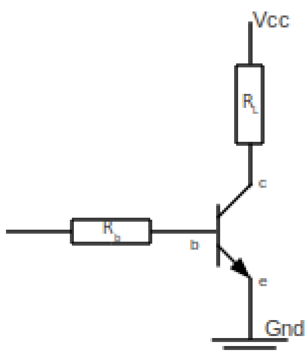
Electronic Circuit Design - Transistor Switch

The transistor is an amplifier, but can be used as a switch by using the transistor in its saturated region. This can be used to switch a significantly larger current than the input signal. As a switch the transistor is often used to take a signal from a digital circuit and use it to switch larger loads than the integrated circuit (IC) can provide.

The circuit below shows a common simple configuration for a transistor switch circuit. It comprises of one NPN transistor, and depicts two resistors. The resistor R_L is not normally a resistor, but represents the resistive value of a device that is being switched. This could be a lamp or relay or some other device that needs a larger current than the input is able to drive directly. The resistor at the base R_b is a resistor used to prevent damage at the base of the transistor. This needs to be large enough to prevent damage to the transistor, but should still allow sufficient current to ensure the transistor switches on. Details of how to determine the size of the resistor are explained below.



How the circuit works

For a transistor to act as a switch it needs to be activated as the saturation region. When switched on in saturation the transistor acts almost as a short circuit allowing current through the load.

If the load being switched is an inductive device, such as a motor, solenoid or relay then a diode should be connected in the reverse direction across the load to prevent any back EMF from damaging the transistor.

Whilst the aim of this is to keep the maths to a minimum we need to use some simple formula to determine the appropriate value for the base resistor R_b. The key equation used here is Ohm's Law.

Calculations

To work out the appropriate level of resistor we need to calculate the appropriate input current to saturate the transistor. The input is normally used at a higher value to ensure that it is well into this saturation region (eg. 10 times the minimum base input current).

First we need to determine the current flowing through the resistor R_L. Depending upon the type of device it may be possible to take this from the datasheet based on the current required to activate or operate the device. If this is not known - or we need to limit this current to protect the device then the resistance can be worked out using ohms law.

$$I = \frac{V_{cc} - V_{ce}}{R_L}$$

V_{cc} is the supply voltage, V_{ce} is the voltage drop across the collector to emitter at saturation. The value of V_{ce} can be found from the transistor data sheet.

The transistor data sheet needs to be checked to ensure that the maximum current through the transistor. On a lower power transistor this could be only 100mA (eg. BC546), but on a high power transistor this could be as high as 15A (eg. TIP3055) with various different values available depending upon the particular transistor. If the I_c max value is too low then either a different transistor needs to be used or a resistor added to limit this current (if the rest of the circuit can work with a reduced current).

After working out the collector current the minimum base current can be found by looking at the gain factor of the transistor. The gain factor is listed on the data sheet as hFE or β

The formula of relationship between the collector current and the base current is:

$$I_c = \beta I_b$$

which we transpose as:

$$I_b = \frac{I_c}{\beta}$$

The gain for a transistor is not constant, but for a switch using the lowest value will ensure the transistor if in the saturation region. Example gain values are 200 to 450 for a BC546 transistor or 45 for a TIP3055 transistor.

To ensure that the transistor is fully switched on even if the load changes then we normally multiply the base current by a factor of 10. If the base current at ten times the required base current exceeds the maximum base current then a value below the maximum base current should be used instead.

To provide the appropriate size resistor we use the following formula.

$$R_b = \frac{V_I - V_b}{I_b \, x \, 10}$$

Where V_I is the voltage input to the base resistor.

Source : http://www.penguintutor.com/electronics/transistor-switch