EEE118: Electronic Devices and Circuits

Lecture IIII

James E. Green

Department of Electronic Engineering
University of Sheffield
j.e.green@sheffield.ac.uk

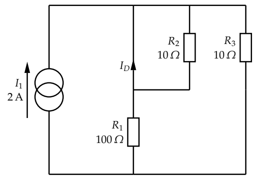
Last Lecture: Review

1. Defined some terminology (Bias, Signals, Passive and Active components)
2. Introduced Diodes as active components having a non linear relationship between voltage and current.
3. Briefly considered how a diode is constructed from semiconducting materials
4. Considered the effect of “forward” and “reverse” biasing a diode.
5. Constructed two linear models of the diode action under forward bias.
6. Defined three distinct states of conduction and non-conduction for a diode
7. Provided a general method for solving conduction state problems in diode circuits.
8. Started working through an example of a conduction state problem.

Outline

1. A Comprehensive Conduction State Example Part A – Continued
2. A Comprehensive Conduction State Example Part B
3. Homework 1
4. Other Types of Diodes
   - Light Emitting Diodes
   - Zener Diodes
   - Schottky Diodes
5. Review
6. Bear

Since superposition is being used, each of the sources must be considered individually and then their effects are combined. As before, choose to consider the current source, I_1, and switch off the voltage sources, V_1 and V_D. Replace both with short circuits.



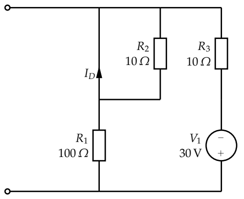
$$I_D = -I_1 \cdot \frac{R_3}{R_1 + R_3} \tag{1}$$

$$I_D = -2 \cdot \frac{10}{100 + 10} \tag{2}$$

$$I_D = -0.18\dot{1}\dot{8} \text{ A} \tag{3}$$

This is a slightly easier current divider problem than before. In potential dividers, larger resistances = larger share of the voltage. Potential dividers are series circuits driven by voltage sources.
In current dividers, smaller resistors = larger share of the current. Current dividers are parallel circuits driven by current sources.

The voltage source, V_1, which was previously replaced with a short circuit (its internal impedance) is now considered alone. I_1 and V_D are replaced by there internal resistances (open and short circuit, respectively).



$$I_D = \frac{V_1}{R_1 + R_3} \tag{4}$$

$$I_D = \frac{30}{100 + 10} \tag{5}$$

$$I_D = 0.27\dot{2}\dot{7} \text{ A} \tag{6}$$

This is a potential divider circuit containing two resistors. The voltage is shared according to the magnitude of the resistances. R_2 *is shorted, no current flows in it.*

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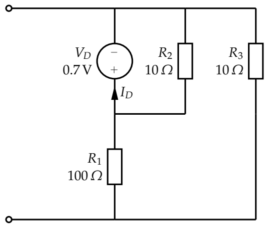

$$-I_D = \frac{V_D}{R_2} + \frac{V_D}{R_1 + R_3} \tag{7}$$

$$-I_D = \frac{0.7}{10} + \frac{0.7}{110} \tag{8}$$

$$-I_D = 70 + 6.36\dot{3}\dot{6} \text{ mA} \tag{9}$$

If R_1 and R_3 are combined (summed because they are in series), this problem reduces to two cases of Ohm’s law.

The contribution to current flow in the diode can be summed from the three circuit problems (one from each source I_1, V_1 & V_D) to yield the total current, I_D.

$$I_D = 0.2\dot{7}\dot{2}\dot{7} + (-0.18\dot{1}\dot{8}) + (-76.36\dot{3}\dot{6} \times 10^{-3}) \qquad (10)$$

$$I_D = 14.54\dot{5}\dot{4}\ \mathrm{mA} \qquad (11)$$

The negative signs are due to the direction of current as drawn on the diagrams. Remember that in power sources current flows in the same direction that the voltage faces but in other elements the direction of voltage and current oppose each other.

Part B.

What magnitude would V_1 have to be changed to in order that the diode would be on the point of conduction (0.7 V across but no current flowing)?

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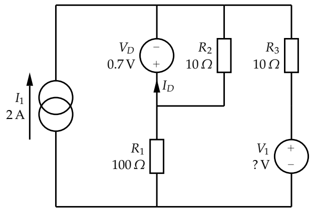
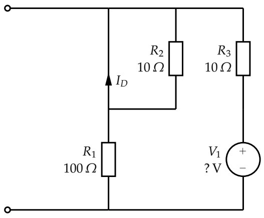


The solution of this problem requires the use of the on the point of conduction definition is used. The diode will have 0.7 V across it in the forward bias direction *and* no current will flow.



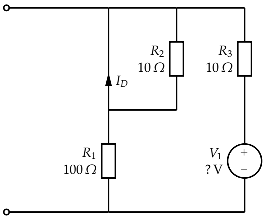
Superposition is used as before, but two of the results are already known.

I_D due to I_1 $\quad -0.18\dot{1}\dot{8}$ A

I_D due to V_D $\quad -76.36\dot{3}\dot{6}$ mA

$$I_D \text{ due to } V_1 = \left(0.18\dot{1}\dot{8} + 76.36\dot{3}\dot{6}\right) \text{ A}$$

Having decided the current that V_1 must provide just enough current to yield $I_D = 0$ A we can work backwards to find the magnitude of the voltage required.



$$I_D = \frac{V_1}{R_1 + R_3} \qquad (12)$$

$$V_1 = I_D\,(R_1 + R_3) \qquad (13)$$

$$= \left(0.18\dot{1}\dot{8} + 0.076\dot{3}\dot{6}\right) \cdot (100 + 10) \qquad (14)$$

$$= -28.4\ \mathrm{V} \qquad (15)$$

To yield 0.7 V forward bias across the diode and 0 A through the diode requires V_1 to have the value -28.4 V. Before leaving the question **consider if the answer to part B is consistent with the answer to part A**. The minus sign is required because the current - as we have defined it - is flowing into the source $(+)$

Homework 1

It is possible to fully attempt Homework 1 now. It is “due in” 14 days from today.

It is also possible to begin attemptting the Diode Conduction State problem sheet now.

Other Types of Diode

The silicon pn junction diode is the most commonly used diode. Several other types exist however, including:

1. Light Emitting Diodes (LEDs)
2. Zener Diodes
3. Schottky Diodes

Light Emitting Diodes

LEDs are found in many applications including indicators (on electronic equipment) and also in power applications such as room lighting. LEDs emit light when they are forward biased by a process known as electroluminescence. The electrons which are promoted into the conduction band in the n-type material recombine in the p-type material loosing their energy as photons. An LED is just a junction diode, but not made from silicon.

Because silicon is an indirect band-gap material electrons loosing energy must also undergo a change in momentum, this requires a phonon interaction. Both energy loss and momentum shift must happen simultaneously - it is very rare. Other quantum mechanical interactions are *much* more likely. In Si electrons tend to loose their energy without producing photons.

Direct band-gap materials including gallium arsenide (GaAs) gallium phosphide (GaP) and gallium nitride (GaN) among others[1] are used to produce light emitting diodes. In these materials no shift in momentum is required for the electrons to loose energy as they recombine and photons are a likely result of the recombination process. **LEDs obey the diode equation** but with differing constants from silicon.

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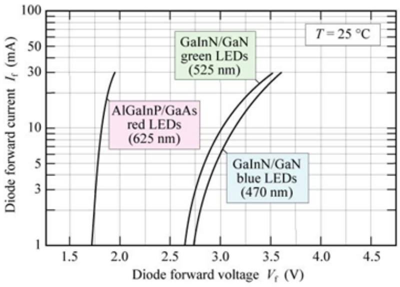
[1] `http://www.oksolar.com/led/led_color_chart.htm`

LED Current Voltage Characteristics

Current - voltage (IV) characteristics for several material systems are shown below[2]. It is common to limit the current (and hence power) dissipated in an LED by adding a resistance in series.



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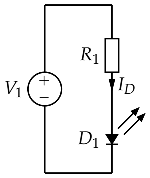
[2] see `http://www.lightemittingdiodes.org`

LED Example



Obtain the forward current (I_D) required to deliver the specified luminous output, and the forward voltage drop (V_D) from the device datasheet. The diode *is* conducting, replace it with a perfect voltage source, V_D. Compute the voltage remaining across R_1. Choose R_1 based on the desired current (I_D) by applying Ohm's law. Assume 600 mA is required and the forward voltage drop is 13 V (Sharp P/N: GW5BQF50K03, £10.50 + VAT) the module will run from a 24 V supply (V_1) which is already available.

$$V_R = V_S - V_D = 24 - 13 = 11 \text{ V} \tag{16}$$

$$R_1 = \frac{V_R}{I_R} = \frac{11}{0.6} = 18.3\dot{3}\ \Omega \tag{17}$$

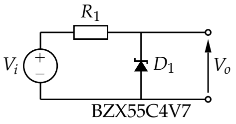
$$P_{R_1} = I^2 R = 0.6^2 \cdot 18.3\dot{3} = 6.6 \text{ W} \tag{18}$$

Zener Diodes

Zener diodes are designed to be operated in reverse breakdown (but can also operate in forward bias). They are designed with a particular breakdown voltage and are sold accordingly. Having broken down the reverse voltage increases very little as reverse current increases. The usual diode model applies but where V_D is replaced with the breakdown voltage. The Zener diode is often used as a voltage reference and in circuits where stabilisation of a DC supply is required.

Breakdown voltage from 3 V to 300 V at power ratings of ∼mW to 100 W are available. Breakdown voltage tolerance of 5% is common.

The Zener (Clarence Zener, 1905 – 1993) effect is another name for quantum mechanical (QM) tunnelling, however most Zener diodes do not operate by QM tunnelling but rather by impact ionisation (II). The Zener effect is dominant in devices where the breakdown voltage is below 5 V and impact ionisation is dominant in devices which breakdown at higher voltages. The temperature coefficient of breakdown voltage is negative for the QM tunnelling and positive for II (in Si). In devices with a breakdown voltage of 4.7 - 6 V the two temperature coefficients nearly cancel. Engineering a circuit design to make use of this particular breakdown voltage range is wise in situations where the circuit performance as a function of temperature is critical.



Schottky Diodes

- Metal - semiconductor junction devices.
- Construction is different to pn devices but circuit characteristics are similar.
- The metal semiconductor junction usually has a lower turn on voltage than pn diodes, values from 0.2 V to 0.6 V are common.
- Schottky[3] diodes use only one type of semiconductor (usually n-type). This allows them to switch faster and sustain greater current densities.

- Radio frequency circuits, up to 100 GHz, where high speed is critical.
- High efficiency applications (e.g. switch mode power supplies)
- Fast voltage clamp circuits, for prevention of transistor saturation.

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[3] Walter H. Schottky, 1886 – 1976

Review

1. Finished the diode conduction state example question from lecture four.
2. Introduced the Light Emitting Diode (LED) and direct *vs.* indirect band-gap.
3. Performed a calculation to set the operating point of the LED.
4. Introduced the Zener Diode and considered the Zener effect and Impact Ionisation.
5. Very briefly considered a voltage regulating circuit using a Zener diode. (more later)
6. Introduced the Schottky Diode.