Class D Amplifiers Empower Mobile Multimedia

To meet growing consumer demands for flexible audio features and hi-fi sound from mobile terminals, designers of handset audio chips are optimising the class D amplifier to meet the special noise and power management demands of mobile applications.

Audio Performance versus Power Budget

Designers of mobile products such as multimedia cellular handsets are today faced with demands to provide versatile, high-quality audio functions including high-output speakerphone modes and simultaneous speakerphone/headphone operation. These are necessary to deliver a wide range of music and video-oriented services to hungry subscribers. To make this possible, more is required of the audio amplifiers in mobile multimedia devices. But since the efficiency of the class AB amplifiers traditionally found in mobile handsets does not exceed 20-25% in most practical situations, a small increase in output power comes at the cost of a large increase in current consumption. Today's mobile consumers will not accept the fashion downsides inherent in this trade-off: shorter battery life, a larger and heavier battery, or both.

High-Efficiency Mobile Amplification

The class D amplifier offers a potential solution to this challenge. By achieving much higher efficiency than class AB amplifiers, these have already enabled home audio-visual equipment such as multi-channel surround sound systems. The audio output specifications now commonly reach 6-channels x 50W plus a 150W bass channel. Such systems would simply not be feasible without class D amplifiers, as the power dissipation resulting from inefficient class AB operation across six channels would result in an insoluble thermal management challenge. The size, weight and cost of a surround sound amplifier designed to class AB principles would also be prohibitive.

Operating on switching principles, rather than exploiting the linear portion of the output transistor characteristic, a class D amplifier is vastly more efficient than a class AB amplifier of similar output power.

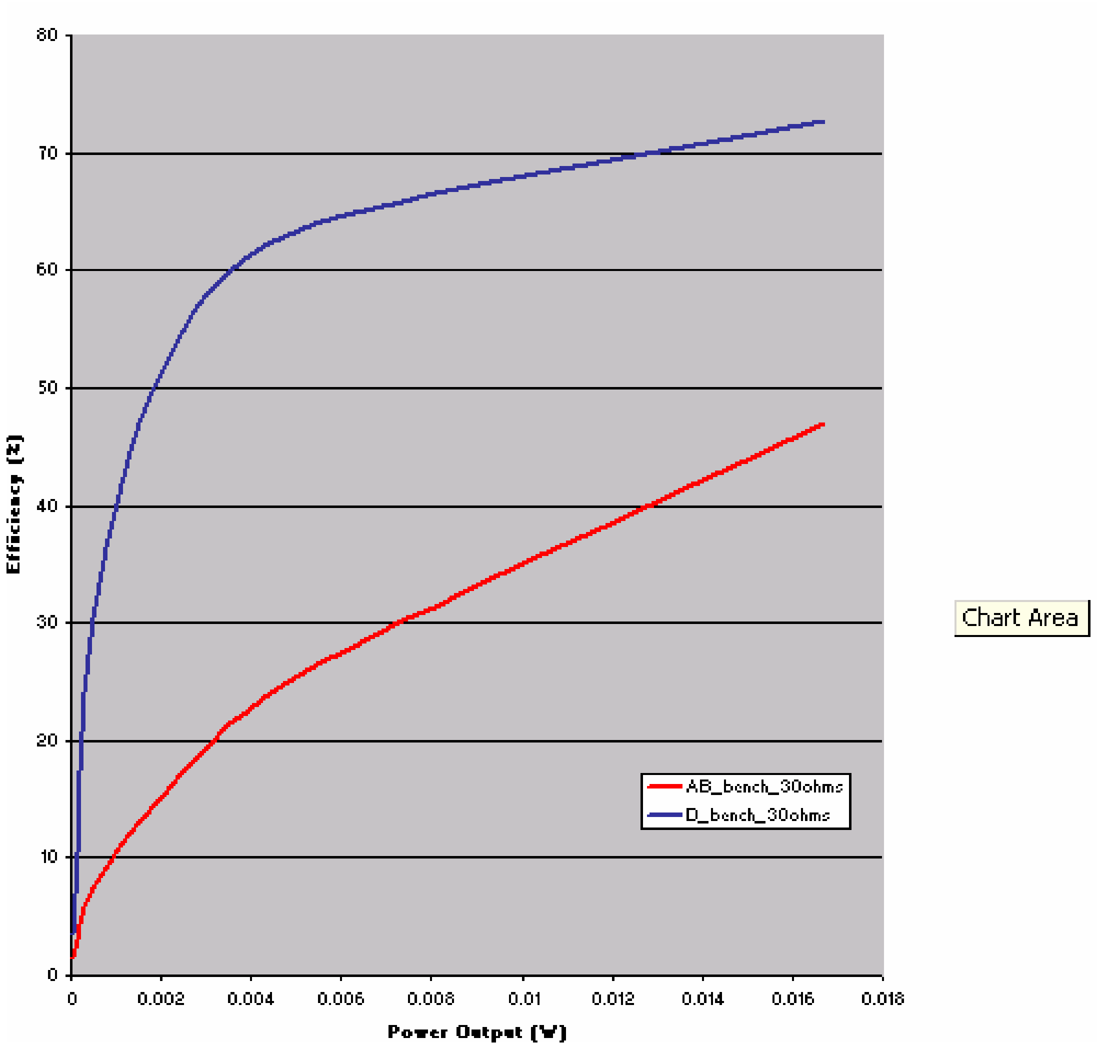

Figure 1 Power Efficiency Comparison, Class AB versus Class D headphone amplifier

In addition, the latest class D designs are now able to achieve very low total harmonic distortion (THD) comparable to high quality class AB performance.

But implementing a class D amplifier suitable for mobile applications is no trivial challenge. In addition to the known issues, including output filter design and management of switching noise, the size constraints prevailing in mobile introduce a new set of issues associated with integrating a high frequency switching amplifier alongside sensitive analogue audio, DSP and power management functions, on the same chip.

Class D Operation, in a Clamshell

Class A, class B and class AB amplifiers are linear amplifiers, in which the output transistors are operated in their active regions. In the case of class A, the transistors in the output stage are operated continuously in their active regions, leading to relatively high current consumption in return for excellent linearity. The maximum efficiency, which occurs only at the maximum signal level, is no better than around 25%. In a class B amplifier, high-side and low-side transistors operate alternately in a push-pull configuration. The theoretical maximum efficiency is around 65% at full power, but is much lower in practice. However, non-linear operation in the crossover region introduces significant distortion. The class AB amplifier uses the class B topology, but the transistors are biased to always operate in the linear region. This eliminates the class B crossover distortion, at the cost of slightly increased power consumption.

In contrast to these linear amplifiers, the class D type is a switching amplifier; indeed, it shares operating principles as well as basic topology with the synchronous buck converter. The audio signal to be amplified is input to a comparator, which compares it with a sawtooth wave. The result is a pulse width modulated square wave; the period is equal to that of the sawtooth, while the pulse width represents a sample of the audio signal. The sawtooth frequency is set very much higher than the maximum audio signal frequency. The PWM square wave – and its inverse – then drive a MOSFET H-bridge, turning opposite MOSFETs on and off to set up an alternating current that represents the square-wave sample of the audio signal. Because the output transistors are either turned hard on or off in order to steer the current, the only losses in a class-D system are $R_{DS(ON)}$ losses in the MOSFETs, and resistive losses in interconnects including the MOSFET lead-frame, PCB traces, and connecting wires. Hence the system is very efficient, with losses only incurred because the devices and interconnections are not ideal.

At the output of the H-bridge, a low-pass filter attenuates the switching frequency, revealing a clean analogue output signal that is basically a time average of the PWM square wave. Setting cut-off frequency just above the desired audio bandwidth results in an accurate representation of the input audio signal. Filter design is critical to achieving a high quality audio output with little distortion. Some class-D amplifiers can achieve total harmonic distortion well below 1%.

Integration Challenges

The small footprint of modern mobile devices places extra constraints on audio design, including the implementation of class D amplifiers. The squeeze on dimensions demands highly integrated audio design, which has already led to the integration of CODECs with audio amplifiers and other mixed-signal functions. This level of integration brings significant challenges in managing noise performance, for example. But when a class D amplifier is introduced to the mix, the noise management challenge moves into another gear. Switching noise, for example, although attenuated in the class D output filter, must also be prevented from corrupting the audio signal path in the analogue portion of the chip. Power supply decoupling, which is important in any class D design if switching noise is not to degrade circuit operation, takes on a greater importance in the context of mixed signal chip design.

Emerging Solutions

When implementing a multimedia CODEC featuring integrated class D output stages, assiduous noise attenuation techniques are required. These may include synchronising the class D switching with other on-chip clocks, chiefly ADC and DAC clocks. This synchronous clocking allows the class D switching noise to be more easily removed than would be the case if the clock signals were asynchronous. Particular attention is also paid to providing a stable and clean analogue rail at a regulated 2.8V or 3.0V.

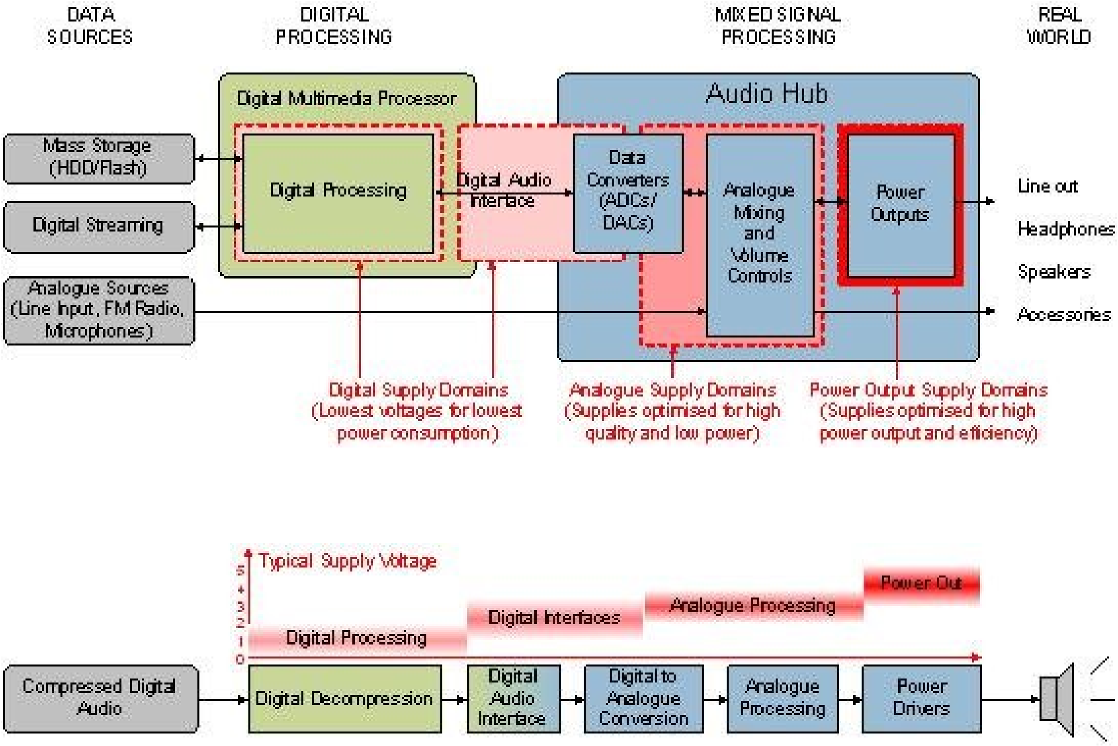

Figure 2 Typical System Block Diagram and Power Domains

Further careful attention to noise management also demands measures to minimise the effects of GSM signalling noise on the audio output. In GSM handsets, the RF power amplifier is powered up at 217 Hz intervals, to send data to network basestations. This makes the audio path susceptible to audible buzzing and clicking at the 217 Hz switching frequency. Very high supply rejection at 217 Hz results in significantly improved audio performance.

External components and wasted power should also be minimised, to meet the demands of mobile applications. For instance, modern high output speakers are usually connected directly to the battery to maximise output power. This has additional implications when integrating CODEC, amplifier and speaker driver functions. Firstly, since the DAC is operated at a substantially lower voltage than the speaker, the signal must be level shifted to drive the speaker sufficiently hard. A gain stage that relies on external components adds to bill of materials, board layout complexity and footprint, leading to a preference for level shifting entirely on-chip.

Secondly, direct battery connection increases the potential for leakage currents capable of quickly running down the battery. Low leakage design maximises the benefits of the power savings enabled by the use of class D technology.

Finally, the increased efficiency of class D amplifiers notwithstanding, some system designers may see problems with switching noise during certain modes of operation; for example when the handset is being operated as an FM radio receiver. An accumulation of system design parameters may conspire to promote excessive interference in the audio output. Dynamically selectable class D or class AB amplification modes give system designers extra flexibility to optimise audio performance under all likely usage scenarios. The amplification mode could be switched under control of the handset software. The switch would be completely transparent to the end user.

Conclusion

Demand for features dominates the mobile design landscape, but energy management has ultimate power of veto. This fact has been the major influence in drawing class D amplification into the mobile arena; designers are under pressure to deliver greater multimedia capability for fewer Watts. It is an effective solution, but optimal implementation demands good audio and mixed signal design skills, to create an integrated solution that will meet small footprint, low component count and low leakage demands implicit in any mobile system requirement.

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