EEE118: Electronic Devices and Circuits

Lecture IX

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EEE118. “Electronic Devices and Circuits”

Part 2: Spring Semester

- Lecture 8. - There is no lecture 8!
- Lecture 9. (Today) A last word on Diodes

Prof. Houston takes over for about 7 weeks.
But after that I’m back to round off with,

- Lecture 10. Transistors
- Lectures 11. & 12. Switching Applications of Transistors
- Lecture 13. CMOS
- Lectures 14. & 15. Amplifying Applications of Transistors
- Lectures 16 & 17. Two Single Transistor Amplifier Circuits
- Lectures 18 & 19. Small Signal Anaysis of Transistor Circuits
- Lectures 20 & 21. Operational Amplifiers
- Lecture 22 & 23. Review and Exam Tips

Outline

Signals

In circuits that include active devices (diode, transistors etc.), signals may be considered "large" or "small".
In this course,

Large Signal

If the signal amplitude is the same order of magnitude as the turn on voltage of an active device the signal is "large".

Small Signal

If the signal amplitude is much smaller than the turn on voltage of an active device the signal is "small".

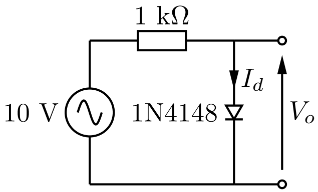
Consider a silicon diode which begins conducting at 0.7 V...

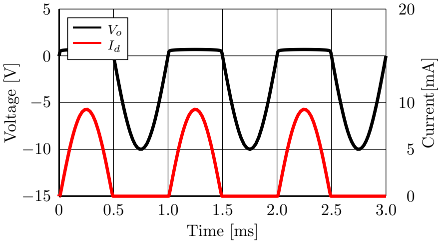
Example of a Circuit with a Large Signal

- The amplitude ("height") of the signal determines how the circuit is analysed.
- If the active devices behave nearly linearly over the range of signal excursion, the circuit can be *linearised* into a single circuit.
- If the active devices behave non-linearly over the range of signal excursion, the circuit may be linearised into several different circuits each having different model parameters for the active device(s).

Typical Simple Conduction State Problem

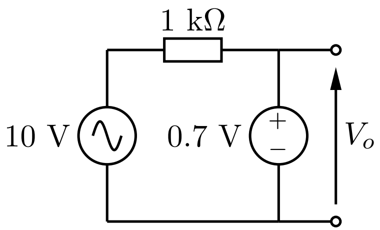
Before the holidays we looked at conduction or non-conduction only. In the circuit below the diode enters conduction when the 10 V source rises above +0.7 V. Otherwise the diode is not conducting.



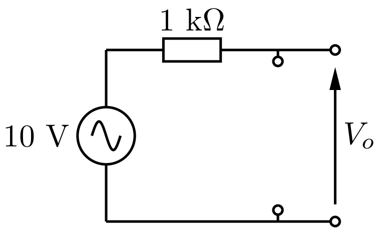


Circuit Linearisation

Diode Conducting:



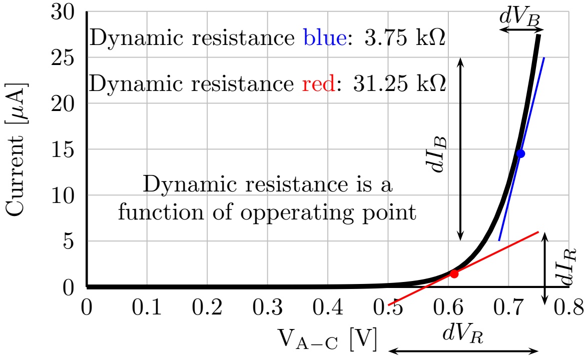
Diode Not Conducting:



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

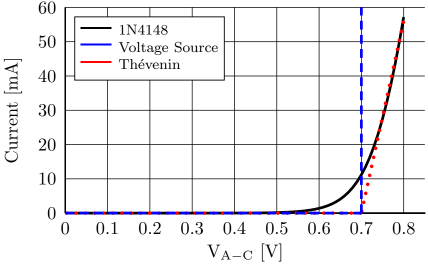
The diode has an internal series resistance, which is proportional to the slope of its characteristic.

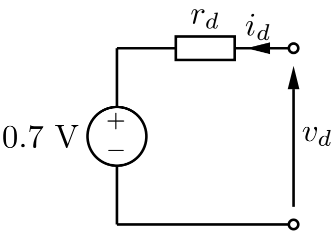


The internal series resistance depends on the current flowing through the diode. The series resistance is changing *continuously*, but over a *small region* it is nearly constant.

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.

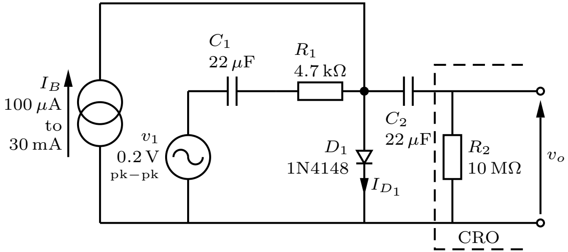




Example Small Signal Diode Application

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?

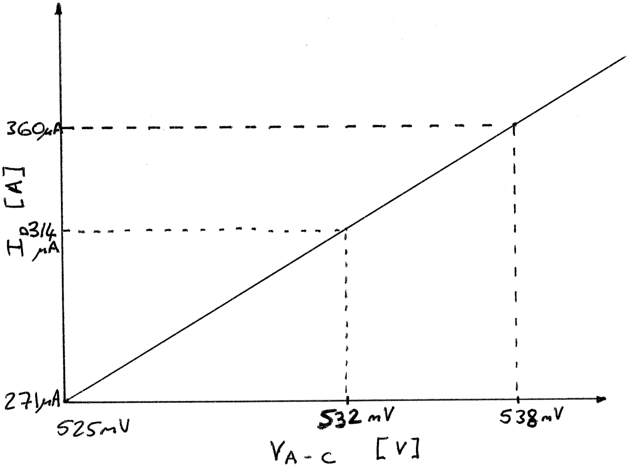
The diode dynamic or incremental or small signal resistance (r_d) varies according to the current flowing through the diode (D_1). The quiescent current in the diode is simply I_B. A voltage will appear across D_1 which is sufficient to sustain the current flowing in it. It will be approximately 0.7 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 when I_B is 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,

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

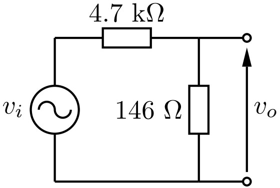
$$= 4846\ \Omega \tag{5}$$

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

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

Small Signal Equivalent Circuit

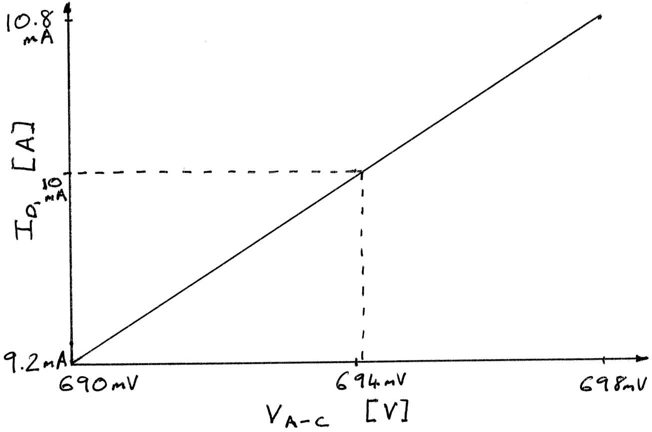
The small signal equivalent circuit is a circuit diagram which shows only the circuit components that influence what happens to the signal. It is how the signal "sees" the circuit.



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

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

Example Diode Characteristic when I_B is 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,

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

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

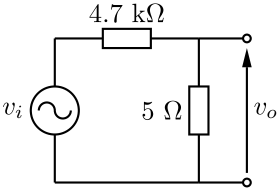
$$i = \frac{v}{r} = \frac{0.2}{4705} \tag{15}$$

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

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

Small Signal Equivalent Circuit

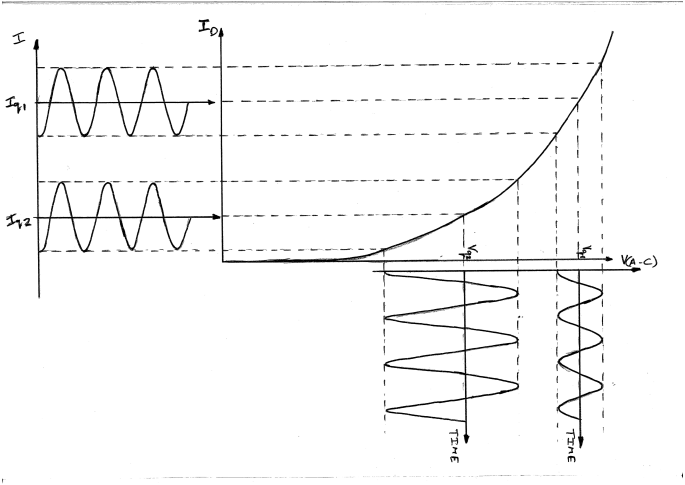
The small signal equivalent circuit has a new value for r_d. Note that the quiescent conditions don't appear in the small signal circuit. Only linear components (R, L, C and Sources) appear in small signal circuits.



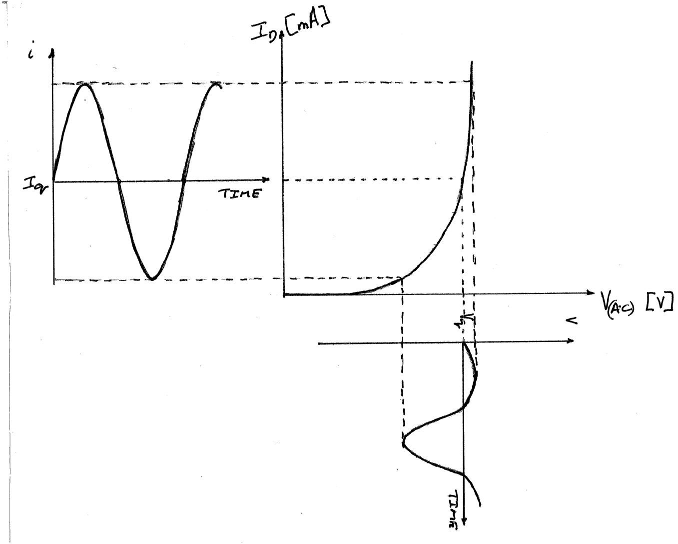
$$\frac{v_o}{v_i} = \frac{5}{4700 + 5} \tag{17}$$

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

Representing Everything on the Characteristic



What happens if v_1 is a "large" signal



Review

- Introduced the idea of small signals and large signals.
- 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.
- Used the device (diode) characteristic to examine the operating point and linearity of a circuit.

All of this builds towards analysis of transistor circuits.