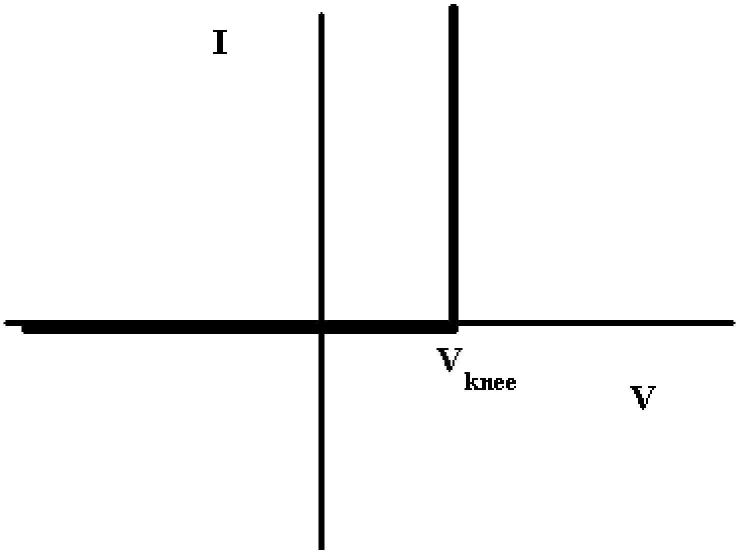
Physics 214 **INTRODUCTION TO LABORATORY ELECTRONICS** **Lecture 9**

Topics: Diodes

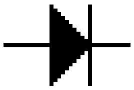
Up until now we've been dealing with 'linear devices': we can write $V = Z I$.
Today we treat a non-linear device: the diode.

A SIMPLE MODEL AND FIRST APPROXIMATION:

the diode is a one-way 'valve' - current flows in one direction through the diode but not the other. A simple graph of I vs V is:

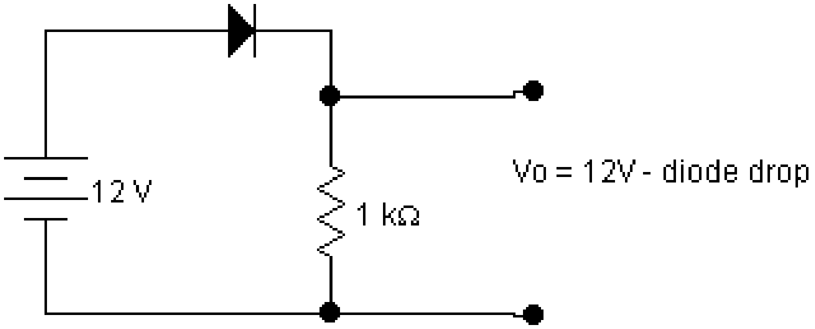


The symbol for the diode:



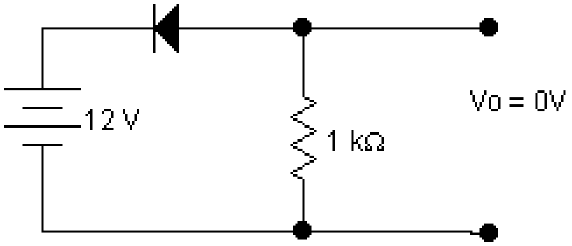
denotes the direction current can flow through the diode. The arrow direction is the direction current will flow. If the voltage is high on the right than on the left, then the current will not flow through the diode.

The value of V at the 'knee' of this graph depends on the construction of the diode: a Si (silicon) diode has a 'diode drop' of ≈ 0.6V whereas for Ge (germanium) the diode drop is ≈ 0.2V. So in the following circuit if the diode is Si, $V_o = 12V - 0.6V = 11.4V$ and if it is Ge, $V_o = 12V - 0.2V = 11.8V$.



When the voltage is well above the diode drop voltage, in this simple model the diode behaves as a pure conductor – the slope of I vs V is infinite so the apparent resistance (slope of V vs I) is zero. i.e. think of it as a funny kind of short: a short with no resistance (like a wire) but which drops the voltage by the diode drop voltage.
When the voltage polarity is arranged to allow current flow the diode is 'forward biased'.

A 'reversed biased' diode will have no current flow in this simple model. For the circuit below, V_o=0.



NOTES:
1) A diode does not have an Ohmic resistance: it is a non-linear device.
2) A circuit containing a diode does not have a Thévenin equivalent circuit.

A BETTER APPROXIMATION:

$$I = \begin{cases} I_r(e^{a \times \mathrm{V}} - 1) & V > 0 \\ -I_r & V_{p.i.} < V < 0 \\ -\infty & V < V_{p.i.} \end{cases}$$

I_r is the reverse saturation current.

For Si $I_r \approx 1\text{-}100$ nA, for Ge $I_r \approx 1\text{-}100\ \mu$A

$a \approx 20\mathrm{V}^{-1}$ for Si at 20°C and $1\mathrm{V}^{-1}$ for Ge.

$\mathrm{V}_{\mathrm{p.i.}}$ is the peak inverse voltage. Avalanche breakdown if $\mathrm{V} < \mathrm{V}_{\mathrm{p.i.}}$

This is still only an approximate model. You'll work with this model in the lab.

With this model, you can calculate a V/I ratio which has units of resistance, but which is not particularly useful. Of more interest is the 'dynamical resistance$r$' which is the slope of the V vs I curve when the diode is forward biased. It varies with voltage:

$$\frac{1}{r_f} = \left.\frac{dI}{dV}\right|_{V_f} = I_r a e^{a \times V_f} \approx I_r a(e^{a \times V_f} - 1) = aI$$

$$r_f \approx 1/aI = [I_r a(e^{a \times V_f} - 1)]^{-1}$$

This is of interest since small AC voltage variations see this changing forward biased dynamic resistance of the diode.

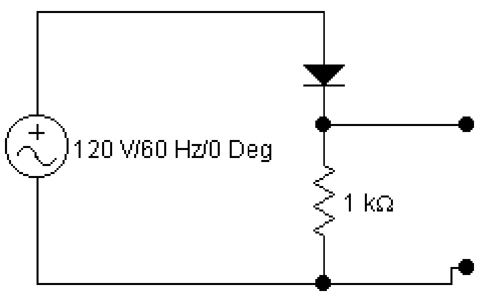
SOME APPLICATIONS:

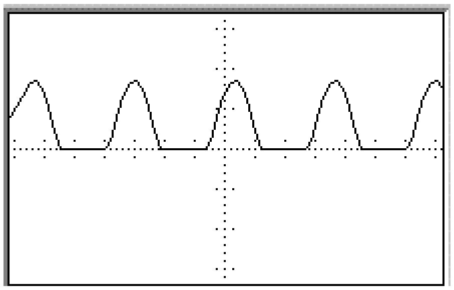
RECTIFICATION

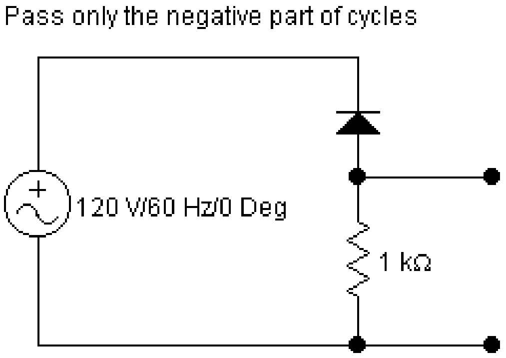
Convert an AC line voltage to a DC voltage.

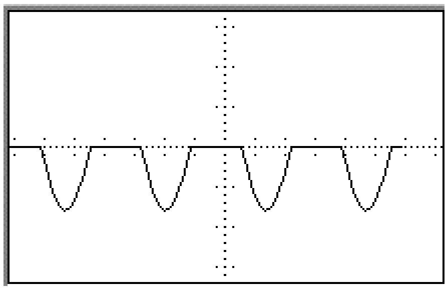
Half-wave rectifier: only half of the AC signal is passed by the diode: either the positive or the negative part of the cycle.

Pass only the positive part of cycles

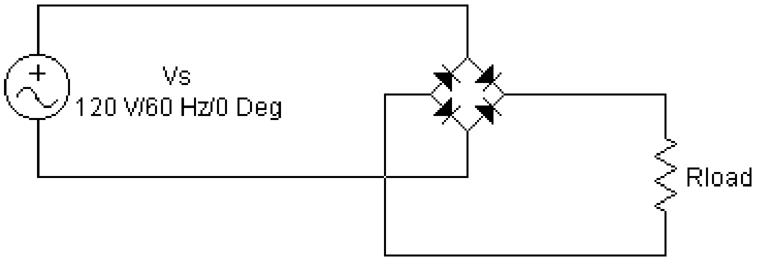


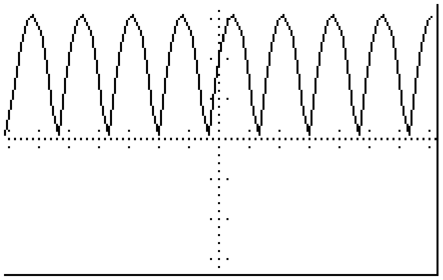




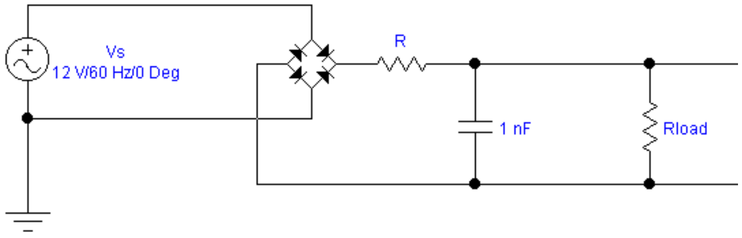


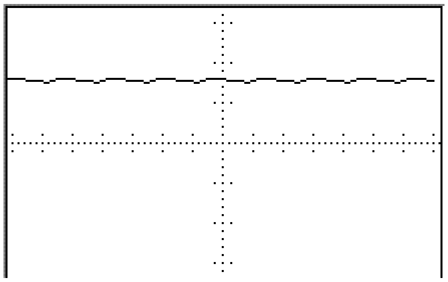
Full-wave rectifier: more clever design gives an output on *both* the negative and positive swings of the input voltage.





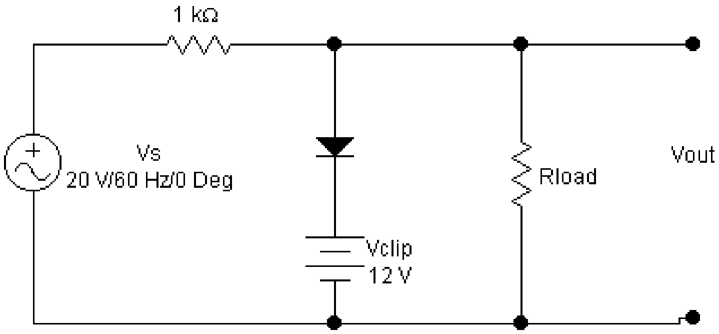
In a DC power supply an RC network follows this: the capacitor charges up and slowly discharges. Some ripple is left. This ripple can be removed using a ‘voltage regulator’.

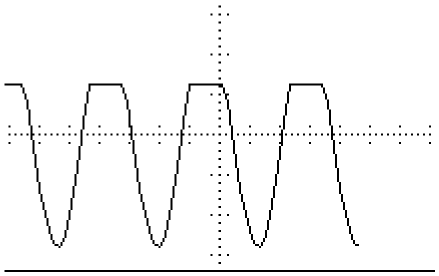




DIODE CLIPPER CIRCUIT

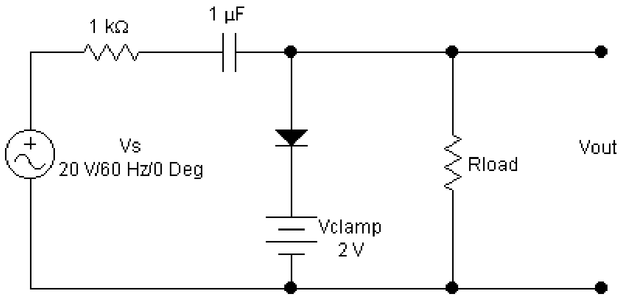
Ensures V_{out} doesn't exceed a predetermined V_{clip}+diode drop. Useful to protect following circuit components.

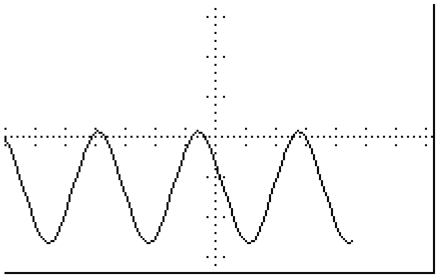




DIODE CLAMP

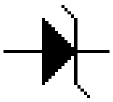
Changes DC reference voltage of an input signal. V_{out}=V_s-V_{clamp}-diode drop.



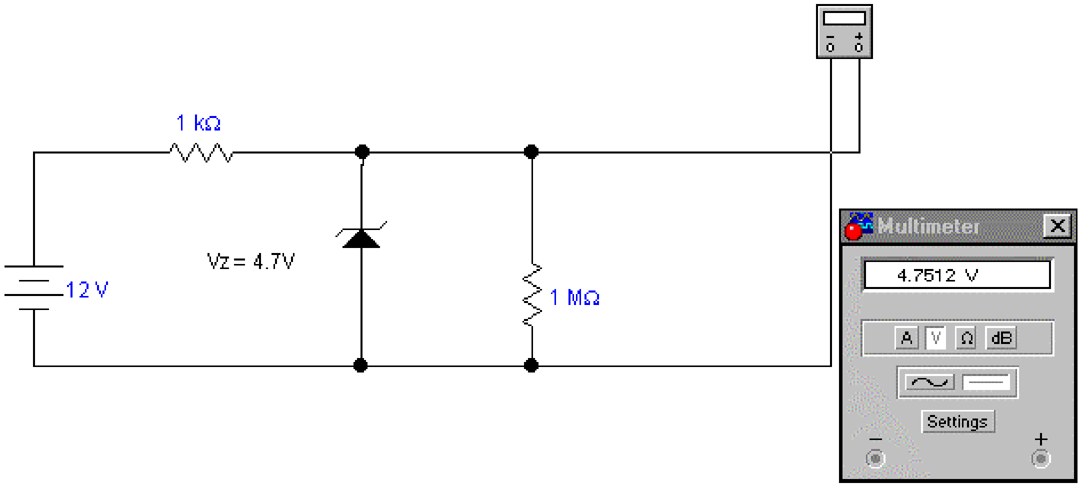


ZENER DIODE

A simple form of regulator is a diode designed to take advantage of the reverse biased breakdown voltage characteristics of the diodes I vs V curve. The symbol for the zener is:



As long as the reversed biases current is kept large enough (10mA rule of thumb) then the voltage will be fixed at a precisely defined ‘breakdown voltage’. Since in this case the diode doesn’t ‘break’ - it’s designed to operate there – one refers to the ***zener voltage***. Typical values of zener voltages are 3.3V, 3.6V, 3.9V, 4.3V,4.7V, 5.1V,..., 27V, 33V, etc.
In practice, one needs circuit components to maintain the 10mA current through the zener.
In the following circuit, without the V_Z=4.7V zener, the voltage across the 1MΩ load resister would be 11.99V. The zener forces a voltage of 4.7V across it, so across the 1kΩ, there is a voltage drop of 12V - V_Z=12V-4.7V = 2.55V.
So it can be used as a "poor man's" voltage regulator.



Zener diodes can also be used to protect circuits: for voltages below the breakdown voltage no (i.e. extremely little) current flows through reversed biased diode.