Driving LEDs with a PIC Microcontroller

Application Note

Introduction

Nowadays, applications increasingly make use of LEDs as a replacement for traditional light bulbs. For example, LEDs are frequently used in the design of automobile tail lights, signal lights, traffic signals, and variable message signs.

LEDs provide several advantages over traditional light bulbs, such as smaller size and longer life. In many applications, the LEDs must be driven with intelligent control circuitry. According to the task at hand, this control circuitry must be able to fulfill various functions and tasks. In the following pages, solutions are provided for various application areas. These solutions are principal suggestions, not a concept ready for series production.

One possible task for control circuitry is regulation of intensity, in case the LED brightness must be set to various levels. A solution is described in the section "Dimming". In addition, the specified brightness should be maintained at a constant level. Fluctuations in the supply voltage, for example, could lead to significant variations in current. In this case, one must insure that the current through the LEDs and thus the brightness is maintained at a constant level. This problem is covered in more detail in the section "Current Regulation".

Another task for control circuitry is failure recognition. Modules consist of individual LEDs which can be tested for total failure. Additional information can be found in the section "Failure Recognition".

A particular characteristic of LEDs is their strong temperature dependency. Since LED brightness is strongly dependent on temperature, the driver circuitry can carry out temperature compensation. Two possible approaches are described in the section "Temperature Compensation".

Furthermore, it may be necessary to adapt the driver for LEDs in different brightness groups by means of hardware selection. This is described in the section "Adjusting for Different Brightness Groups".

In the following applications, a PIC microcontroller is used as a controlling unit.

The PIC Microcontroller

PIC stands for "Programmable Interrupt Controller". The controller described below has been developed by the company Microchip (www.microchip.com). The PIC comes in various sizes and functionality. For development purposes, rewritable devices are available, which can be erased electrically or by UV light. For production, OTP (One Time Programmable) devices are available, which may only be programmed once, but are correspondingly less expensive. PICs may also be obtained in SMD packaging. Although there are some disadvantages (less memory, limited instruction set, limited debugging facilities), the PIC has several advantages over other microcontrollers. It is inexpensive and all of the required hardware is available on one chip. It can be driven at clock rates of up to 20MHz and has exceptionally low power requirements. In addition, the PIC operates within a wide temperature range.

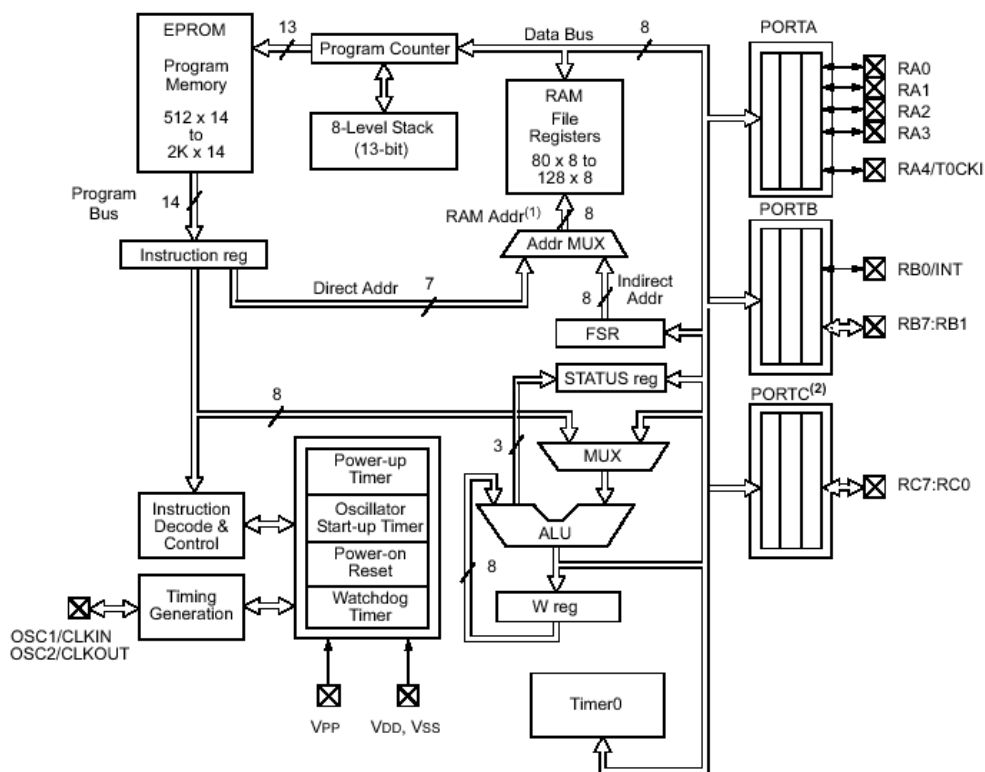Figure 1 shows the block diagram of a typical PIC microcontroller:

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Figure 1: Block diagram of a PIC microcontroller

For the following tasks, several integrated modules of the PIC are used:

Some of the pins of the microcontroller can be configured as analog inputs. The analog voltages can be converted to digital values by means of an A/D module. The signal to be converted is chosen by software, and forwarded to the A/D module. This module requires a constant reference voltage. The voltage can either be applied externally at an input pin, or internally via a so-called voltage reference module. In the latter case, the supply voltage to the PIC must be kept constant by means of a voltage regulator.

Programming the PIC

Hardware

Extensive hardware is not required to program the controller, and is available from several manufacturers. Simple programming devices can also be built from scratch (examples at: www.ic-prog.com).

Software

Software for creating Assembler programs which are downloaded and executed in the controller is available at no charge. The use of a C compiler for the PIC is recommended, however. This allows the program to be easily managed and permits changes to be readily made. These C compilers only offer a subset of the language, however.

LED Layout

When using driver circuitry, the layout of the LED array must be taken into account. In principle, there are three possibilities: a matrix connection with a resistor for the entire circuit, a series connection or a matrix connection with a resistor for each LED. Additional information can be found in the application note "Comparison of different LED circuits". The following applications use a matrix connection with a resistor for each LED (Fig. 2).
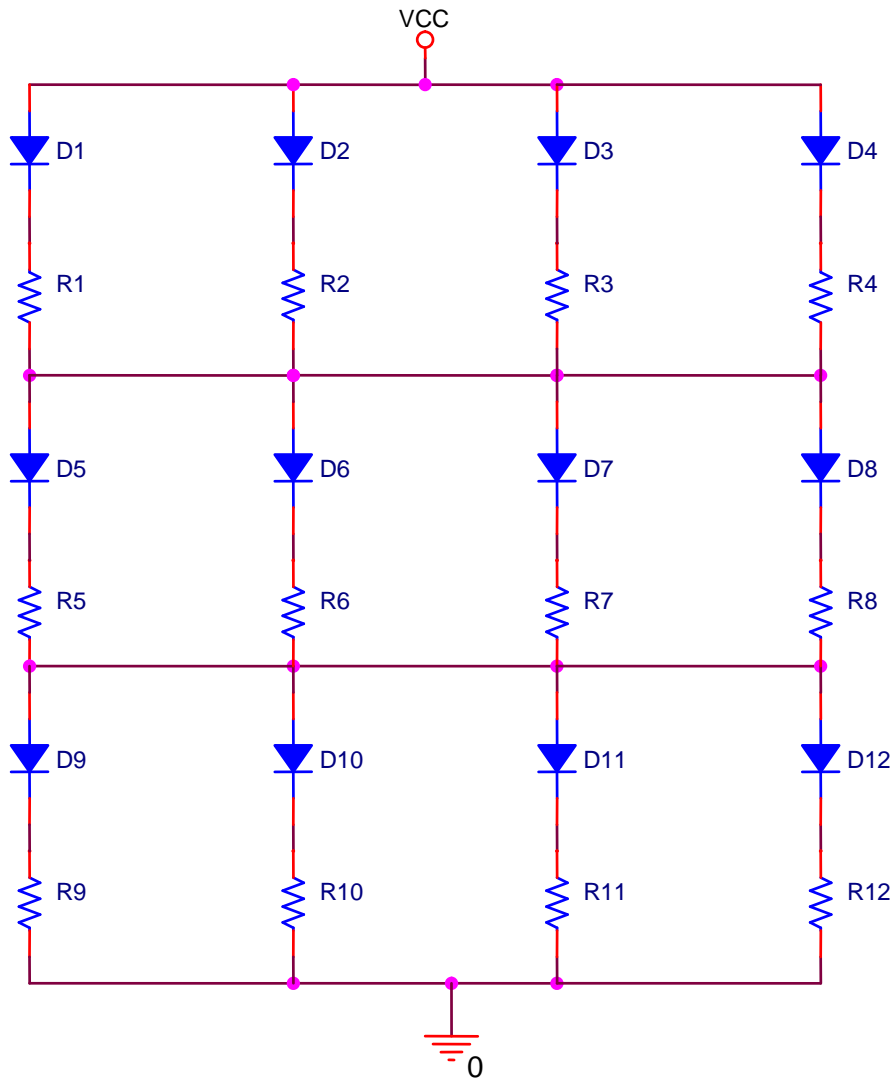
Figure 2: LED array in a matrix connection with one resistor per LED

Each LED possesses its own series resistor. These resistors can be used as reference resistors for adjusting the current in the diode.

If one LED fails, the remaining LEDs continue to function; this is not the case in the series connection, for example. A failure leads to more current in the parallel-connected diodes, however, since the total current would then be distributed among the remaining three paths. An uneven distribution of brightness would arise, although the loss in brightness would primarily be compensated by an increase in current flowing through the remaining LEDs in the same path.

Solutions

The following sections describe the possible functions of the driver circuitry:

Dimming

The first function is the creation of different brightness levels by dimming the LEDs. A simple solution is to use PWM (pulse width modulation). This signal can be easily set and controlled using the built-in PWM module within the microcontroller. This is simply a matter of periodically switching a DC voltage on and off.
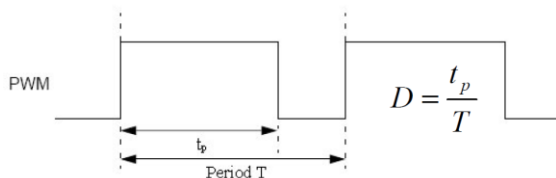
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Figure 3: Representation of a PWM signal

$$D = \frac{t_p}{T}$$

If the period remains constant, the brightness can be regulated by the width of the duty cycle. An advantage of using a PWM signal is that the peak current level remains constant, thus preventing negative effects (such as wavelength shift in InGaN devices) from arising.

Current Regulation

The brightness of the LED should be held constant by the driver circuitry. In order to guarantee that the brightness remains constant, the current through the LED must remain constant. This requires that the current be determined for the individual LEDs. To measure the current passing through the diodes, the series resistor for each diode is utilized. By measuring the voltage across the resistor, the current through the resistor, and thus the current through the diode can be determined. The voltage measurement is carried out by the A/D module of the PIC, in which voltages up to 5V can be compared to a constant reference voltage. The A/D module should not be directly connected across the series resistor, however. For one thing, the voltage levels may be considerably higher than 5V. In addition, the PWM signal must first be converted to a DC signal. After 2 measurements and the subsequent subtraction, a doubled measurement error arises. These problems are eliminated with the following circuit shown in Figure 4.

The positive Input voltage is connected to U2, the negative to U1. The RC components convert the signal to a DC signal. These 2 DC-signals are connected to the operational amplifiers. With various resistors, these two amplifiers are configured as a subtractor.

With this circuit, the DC-Voltage of U1 is subtracted from U2. This difference is now measured by the A/D module.

This allows the controller to react to fluctuations in current. Since the operational amplifiers have very high input impedance, the system is not influenced by the measurement circuitry.
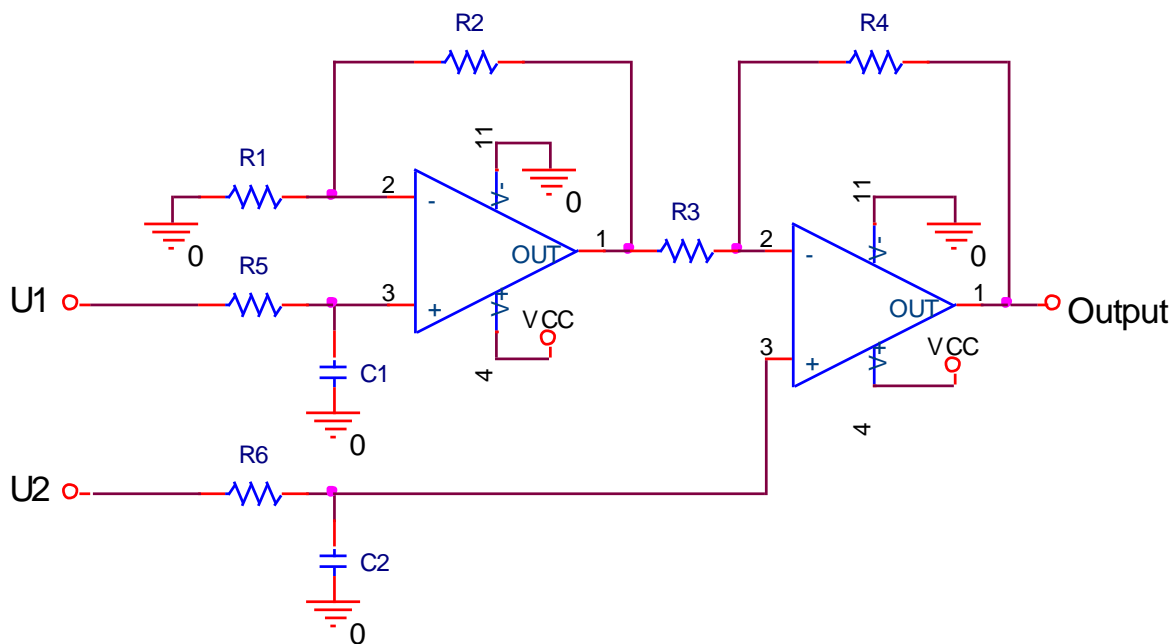

Figure 4: Current measurement circuitry

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Temperature Measurement

Even when the current remains constant, the brightness can vary, however, due to the influence of temperature.
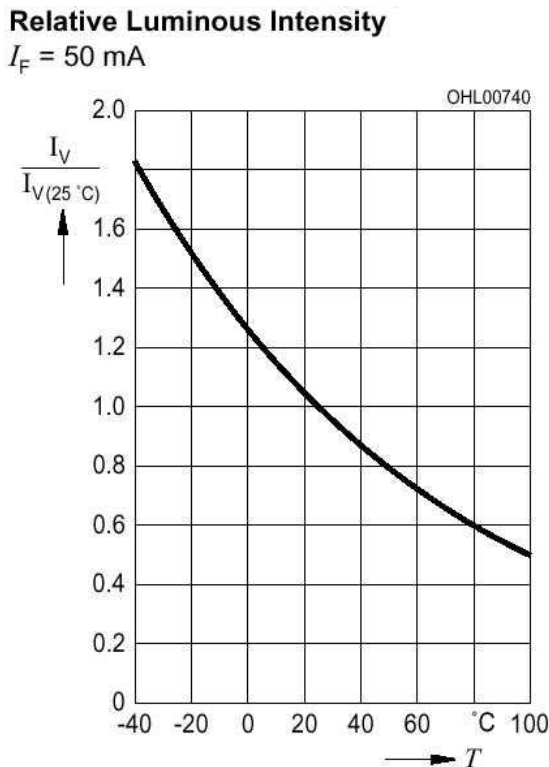The following figure shows this dependency for a Power TOPLED (LA E67B):

Relative Luminous Intensity
$I_F = 50$ mA

Figure 5: Brightness vs. temperature

In order to maintain a constant brightness over an extreme temperature range, temperature compensation must be employed. The measurement of ambient temperature should be as inexpensive as possible, though. For diodes, this compensation does not require a high degree of accuracy. A tolerance of 5°C is sufficient.
The following presents 2 possibilities for temperature measurement:

- via temperature-dependent resistor

The first option is to place a temperature-dependent resistor in series with a tempera-ture-**in**dependent resistor. By measuring the voltage with the A/D module, the tempera-ture can be determined, and the controller can respond accordingly.
The disadvantage of this method is that the response curve of the resistor must be saved as a table of values in the PIC memory.

- via a watchdog timer

With this method, a drawback of the so called watchdog module of the PIC can be used. This module consists of an 8-bit timer which is regulated by an internal RC oscillator. Normally, this timer runs in the background, and is reset by the micro-controller on a regular basis. This allows the controller to return to a defined state if the controller gets stuck due to an error, or in an infinite loop. The RC oscillator used is temperature dependent, however. If one uses an external temperature-compensated clock generator, the temperature can be determined by comparing the two clock generators.
Additional information can be obtained from the manufacturer:
http://www.microchip.com/download/appnote/pic16/00720c.pdf.

This method does not require external components, but the temperature dependency of the watchdog timer is not guaranteed by the manufacturer.

Failure Recognition

Of course, brightness regulation is of no use when an LED no longer functions. The following describes a method for testing individual LEDs within an array for total failure.
For failure recognition, the previously used circuit for measuring current is employed. The total failure of an LED leads to a break in the path, and therefore also causes no current to flow through the series resistor. Naturally, one cannot add current measuring circuitry at every diode, due to the high component cost and real estate involved. The solution here is to use a multiplexer. This allows each diode to be selected and connected to the measurement circuitry.
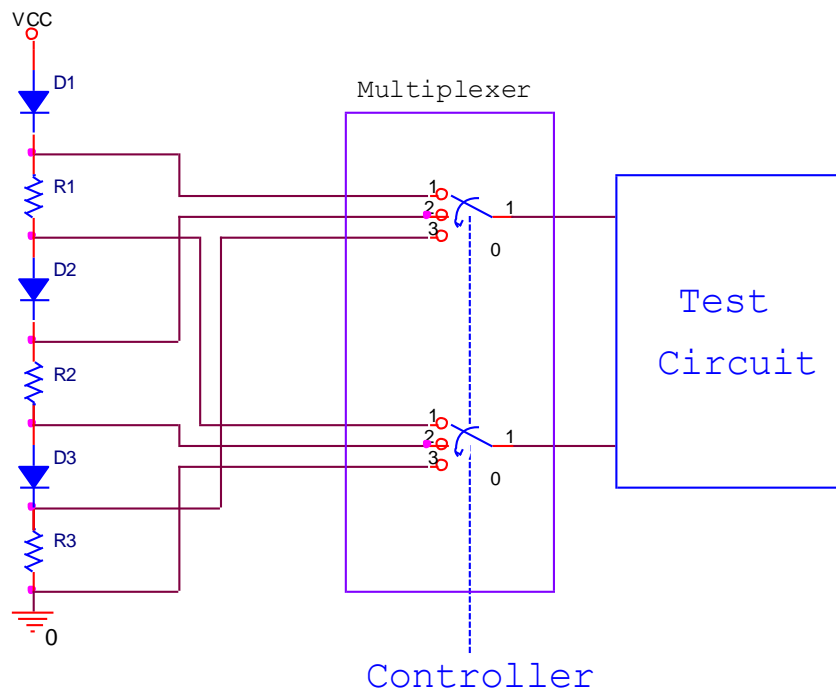
Figure 6: Failure recognition circuitry

The Figure 6 illustrates the technique for a circuit containing three diodes:

The multiplexer can be digitally controlled by the microcontroller. Each LED is assigned an address which allows it to be selected by the PIC, in order to determine the current passing through the diode for current regulation or to assist in failure recognition.

Adjusting for Different Brightness Groups

An additional option for the driver circuitry consists of an adjustment for different brightness groups. With LEDs, it must be noted that diodes of the same type are divided into various brightness groups. The usage of different brightness groups leads to a different brightness of the LEDs at the same current. With the PWM-Signal the brightness can be adjusted. The programmable input/output pins provide the means for adjustment without requiring the controller to be reprogrammed. The individual brightness groups are designated by a number. Enough input pins must be available to be able to differentiate between all numbers. For example, with 3 input pins, 2^3=8 brightness groups can be differentiated. Then, according to the configuration of the input pins (high or low), the number can be specified at the controller input, the corresponding brightness group is selected and the brightness can be adjusted. In the following example, eight different brightness groups can be used.
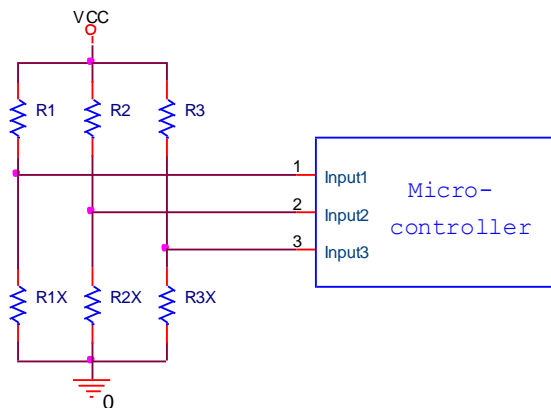

Figure 7: Layout for adjustment of brightness groups

Depending on the value of the resistors R1X to R3X, a high signal (>4V) or low signal (<1V) is applied to the inputs, and the corresponding brightness group is selected.

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Circuit Diagram

In the following figure, the principle construction of the driver circuitry with the previously described applications is described. The LED array consists of nine diodes connected together.

Note:
The PWM signal created by the controller is amplified by a transistor prior to being applied to the array. The amplitude of 5V is too low to drive the array directly.

If the array size is increased, additional paths must be connected to the multiplexer and additional transistors may possibly be required for amplification.
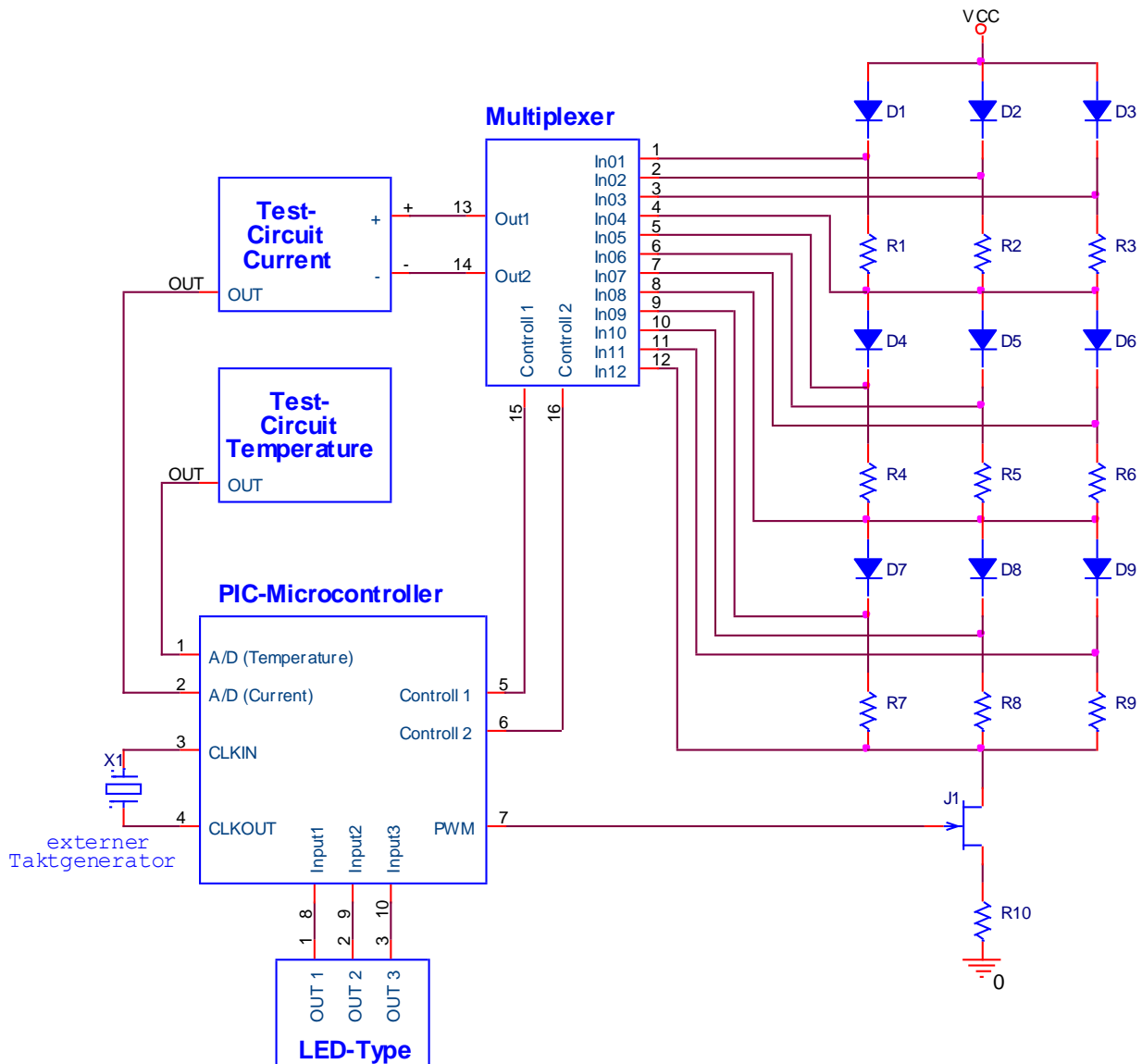

Figure 8: Possible driver circuitry

Further Configuration Options

The solutions described for this relatively complex application can also be implemented individually. For example, extensive circuitry can be eliminated if it is not necessary to test every LED for failure.

Figure 9 shows a simpler configuration without failure recognition and temperature compensation for LEDs connected in series. The current through each path can be determined.

A further possibility is a matrix connection with one series resistor for the entire array (Fig 10). The transistors can also be eliminated when an amplitude of 5V is sufficient. Many PICs have up to three independent PWM modules. The total current through the resistor can be determined without complicated circuitry.
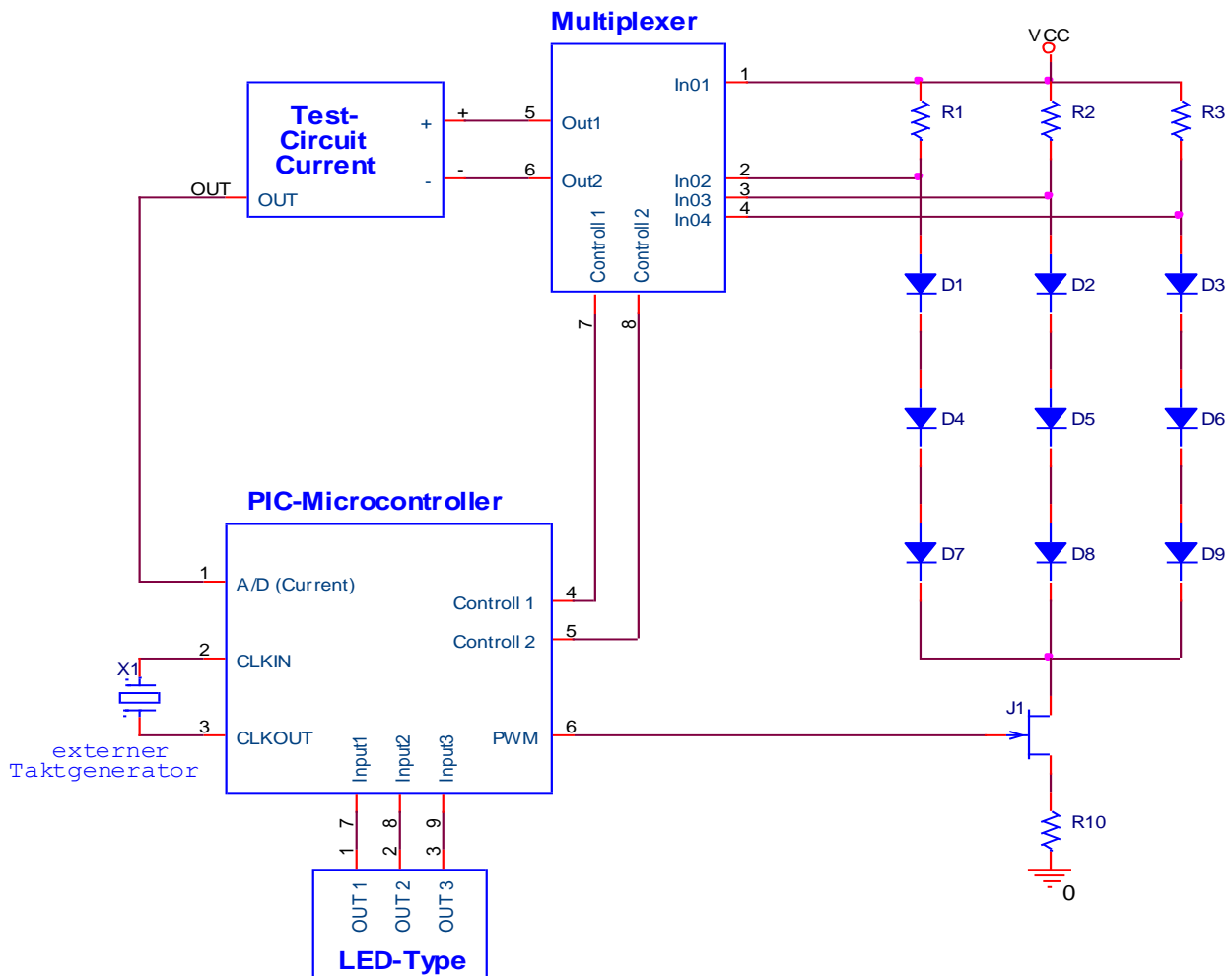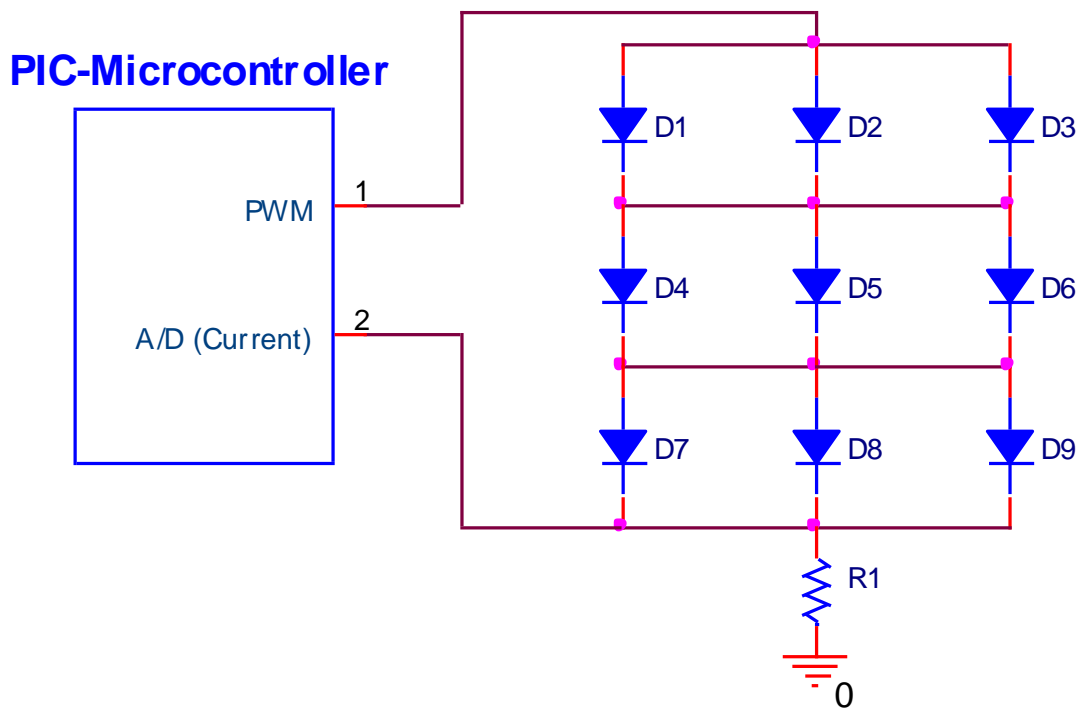

Figure 9: Circuit example with serial connection

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Figure 10: Circuit example with matrix connection

Conclusion

The applications shown here are not restricted to a particular type of LED. The appropriate resistor values must be selected and the temperature characteristics must be entered into a lookup table in memory. Additional options are available when using a controller. Many controllers provide serial communications capabilities (USART, SPI, USB, CAN, etc.), which permit connections to other devices.

The applications described here allow driver circuitry to be created which can be individually tailored to address the tasks at hand.

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