Linear voltage regulator

-functional description-

It is required to design a continuous voltage stabilizer with the following requirements:

- the output voltage has a fixed value of 25V;
- the output current is in the range 0-1A;
- the input voltage is between 30V and 40V;
- the regulator has implemented a thermal protection circuit at a maximum temperature of 100^0 C for the power transistors;
- overvoltage and overcurrent protection circuits.

A linear voltage regulator with series pass transistor is presented in Fig.1

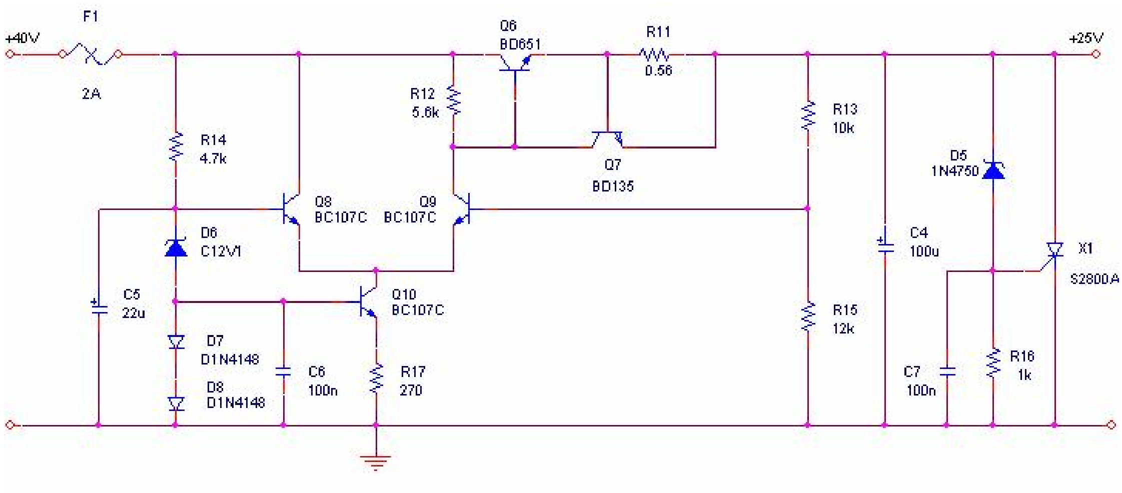

Fig 1. The schematic diagram of a linear voltage regulator with a series pass transistor

As it may be observed, the key element of the scheme is the differential amplifier built with the Q8-Q9 bipolar junction transistors (BJT's).

The differential amplifier is powered by a simple current source formed by Q10 NPN transistor, the resistor R17, and the voltage reference with D7-D8 diodes. The base of Q8 NPN BJT is biased at a fixed voltage value of approximately 13.6V via the D6 Zener and D7-D8 small signal diodes.

The series pass element is a medium power Darlington (Q6) transistor that will need to be mounted on a heatsink.

The negative feedback circuit is performed by the R13-R15 voltage divider. It applies a fraction of the output voltage in the base of Q9 transistor. The differential amplifier will try to equalize this voltage with the fixed voltage of 13.6V from the base of Q8.

It is noted that a surge protector has been adopted through the transistor Q7, which it is in blocking regime during normal operating mode.

The overvoltage protection is performed by the D5-X1 circuit. If the output voltage attains a greater value (27V or more), D5 Zener diode turns into the breakdown regime from the blocking regime, and it ignites the thyristor X1.

It is interesting to note that the protection circuit against the temperature rise is achieved by the thermal fuse F1, which it should be mounted on the same heatsink with Q6, very close to its case.

The C4- C5-C6 capacitors were introduced to filter the noise from the supply lines. The C7 capacitor is mounted to unload accidentally charges which may appear on the X1 grid.

Computing equations

Assuming an average current of 500mA through the load and an output voltage of 25V, the current absorbed by the base of Q6 results from:

$$I_{B6} = \frac{I_{E6}}{h_{fe6min} - 1}$$

The current through R12 is given by:

$$I_{R12} = \frac{V_{in} - V_{BE6} - V_{out}}{R_{12}} = \frac{40 - 1.2 - 25}{5.6} = 2.46mA$$

The collector current of Q9 is:

$$I_{C9} = I_{R12} - I_{B6} = 1.795mA$$

By writting a Kirchhoff II equation on the base eye of the current generator Q10, the following relation is obtained:

$$2V_D = V_{BE10} + R_{17} \frac{h_{fe10} + 1}{h_{fe10}} \cdot I_{C10}$$

With the given data in the diagram, I_{C10} = 3.70mA, so:

$$I_{C8} = I_{C10} - I_{C9} = 1.9mA$$

, which means that the differential stage is operating almost symmetrically.
If the output load has an infinite value, I_{C9} = 2.46mA; if the output load decrease its value, and the current consumption increases to 1A, the base of Q6 will absorb a maximum current of about 1.34mA. This means that the collector current of Q9 transistor is about 1mA.
The potential on the base of Q9 is:

$$V_{B9} = \frac{R_{15}}{R_{13} + R_{15}} \cdot V_{out} = \frac{12}{12 + 10} \cdot 25 = 13.63V$$

The overcurrent protection circuit is formed by the Q7 transistor and the R11 resistor. The collector current of Q7 is:

$$i_{C7} = \frac{I_{C10}}{1 + e^{\frac{Du_{b7}}{V_{th}}}}$$

If the output voltage increases by approximately 25mV, the collector current of Q7 attains 3.27mA, causing a sharp drop of the Q6 base voltage (and a shar drop of the output voltage).
The Q8 BJT has a power dissipation of:

$$P_{D8} = V_{CE8} \cdot I_{C8max} = (40 - 11.4) \cdot 3.7mW = 105mW$$

,which it represents about 1/3 of the maximum permissible value given in the catalog.

The Q6 transistor has a maximum power dissipation given by:

$$P_{D6} = V_{CE6} \cdot I_{C6max} = (40-25)\ 1A = 15W$$

The transistor will be mounted on an aluminium heatsink painted in black colour with the following dimensions:

- thickness 5mm;
- minumum area of 200cm^2 .

The transistor case will be insulated from the heatsink by using a 0.1 mm thick sheet of mica that is previously applied with a silicone grease for heat removal.