executive summary

IC's are widely used in many applications. One of the problems that arises when working with high current and high voltage circuits is the sink current of IC's. Most IC's can only source between 10mA to 25mA. Current boosters are needed to step up the current to an adequate level needed by the circuit. This application note will demonstrate ways to uses transistors as current boosting switches.

keywords

Current Boosters, Transistors, Switches, Relays, PWM
Introduction

Microprocessors and IC’s are used widely in many different applications. These chips could be used as signal-modulating elements i.e. pulse width modulation. Whether they are used in analog, digital or hybrid circuits these elements have some current and voltage limitations. Most IC’s and microprocessors are rated to supply between 10mA to 25mA, however practically this is closer to being between 5mA and 10mA. On the other hand when working with high voltage and high currents circuits, higher amperage will need to be supplied to the rest of the components. In these cases transistors can be used as both current boosters and switching devices.

Microprocessors and IC’s

Suppose a chip is being used to send a pulse width modulated signal. The voltage is going to be switching from high to low at a user set period (see Figure 1). This pulse width modulated signal will go into a resistive, capacitive or inductive load. As mentioned earlier, when the output is high the chip will be able to source approximately 7mA. To be able to drive some of our loads we will need currents higher than 50mA.

![Figure 1: Pulse Width Modulate Signal](image-url)
Transistors

Transistors can operate in several different stages. The most commonly used states are: active, cut-off and saturated. To use the transistor as a current boosting switch it will need to operate in its saturated stage. Transistors have three leads: the base, emitter and the collector (see Figure 2). The datasheet of a transistor will offer three very important specifications to consider: the base-to-emitter ON voltage \( V_{BE(ON)} \), the collector-to-emitter saturation voltage \( V_{CE(SAT)} \), and the transistor current gain \( H_{FE} \). To operate in the saturated mode there are several requirements:

\[
\begin{align*}
V_{BE} &= V_{BE(ON)} \\
V_{CE} &= V_{CE(SAT)} \\
i_B &\geq 0 \\
i_C &\geq 0 \\
i_C &\geq H_{FE}i_B
\end{align*}
\]

Figure 2: Leads of a Transistor
Saturating the Right Transistor

The basic structure to creating a current boosting switch using an NPN and PNP transistor is displayed in Figure 3 and Figure 4 respectively. Please note that the load is not restricted to being strictly resistive. Since every transistor has different specs it is necessary that the correct transistor is chosen to achieve the desired result given the circuit requirements.

**Figure 3**: Current boosting switch with NPN

**Figure 4**: Current boosting switch with PNP
This is a step-by-step process to choosing the right transistor.

**Step 1:**
The first thing that needs to be insured is the transistor’s maximum collector current rating. This needs to be greater than the load current. So for a resistive load:

\[ I_{C\text{ (max)}} \geq \frac{V_s}{R_L} \]

**Step 2:**
The next requirement is the current gain of the transistor. As a rule of thumb chose a transistor current gain five times greater than the ratio of the load current to the maximum transistor current. Therefore:

\[ H_{FE} > 5 \cdot \frac{I_L}{I_{C\text{ (max)}}} \]

**Step 3:**
Now that these two specifications have been found the correct transistor can be chosen. There are many lists available of transistors and their specifications available online.

**Step 4:**
Circuit still needs a resistor to limit the voltage going into the base of the transistor. The resistor can be approximated as the ratio of the product between the voltage coming out of the IC and transistor current gain and five times the load current. Therefore:

\[ R_B = \frac{V_{IC} \cdot H_{FE}}{5 \cdot I_L} \]

**Step 5:**
Finally, some loads may require a protection diode across them to ensure no reverse leakage current from damaging the load.
Example

Assume that a microprocessor is sending out a PWM signal with a high of 5V and a low of 0V to a relay. The relay has 270Ω coil resistance. The microprocessor can only output 10mA. The relay needs about 50mA to operate. The supply voltage for the relay is 13.8V. The current needs to be boosted and then sent to the relay. A transistor stage will be used.

Procedure

Step 1: Finding \( I_C(\text{max}) \)

\[
I_C(\text{max}) \geq \frac{V_s}{R_L} = \frac{13.8}{270} \]

\( I_C(\text{max}) \geq 51.13mA \)

Step 2: Finding \( H_{FE} \)

\[
H_{FE} \geq 5 \cdot \frac{I_L}{I_C(\text{max})} \\
H_{FE} \geq 5 \cdot \frac{51.13m}{10mA} \\
H_{FE} \geq 25.56
\]

Step 3: Choosing the right transistor

The 2N222A NPN transistor satisfies all the specification.

Step 4: Choosing the resistance

\[
R_B = \frac{V_{IC} \cdot H_{FE}}{5 \cdot I_L} \\
R_B = \frac{5 \cdot 220}{5 \cdot 51.13m} \\
R_B = 4.3028K\Omega \\
R_B \approx 4.7K\Omega
\]

4.7KΩ was chosen because that is the closest standard resistor value.
Simulation

**Figure 5** displays the pulse width modulated signal from the microcontroller. The high is 5V and the low is 0V.

![Pulse Width Modulated Signal from Microprocessor](image)

**Figure 5**: Pulse Width Modulated Signal from Microprocessor

**Figure 6** displays the current through the base of the transistor, which is switching from 0A to about 10mA.

![Current through the base of the transistor](image)

**Figure 6**: Current through the base of the transistor
Figure 7 displays the current through the collector, which has now been boosted to about 50mA. The collector current is also switching as the input voltage switches.

Figure 7: Current through the base of the transistor

Conclusion

IC’s are very powerful tools in the realm of electrical engineering. They can offer a range of simple scaling and inverting options to very complex modulation options, however their sink currents limit their use in high current circuits. To solve this problem transistors are used to boost the current while maintaining the functionality of the system. This application note offers tools and techniques to do that.
References

