EEE118: Electronic Devices and Circuits

Lecture X

James Green

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

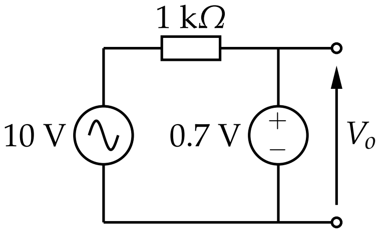
Review

- Reviewed the principle of operation of Zener diodes (impact ionisation).
- Used the device (diode) characteristic to examine the operating point and linearity of a circuit.
- Introduced the Zener diode shunt regulator circuit.
- Provided a method for designing the component values of the regulator.
- Introduced the idea of small signals and large signals.
- Considered the effects of distortion that large signals experience due to the non-linear nature of the diode characteristic with an audio example.

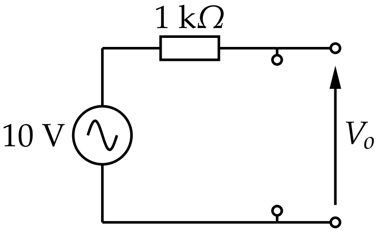
Outline

Circuit Linearisation

Diode Conducting:



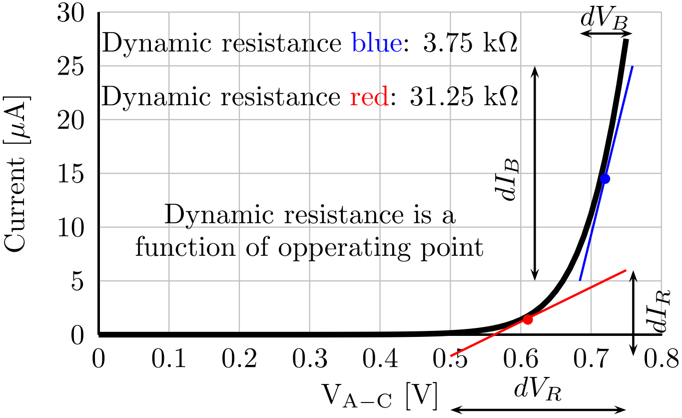
Diode Not Conducting:



In this model the diode is a perfect voltage source (0.7 V) with no internal resistance. The model can be improved by the addition of a resistance in series with the voltage source - remember Thévenin...

Diode with Internal Resistance

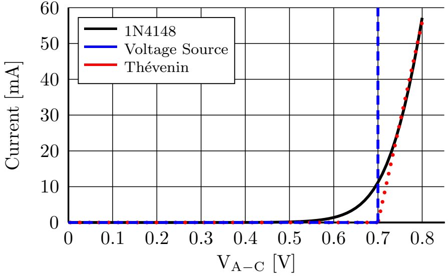
The diode has an internal series resistance, which is proportional to the slope of its characteristic.

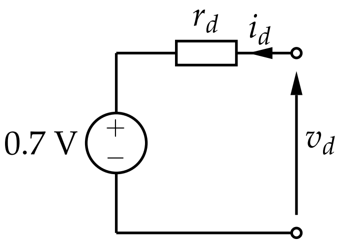


The internal series resistance depends on the current flowing through the diode. The series resistance is changing *continuously*,

Diode with Internal Resistance Model

Adding a constant resistance in series with the voltage source improves the accuracy of the diode model, but the diode resistance changes with diode current so many different values of resistor may be needed. We use a fixed resistor based on the operating point or quiescent conditions. It is important that the signal is *small* with respect to the quiescent conditions otherwise the use of a single value of resistor will not accurately represent the diode operation.

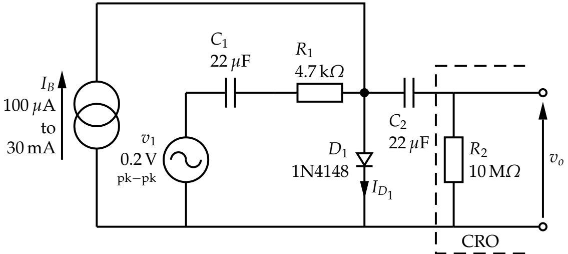




Example Small Signal Diode Application

Problem

Your friend is watching TV in the next room. You can hear the TV all the time but the adverts are louder than the normal programming. It's the adverts that are disturbing your thoughts while attacking a particularly difficult EEE118 problem sheet. Your friend is unwilling to turn the TV down, so you decide to build a circuit to automatically control the volume of the TV to a constant level.



The Components

Name	Purpose
I_B	Sets the operating point of the diode.
v_1	The TV audio output.
C_1	A capacitor to block any DC voltage from the TV which might bias the diode.
R_1	The upper resistor in a potential divider.
D_1	The lower (small signal) resistor in a potential divider.
C_2	A capacitor to block the $\sim$0.7 V across the diode from passing a current into the oscilloscope (CRO).
R_2	A simple approximation to an oscilloscope probe.

How Does It Work?

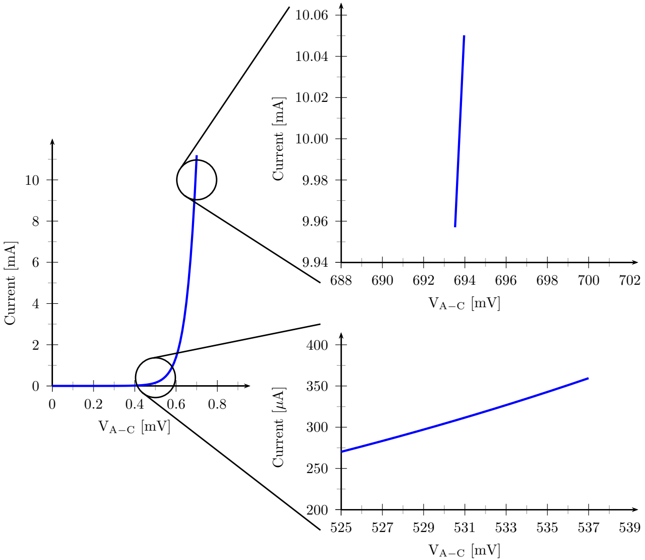
The diode dynamic or incremental or small signal resistance (r_d) varies according to the current flowing through the diode (D_1). The quiescent current in the diode is simply I_B. We aim to make the signal current small with respect to I_B in order that r_d will vary only with I_B. A voltage will appear across D_1 which is sufficient to sustain the current flowing in it. It will be approximately 0.7 V. The value of I_B should be set by the average amplitude of the TV output (perhaps by using a peak detector with a long time constant, but this is ignored, for now...). When the TV volume is "loud" I_B will be larger and so r_d will be smaller and will drop a smaller share of the TV's sound signal. Since r_d is the lower leg of the potential divider - across which the output is taken - the volume will be reduced. This is an example of feedback.

Two Operating Points

We will inspect two examples at different values of I_B to observe the effect on the value of r_d and the output of the circuit. The total diode current is the sum of the quiescent current (I_B) and the current flowing in the potential divider due to v_1.

The linearisation of the circuit requires that the signal current due to v_1 does not change the total current so much that the exponential shape of the diode's IV characteristic becomes significant. To ensure the Thévenin model of the diode holds the diode characteristic must approximate a straight line.

Example Diode Characteristic at Two Operating Points



I_B Small: Calculate Some Important Parameters

We would like to know the small signal resistance of the diode,

$$\frac{\Delta I}{\Delta V} = \frac{1}{r_d} \tag{1}$$

$$\frac{1}{r_d} = \frac{360\ \mu\mathrm{A} - 271\ \mu\mathrm{A}}{538\ \mathrm{mV} - 525\ \mathrm{mV}} \tag{2}$$

$$r_d = 146\ \Omega \tag{3}$$

And the total *signal* current,

$$r_{total} = 4.7\ \mathrm{k}\Omega + 146\ \Omega \tag{4}$$

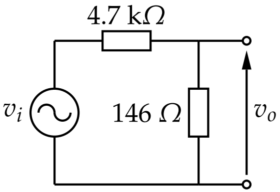
$$= 4846\ \Omega \tag{5}$$

$$i = \frac{v}{r} = \frac{0.2}{4846} \tag{6}$$

$$= 41.2\ \mu\mathrm{A}_{\mathrm{pk-pk}} \tag{7}$$

I_B Small: Small Signal Equivalent Circuit

The small signal equivalent circuit is a circuit diagram which shows only the circuit components that influence what happens to the signal. It is how the signal "sees" the circuit.



$$\frac{v_o}{v_i} = \frac{146}{4700 + 146} \tag{8}$$

$$\approx 0.03\ \frac{\mathrm{V}}{\mathrm{V}} \tag{9}$$

I_B Large: Calculate Some Important Parameters

We would like to know the small signal resistance of the diode,

$$\frac{\Delta I}{\Delta V} = \frac{1}{r_d} \tag{10}$$

$$\frac{1}{r_d} = \frac{10.8\ \mathrm{mA} - 9.2\ \mathrm{mA}}{698\ \mathrm{mV} - 690\ \mathrm{mV}} \tag{11}$$

$$r_d = 5\ \Omega \tag{12}$$

And the total *signal* current,

$$r_{total} = 4.7\ \mathrm{k}\Omega + 5\ \Omega \tag{13}$$

$$= 4705\ \Omega \tag{14}$$

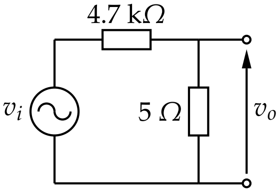
$$i = \frac{v}{r} = \frac{0.2}{4705} \tag{15}$$

$$= 42.5\ \mu\mathrm{A}_{\mathrm{pk-pk}} \tag{16}$$

Note, making R_1 much larger than r_d controls r_{total} and so keeps the peak to peak value of i almost constant.

I_B Large: Small Signal Equivalent Circuit

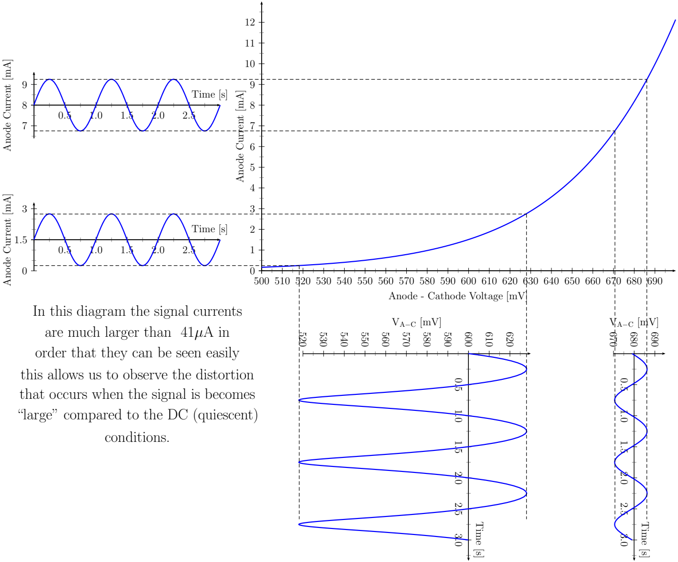
The small signal equivalent circuit has a new value for r_d. Note that the quiescent conditions don't appear in the small signal circuit. Only linear components (R, L, C and Sources) appear in small signal circuits.



$$\frac{v_o}{v_i} = \frac{5}{4700 + 5} \tag{17}$$

$$\approx 0.00106 \ \frac{\mathrm{V}}{\mathrm{V}} \tag{18}$$

Representing Everything on the Characteristic



In this diagram the signal currents are much larger than $41\mu A$ in order that they can be seen easily this allows us to observe the distortion that occurs when the signal is becomes "large" compared to the DC (quiescent) conditions.

Transistor Definition

Definition

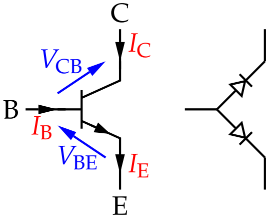
A transistor is a three terminal semiconductor electronic device which is capable of power amplification.

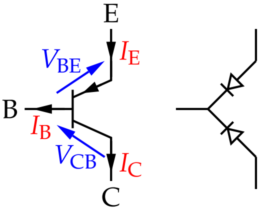
Different from a transformer or resonant circuit which can only increase the amplitude of current *or* voltage. Several different kinds of transistor exist (BJT, MOSFET, JFET) and Valves.

- BJT is the most common small signal amplifier.
- MOSFETs are more common in large signal applications such as switching power supplies.
- MOSFETs also find use in integrated circuits (producing them on a semiconductor wafer is easy c.f BJT).
- JFETs are found in ICs but are also used as discrete devices.
- Thermionic valves are limited to specialist applications (e.g. high power microwave generation, radio and RADAR transmission, specialist audio applications.)

Bipolar Junction Transistor

The bipolar transistor[1] was invented by John Bardeen, Walter Brattain and William Shockley in the late 1940s at Bell Labs. Read: `http://dx.doi.org/10.1109/5.658752`. They shared the 1956 Nobel Prize. The BJT is a semiconductor device composed of three semiconductor regions N-P-N or P-N-P named Emitter (E), Base (B) and Collector (C). The NPN can be thought of as two diodes with their anodes connected together. The PNP, two cathodes connected.





Why can't two diodes be used to make a transistor?

[1] from "transfer-resistor"

JEDEC Numbering System

At least three numbering systems exist but not all part numbers apply the rules, JIS, Pro Electron and JEDEC.

- JEDEC the The Joint Electron Devices Engineering Council was formed in 1958 as a part of the Electronic Industries Association (EIA).
- It standardises semiconductor part numbers used in the USA.
- The code is [Number] 'N' [Serial Number] [Suffix Optional].
- Where, 1 - Diode, 2 -Transistor, 3 - Dual-Gate, 4 - Optocoupler (LED + photo diodes), 5 - Optocoupler (LED + Transistor).
- The suffix is optional and is A - low gain, B - medium gain and C - high gain.
- e.g. 2N3904 and 2N2222 are transistors. 1N4148 and 1N4007 are diodes.

Pro Electron Numbering Systems

- European Numbering or "Pro Electron" system. Designated by the European Electronic Component Manufacturers Association of which Pro Electron has been a part since 1983.
- The code is [Letter] [Letter] [Serial Number]
- First letter is A, B, C or R - depends on band-gap
- Second letter indicates device function or application.
- Serial number is an identifier for the device
- e.g. BC182 (Silicon, low power audio frequency transistor) BZX55C4V7 (Zener Diode)
- See handout for full details.

Review

- Introduced the idea of a dynamic resistance or small signal resistance.
- Compared the voltage source model and thévenin model of a diode.
- Considered how capacitors can be used to block quiescent conditions (DC) but pass signals (AC).
- Introduced the idea of a small signal equivalent circuit - How the signal "sees" the circuit.
- Introduced the bipolar transistor.
- Briefly discussed two numbering systems for active devices.