

Diode models

day12 - Dan White <dan.white@valpo.edu>

1. Circuit I/V models

Many times it is not necessary to solve for the exact diode voltage and current with the Shockley equation. Instead, a simpler model provides adequate and much quicker results. The *constant-voltage* model provides a good balance between accuracy and analysis ease—it is our most frequently used model. Its behavior can be classified into two states:

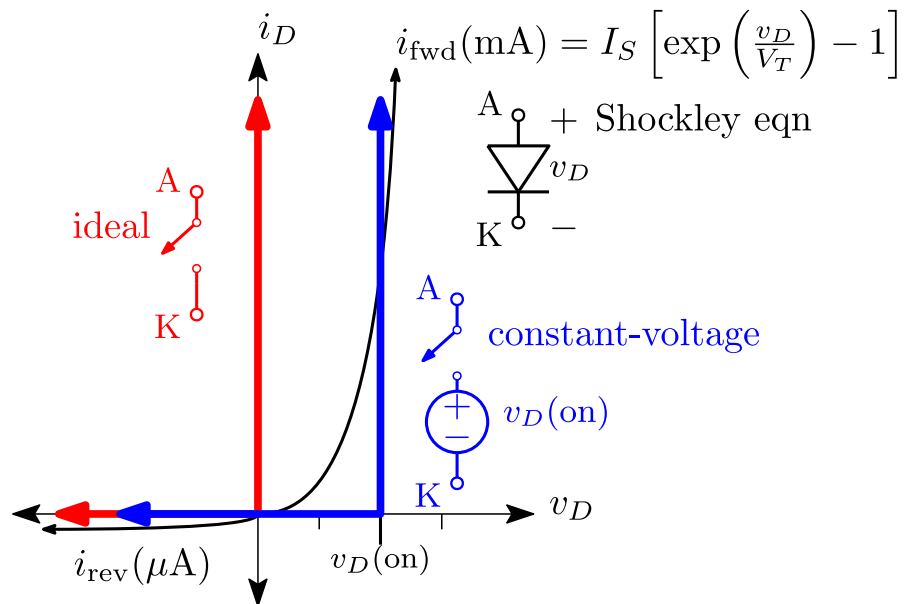


Figure 1. Comparing curves for three diode models

Forward bias (ON)

- $v_D = v_D(on) \approx 0.6$ V.
This value depends on the general magnitude of forward currents expected and the diode type (silicon 400-800 mV, germanium 200-400 mV, Schottky 100-500mV, etc.).
- Check: $i_D \stackrel{?}{\geq} 0$. Positive is good. If zero, you may need to use a better model.

Reverse bias (OFF)

- $i_D = 0$
- Check: $v_D \stackrel{?}{\leq} v_D(on)$. Usually *negative* or zero. If in range $[0 \dots v_D(on)]$, you may need to use a better model since this is the range of worst error for this simple model.

Analyzing a circuit with diodes is then an iterative process of finding the ON/OFF states of the diodes at each time and replacing with the appropriate model. This process becomes quick with practice and helps to understand the overall operation of a circuit.

- ☐ **Guess** the state of each diode
- ☐ **Analyze** the circuit for the diode currents and voltages using the selected models
- ☐ **Check** the values against the model validity V / I conditions
- ☐ **Repeat** until *all* checks pass simultaneously

2. Simulator model

Figure 2 shows the usual model that a circuit simulator uses for finding the current through a diode. It includes the effects of junction and diffusion capacitances, bulk series resistance, and temperature (including I_S 's dependence).

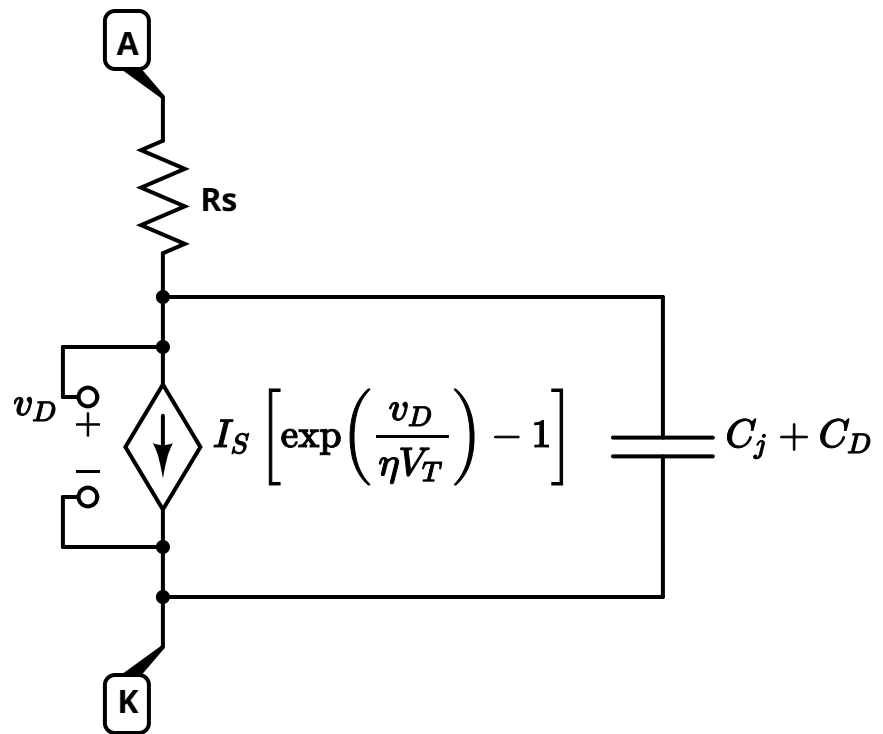


Figure 2. SPICE diode model

$$C_j = \frac{C_{j0} A}{\left(1 - \frac{v_D}{V_0}\right)^m} \text{ for } i_D \leq 0 \quad (1)$$

$$C_D = \frac{\tau_T}{\eta V_T} i_D \text{ for } i_D \geq 0 \quad (2)$$

This model is “ok” for hand-solving a one-diode circuit, and no problem for a SPICE simulation, but a **total nightmare** for hand-solving a circuit with two or more diodes!

An engineer would choose to analyze a circuit *by hand* in order to:

- understand** a circuit's operation
- to develop **intuition** and so be able to
- predict** its general behavior under various inputs and other conditions.

“SPICE gives **numbers** not **intuition**

— Dr. White

3. Ideal diode

The simplest possible description of a diode's behavior is:

- When *current* flow is positive, the diode behaves like a short-circuit.
- When the *voltage* is negative, the current is zero.

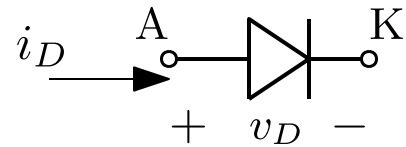


Figure 3. Direction and polarity

This is a **one-way valve** for current.

“on” state $v_D = 0$ and $i_D > 0$... a short-circuit

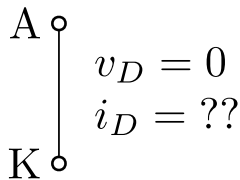
“off” state $v_D \leq 0$ and $i_D > 0$... an open-circuit

The **bold** inequalities indicate which values of diode current or voltage are set by the rest of the circuit. This is the same way that you can't know a voltage source's current by looking at only the source—it depends on what it's connected to.

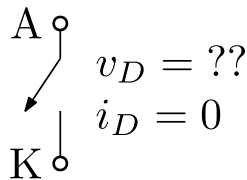
A circuit symbol for this is a single-pole single-throw (SPST) switch whose state depends on the local conditions.

▼ (draw this for the ON and OFF states)

ON



OFF



The important observation is that these two models are each individually **linear**. HOWTO use this model when analyzing a circuit with diodes:

- **Guess** a state for the diode: on/off
- **Replace** the diode symbol with either a short- or open-circuit. Keep the A/K terminals and don't collapse the wire so that you can still find the current through the device model.
- **Solve** the circuit using normal linear circuit analysis tools.
- **Check** that v_D or i_D are consistent with your guess.
 - If not, then switch the guess to the other state and re-analyze.

3.1. Example 1

Find the DC solution of this circuit (all voltages and currents). Use the *ideal* model and OFF for your first guess.

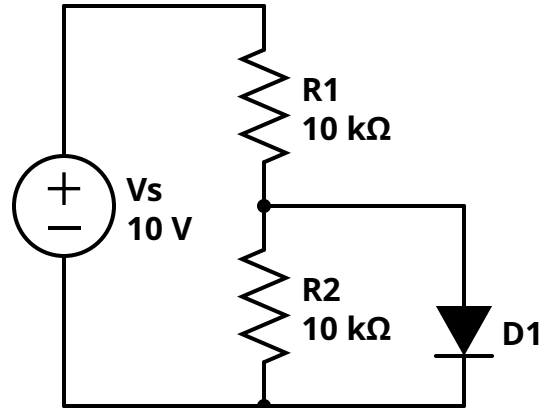


Figure 4. Practice circuit 1

3.2. Example 2

Find the DC solution of this circuit (all voltages and currents). Use the *ideal* model and 0N for your first guess.

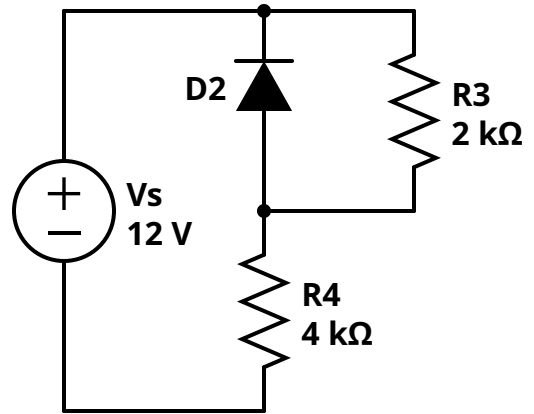


Figure 5. Practice circuit 2

4. Constant voltage model

Go back and look at Figure 1 again.

- The black curve represents the actual I/V curve for a diode.
- The red curve is the I/V curve for the ideal one-way valve or switch model.
- The blue curve is a better match to the actual I/V curve.

The blue model is the **constant voltage** model and simply adds a voltage source in series with the one-way valve switch.

One important thing to remember is that the internal voltage source must *always absorb power*. This is easy to ensure by making sure that the diode current is always positive, which is true when the device is **forward-biased**.

4.1. Example 3

Find the DC solution of this circuit (all voltages and currents). Use the *constant voltage* model and your own guess.

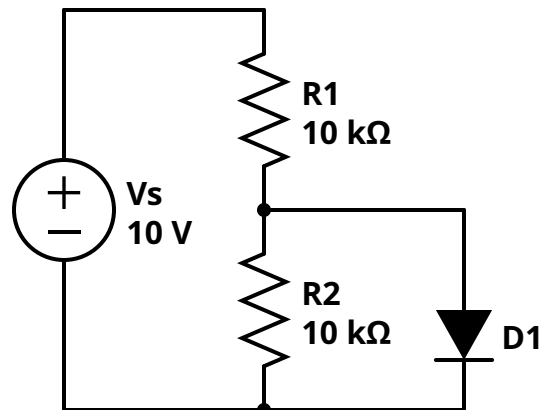


Figure 6. Practice circuit 1

4.2. Example 4

Find the DC solution of this circuit (all voltages and currents). Use the *constant voltage* model and your own guess.

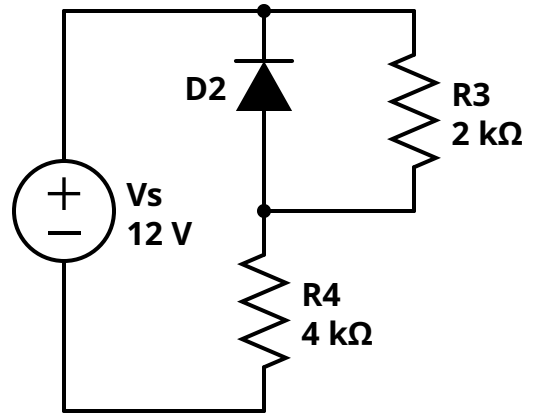


Figure 7. Practice circuit 2