Lecture 12, Oct 18, 2023

Regulator Circuits

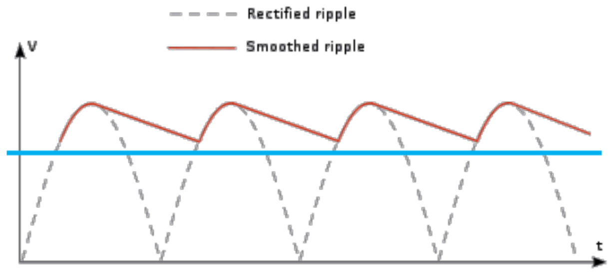

Figure 1: Voltage regulator input vs. output.

- The goal of a regulator is to produce a constant DC output voltage (generally from a higher input voltage) which is constant and steady under load variation
- A regulator is often attached to the output of an AC rectification circuit, which is noisy and contains ripples
- We want the output of our regulator to look like the blue plot above, even if the input voltage varies or if the output load draws varying amounts of current
- Two properties of regulators are of interest:
  - *Line regulation*: holding output constant while input voltage changes
    - This is usually analyzed under the worst-case load current scenario
    - For simple regulators, the highest load current is typically the worst-case scenario; for more complex regulators this can be the lowest load current
    - This is generally quantified as the difference between V_{OUT} at maximum V_{IN} and V_{OUT} at minimum V_{IN} (both at the worst load current), normalized by the design V_{OUT} (nominal value)
      - Note sometimes the V_{OUT} at max or min input voltage are used as normalization for more complex circuits
    - Line regulation is often expressed as a percentage, which would be the percent change in V_{OUT} for every 1% change in V_{IN}
      - Single digit values are good, double digit values are generally poor
  - *Load regulation*: holding output constant while load current changes
    - For simple regulators, the lowest input voltage is typically the worst-case scenario
    - This is generally quantified as the difference between V_{OUT} at minimum load and V_{OUT} at maximum load (both at the worst input voltage), normalized at the V_{OUT} at maximum load
      - Note we are doing min minus max, because generally with a higher load we expect the output voltage to go down
      - Some manufacturers will normalized by V_{OUT} at minimum load or nominal V_{OUT}
  - Load and line regulation are signed quantities, but they are typically positive unless there is feedback in the circuit
- For most simple (no active feedback) regulator circuits, the ends of the input/current draw ranges are usually where the regulator behaves the poorest
- Most regulator circuits take advantage of the fact that the voltage drop across a diode in forward bias is nearly constant
  - Typically if a regulator circuit is working, diodes will be in forward bias mode
- Let's try to design a regulator with the following requirements:
  - Input voltage varies from 10-15V
  - Load current varies from 0-1A
  - Desired output is 9V
- Example: series diode regulator

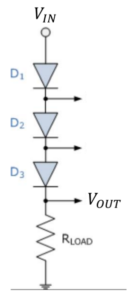

Figure 2: Series diode regulator.

- R_{LOAD} is a placeholder load which can draw varying amounts of current as specified above
- We will be using the piecewise-linear model with $V_{D_0} = 0.5\,\text{V}$ and $r_D = 0.1\,\Omega$
- On a high level we expect the output to be a constant voltage offset from the input due to the series diodes
- This regulator has poor line regulation, but good load regulation
- To find line regulation, we solve the circuit for $V_{IN} = 10\,\text{V}$ to $15\,\text{V}$; in both cases we solve with $I_{LOAD} = 1\,\text{A}$ since it is our worst-case scenario
  * Assuming forward bias on all diodes, we have 3 resistors r_D in series and 3 voltage sources V_{D_0} in series
  * Note generally when diodes are in series with no connections in-between, they will always have the same state
  * At $V_{IN} = 10\,\text{V}, I_{LOAD} = 1\,\text{A}$ each r_D has a voltage drop of $0.1\,\text{V}$ and each V_{D_0} has a voltage drop of $0.5\,\text{V}$, resulting in $8.2\,\text{V}$
  * At $V_{IN} = 15\,\text{V}$, the analysis is similar and we get $13.2\,\text{V}$
  * The line regulation is then $\dfrac{13.2 - 8.2}{9} = 55.6\%$, which is very bad
  * Note for this circuit, it doesn't matter what load current we chose
- To find load regulation, we solve the circuit for $I_{LOAD} = 0\,\text{A}$ to $I_{LOAD} = 1\,\text{A}$
  * First assume $V_{IN} = 10\,\text{V}$, then at $I_{LOAD} = 0\,\text{A}$ we have $8.5\,\text{V}$ and at $I_{LOAD} = 1\,\text{A}$ we have $8.2\,\text{V}$
    - The load regulation is $\dfrac{8.5 - 8.2}{8.2} = 3.7\%$ which is pretty good
  * If we solve at $V_{IN} = 15\,\text{V}$, we get $13.5\,\text{V}$ at no load and $13.2\,\text{V}$ at maximum load
    - The load regulation is $\dfrac{13.5 - 13.2}{13.2} = 2.3\%$, which is better than the minimum input voltage case
    - This confirms that the minimum input voltage is the worst case