The Class-I Amplifier

Class-I, also known as BCA (Balanced Current Amplifier) is Crown's patented, cutting-edge technology that gets more power out of an amplifier with less waste than was ever before possible.

Class-I technology offers several key advantages. It provides unprecedented efficiency, requiring less power from the AC supply than other designs and that can add up to significant cost savings over the life of the amplifier. Class-I handles reactive loudspeaker loads easily and gracefully, by reusing energy returned from the loudspeaker rather than dissipating it as heat or forcing the amp into premature current limiting. This characteristic means class-I amplifiers run better and longer—especially at lower impedances. It also makes them more reliable, since they are not constantly stressed to their limits or subjected to excessive heat. Best of all, as proud owners can attest, amplifiers with class-I technology sound great, with a powerful, accurate sound that stands out from the competition.

Crown's class-I "switching" technology is a completely new adaptation of switching (PWM) amplifier design. This paper provides a simplified overview of Class-I, but before we explore its inner-workings, we need to look at the foundation of all previous high-power amplifier designs in order to fully appreciate how class-I stands apart.

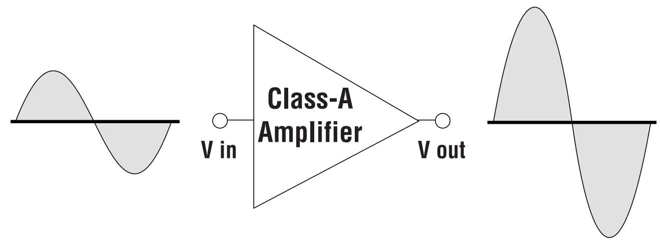
TRANSISTOR OPERATION

To understand the different amplifier classes, it helps to understand a little about how transistors operate. Bias is a technical term referring to the static operating condition of an electronic device, such as a transistor. In other words, bias defines how much conduction takes place in the transistor with no dynamic signal input. Transistors may operate in three possible states: cutoff, saturation, or somewhere in between. The cutoff state is when there is not enough signal present to cause the device to conduct. Saturation refers to when the device has reached maximum conductivity. Amplifiers referred to as "dissipative" control their output by operating in the region between cutoff and saturation.

CLASS-A

Class-A amplifiers are the simplest in design, and can be the most distortion-free of all amplifier classes. In class-A, the output devices are biased on all the time with a current large enough to produce the largest output signal.

Some class-A amplifiers may employ both a positive and negative device in a push-pull arrangement to increase output power, but both devices still are biased on and conduct all the time. Class-A amplifiers are generally considered to be the most accurate of all classes in low to moderate power ranges and are useful for applications such as preamp stages; however, they create tremendous amounts of heat due to their very low efficiency, making them impractical for high-power amplification. Other amplifier classes have been developed over time to overcome the class-A efficiency problem.

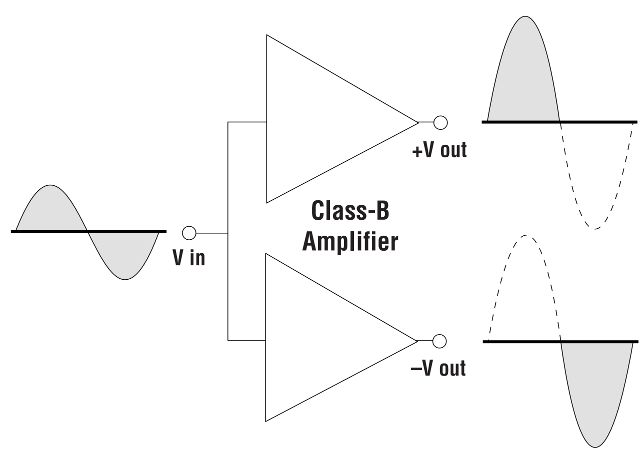


Class-A Operation

CLASS-B AND TIME ALTERNATION

Class-B was invented as a solution to the efficiency problem with class-A. The invention of class-B is significant in that with it came the concept of time alternation, which has been the foundation of virtually all power amplifier designs used for audio reproduction and industrial power since about 1931 to the present. While many incremental improvements have been brought to market since that time, none have varied from the basic time-alternation paradigm.

The basic class-B amplifier implements two devices in the output stage in a "push-pull" arrangement, with each amplifying half of the waveform, and the devices operate in strict time alternation. When the signal goes positive, the positive device conducts while the negative



Class-B Operation

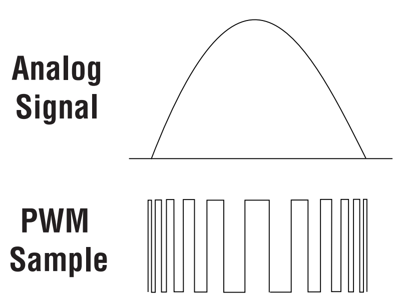
device is biased off. In turn, when the signal goes negative, the positive device biases off while the negative device turns on and conducts the negative portion of the signal.

This configuration provides much greater efficiency than class-A. The problem with class-B is that it can create distortion at the zero-crossing point of the waveform, making it unsuitable for precision amplifier applications. Improvements to and variations of class-B have been developed to solve the crossover-distortion problem, and many are in common use today; however, all operate under the push-pull and time-alternation paradigms.

All amplifier classes have theoretical limits to their efficiency, meaning they all waste a portion of the energy they draw from the AC mains supply. Dissipative designs such as class-A, class-B and other variations, have theoretical limits well below those of “switching” designs since they operate in that region between cutoff and saturation. This lower efficiency may not be a particular problem with lower power applications; however, it can be a major factor in large amplifiers, and when several amplifiers are being used in an application. AC mains power may be limited and/or expensive to supply, and excessive heat created by dissipative amplifiers can also be inconvenient and costly to deal with.

PWM

PWM (Pulse Width Modulation) has been used for years in non-precision amplifiers to achieve very high efficiency. A PWM converter modulates the analog signal onto a fixed-frequency carrier wave, creating pulses



PWM Sampling of an Analog Waveform

that vary in width depending upon the amplitude of the signal's waveform. This creates a “sampling” of the signal, which is then converted back to analog to drive the load. The output devices “switch” between fully on (saturation) and fully off (cutoff) states, so they waste very little energy.

THE TIME-ALTERNATION PROBLEM IN PWM

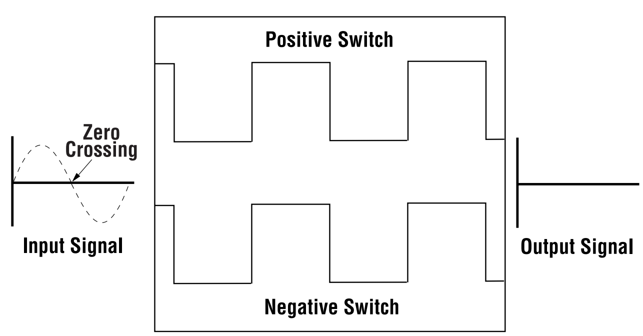
The primary drawback to using previously existing (class-D) PWM technology in a precision, high-power audio amplifier output stage has been that in order to keep distortion sufficiently low, accurate timing circuitry is absolutely critical. Even the slightest variation in timing can cause both positive and negative switching devices to be on at the same time, allowing high “shoot-through” current to destroy the output circuitry. In essence, the time-alternation paradigm works well for dissipative amplifiers, but not so well for switching ones.

Crown invented a highly reliable PWM amplifier output stage that produces very little audible distortion, and solves the reliability challenge. This was made possible by adapting, for the first time in amplifier design, the very opposite of time alternation.

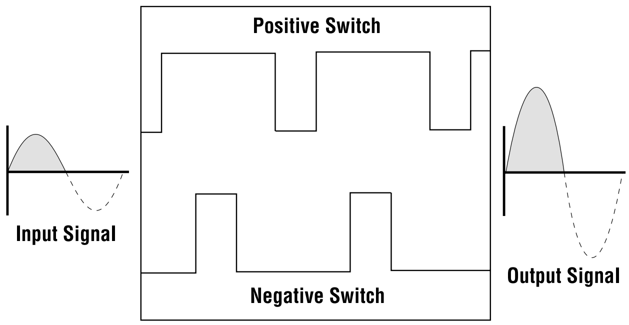
CLASS-I OPERATION

The push-pull paradigm is part of class-I but the time-alternation paradigm is not. In class-I, two sets of switching output devices are arranged in a “parallel” fashion and operating balanced in time, with both sets sampling the same input waveform. One set is dedicated to the positive current portion of the waveform, and the other to the negative current portion. When there is no signal applied, or when a signal varying in amplitude reaches the "zero crossing" between positive and negative, the switching devices are being turned on and off simultaneously with a 50% duty cycle. The result is the formation of two balanced and canceling high-frequency output currents with no net output at the no-signal condition. The two output currents are said to be “interleaved,” and class-I is named from this interleaved characteristic.

To produce a positive output signal, the output of the positive switching device is increased in duty while the negative switching device is decreased by the same

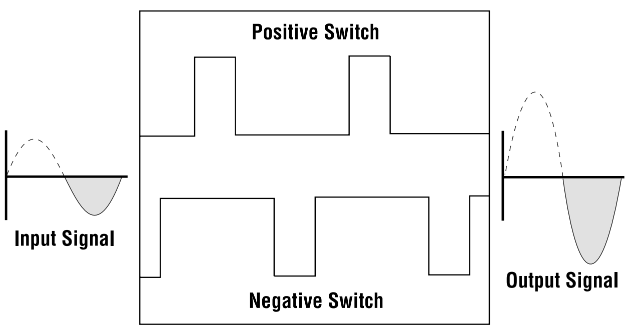


Class-I Switches, Signal at Zero Amplitude amount. Class-I uses symmetrical interleaved PWM, meaning both the leading edges and trailing edges of the pulse are varied according to the amplitude of the signal, and the spacing between pulse centers remains constant. Both the positive and negative switch pulses remain aligned on-center, and the net output current is positive.



Class-I Switches, Positive Signal

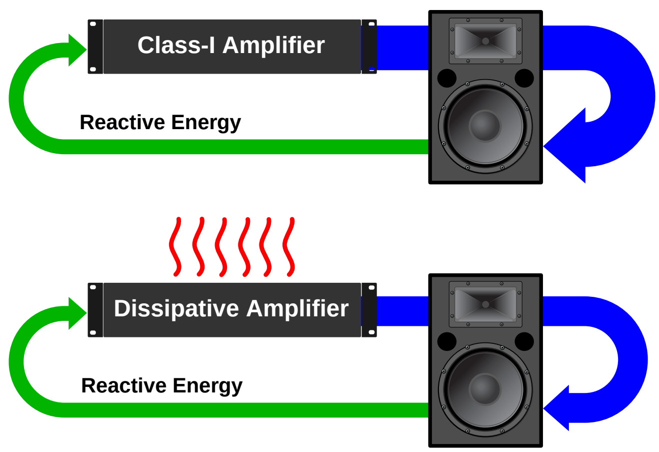
Likewise, to produce a negative output signal, the output of the negative switching device is increased in duty while the positive switching device is decreased by the same amount. Again, both switch pulses remain aligned on-center, and the net output current is negative.



Class-I Switches, Negative Signal

The result of using interleaved PWM is that by operating the switching devices at 250 kHz, the signal is effectively modulated at 500 kHz since both the leading and trailing edges of each pulse contribute to the output ripple current. This arrangement further increases efficiency, since switching losses are effectively halved by operating the switching devices at 250 kHz, rather than at 500 kHz as would be necessary with class-D designs to achieve the same effective sampling of the waveform.

Class-I amplifiers also have all of the nearly ideal power converter attributes of class-D PWM amplifiers, in that reactive loudspeaker loads are easily driven. The reactive energy returned from the loudspeaker to the amplifier is reabsorbed and output again to the loudspeaker with little loss. Non-switching, dissipative amplifiers are forced to dissipate all of the returned energy and more in the form of heat. This means class-I amplifiers are louder than other amplifiers with comparible power specs, yet they stay much cooler, and can be lighter since they don't need nearly as much mass for heat dissipation.



Reactive Energy Returned to Amplifier From Loudspeaker

With it's rock-solid reliability, high quality audio reproduction and unmatched efficiency, Crown's patented class-I technology creates a totally new paradigm for amplifier design that represents the future of professional amplifiers.

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