## Experiment 5: Diode circuits

**Goal:** To measure the I-V curve of a silicon signal diode and use it to construct a half-wave rectifier circuit smoothed by a simple RC filter.

**Background notes:**

A diode is a circuit element fabricated from semiconducting materials which conducts electric current in one direction only. The relation between I and V is **nonlinear.**

A typical I-V curve for a semiconductor diode is shown below (left), next to a simplified model (below, right). We refer to "forward bias" as the polarity of applied voltage which, at sufficient level ($V > V_t$) "turns on" the diode's current-carrying ability. Reversing the polarity, essentially zero current is conducted until a very large reverse bias voltage is applied, which causes breakdown ($V < -V_B$). For a typical silicon signal diode, $V_t = 0.6V$; $V_B$ is 10 to 100× larger and is device-specific. This property leads to many practical applications in the rectification of AC → DC signals, one of which will be explored in this lab.

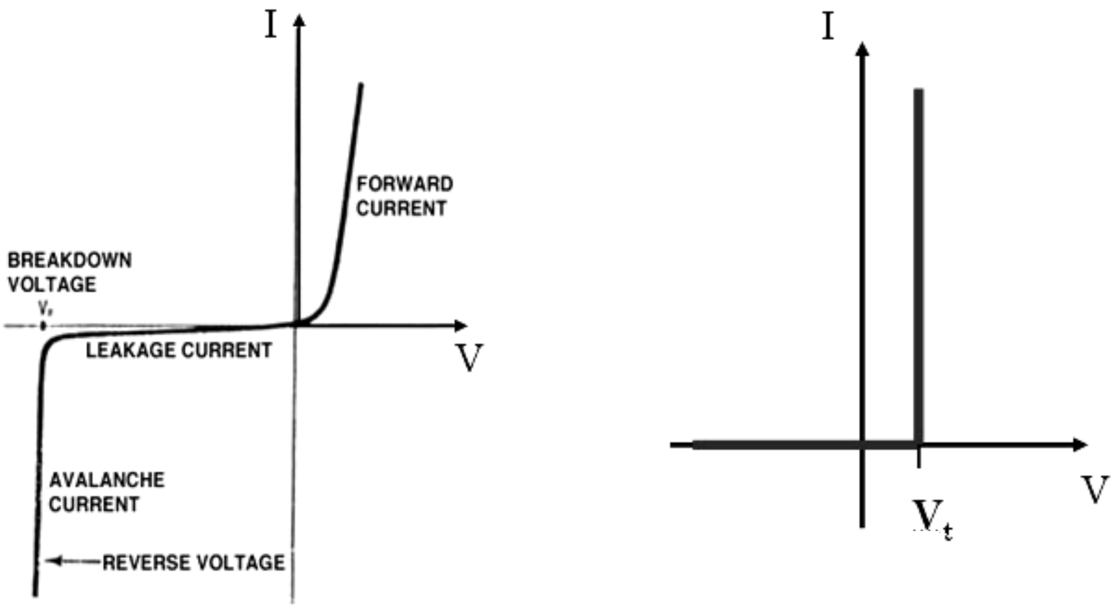
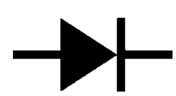



**Fig 1: a) semiconductor diode I-V curve; b) idealized diode I-V curve.**

The diode circuit symbol is shown at the right; the arrow indicates the direction of current flow in the forward bias direction, for $V \geq V_t$.



**Note** :

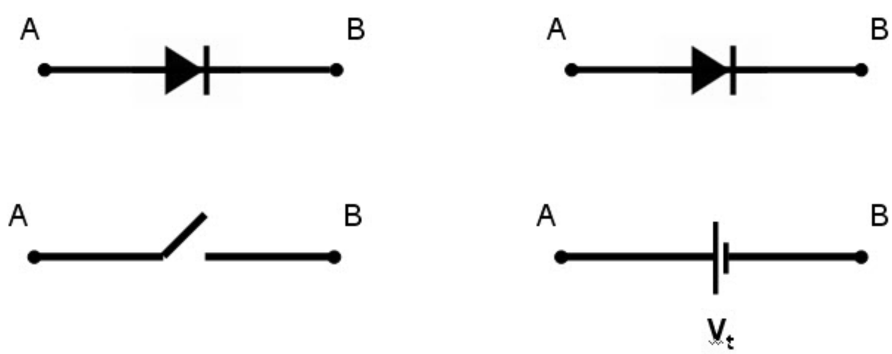
The slope of the "real" diode I-V curve in the conducting state is $dI / dV = 1 / R >> 0$ (Fig. 1. a) , i.e. in the "on" state, the real diode has a very small, voltage-dependent ac resistance**;**

in the simplified "ideal" case (Fig. 1. b) the slope $dI / dV = 1 / R = +\infty$ for $V = V_t$, i.e. $R_{ac} = 0$ for the ideal diode when it is conducting current, and it is not possible to maintain any potential difference greater than $V_t$ across the real diode under forward bias.

→ This means that a series resistor must always be inserted in series with a diode in order to limit the current flow so that the diode does not overheat when it is turned "on" !

Likewise, under reverse bias, the diode has very high (Fig 1. a), or effectively infinite resistance (Fig. 1. b).

→ **The diode acts like a switch, which is either open or closed depending on the bias voltage !**




**(a) Reverse Bias ($V_A < V_B$)** **(b) Forward Bias (on)**

**Fig. 2: Ideal diode equivalent circuit elements**

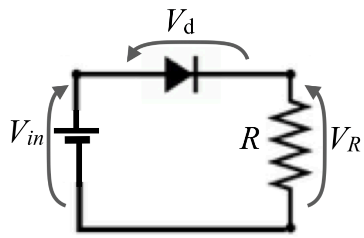



**Fig. 3: Diode characterization circuit.**

**Pre-Lab exercises:**

**a)** For the circuit of Fig. 3, and assuming an ideal diode with $V_t = 0.6$ V, what are the potential differences across the diode $V_d$ and across the resistor $V_R$ as the input bias voltage $V_{in}$ is varied from 0 to 10 Volts? Draw the equivalent circuits to help you work this out, and draw sketches of $V_d$ vs $V_{in}$ and $V_R$ vs $V_{in}$.

**b)** Predict the voltage across the resistor, $v_R$, when the input voltage is supplied by an ac function generator: $v_{in} = V_0 \sin(\omega t)$ where $V_0 > V_t$. *(This is what the waveform will look like on an oscilloscope triggered on positive slope and zero threshold!)* Draw a sketch of both $v_{in}$ and $v_R$ on the same scale, as a function of $t$.

**c)** Now consider adding a capacitor in parallel with the resistor, as shown in Fig. 4. The result, for an appropriate choice of RC time constant relative to the ac period, is a dc voltage across the capacitor, with some ac "ripple" as shown in Fig. 4. b).

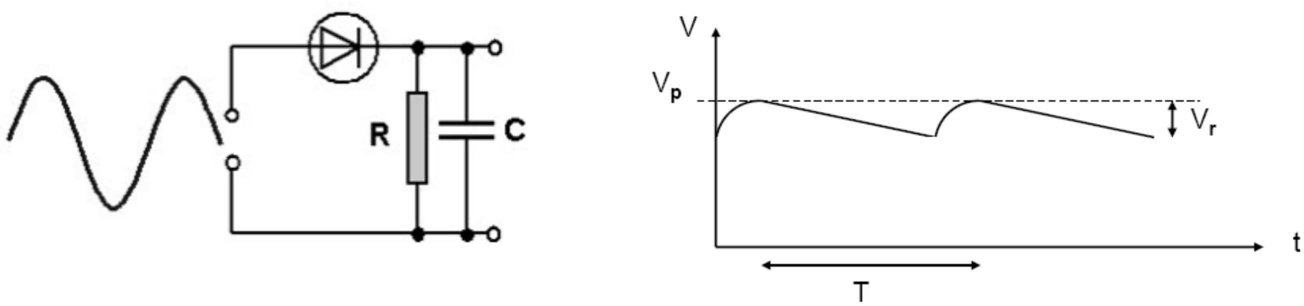


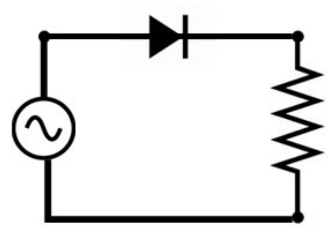

**Fig. 4: a) RC filtered rectifier circuit** **b) capacitor voltage waveform**

Think carefully about what portion of the ac cycle corresponds to current flowing to charge the capacitor. What happens when the diode turns off? Draw the equivalent circuit in this situation, to show that the capacitor will then discharge through the resistor until the diode turns on again.

For a choice of $RC$ time constant that is large compared to the period of the ac signal, the exponential decay of the capacitor charge can be approximated as linear. Show that in this case, the ratio of the peak-to-peak ripple voltage to the peak (dc) value is **approximately** given by: $\frac{V_r}{V_p} = \frac{1}{RCf}$, where $f$ is the temporal frequency of the ac waveform.

**Experiment: Half Wave Rectifier Circuit:**

**Components needed:**



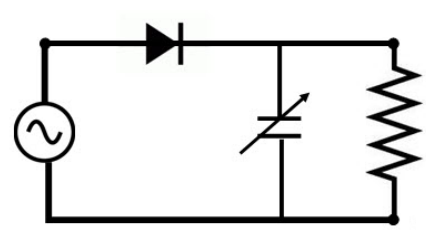
- 10 kΩ resistor
- 1N4446 diode
- Variable capacitance box
- Oscilloscope
- ac function generator

**1. Rectifier**

Assemble the circuit indicated above. Set the function generator to produce a sine wave at a convenient amplitude and frequency (suggested values: ~ 5 V, 500 Hz). Trigger the oscilloscope on the function generator signal (channel 1), and examine the voltage across the resistor on channel 2. Use dc coupling for both channels.

Record a screen capture (see sample data, next page). Carefully measure the difference between the two signal amplitudes. Is it consistent with expectations?

**2. Filtered rectifier**



Connect the variable capacitance box in parallel with the resistor as shown in the figure.

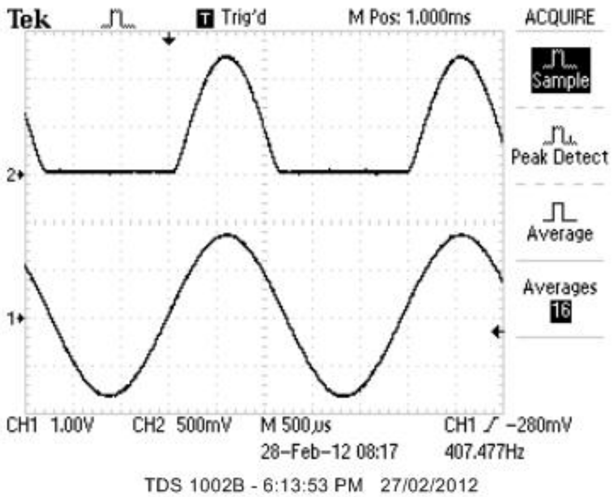
Experiment with different capacitance settings to produce an approximately dc voltage waveform across the resistor.

Record a screen capture (see sample data, next page) and note the frequency and capacitance setting.

Switch channel 2 to ac coupling mode and turn up the gain so that you can measure the peak-to-peak ripple accurately from the oscilloscope screen.

Measure the peak voltage and peak-to-peak ripple for the filtered resistor signal for several different capacitance values. Does the ratio $V_r/V_p$ vary as expected with the value of $C$ ?

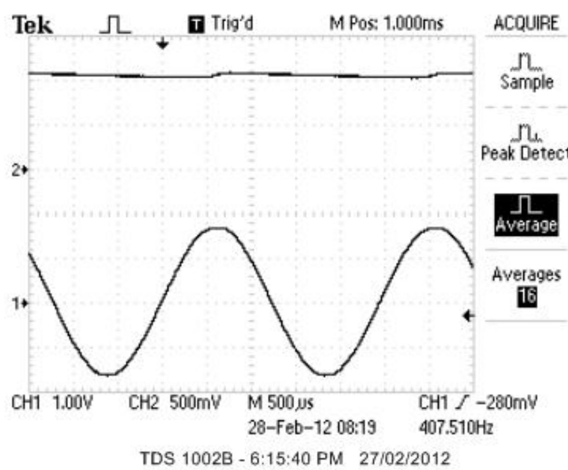
**Sample Data, ac rectifier circuit:**

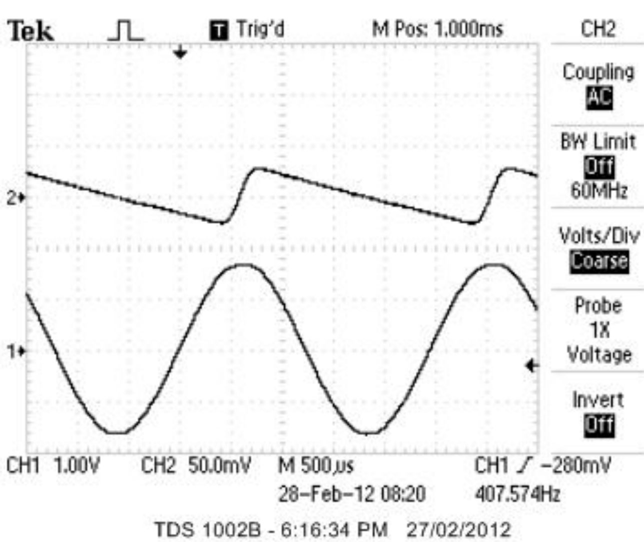



**Channel 1: ac generator signal**

**Channel 2: voltage across 10 kΩ resistor**

**Channel 2: voltage across resistor with 4 μF capacitor in parallel**




**Channel 2: same as above, but with – ac coupling and higher channel gain to enhance sensitivity**