# Lecture 9: Limiting and Clamping Diode Circuits. Voltage Doubler. Special Diode Types.

We'll finish up our discussion of diodes in this lecture by consider a few more applications. We'll discuss limiting and clamping circuits for diodes as well as voltage doubling circuits.
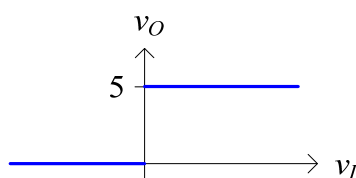
## Voltage Limiting Circuits

These types of circuits are used to "cap" voltages between preset limits. These are useful as voltage protection circuitry or as signal "conditioning."

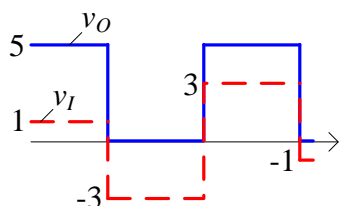Examples of such circuits are shown in text Figure 3.35:

(e)
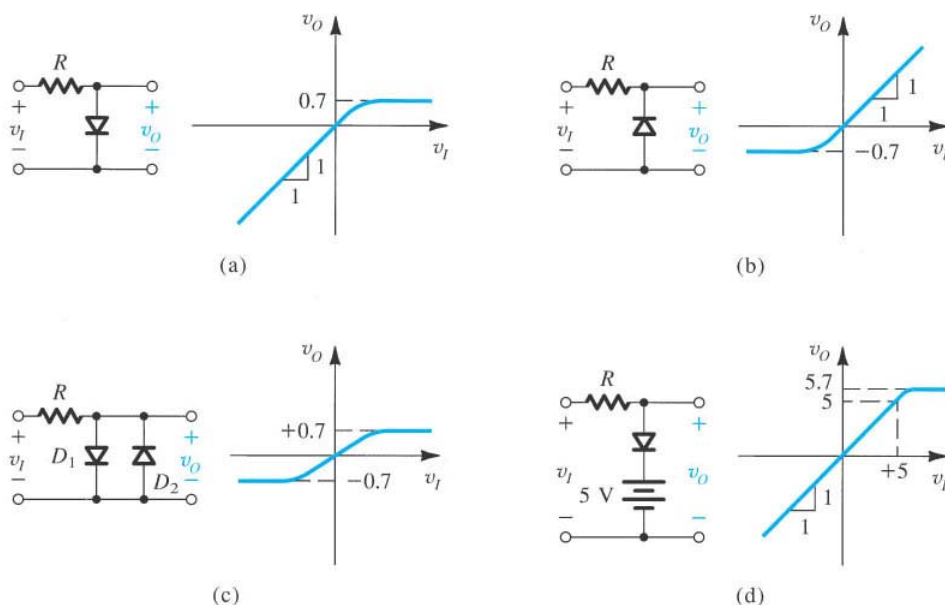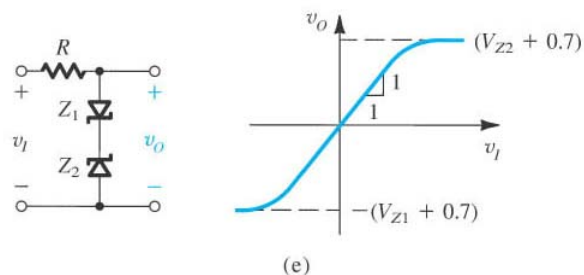
A simple signal conditioning example is a circuit with the following transfer function:



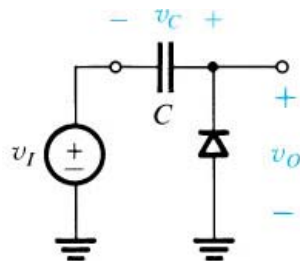Then one would see this output voltage $v_O$ for this particular input voltage $v_I$:



A circuit with ideal diodes can be designed to realize the above transfer function from a combination of the concepts shown above in Fig. 3.35:
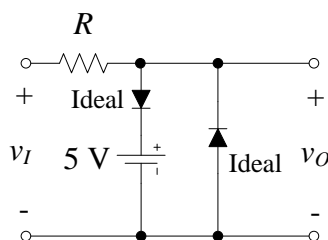
# Clamped Capacitor Circuits

An idealized circuit of this type in shown below:



(Fig. 3.36b)

There are three important things to note about this circuit:
1. The ideal $D$ keeps $v_O \geq 0$.
2. $C$ charges <u>only</u> when $v_I < 0$. Without a load, there is no other path for current.
3. The $v_C$ polarity is positive as shown above.

With these insights, let's look at a specific example to illustrate the operation of this circuit. Consider this input voltage:
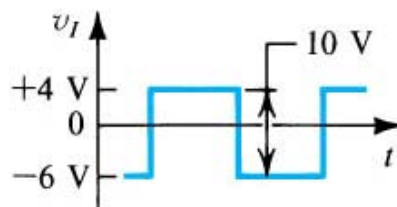


(Fig. 3.36a)

$C$ in Fig. 3.36b will eventually charge completely so that $v_C = +6$ V. In that case, the lowest output voltage will be "clamped" to zero. The output voltage will appear as:

(Fig. 3.36c)
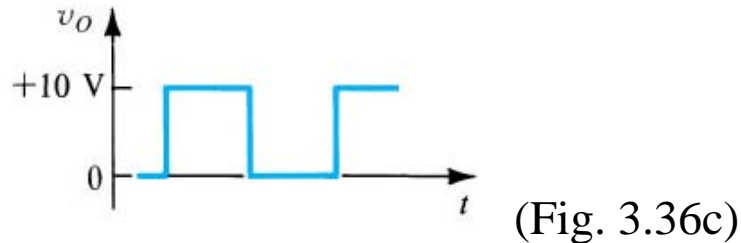
Hence, this is called a clamped capacitor circuit. Without the diode present in this circuit, the capacitor would not retain any net charge per period so it would never "charge up" to 6 V.

Note that here we are looking at the steady state response. It may take a few periods for the capacitor to completely charge. We're not looking at the transient response.

There are two applications of the clamped capacitor circuit discussed in the text.

(a) **Pulse width modulation detector**. PWM is used for motor speed control, for example. The width of the pulse contains the information.
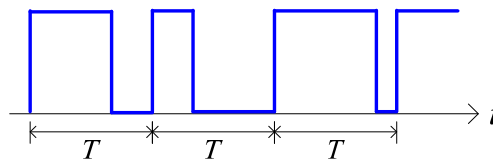


To demodulate the signal, one AC couples to give zero time average voltage (i.e., 0 VDC). The signal is then passed through a clamped capacitor circuit to give a

well-defined DC component, then through a low pass filter to extract the DC.

This DC voltage is the time average value, which changes depending on the width of the pulses (if the period is constant, as assumed).

(b) **Combined clamped capacitor with peak rectifier**. This is also called a voltage doubler circuit.



Clamped          Half-cycle peak
capacitor            rectifier
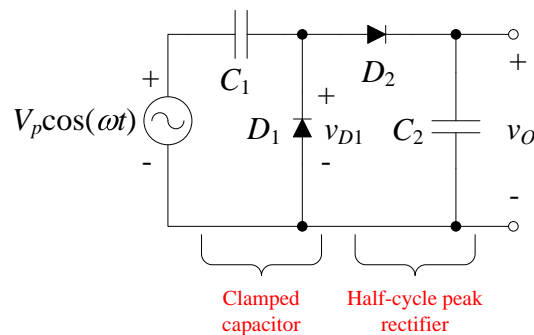
Ignoring the transient behavior when the input voltage is first applied, $v_{D1}$ is:
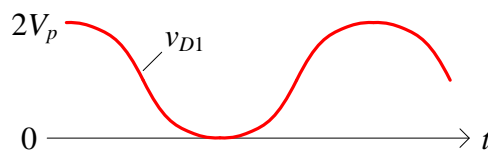


This voltage is fed to a half-cycle peak rectifier yielding the output voltage:
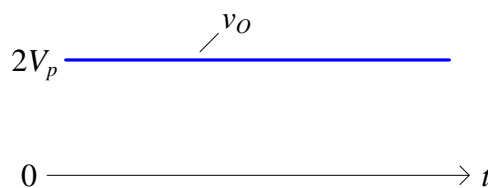
It's obvious now why this is called a voltage doubler circuit.

# Special Diode Types

1. **Schottky barrier diode**. Often just called a "Schottky diode." (Used in Laboratory #1 and in the NorCal 40A in EE 322.)

   These are formed from a metal and an *n*-doped semiconductor. The big difference from a silicon diode is a smaller forward-bias voltage drop of approximately 0.2 V.

   Also, because all conduction current in a Schottky diode is carried by majority carriers (electrons) there is little to no junction capacitance due to the absence of minority carrier charge accumulation in the vicinity of the depletion region.

   Because of this, one would expect the switching speeds of the Schottky diodes to be faster than silicon diodes, for example

2. **Varactor**. A reversed biased diode acting as a voltage-controlled capacitance. (Used in the NorCal 40A in EE 322.)

To understand the operation of the varactor, recall that in the *pn* junction:
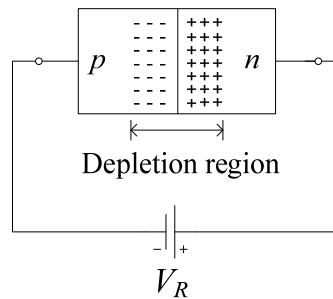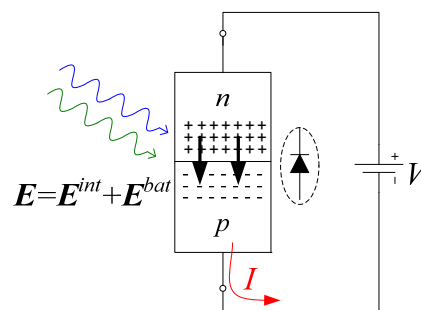


This separated charge region acts as a capacitance. As shown in the text, the junction capacitance can be expressed as

$$C_j = \frac{C_{j0}}{\sqrt{1 + V_R/V_0}} \qquad (3.55),(1)$$

It is readily apparent from this equation that as $V_R$ changes, so does $C_j$. (This model is used in Spice.)

3. **Photodiodes**. This is a reversed biased *pn* junction illuminated by light:



When the *pn* junction is exposed to incident light in the correct frequency band(s), the incident photons can break covalent bonds in the depletion region thus generating electron-hole pairs. These are swept away from the junction

by the electric field in the depletion region with $e^-$ to the $n$ region and holes to the $p$ region.

Thus a <u>reverse bias current</u> has been generated. This is called a photocurrent.

4. **Light Emitting Diode (LED)**. This is the reverse of the photodiode. In the LED, a *pn* junction is forward biased:
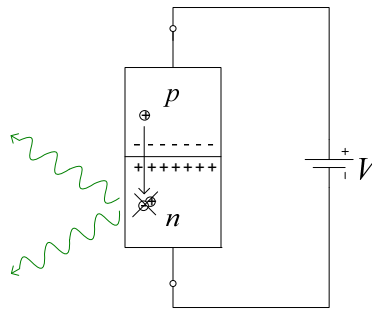


When electron-hole recombination occurs, light can be given off in certain types of semiconductors such as GaAs.