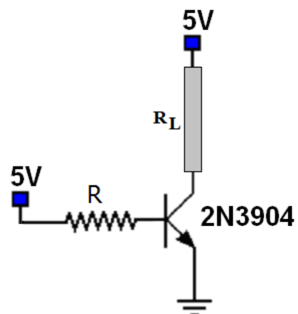
Electronics

Current sources

Problem 1.- Design a current source with a constant output of 8mA for a variable resistance in the range of 0-250ohm.

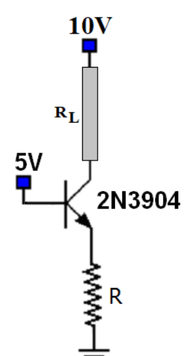
Solution: When the load has its maximum value of 250 ohm, the drop in voltage will be 2V. So we need to design a current source that allows at least a 2V output. Here is one possibility:



To assure that the current in the load be 8mA, the base current should be 80µA (assuming beta = 100) and then R is:

$$R = \frac{5V - 0.7V}{80\mu A} = 53.8k\Omega$$

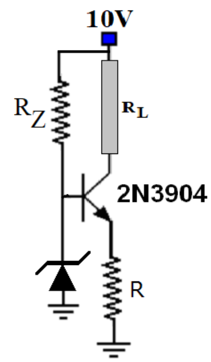
This is not a very good design because of the strong dependence of the current on the value of beta. A better option is this circuit, with a resistance in the emitter side:



To obtain 8mA we design $R = \frac{5V - 0.7V}{8mA} = 538\Omega$

This way we avoid the dependence on beta, although there is still an error due to the base current (which you could correct) and we need two voltage sources.

Other option is suing a Zener diode instead of the 5V source:



If the maximum base current required happens when beta is 50 then:

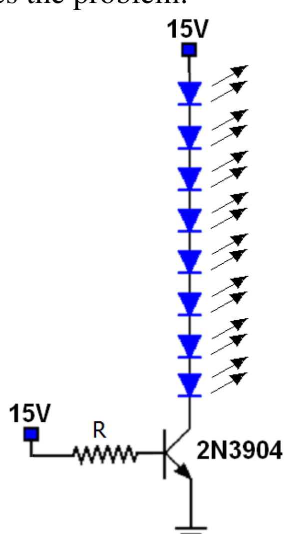
$$I_{B-\max} = \frac{8mA}{50} = 400\mu A$$

So R_Z needs to be $R_Z = \frac{10V - 5V}{400\mu A} = 12.5k\Omega$ and R stays the same as the calculation above.

Any other higher value of beta will make the diode take the excess current and maintain the load at 8mA.
Yet another possibility is using a "current mirror" to accomplish this.

Problem 2.- You have a 15V source and need to feed 8 red LEDs (V_D=1.8V at 10mA). Design a circuit that keeps this condition with a transistor 2N3904 (beta=100).

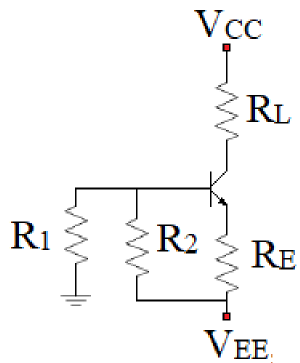
Solution: The following circuit solves the problem:



To keep the current in the diodes at 10mA, the base current has to be 0.1mA and R will be:

$$R = \frac{15V - 0.7V}{0.1mA} = 143k\Omega$$

Problem 3.- Use the circuit below as a base to design a current source with a constant 10mA for a variable load R_L of 1-2 kohm. Find values of V_{EE}, V_{CC}, R_1, R_2 and R_E. You can assume that the transistor has a gain β~100 and enough capacity to dissipate the required power.

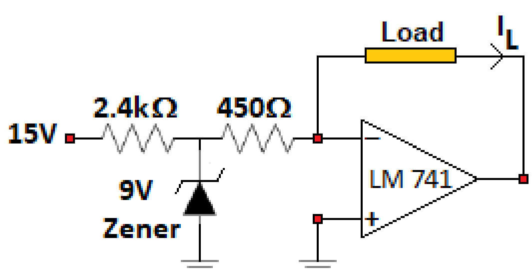


Solution: The voltage in the load will vary from 10V and 20V since the resistance will be between 1 and 2 kohm and the current needs to be 10mA. This means that V_{CC} has to be at least 20V greater than the collector voltage.

If the collector current is 10mA, the base current will be 100μA (with a gain of 100).

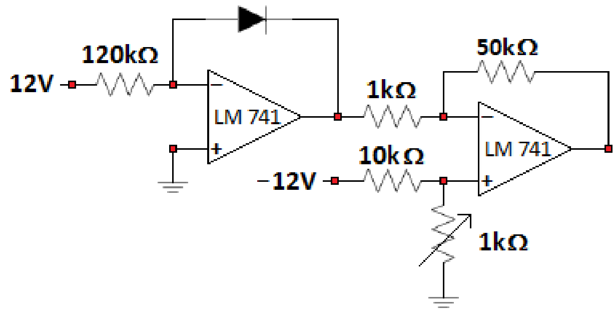
In a simple design, let us say R_1=0 and R_2 open (infinite resistance). In this case V_{EE} has to be enough to maintain 10.1mA in R_E plus the 0.7V drop between base emitter, for example if R_E=1kohm we can choose V_{EE}=-10.8V

Problem 4.- A colleague builds a circuit to generate a constant 20mA current for a variable load of 0-250 ohm using an opamp and a Zener diode, but it doesn't work. Can you explain why? What would you change to make it work?



Problem 5.- In a cryogenic medical application you need to measure temperature with a diode sensor. To do this, it is necessary to design a 100μA current source that will feed the sensor and a circuit that does not load it and converts the signal linearly from the range 0.55V-0.75V to 0-10V.

Solution: There are multiple ways of accomplishing this. For example the circuit below



The 12V source with the 120kohm resistor gives 100µA for any voltage in the diode. Notice that the diode is in the feedback loop.

The diode voltage drop from 0.55V to 0.75V will appear at the opamp output (negative with respect to the ground) and this way the amplifier will not load the diode.
To obtain 0.55V as reference a 1kohm potentiometer is connected in series with a 10kohm resistor and a -12V source, which allows a precise calibration. Alternatively it is possible to choose two precision resistors to divide the voltage.
The signal, after subtracting the 0.55V will be in the range of 0V to -0.2V, so the amplifier has a gain of -50 to obtain 0-10V.

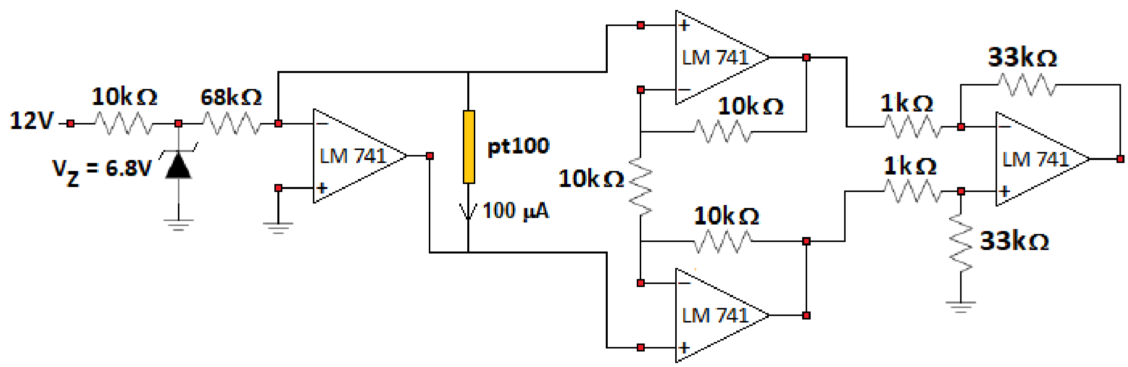
Problem 6.- To measure temperature, a scientific instrument uses a platinum resistor of 100 ohm at 0 ºC. To obtain a high precision the circuit uses four wires, two to circulate 100µA throught the resistor and two to measure the voltage.

a) Design the current source.
b) Design an amplifier to increase the signal to 1V.

Solution: There are multiple ways of solving this problem. First let us look at what we want to do. These platinum resistances are called pt100 and are very common in industry to measure temperature. When the temperature increases, so does the resistance in ohms. The simplest measurement scheme is to pass a constant current (in the example 100µA) and measure voltage, so R = V/I.

The accuracy of the measurement depends on the current source. An error of 1% in the current translates to 1% error in the resistance, which in turn is an error of ~3 ºC in temperature. That is why it is important to design an accurate source. Another issue is the resistance of the wires. Since that additional resistance depends on the length of the wires, a 4 wire scheme is used to remove that variable. There will be a very small current in the two voltage measurement wires, but much less than in the current loop.

Going back to the current source design, it could be built with the circuit shown below using one Zener diode and an opamp. With a current of 100µA the voltage in the resistance will be 10mV and we would need an amplification of 100. For the voltage circuit we take two wires and we connect them to buffers and an instrument amplifier of 100 gain.


12V
10kΩ
68kΩ
V_Z = 6.8V
LM 741
pt100
100 µA
LM 741
10kΩ
10kΩ
10kΩ
LM 741
1kΩ
1kΩ
33kΩ
33kΩ
LM 741