AX5689

Digital audio converter and amplifier controller

General description

The AX5689 is an 8 channel data converter- and controller IC with PWM outputs for digital audio amplifiers.

On-chip high-performance low latency sigma-delta data converters measure the analog signal directly at the speaker terminals and provide feedback to the digital controller.

A total of 8 ADCs enables flexible configurations, not only for control loop feedback, but also for analog audio input, supply and temperature sensing, etc.

A sophisticated and versatile digital controller enables feedback after the output filter such that it corrects for distortions caused by the supply, power stage and analog output filter. The digital implementation of the loop filter allows aggressive filtering with up to 5 orders per channel, instead of the traditional 2nd order.

The already high performance per channel becomes exceptional when multiple slices are used in parallel. The linear ADCs and high loop gain enables distortion lower than 0.003% and damping factors in excess of 1000.

This product is still in development and all information in this datasheet is preliminary and subject to change. Information is confidential and should not be distributed

Features

- Digital class-D controller with feedback after filter
- 8 controller slices and 8 ADCs enable 8 single-ended channels, 4BTL, combinations and other uses
- 105 dB dynamic range, Up to 114dB with parallel ADCs
- 0.003% THD
- Serial audio interface with 44.1kHz-192kHz sample rates
- Configurable interconnections between slices and ADCs for versatility and MIMO control.
- Volume control and soft mute

Applications

- High-end audio amplifiers and entertainment systems
- Active loudspeaker systems
- Active noise reduction systems
- High-resolution low latency data-conversion
- High-speed closed loop controller

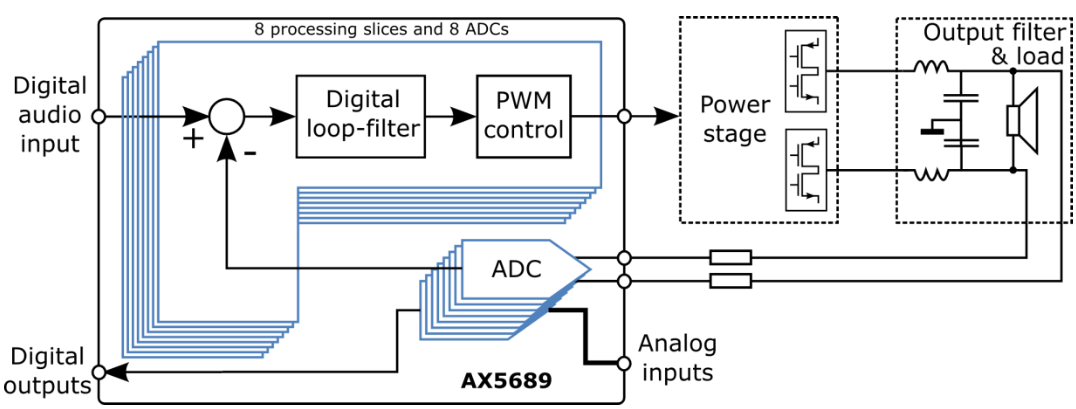

Figure 1 Application of the AX5689

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2 Block diagram

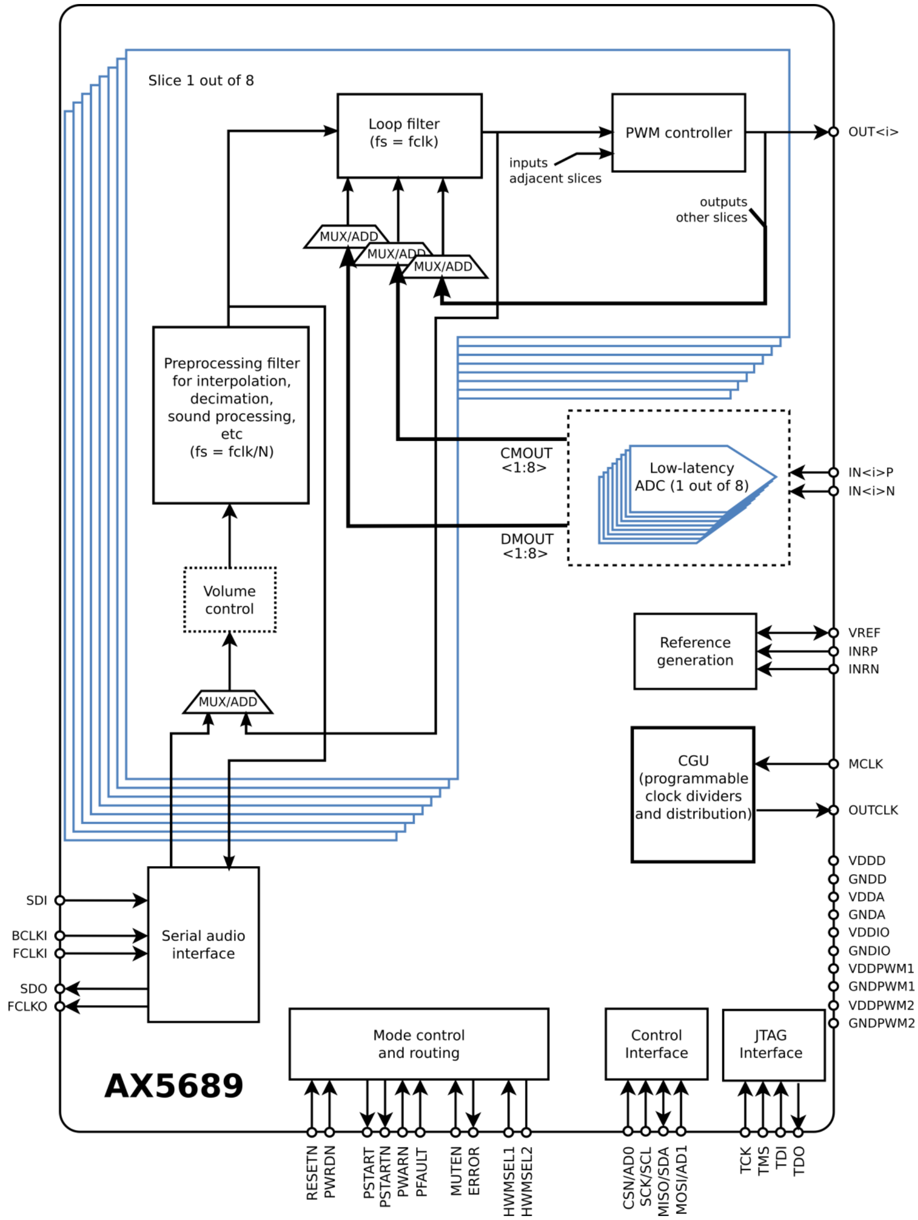

Figure 2: Functional block-diagram of the AX5689

2.1 Package

The exact package is to be determined. The most likely candidate is a QFP, preferably a QFP64.

3 Features

- High dynamic range
  - 105B A-weighted with one ADC per channel
  - >114dB A-weighted with 8ADCs per channel
- HD audio compatible
  - <0.03% THD to 40kHz
- Class-D with feedback after filter with high loop-gain
  - Flattens LC transfer
    - Enables lower $f_{corners}$
    - Enables under damped filters with small L
  - Suppresses nonlinearities in L and C
- High-loop gain also gives high suppression of:
  - Supply disturbance
  - Power stage artifacts such as dead-zone or crossover distortion
- Reduction of external components and BOM costs:
  - No separate DACs or ADCs required
  - No external filtering needed for on-board ADCs
  - For class-D:
    - Can optimize L/C values for cost while maintaining flat transfer
    - Non-linear L and C are possible
    - Boucherot cells (a.k.a. Zobel networks) can be omitted as LC response is damped by feedback
- Low latency ADCs (8 instances)
  - Primary functions:
    - Load voltage conversion
    - High-performance analog inputs
  - Other functions:
    - Power stage supply sensing
    - Current sensing
    - Auxiliary audio inputs
    - Analog volume control input
    - Multi-purpose (temperature sensing, etc)
- Integrated high-quality ADC reference with bandgap noise rejection
- Flexible PWM controllers:
  - Single-ended (SE) or bridge-tied-load (BTL) output channels
    - Single-ended outputs can either be capacitively coupled, have a symmetric supply or use one channel as common return.
  - Differential (AD) or tri-level (BD and BD+) modulation
    - BD+ modulation has low common-mode and low differential mode radiation
  - PWM frequencies programmable from *300kHz* up to 1/3*f_{clk}
  - Also supports PDM output
  - PWM phases selectable per channel (for staggered phases)
- Flexible routing and configurations from 1-8 channels:
  - Digital audio inputs can be routed to one or more control loop slices

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  - Analog inputs can be routed to one or more control loop slices and ADCs can be combined for lower noise
- PWM outputs usable for:
  - Interface to class-D power stage
  - Line-level DAC outputs (with passive RCRC or LC filter network)
  - Class-AB amplifier input signals to enable class-AB with digital feedback
    - With output filter either before or inside the class-AB amp.
    - *TBD for future/special versions? feedback can be taken from after the line transformer in e.g. tube amplifiers.*
  - Headphone PWM output *(It is to be determined whether the outputs themselves have low output impedance or whether an intermediate headphone driver is needed)*
- Digital serial audio interface:
  - 16 – 32 bit.
  - 44.1-, 48-, 88.2-, 96-, 176.4-, and 192-kHz Sampling Rates
- Soft volume control and mute.
  - Supports different programmable rates for volume, soft-mute and fast-mute transitions.
  - Analog volume control possible with one of the on-board ADCs
- 3.3V inputs *(5V tolerant inputs T.B.D)*
- *1.8*-3.3V digital outputs *with separate supply for easy swing control*
- Hardware mode, to enable operation without microcontroller
  - Two dedicated inputs can select between 4 common use-case
  - Easy to use

4 Functional description

4.1 General

The AX5689 is a controller IC for digital audio reproduction. It contains specialized low-latency ADCs that can sense output signals directly at the load and sophisticated digital control algorithms that enable a mixed-signal closed-loop system with high bandwidth, high loop-gain and compensation for external output filters.

An amplifier that uses the AX5689 can achieve high performance at low cost, as all backend error sources are highly suppressed by the loop gain. This results in relaxed requirements for the power supply and the power stage. For class-D amplifiers with feedback after the output filter this also results in relaxed requirements for the filter components and their associated costs.

The AX5689 is usable with many different amplifier configurations. The loads can be connected either in a bridge-tied-load or single-ended fashion, including AC-coupled loads or power stages with symmetric supply. For BTL operation, two slices can be configured such that one process the differential mode signal and the other controls the common-mode. The common-mode controller ensures that the outputs are biased properly in any of the configurations and ensures low-pop startup and shutdown.

A flexible PWM controller converts the signal to 1-bit form with a wide selection of pulse frequencies and modulation methods. The PWM outputs can be fed directly to a switching power stage that is followed by an output reconstruction filter. For other uses or other types of amplifiers, the PWM outputs can also be fed first to a (passive) reconstruction filter that removes the high-frequency switching components. The filter compensation on the AX5689 can correct for a wide range of external filters, provided that their order is not higher than two at frequencies close to the audio band.

For best performance, the ADC inputs that feedback the signal should be connected directly at the load-point (regardless of whether the load is a speaker, a line-level output or something else). If however the external filters have an overall roll-off with a higher order than two, then an intermediate point should be chosen for the feedback.

The AX5689 has a modular structure with flexible routing. The overall signal processing path consists of a digital input interface, volume control, an interpolation stage , the digital loop-filter and PWM controller. Eight copies (slices) of this signal path are available to enable operation with up to eight channels per chip. Each of the slices is separately configurable and cross connections between the slices enable MIMO control. Next to the 8 signal processing slices, 8 ADCs are included on the AX5689. Selectable routing between the ADCs and the slices not only simplifies PCB layout, but also enables different signal configurations. ADCs can be used either for the feedback, or can be used to convert analog input signals. Outputs of multiple ADCs can also be combined. When the inputs of these combined ADCs are also connected to the same signal, then they can achieve higher performance (as the noise of multiple ADCs scales down compared to their combined signal). ADCs can also be selected for auxiliary functions such as analog volume inputs or supply sensing. The outputs of a selection of the ADCs can be decimated and made available through a serial digital output interface.

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5 Application example

The example application diagram in Figure 3 shows the application of the AX5689 as amplifier controller for an integrated stereo class-D power stage in BTL configuration. The audio inputs can be chosen to be either digital or analog. The digital audio inputs are connected via the serial audio interface. The analog audio inputs can be connected via the analog inputs of the ADC’s, which can then be routed to the input of digital control loop. The analog input data can also be made available as digital output data through the serial audio interface.

As this example assumes usage without a microcontroller, operation modes are selected with hardware mode settings. Depending on the type of input (analog or digital), the AX5689 can be chosen to start-up in different hardware modes (HWMSEL1 = 1; HWMSEL2 toggles between 0 and 1 for analog or digital input). Note that in both modes AX5689 is enabled for 4 channels. It is therefore also possible to connect a second power stage for 4 channel operation.

In this example application the PWM outputs from slice 1 and 2 (OUT1P/OUT1N and OUT2P/OUT2N) of AX5689 are connected to inputs IN1A through IN2B of the power stage.

The outputs OUT1A through OUT2B (differential output terminals) are fed back to the input of the analog inputs of the AX5689. The AX5689 will process the signal through the ADC back to the input of the digital loop filter. This way the feedback loop is closed including the power stage and its filter section. By including the filter section inside the loop, it is possible to correct for non-linearity introduced by this section. Next to improved linearity, the feedback loop also dampens the LC filter by creating a low output impedance. This way the Zobel/Boucherot networks that are usually incorporated inside the filter section can be omitted.

The example application diagram is work in progress. Full connection diagram which includes for example supply connections, decoupling, etc. will be added in future versions.

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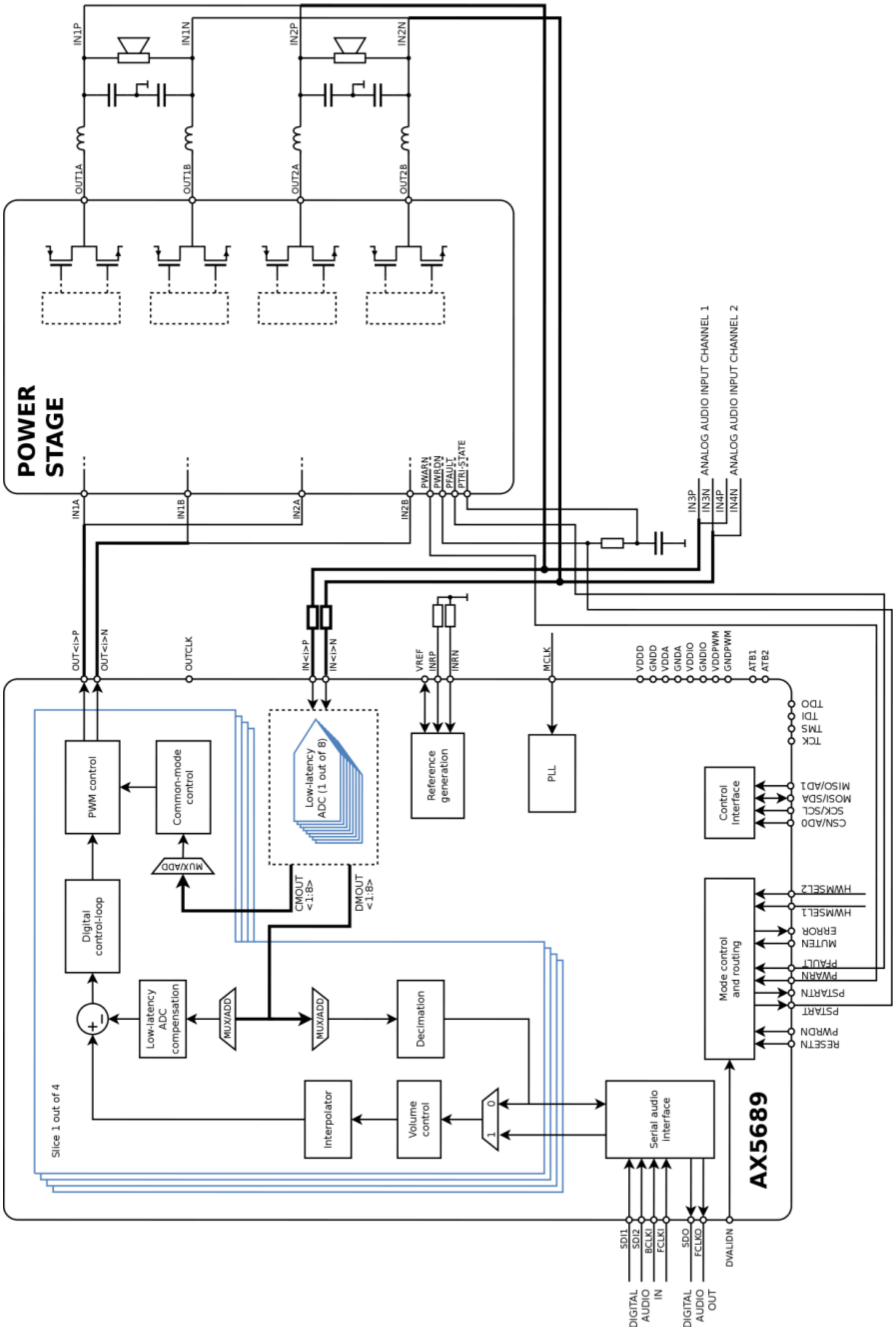

Figure 3 Application diagram

6 Specifications

6.1.1 Electrical specifications

Table 1

Parameter	Description	min	typ	max	units
	DC characteristics				
I_{DDD}	Digital supply current - Operating, all slices active - Power down			~50 0.01	mA
I_{DDA}	Analog supply current - all ADCs active - Power down			~100 0.01	mA
V_{REF}	Reference voltage	0.85	0.9	0.95	V
V_{OS}	Input-equivalent (ADC) offset			~100	μV
ΔG	Gain mismatch	-1	0	1	dB
ADC / Mixed signal performance characteristics					
THD+N	Total harmonic distortion and noise 100Hz, Vin = ½*Vin-peak 1kHz, Vin = ½*Vin-peak 6kHz, Vin = ½*Vin-peak	 -80 -80 -80	 -90 -90 -90		dB
SNR_{peak}	Peak signal to noise ratio		90		dB
DR_{DM}	Dynamic Range		105		dB Awtd
X_{talk}	Inter channel crosstalk	~60			dB
PSR	Power supply rejection	~60			dB
	TBD: More specs to be added:				

6.1.2 Typical characteristics

As the integrated product is not yet available, the concept of digitally controlling a class-D power stage with feedback after the filter has been verified using a multi-chip bench demonstrator. Results of this multi-chip bench demonstrator are given in this section.

The multi-chip bench demonstrator includes:

- PCB containing low-latency ADC
- Spartan-3 FPGA
- TFA9810 class-D power stage

The TFA9810 uses 14.4 V supply rail and is connected in BTL configuration to a 8 ohm load. Feedback is taken at the speaker terminals to include the LC filter section and fed back to the inputs of the low-latency ADC. The complete digital control loop (including filter compensation and PWM controller) is implemented on a Xilinx Spartan-3 FPGA. A digital input is connected using I2S.

The following graphs show the results of the digital amplifier connected to the measurement equipment (APx526 by Audio Precision).

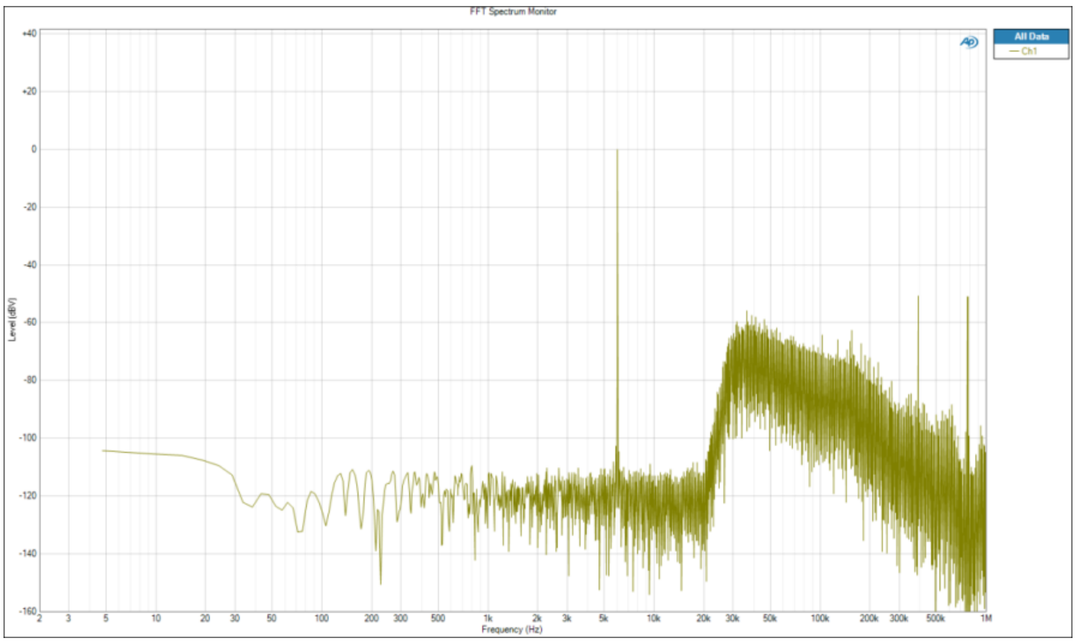

Figure 4: Spectrum of the output signal with 6kHz - 0dBV input. Harmonic distortion ratio >100dB.

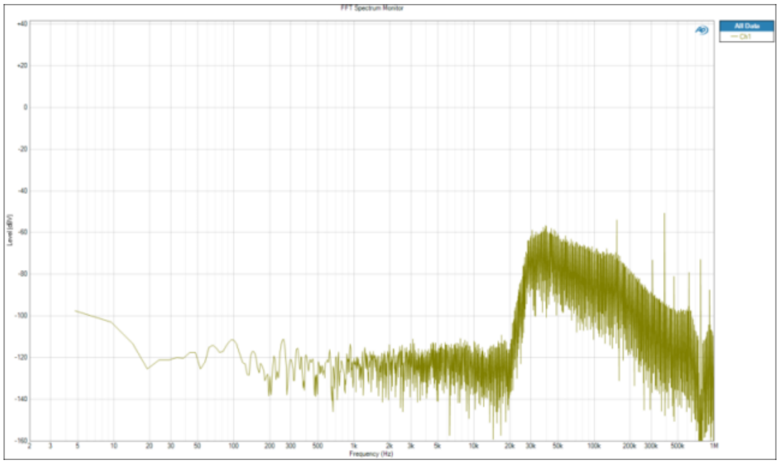

Figure 5: Spectrum of the output signal without input. Noise floor (integrated noise in audio band) <50uVrms (A-weighted).

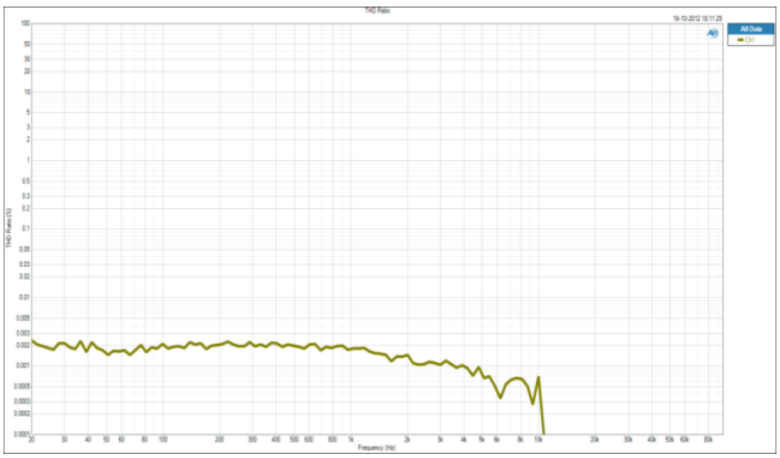

Figure 6 THD ratio vs. Frequency. Measured with 0 dBV output signal. THD ratio approximately 0.002% across audio band.

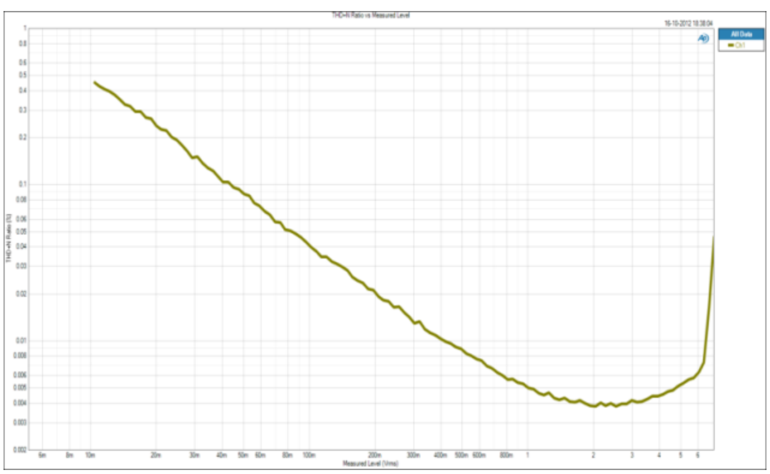

Figure 7 THD+N ratio vs. measured output level (Vrms). Measured with input frequency of 1 kHz. THD+N decreases to 0.004% for 0dBV output signal.

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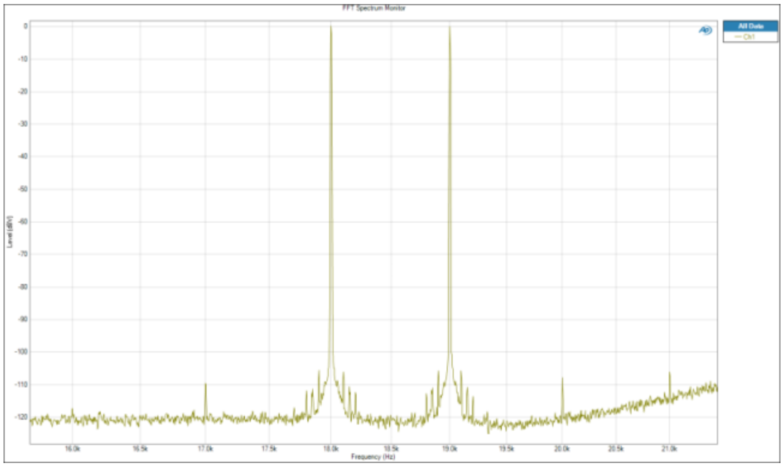

Figure 8 Output spectrum with 18 and 19 kHz input signal. Third order intermodulation distortion -110 dB

7 Revision history

Revision	Date	Reason for revision
D2g	20150216	Derived from version AX5689_amplifier_controller_datasheet_D2g

Table 2: Document revision history

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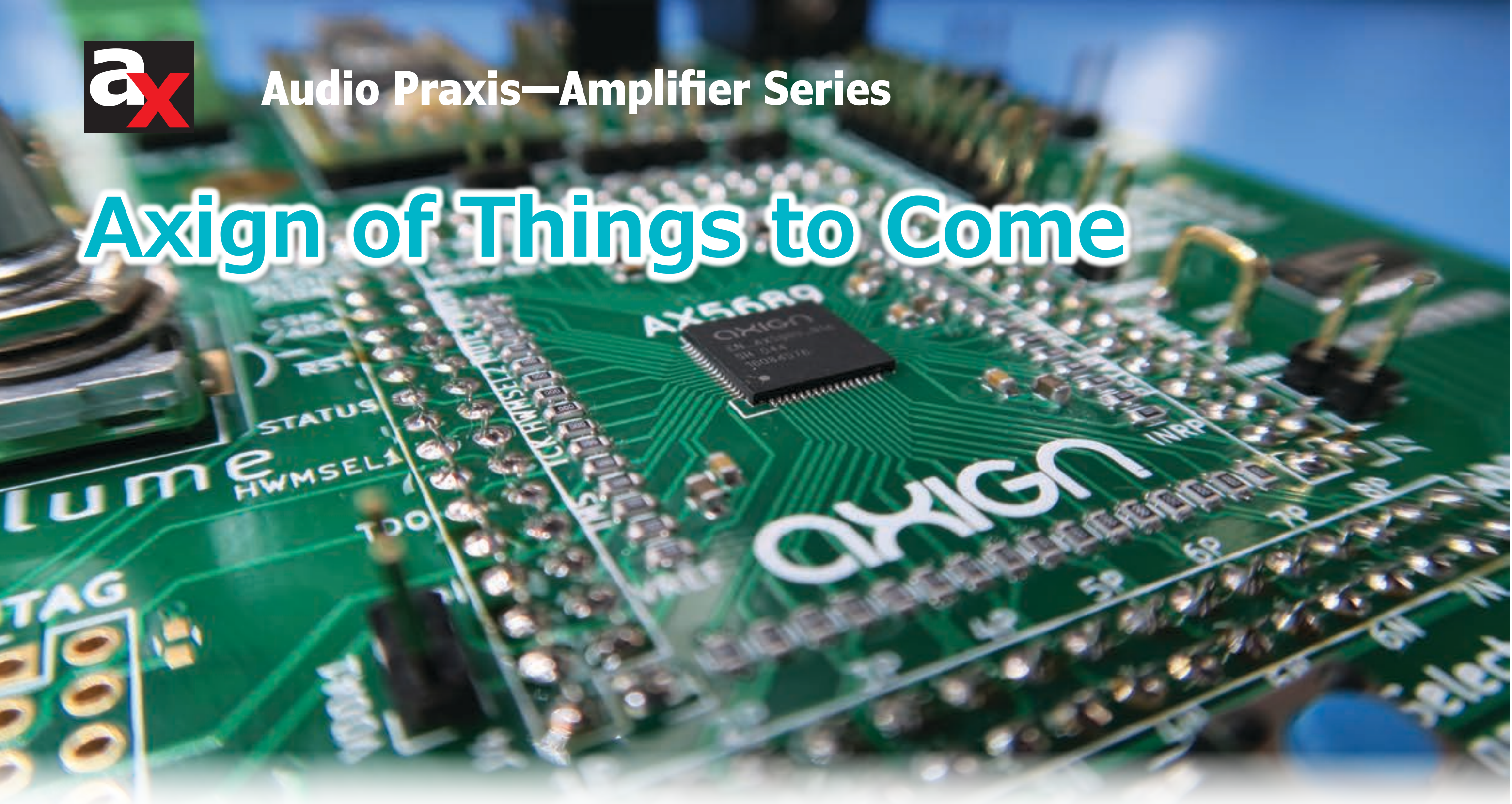
Axign of Things to Come



Axign is a new company from The Netherlands, founded by former Philips and NXP employees who worked on the pioneering Class-D efforts. Established in 2014, their efforts have resulted in the development of the AX5689, a Class-D audio amplifier controller chip in a QFN package. The solution uses a digital control loop with feedback behind the output filter, across the loudspeaker terminals. It requires a digital input signal and suppresses all artifacts with a fifth-order digital feedback loop. *audioXpress* visited the company to find out more information.

By
Ward Maas
(The Netherlands)

A traditional application area for Class-D amplifiers is high-power amplification for professional use. Efficiency, weight, and reliability are determinant factors for such uses. They might be workhorses, but audio-quality-wise, they have not been good enough to run in the Kentucky Derby. In the past few years, however, the industry has seen the rise of high-quality Class-D amplifiers. Not only did they keep (and reinforce) their traditional strengths, but claims have been made (and confirmed) that they could also play a role in high-end audio applications. From that moment on, the entire game started to change.

The combination of high-quality and low cost is, as could be expected, irresistible to audio manufacturers. Most people listening to Class-D amplifiers, do recognize the qualities in the bass area, but doubt the merits in the mid and high regions. Checking a datasheet often reveals some Class-D artifacts in the distortion curves and some load dependent behavior. As we have said in previous articles dedicated to this topology, we saw a dramatic change in performance as more Class-D manufacturers are able to minimize these effects.

So, the use of Class-D in the high-end market is now a reality. The new Marantz PM 10 flagship, powered by Hypex Ncore Class-D amplifiers, is one of the obvious examples. And for those who still have doubts, that's where the efforts of Dutch chip developer Axign can persuade even the most reluctant "traditional" analog diehard. To put it simply, Axign's new AX5689 chip lays a very high-speed feedback loop around a Class-D amplifier, transforming its performance to almost theoretical levels. Too good to be true? Let's see.

Challenges with Class-D Amps

Back in the days when Bruno Putzeys at Philips developed the first self-oscillating Class-D amps, these efforts were also used in their semiconductor branch (now known as NXP Semiconductors), specifically by the group that developed amplifiers for automotive applications. One of the key concerns in developing high-quality Class-D amplifiers is the

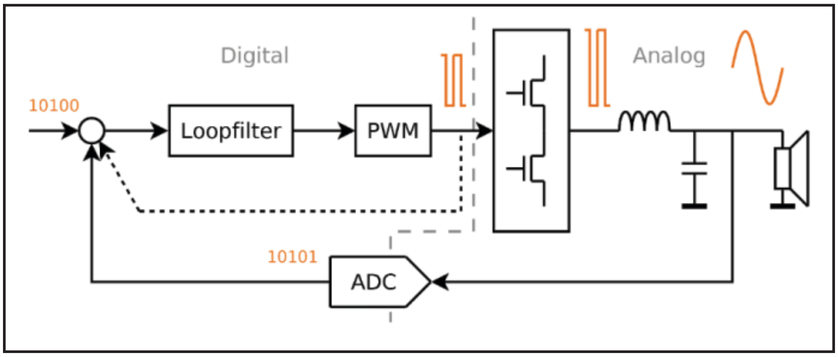


Figure 1: The AX5689 is a Class-D amplifier controller chip in a QFN package. It has a high speed digital control loop with feedback behind the output filter.

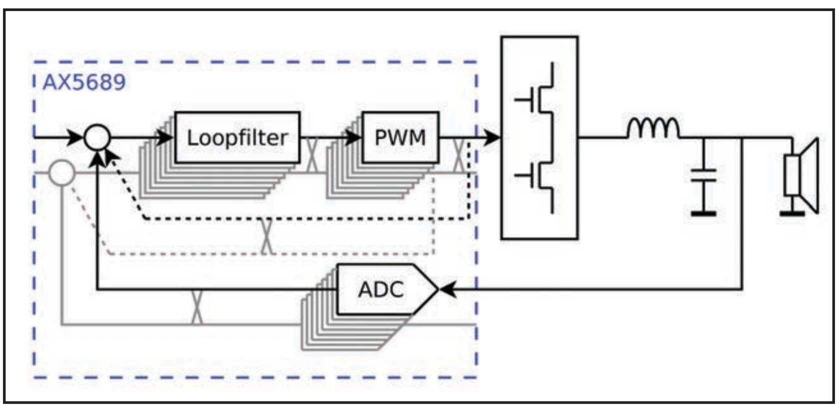


Figure 2: The AX5689 has eight identical programmable high-order digital loop filters, PWMs, and ultra-fast LLADCs. It is suitable to control eight loops in real time.

amount of obtainable loop gain without getting into stability problems. Often the obtainable gain is rather low. To avoid a load-dependent performance, a feedback after the output filter is also desired.

But, there are a few ways to tackle these problems. The use of nested feedback loops is not an easy path, but as more and more experience is gained with this kind of solution, the quality of Class-D amps has improved step-by-step over the last few years.

Another solution is to use a high-speed ADC, comparing the analog output signal with the digital input signal and then do a correction in the digital domain. However, such a solution requires a major development effort—an effort that could not be made by NXP Semiconductor at that time due to capacity limitations. The high-speed ADC was seen as the most critical development item and it was outsourced to Axiom-IC (now Teledyne-DALSA). Then, after an extensive market research and many discussions with potential customers, Jeroen Langevoort (formerly of NXP Semiconductors) took the project and development ideas and established Axign. Supported by Teledyne and Daniel Schinkel, who was strongly involved in the ADC development, the design of the AX5689 was realized.

The AX5689

The AX5689 is a digital amplifier controller that compares the analog signal at the loudspeaker terminals with the input signal (see **Figure 1**). All the disturbances in the loop (e.g., the power supply ripple and nonlinearity from the power stage and

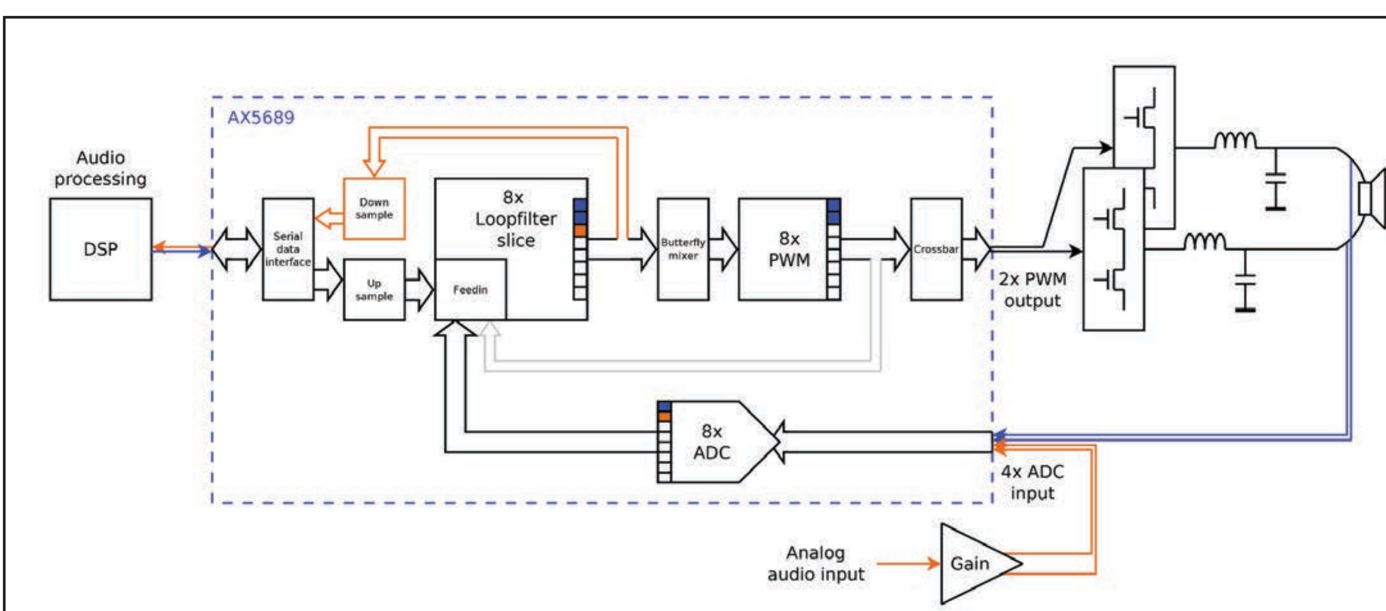


Figure 3: An application example shows that a complete audio system can be built with an AX5689. Adaptation to an active loudspeaker system is easily done.

SNR	115 dB to 124 dB
THD vs. frequency	>0.001% (10 W, 20 Hz to 20 kHz)
Output noise	25 µV (for a 2× 100 W/4 Ω solution)
Channel separation	>100 dB (20 Hz to 20 kHz)
Output impedance	<2 mΩ (20 Hz to 20 kHz)
Frequency response -3 dB	DC – 35 kHz (20 Hz to 20 kHz flat, load independent)
IMD (19 kHz and 20 kHz)	below -100 dB

Table 1: These are the results for the AX5689 Class-D audio amplifier controller chip.

reconstruction filter) are compensated in real time and suppressed thanks to the extraordinarily high digital loop gain. The analog signal at the load is converted by a high-performance low-latency ADC. The latency is in the order of 20 nanoseconds, giving a total of 200 nanoseconds to act for a bandwidth of 5 MHz.

The AX5689 has eight identical processing slices and eight ADCs, making it suitable to control eight loops in real time (see **Figure 2**). This enables a wealth of configuration possibilities (see **Figure 3**). This means the chip can be used for the Class-D controller function and for other periphery audio functions. One of the interesting possibilities is the option to parallel the sections and increase the already impressive 115 dB signal-to-noise ratio (SNR) to 124 dB, on set level. With the AX5689, silence becomes silence again.

To be clear, this is a Class-D controller not an output stage. It will control whatever Class-D output stage is used. It is even fast enough to include an already available controller in the loop. So how do you demonstrate the qualities of such a product? Well, it's rather easy. First, you take a reference design from the most well-known Class-D amplifier manufacturer and see how much you can improve that design. Second, you listen to the results and check how it sounds.

After a long time in development, the guys at Axign ended up with the results shown in **Table 1**. The proof is in. But those results did not come automatically. At the moment, a fifth-order loop filter is used. Theoretically, a 56th order could be implemented. Not very practical, but it gives an idea of the chip's capabilities. So yes, it took some time before the expected results were realized.

Putting the Chip to the Test

For a real-world test, the AX5689 was used in combination with a few Texas Instruments (TI) and STMicroelectronics chips (the TAS5558, the TAS5624A, the TAS5342A, and the STA516B, respectively). Looking at **Figure 4**, we see the THD+N vs. Pout graph for 100 Hz, 1 kHz, and 6 kHz at 4 Ω for both the STA516B and the TAS5342A. The first part of the graph is determined by the noise floor. Then when the amplifier starts to clip, the distortion starts to rise. No traditional Class-D artifacts can be seen.

Figure 5 shows a direct comparison

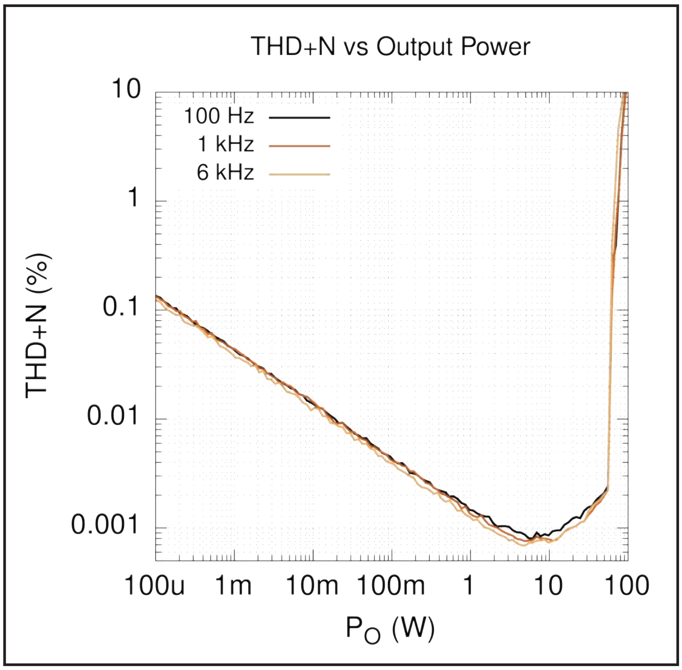


Figure 4: The AX5689 + STA516B or AX5689 + TAS5342A Pout in 4 Ω PVDD = 28 V, 2× LLADC per BTL, BD mod. A difference between the STA516B and the TAS5342A could not be observed.

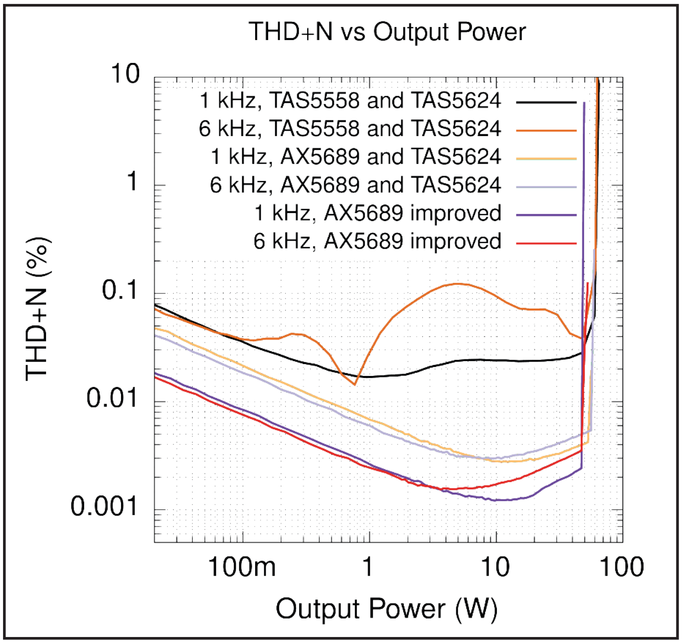


Figure 5: The improvements are clear. The AX5689 is a significant improvement over the TAS5558. Not satisfied with the initial results, the Axign team obtained even better performance after optimizing the chip's parameter settings.

between the TI output stage TAS5624A with a TI controller TAS5558 and the same TAS5624A with the Axign controller AX5689. Clearly, the AX5689 has better control over the output stage. After the first test, the settings of the AX5689 were adapted, providing an even better performance. **Figure 6** reveals an interesting phenomenon. The less sophisticated TAS5342A performs slightly

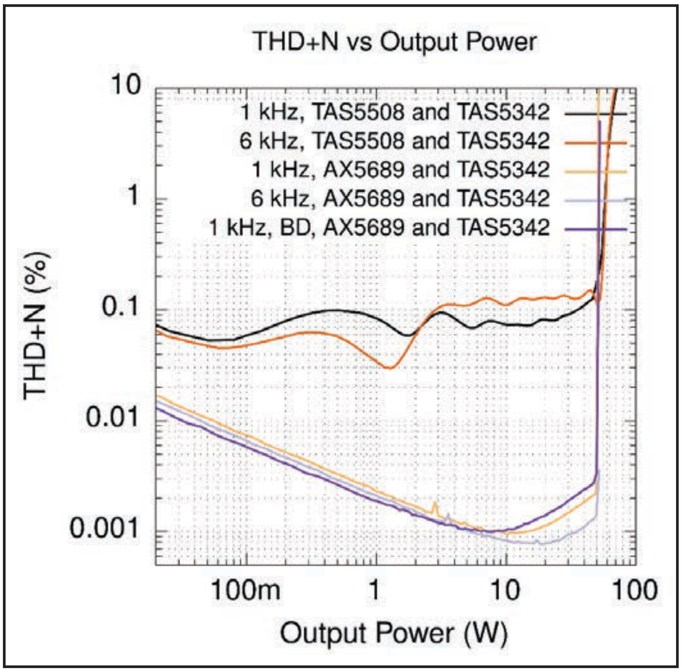


Figure 6: The team also made large improvements in the distortion performance as well. It is interesting to note that the TAS5342A performs better distortion-wise than the TAS5624A. Not having to "wrestle" with an internal feedback loop, the AX5689 performs better.

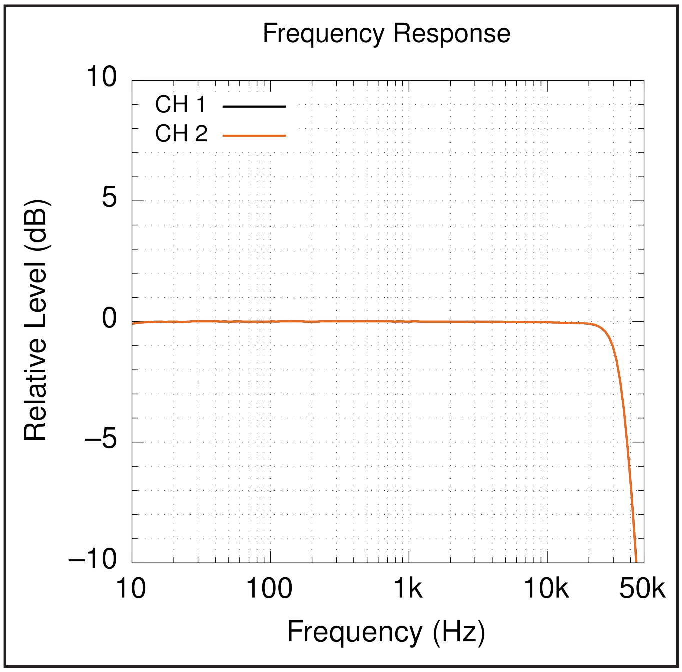


Figure 7: A straight line can be seen in this frequency response. Since the feedback occurs behind the output filter, no load dependent under- or over-damping can be observed.

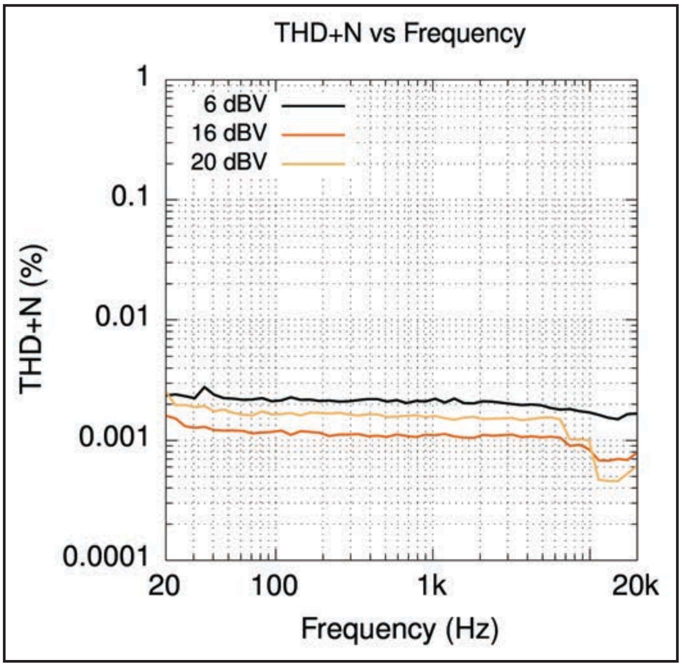


Figure 8: The AX5689 + STA516B THD+N vs. Frequency at 4 Ω PVDD = 28 V. Most Class-D amplifiers do suffer from an increasing distortion with the frequency. Distortion itself is very low with only a small output power dependency.

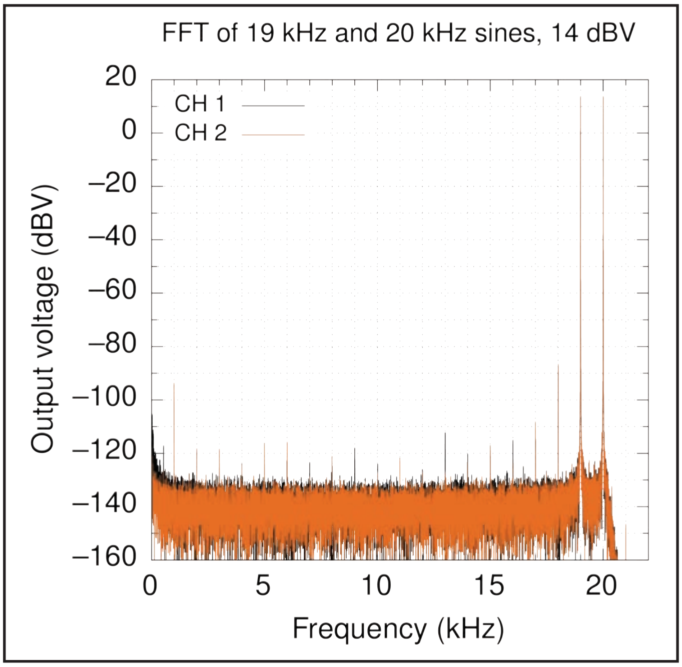


Figure 9: The intermodulation distortion (IMD) with 19 kHz and 20 kHz is below -100 dB. A value that can be shown! Nonlinear behavior is under control.

Photo 1: Prior to Axign, its CEO Jeroen Langevoort was with Royal Philips Electronics and NXP Semiconductors holding various R&D positions. In his work, he was in charge of all developments within the audio amplifiers group and introduced about 30 new products including dedicated automotive Class AB amplifiers and switching Class-D amplifiers. After starting his own consultancy firm to help companies develop their own "mean and lean" product development machines, Langevoort took over as CEO of Axiom-IC and the development of the low-latency ADC that is now at the heart of the Axign controller IC.

better. Having to cope with the TAS5624A's internal control loop is apparently challenging the AX5689 to bring out the maximum possible performance of the output stage.

Another important feature of the AX5689 is that it measures the output signal after the output filter. **Figure 7** shows a frequency response curve, which is a very straight line until 20 kHz (±0.05 dB). The same frequency curve can be observed at 4 Ω or 8 Ω, which is a very uncommon result. Looking at traditional Class-D amplifiers, the frequency response is very dependent on the load. **Figure 8** shows very low values in the TDH+N vs. Frequency graph. Again, it is an almost straight line (almost power independent), not typically seen with the Class-D amplifiers on the market today. And the icing on the cake is revealed in **Figure 9**, which shows the intermodulation distortion (IMD) with 19 kHz and 20 kHz—where a -100 dB is achieved.

The results are simply stunning. These results are not only extremely good for Class-D amplifiers, but there are not many other amplifiers that can match these results.

For any manufacturer that wants to check these results, there are demo kits, and with the available samples, they can check the AX5689 with their own output stages. Several manufacturers already did this and they confirm the results. As the feedback inputs of the AX5689 are current controlled, output stages from a few watts up to several kilowatts can easily be configured.

Music to the Ears

Now, the million-dollar question is, of course, how does it sound? A demonstration setup was assembled on the premises of Axign, in Enschede, The Netherlands. The demo amp with one of the first samples of the AX5689 was built into a small suitcase for easy demonstrations. A set of small and medium

Photo 2: Richard Langezaal is Director of Marketing at Axign with a bachelor's degree in Electronic Engineering. He has 25 years of experience in the semiconductor business where he held several technical and management positions in the audio amplifier group, and marketing positions for lighting solutions. He has a broad knowledge of audio amplifier systems from a customer and chip producer perspective. Richard has a passion for audio, business development, and sales. Richard has built his own 600 W UcD Class-D audio amplifier solution based on ICs from his own product portfolio.

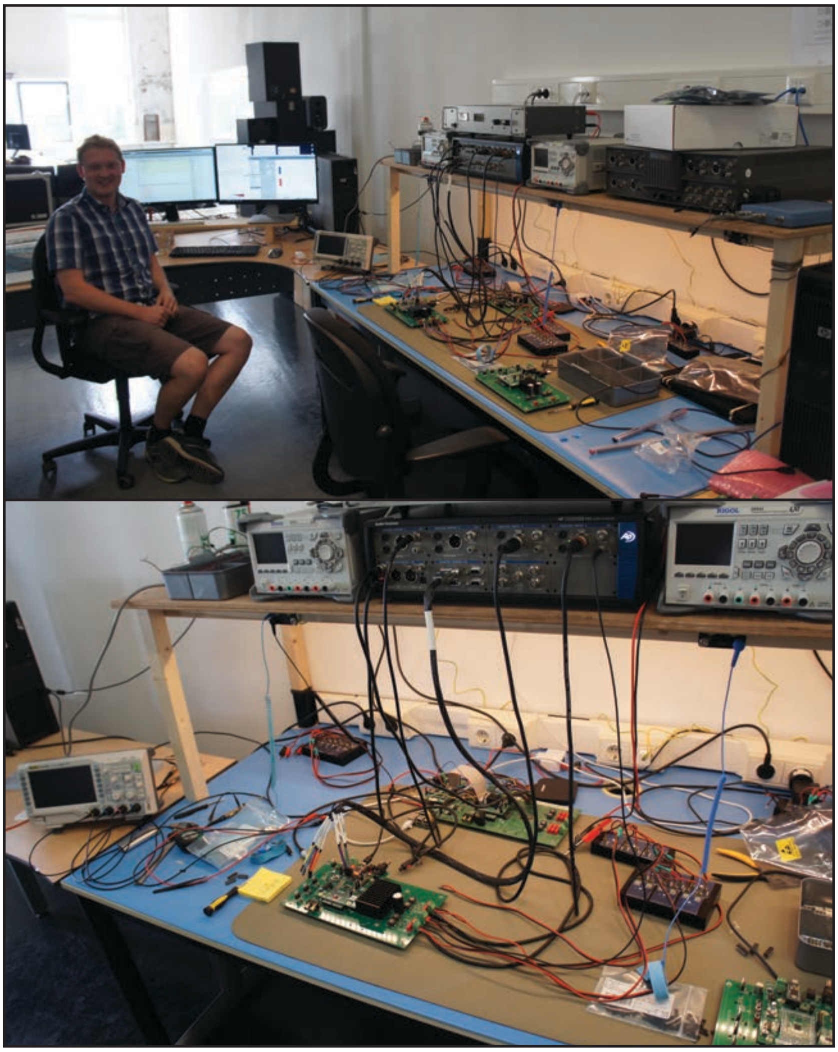


Photo 3: System application engineering is in progress by Tim van Doesum (a). Interesting results were obtained when output filter stages proved to be much simpler and less expensive. More rewarding was the testing with the reference designs of well-known Class-D amplifier manufacturers. The improvements neared theoretical values proving that, not only they were on the right track, they were onto something big here. This is the measurement set up on the bench (b).

sized Bowers & Wilkins (B&W) loudspeakers were used. Actually, these were the private loudspeakers of the management team. The creation of a full-scale demo room is in the planning stages.

The first thing that stands out is the absolute absence of noise. With no music, there is no sound. Then, when the music starts, there is this tremendous detailed soundstage where each instrument and voice has its own place. Combined with the tight bass control, it presents a wonderful, transparent picture. It is also very pleasant during long listening sessions. Wow!

Getting back to earth, I guess the audio quality I heard can be contributed to the improvements in the mid and high regions resulting in this performance. My impression is that the loudspeaker is very controlled and that the amplifier dictates what the loudspeaker has to do, and not the other way around. Feedback after the output filter clearly has its advantages.

Walking the Miles

During the last six months Langevoort (see **Photo 1**) and Director of Marketing Richard Langezaal (see **Photo 2**) have appeared at audio and consumer electronics shows with their small business suitcase and a pair of small, portable B&W loudspeakers. The two men have met with several audio companies to demonstrate that their designs can perform to a new unheard level (see **Photo 3**). Now, companies are asking the question, "Should we rethink our amplifier strategy?"

"Once we can demo, we are in," says Langezaal. "It starts with the silence, then the music does the rest."

It must be said that the AX5689 is not a chip that you just put in your design and the performance is there. The design team went through a lot of trial and error before the AX5689 started to perform as expected. For an audio manufacturer that wants to use the chip to its full potential, the datasheets and certainly the development package are absolutely essential. Further support from Axign will prove beneficial and speed up the development process.

And, there is one item that has not yet been discussed. Costs. Being impressed with the performance is nice, of course, but the cost of the chip and the implementation are important for its commercial success. At the moment, the first samples and demo boards are available for manufacturers (see **Photo 4**).

Production samples are scheduled to be available in the fourth quarter of 2017 (at the time of writing). Qualification and release to the market will be in 2018 and beyond. Prices are quantity dependent but are in line with other controller chips. The truth is that the price/performance ratio for a high-quality Class-D amplifier goes from unbeatable to …well, more unbeatable?

Final Thoughts

The AX5689 is a game changer. Class-D amplification no longer aspires to be at par with other forms of high-quality amplification, it can now claim the throne. Due to its highly versatile structure, we can expect to see this chip not only in amplifiers but also in more complex surroundings (e.g., soundbars, soundplates, active loudspeakers, and certainly the new ascending category of voice controlled home systems). The AX5689 is also a proof of concept that the days when a cheap product sounds cheap will come to an end. Clever algorithms will take over audio amplification.

For a young company such as Axign, these are exciting times. For many startups, the first funding is based on the belief of having a good idea. Proving that the idea not only works but can be seen as a solution that will have a profound influence on the audio industry, is expected to provide funding on a larger scale. Growth will not be difficult.

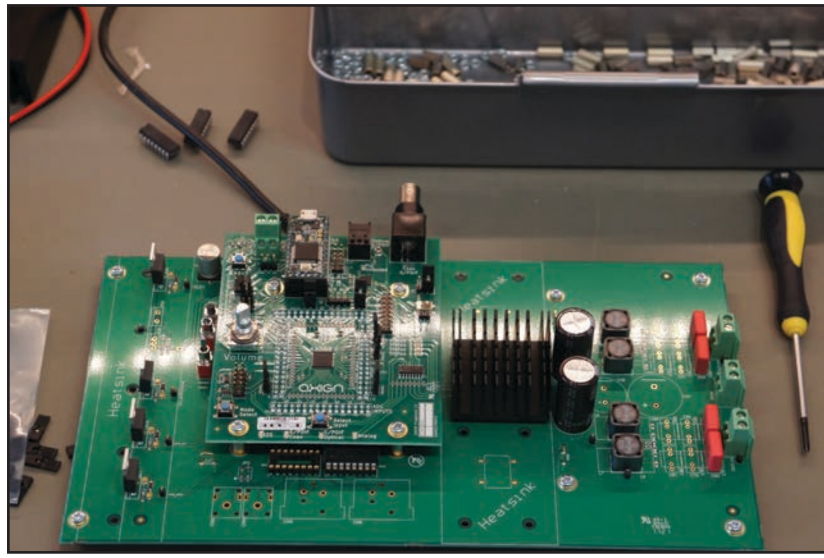


Photo 4: The AX5689 demo board served as the playground for many tests. It is built in a universal way to make it adaptable to all the tests you could imagine.

About the Author

Ward Maas is the owner of Pilgham Audio. He studied electronics, marketing, and amplifier design. During his career in consumer electronics, Ward worked in areas ranging from CD standardization to radio and television to personal GPS navigation. Ward has worked on an extreme low-noise magnetic cartridge preamplifier and several special amplifier products. As the CTO of "Witchworld," a theme park near Amsterdam, he also works with animatronics. He lives in Almere, Netherlands, with his wife and son.