SIEMENS

Driving High-Level Loads
With Optocouplers
Appnote 4

Frequently a load to be driven by an optocoupler requires more current, voltage, or both, than an optocoupler can provide at its output.

Available optocoupler output current is found by multiplying input (LED section) current by the "CTR" or current transfer ratio. For worst-case design, the minimum specified value would be used. The minimum CTR of the IL1 is 20%. Temperature derating is not usually necessary over the 0°C to +60°C range because the LED light output and transistor beta have approximately compensating coefficients.

Multiplying the minimum CTR by 0.9 would ensure a safe design over this temperature range. Over a wide range, more margin would be required.

The LED source current is limited by its rated power dissipation. Table 1 shows maximum allowable I_F versus maximum ambient temperature.

Values for Table 1 are based on a 1.33 mW/°C derate from the 100 mW at 25°C power rating.

Table 1

Maximum Temperature	I_F Maximum
40°C	50 mA
60°C	35 mA
80°C	17 mA

Obviously, one can increase the available output current either by choosing a higher CTR-rated optocoupler or by providing more current, or both. Table 2 shows the minimum available output current for the IL1, at T_A=60°C (from Table 1) and a 10 percent margin for temperature effects.

Table 2

P/N	I_{CE} (min) mA
IL1	6.3

If the IL1 is being operated from logic with 5 volt driving transistor and 0.2 volt V_{CE} saturation is assumed for the driving transistor; a 75 ohm R_{IF} resistor will provide the 48 mA. The forward voltage of the IR-emitting LED is about 1.2 volts. Figures 1A and iB show two such drive circuits.
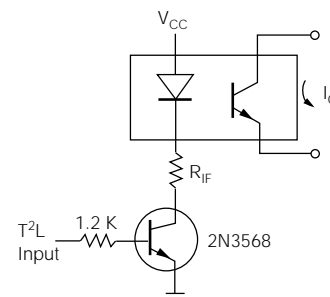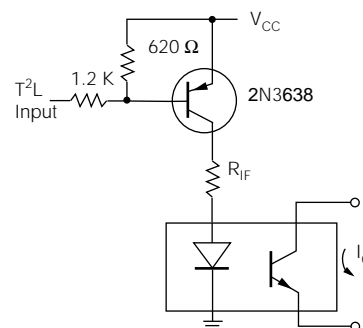

Figure 1A. NPN Driver

Figure 1B. PNP Driver

A "buffer-gate," such as the SN7440 provides a very good alternative to discrete transistor drivers. Figure 2 shows how this is done. Note that the gate is used in the "current-sinking" rather than the "current-sourcing" mode. In other words, conventional current flows into the buffer-gate to turn on the LED. This makes use of the fact that a T^2L gate will sink more current than it will source. The SN7440 is specified to drive thirty 1.6 mA loads or 48 mA. Changing R_{IF} from 75 to 68 ohms adjusts for the higher saturation voltage of the monolithic device.
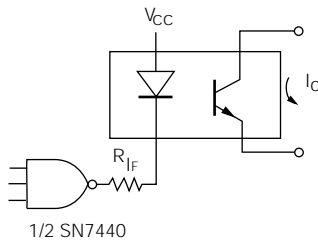
Figure 2. Buffer-Gate Drive

More Current

For load currents greater than 6.3 mA, a current amplifier is required. Figures 3A and 3B show two simple one-transistor current amplifier circuits.
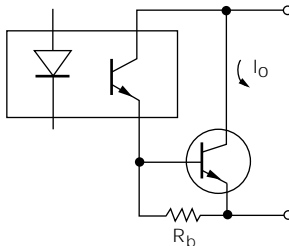
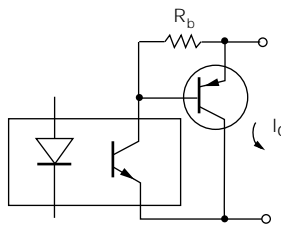

Figure 3A. NPN Current Booster

Figure 3B. PNP Current Booster

Since the transistor in the optocoupler is treated as a two-terminal device, no operational difference exists between the NPN and the PNP circuits. R_b provides a return path for I_{CBO} of the output transistor. Its value is: $R_b = 400$ mV/I_{CBO} (T) where I_{CBO}(T) is found for the highest *junction* temperature expected.

Assume that leakage currents double every ten degrees. Use the maximum dissipated power, the specified maximum junction-to-ambient thermal resistance, and the maximum design ambient temperature in conjunction with the specified maximum 25° I_{CBO} to calculate I_{CBO}(T)

As an example, suppose a 2N3568 is used to provide a 100 mA load current. Also assume a maximum steady-state transistor power dissipation of 100 mW and a 60°C maximum ambient. The transistor junction-to-ambient thermal resistance is 333°C/watt, so a maximum junction temperature of 60 + 33 or 93°C is expected. This is about 7 decades above 25°C. Therefore, I_{CBO}(T)=I_{CBO}(max) x 27=50 nA x 128=6.5 µA. A safe value for R_b is 400 mV/6.5 µA=62 kilohms.

Working backwards, maximum base current under load will be I_O/h_{FE}(min)=100 mA/100=1 mA. Current in R_b is V_{BE}/R_b= 600 mV/60k=10 µA, which is negligible. An IL1 with a 9 mA drive would operate effectively.

If the load requires more current than can be obtained with the highest beta transistor available, then more than one transistor must be used in cascade. For example, suppose 3 amperes load current and 10 watt dissipation are needed. A Motorola MJE3055 might be used for the output transistor, driven by a MJE205 as shown in Figure 4. Using a 5°/watt heat sink and the rated MJE3055 junction-to-case thermal resistance of 1.4°/watt, we find that junction temperature rise is 6.4 x 10, or 64°. Therefore maximum junction temperature is 124°C. This is 10 decades above 25°C making I_{CBO}(T)= 2^{10} I_{CBO}(max)=10^3 I_{CBO}(max).
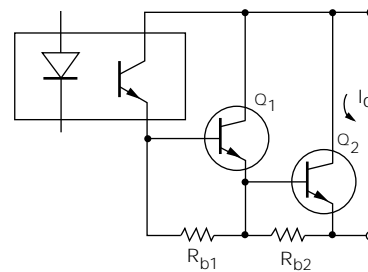

Figure 4. Two NPN Current Boosters

I_{CBO}(max) at 30 volts or less is not given, but I_{CEO} is. Using (for safety) a value of 20 for the minimum low current h_{FE} of the device, I_{CBO} could be as large as I_{CEO}/20=35 µA. Then I_{CBO}(T) is 35 mA and R_{b2}=400 mV/35 mA=11 ohms. For I_b use I_O/h_{FE} (min at 4 A)=3 A/20=150 mA. I_{Rb2}=600 mV/10 ohms=60 mA, so $I_{e(Q1)}$=210 mA.

Maximum power in Q_1 will be about 1/14 the power in Q_2 since its current is lower by that ratio and the two collector-to-emitter voltages are nearly the same. This means Q_1 must dissipate 700 mW.

Assuming a small "flag" heat sink having 50°/watt thermal resistance, we find the junction at about 95°C. The 150°C case temperature I_{CBO} rating for this device is 2 mA, so one can work backwards and assume about 1/30 of this value, or 70 µA. On the other hand, the 25° rated I_{CBO} is 100 µA. Choosing the larger of these contradictory specifications, R_{b1}=400 mV/0.1 mA=4k≈3.9 k. Q_1 base current is $I_{E(Q1)}$/ $h_{FE(Q1-mjn)}$=210 mA/50*=4.2 mA. Total current is $I_{b(Q1)}$ + I_{Rb1}=4.2 + 0.24=4.5 mA. Table 2 shows that an IL1 could be used here.

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*Minimum hFE is obtained using the specification at I_{CE}=2 A and the "Normalized DC Current Gain" graph given in Motorola's "Semiconductor Data Book", 5th edition, pp. 7–232 and 7–233

More Load Voltages

All of the current-gain circuits shown so far have one common feature: load voltage is limited by the 30 volt rating of the IL1 not by the voltage or power rating of the transistor(s).
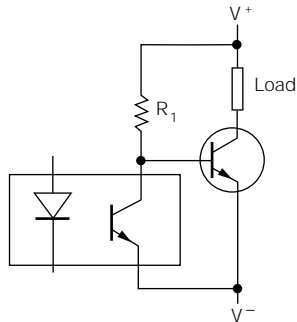

Figure 5A. NPN HV Booster

Figure 5A shows a method of overcoming this limitation. This circuit will stand off BV_{CEO} of Q_1. The voltage rating of the phototransistor is irrelevant since its maximum collector-emitter voltage is the base emitter voltage of Q_1 (about 0.7 volts).
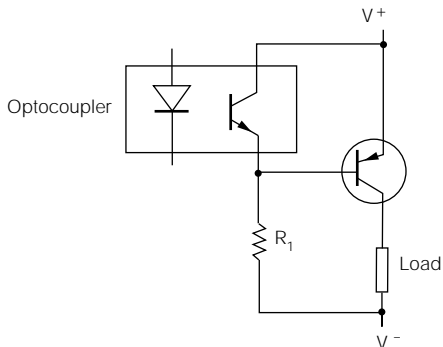

Figure 5B. PNP HV Booster

Unlike the "Darlington" configurations shown previously, this circuit operates "normally-ON." When no current flows in the LED the phototransistor, being OFF, allows R_2 current to flow into the base of Q_1, turning Q_1 ON. When the optocoupler is energized, its phototransistor "shorts out" the R_2 current turning Q_1 OFF.

The value of R_1 depends only on the load-supply voltage $V^+ - V^-$, and the maximum required Q_1 base current. This is derived from the minimurn beta Of Q_1 at minimum temperature and the load current. The required current-drive capability is the same as I_{R1}. since I_{R1} changes negligibly when the circuit goes between its "ON" and "OFF" states.

In some applications either more current gain will be required than one transistor can provide or the power dissipated in R_1 will be objectionable. In these cases, simply use the Darlington high-voltage boosters shown in Figure 6A.
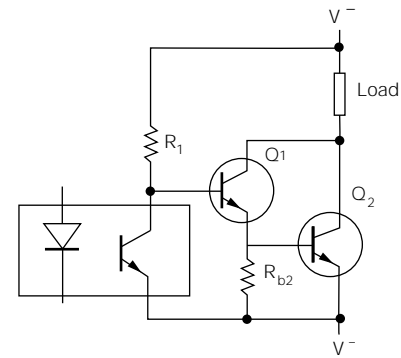

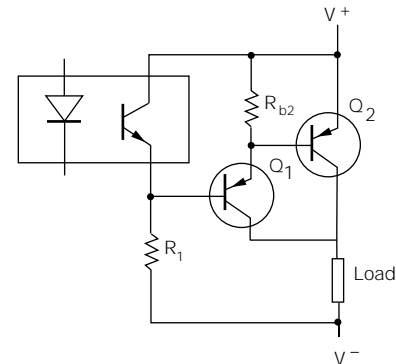**Figure 6A. NPN Darlington HV Booster**

Figure 6B. PNP Darlington HV Booster

If more than one load is being driven and their negative terminals must be in common, use the PNP circuit (Figure 6B). Otherwise, the NPN is better because the transistors cost less. Performance characteristics of the NPN and PNP versions are identical if the device parameters are also the same.

Applications

Optocoupler isolated circuits are useful wherever ground loop problems exist in systems, or where dc voltage level translations are needed. In many systems so-called interpose relays are used between a logic circuit section (which may be a mini-computer) and the devices being controlled. Sometimes *two levels* of interpose relays are used in cascade either because of the load power level or because of extreme difficulties with EMI. Optocouplers aided by booster circuits such as those described can replace many of the relays in these systems.

The reed relays, typically used as the first level of interpose and mounted on the interface logic cards in the electronic part of the system, are almost always replaceable by optocouplers since their load is just the coil of a larger relay. This relay may have a coil power of 1/2 to 5 watts and operate on 12, 24 or 48 volts dc.

Assuming worst-case design techniques are carefully followed, system reliability should improve in proportion to the number of relays replaced.