# Final Report - Muon Detector Upgrade with voltage regulation

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## 1. Introduction.

The two components that need voltage regulation are the SiPM and the ADC. The SiPM needs 27V in input and the ADC needs 3,3V. The LM317 datasheet says that it can provide voltage from 1,2 to 37V so this device might suit with our components.

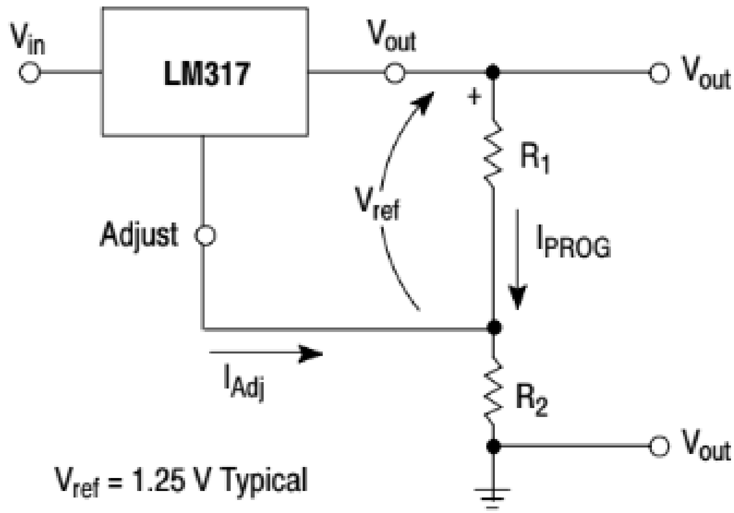
An important characteristic of a voltage regulator is his dropout voltage . It is the minimum voltage difference between the output and input that the regulator can work with. If we go under this value, I may cause stability issues and this is the last thing we want since we are trying to cut the noise of the output signal. However, the aim is to put the detector on a small rover, it means that we have to make sure the output voltage will remain constant even if the battery is low. In this case, it is harder to ensure that the voltage difference is above the dropout value.

In our case, the LM317 has a dropout voltage between 2 and 3V, depending of the junction temperature, so we have to take 3V. It will be fine for the SiPM which needs 27V because we take the supply from a 3,3V pin on the Raspi. The solution is just to put 3V more from the booster. For the ADC, it is not possible to use the LM317 because we take 5V input from the Raspi and give 3,3V output. It makes a difference of only 1,7V, which is not enough to ensure stability with the LM317. We have to find a low dropout voltage regulator.

## 2. Photomultiplier.

### 2.1. Setting the output value.

For the SiPM, we use the LM317. This is its basic configuration :




Depending on the application we use it for we have to add extra components, but the method to set the output voltage is universal. The values of the two resistances set the output voltage, and the LM317 keep it constant as long as the input voltage is high enough.
There are three pins : input, output and adjust. The voltage difference between output and adjust is kept by the LM317 at 1,25V, no matter what. This is the reference voltage. Knowing this, we can now get two equations of voltages by following two different paths on the circuit :

1) $V_{R1} = V_{ref} = R_1 x I_{prog} = 1{,}25V$
   $\Rightarrow I_{prog} = V_{ref}/R_1$
2) $V_{R2} = R_2 x (I_{adj} + I_{prog})$
   $\Rightarrow V_{R2} = R_2 x I_{adj} + V_{ref} x (R_2/R_1)$

So :

$$V_{out} = V_{R1} + V_{R2} = R_2 x I_{adj} + V_{ref} x (1 + R_2/R_1)$$

It is said in the datasheets that $I_{adj} < 100\mu A$, so $R_2 x I_{adj} << V_{ref} x (1 + R_2/R_1)$

Thus :

$$V_{out} = V_{ref} x (1 + R_1/R_2) \quad \text{in Volts}$$

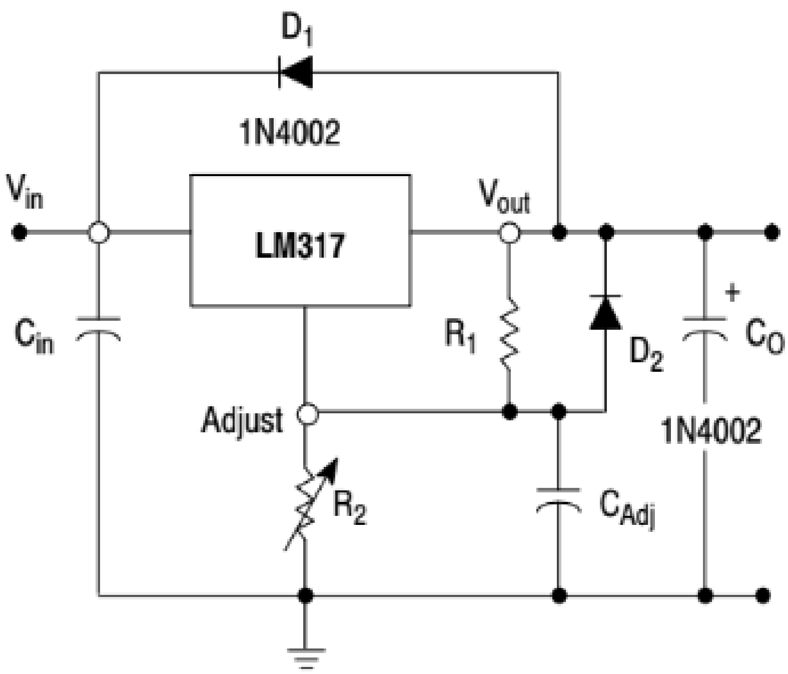
With : $V_{out}$=27V ; $V_{ref}$=1,25V ; $R_1$ always set at 240Ω

So : $R_2 = R_1 \times (V_{out}/V_{ref} - 1) = 240 \times (27/1{,}25 - 1) \simeq 5k\Omega$

So we need to use 5kΩ for $R_2$, in order to get 27V in output.

### 2.2. Ensuring the regulation with capacitors.

The LM317 needs to be in a special configuration in order the ensure the voltage regulation. This configuration is given in the datasheet :




For better performances and to improve load regulations, the programming resistance R1 should be as close as possible to the regulator and R2 should be close to the ground.

For the input capacitor $C_{in}$, we use a 0,1µF disc. This capacitor will reduce the sensitivity of the detector, lowering the noise. It is necessary because the regulator is located far from the power supply, according to the datasheet.

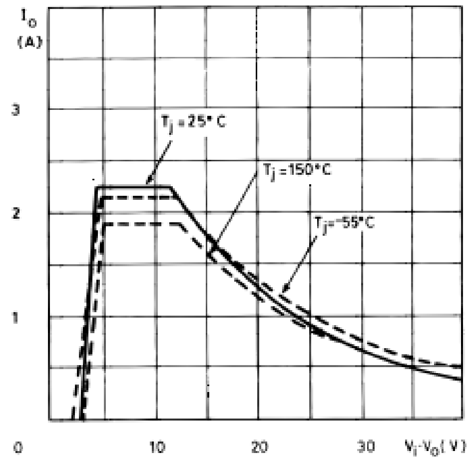
$C_{adj}$ is 10µF. It prevents ripple from being amplified as the output voltage is increased.

$C_{out}$ of 25µF improves the transient response of the system. This is important in our application because we need the detector the be very reactive.

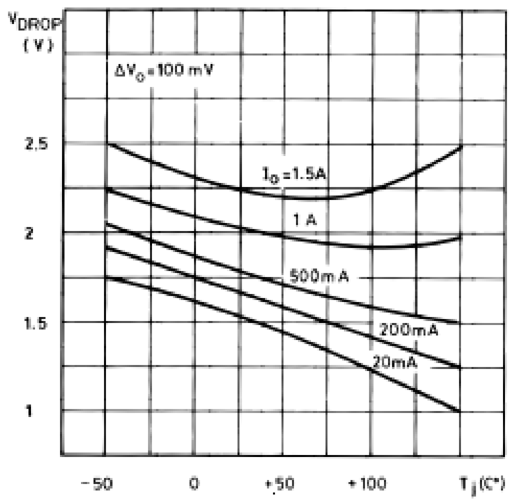
Two protection diodes are used in order to protect the regulator from capacitor discharges, when the detector would be shut down.

### 2.3. Other interesting informations.

This graph helps to predict the maximum output current the LM317 can provide for different input to output voltage differences. It is interesting because it clearly shows at which point the regulator does not work anymore. It illustrate the concept of dropout voltage and helps to understand it.



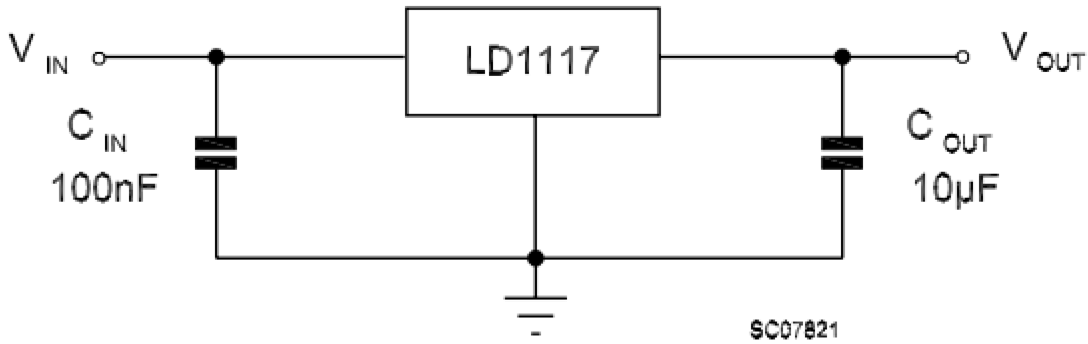

This graph shows how the junction temperature influence the typical characteristics of the regulator, like the dropout voltage for exemple. It is therefore important to maintain an acceptable temperature to keep the stability of the voltage that the regulator supplies.



## 3. Analog-to-Digital Converter.

The ADC can not be supplied by the LM317 because its dropout voltage of 3V is to high. There are a lot of low dropout voltage regulators made for 5V input and 3,3V output because these are very common supply voltages in electronics. But I had to do with the ones Davin gave me and after checking the datasheets of the two of them, it seemed that one of them is be fine. It is the LD33V3, which is a LD1117 type but for 3,3V output, so you have to use ctrl+f in the datasheet.

The LD33V3 is much easier than the previous voltage regulator because it has a unique configuration.




The input capacitor needs 0,1µF and the output 10µF.

## 4. Potential use of heat sink.

In some applications, the voltage regulators dissipate a lot of power and the to get a heat sink. The power dissipation is needed to know at which temperature the junction of the regulator will rise. It is important because, like I said before, the typical characteristic can be modified under other temperature, and we want to make sure regulator will work properly. The power dissipation $P_D$ is given by :

$$P_D = I_{out} \times (V_{in} - V_{out}) \quad \text{in Watts}$$

Then we are able to know the junction temperature $T_J$ to see if we will need a heatsink or not.

$$T_J = T_{amb} + P_D x \Theta_{JA}$$

With : $T_{amb}$ the ambient temperature ; $\Theta_{JA}$ the junction to air resistance (in °C/W)

In our case, the SiPM and ADC only drain current lower than the mA, so the power dissipation will be close to the mW which is very low. Thus the temperature rise will be very low, and the junction temperature should be close to the ambient temperature. So we do not need a heat sink. However, this study was still interesting because I had later to face overheating issues, but of the Raspi CPU.

## 5. Wiring on the breadboard.

Most of the components like the SiPM, the ADC or the booster were already wired to the Raspi. I only had to add the two regulators, but I had therefore to use one more breadboard because there wasn't enough space anymore. This is not ideal because the detector will be put into a box and on a rover. The drawback is now that the detector takes more space.

The detail of the knew wiring can be seen on the new electrical diagram.

I did not understand why but at some point the Raspi started to overheat for no obvious reason. It was not capable of running the main codes anymore, which was a big problem for all the testing part. Two options are possible to overcome overheating for a Raspi : getting a heat sink or a fin. The fin is still possible but it take a lot of space and that is not suitable for us because we want to put the detector in a box. It also takes a pin of the Raspi, and we already use them all for the extension. I chose to use a heat sink because a know these better, and get a few on Amazon.

So I first used one heat sink and the temperature still rises but less. It is possible to check the temperature of the CPU by entering "vcgencmd measure_temp" in the terminal. The temperature take a little bit more than five minutes to stabilize. At the end I get a temperature of 68°C which is a lot. The programs can run but not very good, they take more time that they should and this is very bad for the muon detection because the clock is disturbed.

In general, between 20 and 40°C are normal temperatures, acceptable for 40 to 60, and usually above 60°C is too high for the Raspi. So it still was too hot in order to ensure stability.

The only solution I came up with was to stick other heat sink to the one I already use, and it works pretty good. After having done the same test, I finally got 59°C when the temperature is stabilized. The rising time is approximately the same because the temperature rise is a linear system.