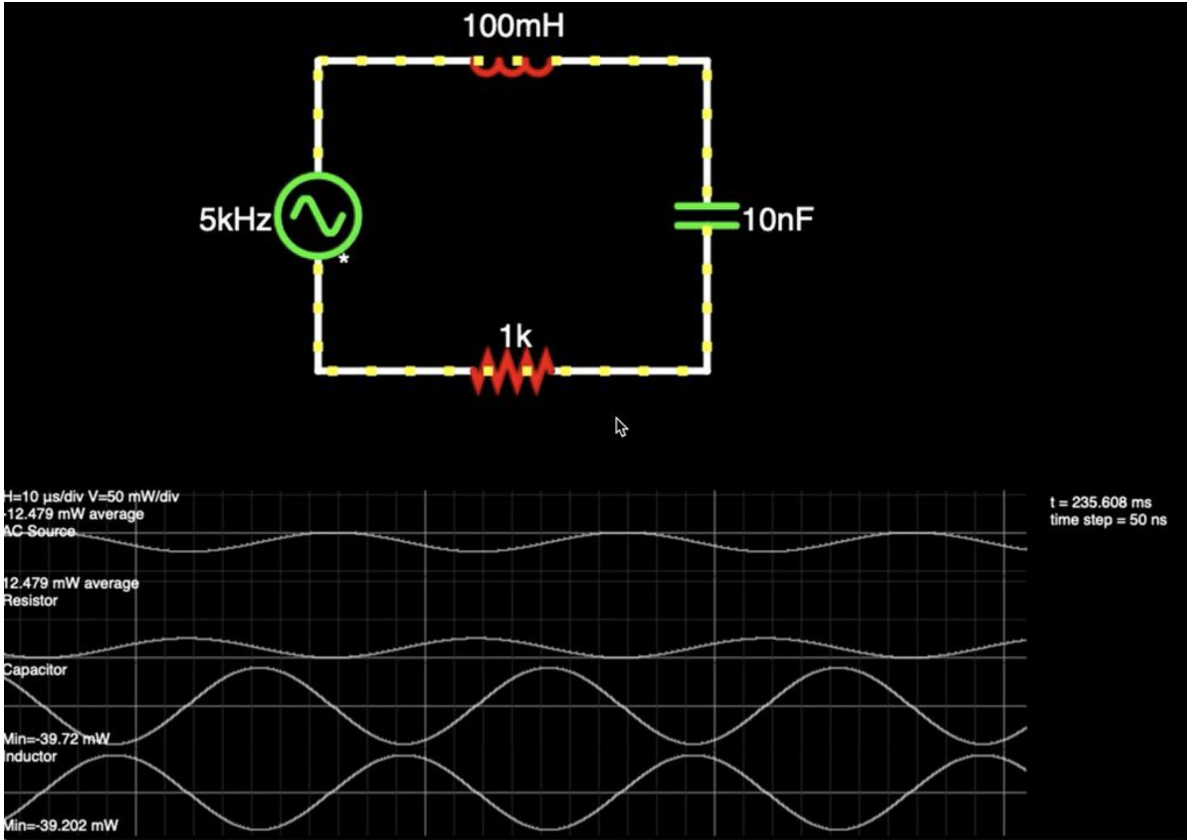
This is an LCR meter. It measures L, C, and R.

Please turn it off when you’re done using it.

LCR Circuits

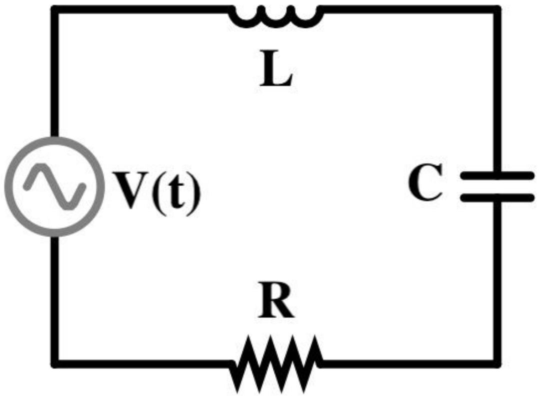


Series LCR Falstad Simulation



Impedance of LCR in series

$$
\begin{aligned}
Z_{RLC} &= Z_R + Z_L + Z_C \\
&= R + j\omega L + \frac{1}{j\omega C} \\
&= R + j\left(\omega L - \frac{1}{\omega C}\right) = |Z_{RLC}|e^{j\phi} \\
&= R + j\frac{L}{\omega}\left(\omega^2 - \frac{1}{LC}\right) \\
\therefore |Z_{RLC}| &= R\sqrt{1 + \frac{L^2}{R^2\omega^2}\left(\omega^2 - \frac{1}{LC}\right)^2} \\
\phi &= \tan^{-1}\frac{L\left(\omega^2 - \frac{1}{LC}\right)}{\omega R}
\end{aligned}
$$



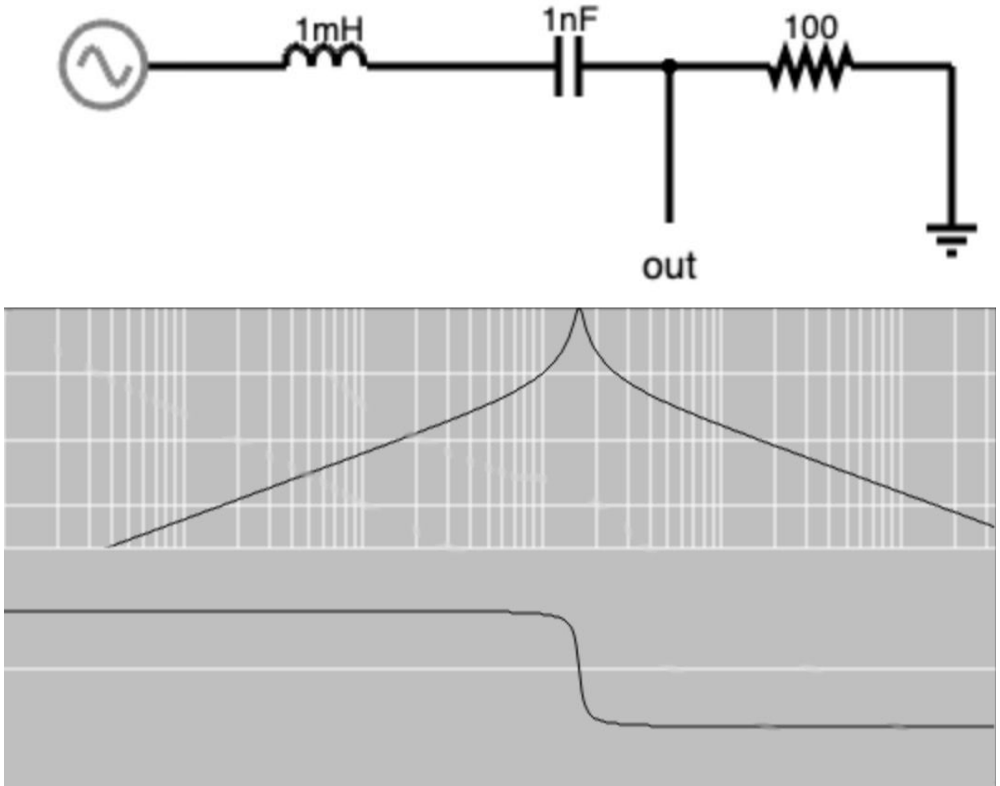
LCR Resonance

- Because the impedances of inductors and capacitors are 180° out-of-phase, they can cancel each other out at the resonant frequency where their magnitudes are the same:

$$f_0 = \frac{1}{2\pi}\omega_0 = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}$$

- The impedance has it minimum value, $|Z_0| = R$, at resonance, so the current (and hence voltage drop across the resistor) is a maximum.

Simple LCR Resonant circuit

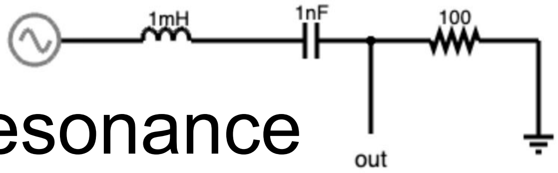


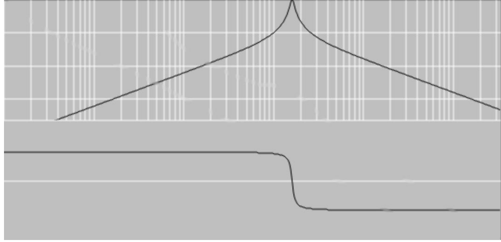
[Falstad Filter example]

Attenuation $A(f) = \frac{|V_{\text{output}}\, f|}{|V_{\text{input}}(f)|}$

Phase

Phase and Width of Resonance

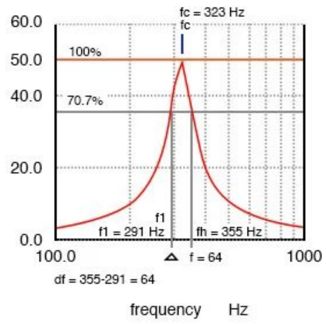




- At high frequencies the inductor dominates the impedance so the voltage V leads the current I, while at low frequencies the capacitor dominates so I leads V. At resonance, $\phi_0 = 0$.
- The width of the resonance is parameterized by the half-power points ($\omega\pm$) on either side of the resonant frequency.
  - The circuit current is $I = V_{AC}/Z_{LRC}$, so the resistor power dissipation $P = I^2 R = V_{AC}^2 R / Z_{LRC}^2$ is halved when circuit impedance Z_{LRC} increases by $\sqrt{2}$
- This happens when $\left(\omega L - \frac{1}{\omega C}\right)^2 = R^2$
- I.e. the half-frequencies are $f_\pm = \frac{\omega_\pm}{2\pi} = \frac{\pm R + \sqrt{R^2 + 4L/C}}{4\pi L}$

  The phase at half-power points is 45°

https://www.allaboutcircuits.com/textbook/alternating-current/chpt-6/q-and-bandwidth-resonant-circuit



Bandwidth and Q value of resonance

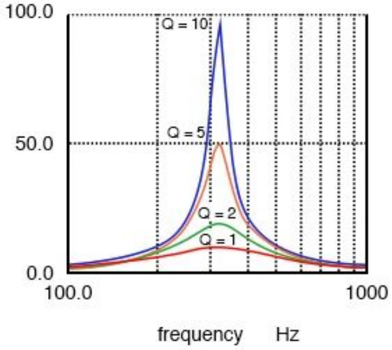
- The bandwidth of a resonant circuit is the Full Width at Half Maximum (FWHM), i.e. the difference between the half-power points

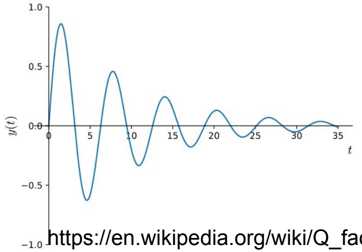
$$BW = f_+ - f_- = \frac{R}{2\pi L} = \frac{f_0}{Q}$$

- where Q is the quality factor:

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

- Roughly speaking, is the decay time of energy stored in the circuit, measured in units of the period (i.e. inverse of frequency)





https://en.wikipedia.org/wiki/Q_factor

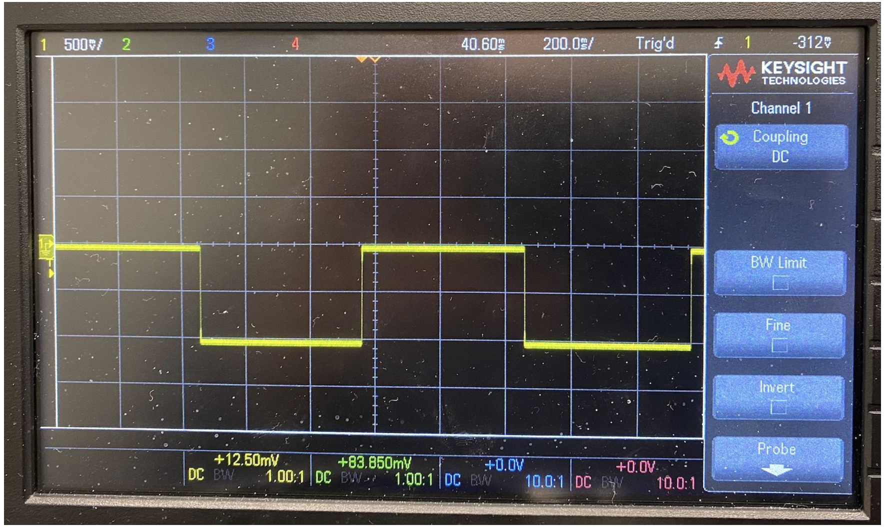
Bandwidth (BW)

- The analog bandwidth of an oscilloscope (and other systems) is conventionally defined as the frequency range over which the output amplitude of an input sine wave is reduced by no more than 3 db (~ 30%), and hence the power is reduced by no more than a factor of two.
- The rise time (t_{rise}), of an oscilloscope, (the time it takes for the oscilloscope to trace out an instantaneous change in its input), is related to the bandwidth. Typically $BW \times t_{\text{rise}}$ ~ 0.35 − 0.55
  - Note: Decibels are defined in terms of power ratios $G = 10\log_{10}(P_{\text{out}}/P_{\text{in}}) = 20\log_{10}(V_{\text{out}}/V_{\text{in}})$ (since $P \propto V^2$).

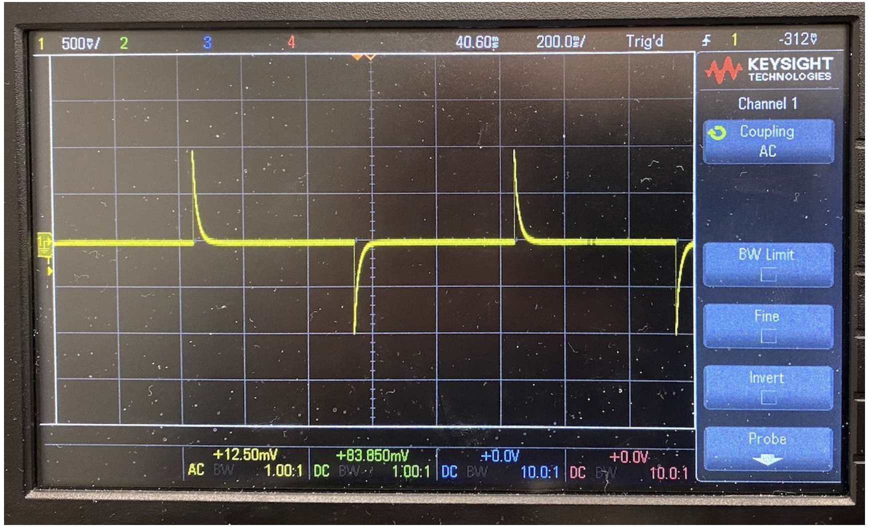
Scope AC/DC coupling

1 Hz Square Wave

DC coupling



AC coupling



Modeling of a “realistic” scope

- Keysight scope datasheet
- Input impedance/capacitance?
- And the 10 Hz cutoff frequency?
- Start with this link

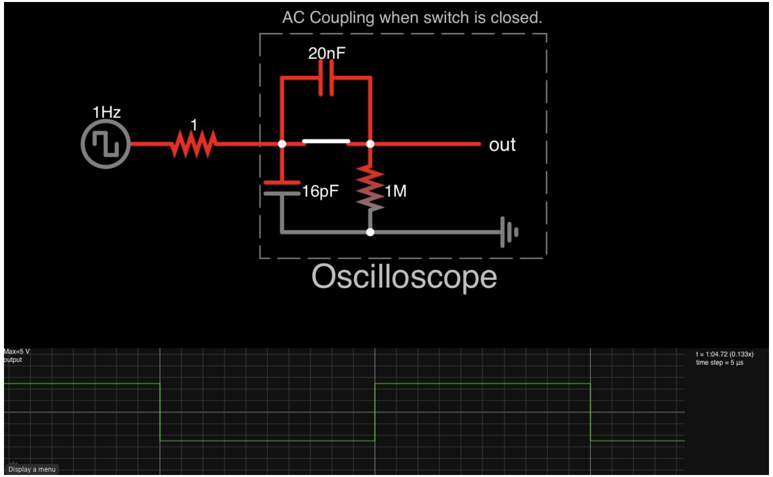
Vertical system

	All Models
Input coupling	DC, AC (10 Hz cutoff frequency)
Input impedance/capacitance	1 MΩ ± 2%, 16 pF ±3 pF

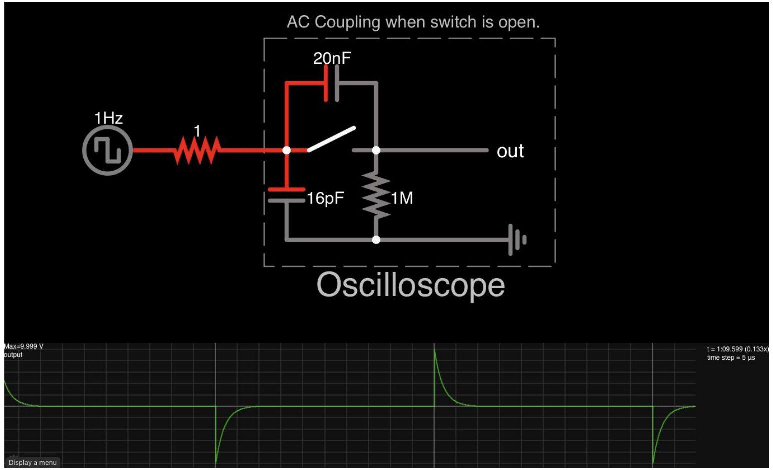
Inside the scope?

1 kHz Square Wave

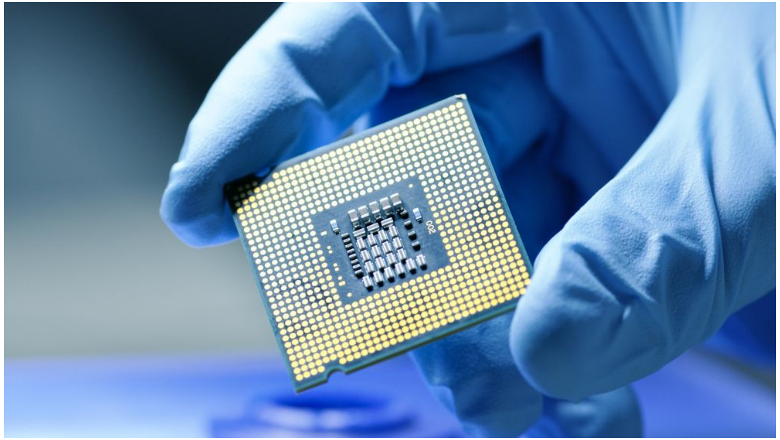
DC Coupling

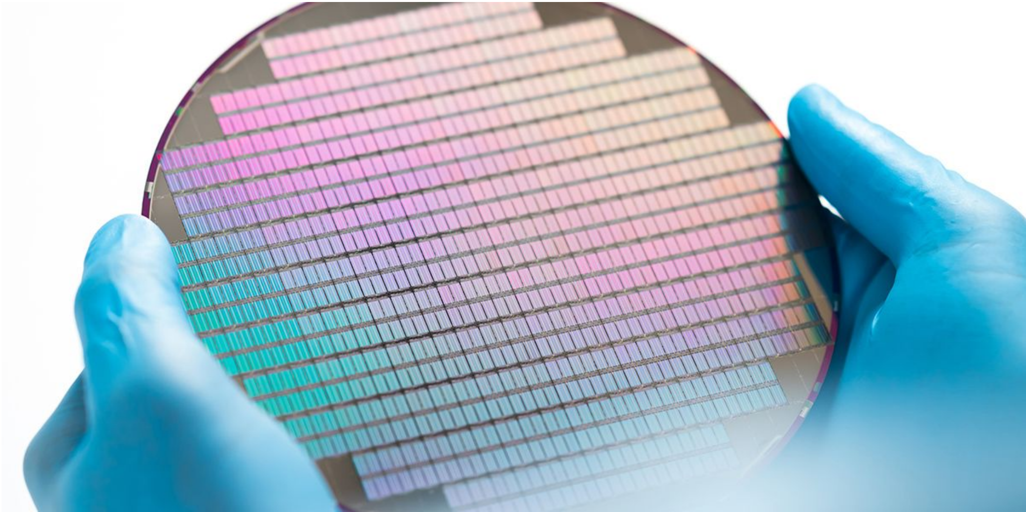


AC Coupling



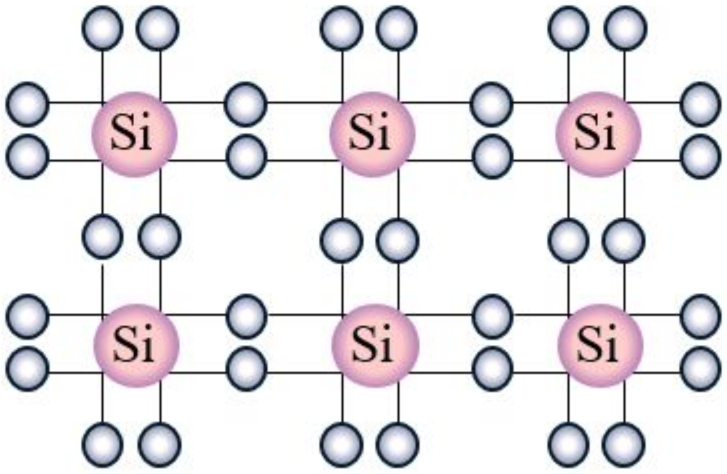
Semiconductors

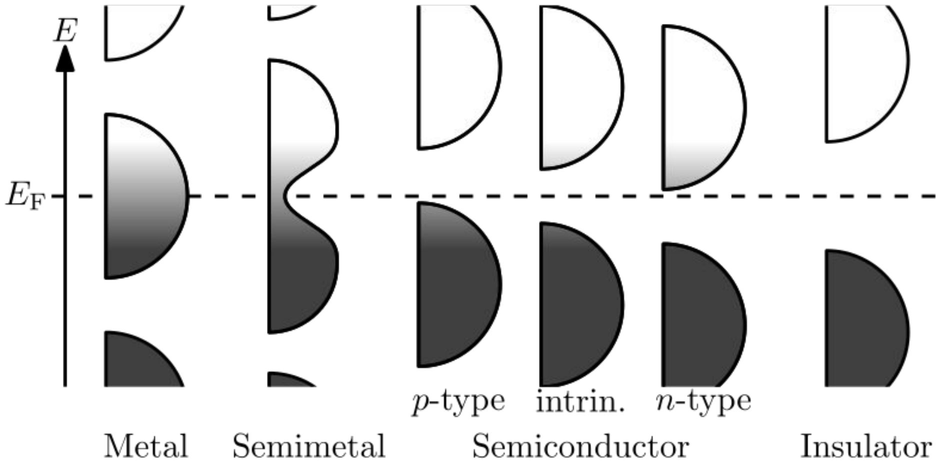




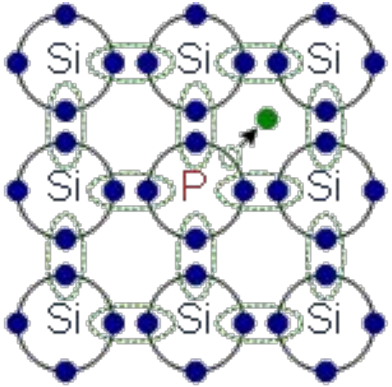
Semiconductors

- Conductivity falls between metal and insulator…
- Slight doping can alter its property drastically

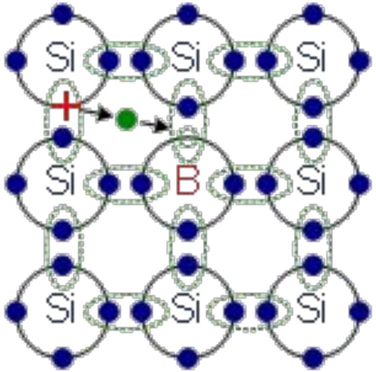




Semiconductors - silicon doping



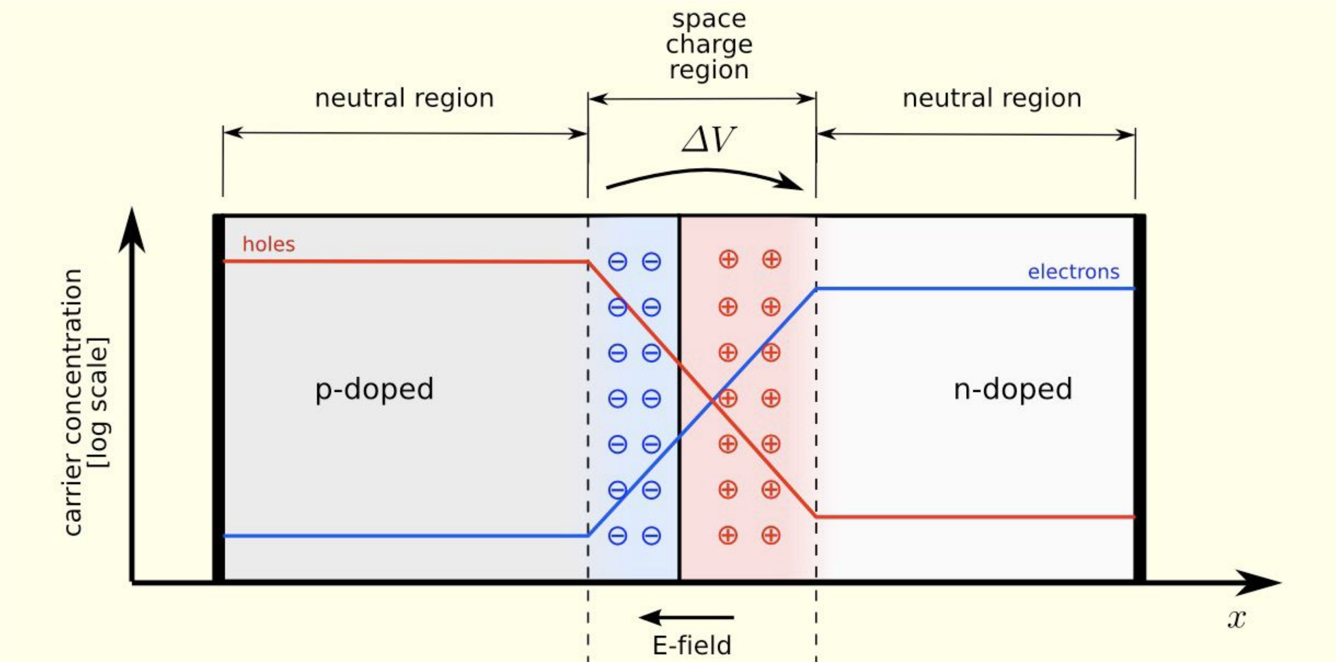
The phosphorus atom donates ist fifth valence electron. It acts as a free charge carrier.



The free place on the boron atom is filled with an electron. Therefore a new hole („defect electron") is generated. This holes move in the opposite direction to the electrons

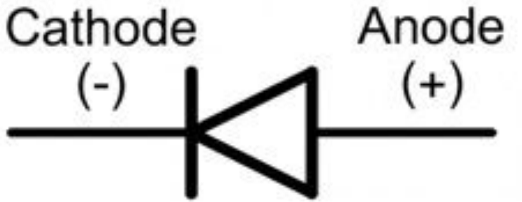
https://www.halbleiter.org/en/fundamentals/doping/

Semiconductors - PN junction

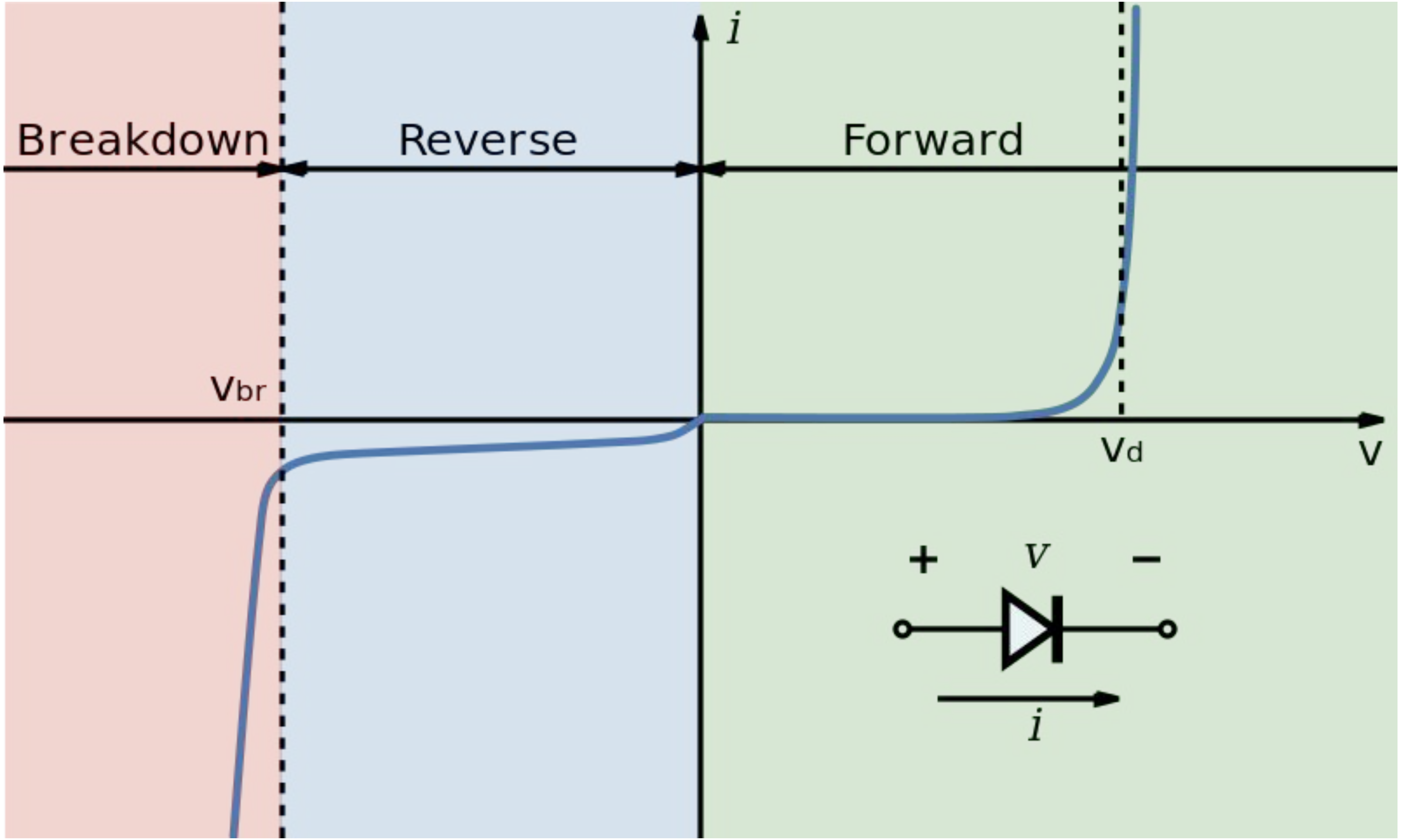


(credit: Wikipedia)

Diodes



- An ideal diode has zero resistance when a voltage is applied in one (“forward biased ”) direction, and infinite resistance in the opposite (“reverse biased ”) direction.
- Real diodes
    - don’t conduct in the forward direction until the applied voltage is greater than a non-zero threshold voltage
    - have non-zero impedance when conducting in the forward direction.
    - have a small leakage current when reverse biased.
    - allow large reverse currents to flow when the reverse bias exceeds some breakdown voltage
    - usually require a current-limiting resistor in series to keep the current below the rated current.



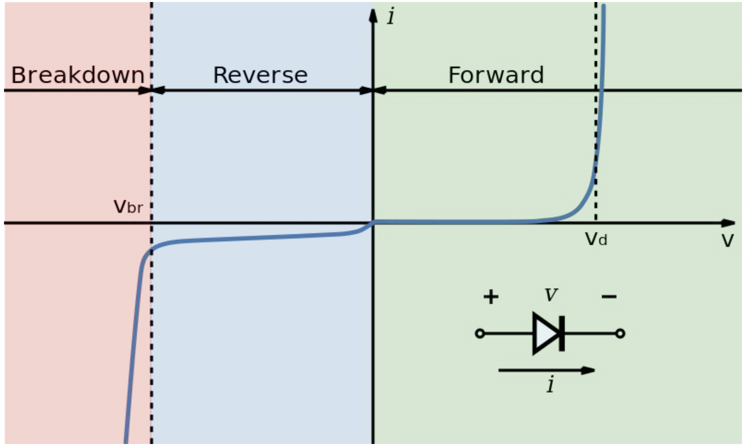
Real diode Voltage-Current curve (credit: Wikipedia)

Diode I-V Model

- The simplest model for the forward current of a real p-n junction diode is that it grows roughly exponentially

$$i = i_s \left(e^{\frac{eV}{k_B T}} - 1 \right)$$

  - e is the electron charge
  - V is the voltage across the diode,
  - k_B is the Boltzmann constant,
  - T is the diode temperature,
  - i_S is the reverse bias saturation current



Light Emitting Diode (LED)

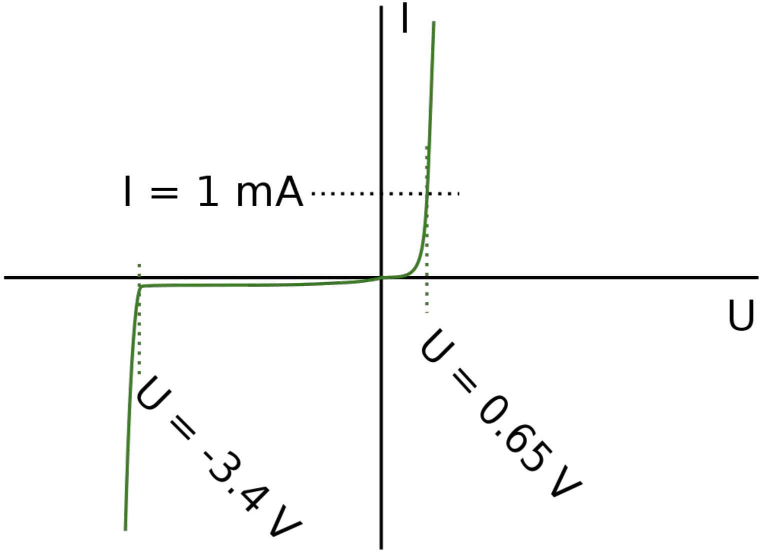
The are many different types of diodes, e.g rectifier, signal, LED, Zener, …

A light emitting diode (LED) emits light when a current passes through it. The photon wavelength depends on the energy gained by the electrons as they pass through the diode.

- To produce visible photons requires a relatively large forward voltage drop across the diode, ranging from ~ $1.5V$ for red light to ~ $3.5V$ for blue or white light.

Zener Diode

At high enough reverse voltage, all diodes eventually break down and conduct, but zener diodes have relatively low and well defined breakdown voltages that can be used to limit and control voltages in a circuit.



I-V characteristic of a 3.4-volt Zener diode (credit: Wikipedia)

AC → DC

AC-to-DC Power Supply

A basic, albeit not very efficient, AC to DC converter can be created by simply inserting a diode to rectifyat the input of an RC Low-Pass filter. The diode *rectifies* the voltage, allowing the capacitor to charge when current is flowing though the diode in the forward direction, but preventing the capacitor from discharging when the voltage is reversed. As long as the RC time constant is much longer than the AC input frequency, the capacitor will charge to close to the peak AC voltage. A zener diode can be put across the output for a fixed output voltage lower than the peak AC voltage.

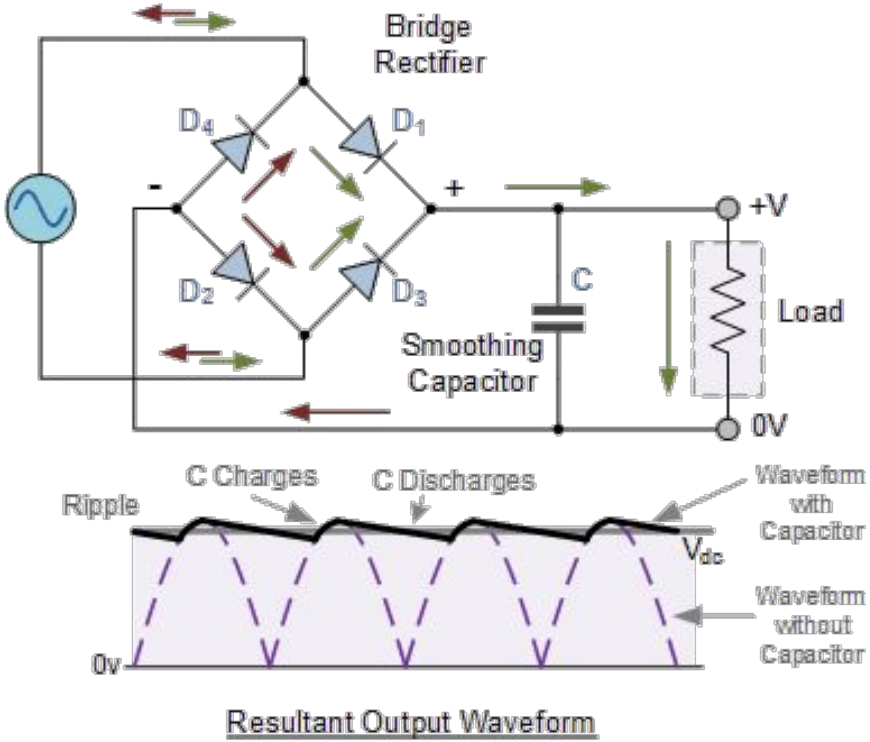
- The RC time constant should be much longer than the AC input frequency.
- An electrolytic capacitor is fine, but make sure it is inserted with the correct polarization.
- When simulating this, some additional resistors may be needed to prevent shorts.

R-8) Using a 1N4001 rectifier diode, a 3.9V zener, a capacitor, and whatever resistor(s) you need, design and build an circuit that takes a 20Vpp 60Hz square-wave input and outputs about 3.9V DC across a 1k output resistor, with less than about 5% ripple.

- Any DC voltage in the range 3-5V is fine.
- The 1k resistor is the output load; it is not the *R* in the RC circuit.
- *Ripple* is the amount of AC variation in the output.

Include in your report a Falstad circuit simulation of your final design, and include a photo of your scope showing the AC input and DC output signals.

Full Wave Bridge Rectifier



https://www.electronics-tutorials.ws/diode/diode_6.html

Full Wave Bridge Rectifier

Clean up after you are done

Yes, this slide is still here!

Questions?