Pulse Width Modulator

for 12 and 24 Volt Applications

Homebrew

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A pulse width modulator (PWM) is a device that may be used as an efficient light dimmer or DC motor speed controller. The circuit described here is a general purpose device that can control DC devices which draw up to a few amps.

The circuit may be used in 12 or 24 volt systems with a few minor changes. This device has been used to control the brightness of an automotive tail lamp, and as a motor speed control for small DC fans of the type used in computer power supplies.

Pulse Width Modulation

A PWM circuit works by making a pulsating DC square wave with a variable on-to-off ratio. The average on time may be varied from 0 to 100 percent. In this way, a variable amount of power is transferred to the load. The main advantage of a PWM circuit over a resistive power controller is the efficiency.

At a 50 percent level, the PWM will use about 50 percent of full power, almost all of which is transferred to the load. A resistive controller at 50 percent load power would consume about 71 percent of full power; 50 percent of the power goes to the load, and the other

21 percent is wasted heating the dropping resistor. The PWM circuit will typically waste well under 1 percent of the power, depending on the load current. It takes a constant trickle of power to operate, so the efficiency improves with higher power loads.

Advantages

Load efficiency is almost always a critical factor in renewable energy systems. An additional advantage of pulse width modulation is that the pulses are at the full supply voltage and will produce more torque in a motor by being able to overcome the internal motor resistances more easily. A resistive speed control will present a reduced voltage to the load, which can cause stalling in motor applications. Finally, in a PWM circuit, common small potentiometers may be used to control a wide variety of loads, whereas large and expensive high power variable resistors are needed for resistive controllers.

Disadvantages

The main disadvantages of PWM circuits are the added complexity and the possibility of generating radio frequency interference (RFI). RFI may be minimized by locating the controller near the load, using short leads, and in some cases, using additional filtering on the power supply leads.

This circuit has some RFI bypassing in the form of a capacitor (C3) across the load, and produced minimal interference with an AM radio that was located under a foot away. Radio interference was undetected at greater distances. If additional filtering is needed, a car radio line choke may be placed in series with the DC power input. Be sure not to exceed the current rating of the choke.
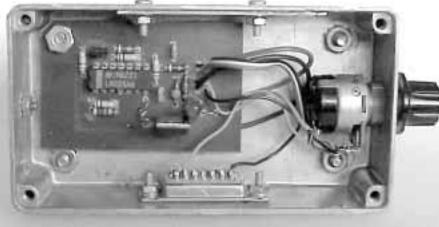
Theory

The PWM circuit requires a steadily running oscillator to operate. U1a and U1d form a square/triangle waveform generator with a frequency of about 400 Hz. U1c is used to generate a 6 volt reference voltage which is used as a virtual ground for the oscillator. This is necessary to allow the oscillator to run off a single supply instead of a +/- voltage dual supply.

U1b is wired in a comparator configuration and is the part of the circuit that generates the variable pulse width. A comparator is a circuit in which the op-amp's output is true or false depending on whether the voltage on the op-amp's plus input is higher than the minus input (true) or vice versa (false). U1b pin 6

Pulse Width Modulator Specifications

Item	Specification
PWM frequency	400 Hz
Maximum current with IRF521 FET	9 A continuous, 27 A peak
Maximum current with IRFZ34N FET	26 A continuous, 100 A peak
PWM circuit current	1.5 mA at 12 V with no LED and no load
Operating voltage	12 or 24 V, depending on the configuration

receives a variable voltage from the R6, VR1, R7 voltage ladder. This is compared to the triangle waveform from U1d pin 14. When the waveform is above the pin 6 voltage, U1 produces a high output. Conversely, when the waveform is below the pin 6 voltage, U1 produces a low output. By varying the pin 6 voltage, the on/off points are moved up and down the triangle wave, producing a variable pulse width.

Resistors R6 and R7 are used to set the end points of the VR1 control. The values shown allow the control to have a full on and a full off setting within the travel of the potentiometer. These part values may be varied to change the behavior of the potentiometer.

Q1 is the power switch. It receives the modulated pulse width voltage on the gate terminal and switches the load current on and off through the source-drain current path. When Q1 is on, it provides a ground path for the load. When Q1 is off, the load's ground is floating. Care should be taken to insure that the load terminals are not grounded or a short will occur. The load will have the supply voltage on the positive side at all times.

The controller with a DC muffin fan.

LED1 is optional and gives a variable brightness response to the pulse width. Capacitor C3 smooths out the switching waveform and removes some RFI. Diode D1 is a flywheel diode that shorts out the reverse voltage kick from inductive motor loads. In the 24 volt mode, regulator U2 converts the 24 volt supply to 12 volts for running the PWM circuit. Q1 switches the 24 volt load to ground, as it does for the 12 volt load. See the schematic for instructions on wiring the circuit for 12 or 24 volts.
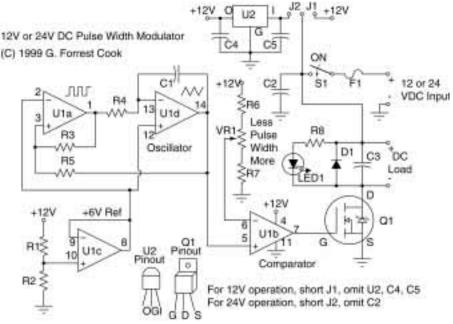
At the 1 amp current level, no heat sink is needed on Q1. However, if you will be switching more current, a *large* heat sink is *mandatory.* Q1 may be replaced with a higher current device such as an IRFZ34N. All of the current handling devices, switch S1, fuse F1, and the wiring between the FET, power supply, and load should be able to handle the maximum load current.

To prevent shortening the life of the FET, it is advisable to run the circuit below the maximum rated current. Eighty percent of maximum is a safe range to work with. Inductive loads such as motors have huge peak current ratings, and exceeding the ratings of the FET will guarantee part failure. Take into account the maximum current for the motor when it is stalled. High power motor controllers require extra clamping circuitry for reducing high voltage spikes. This is usually done with zener diodes across the FET D-S terminals. Information on such circuitry is beyond the scope of this article—consult the data sheets from the FET manufacturer (International Rectifier Corp, www.irf.com).

PWM Parts List

U1	LM324N quad op-amp
U2	78L12 12 V regulator
Q1	IRF521 N channel MOSFET
D1	1N4004 silicon diode
LED1	Red LED (any kind should work)
C1	0.01 µF ceramic disc capacitor, 25 V
C2–C5	0.1 µF ceramic disc capacitor, 50 V
R1–R4	100 K 1/4 W resistor
R5	47 K 1/4 W resistor
R6–R7	3.9 K 1/4 W resistor
R8	2.7 K 1/4 W resistor
VR1	10 K linear potentiometer
F1	3 A, 28 VDC fast-blow fuse
S1	toggle switch, 5 A

PWM Schematic

12V or 24V DC Pulse Width Modulator
(C) 1999 G. Forrest Cook

For 12V operation, short J1, omit U2, C4, C5
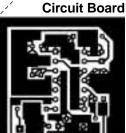For 24V operation, short J2, omit C2

Construction

The prototype for this circuit was constructed on a regular IC proto board, with parts and wires stuck into the proto board holes. One version of the finished circuit was used to make a variable speed DC fan. The fan was mounted on top of a small metal box and the PWM circuit was contained inside the box.

I built a simple circuit board using a free circuit board CAD program, PCB, which runs on the Linux operating system. The circuit board image was printed with a PostScript laser printer onto a mask transfer product called Techniks Press-n-Peel blue film. The printed film is then ironed on to a cleaned piece of single sided copper-clad board.

The circuit board is etched with ferric chloride solution. A board pattern is shown at right. This may be photocopied onto a piece of Press-n-Peel blue film. The circuit board and parts layout are available for download from www.homepower.com. Holes are drilled with a fine gauge drill bit, parts are soldered in, and the board is wired to the power and load. This technique is great for producing working boards in a short time, but is not suitable for large numbers of boards.
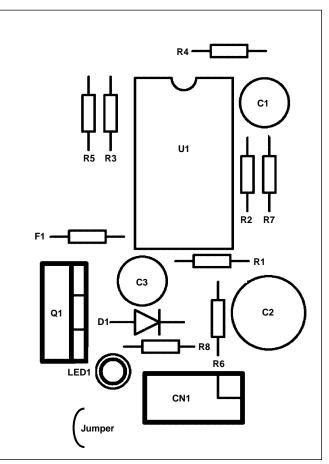
PWM Circuit Board

Alternately, the "dead-bug" construction method may be used. The name "dead-bug" comes from the appearance of the circuit board, with chips and parts strung together at random angles. This involves taking a piece of blank copper PC board, gluing a wire-wrap IC socket to the board with five minute epoxy, then soldering all of the parts to the wire wrap pins. Grounded pins can be soldered directly to the copper board. No alignment should be necessary with this circuit.

The PWM component locations pictorial is shown from the parts side—solder on the other side of the board. The circuit board is for the 12 volt version of the circuit. It may be used for 24 volts by wiring an external 12 V regulator for the +12 V

PWM Component Locations

supply, and moving the parts at the DC load + terminal to 24 V power.

Circuit board connections for CN1 (pin 1 is marked with a square):

1 VR1-low
2 VR1-high
3 +12 V power from fused line
4 VR1-center
5 Load +
6 Spare ground
7 Load -
8 Ground return for 12 V power

Use

This circuit will work as a DC lamp dimmer, small motor controller, and even as a small heater controller. It would make a great speed control for a solar-powered electric train. I have not tried the circuit with larger motors. In theory, it should work in applications such as a bicycle motor drive system. If you experiment with this, be sure to include an easily accessible emergency power disconnect switch in case the FET shorts on.

Keep in mind that the pulse current through DC motors will be many times the average motor current rating. The FET will be destroyed if its specifications cannot handle the full pulse current. FETs may be wired in parallel to increase their current.

Wire the circuit for 12 volts or 24 volts as per the schematic, connect the battery to the input terminals, and connect the load to the output terminals. Be sure not to ground either of the output terminals, or anything connected to the output terminals, such as a motor case. Turn the potentiometer knob back and forth; the load should show variable speed or light.

Access

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Parts:
Jameco, 1355 Shoreway Rd., Belmont, CA 94002 800-831-4242 or 650-592-8097 Fax: 800-237-6948 or 650-592-2503 info@jameco.com • www.jameco.com

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