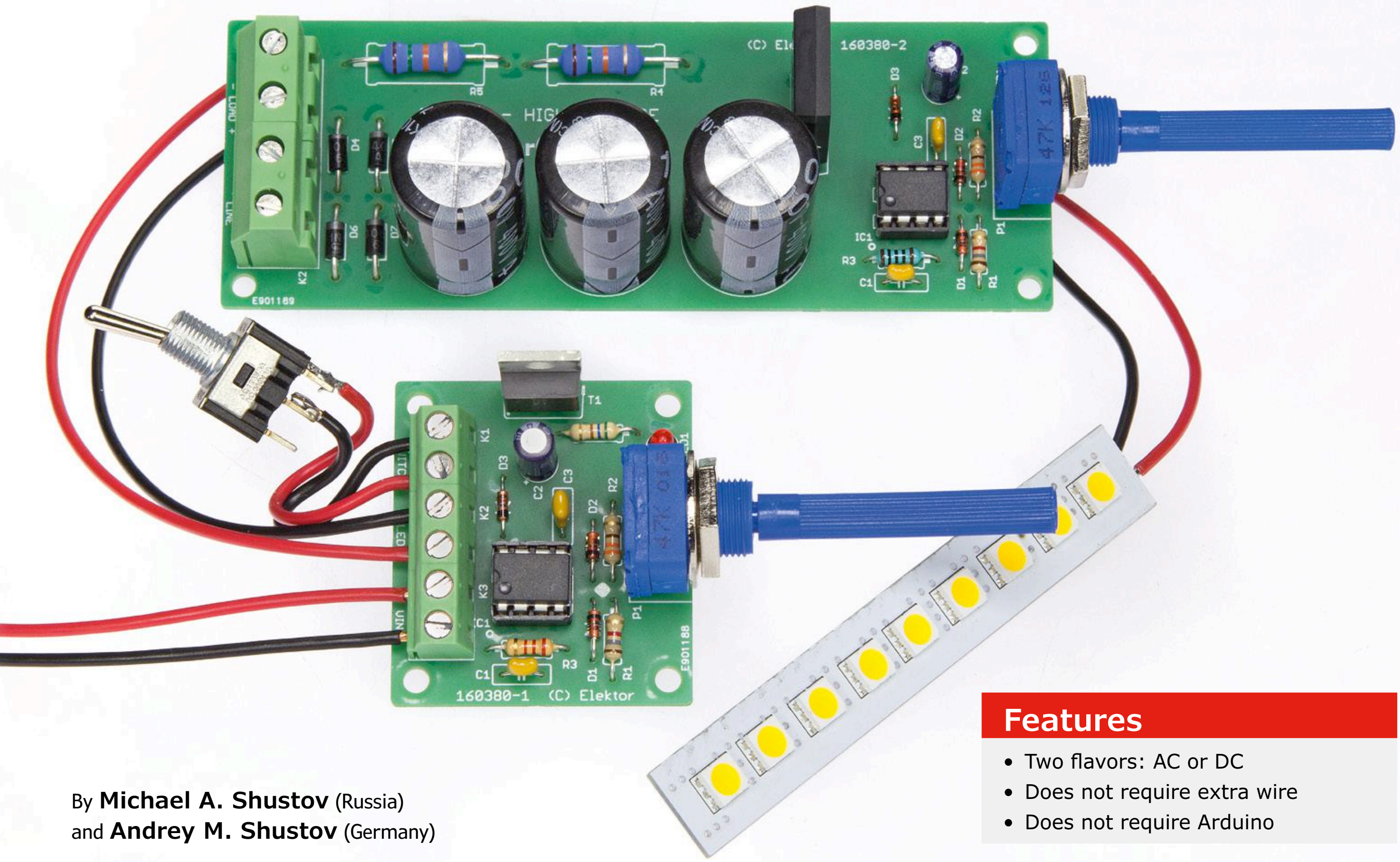
2-Terminal Dimmer

controls LEDs, lamps and heaters



By **Michael A. Shustov** (Russia)
and **Andrey M. Shustov** (Germany)

Features

- Two flavors: AC or DC
- Does not require extra wire
- Does not require Arduino

In the past, rheostats (today also called potentiometers) were connected in series with a load to control the current flowing through the load. Although simple, this technique has some disadvantages.

First of all, the current can only be controlled when the load is active. Secondly, the heating of the rheostat results in significant losses. Furthermore, controlling the intensity of a light flux emitted by light-emitting diodes (LEDs) with a rheostat is almost impossible owing to the nonlinear current-voltage characteristics of LEDs. Pulsewidth modulation (PWM) is a better and much more efficient way to smoothly change the intensity of heating and lighting devices (incandescent lamps and LEDs), or to control the speed of a motor.

Dimmers controlling the intensity of light sources are usually connected in parallel with the power supply; they are three-terminal devices. Two terminals connect to the power supply while the third connects to the load. Such dimmers

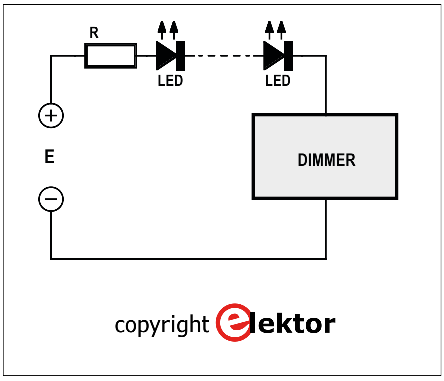


Figure 1. The dimmer is in series with the LED(s) and requires only two wires.

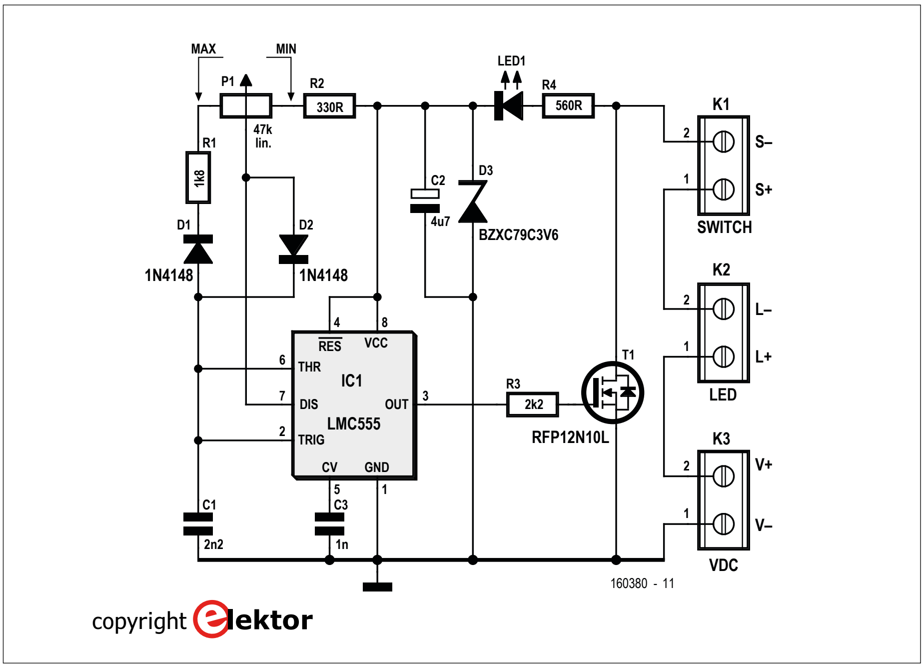


Figure 2. The DC version of the series dimmer.

PROJECT INFORMATION

LED lighting PWM dimmer Danger! 555

entry level
➡ intermediate level
expert level

2 hours approx.

Soldering iron, common sense

£12 / €15 / $17 approx.

cannot be used in place of conventional double-pole switches, since they require an additional third power wire for proper connection. To overcome this problem we propose a two-terminal dimmer connected in series with the load (LED, lamp or a heating element) instead of a switch, see **Figure 1**. Contrary to a switch, the dimmer allows adjusting the load current from almost 0 to about 97% of its maximum value. The dimmer is powered through the load when its switching element is disconnected and the current through the load is minimal.
An inconvenience of both two-terminal and three-terminal dimmers is their residual current consumption, but it is insignificant compared to the current when the load is powered.
The dimmers described below can be used with household lighting devices, thermostats, and for instance back-up or secondary lighting.

Two-terminal DC-powered dimmer

At the heart of the dimmer (see **Figure 2**) is the good old 555 timer IC in its low-power CMOS guise called LMC555CN. It is wired as a pulse generator with variable duty cycle, a well-known circuit, nothing new under the sun. The output of IC1 drives power MOSFET T1 which in turn switches on and off the load (the LED) as dictated by the PWM signal. The PWM signal has a frequency of approximately 6 kHz, i.e. way too fast for the human eye to notice. The pulse/pause ratio or duty cycle is adjusted with potentiometer P1; the minimum and maximum values for the pulse width are determined by resistors R1 and R2.

Up to here the dimmer is a standard three-terminal shunt regulator. The trick to get rid of one terminal is to use the load's supply to power the circuit. This is achieved by charging C2 through R4 and LED1 when T1 is not conducting. Zener diode D3 limits the voltage to 3.6 volts. LED1 serves as a power-on indicator and also makes it easier to find the dimmer in the dark.
Transistor T1 can withstand up to 100 V and conduct 12 A, but not at the same time (the PCB only handles up to about 2.5 A anyway). According to its datasheet it can dissipate up to 60 watts, and it should be mounted on a suitable heatsink when it has to handle more than 1 watt. R4 determines the maximum supply voltage, 20 V here.
With the values given in the schematic we measured a quiescent current of 3.5 mA (i.e. when the duty cycle is 0%). That's enough current to make certain LEDs light up noticeably. Reducing the value of R2 to 75-100 ohms may improve the situation. In addition, increasing the value of R5 will reduce the minimal current too. A switch can be connected to K1 to completely turn off the dimmer.

AC Line-powered dimmer

It is, of course, possible to adapt the dimmer for use with an AC power supply like the 230 VAC line voltage available in households in many countries all over the world (115 VAC will work too.) To achieve this feat two hurdles have to be taken:

- Finding a suitable power transistor capable of handling such high voltages;
- converting the AC voltage to a DC voltage.

The second point requires some attention. Simply rectifying the AC line voltage is not good enough, as heavy loads like incandescent light bulbs will flicker, making filtering mandatory. Furthermore, the rectified line voltage is about 325 V (163 V for 115 VAC line voltage), which is too high for standard household light bulbs (several identical lower-voltage light bulbs connected in series can be used, however). Because of these practical limitations, what follows is mainly to illustrate our point and is not recommended for use in real life.
Figure 3 shows the 230-VAC version of the dimmer. The most noticeable change is the addition of the rectifier (D4-D7) and the supply filter made up with C4, C5 and C6. We also added a skull & bones symbol to make clear that potentially lethal things are going on here.
The filter capacitor is made with three

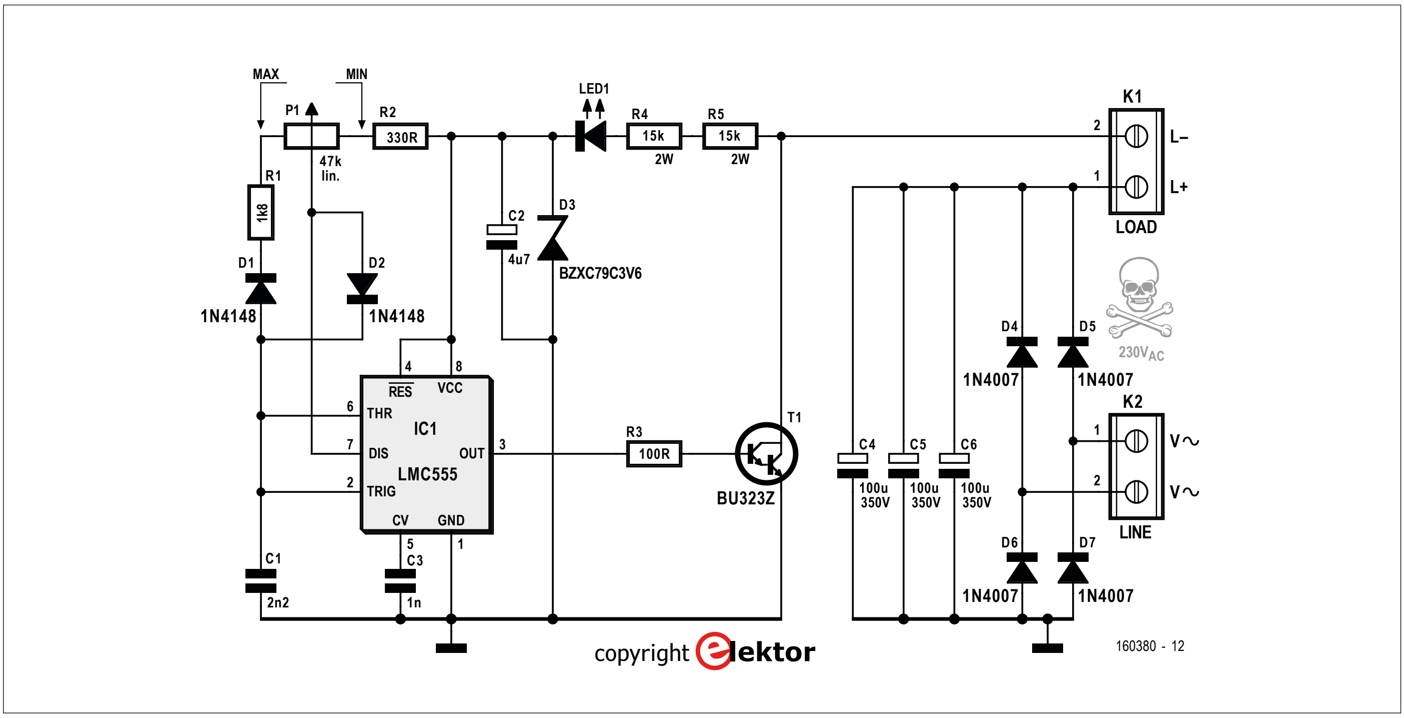


Figure 3. This dimmer circuit is dangerous and may kill you. Do not look at it too long.

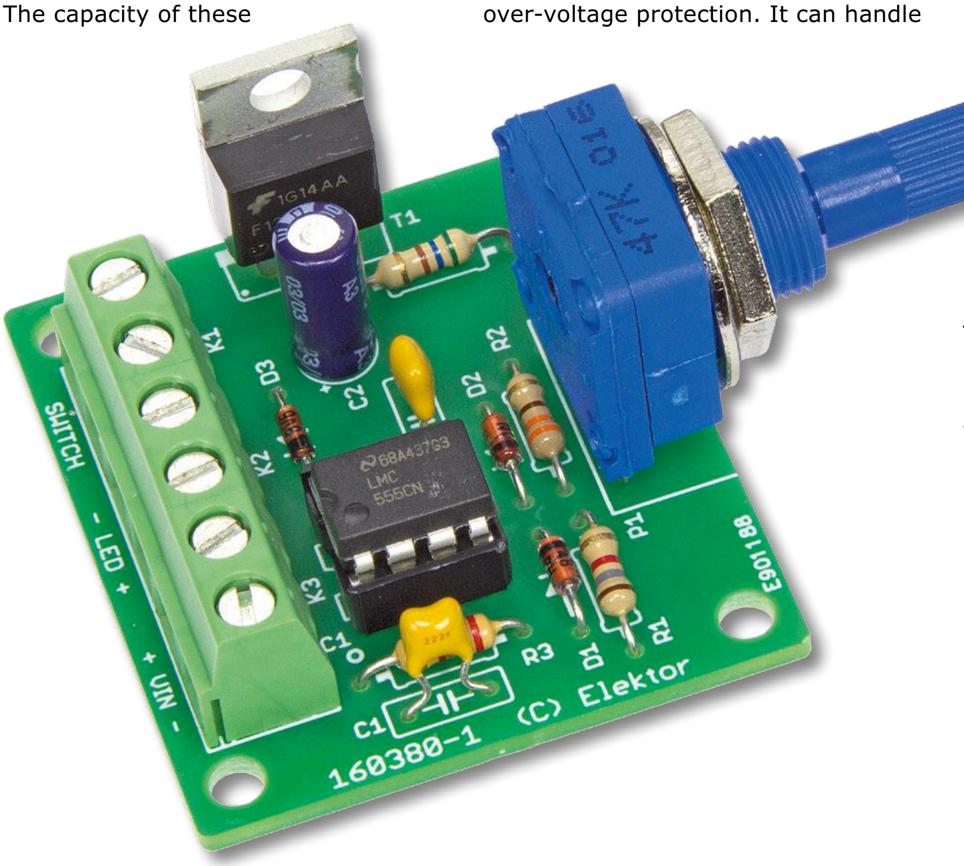
separate devices because one big one is difficult to find and rather expensive. With three times 100 µF (350-V types minimum) and a 100-W light bulb the voltage ripple at the output will not exceed 3% (approx.). This is invisible to the human eye. For heavier loads the values of C4-C6 must be increased; for light loads they can be decreased. The capacity of these capacitors is not critical when a heating element is used as a load.

Besides the clearly visible schematic changes there are also a few more subtle changes. Transistor T1 for once is now a BU323Z Darlington power transistor instead of a MOSFET. This transistor is designed for 230-VAC inductive switching applications and has built-in over-voltage protection. It can handle up to 150 W (with a suitable heatsink!). If you are tempted to replace this transistor by something "sturdier", keep in mind that the rectifier diodes D4-D7 are specified up to 1 A and 3 W.

Let's do some math

When using LEDs (just one or a few in series) for illumination purposes, the resistance of a current limiting resistor R has to be calculated (**Figure 1**), and its power rating must be determined.

The forward voltage U_{LED} of an LED depends on its color, see **Table 1**. We can now estimate the resistor value with the following equation:



$$R = \frac{U_{SUP} - n \times U_{LED} - U_{T1}}{0.9 \times I_{LED}} \quad [\Omega]$$

Where U_{SUP} is the supply voltage, n is the number of LEDs, U_{T1} the voltage dropped by transistor T1, and I_{LED} the maximum current through the LED(s). Consult the LED's datasheet for the exact values of U_{LED} and I_{LED}. The power rating for the resistor can be calculated with

$$P_R = (I_{LED})^2 \times R \qquad [W]$$

Examples

1. (Figure 2) Assume n = 1, U_{LED} = 3 V, I_{LED} = 0.05 A, U_T = 0.04 V, U_{SUP} = 20 V. Then R = 377 Ω, or, rounded off to the nearest higher standard value, 390 Ω. The resistor should be able to absorb $(0.05)^2$ × 390 = 0.975 W, or, rounded off to a common value, 1 W.

2. (Figure 2) Assume U_{LED} = 2 V, I_{LED} = 0.02 A, U_T = 0.04 V, U_{SUP} = 16 V. If we limit $n \times U_{LED}$ to 80% of U_{SUP}, then n = 6. In this case R becomes 220 Ω, and its power rating should be better than 88 mW (0.125 W would be a good standard value).

3. (Figure 3) Assume U_{LED} = 2.5 V, I_{LED} = 0.05 A, U_T = 3 V, U_{SUP} = 325 V. If we limit $n \times U_{LED}$ to 80% of U_{SUP}, then n = 104 and R = 1,378 Ω. The nearest standard value would be 1.5 kΩ. Its power rating should be better than 3.75 W. The required resistor can be realized by connecting two 2 W, 3 kΩ resistors in parallel. With these numbers the current through the LEDs becomes (U_{SUP} – n × U_{LED} – U_T) / 1500 = 0.041 A, meaning that T1 has to dissipate $U_T \times I_{LED}$ = 0.125 W. It should be able to do this without a heatsink.

Table 1. Forward voltages related to the color of the light emitted by an LED.

Color	Wavelength [nm]	U_{LED} [V]
Infrared	≥ 760	≤ 1.6
Red	610 – 760	1.6 – 2.0
Orange	590 – 610	2.0 – 2.1
Yellow	570 – 590	2.1 – 2.2
Green	500 – 570	2.2 – 2.5
Blue	450 – 500	2.5 – 2.7
Violet	400 – 450	2.7 – 3.1
Ultraviolet	≤ 400	≥ 3.1
White	–	3 – 3.7

Final words

We can't repeat it enough times: the circuit from Figure 3 is dangerous; it carries lethal voltages and may kill you or someone else when used without having taken proper precautions first. Do not build this circuit. Do not use it either, even if you didn't build it. The authors and Elektor take no responsibility or liability, so far as legally possible, for any damages caused by the use of the circuits presented in this article.

(160380)

Web Link

[1] www.elektormagazine.com/160380

COMPONENT LIST

Resistors
R1 = 1.8kΩ
R2 = 330Ω
R3 = 2.2kΩ
R4 = 560Ω
P1 = 47kΩ, potentiometer, linear

Capacitors
C1 = 2.2nF, 0.2" pitch
C2 = 4.7µF, 2mm pitch
C3 = 1nF, 0.2" pitch

Semiconductors
D1,D2 = 1N4148
D3 = BZX79C3V6
IC1 = LMC555CN
LED1 = red, 3mm
T1 = RFP12N10L

Miscellaneous
K1,K2,K3 = 2-way PCB screw terminal block, 0.2" pitch
PCB # 160380-1