EEE118: Electronic Devices and Circuits

Lecture IIII

James Green

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

25th November 2012

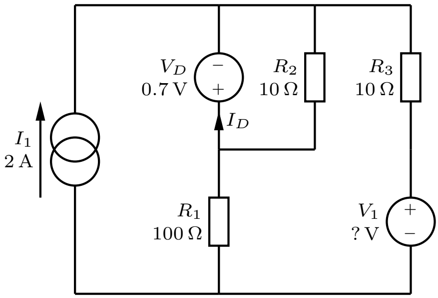
Last Lecture: Review

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. Worked through an example of a conduction state problem.

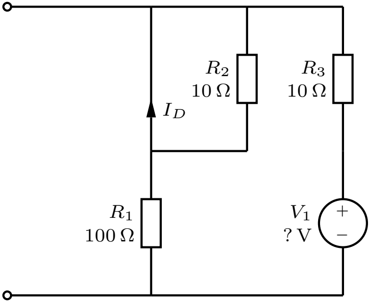
Outline

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)?



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.

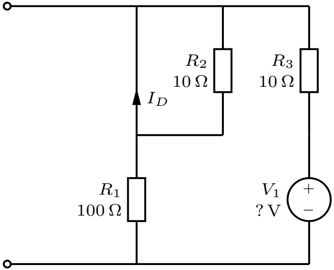


Superposition is used as before, but two of the results are already known.

I_D due to I_1	$-0.18\dot{1}\dot{8}$ A
I_D due to V_D	$-76.36\dot{3}\dot{6}$ mA

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

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.



$$I_D = \frac{V_1}{R_1 + R_3} \quad (1)$$

$$V_1 = I_D\,(R_1 + R_3) \quad (2)$$

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

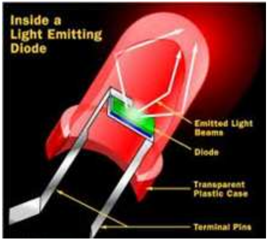
$$= -28.4 \text{ V} \quad (4)$$

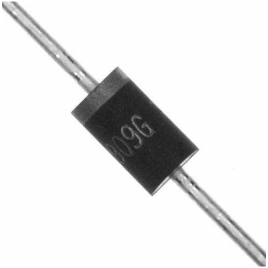
To yield 0.7 V forward bias across the diode and 0 A through the diode requires V_1 to have the value -28.4 V. Before leaving the question **consider if the answer to part B is consistent with the answer to part A**. The minus sign is required because the current - as we have defined it - is flowing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

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.

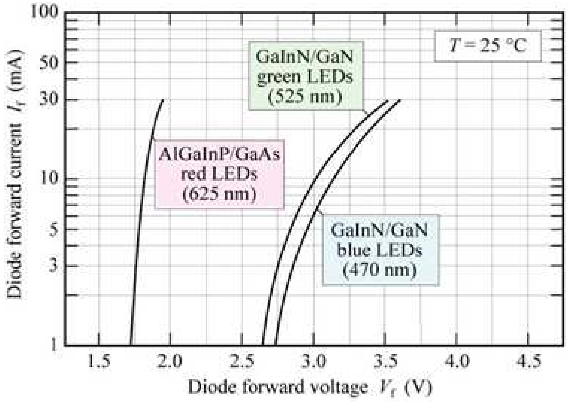
Because silicon is an indirect band-gap material electrons loosing energy must also undergo a change in momentum, this requires a phonon interaction. Both energy loss and momentum shift must happen simultaneously - it is very rare. Other quantum mechanical interactions are *much* more likely. In Si electrons 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.

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

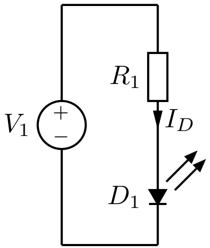
LED Current Voltage Characteristics

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.



[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.

$$V_R = V_S - V_D = 24 - 13 = 11 \text{ V} \tag{5}$$

$$R_1 = \frac{V_R}{I_R} = \frac{11}{0.6} = 18.3\dot{3}\ \Omega \tag{6}$$

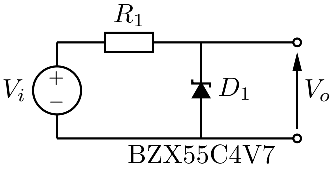
$$P_{R_1} = I^2 R = 0.6^2 \cdot 18.3\dot{3} = 6.6 \text{ W} \tag{7}$$

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[3] 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.



[3] Clarence Zener, 1905 - 1993

Schottky Diodes

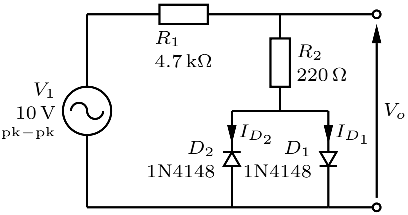
- Metal - semiconductor junction devices.
- Construction is different to pn devices but circuit characteristics are similar.
- The metal semiconductor junction usually has a lower turn on voltage than pn diodes, values from 0.2 V to 0.6 V are common.
- Schottky[4] diodes use only one type of semiconductor (usually n-type). This allows them to switch faster and sustain greater current densities.

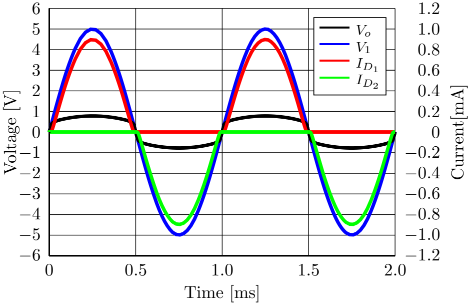
- Radio frequency circuits, up to 100 GHz, where high speed is critical.
- High efficiency applications (e.g. switch mode power supplies)
- Fast voltage clamp circuits, for prevention of transistor saturation.

[4] Walter H. Schottky, 1886 – 1976

Conduction State Problems with Variable Sources

Some circuits are driven by large amplitude signals. Occasionally the circuit conditions vary so greatly depending on the signal that diodes are switched on and off by the effects the signal has on the surrounding circuit. This is sometimes called large signal analysis. Because the signals are sufficiently large to adjust the operating point or quiescent conditions.





What does this circuit do? What applications does it have?

Applications of this Circuit

This is a kind of limiting circuit. It is one of the simplest in a class of wave-shaping circuits that will be considered further in this course and again in Analogue and Switching Circuits (EEE340).

Description of Operation

The voltage at the output is limited to the sum of the voltage drop of the forward biased diode and the voltage dropped across R_2 due to the current flowing in it. Provided the input voltage is greater than +0.7 V or less than -0.7 V, one of the diodes will be conducting.

Assuming V_1 is a good approximation to Button V_o will sound something like Button .

Increasing the amplitude of the input signal causes the limiting to become more pronounced. Increasing the value of R_1 or reducing the value of R_2 would have similar overall results.

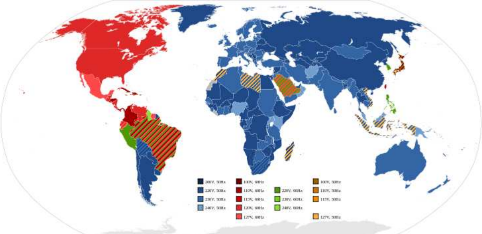
Five Diode Circuits

Five common circuits consisting of resistors capacitors and diodes will be examinable in this course, including:

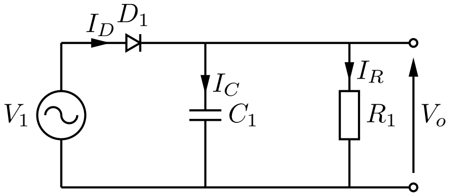
1. Peak detector
   - e.g. AM radio demodulator
2. Voltage clamp
   - e.g. Preventing switching transistor saturation, distorting guitars etc.
3. Voltage multiplier
   - AC to DC conversion with doubling, many specialist PSU applications.
4. Diode rectifier circuit (three types of power supply)
   - Half-wave (one diode)
   - Full-wave (two diode)
   - Bridge (four diode)
5. Zener diode voltage regulator
   - Stabilise DC voltages having a small AC component or ripple

Peak Detector

One of the commonest applications of diodes is the conversion of an alternating current into a unidirectional current. This conversion process occurs in the signal detector parts of radio based systems and in power supplies designed to convert power from an alternating current distribution system - such as the UK's 50 Hz land based power distribution system or the 400 Hz distribution systems found in marine and airborne applications - into a good quality direct current source for electronic circuitry. Signal based applications of rectifiers will be discussed first.



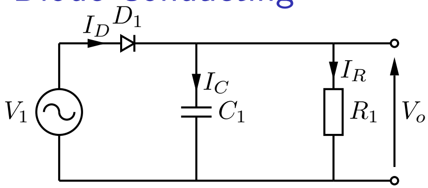
Peak Detector



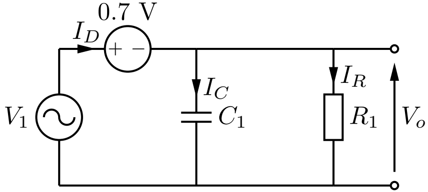
The key elements of source, V_1, diode, D_1, and capacitor, C_1, are connected in series and it is quite common to find a resistor, R_1, in parallel with the capacitor. The source may be a transformer secondary as is common in radio circuits or an amplifier output as is more typical of instrumentation systems. The circuit has two distinct states based on the conduction or non-conduction of the diode.

1. The diode is conducting (above), capacitor charges
2. The diode is not-conducting (shortly), capacitor discharges

Peak Detector - Diode Conducting

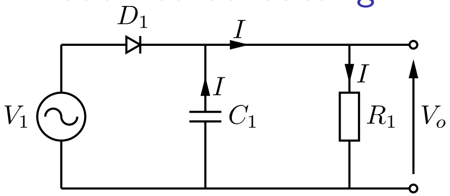


Since the diode is conducting, replace with 0.7 V source.

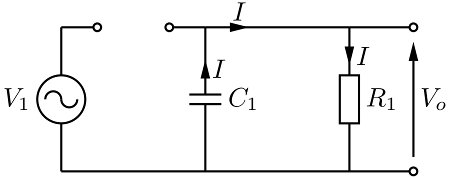


The diode current charges C_1, and dissipates power in R_1. The charging current is limited by the diode series resistance. The voltage on C_1 can not increase above $V_1 - 0.7$.

Peak Detector - Diode Not Conducting

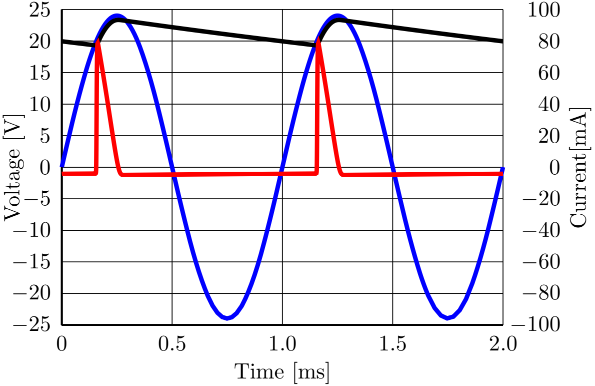


Since the diode is not conducting, replace with open circuit



C_1 discharges through R_1. Voltage across C_1 falls as discharge proceeds. The shape of V_o is often a good approximation to a triangular waveform.

Peak Detector Graph



V_1: Blue, V_o: Black, I_{C_1}: Red

The integral of the capacitor current (area under the graph) sums to zero in one whole cycle.

Review

1. Finished the conduction state example from lecture three.
2. Introduced the 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.
7. Inspected a circuit with time dependent sources.
8. Considered an application of that circuit (A voltage clamp, more later).
9. Begun looking at five examinable diode circuits, starting with the peak detector.