Class D Switching Amplifiers

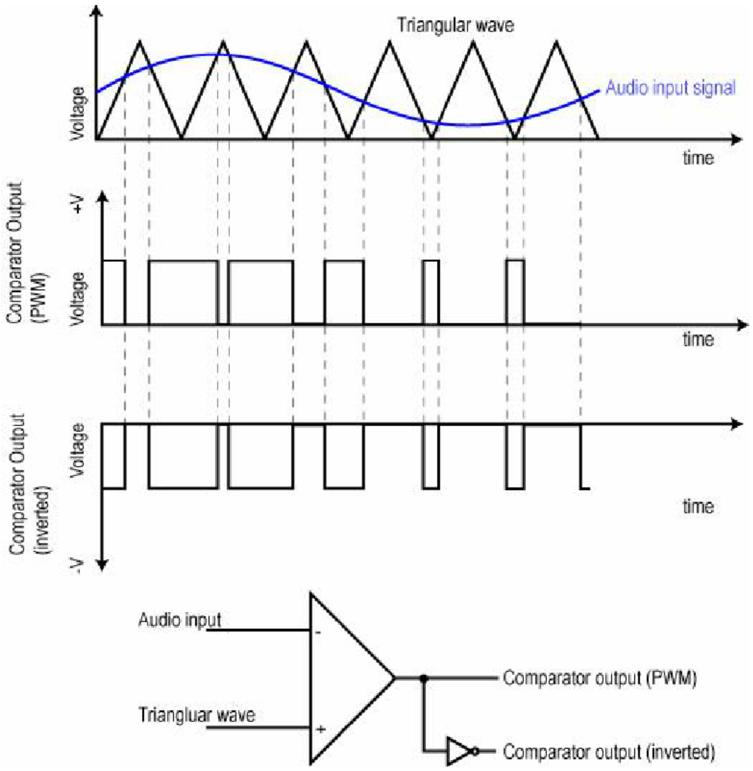
Introduction to Switching Amplifiers

If the signal to be amplified is applied to a transistor switch, the transistor will alternately conduct and cut off producing binary rectangular pulses at the input signal frequency. This approach virtually destroys the information in the signal except for the frequency.

Significant harmonic distortion occurs. The big question becomes how can a switching amplifier amplify analog signals faithfully? The answer is through the use of a technique called pulse width modulation (PWM).

PWM converts the varying amplitude and varying frequency AC signal into a constant amplitude pulse stream. The width of the pulses carries the information to be amplified. The type of amplifier using this technique is referred to as a class S amplifier. Class S amplifiers today are commonly referred to as class D amplifiers. Classes D and S are switching amplifiers that are either off or on and use pulse width modulation for DC and audio amplification.

Pulse Width Modulation



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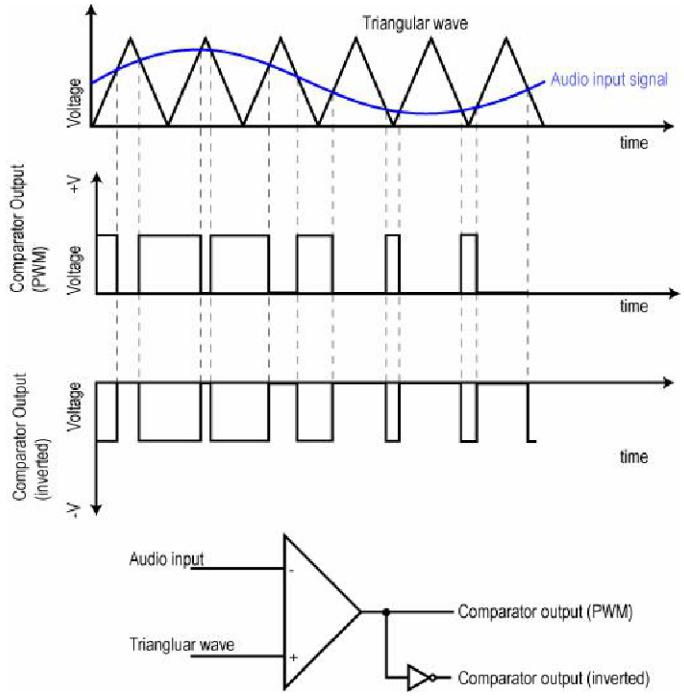
Pulse Width Modulation

Pulse width modulation (PWM) is generated by comparing the audio or other signal to be amplified to either a triangular or sawtooth wave.
The two signals are applied to an op amp comparator. The comparator switches between two output levels. The power levels are positive and negative. depending upon whether the triangular or sawtooth wave voltage is greater than or less than the amplitude of the audio signal.

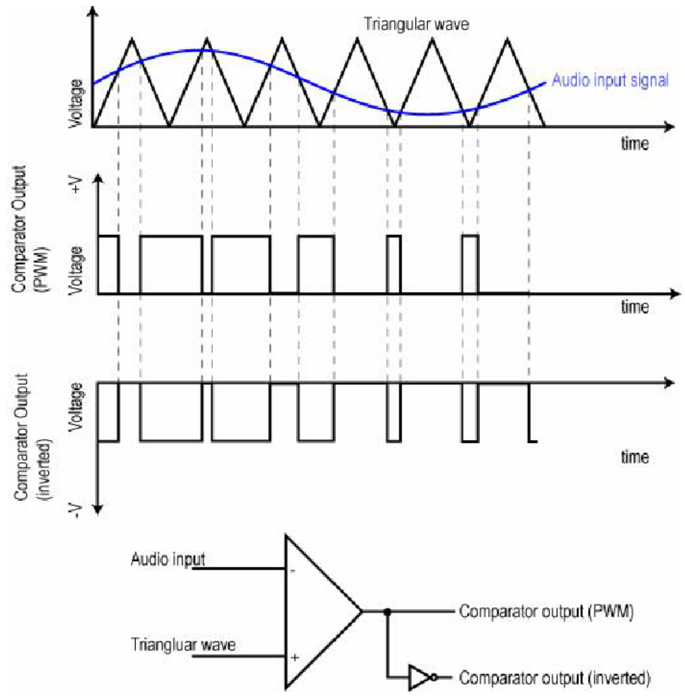


Pulse Width Modulation

The comparator output pulses vary in width or duration depending upon the amplitude of the audio signal.

At high input amplitudes, the pulses are wide and at low amplitude, the pulses are narrow.

The complete content of the audio signal is contained within the width of the pulses.



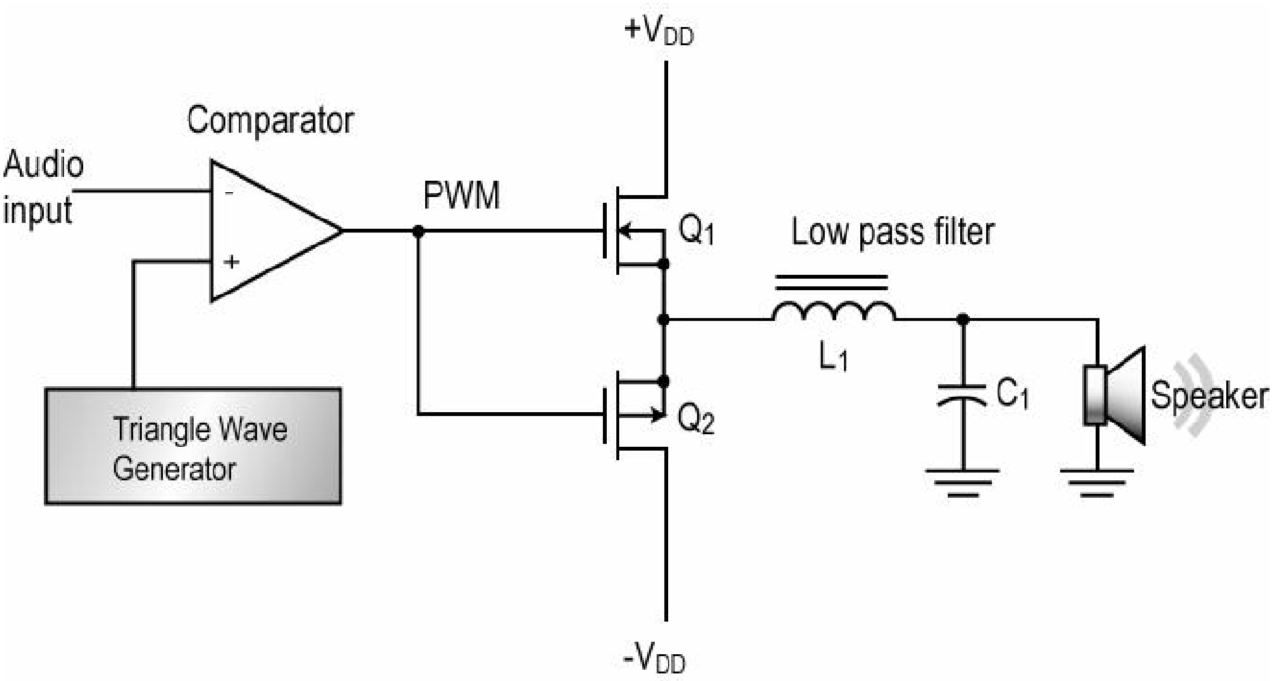
Demodulating PWM

The original audio signal may be recovered by simply passing the PWM signal through a low pass filter. This is usually a simple LC filter with a cut-off frequency a bit higher than the upper frequency of the signal being amplified. The low pass filter smoothes the pulses back into the original signal by averaging the pulses. Long pulses produce higher output levels than narrower pulses.

PWM actually causes the duty cycle of the pulses to vary.

A simulation provided in the Learning Resources section of this module shows how changing the pulse width varies the duty cycle and how the average output voltage of the low pass filter varies with pulse width.

Class D Amplifier Operation



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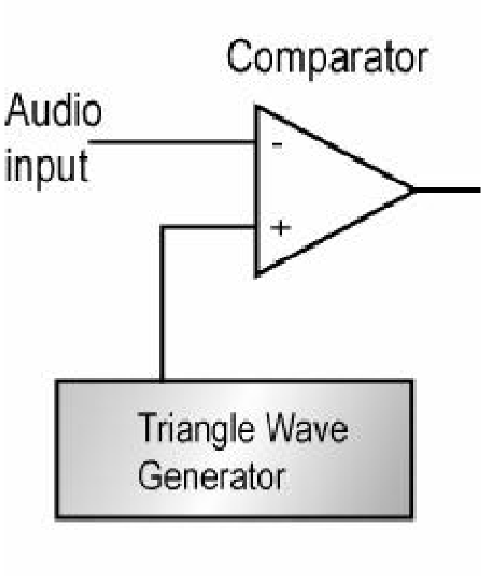
Class D Amplifier Operation



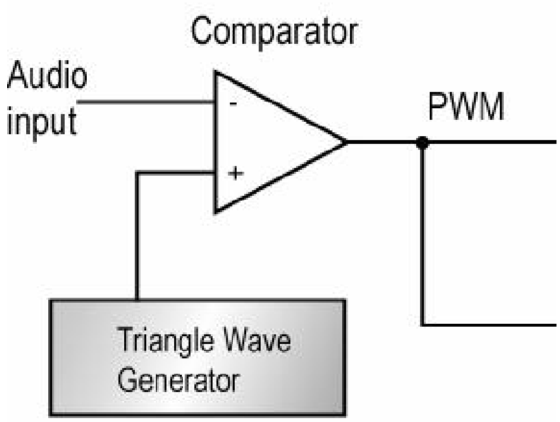
Class D amplifiers are primarily used for the amplification of audio signals, direct current (DC), and low frequency signals used in industrial control systems.

The input signal is applied to one input of an op amp comparator where it is compared to a high frequency triangular wave.

Class D Amplifier Operation

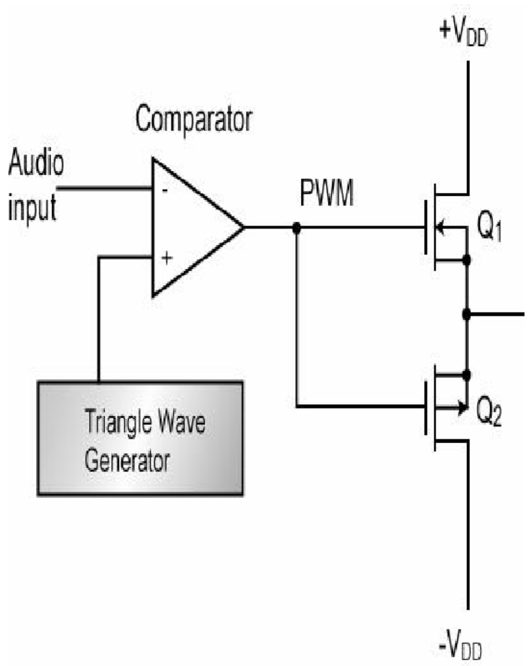
As the input signal varies, the comparator produces a constant frequency rectangular wave output with a pulse width proportional to the amplitude of the input signal. The comparator output is the PWM signal. The frequency of the signal is constant but the duty cycle of the pulses is varied.

The frequency of the triangular wave is usually in the 100 kHz to 1 MHz range. It must be much (usually ten times) higher than the minimum of the highest frequency to be amplified.

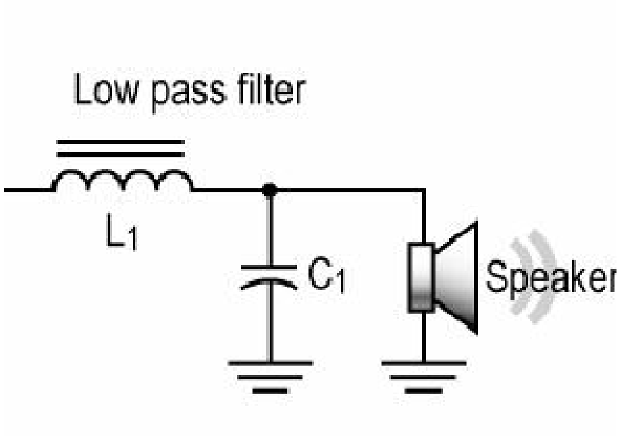


Class D Amplifier Operation

The PWM pulses at the comparator output are then applied to the complementary enhancement mode MOSFETs. The MOSFETs switch the supply voltages off and on according to the PWM signal. The positive pulses turn on the N-type MOSFET while the negative pulses turn on the P-type MOSFET.



Class D Amplifier Operation



The resulting pulse signal is applied to the load. Typically the load is a speaker but in an industrial application, the load is a motor, valve, or other actuator.

The high frequency pulses are averaged in the load to produce the original signal. In most cases, the low pass filter is used to eliminate switching transients and harmonics and leave only the desired signal. The low pass filter has a cut off frequency just above the upper frequency limit of the signal being amplified.

Switching Amplifier Power Dissipation

The switching transistors generate little power or heat when on and none when they are cut off.

Switching MOSFETs have very low “on” resistances of only a few ohms or less. They do consume some power when conducting but it is only a very small amount.

A small amount of power is also dissipated as the transistor switches from off to on and on to off. The rise and fall times are finite and fast. However, the transistor does pass through the linear region of the transistor for a short time where there is some power dissipation.

It is possible to build class D amplifiers for power levels of up to about 1500 watts.

Advantages of Switching Amplifiers

The primary advantage of a switching amplifier is high efficiency. The typical efficiency of a linear power amplifier is rarely greater than 50-60% because half of the total power used is lost as heat. The efficiency of a class D amplifier is very high. Switching amplifiers made with MOSFETs can typically achieve real efficiencies of 90% simply because of the lower power dissipation in the transistors while switching.

Efficiency (η) is the ratio of output power (P_o) to the DC input power (P_{dc}).

$$\eta = (P_o/P_{dc}) \times 100$$

The input power is the total DC power drawn from the power supplies. It is the sum of the output (load) power plus the power dissipated in the transistors and, to a lesser extent, other components.

Advantages of Switching Amplifiers

Since there is minimal power loss and very low heat dissipation, no special cooling solutions are needed.

Switching amplifiers are ideal for applications where battery power is used because they conserve precious battery power. This reduces the number of recharges or battery replacements needed.

Another benefit of switching amplifiers is a major reduction in size and weight. Switching amplifiers operate at very high frequencies and use smaller, lighter components.

Switching amplifiers for power levels up to about 50 watts are implemented primarily as integrated circuits making them extremely small.

Switching amplifiers exceeding 100 watts or more use larger, external discrete MOSFETs.

Disadvantages of Switching Amplifiers

There are three major disadvantages of switching amplifiers but they can easily be overcome.

The first disadvantage of switching amplifiers is the noise and high frequency transients produced by the switching process.

This disadvantage is easily overcome because the switching transients produce harmonics well beyond the frequency range of the signals being amplified and are easy to filter out.

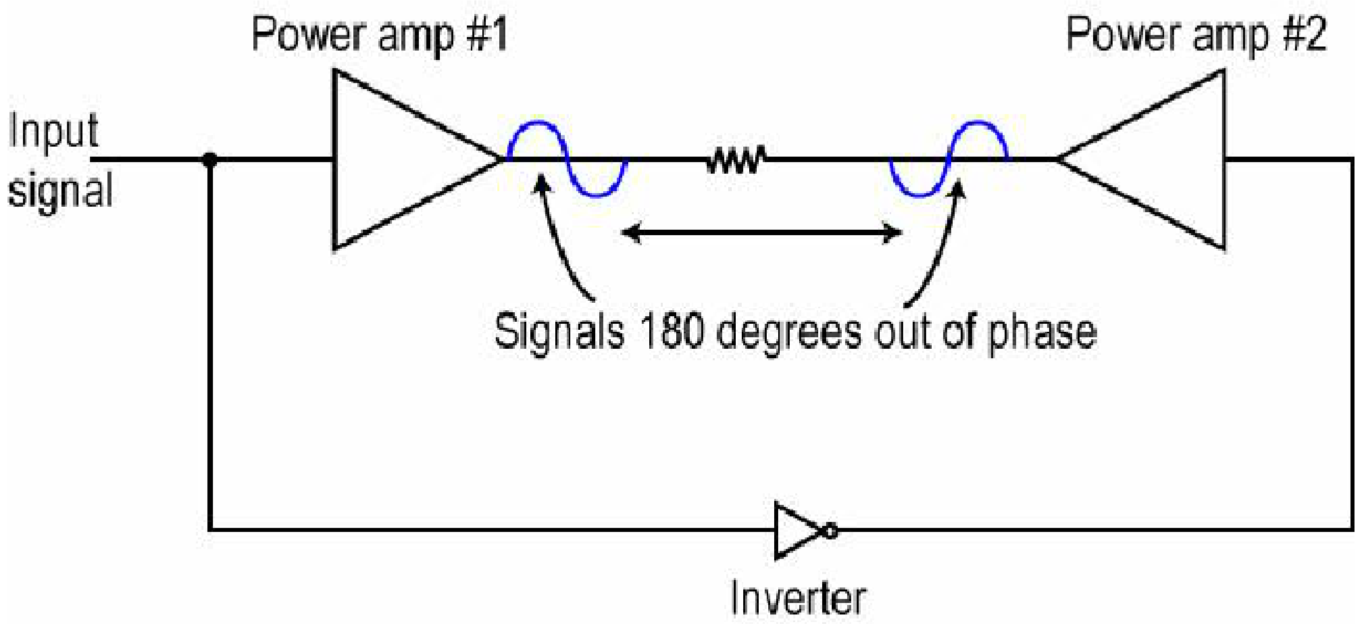
Disadvantages of Switching Amplifiers

A second disadvantage is higher total harmonic distortion (THD). THD is a measure of the amount of harmonic distortion introduced by the amplification process. Linear amplifiers typically have less distortion.

However since THD in a switching amplifier can be reduced to a very low level, this type of amplification is suitable for all but the most demanding high fidelity reproduction.

A third disadvantage is that switching amplifiers require both positive and negative power supplies. This disadvantage can be overcome with a bridge circuit configuration.

The Bridge Amplifier



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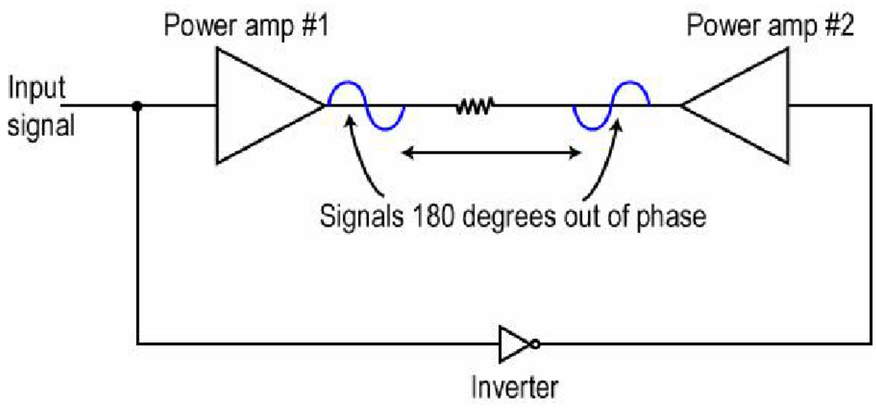
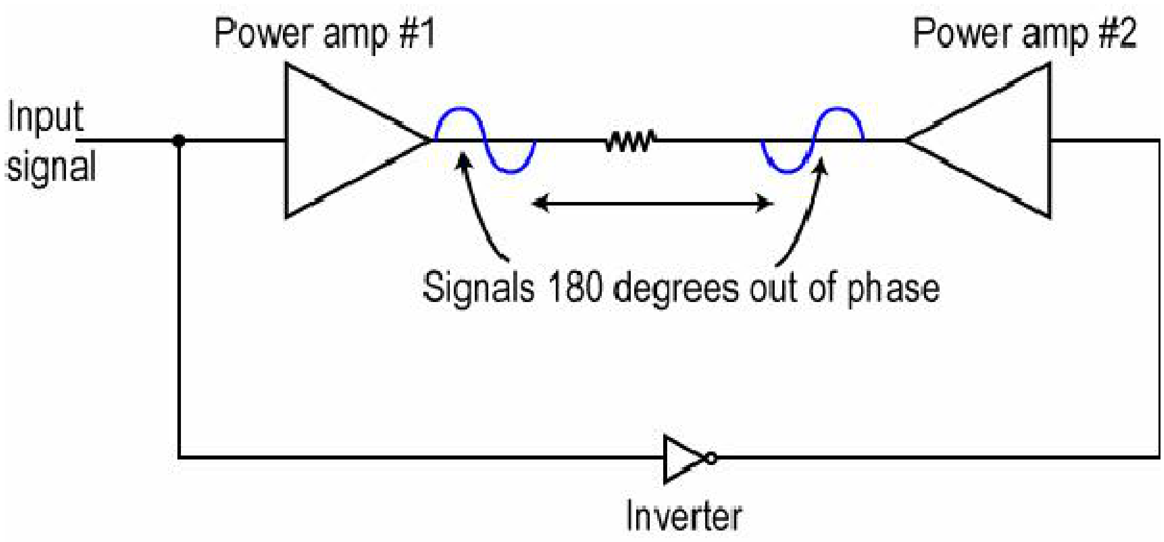
The Bridge Amplifier



A bridge amplifier can be used with both linear and switching amplifiers to boost output power for a given supply voltage. It eliminates the need for both positive and negative power supplies.

The input signal to be amplified is applied to power amplifier #1 and a signal inverter producing a 180° phase shift. The inverter feeds an identical power amplifier #2. The load, usually a speaker, is connected between the two amplifier outputs.

The Bridge Amplifier



The two power amplifier outputs are 180° out of phase with one another. When one side of the load is at a maximum negative value, the other is at the maximum positive value.

The result is that the peak-to-peak voltage swing across the load is twice the value that can be achieved with a single amplifier.

Bridge Amplifier

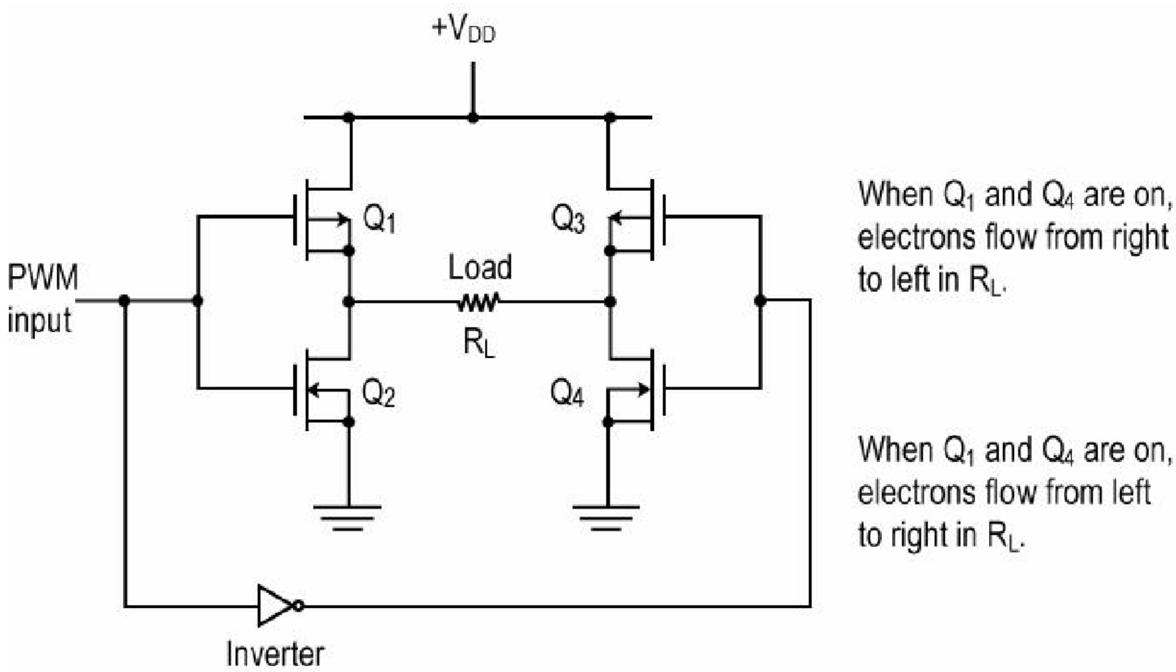
Since the output power is proportional to the square of the load voltage ($P_o = V^2/R_L$), doubling the voltage produces a four times increase in output power.

This is an excellent way to achieve higher output power with lower power components and circuits.

Amplifiers used in a bridge configuration may be complementary symmetry class AB linear amplifiers or complementary MOSFET switching amplifiers.

Since the load is floating (neither end is common or at ground), a single power supply can be used to achieve AC in the load.

Bridge Amplifier



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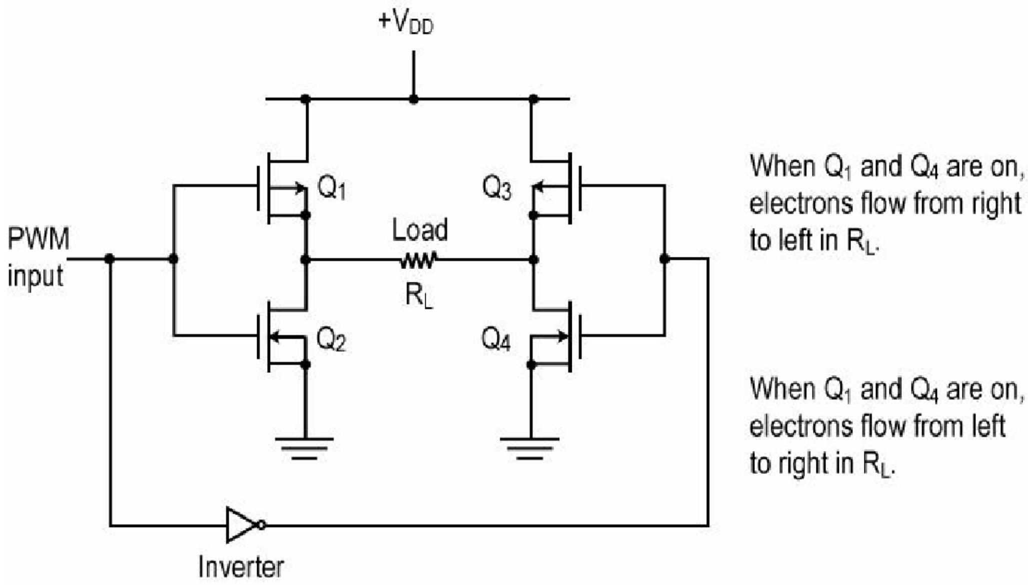
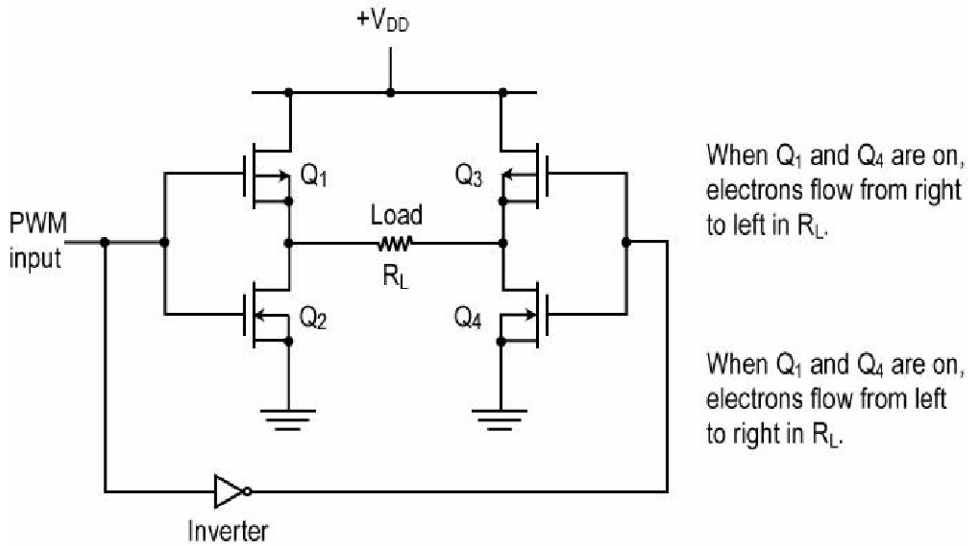
Bridge Amplifier



In a bridge amplifier, transistors form the arms of a bridge while the load is connected between the two.

Transistors Q_1 and Q_2 form the complementary switches at the output of one switching amplifier. Q_3 and Q_4 are the output switches of the second amplifier.

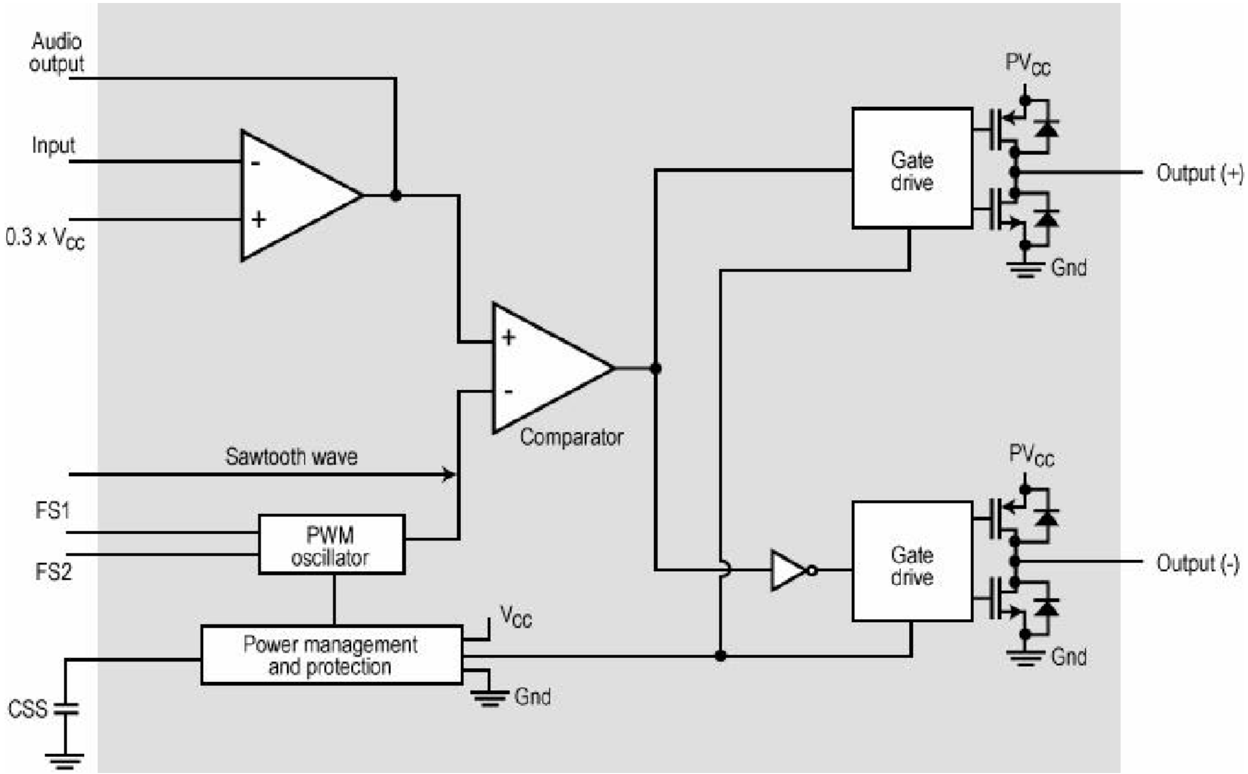
Bridge Amplifier



The current through the load may be in either direction producing AC but requires only a single polarity DC supply voltage.

This configuration is often referred to as an H-bridge. The load is said to be a bridge-tied load (BTL).

Typical IC Class D Amplifier



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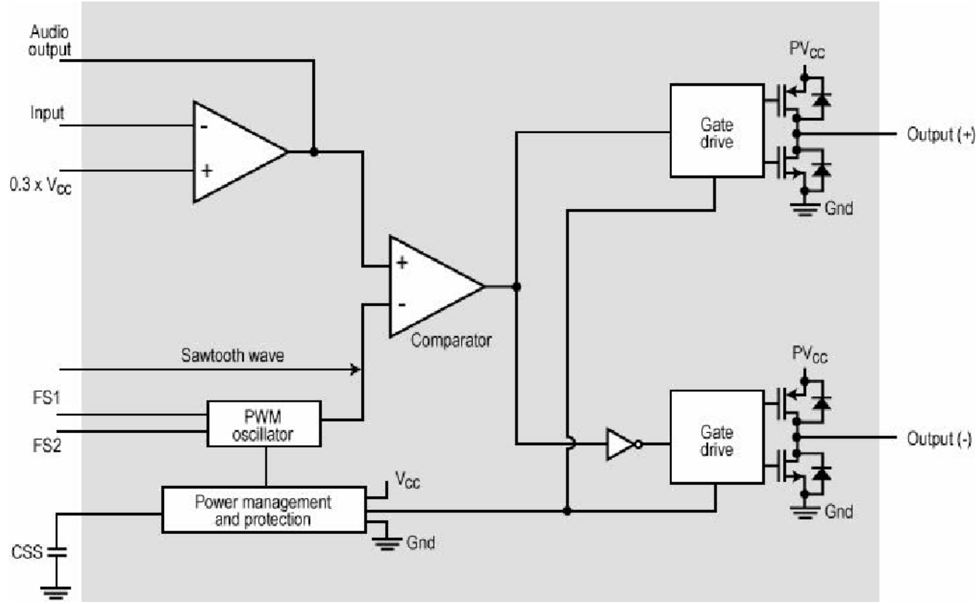
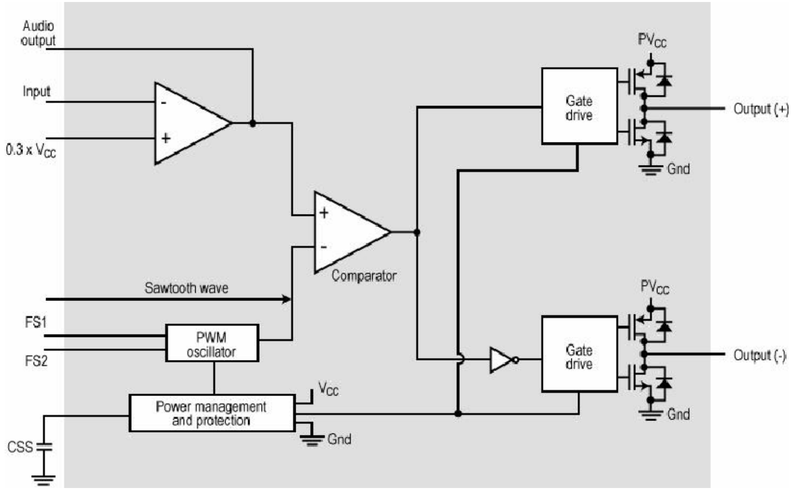
Typical IC Class D Amplifier



This illustration shows a block diagram of the Maxim Integrated Products MAX4295 class D amplifier integrated circuit.

It consists of an input op amp, an op amp comparator, and a PWM oscillator. The input op amp gain can be set with external resistors. The PWM oscillator generates a sawtooth signal for the comparator.

Typical IC Class D Amplifier



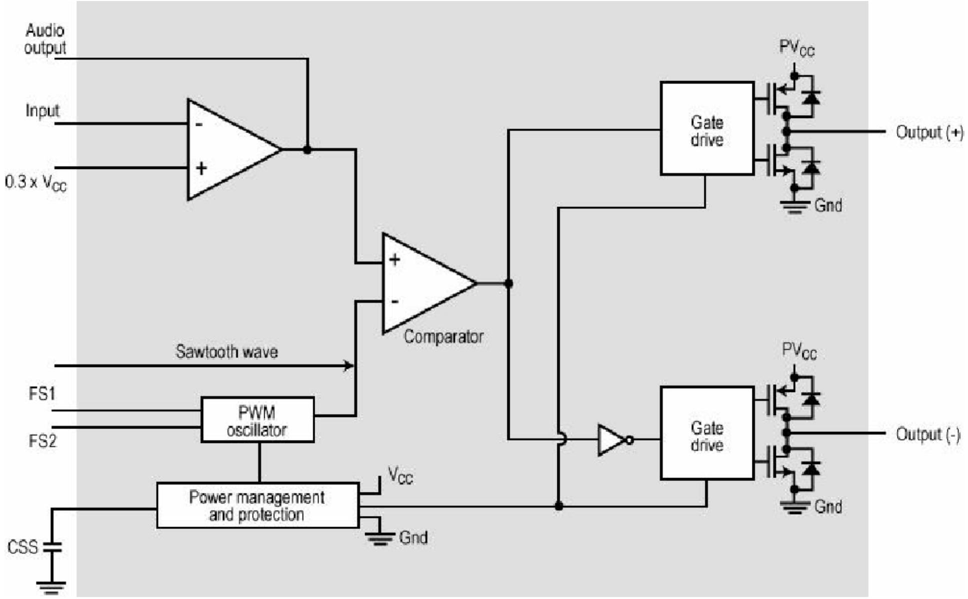
The frequency of the sawtooth is selectable with two binary inputs FS1 and FS2 according to the code where 0 = ground and 1 = supply voltage.

00 = 125 kHz, 01 = 250 kHz, 10 = 500 kHz, 11 = 1 MHz

The sawtooth frequency should be at least ten times the highest input frequency to be amplified. Lower sawtooth frequencies give the best efficiency and lowest THD.

The comparator drives a pair of complementary MOSFET switches 180° out of phase.

IC Class D Amplifier

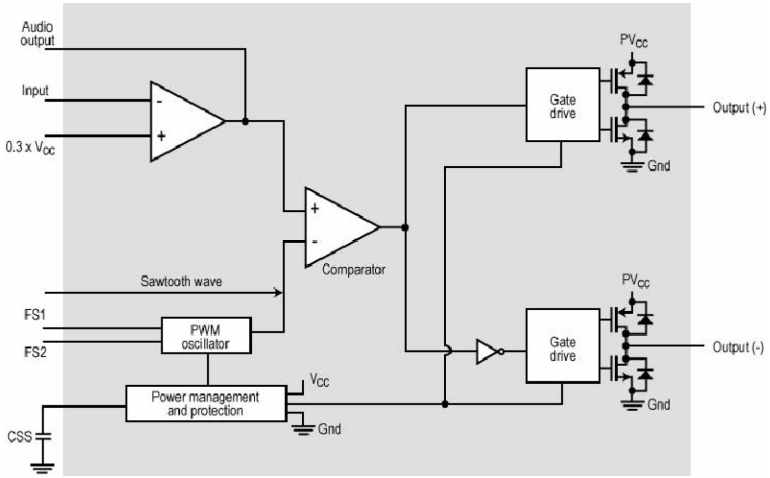


This circuit operates with a single supply voltage from 2.7 to 5.5 volts.

Power output is 0.7 watts with a 3 V supply and 2 watts with a 5 V supply. The load is typically a 4 ohm speaker.

With a sawtooth frequency of 125 kHz, the efficiency is 87% and the total harmonic distortion plus noise (THD+N) is only 0.4%.

IC Class D Amplifier

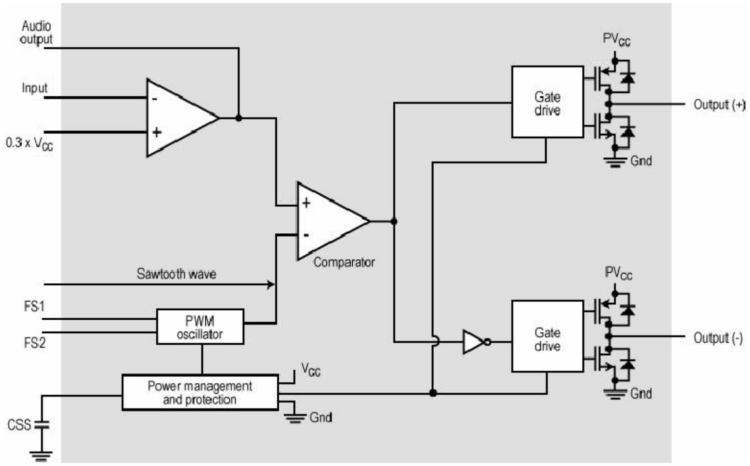


This amplifier may be used with either a bridge-tied load or single-ended load. The speaker is connected to one of the outputs and the other side is connected to ground.

When used in the single ended mode, a DC blocking capacitor is needed in the output. The BTL connection is preferred because higher output power is possible and the output DC blocking capacitor is not needed.

The diodes across the MOSFETs are used for transient protection when an inductive load like a speaker is used.

IC Class D Amplifier

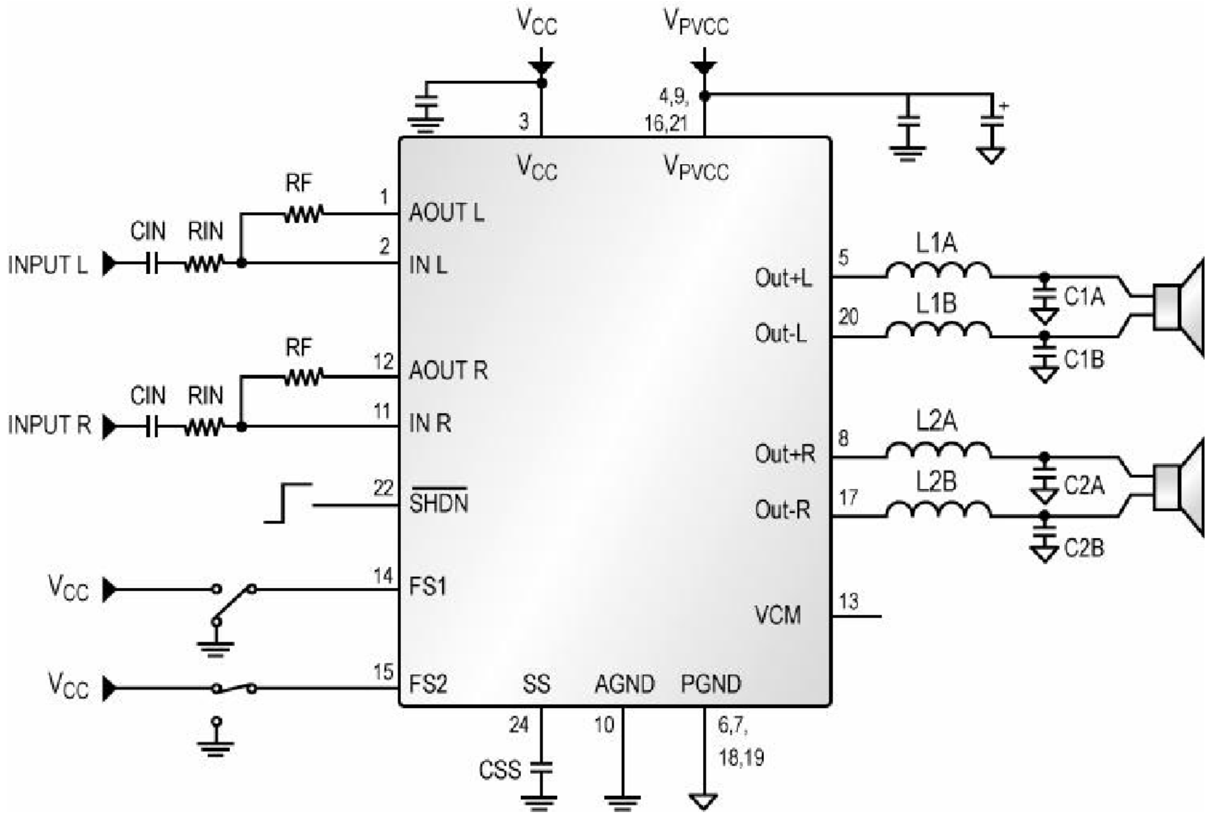


The output filter is usually a two pole (stage) Butterworth LC filter with a cut-off frequency just above the highest amplified frequency. For a 20 kHz output, the filter cut-off is about 30 kHz.

The MAX4295 is housed in a 16-pin plastic flat package with dimensions of 4 x 8 mm. It does not need heat sink.

A linear amplifier of the same power would have a package at least twice as large and a heat sink would be required.

Class D Amplifier Connections



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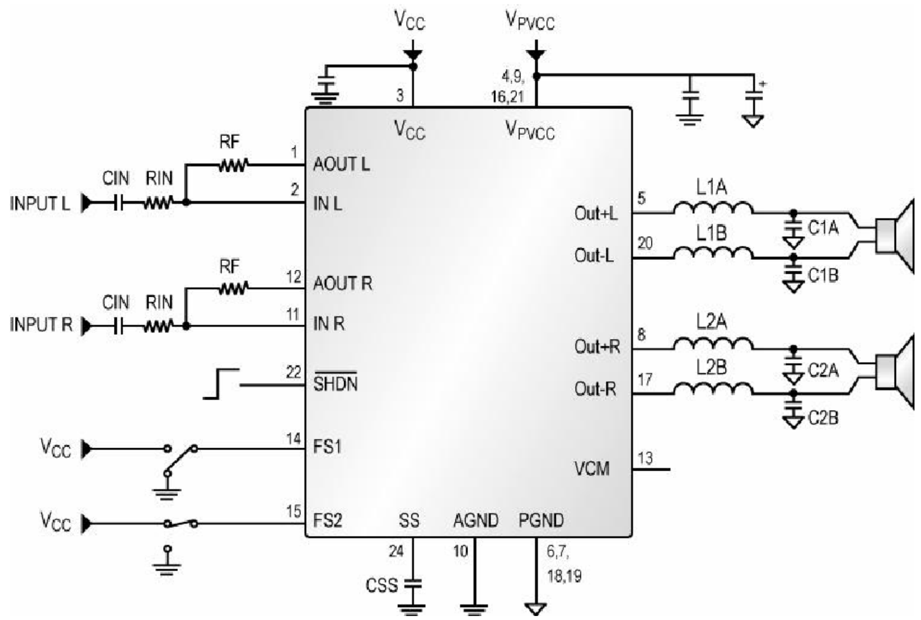
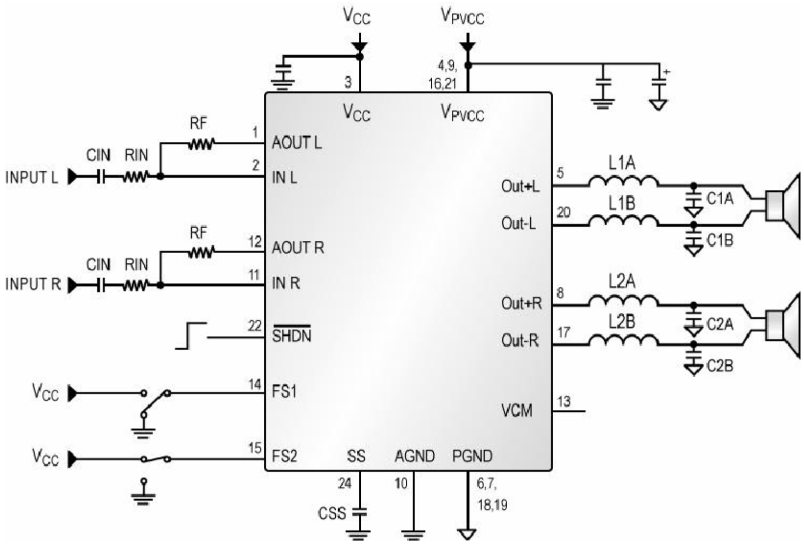
Class D Amplifier Connections



A stereo version of this chip MAX4297 is available. It has two channels and four outputs to support two speakers or headphones.

Two channels of audio are provided, INPUT L and INPUT R. The input amplifier gain is set by resistors RF and RIN.

Class D Amplifier Connections



In the Max4297, the frequency of the sawtooth is selected by the switches. The frequency is 125 kHz.

There is one LC pole in each line in the low pass LC filters.

Both DC supply lines are bypassed with external capacitors. V_{pvcc} is the MOSFET supply. It is usually high to give the desired output power.

Digital Input Class D Amplifiers

In the class D amplifiers discussed, the PWM circuit converts the analog audio signal input into the binary switching signal that drives the output transistors.

However, many class D audio amplifiers receive their inputs from digital sources. Typical digital sources are CD players, MP3 players, and DVD players.

Digital audio is serial binary pulses representing the sampled analog audio signal. CD players output their serial data at 44.1 kHz, DVD players at 48 kHz.

Some class D amplifiers have a special controller or digital signal processor (DSP) chip that accepts the serial digital data and converts it into the appropriate PWM switching signal.

Class D Amplifier Applications

There are two primary applications for class D switching amplifiers: battery-operated portable products and very high power amplifiers.

High efficiency is a desirable trait in any battery powered device because it extends battery life and minimizes the need for battery replacement or recharging.

The lack of heat and very small size are also desirable characteristics for portable devices.

Class D amplifiers are already used in:

- Boom boxes
- Cell phones
- Cordless phones
- Laptops
- MP3 players
- PDAs
- Portable radios/TVs/CD/DVD/tape players

Class D Amplifier Applications

Applications for the class D amplifiers include car radios, larger auto sound systems, portable or non-portable public address (PA) systems, and computer sound cards (PC audio).

Class D amplifiers are also showing up in high end high power stereo sound systems. New designs have reduced the THD to a very low level. This makes switching amplifiers competitive with traditional linear power amplifiers.

Class D Amplifier Applications

Class D amplifiers are also used in the popular multiple speaker "surround sound" systems.

Each small speaker can contain its own distributed amplifier thanks to its small size, low heat, and power efficiency. These speakers are called active speakers. They can also be battery powered.

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Class D Switching Amplifiers

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