
Dimming AC Incandescent Lamps Using A PIC10F200

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INTRODUCTION

One of the earliest circuits in home electronics is the venerable incandescent AC lamp dimmer. It is also one of the most challenging circuits to get right. In this technical brief we will examine how using a microcontroller can both simplify the circuit and make it efficient.

THEORY

Early dimmers were very simple circuits, not much more than a high-current rheostat (variable resistor) wired in series with the lamp. For low-light conditions, it was adjusted to a high resistance, reducing the current through the lamp filament. For high-light conditions, it was adjusted for a low resistance increasing the current flow in the filament. However, because it was essentially a current limiting resistor, it typically dissipated a lot of heat, especially in the middle of its range. So the search was on for a more efficient method of dimming.

With the advent of semiconductor thyristors, a new method of dimming was born. The method of dimming involved delaying the turn-on time of a triac until a controlled time after each zero crossing. Because the zero crossing resets the triac (turning it off), the delay essentially pulse width modulated the lamp, delivering only a portion of the potential current in each cycle and dimming the AC lamp.

Generating the delayed triggering of the triac initially involved an RC network with a variable R, which created the required time delay. However, as simple as the circuit is for a RC gate drive, it still suffers from nonlinearity's due to the sinusoidal shape of the AC waveform. Production dimmers alleviated this problem by creating a custom potentiometer with a nonlinear resistance curve, which approximated linear dimming. But, due to the high voltages involved, there was still a significant amount of heat dissipated in the resistor.

So, what about using a microcontroller to control the triac? It can generate an appropriate timing delay using a table to produce a linear dimming curve, and a microcontroller opens up a number of user interface possibilities. Unfortunately, microcontrollers do not run at AC line voltages, they need a low-voltage DC power supply to operate. Transformerless designs can supply the lower voltage, but their low efficiency would still dissipate a significant amount of heat.

It is at this point that nano-Watt technology comes to the rescue. Given its extremely low-current consumption, it is possible to reduce the heat generated in the transformerless power supply down to reasonable levels.

Note: No mention of EMI/RFI filtering is made in this design. Any production design must have EMI/RFI filtering to prevent noise generated as part of the dimming progress from interfering with external systems.

HARDWARE

A nano-Watt microcontroller can be used to generate a feature rich dimmer design. For this design, we will be designing an AC dimmer for incandescent lamps with the following features.

1. Capable of delivering 100-200 Watts of power at 110 VAC.
2. Two user interfaces; one based on an infrared remote control system, and the second based on interruptions of the AC supply caused by the user toggling the switch for an existing in-house switched outlet.
3. Low-power dissipation, resistor-based transformerless power supply.
4. Small form factor.

The first step in the design is to choose a triac for the switching circuit. In order to make an informed decision, we will need to cover a few triac basics first.

A triac is essentially two Silicon Controlled Rectifiers, or SCR, cross-connected with their gate inputs tied together. Because it is SCR based, once the device begins conducting, it will continue to conduct until the current flowing through the device goes to zero. So, in operation, the triac is an open circuit between the AC supply and the lamp until the minimum gate current is either sourced or sunk through the gate pin. The triac is then latched on until the current through the device goes to zero at the next zero crossing of the AC waveform.

While this description gives you a general idea of how the device works, there are a few specifics that are missing. First of all, the triac does not latch on until the minimum holding current flowing through the device is reached. Second, the two main pins of the triac are not completely interchangeable as the description implies. This is because the bias current for the triac is dependent, to an extent, on the direction of the bias current and the direction of the load current in the device. These combinations of current directions are referred to as the conduction quadrants for the device. Using the convention of MT1 and MT2 for the main terminals, the four quadrants are defined as follows:

- Quadrant one, current flow into MT2 and out of MT1, with a positive current flow into the gate.
- Quadrant two, current flow into MT2 and out of MT1, with a negative current flow out of the gate.
- Quadrant three, current flow into MT1 and out of MT2, with a negative current flow out of the gate.
- Quadrant four, current flow into MT1 and out of MT2, with a positive current flow into the gate.

The reason this is important is because the minimum gate current for quadrant four is typically higher than for quadrants one through three. And because we will be trying to reduce current where possible, avoiding quadrant four operation is desirable.

So when we choose a triac, we will want a small sensitive-gate triac capable of switching 4 amps. It should have a minimal hold current requirement so we can limit the amount of time that we will have to supply a gate current.

In addition, our power supply must have its 5 VDC rail tied to the same AC line as the triac, to avoid bias in quadrant four. This will cause the circuit to only sink current out of the triac gate, forcing operation in quadrants two and three.

A L6004D3 device from Teccor only requires a typical gate current drive of 3 mA and the minimum hold current is less than 5 mA. In addition, the device is available in a small package for a compact circuit.

Assume that the load is a 100 Watt light bulb with a typical filament resistance of approximately 1Ω. The triac should be conducting 5 mA when the AC line voltage reaches 5V. Translating this into a conduction angle, the 5 mA hold current should have been reached 2 degrees following the zero crossing (see Equation 1).

EQUATION 1:

$$\text{Angle} = \text{invsin}(5V/(110V * 1.414))$$

Assuming a 60 Hz system, the minimum 5 mA hold current should be achieved after 93 microseconds of bias current (see Equation 2).

EQUATION 2:

$$\text{Time} = (1/60 \text{ hz}) * (2^\circ/360^\circ)$$

So, we only need to hold the bias current of 3 mA for approximately 100 μS to latch the triac on. If we average the narrow pulse of current over ½ of a 60 Hz cycle, it gives us an average current requirement for the triac bias of less than 37.5 μA.

Note: Here is one of the significant advantages of using a microcontroller in dimming. Because the microcontroller only needs to hold the gate bias for less than 100 μS, not the full half cycle, there is a savings of over 98% of the bias current for the triac, alone.

Our next challenge is to determine which nano-Watt device to use in our dimmer circuit. We will need three I/O; one for the triac gate drive, one for the AC zero crossing detection and one for the data output from the IR receiver module.

The smallest nano-Watt device meeting these requirements is a 6-pin PIC10F200 in a SOT-23 surface mount package. It has 3 I/O with 1 input only pin, a single pin current drive capability of 25 mA and when powered up and running at 5 VDC, it only requires 350 microamps to operate and only 1/10th of a microamp when asleep. So, it should be a perfect low-power microcontroller for the design.

The next requirement is a low-current IR receiver module for the remote control half of the user interface. It should draw a minimum current while in operation and be capable of receiving a 38 kHz modulated IR beam and decode it into a simple 1 line output.

The Sharp GP1UD261RK fits the requirements, operating from a 2.7 to 5.5 VDC supply. It draws on 200 μ A of current to operate and it is designed to pull its output low when subjected to IR light modulated at 38 kHz.

Now that there are three main components, we must construct a power budget for the design:

1. The IR receiver module will draw 200 μ A continuously.
2. The microcontroller will draw 350 μ A when operating and less than 1/10th of a μ A when asleep.
3. The triac will need an average current of less than 40 μ A.

The total current requirement for the system is less than 590 μ A. Quite a savings considering that holding the gate bias current for the full cycle would require 5 times this current.

Given the power budget, we can design a resistive transformerless power supply consisting of two-current limiting resistors R1 and R2, a low current 5.6V zener diode with an equally low current rectifier diode and a small 330 μ F filter capacitor (see Equation 3). The resulting supply will produce .6 μ A at 5 VDC with a ripple of less than 30 mV. Further, if the IR receiver is powered down, the supply can hold up the operating microcontroller for at least 3.77 seconds before falling below 2 VDC and shutting down the microcontroller (see Equation 4).

EQUATION 3: FILTER CAPACITOR CALCULATION

$$(5V - V_{RIPPLE})/5V = e^{-16 \text{ mS}/((5V/6 \text{ mA}) * C = 330 \mu\text{F})}$$

EQUATION 4: TIME TO SUPPLY DROOP TO 2V

$$T(2V) = I_n(2V/5V) * ((5V/4 \text{ mA}) * 330 \mu\text{F})$$

$$T(2V) = 3.77 \text{ seconds}$$

Given a 1N4690 zener diode only requires 50-100 μ A to generate a voltage of 5.3 to 5.8 VDC, the current limiting resistors in the power supply will only have to conduct .7 mA total to maintain a 5 VDC output. If the line voltage is split across 2 resistors for safety, this means each resistor will only dissipate 55 mW, assuming each resistor is a 11K resistor (see Equation 5).

EQUATION 5:

$$R1 + R2 = (110\text{VAC} * 1.414)/(100 \mu\text{A} + 600 \mu\text{A})$$

$$R1 = R2 = 11k$$

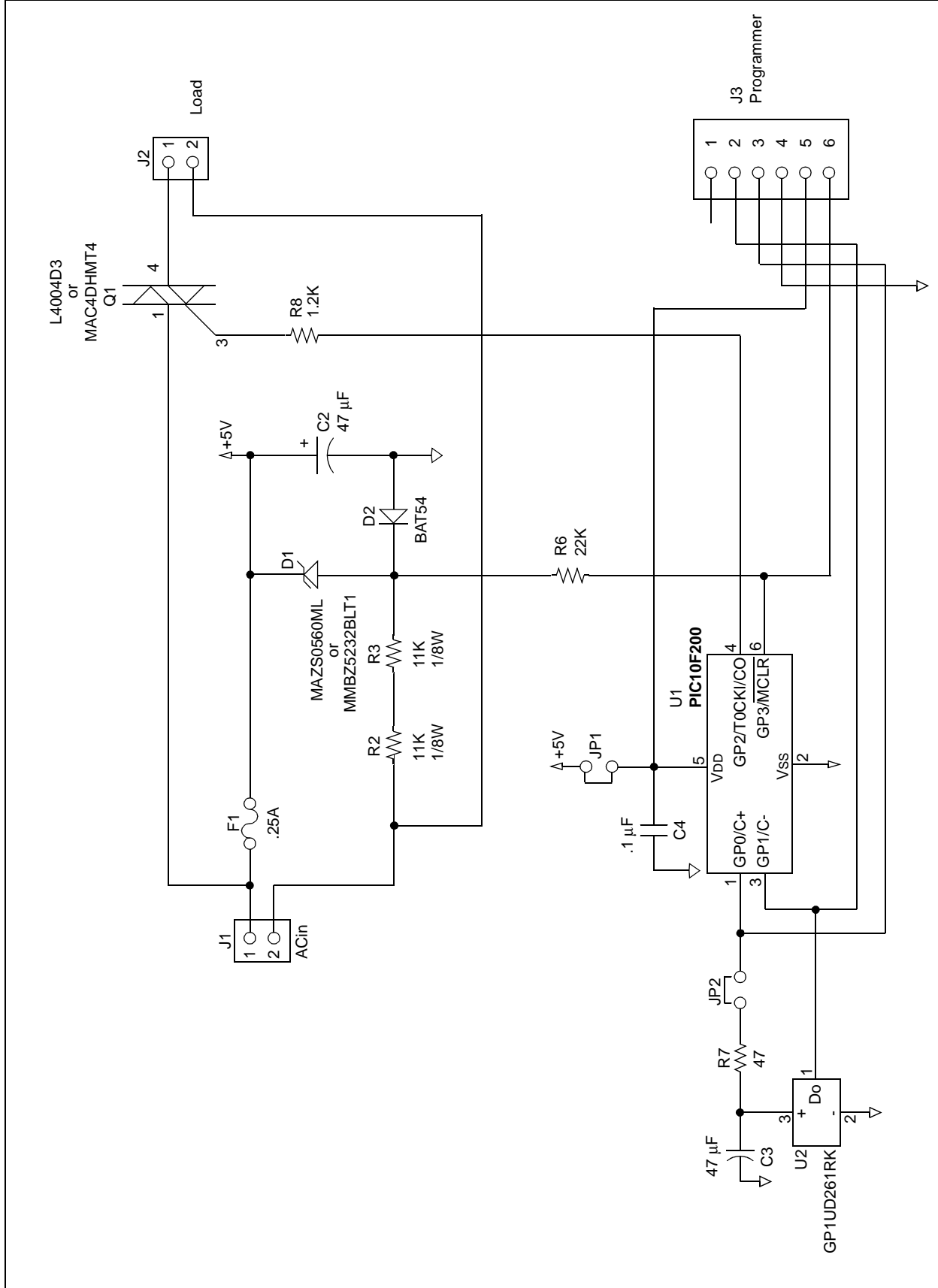
$$P_{resistors} = ((110\text{VAC} * 1.414 * 700 \mu\text{A})/2)$$

The resulting circuit is shown in Figure 1.

Note: The extra I/O on the PIC10F200 has been used as a power supply for the IR receiver module. This is done so the circuit can power-down the module when it detects that the AC line voltage has been removed.

TB094

FIGURE 1: PIC10F DIMMER



SOFTWARE

Note: When using the programmer, the circuit **MUST** be disconnected from the AC power **FIRST!**

The software for the system is relatively simple. When an AC zero voltage crossing is detected on the GP1 input, the change in state wakes the microcontroller using the Reset-on Change function of the pin. The microcontroller wakes and determines the source of the reset by checking the TO, PD and GPWUF flags in the STATUS register. See TB082, “*Understanding Reset Events on the PIC10F20X*”, (DS91082), for more information. Then the microcontroller performs the following:

1. Checks the state of the IR receiver module output.
2. If it is high, the microcontroller moves on to determine the appropriate delay for triggering the triac, based on the current intensity value.
3. Waits the delay.
4. Generates a 100 μ S pulse on the gate of the triac.
5. Returns to sleep.

If the output of the IR receiver module is low, the microcontroller first counts the low state and then moves to generate the delay and pulse.

If the output of the IR receiver module is high and the previous output sample was low, the firmware decodes the command by length and makes the appropriate change in the intensity value. Then it moves to determine the appropriate delay, waits the delay and generates the gate pulse for the triac before, once again, going to sleep.

A secondary routine, wake-up on change, keeps track of the total number of 60 Hz wake-up on change events. If the number is sufficient for 4 hours of operation, the intensity value is set to zero as part of a timer-based shutdown to conserve energy.

If the microcontroller wakes due to a Watchdog Timer time-out, the 60 Hz wake-up on change has missed multiple cycles indicating that the 60 Hz power has been removed. The firmware then powers down the IR receiver module to reduce power consumption and increments the intensity value for the system.

A secondary routine in the Watchdog Timer time-out counts the number of time-outs and if it exceeds 5 seconds, it resets the intensity value to zero. This is done as part of the switched power user interface. If the power is removed for 5 seconds, the system assumes it is to be turned off and sets the intensity value to zero. However, with the microcontroller sleeping the majority of the time, there is no guarantee that the supply voltage will drop below 2 VDC and cause a Power-up Reset in the microcontroller. So, this secondary routine has been added as a back-up shutdown function.

IR REMOTE CONTROL

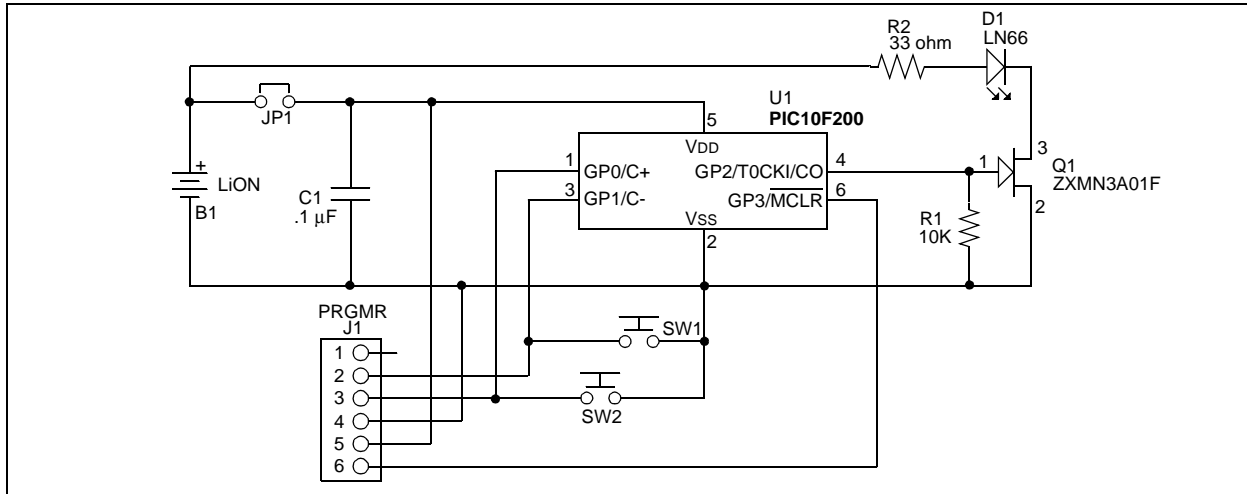
The IR remote control for the system is also based on a PIC10F200. It uses the wake-up on change function of the I/O to wake it whenever a button is pressed. It then generates one of two different modulated outputs, depending on which button was pressed.

The carrier frequency is 38 kHz to match the receiver modules in the dimmer circuit. The two different modulations differentiate the intensity of the Up and Down commands, as indicated by the button pressed to wake the remote. While the button is held down, the firmware in the remote will repeat the command pulse width. When the button is released, the circuit then turns off the LED and goes to sleep to conserve battery life.

A circuit for the remote control is shown in Figure 2. The microcontroller is powered directly from the 3.0 VDC lithium coin cell. The two push buttons are connected to the GP0 and GP1 inputs for their ability to generate a wake-up on change. The transistor that drives the IR LED is driven by GP2.

For more information on the IR Transmitter design, refer to the Application Notes regarding infrared connectivity listed on the Microchip web site at www.microchip.com.

FIGURE 2: IR REMOTE CONTROL TRANSMITTER



CONCLUSION

In the preceding sections, it was mentioned that a microcontroller is advantageous in a dimming circuit because it can compensate for the inherent nonlinearity of the dimming process. As we have seen in this design process, it is also advantageous from a power point of view as well. Keeping the microcontroller in Sleep mode reduces the overall current draw to a minimal level. And, using a minimal bias pulse to fire the triac further reduces current draw. Together the savings is over 98% of the original triac bias current. At a cost of only 20% in increase power supply current for the microcontroller, this leaves a net reduction in the circuit current draw of over 78%. The result is a significant savings in power dissipated in the transformerless power supply design, which means much less expensive components can be used.

MEMORY USAGE

Dimmer

- Program Memory – 225 words
- Data Memory – 13 bytes

Remote Control

- Program Memory – 68 words
- Data Memory – 4 bytes

Documentation

- AN954, "Transformerless Power Supplies, Resistive and Capacitive", (DS00954)
- TB082, "Understanding Reset Events on the PIC10F20X", (DS91082)

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