Digital does analog

Class D audio amplifiers give analog sound a digital touch.

Robert Repas
Associate Editor

Makers of portable electronic devices are in a continuous struggle to add innovative features while getting a long operating life from an internal power source. Nowhere is this demonstrated more effectively than in the cellular phone, which has come to function like a computer terminal, music player, and camera for both pictures and video.

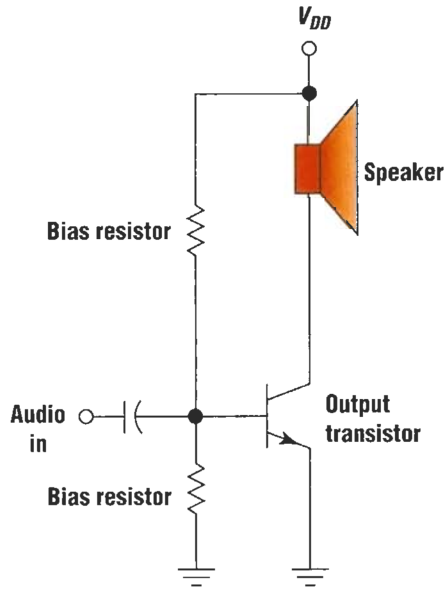
Digital circuits, of course, make such versatility possible. But consider how a digital circuit looks to its power source. It's well known that maximum power is transferred, and thus used, when input and output impedances match. By swinging from full on to full off, the digital circuit remains in that middle matched-impedance high-power state only a fraction of the time.

Despite all the roles a cell phone plays, its reproduction of audio signals still constitutes one of its most power-hungry uses. The creation of sound typically requires the motion of air molecules creating pressure waves that push against the human eardrum. To push air requires power — an almost continuous drain of power as long as the sound is playing, whether it's a voice during a phone conversation or the rock band's latest hit single.

To reproduce sound, a speaker moves a cone or diaphragm in response to a change in current or voltage. Because sound is analog, the current or voltage tracks over a broad range of values to reproduce the exact motion to create the proper pressure wave. Instead of the full-on or full-off digital values, speaker current is a constantly changing value more within the center of its range rather than the extremes.

Because audio reproduction is so power hungry, designers of portable electronic gear give it a lot of attention. One technique they've come up with to handle the generation of sound yet prolong battery life is the Class D amplifier. Class D amplifiers give batteries 2.5× longer life then they would have using more conventional amplifiers. To understand how Class D amplifiers accomplish this task, it's important to understand how previous amplifiers worked.

Class A amplifier

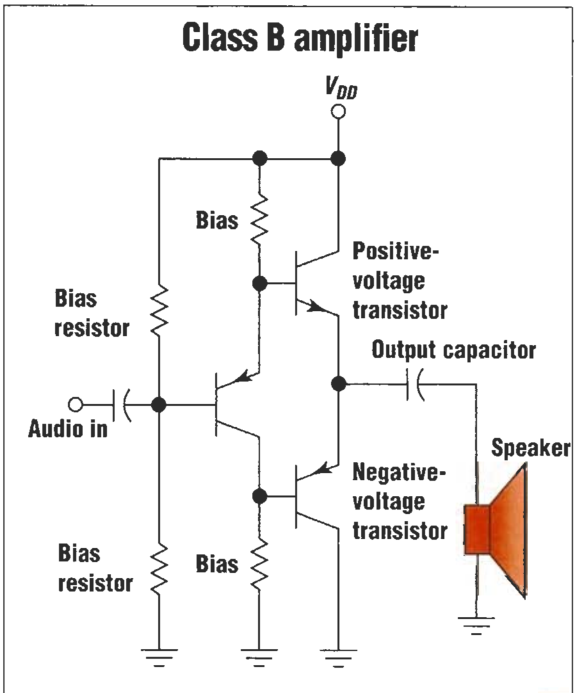


Class A amplifiers bias their output to the middle of their linear region. *The amplifier continuously draws current even in its quiescent state. While its theoretical efficiency is 25%, it rarely exceeds 20% and is usually far less efficient in actual use.*

To be effective, amplifiers must make the output signal faithfully reproduce the shape of the input signal at greater values of voltage and current. The ratio between the input and output-signal levels is called the gain of the amplifier. Amplifier gain should remain the same across the entire range of input voltages and currents.

An amplifier that maintains the same gain factor over a given range of input values is said to be linear within that range. A change in the gain of an amplifier with different input values distorts the output signal. The shape of the output signal no longer matches the shape of the input signal and the amplifier is said to be nonlinear.

Speech with a high degree of distortion is difficult to understand. Music with a high degree of distortion may actually produce pain in the listener's ears. Amplifiers used to reproduce either should remain linear as much as possible.



Class B amplifiers use two output transistors in a push-pull configuration. One transistor pushes electrons to the load while the other pulls electrons from the load. Only one transistor is on at a time, so quiescent power is near zero. However, signal distortion is high at the crossover point. That's the point when the output crosses over from one polarity to the other. Class AB amplifiers look the same schematically, but the output transistors are biased so their turn-on regions overlap, reducing distortion at the crossover point.

The efficiency of an amplifier describes how much of the power that goes into the amplifier comes out of the amplifier. Simply stated, it's the ratio of power out to power in. An amplifier that outputs 15 W with an input power of 50 W is said to be 30% efficient.

Power loss in amplifiers was well known before the life of battery-powered devices boosted its importance. Electronic engineers classified amplifier designs according to how the amplifier handled the transfer of power from input to output. Today, there are five recognized amplifier classifications designated by a series of letters.

Class A amplifiers are the most linear of all amps, and thus are the most faithful at reproducing the exact shape of the sound. Unfortunately, they are also the most inefficient. Class A amplifiers are biased to operate at the center of their linear region. This allows the amplifier to respond equally well to both positive and negative input voltages.

Because the bias voltage is set to the center of the range, current is always flowing through the amplifier, even when no signal is present. This is known as the quiescent current demand. The end result is that Class A amplifiers are always drawing power. They can never exceed 25% efficiency and in fact rarely do better than 20% at full power. Without an input signal Class A amplifiers have 100% power loss. Obviously, Class A amplifiers are not a good choice for battery operation.

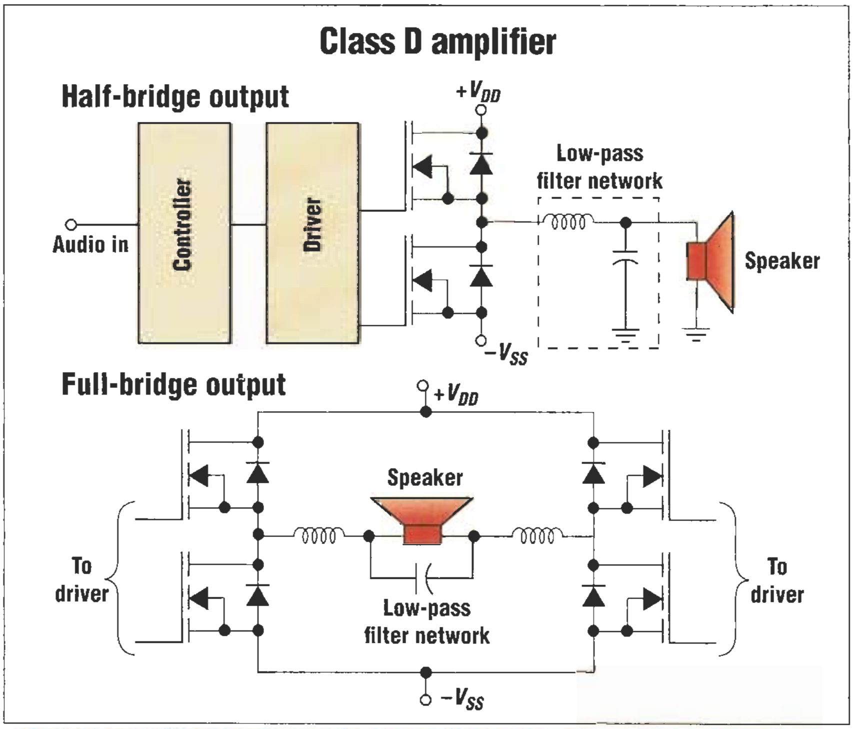
The key to improving efficiency is to turn off the output so that it isn't drawing current without an input signal. Class B amplifiers do just that. They use two transistors that work with opposing polarities. Without an input signal, both transistors are turned off, preventing current flow. When a positive voltage is applied, the positive-voltage transistor turns on, making the output voltage positive. Power flows from the positive power source through the load. A negative voltage does the same for the negative transistor. Since only one transistor is on at a time, the efficiency of a Class B amplifier improves to a possible high of 50%. Even more important, without a signal Class B amplifiers are effectively off, drawing very little power from the battery.

The main drawback to Class B amplifiers occurs when the transistors become nonlinear as they approach their turn-off point. This nonlinearity distorts the output signal as it switches polarity. To reduce the distortion, electronic engineers created the third class of amplifier, the Class AB.

Class AB amplifiers look exactly like Class B amps, but the transistors are biased so that one turns on before the other turns off. This helps smooth the transition from one polarity to another, and reduces the amount of distortion in the output signal. However, the price to pay is slightly more power loss as both transistors turn on at the same time. Without an input signal, the quiescent current of the amplifier also rises compared to a true Class B amplifier.

Class C amplifiers were the most-efficient amplifiers for many years. However, the nonlinearity inherent to Class C operations precluded their use for audio systems. A Class C amplifier is biased well into its cutoff point. It responds only to the very peak of the input signal, turning on for only a short period of time. Class C amplifiers could only be used with tuned radio-frequency circuits that could restore the original shape of their waveform by a resonant circuit. Thus, Class C amplifiers were only used for radio-frequency power amplifiers in transmitters.

Battery-operated equipment demanded even better efficiencies than Class B offered to obtain long battery life. That demand has been answered with the latest amplifier classification, the Class D amplifier. Not only is it the next



Class D amplifiers possess outputs similar to those found on servomotor-control systems with a speaker taking the place of the motor. Pulse-width-modulation techniques control the power delivered to the speaker while the output transistors cycle between full-on and full-off modes at a high switching rate.

classification letter, it also identifies the technique used by the amplifier's output — a digital output.

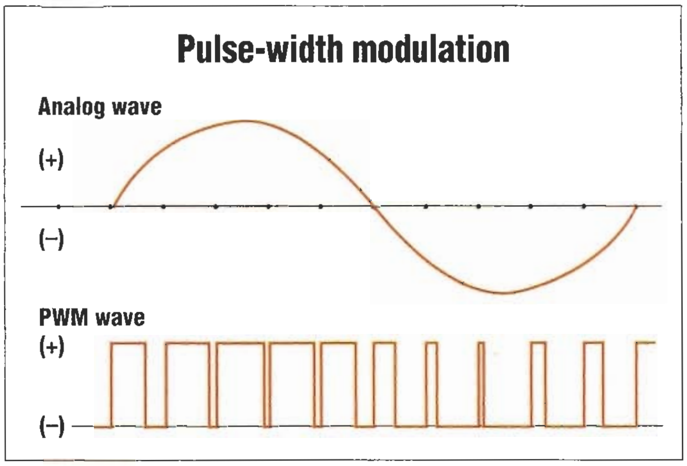
Class D amplifiers are pulse-width modulated (PWM) or switching amplifiers. In this amplifier, the output transistors are either full on or full off. This reduces power loss in the output transistors and places it strictly on the output load, where it belongs. Class D amplifiers can best 90% efficiencies with distortion levels that may actually be better than some Class A amplifiers. With 90% of the battery power hitting the speaker, battery life is extended to at least twice that of a Class B amplifier.

Instead of an analog signal applied to the speaker, a Class D amplifier applies a square-wave output switching rapidly between the supply rails. The frequency of this square wave is typically at least 10× the highest frequency the speaker sees. Typical human hearing response is from 20 to 20,000 Hz, so most Class D outputs have a minimum square-wave frequency of 200 kHz. They can reach as high as 2 MHz.

There are two basic output designs for Class D amplifiers. Outputs are either half bridged or full bridged, depending on the type of power supply. Half-bridge outputs are usually found with dual-polarity power sources while a single-polarity supply works with a full-bridge output.

The effective voltage applied to the speaker is based on the duty cycle of the pulse-width modulation. A duty cycle of 50% places the equivalent of one-half of the supply voltage on the speaker. As duty cycle goes up, the voltage on the speaker becomes more positive. When duty cycle falls, the voltage also drops becoming more negative.

The output of the Class D amplifier is usually fed through a



Pulse-width modulation substitutes the duty cycle of a switched waveform for the value of an analog voltage. The chart shows typical output pulse widths for different points along the sine wave. The PWM wave possesses a 50% duty cycle without an output signal and is at least 10× the frequency of the highest sine-wave output frequency.

low-pass filter that removes the high-frequency switching component. However, a new series of digital amplifiers are now appearing that no longer requires this filter. The filterless amplifiers provide direct connection to the output speakers, reducing component count and improving reliability of the circuit. They also include built-in safety-related items such as short-circuit and thermal-overload protection.

While the ideal Class D amplifier has no distortion and no noise generation in the audible band, practical Class D amps contain imperfections that do affect their performance. Areas of concern include nonlinearity in the PWM signal due to limited resolution or timing jitter, timing errors, finite on resistance in the output devices, parasitic components that cause ringing, and power supply fluctuations.

Most of these are controllable with the proper selection of quality components. The development of Class D amplifiers on-a-chip and in power module blocks with internal drive transistors goes a long way to reducing these errors. For example, the standard power-supply rejection ratio for a normal Class D amplifier is basically 0 db. A change in the power-supply voltage would change the amplitude of the output signal proportionally introducing distortion.

This was especially true with the early half-bridge designs that were prone to a condition known as bus pumping. Residual output current, typically from the low-pass filter inductor, would reflect through the opposite half of the bridge back into the power supply, pumping up its voltage due to the internal resistance of the supply. Modern Class D amplifier modules now compensate for changes in power-supply voltage. Most modules also use full-bridge outputs that don't suffer from the bus-pumping effect. So many of these modules now provide power-supply rejection ratios up to 90 dB.

Modern Class D amplifiers are revolutionizing battery-powered audio devices, prolonging battery life while shrinking size versus power. And you can expect them to invade line-powered equipment as well providing more power in smaller boxes. One manufacturer today makes a 25-W/channel stereo Class D power amplifier in a single-chip package less than a half-inch square. You can be sure higher-powered amplifiers are on the way. **MD**