Industrial Electronics
Practicum 0

Summary on linear regulator LM317

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Laboratory report

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1 Introduction

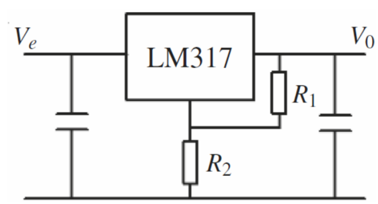
This practicum aims to study, dimension, simulate, and implement an LM317 linear regulator system, and analyze different aspects and parameters that impact the circuit's functionality.

The LM317 is a voltage regulator that is commonly used in electronic circuits. It is designed to provide a constant output voltage, regardless of variations in input voltage or load. It does this by using a reference voltage and an adjustable resistor to control the output voltage. The reference voltage is set using a pair of external resistors, and the output voltage can be adjusted by changing the resistance of the adjustable resistor. This allows the LM317 to be used in a wide range of applications, such as providing a stable power supply for a circuit or controlling the output voltage of a battery.

2 Preliminary task

Our goal is to implement an LM317 regulation system, which has an input of **5V** and an output of **3V3**. To accomplish that, we must scale different parameters, that we will develop in the subsection 2.1 to 2.4

2.1 Resistive bridge sizing



$$V_0 = 1{,}25 \times \left(1 + \frac{R_2}{R_1}\right)$$

FIGURE 1 – Resistive-bridge schematic and formula in the datasheet
Source: LM317 datasheet

The formula in the datasheet neglects the breakdown current of the internal Zener diode, we decided to take consideration of it in our calculations.

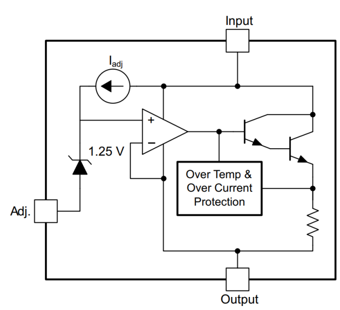


FIGURE 2 – Functional bloc diagram of LM317
Source: LM317 datasheet

The voltage of the internal zener diode is **1.25V**, this is the reference and minimum voltage of the regulator. To dimension the resistive bridge, we must take into account the breakdown current of the diode which is **50uA**, when this condition is met, we know that the voltage between the output and the ADJ pin is the same as the reference voltage. We can then set an arbitrary value for one of the resistors knowing that the total voltage at the output must be **3.3V**. We decided to have a current of **50uA** through R1, to reduce the power dissipation in the bridge.

2.1.1 Sizing formulas

As described bellow, we have as parameters :
$I_{adj} = 50[uA]$
$I1 = 50[uA]$
Where I1 has been fixed by us to avoid having too much unnecessary current in the resistor bridge..
$U1 = 1.25[V]$

$$R1 = \frac{U1}{I1} \tag{1}$$

$$R2 = \frac{U2}{I2} = \frac{Uout - U1}{I_{adj} + I1} \tag{2}$$

As equation (1) and (2) state, in our application we found the values :
$R1 = 25\ k\Omega$
$R2 = 20.5\ k\Omega$

2.2 Maximum output power calculation

Since we have very few loss current in the resistive bridge, we decided to neglect it.
We have as parameters :
$U_{in} = 5[V]$
$U_{out} = 3.3[V]$
$I_{out} = 100[mA]$ (Specification)

$$P_{max} = (U_{out} - U_{in}) * I_{out} \tag{3}$$

By applying equation number (3) to our application, we found the value :
$P_{max} = 330\ mW$

2.3 Input provided power

In this subsection, we will continue to neglect the diode breakdown current. To have as an output current **100 mA** we sized an output resitor by applying this formula :

$$R_L = \frac{U_{out}}{I_{out}} \tag{4}$$

So our load resistor value is **33 Ω**.

We can now define our different powers in the systems :

$$P_{out} = U_{out} * I_{out} \tag{5}$$

$$P_{in} = U_{in} * I_{out} \tag{6}$$

$$P_{reg} = P_{in} - P_{out} \tag{7}$$

Calculated values for our application :
$P_{out} = 330\ mW$
$P_{in} = 500\ mW$
$P_{reg} = 170\ mW$

2.4 Temperature of the LM317 junction without cooling

Finally, we have been asked to estimate the temperature of the LM317 junction, without cooling. Specification set the ambient. The datasheet provides us the thermal resistance between the junction and the ambient. So we have :
$T_A = 35\ C$
$Rth_{JA} = 37.9C/W$
We can define the temperature of the junction by :

$$T_J = T_A + Rth_{JA} * P_{reg}$$

Calculated values for our application :
$T_J = 41,44\ C$

2.5 Simulation of the system

In this section we will simulate our system to corroborate our previously dimensioned system (From section 2.1 to 2.3).

Simulation schematic :

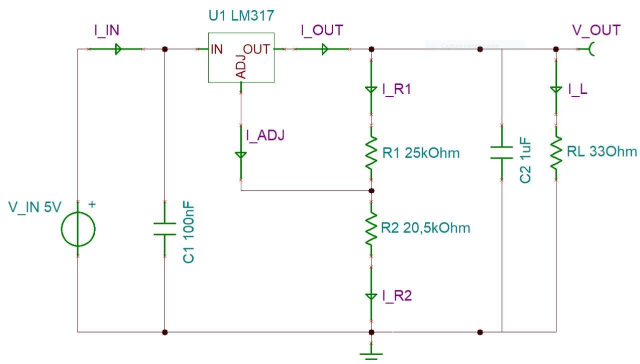


FIGURE 3 – Schematic of the first part
Source: Authors

Simulation method :
In order to perform our simulations, we used the DC analysis tool of Tina TI.

Simulation results and analysis :

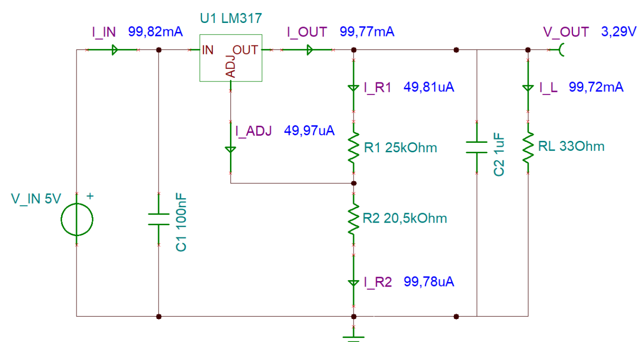


FIGURE 4 – Simulation of the first task
Source: Authors

As we can see on the figure 4, the output voltage is well dimensioned knowing that there is **3.3V** on the load resistance, and a current of **100mA**. We can also see that the breakdown current of the diode is $\sim 50\mu A$ which is consistent with the datasheet.

3 Main task

3.1 Schematic proposal for limiting output current to 250mA

We were asked to design a proposed scheme to limit the output current to 250mA, to do this we decided to change the principle of the connections to create a current source using the LM317.

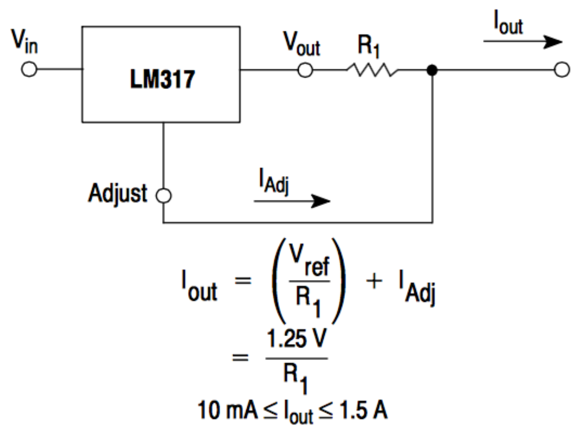


Figure 26. Current Regulator

FIGURE 5 – Current source with LM317
Source: Stackexchange "lm317-µa-constant-current-source-possibility"

We use the reference voltage (**1.25V**) of the internal diode, so the output current depends on the resistance **R1** plus the leakage current of the diode.

By adding and changing a load resistor in the circuit, the induced output current will vary, as will the voltage, but the current will not exceed : $\frac{Vref}{R1} + I_{ADJ}$

3.2 Plotting output tension depending on output current

One of the unique features of the LM317 is its ability to automatically adjust its output voltage in response to changes in temperature. This is accomplished using a built-in temperature-sensing circuit that monitors the temperature of the LM317 and adjusts the output voltage accordingly.

When the temperature of the LM317 increases, the temperature-sensing circuit will cause the output voltage to decrease slightly. This helps to prevent the LM317 from overheating and ensures that it continues to operate within safe temperature limits. Similarly, when the temperature of the LM317 decreases, the temperature-sensing circuit will cause the output voltage to increase slightly. This helps to maintain a stable and consistent output voltage, even in changing temperature conditions.

Overall, the LM317's ability to regulate according to temperature makes it a versatile and reliable choice for applications that require a constant output voltage, such as in power supply circuits and battery chargers.

We will observe this characteristic through our following measurements.

3.2.1 List of all the instruments

Instrument	Designator	Reference
Oscilloscope	P1	ES.SLO2.05.01.08
Current probe	P2	ES.SLO1.00.06.04
DC power supply	G1	ES.SLO2.00.00.31
Electronic load	G2	ES.SLO2.00.02.60
Waveform generator	G3	ES.SLO2.00.00.138

3.2.2 Measures

<u>Measurement schematic :</u>

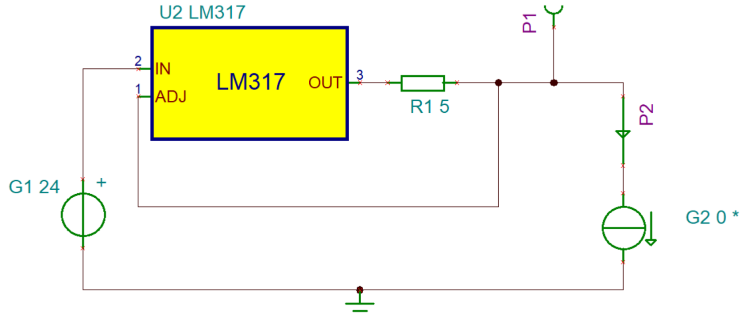


FIGURE 6 – Measurement schematic for output voltage depending on output current
Source: Authors

<u>Measurement method :</u>

In order to perform the requested measurements, we had to change the induced current of the electronic load at each iteration, with a step of 10mA, and measure the current and voltage.

<u>Measures :</u>

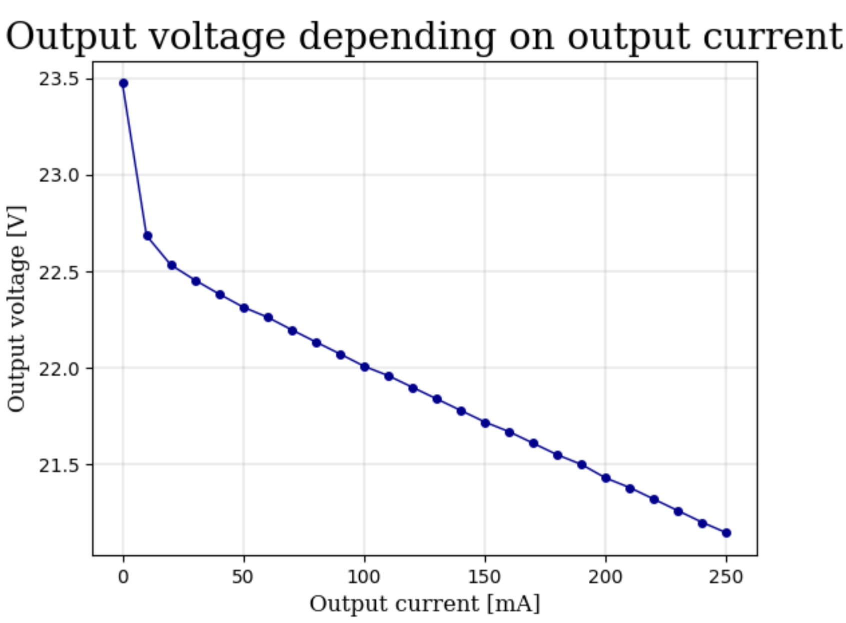


FIGURE 7 – Point G measurements
Source: Authors

Analysis :

As we can see on figure 7, When no current is inducted on the output, the potential voltage on the load is at its maximum ($\sim 24V = \sim Vin$). We can see that when a larger current is induced, the voltage drops, which is mainly due to the voltage loss on the serial resistor. We also noticed during the measurements that when the electronic load is short-circuited, we have an output current of **255mA** (which is slightly higher than our sized maximum) and an output voltage of **0V**.

3.2.3 Simulation

The simulation schematic is the same as the one in figure 6.

Results :

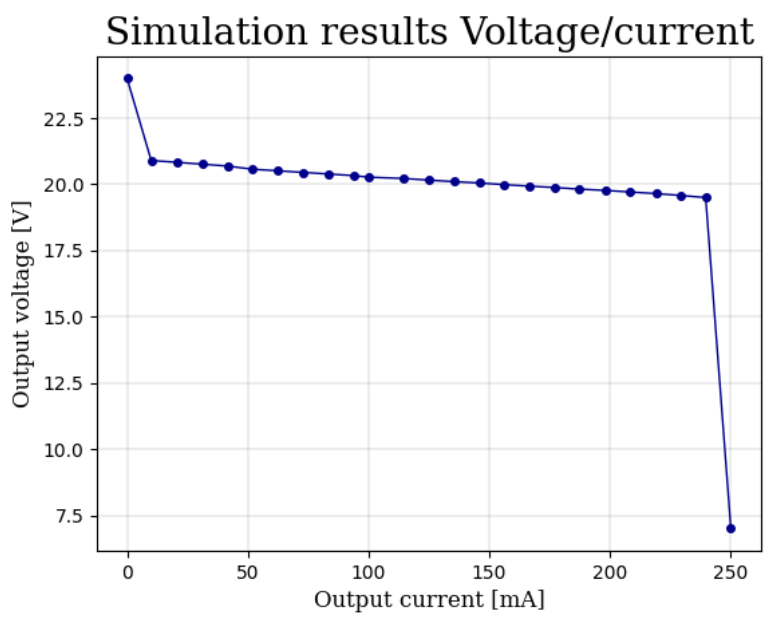


FIGURE 8 – Simulation results
Source: Authors

Analysis :

We can see that the simulation results are similar to our previous measurements, except that the delta between the highest and lowest voltage is smaller in the simulation, probably because the simulation does not take into account all the hardware contingencies.

3.3 Oscillogram of the output current depending on the output tension

The internal temperature-sensing circuit that monitors the chip's temperature can also adjusts the amount of time that the regulator is on to maintain a stable output voltage, and we will observe this feature under this section.

3.3.1 Measurements

Schematic :

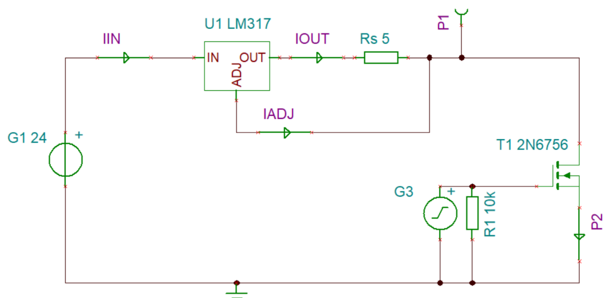


FIGURE 9 – Measurement schematic
Source: Authors

Measure :

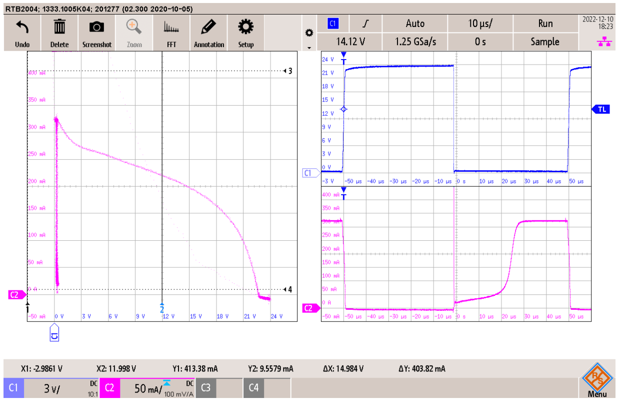


FIGURE 10 – Oscillogram
Source: Authors

Analysis :

We can see on the figure 10, when no heat sink is used, that the LM317 adjusts the amount of current supplied to the load, in order to maintain a stable output voltage over time. By adding a heat sink to the TO-220 package, the output current supplied increases more rapidly when the MOSFET switches.

3.3.2 Simulation

Results :

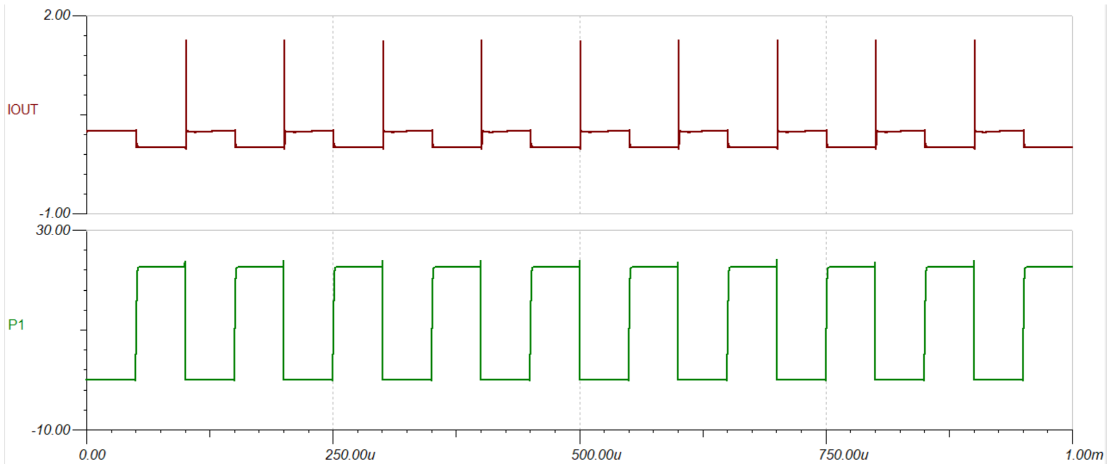


FIGURE 11 – Simulation results
Source: Authors

Simulation analysis :

We can see that the simulation does not take into account the heating of the component, because the output current is always ON when the mosfet conducts, which means that the internal temperature sensor and control is not simulated. What is similar to the measures is the current peak when switching, it is certainly due to a capacitive phenomenon.

3.4 Dissipated power calculation

We can calculate the power dissipated in the LM317 using the same formula as before and taking in consideration the duty cycle.
$\alpha = 50\%$

$$P_{reg_{ON}} = (U_{in_{ON}} - U_{out_{ON}}) * I_{out_{ON}} \tag{8}$$

$$P_{reg_{OFF}} = (U_{in_{OFF}} - U_{out_{OFF}}) * I_{out_{OFF}} \tag{9}$$

$$P_{reg_{TOT}} = P_{reg_{ON}} * \alpha + P_{reg_{OFF}} * (1 - \alpha) \tag{10}$$

Calculated values for our application :
$P_{reg_{ON}} = 6W$
$P_{reg_{OFF}} = 0W$
$P_{reg_{TOT}} = 3W$

Datasheet set the maximum allowable power dissipation as :

$$P_{MAX} = (T_{J_{MAX}} - T_A)/Rth_{JA} \tag{11}$$

In our case, this value is :

$$P_{MAX} = 3,03W \tag{12}$$

So this mean we reached the absolute maximal power that our LM317 can dissipate. Going higher than this value would impact reliability and/or trigger temperature protections.

3.5 Estimation of the junction's temperature without cooling

$T_A = 35\ C$
$Rth_{JA} = 37.9C/W$
We can define the temperature of the junction by :

$$T_J = T_A + Rth_{JA} * P_{reg_{TOT}}$$

Calculated value for our application :
$T_J = 148,7\ C$

The datasheet set the maximal admissible temperature to 150°C.

3.6 Short-circuited output - dissipated power calculation

When short-circuiting the output, we get the maximal current possible. As the output is grounded, all the voltage occurs in the LM317. This leads to a situation where the LM317 needs to dissipate a lot of power, which we calculated this way :

$$P_{reg} = (U_{in} - U_{out}) * I_{out} \tag{13}$$

Calculated values for our application :

$P_{reg} = 6W$

4 Conclusion

In this practicum we learned how to configure and use a circuit based on the LM317 regulator.
We first established the way of using it as a voltage regulator. We needed to take in consideration the ADJ current that was neglecated by the datasheet to fit to our specific application. We then made sure that our sizing was correct. We then simulated our circuit to confirm that, which was working as expected by specifications.
Secondly, we used the LM317 as a current limitator. We found a schematic in the datasheet composed of only a single resistor. We made sure that the current limitation was working by short-circuit the output. We then made some measurement to observe the change in the output voltage in comparaison with output current. We made sure that the LM317 could handle all the power dissipation by calculating it. We saw that the circuit was at its maximum capabilities and even exceed it sometimes which triggered its internal protections.

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