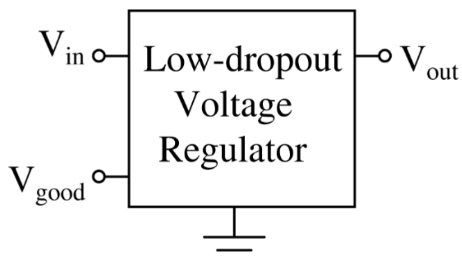
EE313 Laboratory #2 (v2)

Low-Dropout Voltage Regulator

Design a simple method to measure the β_F and β_R of a pnp transistor.

Design a low-dropout (0.7V max) voltage regulator with an output current of 90mA. A green LED should turn on if the regulator output is good. Use a power pnp BJT (BD136) to regulate the voltage, an OPAMP (LM358) to provide the feedback, and a Zener diode as the voltage reference.

The output voltage should be 6.5+mod(YourIDNumber,10)/2.



Specifications:

1. Line regulation: When V_{in} is between V_{out}+0.7 to V_{out}+6, the output voltage, V_{out}, changes by no more than 10mV when the output current is 20mA (R_L=V_{out}/0.02).
2. Load regulation: When V_{in}=V_{out}+2, the output voltage, V_{out}, changes no more than 50mV when the output current changes between 5mA and 90mA (R_L is varied between V_{out}/0.005 to V_{out}/0.09)
3. A green LED should turn on if the regulation is achieved. Otherwise, it should turn off, in particular, when the input voltage is too low to achieve the voltage regulation: V_{out}+0.25 with $R_{L=}V_{out}$/0.09

Preliminary work (Due February 25, 2024)

Simulate your design using transient analysis of LTSpice to show the performance under the conditions given above: (Use the provided Spice files, LM358.txt for LM358 and BD136.txt for BD136 simulation. (Place LM358.txt and BD136.txt in the working directory. Insert .include LM358.txt and .include BD136.txt directives into the schematic. Define the Value property of the opamp2 symbol as LM358 and the value property of the pnp symbol as BD136. Replace BF=100 in BD136.txt to simulate a transistor with a lower βF.) For LED, use one of LEDs available in LTSpice library.

Use a Zener diode connected to the output via a series resistor to provide the reference voltage. Note that a Zener diode should dissipate no more than 50mW. An OPAMP can compare the reference voltage with a scaled version of the output voltage to provide the base current of the PNP transistor as feedback. You may choose one of the Zener diodes available in LTSpice library.

Use a 3.3Ω resistor in series with the emitter of the PNP transistor to provide β_F stability.

You need to stabilize the feedback loop by using a capacitor between the output pin and the OPAMP's negative input pin to slow the OPAMP's response.

Use an electrolytic capacitor at the output to provide stability.

From the datasheet of BD136, find the junction to ambient thermal resistance ($R_{\theta JA}$), junction to case thermal resistance ($R_{\theta JC}$), and the maximum junction temperature (T_{Jmax}). Estimate the junction temperature (T_J) and case temperature (T_C) of BD136 when V_{in}= V_{out}+3 and when a load resistor is connected at the output, drawing a current of 90mA. Assume that the ambient temperature is T_A=25°C.

To measure the line regulation in LTSpice, use a sinusoidal voltage source with a DC voltage of V_{out}+3.35 and a magnitude of 2.65. The peaks of this sinusoidal signal vary between V_{out}+0.7 and V_{out}+6. Initially, use a frequency of 50Hz. Then, find the highest frequency of sinusoid, where the output ripple requirement of 10mV is satisfied. This frequency can be further increased by reducing the value of the capacitor used in the OPAMP feedback. On the other hand, if that capacitor is chosen too small, the regulator may oscillate.

Provide a schematic of your design.

Upload your LTSpice source file *.asy into Moodle.

Experimental work (Due March 3, 2024)

Measure β_F and β_R of the BD136 pnp transistor.

β_F	β_R

Build your design on a breadboard. Test the six conditions below and fill in the table below. For the R_L value, choose the nearest standard value. Note that we do not have a power supply that can provide DC+AC, which LTSpice can provide.

V_{in}=V_{out}+0.7	R_L=V_{out}/0.02	V_{out}	LED On/Off
V_{in}=V_{out}+6	R_L=V_{out}/0.02	V_{out}	LED On/Off
V_{in}=V_{out}+2	R_L=V_{out}/0.005	V_{out}	LED On/Off
V_{in}=V_{out}+2	R_L=V_{out}/0.09	V_{out}	LED On/Off
V_{in}=V_{out}+0.25	R_L=V_{out}/0.09	V_{out}	LED On/Off
V_{in}=V_{out}+3	R_L=V_{out}/0.09	V_{out}	T_C (°C)

Provide a picture of your breadboard in the report.

Calculate the dissipated power on the load resistor. Note that common axial resistors are rated for only 250 mW. 350mW may be acceptable in the lab. Hence, you must use a power resistor or several resistors in series/parallel if the power dissipation exceeds this value. For example, if V_{out}=11V, and R_L=120Ω → $P_{out}=V_{out}^2/R_L$=1W → use three resistors in parallel: 330 || 390 || 390 =122Ω.

Connect the heat sink to BD136. Keep the conditions the same. Measure the heat sink temperature after it reaches a steady state. Find the thermal resistance of the heat sink.

Grading criteria:

Preliminary work (10 pts)

β_F and β_R measurement methods. 1pt.

Satisfaction of three criteria in LTSpice: 7.5pts, 3+3+1.5

Temperature analysis of BD136: 1.5pts

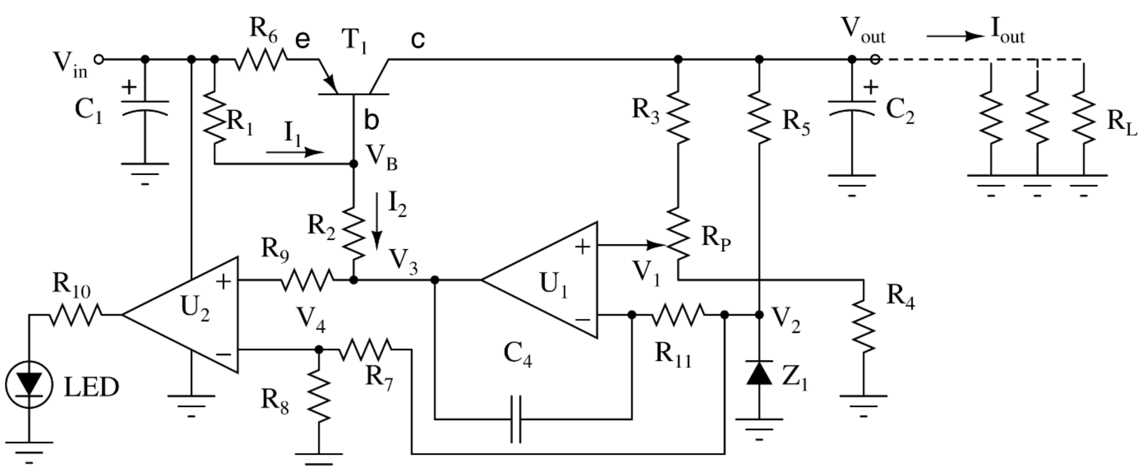
Experimental work (10 pts)

β_F and β_R measurements. 1pt.

Experimental satisfaction of six criteria shown in the table: 9 pts, 1.5pts each

Hints:

You may use the following circuit:



1. Choose a Zener diode Z_1, so that its voltage V_2 is smaller than $0.85V_{out}$.
2. Choose R_5 such that the Zener diode carries a current of 3mA: $R_5=(V_{out}-V_2)/0.003$
3. Choose R_3 and R_4 so that $V_1=V_{out}\,R_4/(R_3+R_4)=V_2$. Choose R_3+R_4 larger than 100K and smaller than 200K. Use a 10K pot (R_p) for fine adjustment of V_1.
4. Choose $R_{11}=R_3 \parallel R_4$ to have the OPAMP see equal resistors on its inputs.

5. Choose R_7 and R_8 so that V_4=0.4V=$R_8/(R_7+R_8)$ V_2. Choose R_7+R_8 such that $V_2/(R_7+R_8)$ is smaller than 1mA (Hence, Z_1 has a current of at least 3−1=2mA).
6. Choose $R_9=R_7\|R_8$ to have the OPAMP see equal resistors at its inputs.
7. Choose R_6=3.3Ω.
8. Choose R_2 such that $I_2=I_{Bmax}+I_1$ while $V_3=V_{3min}$. Or $(V_{Bmin}-V_{3min})/R_2=I_{outmax}/\beta_{Fmin}+(V_{inmin}-V_{Bmin})/R_1$. $R_1=R_2/3$, as explained below.
   Note that the worst case occurs when $V_{in}=V_{out}+0.7$. To keep T_1 in ACT, we must have $V_{Bmin}=V_{out}-0.4$.
   V_{3min}=0.5V for the OPAMP to keep it safely in the linear region.
   β_{Fmin}=40 from the datasheet of BD136.
   Combining the equations, $R_2=\beta_{Fmin}(V_{out}-4.2)/I_{outmax}=40(V_{out}-4.2)/0.09$. Choose R_2 as the next smaller standard value.
9. Choose R_1 so that $(V_{in}-V_{3max})\,R_1/(R_1+R_2)$ = 0.5V=V_{EB} is sufficiently small to turn off the transistor when I_{out}=0. Note that $V_{3max}=V_S-2=V_{in}-2$ for LM358. Hence, 2 $R_1/(R_1+R_2)$ = 0.5V or $R_1=R_2/3$. Use the next larger standard value.
10. Choose C_1=10µF or larger with a sufficient voltage rating.
11. Choose C_2=100µF or larger with a sufficient voltage rating.
12. Choose C_4 so that $R_{11}C_4$=0.5µs will kill the feedback loop oscillation. If the simulation is too slow, you probably have an oscillation. Make C_4 larger.
13. Limit the LED current to 5mA by choosing the current limit resistor R_{10}.
    $R_{10}=(V_{inmin}-2-V_{LED})/0.005=(V_{inmin}-3.7)/0.005$.

In LTSpice or the experiment, check that V_3 lies between 0.5V and V_{in}−2.