

Lecture 3: Diodes. Amplitude Modulation. Diode Detection.

Diodes are the fourth basic discrete component listed in Lecture 2. These and transistors are both nonlinear devices. Nonlinear devices are necessary for electrical communications.

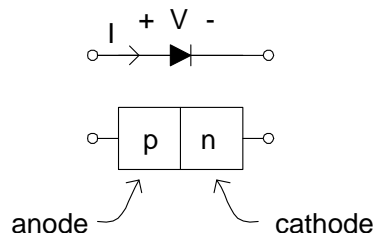
There are **four types of diodes** used in the NorCal 40A:

1. **Silicon** – used for rectification, electronic switching.
2. **Schottky** – used for reversed power supply voltage protection and in the AGC.
3. **Zener** – used for overload voltage protection of the power amplifier.
4. **Varactor** – used to control the transceiver frequency (VFO).

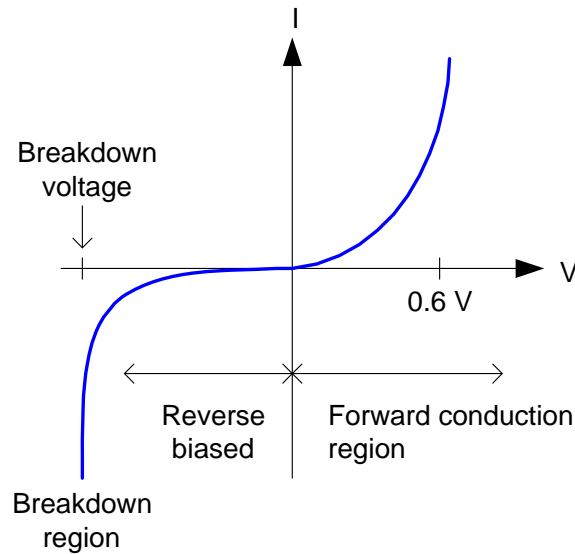
Most of these diodes are formed from a junction of doped semiconductors, which we will discuss next.

pn Junction

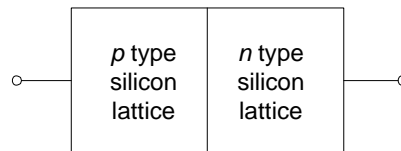
The basic operation of the *pn* junction should be familiar to you:



The diode has four characteristic regions (Fig. 2.14):



A typical *pn junction* is formed as



where

- (1) ***n-type*** is silicon doped with pentavalent impurity elements such as phosphorus. These atoms displace silicon atoms (having four valence electrons) with phosphorous atoms (having five valence electrons). Consequently, one extra electron is available to move through the lattice.
- (2) ***p-type*** is silicon doped with trivalent impurity elements such as boron (having three valence electrons). Consequently, the regular silicon lattice has “holes,” or locations in the lattice that can accept a free electron. This “hole” can also move through the lattice.

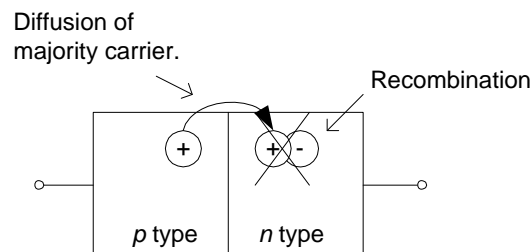
Nevertheless, the entire n -type and p -type regions remain charge neutral at all times! The dopant atoms are also charge neutral.

At room temperature, thermal ionization breaks some covalent bonds. In n -type materials we then have free electrons while in p -type materials we have free holes.

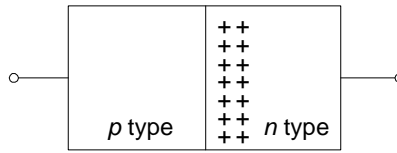
Depletion Region

When the p - and n -type materials are placed in contact (forming a **junction**), two things happen in the contact region:

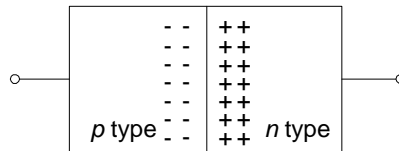
- (1) **Holes diffuse** (random motion due to thermal agitation) across the junction (diffuse because the hole concentration is higher in p type) into the n -type region and **recombine** with majority electrons.



With this electron now “gone,” we have “uncovered” a positive charge from the dopant atom in the n -type region. This forms a positively charged region.



- (2) Similarly, the majority carriers in the n -type region (**electrons**) **diffuse** across the junction and **recombine** with majority holes in the p -type region. This uncovers negative bound charge.

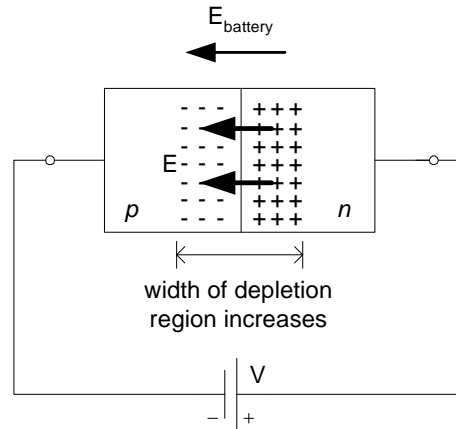


This contact region between the p and n regions now has a bound volume charge density. It is called the **depletion region**. This may seem an unexpected name since only in this region is there a net volume charge density (aka space charge)!

Reverse and Forward Biased Junction

There are two important states for a pn junction, the reversed biased and forward biased states:

- (1) **Reversed biased state:**

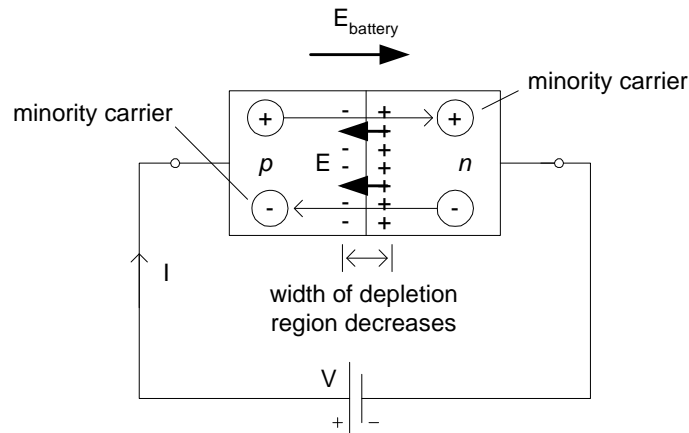


The electric field produced by the battery E_{battery} adds to the electric field of the space charge E in the depletion region. This increases the width of the depletion region.

Consequently, the “majority carriers” cannot flow through the depletion region: holes in the p material are opposed by \bar{E} in the depletion region, as are electrons in the n material.

Hence, little current flows (only the drift current I_s) unless the junction **breaks down**. This occurs when E_{battery} is strong enough to strip electrons from the covalent bonds of the atoms, which are then swept across the junction.

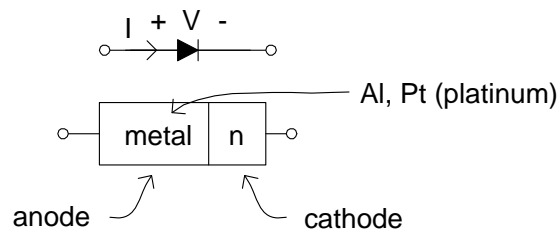
(2) Forward biased state:



When V is large enough so that $E_{\text{battery}} > E$, then the majority carriers can flow through the depletion region: (i) holes are swept from the p to n regions, and (ii) electrons are swept from the n to p regions. We now have current!

Overview of the Four Diode Types

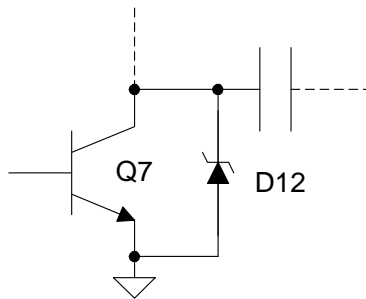
1. **Silicon** – small signal diode. Typical of those used in the EE labs. You'll be using a 1N4148 in the NorCal 40A. (Note: the “1N” refers to diodes, while “2N” refers to transistors.)
2. **Schottky** – made from a contact of metal and doped silicon:



There are two main differences between Schottky and silicon diodes:

- a. The **forward bias voltage drop ≈ 0.2 V**, which is lower than the 0.6 to 0.7 V for silicon diodes.
 - b. There is no time delay associated with minority carrier accumulation at the junction. Schottky operation is based on *majority* charge carriers injected into the metal from doped silicon.
3. **Zener** – These transistors are operated in the reverse breakdown region to keep the voltage from exceeding a prescribed value.

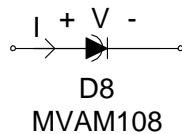
In the NorCal 40A, a 1N4753A, 36-V Zener (D12) appears across the output of the power amplifier transistor Q7:



From the Q7 datasheet (p. 371), the maximum output voltage $V_{CEO} = 40$ V. Consequently, when reversed biased D12 keeps Q7 from exceeding 36 V (and hence V_{CEO}) and damaging itself.

4. **Varactor** – when reversed biased, the capacitance of these diodes can be predictably varied by changing the reverse bias voltage. In other words, these are voltage-controlled capacitors.

The NorCal 40A uses a varactor in the VFO to control the operating frequency of the transceiver:



From the data sheet for the MVAM108 on p. 363, C_T varies from 500 pF to 40 pF as V varies from -1 to -9 V, respectively. (Breakdown occurs at -15 V, which would not be a desirable mode of operation for a varactor.)

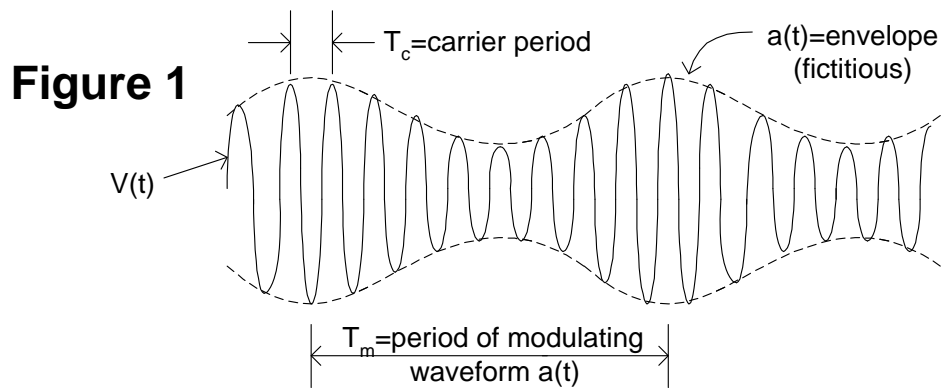
Modulation/Demodulation

As we've just seen, there are many applications for diodes in electronics. Another common application for silicon diodes is the demodulation of AM (amplitude modulated) signals.

An AM signal can be mathematically expressed as

$$V(t) = \underbrace{V_c \cos(2\pi ft)}_{\text{carrier}} + \underbrace{a(t)}_{\text{modulating waveform}} \cos(2\pi ft) \quad [\text{V}] \quad (2.62), (1)$$

An example plot of such a waveform is shown in Fig. 1.4(a):

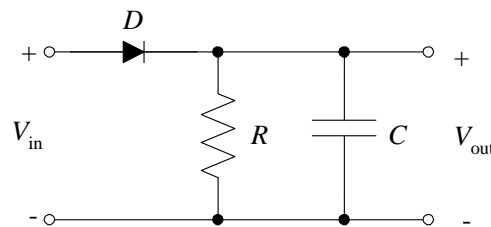


Modulation is the process of varying the radio frequency (RF) carrier in some manner as a means of conveying information. Here the information is conveyed in the amplitude of the carrier, which is why this is called **amplitude modulation**.

In the NorCal 40A, the carrier frequency $f \approx 7$ MHz.

In order for us to hear the information that is being conveyed by the RF signal, we must demodulate the signal.

A simple **detector** (an example of a demodulator) is shown in Fig. 2.29:



Actually, this is a nice example of a direct conversion receiver as discussed in Lecture 1.

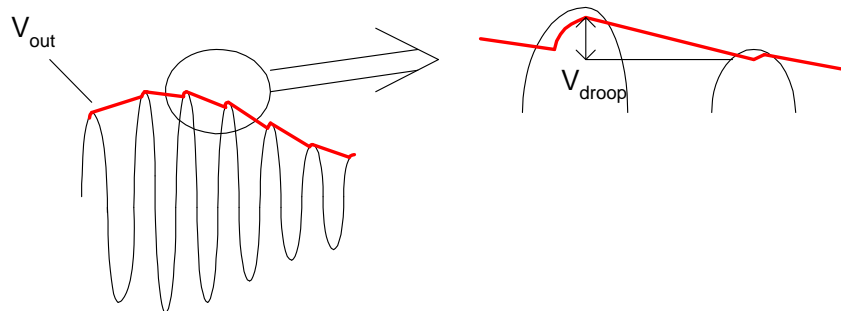
A detector is one “stage” or section in a receiver in which the modulation is recovered or extracted from the RF signal.

(Note that the NorCal 40A is a superhet receiver so the demodulation is a more complicated circuit than this simple diode detector.)

We begin with the modulated waveform in Fig. 1 fed to a detector as V_{in} . If $\tau = RC$ is much less than T_m and much greater than T_c

$$T_c \ll \tau \ll T_m$$

then V_{out} will appear as



V_{out} is a good approximation to $a(t)$, the modulating signal in (1).

In Prob. 4, you will directly generate an AM waveform using the Agilent AWG. It’s a very simple process. You need to specify only three parameters: the carrier frequency, the modulating waveform frequency and the percent modulation (from 0 to 120 %).

The circuit of Fig. 2.29 will be used to demodulate the signal. Note that in this problem, $D = 1N4148$ as listed in [Appendix A “Equipment and Parts.”](#) This appendix contains a lot of useful information concerning the end-of-chapter problems.