Work-Ready Electronics

Synchronizing Curriculum to the Rapidly Changing Workplace

Module: **Switching Power Supplies**

WORKREADY ELECTRONICS

Switching Power Supplies

Most electronic equipment is made up of integrated circuits that require specific values of DC voltage for operation. In handheld, portable equipment, voltage comes from a battery. Non-portable equipment uses an internal power supply, generally one that converts standard AC line voltage into one or more fixed DC voltages. This is known as a linear power supply, especially if it uses linear amplification and feedback in the regulator.

Alternately a switching power supply is used. In fact, switching power supplies, referred to as switch-mode power supplies (SMPS), are used far more frequently in modern equipment than linear supplies because they offer distinct advantages over linear supplies. This means that knowledge of SMPS has now become essential to electronic technicians.

What Technicians Need to Know

- Terminology related to switch mode power supplies (SMPS)
- Types of switching power supplies
- Circuits and operation of switching power supplies
- Applications of switching power supplies
- Advantages and disadvantages of SMPS
- How to troubleshoot switching power supplies

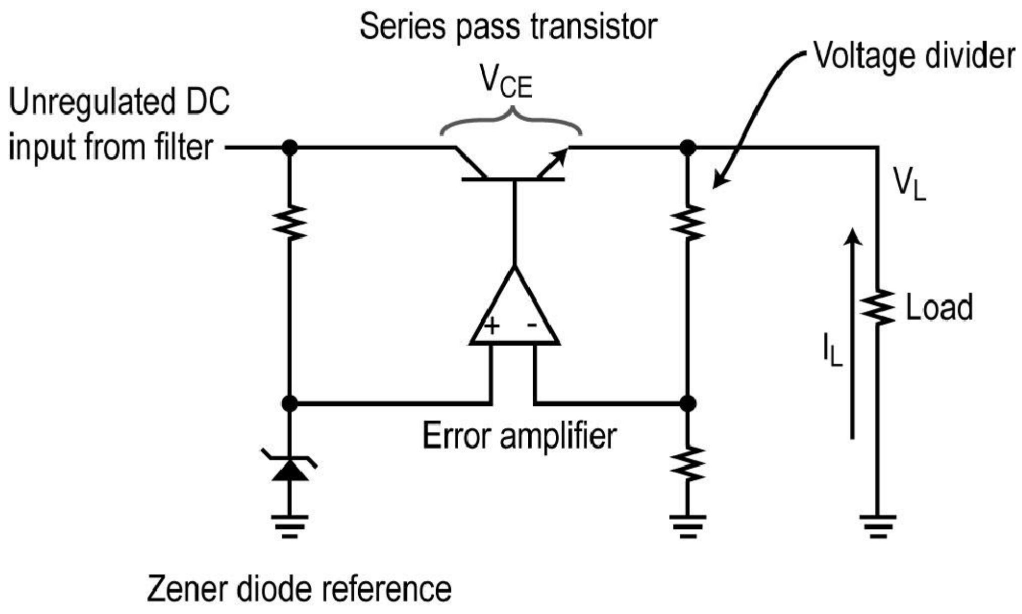
Switching Power Supplies

Switching power supplies represent over 80% of all power supplies in use due to their superior capabilities for power conversion and regulation.

The switching power supply is sometimes referred to as a switch-mode power supply (SMPS) or a switcher. Switchers use switching transistors rather than linear amplification for power conversion and regulation.

The three basic types of switching power supplies are the switching regulator, the DC-DC converter, and the inverter.

Typical Linear Regulator



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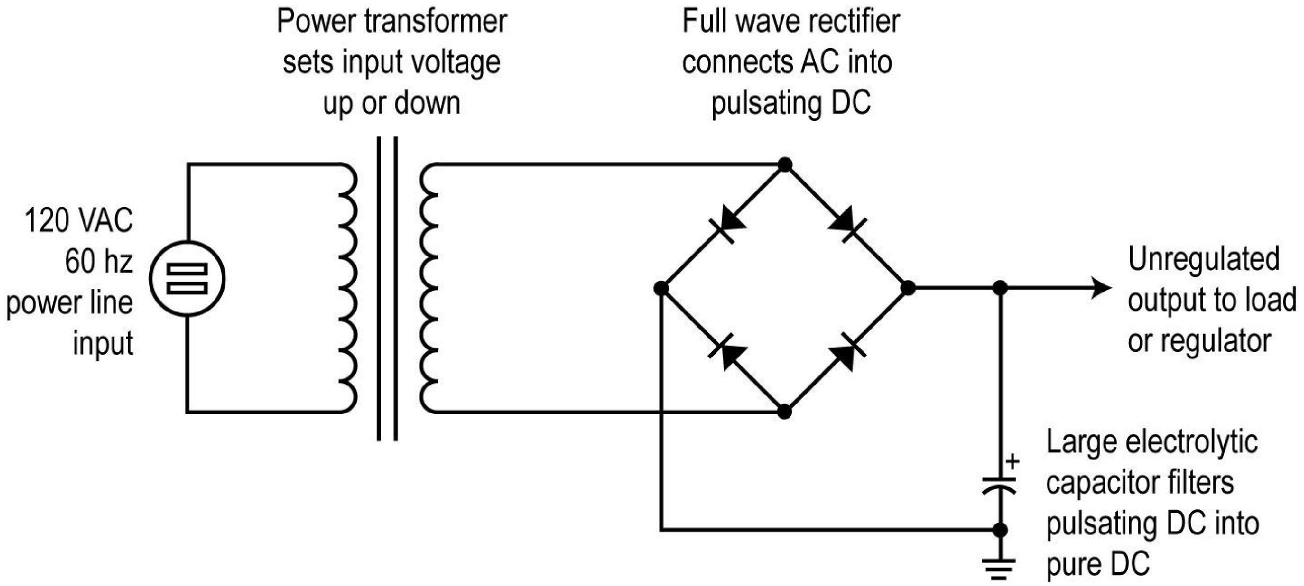
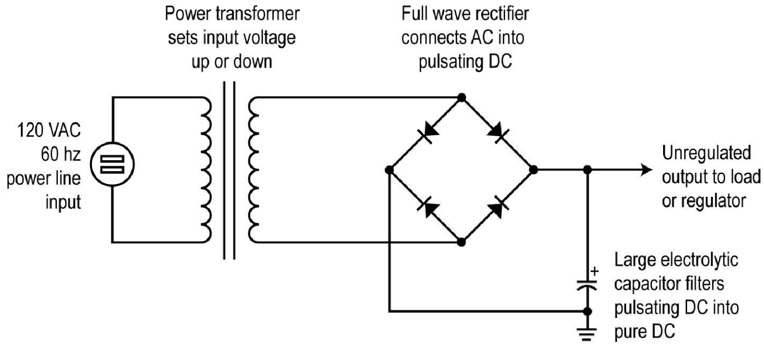
Linear Power Supplies and Regulators

Switching power supplies are best understood and their benefits appreciated more if linear supplies and regulators are understood.

A typical linear power supply without a regulator is shown below.



Linear Power Supplies and Regulators



Linear power supplies use linear regulators.

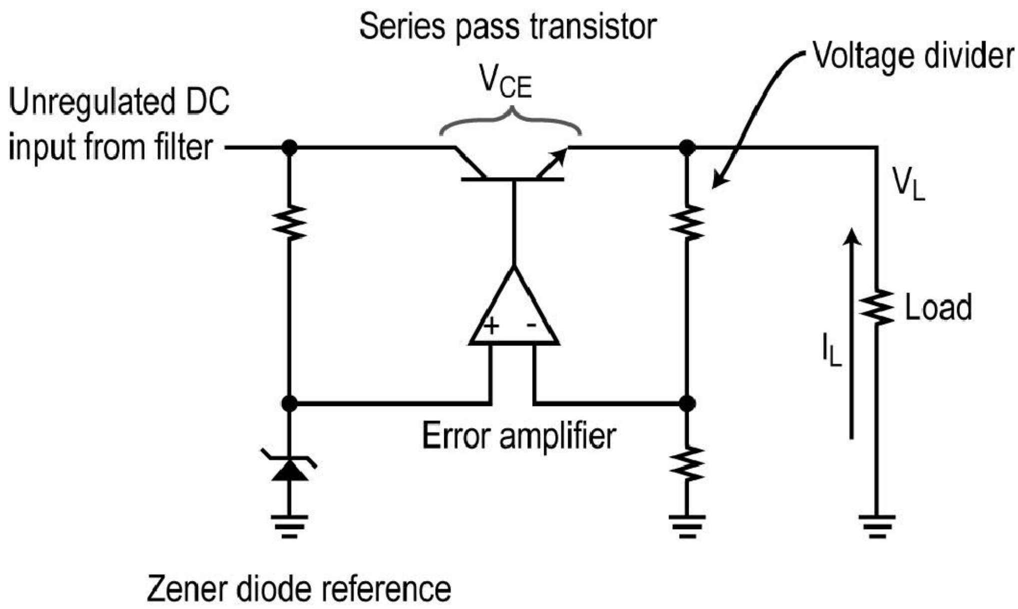
Linear regulators use continuously conducting transistors to control the output voltage.

Linear regulators use feedback to maintain a constant output voltage overcoming both AC line variations as well a load variations. They also compensate for power supply ripple.

Linear regulators usually use a transistor in series with the load to adjust the output voltage.

Most linear regulators are in integrated circuit form.

Typical Linear Regulator



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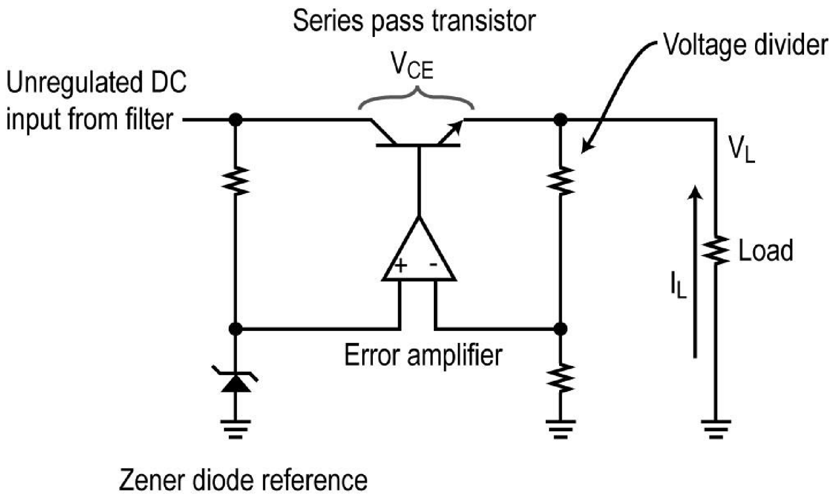
Linear Regulator Operation

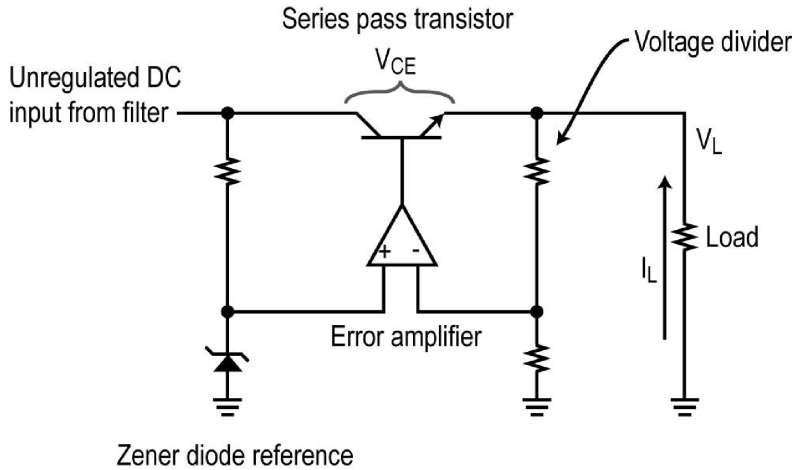


The input is a constant unregulated DC voltage higher than the output voltage.

A Zener diode provides a stable voltage reference.

An op amp serves as an error detector amplifier. It compares a sample of the output voltage from R2 and R3 to the Zener reference.

Linear Regulator Operation



Any change in output voltage is amplified and applied as a control signal to the base of the series pass transistor Q1. Q1 may also be a MOSFET.

Series pass transistor Q1 adjusts its conduction up or down to compensate for the output voltage change.

The voltage drop across Q1 V_{CE} must be 2 to 3 volts or more (called overhead) for the circuit to work properly.

Linear Regulator Limitations

A great deal of power is wasted in the series pass transistor (P_{Q1}) but this cannot be avoided. $P_{Q1} = V_{CE}(I_L)$. I_L is the load current.

The load power is the product of the load voltage (V_L) and the load current (I_L) $P_L = V_L(I_L)$

The total power (P_T) to be delivered by the power supply is the sum of the power in the load (P_L) and the power lost in the series pass transistor. $P_T = P_L + P_{Q1}$

Efficiency is P_L/P_T expressed as a percentage.

Efficiency in linear regulators is never higher than about 50%.

Lost power is wasted as heat.

Example

Assume a DC input of 15 volts and a load voltage V_L of 5 volts.

The voltage across Q1 is $V_{CE} = 15 – 5 = 10$ volts.

Assume the load current is .6 amps.

The load power is $P_L = V_L(I_L) = 5(.6) = 3$ watts.

Power lost in the transistor $P_{Q1} = V_{CE}(I_L) = 10(.6) = 6$ watts.

Total power $P_T = P_L + P_{Q1} = 3 + 6 = 9$ watts

Efficiency is $P_L/P_T = 3/9 = .3333$ or 33.33 %

Compare this to switching regulators that have efficiencies of greater than 80%.

Switching Regulator Operation

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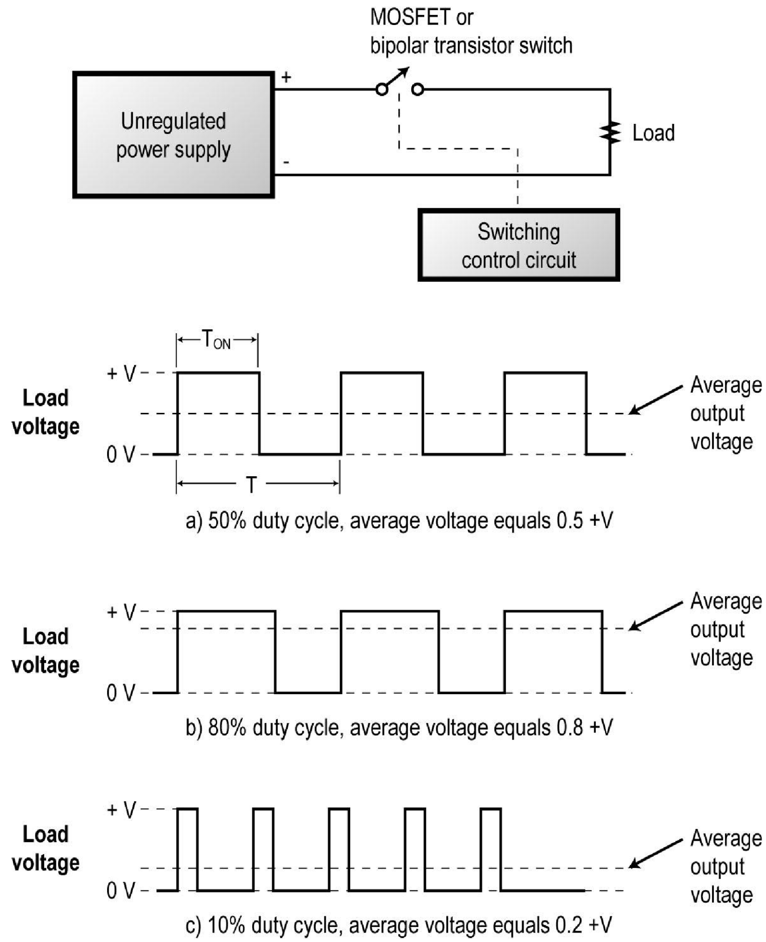
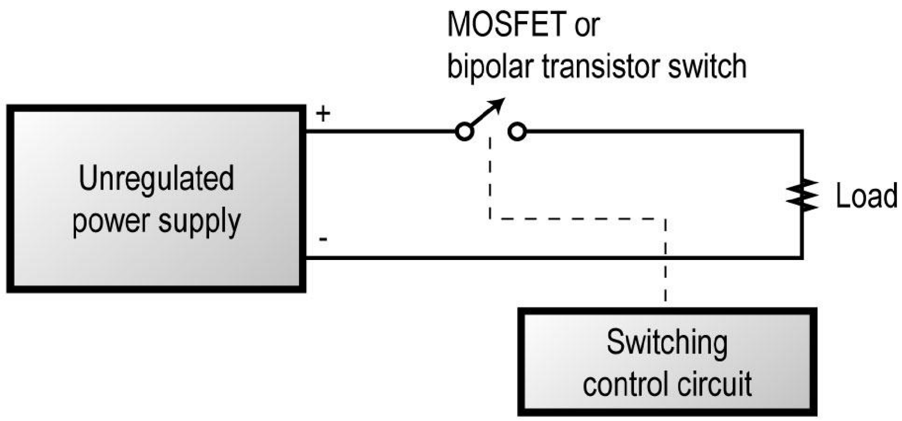


Switching Regulators

Switching regulators perform the same function as linear regulators in a power supply. They are similar in architecture because both use a series pass transistor to control the output voltage. However, instead of the transistor acting as a continuous linear control element in series with the load, the transistor is used as a switch. It chops the unregulated DC into rectangular pulses that are averaged before appearing across the load as regulated DC. An inductor and capacitor are used in the filter to store energy when the transistor is on and release it to the load when the transistor is off.

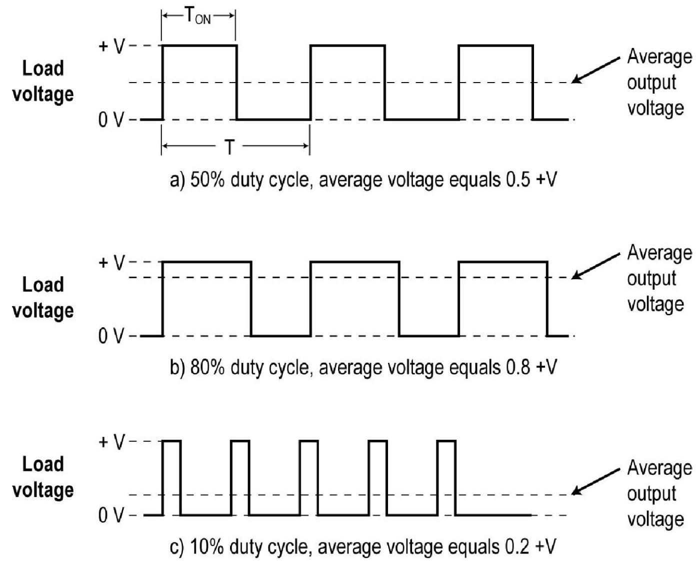
Switching regulators are used in all electronic equipment except battery chargers, vacuum tube equipment, and some medical equipment. Their greatest use is in personal computers, TV sets, and commercial communications equipment.

Switching Regulator Operation



The basic switching arrangement shows a MOSFET switch used in most modern circuits. The switch is turned off and on by a control circuit. The actual switching frequency (f) can be anything from about 20 kHz to as much as 1MHz. Frequencies typically range from 50 kHz to 500 kHz.

Switching Regulators Operation (continued)



The average DC voltage across the load depends upon the pulse voltage amplitude (Vp) and the duty cycle. This is expressed as: $V_{avg} = V_p \times DC$

V_{avg} = average DC load voltage

V_p = pulse input voltage

DC = duty cycle as a fraction

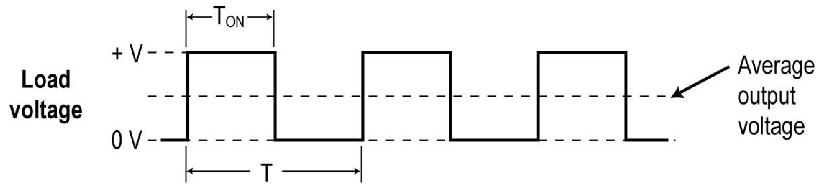
Switching Regulators Operation (continued)

The duty cycle (DC) is the ratio of the pulse at time T_{on} to the period of the pulse train T where T = 1/f (inverse of the switching frequency). It is usually expressed as a percentage but commonly used in a fraction form for calculations:

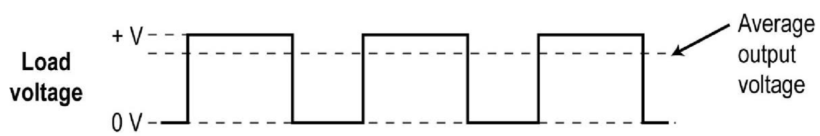
$DC = (T_{on} / T) \times 100$

Assume a pulse voltage of 12 volts with a 50% duty cycle. The average load voltage will be:

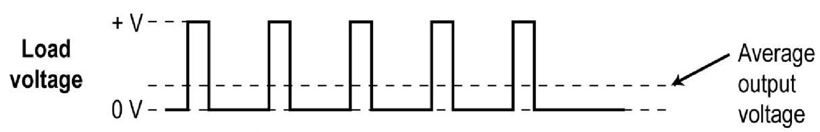
$V_{avg} = 12 \times .5 = 6$ volts



a) 50% duty cycle, average voltage equals 0.5 +V



b) 80% duty cycle, average voltage equals 0.8 +V



c) 10% duty cycle, average voltage equals 0.2 +V

Switching Regulators

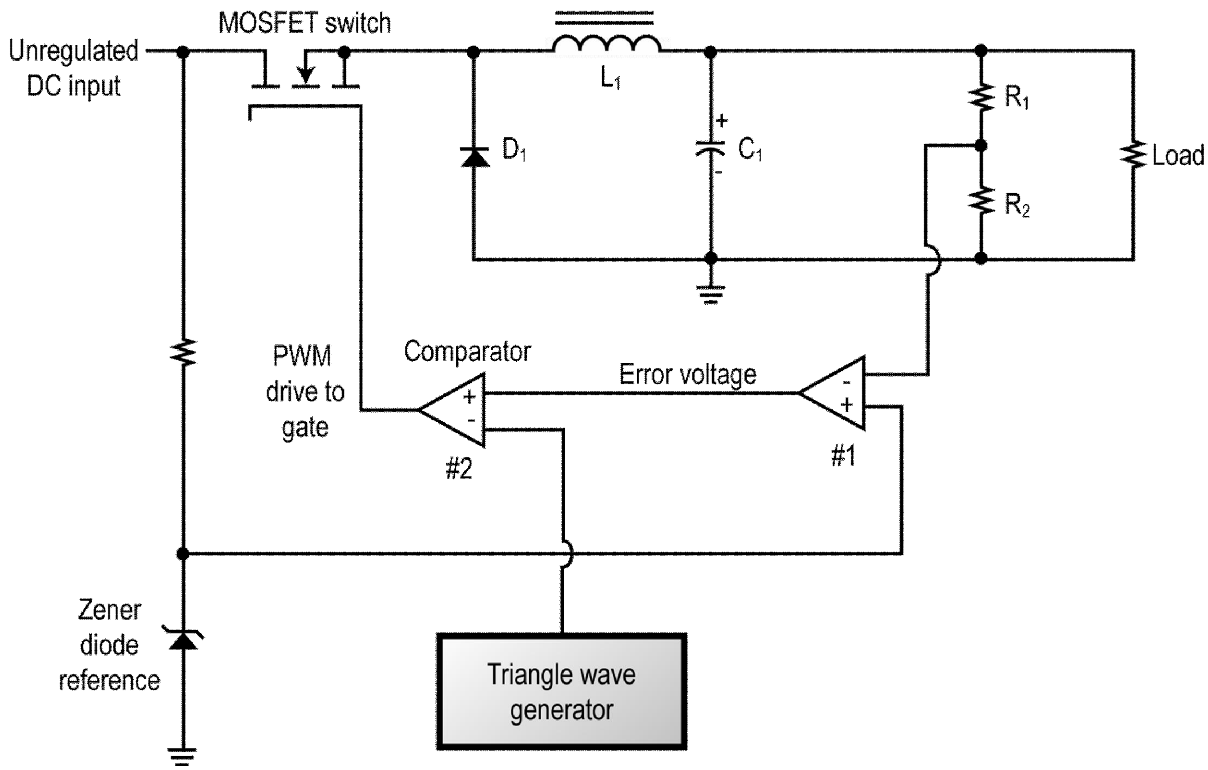
Switching regulators perform the same function as a linear regulator by maintaining a constant DC output compensating for AC line and DC load variations.

Switching regulators have an efficiency of greater than 80 %.

The three popular switching regulator types are the Buck, Boost, and Buck-Boost.

All three types are available in IC form and typically use a MOSFET as a switch. The MOSFET may be inside the IC for low power applications or a separate external discrete power MOSFET for high power applications.

Buck Regulator



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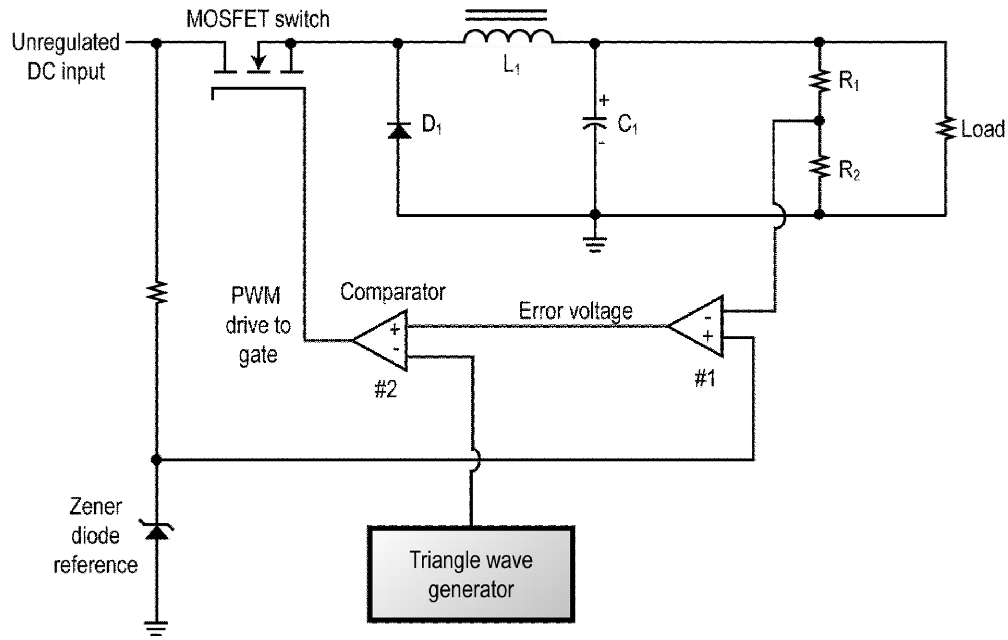
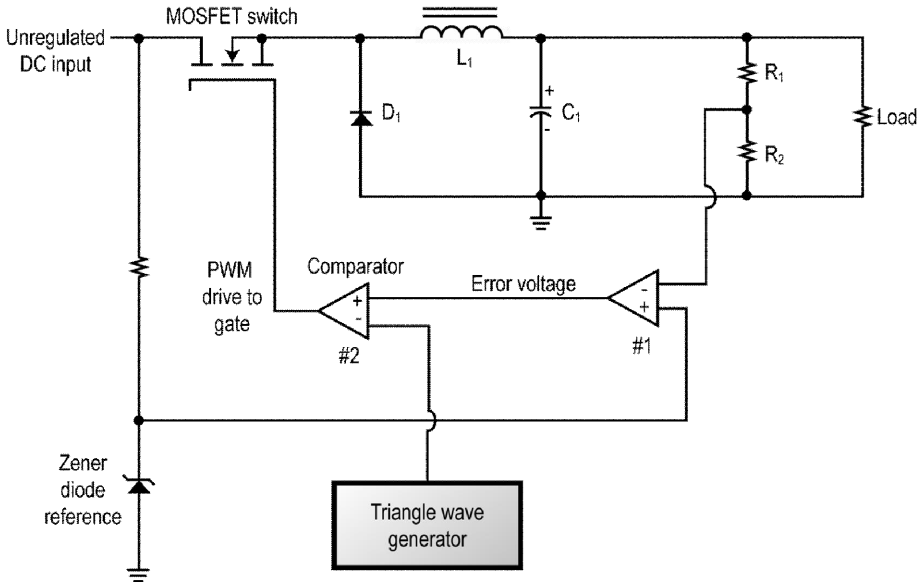
Buck Regulator Operation



The input is a constant unregulated DC.

A Zener diode is used as a voltage reference for the feedback control.

Buck Regulator Operation

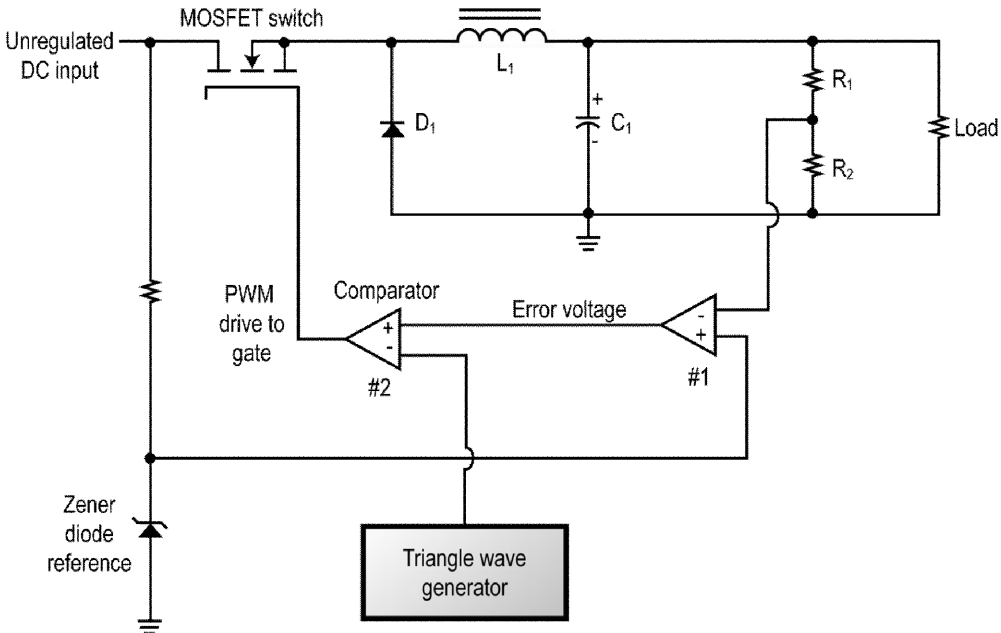


A MOSFET switch Q1 “chops” the fixed DC into pulses.

The pulses are applied to the load through a low pass filter made up of C_1 and L_1 that smoothes the pulses into a constant regulated DC.

A feedback control circuit made up of op amps 1 and 2 and the triangle wave generator make up a pulse width modulator (PWM) that maintains a constant output voltage.

Buck Regulator Operation (continued)

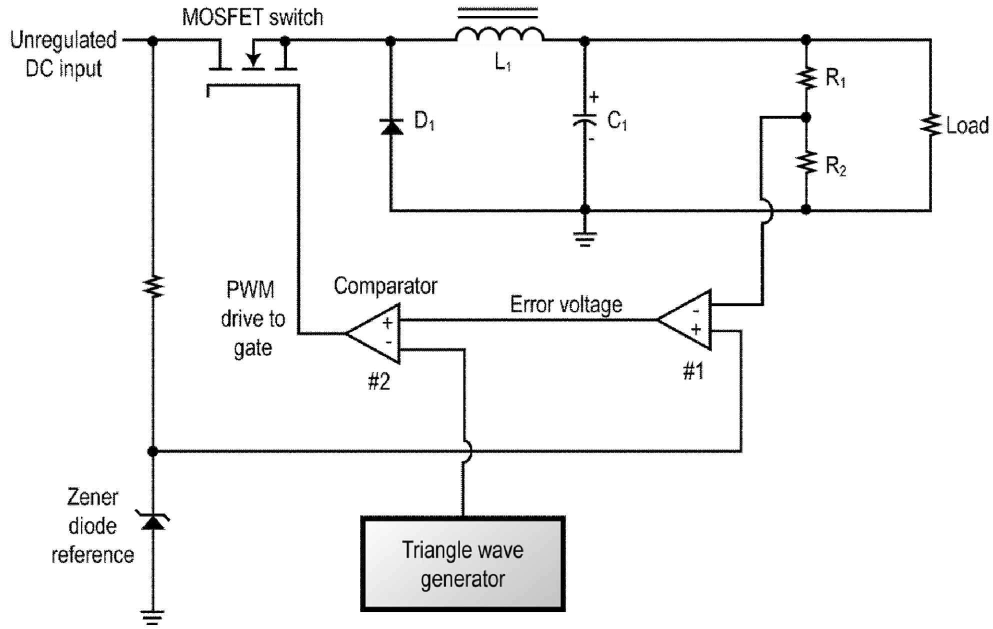


When Q_1 turns on, C_1 charges to the pulse voltage through L_1.

When Q_1 turns off, the magnetic field around L_1 collapses producing a voltage with the polarity shown.

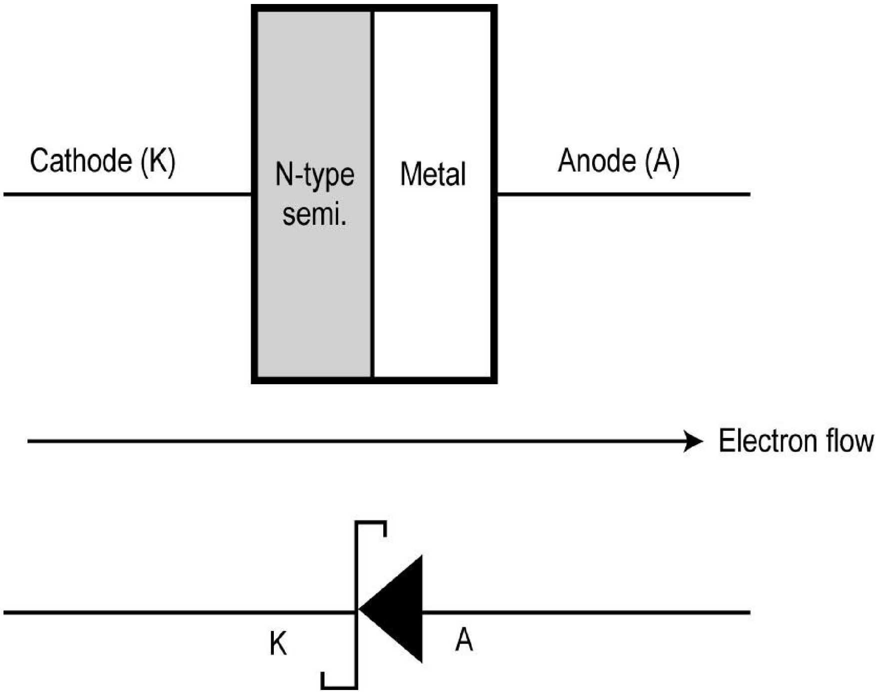
The voltage across L_1 forward biases D_1.

Buck Regulator Operation (continued)



D_1, a Schottky diode, is called a catch or freewheeling diode.
It completes the current path from L_1 to C_1 keeping C_1 charged.
The voltage across C_1 is the load voltage.
C_1 discharges into the load during the time Q_1 is off.
This cycle repeats when Q_1 turns on again.

Schottky Diode



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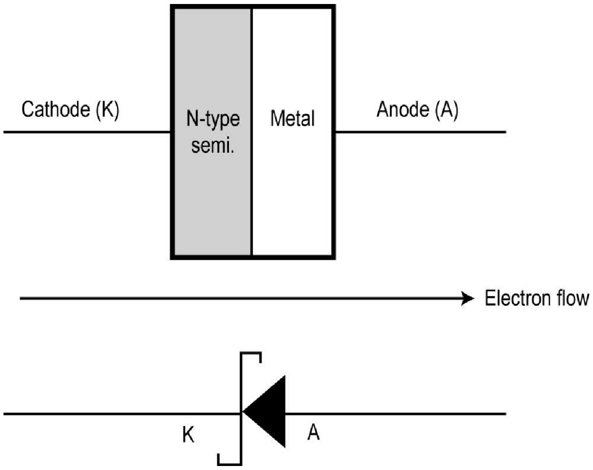
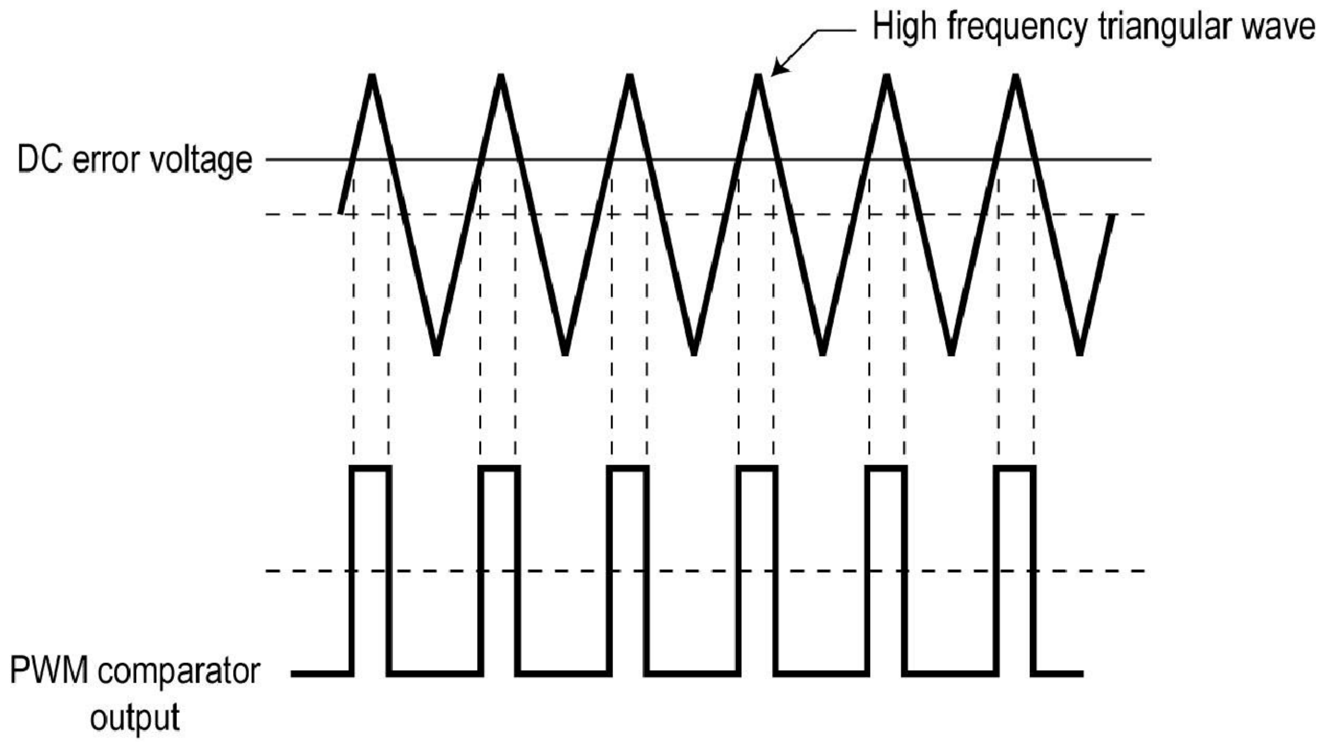
Schottky Diode



A Schottky diode is also called a hot carrier diode. It uses a metal-semiconductor junction rather than the traditional PN junction. Schottky diodes switch much faster than standard silicon diodes. (Nanoseconds not microseconds.) Diodes in switching power supplies must switch fast because of the high switching frequencies used (50 kHz to 1 MHz). Standard silicon diodes are too slow and produce a huge waste of power with their higher forward voltage. Forward voltage drop is only 0.2 to.0.4 volts in a Schottky diode. This means less power is lost during conduction.

Pulse Width Modulation Waveforms



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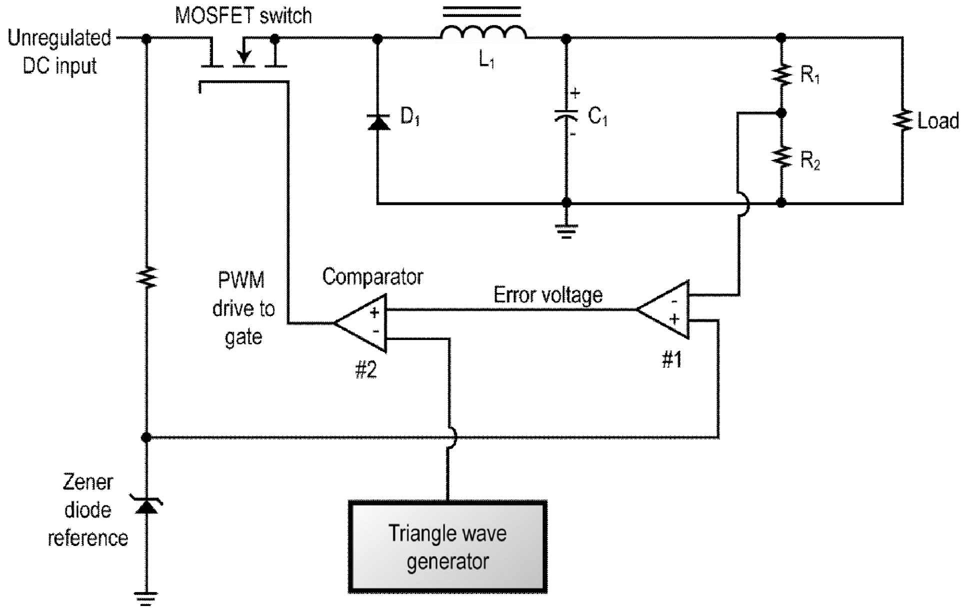
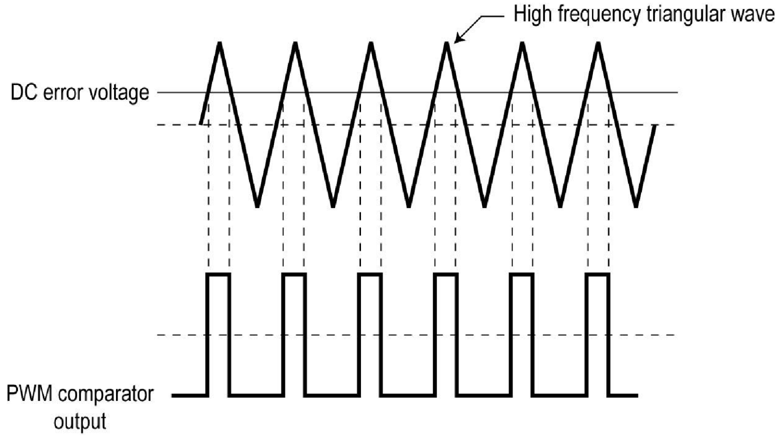
Pulse Width Modulation



The buck regulator uses a technique called pulse width modulation (PWM) to maintain a constant output voltage.

A sample of the output voltage from R_1-R_2 is compared to the Zener reference in op amp comparator #1. This produces an error voltage.

Pulse Width Modulation

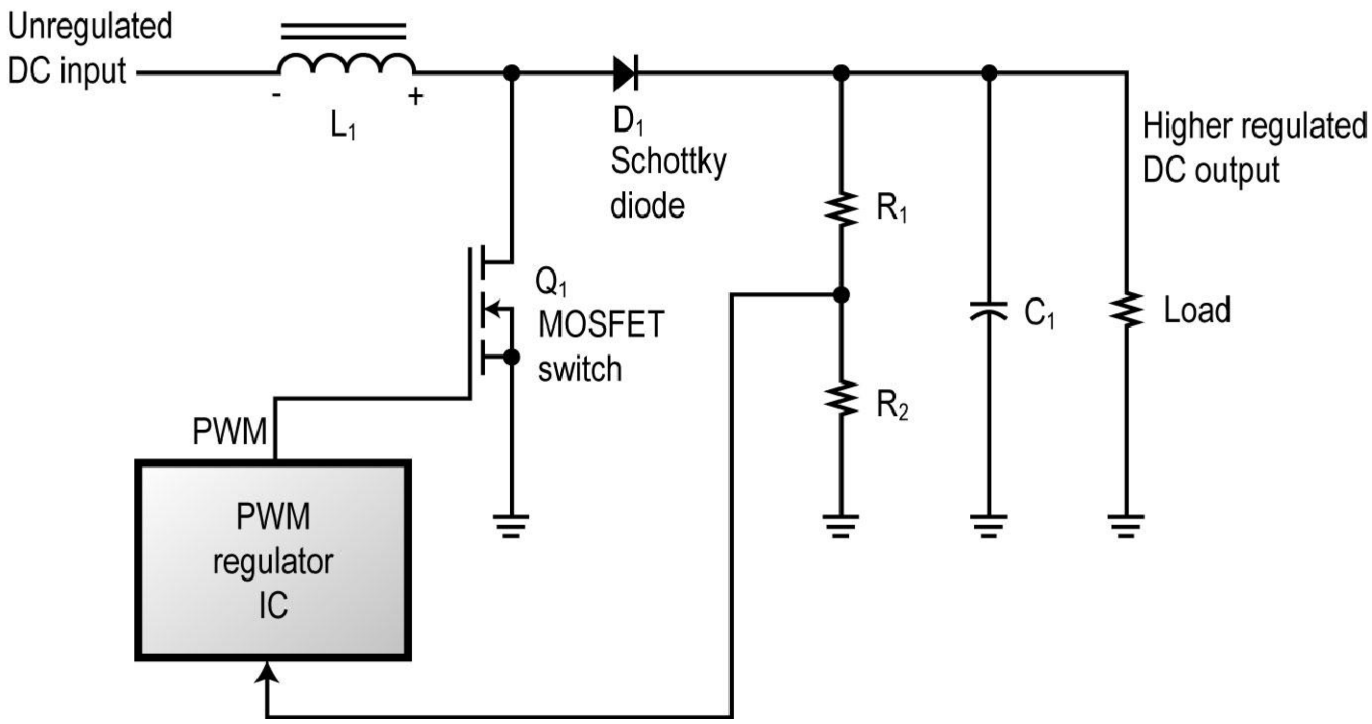


The error voltage is compared to a triangle wave in the 50 kHz to 500 kHz range in op amp comparator # 2. This produces a PWM output waveform of the same frequency. The output of comparator # 2 turns the MOSFET Q_1 off and on with the duty cycle set by the error voltage level.

The duty cycle of the PWM wave driving Q_1 varies to compensate for any output voltage changes. If the output voltage goes up, the error voltage goes up and the duty cycle decreases to lower the average output. If the output voltage goes down, the error voltage decreases and the duty cycle increases to increase the average output.

The regulator also compensates for the triangular ripple voltage variations produced by the charging and discharging of C_1 through L_1.

Boost Regulator



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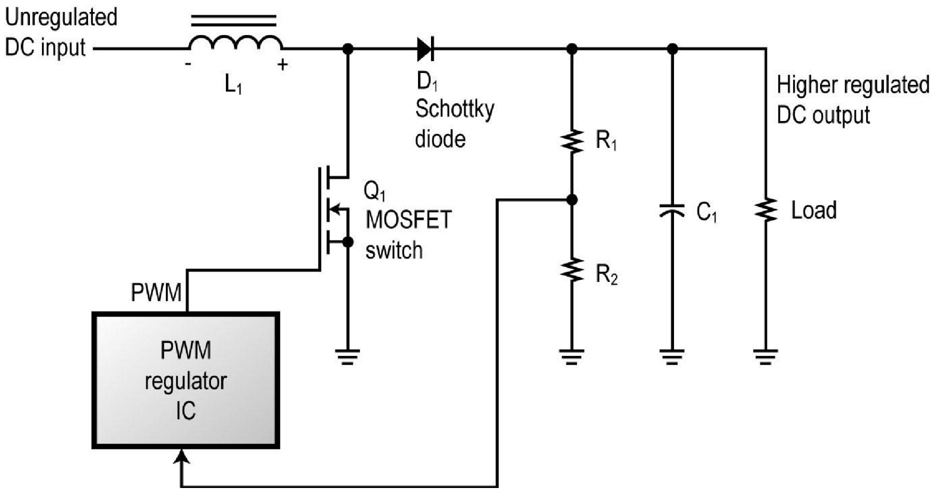
Boost Switching Regulator



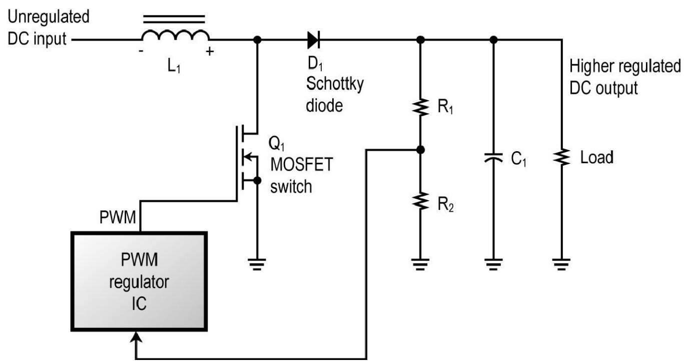
The second type of switching regulator is the boost switching regulator. The output voltage may be higher than the input voltage thanks to the energy storage capabilities of an inductor.

A typical application is to generate an output voltage higher than the battery input voltage available in portable devices.

Boost regulators also use PWM to maintain a constant output voltage.

Boost regulators are available in IC form.

Boost Regulator Operation



The input is a constant unregulated DC.

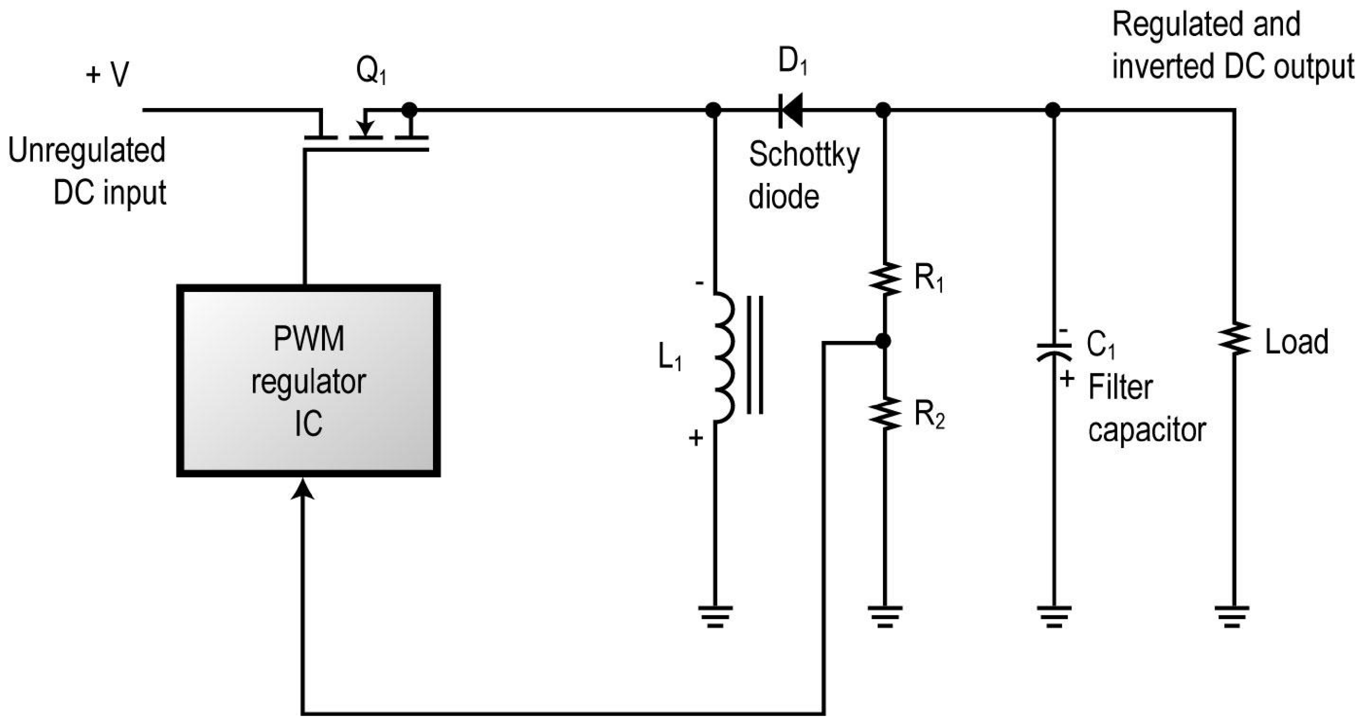
MOSFET Q_1 switches off and on at a 50 kHz to1 MHz rate.

When Q_1 is on, current flows in inductor L_1 and energy is stored as a magnetic field. When Q_1 switches off, the magnetic field collapses inducing a voltage in L_1 with the polarity shown.

The voltage of L_1 adds to the unregulated input voltage and forward biases Schottky diode D_1 and then charges C_1.

The output voltage is the voltage across C_1. PWM is used to maintain a constant output voltage.

Buck-Boost Regulator



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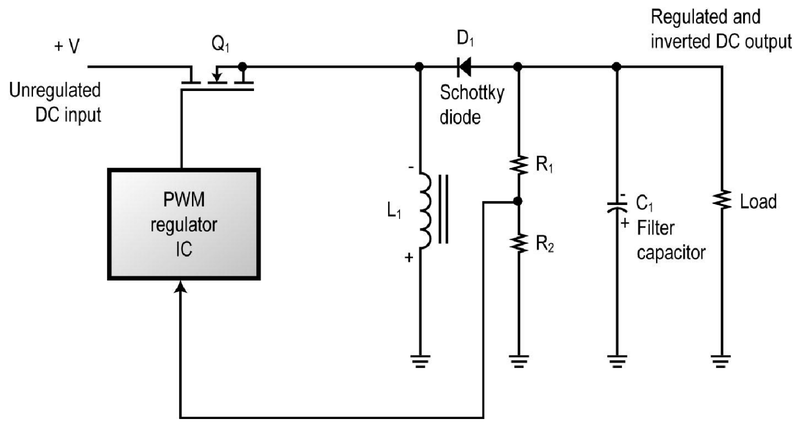
Buck-Boost Regulator



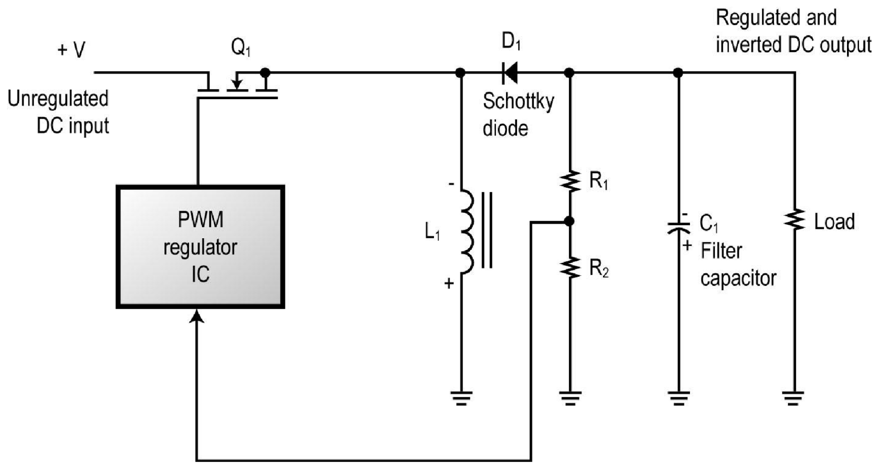
The third type of switching regulators is the buck-boost regulator. The buck-boost regulator may have an output voltage either lower or higher than the DC input.

The output voltage polarity may be the opposite of the input voltage polarity.

Buck-boost regulators use PWM to maintain a constant output voltage.

They are available in IC form.

Buck-Boost Regulator Operation



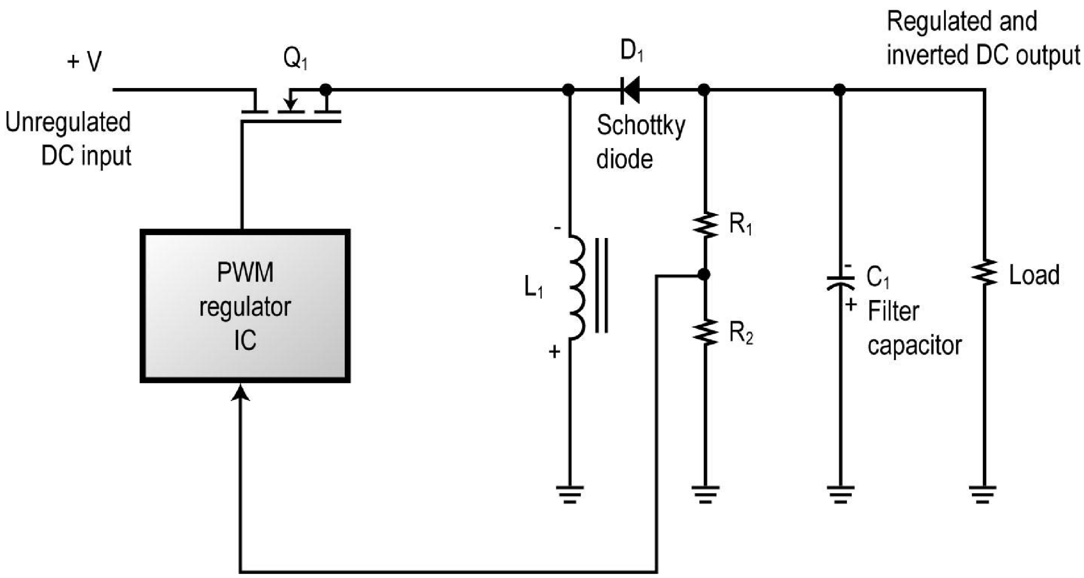
The input is an unregulated constant DC.

MOSFET Q_1 switches off and on at a 50 kHz to1MHz rate.

When Q_1 conducts, the input voltage causes current flow in inductor L1 storing energy in a magnetic field.

When Q_1 switches off, the magnetic field around L_1 collapses inducing a voltage with a polarity opposite that of the input.

Buck-Boost Regulator Operation



The voltage across L_1 forward biases Schottky diode D_1 and charges C_1.

The output voltage is across C_1.

PWM is used to maintain a constant output voltage.

Switching Regulator Summary

- Switching regulators are very efficient. Efficiency from about 80% to in excess of 95% are possible.
- Switching regulators operate at frequencies usually in the 50 kHz to 1 MHz range. This requires MOSFETs and diodes to switch very quickly and minimize power loss.
- Switching regulators use PWM to maintain a constant output.
- Most switching regulators are implemented in IC form. The inductor, filter capacitor, and Schottky diode in the regulator circuits are usually external discrete components.
- The MOSFET may be internal to the IC for low power devices but is an external discrete device for high power.
- Switching regulators do produce a very low level output ripple that is triangular in shape.
- Switching regulators do generate noise and switching transients that can radiate and be conducted to other circuits. However, with adequate shielding and filtering, the noise and transients can be reduced to a suitable level.
- Over 75% of all electronic equipment uses switching regulators.

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SMPS Knowledge Probe 1

SMPS Basics and Switching Regulators

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