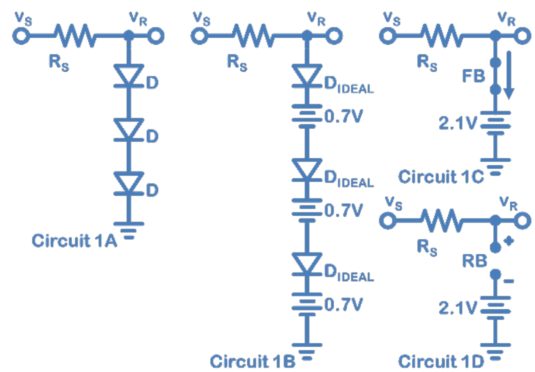
EECS 312 – Electronic Circuits I –Notes

Carl Leuschen – Spring 2023

The Voltage Regulator and Modeling the Diode Resistance



Circuit 1A shows a 2.1V regulator using 3 diodes in series. The circuit is modeled using the 0.7 CVD model in 1B, and Circuits 1C and 1D show the circuits used for finding the transfer function for both FB and RB.

$v_R(v_S)$ = 2.1 V, for v_S>2.1 V

$v_R(v_S)$ = v_S, for v_S<2.1 V

Based on this analysis, the regulator behaves ideally as long as the source voltage, v_S, is greater than 2.1 V. For v_S>2.1 V, the regulated voltage, v_R, stays steady at 2.1 V regardless of any noise or spikes on the source voltage.

However, measurements of an actual regulator constructed with real diodes does not show this ideal behavior, and there will be some variation in the regulated voltage due to a change in the source voltage. This relationship ($\Delta v_R/\Delta v_S$) is referred to as **line regulation** and has an ideal value of 0 (what the analysis using CVD model shows, but not with the actual device).

The Question: *Why does the actual circuit show a change in the regulated voltage with a change in the source voltage when CVD analysis does not show this behavior?*

The Answer: *Because the CVD model is a simplified and does not account for the slope of the exponential i-v characteristic in forward bias.*

The Problem: *The CVD model is not good enough to account for how the diode reacts to small variations in the circuit, but the exponential model is too complicated to use for circuit analysis.*

The key feature missing in the CVD model is the slope of the exponential characteristic near the operating point of the diode (V_D,I_D). A slope in the i-v relationship is modeled using a resistor, r_d.

The Solution: *A small resistor, r_d, is added in series with the CVD model (total of $3r_d$ since there are 3 diodes). A more accurate transfer function $v_R(v_S)$ is obtained.*

$$v_R(v_S) = 2.1 + \frac{3r_d}{R_S + 3r_d}(v_S - 2.1) \quad \text{for} \quad v_S > 2.1, \quad \text{and} \quad v_R(v_S) = v_S \quad \text{for} \quad v_S < 2.1$$

Here we see that $\Delta v_R/\Delta v_S = 3r_d/(R_S+3r_d)$. The value of r_d is determined by evaluating the slope of our exponential model at the CVD operating point (V_D,I_D). For this case,

CVD analysis: $I_D = \frac{(v_S - 2.1)}{R_S}$ *no resistor r_d included*

Slope (di_D/dv_D): $\frac{di_D}{dv_D} = \frac{I_S e^{\frac{v_D}{nV_T}}}{nV_T}$

Evaluated at I_D: $\left.\frac{di_D}{dv_D}\right|_{(V_D,I_D)} = \frac{I_S e^{\frac{V_D}{nV_T}}}{nV_T} = \frac{I_D}{nV_T}$

Resistance (1/slope): $r_d = \frac{nV_T}{I_D} = \frac{R_S nV_T}{(v_S - 2.1)}$ *refine the CVD model by adding r_d*

Values of R_S = 1 kΩ, n = 2, and v_S = 3.5 V results in r_d = 35.7 Ω and a line regulation of $\Delta v_R/\Delta v_S$ = 0.096.