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AND8198/D

Using the NUD4001 to Drive High Current LEDs

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APPLICATION NOTE

Introduction

The use of Light Emitting Diodes (LEDs) has increased dramatically over the past few years. LEDs have become almost commonplace in applications such as traffic lights, brake lights, turn indicators and backlighting because of their longevity compared to incandescent bulbs. To keep the LEDs light output constant, the current through the device must be constant. There are many possible solutions to achieve this, ranging from a series resistor to a linear regulator to a switching power supply. Each one offers its own particular advantages. One of the main considerations with lighting suppliers is the cost. Above all, we must keep in mind that the competition is an incandescent bulb, and although the LED solution may be superior in terms of lifetime, the up front cost must be a close as possible to the cost of a simple bulb.

NUD4001

The NUD4001 from ON Semiconductor is a low cost versatile LED driver. The device allows the user to set the current with an external resistor and it is capable of delivering currents of up to 500 mA in a SO8 package. Of course, the 500 mA output current depends on a number of factors including input and output voltage, the number of LEDs driven and the amount of heatsinking that is provided on the PCB.

As described in the data sheet and application note AND8156/D, the maximum power dissipation for the NUD4001 is about 1.13 W, which limits the NUD4001 to driving 1 W LEDs. There are a number of ways to squeeze the last bit of heat of the NUD4001, including the use of a series resistor in situations where the input to output differential is high, or the use of multiple NUD4001 to share current. These techniques are described in the documents mentioned above and in the Design Guide available on the ON Semiconductor website at:

http://www.onsemi.com/pub/Collateral/DESIGN_GUIDE−D.XLS

These techniques are very useful in many applications but do not make up for the limitations of the SO8 package that houses the NUD4001. We could use a switching power supply solution at higher power level but that introduces extra cost, complexity and EMI to the design.

In this article, we use the NUD4001 as a control IC to drive an external Power transistor that carries most of the LED current. It offers all the advantages of the NUD4001, an easily selectable current, low cost, and versatility but with the capability of delivering higher currents to power 3 W LEDs.

NUD4001 Circuit Description

The representative block diagram of the NUD4001 integrated current source is shown in Figure 1.

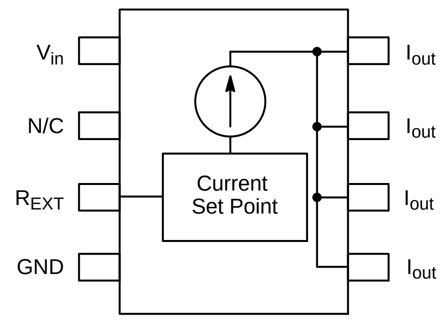

Figure 1.

An external resistor connected between Pin 1 and Pin 3 sets the output current. There is a voltage drop of approximately 0.7 V between these two pins so the output current becomes:

$$\frac{0.7\ V}{R_{EXT}} = I_{OUT}$$

The NUD4001 maintains this current independent of input voltage as long as the minimum voltage overhead is available.

A typical NUD4001 circuit is shown in Figure 2.

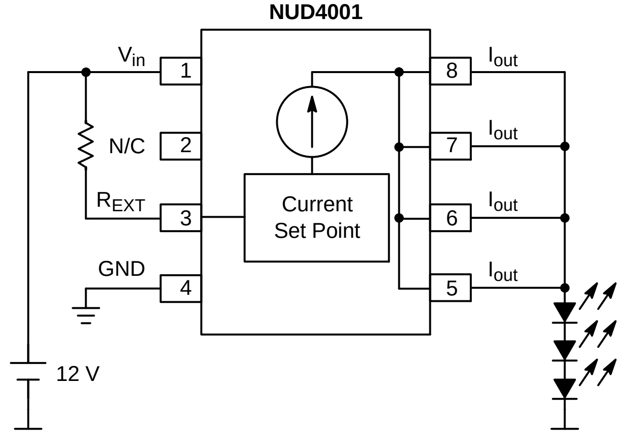

Figure 2.

If the LEDs are 1 W devices (with a load current of 350 mA), the power dissipation in the NUD4001 is approximately 0.355 W. The detailed calculations are available in the NUD4001 data sheet.

If the LEDs are 3 W LEDs as could be expected in an Automotive tail light application, the power dissipation is increased to the point where the NUD4001 alone will not be able to handle the extra heat generated.

Using the NUD4001 with an External Power Transistor

Figure 3 shows the NUD4001 as a control IC that regulates the current through an external PNP transistor (in this case, the MJB45H11). Since the majority of the current flows through the MJB45H11 power transistor, it dissipates most of the power and needs additional heatsinking. In this case, we use additional copper on the PCB, but a TO−220 package can also be bolted to a commercial heatsink or to the same heatsink material that is used for the LEDs.

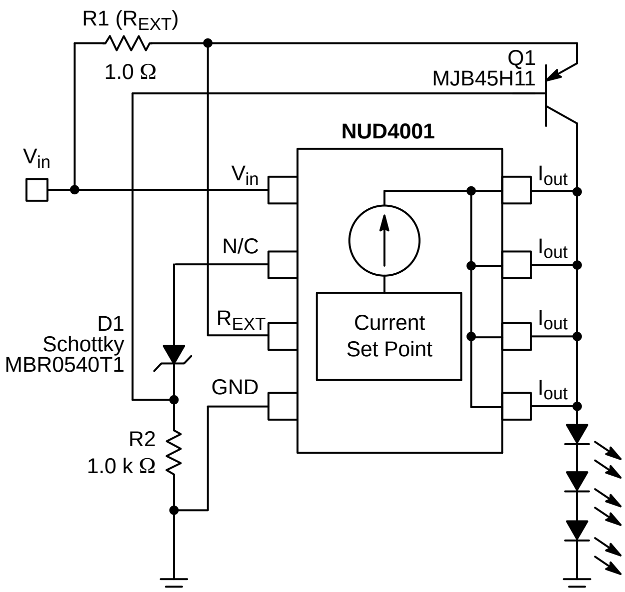

Figure 3.

Looking at the Figures 1 and 2, for the NUD4001, one of the first things you will notice is that Pin 2 is marked as N/C (or no connect). Normally this is the case, but Pin 2 is also available to drive an external transistor.

In the circuit shown in Figure 3 the diode D1 and external resistor, R2, with the internal circuitry both work to set up a base current for the external pass transistor, Q1. The additional voltage drop across the diode D1 ensures that there is a sufficient V_{BE} to turn on the external transistor Q1. Although a Schottky diode is used in this schematic, D1 can easily be replaced with a less expensive signal or switching diode if required.

Q1 delivers most of the output current to the LEDs without contributing any additional voltage drops in the circuit. As long as the circuit has sufficient headroom to operate, the external transistor will carry most of the current.

We will use the following design example to illustrate the operation of the circuit.

Design Example

To drive three 3.0 W LEDs in series with an input voltage that ranges from 12 V to 16 V:

V_{LED} per LED = 3.5 V
I_{LED} = 700 mA
V_{IN} = 19 V to 16 V
T_A = −40°C to 85°C

1. Calculate R_{EXT}

$$\frac{0.7\text{ V}}{I_{OUT}} = R_{EXT} = \frac{0.7\text{ V}}{0.7\text{ A}} = 1.0\ \Omega$$

2. Define V_{LED} for the LED string.

$$V_{LED} = 3.5 \times 3 = 10.5\text{ V}$$

3. Calculate the Voltage drop across the NUD4001 and associated circuitry.

$$V_{DROP} = V_{in} - V_{LED} - V_{SENSE}$$

$$V_{DROP} = 12\text{ V} - 10.5\text{ V} - 0.7\text{ V}$$

$$V_{DROP} = 0.8\text{ V}$$

At high line:

$$V_{DROP} = 16\text{ V} - 10.5\text{ V} - 0.7\text{ V}$$

$$V_{DROP} = 4.8\text{ V}$$

4. Calculate the power dissipation in the NUD4001 and external transistor at high line.

$$P_D = V_{DROP} \times I_{LED} = 4.8\text{ V} \times 0.7 = 3.36\text{ W}$$

5. Calculate the power dissipation in the NUD4001 control circuitry based on the information in Figure 4 of the data sheet.

There will be some additional current flowing through the NUD4001 due to the external resistor R2 and Schottky diode D1. A good estimate is to take 1.1 times the value shown in Figure 5 as being the new internal power dissipation in the control section of the NUD4001.

Using the graph, for a V_{in} of 16 V, the power dissipation is approximately 0.13 W, so, allowing for the extra current through the control section of the NUD4001 we calculate the P_D from:

$$P_{D(Cont.NUD4001)} = 0.13\text{ W} \times 1.1 = 0.143\text{ W}$$

6. Calculate the Power Dissipation in the Driver section of the NUD4001. While it is difficult to calculate the current through the NUD4001, it is easy to measure with a current probe or meter by comparing the current flowing through the various paths to the load. As an example, with V_{in} = 13.7 V at room temperature, the current through the MJB45H11 is measured as 694 mA. The total output current is measured at 694 mA also, leaving less than 1 mA to flow through the NUD4001.

The power dissipation is given by:

$$P_{D(NUD4001)} = 0.8\ V \times I_{OUT(NUD4001)}$$

$$P_{D(NUD4001)} = 0.8\ V \times 0.001 = 0.0008\ W$$

7. Calculate the total Power Dissipation in the NUD4001.

$$P_{D(TotalNUD4001)} = P_{D(Cont.NUD4001)} = P_{D(NUD4001)}$$

$$P_{D(TotalNUD4001)} = 0.143\ W + 0.0008\ W = 0.144\ W$$

8. Calculate the heatsink requirements for the NUD4001 based on the information in Figure 11 in the data sheet. This graph is reproduced as Figure 5 in this paper. From Figure 4, the worst case $R_{\theta JA}$ = 170°C/W with minimum board area.

$$P_D = \frac{T_{JMAX} - T_A}{R_{\theta JA}} = \frac{150°C - 85°C}{170} = 0.382\ W$$

This is well above our calculated P_D of 0.144 W, so the NUD4001 will need only a minimum pad size heatsink area in this application.

9. Select a heatsink for the external pass transistor.

As calculated in Step 4, the power dissipation at high line (V_{in} = 16 V) is just over 3 W.

Unfortunately, the MJB45H11 data sheet contains little useful thermal information so we have to depend on other data. The $R_{\theta JA}$ is listed at 75°C/W, this is most likely the figure with a minimum pad size.

Figure 6 shows a graph of Thermal Resistance vs. Pad size for a typical D^2PAK.

The pad size to dissipate 3.3 W will need to be greater than 30 mm square. At higher power dissipation it is advisable to use a TO−220 package and a heatsink.

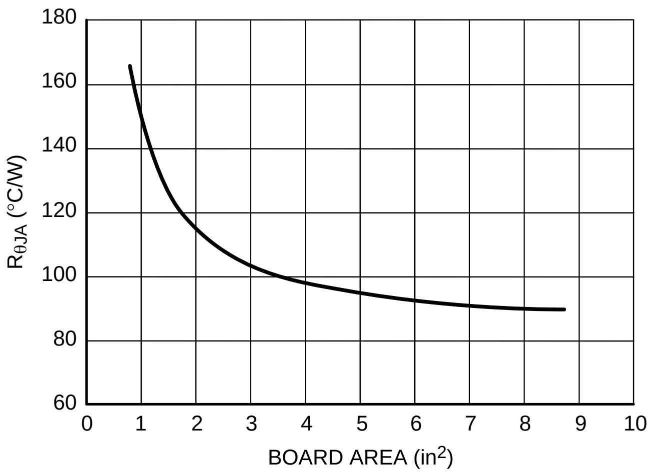

Figure 4. $R_{\theta JA}$ versus Board Area

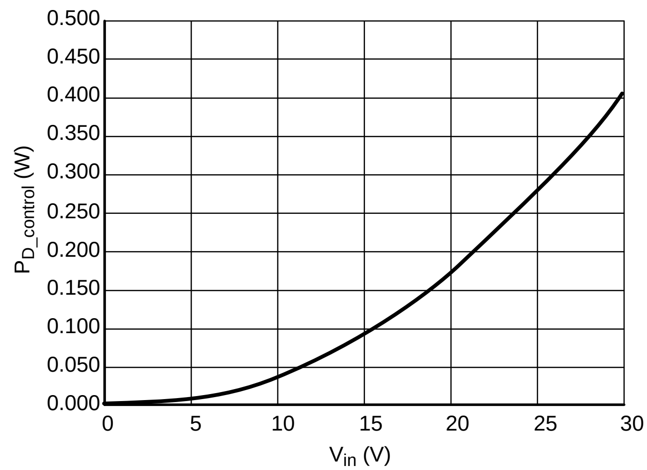

Figure 5. Power Dissipation vs. V_{in} for the NUD4001

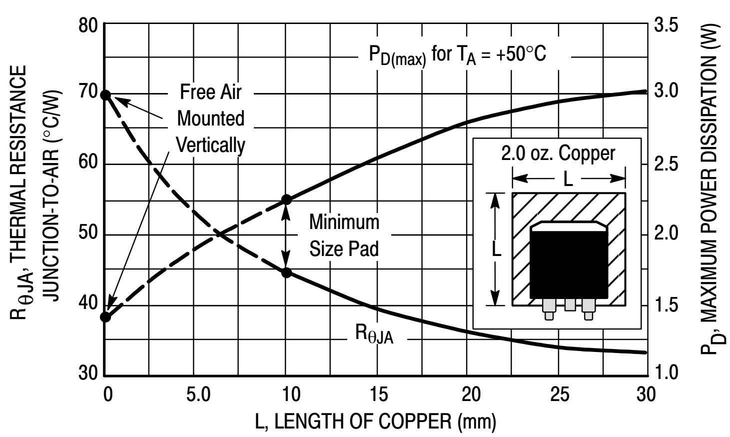

Figure 6. Thermal Resistance vs. Pad Size for a Typical D^2PAK

Current Sharing

As mentioned earlier, the external transistor will carry most of the current provided the circuit has sufficient headroom to operate properly. In the circuit described here, the 3 LEDs have a combined forward voltage of 10.1 V at 700 mA. The NUD4001 needs approximately 1.4 V of headroom. If the input voltage drops below about 11.5 V there is insufficient voltage to fully turn on the external transistor and the NUD begins to carry more of the output current. This is illustrated in Figure 7.

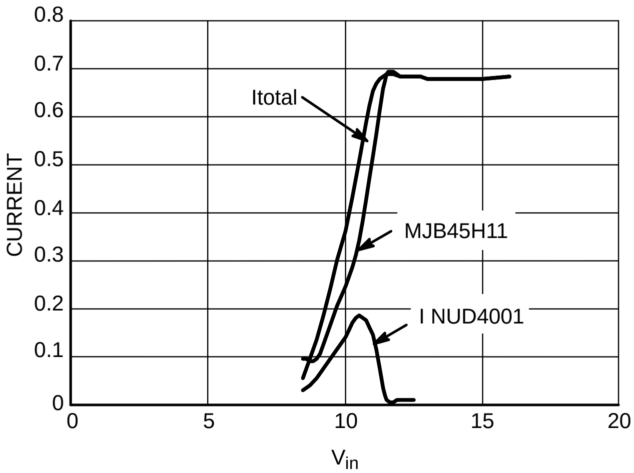

Figure 7. Current Sharing

Conclusion

The NUD4001 works well as a control IC for high current applications and the user now has to contend with the easier task of heatsinking an external transistor in a power package such as a DPAK, D^2PAK or TO−220. This circuit is also applicable where there is a large difference between the input voltage and the LEDs forward voltage, e.g., where one or two LEDs are driven from a 12 V source.

References

[1] NUD4001/D − ON Semiconductor Data Sheet.
[2] AND8156/D − ON Semiconductor Application Note.

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