Technical article

PWM audio D/A converter: Cost breaking while maintaining performances

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Audio electronic systems are facing major changes since the rising of ubiquitous devices using voice capabilities. Audio processing combined with high performance converters is becoming the critical contributor to deliver the greatest sound experience. This has led System-on-Chip (SoC) providers and Semiconductor IP suppliers to find the best compromise between cost, performance and flexibility.

In applications requiring to playback sound, two implementations of Digital-to-Analog Converters (DAC) have co-existed for several decades:
- Analog delta-sigma converters with drivers
- Pulse Width Modulation (PWM) converters with external application schematics

The purpose of this paper is to debunk many unfounded certitudes and reveal unknown characteristics of PWM audio DAC.

PWM modulation principle

The conventional approach, with analog delta-sigma converters, is based on mixed-signal circuitry using over-sampling digital filters associated with an integrated analog reconstruction filter. Here, the digital to analog conversion is made within the circuit and the output signal is analog, likely to be driven by a class AB amplifier.

Unlike this solution, the digital to analog conversion in PWM converters is based on a modulation technic (see Figure 1) that allows coding the analog signal by using only two voltage levels: the so-called Pulse Width Modulation. For years, the implementation of such modulation technics was considered sensitive design that required large analog circuitry. Especially in Integrated Circuits (IC), there was no need for such a trick. PWM had been reserved for Class D amplification. Other applications were the turf of traditional analog output, with D/A reconstruction filters and analog amplifiers. However, new parameters are changing the game and bringing PWM digital converters under the spotlights.
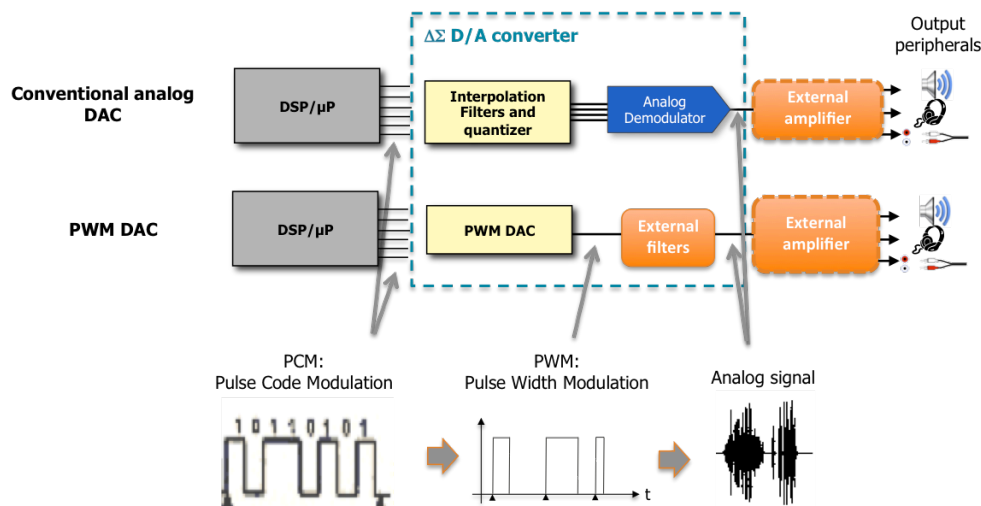

Figure 1: Principle of operation of conventional audio DAC and PWM audio DAC

PWM DAC: A high resolution D/A converter squeezing into minimal area

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The design of PWM DAC has evolved in recent years and PWM implementations are no longer the privilege of analog designers. New architectures, mixing quantization error shaping from Delta-Sigma and PWM technics, allow designing high performance PWM modulators from basic logic elements only. This approach results in a drastic area reduction that directly benefits from Moore's Law.

On the other side, traditional D/A converters still need large analog circuits, which are often the bottleneck of area reduction in today's IC requiring advanced sound processing. Figure 2 shows 0.08 mm^2 in a 28 nm process for a high performance D/A converter: there is nothing more to say… Which integrated analog solution can provide such a low silicon area?
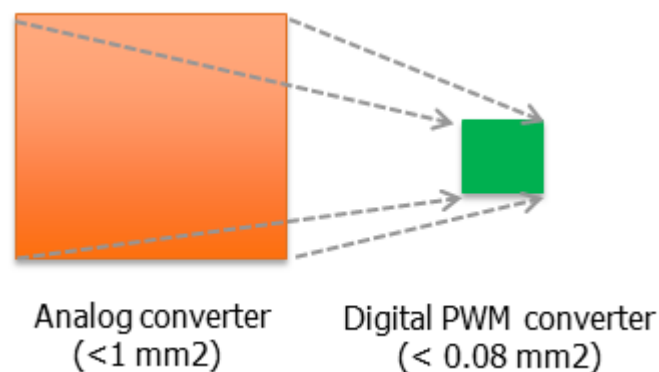

Figure 2: Silicon area - Analog stereo converter vs digital stereo PWM converter

The myth of costly application schematics

Now, let us put an end to a widely promoted, generally accepted and completely erroneous belief: an integrated PWM needs a high cost application schematic. The truth is definitely not.

It is a prejudice to believe that traditional analog converters do not require external components. Generally the following are forgotten:
- Decoupling capacitors for dedicated power supplies of audio drivers
- Capacitors for low noise reference
- Decoupling capacitors for audio interface (up to 220 uF for headphone applications)

Even true-ground solutions, promoted as cap-less solutions, need very low ESR capacitors for the inverter charge-pump. It can also be added that a dedicated low drop-out (LDO) regulator is often used for noise resilience purposes. In the end, the Bill of Material (BoM) may not differ so much from PWM DAC to analog DAC when considering the overall BoM cost.

When it comes to advanced processes, the geometry miniaturization goes with the lowering of the power supply voltage at 1.8 V. At this level, the maximum output power is theoretically limited to around 50 mW for a single-ended output on an 8 Ω load and a single line output cannot reach much more than 600 mVrms,

These voltage levels are clearly not appropriate to address most of the common application requirements. Indeed, most audio applications already require an external amplification stage. For instance, in Set-Top-Box applications, in order to match the requirements of standards when using a converter designed in an advanced process, an operational amplifier has to be used on PCB.
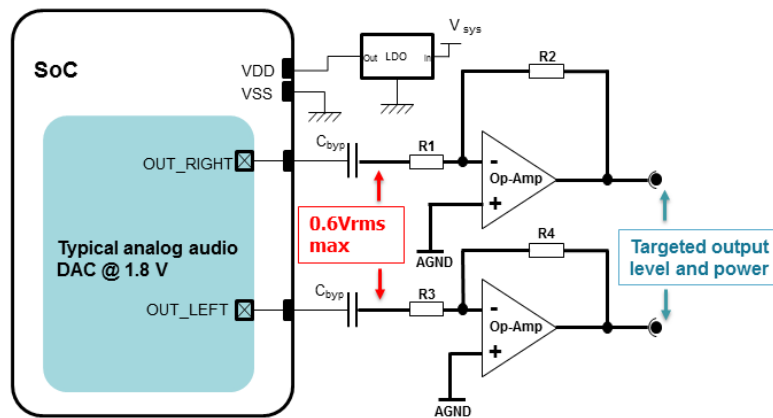
Figure 3: Application schematic using analog converter

The external amplification schematics for an analog DAC (see Figure 3) can be slightly adapted to fit most audio applications when using a digital PWM converter (see Figure 4). At the end, the BoM difference between the traditional analog converter and the PWM solution is just two single capacitors of a few hundreds of pF.
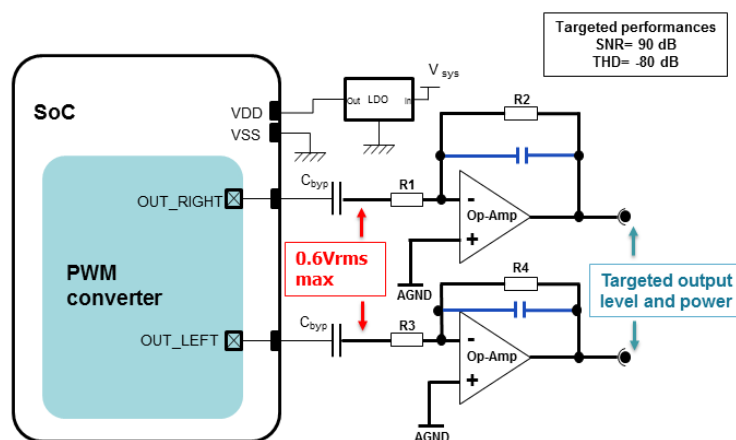
Figure 4: Application schematic using digital PWM converter

Although analog designers can use cascode architectures to be able to supply the CODEC at a higher voltage, these solutions have a cost in silicon area as well as complexity, especially when the gap between the targeted power supply level and the supported power supply level continues increasing. In addition to that, the routing of power elements in IC is becoming a nightmare as the resistance of metal layers is also drastically increasing in advanced processes (metal sheet resistance is approximately four times greater in 28 nm than in 65 nm).
Integrating the audio amplification stage in advanced processes is clearly a dead-end and not a cost effective solution.

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The drastic reduction of Time To Market

In return, a digital PWM approach offers the straightforward advantage of FPGA prototyping. The design can be verified in a measurement environment. The application schematic can then be optimized according to the targeted performances. Therefore, this approach secures the development process and reduces the time to market.

Moreover, when integrating only the signal processing and adapting the application schematics, the same IC can be used for various applications. A custom analog solution does not offer this high level of flexibility.

The myth of poor audio quality

To help system engineers to optimize their design, Dolphin Integration offers integration support with a wide range of application schematics: low cost headphone, line-out, high-end line-out, etc.
All specifications include tolerance templates that give the spectral sensitivity to the power supply noise and to the long term jitter. Regulator and oscillator performances can be compared to these reference templates and selected so that the targeted audio performances will be reached. Additionally, behavioral models can be provided to simulate a given schematic configuration for further optimization.

Depending on the application schematic optimization (BoM cost reduction, optimized performances, standard compliance…), SNR performances have been measured from 85 dB to 107 dB. Indeed, there is no question that PWM solutions offer high SNR and dynamic range for very efficient power consumption and low silicon area. However, it is important to highlight that the overall audio performances are not limited to the SNR. Other performances, like distortion and crosstalk, need to be carefully taken into account. Actually, even if the PWM converter is a fully digital architecture, analog issues need to be properly assessed, mainly during the integration at SoC and PCB level.

In order to help customers properly integrate digital PWM converters, Dolphin Integration provides a set of rules and guidelines. First, as non-idealities in I/Os are critical (mainly distortion during transitions and timing propagation mismatch), Dolphin Integration provides the selection of all the required I/Os (power supplies and signal) from any available library. This is associated with a layout configuration that guarantees the robustness to ESD. The output I/Os are selected for their driving capabilities and timing characteristics. The power supply I/O are selected and placed to reduce crosstalk and optimize performances. Additionally, timing requirements are also provided from the ViC outputs to the I/O inputs, so that the SoC integrator is able to check the propagation mismatch during timing analysis.

Finally, Dolphin Integration's analog experts review the integration of the ViC at SoC level in order to ensure that the SoC integrator respects all given rules and guidelines. This allows achieving high audio performances that compete, and more often exceed, the performances of traditional analog audio converters. Following these requirements, the distortion rate (THD) has been measured at less than 0.006 % (THD < -85 dB) and crosstalk rejection at more than 80 dB.

The myth of EMI

From specific application contexts, some have wrongly concluded that Electro-Magnetic Interference (EMI) is systematically associated with PWM. It is important to understand where this prejudice comes from. The PWM technic was originally dedicated to high power applications, like digital motor control or high power audio (> 30 W). These applications need low impedance load, often coupled with a high serial inductance, which induces high current spikes during PWM transitions. Such high current loops indeed induce magnetic fields and interference with other electronic circuits.

Concretely, when a PWM converter is connected to an external amplifier, the current sent from the PWM stage to the load remains low (typically less than 1mA).

This case is far different from a direct connection to an inductive load. Even for high power sound applications, the issue is related to the power stage itself rather than the integrated digital processing. For instance, an application schematic using a class AB amplifier with a PWM converter will not be subject to EMI because of its PWM input.

The rising of audio digital interfaces

Last but not least, one of the reasons for choosing a PWM digital D/A converter is the rising of audio digital interfaces. In today's advanced electronic systems, audio is one of the last bastions of analog interfaces. However, with the growth of digital microphones, audio digital interfaces are now widely supported. A/D converters are integrated in the same package as the MEMS microphone, so that there is no longer the need to convey the analog signal from the sensor to the converter on the PCB. PDM or I2S interfaces are used to communicate with the application processor or the dedicated audio DSP.

For D/A converters, even if MEMS speakers are still a marginal solution, some IC amplifiers already support a digital input (basically PWM or PDM). The digital PWM from Dolphin Integration can be directly connected to such PWM-input amplifiers. As all digital interfaces, it is a very robust approach, less sensitive to noise coupling and interferences. Moreover, PWM frequency is generally low (typically 375 kHz or 750 kHz) so it does not require managing specific timing constrains at board level.

To complete its PWM offering, Dolphin Integration now also offers full digital converters with PDM interfaces. These ultra-compact converters are dedicated to advanced process nodes and digital audio interfaces.

Summary - are traditional analog converters becoming a niche market?

Meeting low silicon area and high flexibility challenges for next generation audio SoCs implies breaking conventions and adopting disruptive approaches.

Therefore, the time is ripe to dispel any prejudice concerning audio architectures and to re-invent audio paths to find the best compromises between cost savings and performances. In that race, full digital PWM converters are naturally the appropriate successor to traditional analog audio converters designed in advanced processes for various applications.

Dealing with these audio challenges requires the low silicon area, high audio quality, PCB optimization flexibility, and FPGA prototyping advantages provided by PWM converters!

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Explore Dolphin Integration IP here:

- sDACa-MT1.03 (28 nm)
- sCODa-MT-LR.05 (40 nm)
- sCODa-MT-LR-FA.02 (SMIC 55 LL)

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After a brief experience in I/O and physical design (2003-2004), Paul Giletti became an analog design engineer in Dolphin Integration. Specialized in delta-sigma converters and audio power amplifiers, its R&D works mainly focus on high density and low power design for high performance audio applications.
He graduated in electronic and signal processing from the Polytechnical National Institute of Toulouse (INPT-ENSEEIHT, 2003)

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Vincent Richard is Product Marketing Manager for Audio IP. He joined Dolphin Integration in 2012 after a master degree in Management of Technologies and Innovation at Grenoble Business School. He is in charge of the product definition and promotion of audio and measurement silicon IPs. He holds a Microelectronic Engineering Master degree in Integrated Circuit design.

About Dolphin Integration

DOLPHIN Integration contributes to "enabling low-power Systems-on-Chip" for worldwide customers - up to the major actors of the semiconductor industry - with high-density Silicon IP components best at low-power consumption.
"Foundation IPs" includes innovative libraries of standard cells, register files and memory generators as well as an ultra-low power cache controller. "Fabric IPs" of voltage regulators, Power Island Construction Kit and their control network MAESTRO enable to safely implement low-power SoCs with the smallest silicon area. They also star the "Feature IP": from ultra-low power Voice Activity Detector with high-resolution converters for audio and measurement applications to power-optimized 8 or 16 and 32 bit micro-controllers.

Over 30 years of experience in the integration of silicon IP components, providing services for ASIC/SoC design and fabrication with its own EDA solutions, make DOLPHIN Integration a genuine one-stop shop addressing all customers' needs for specific requests.
It is not just one more supplier of Technology, but the provider of the DOLPHIN Integration know-how!