A New Generation ICEpower

By
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(The Netherlands)

In this new article series, *audioXpress* will explore the history, recent developments, and new-generation products from some of the most innovative amplifier platform companies serving all segments of the audio industry. We start with a visit to Danish amplifier powerhouse ICEpower and check out its most recent and advanced Class-D platform, ICEedge.

The history of ICEpower, interesting as it is, may not be known by everyone. It is interesting because it clarifies where the company stands today and provides a look at its plans for the future.

ICEpower, founded by Karsten Nielsen, has close ties to the Danish iconic company, Bang & Olufsen. In 1999, Nielson's doctoral work at the Technical University of Denmark drew the attention of the Bang & Olufsen management, resulting in a joint venture that created the foundation for a new business. At that time, Class-D technology was maturing and generating increasing interest in the audio world. The advantages of high efficiency, high power density amplifiers made possible by the new Class-D topology, were clear. (Nielsen's 1998 PhD thesis is a good introduction to Class-D amplification and is still available on the ICEpower website at www.icepower.dk/en/technology/publications.)

Symbiotic Relationship

Having a close relationship with a much larger company makes it possible to access their resources, design tools, technical experience, and business knowledge. A huge advantage for a new small company, it enabled ICEpower to quickly become one of the leading companies in the amplification world. Starting in high-end niche markets, ICEpower developed a range of premium quality audio power conversion engines used by some of the world's most prestigious brands, such as Bowers & Wilkins, Pioneer, Alpine, Samsung, Audi, and Bang & Olufsen's own products. Gradually, the company built a powerful OEM business, delivering platforms used in low power systems (e.g., mobile phones) to large scale pro audio line array systems.

In early 2016, realizing that the business could expand further on its own, a decision was made to separate from Bang & Olufsen. In April of 2016, a management buyout supported by Industry Development (Industri Udvikling), a Danish private equity company, allowed ICEpower to become an independent entity.

One of the first strategic moves of the newly formed organization was to merge with Audio Bricks

and acquire its holding company, Bolecano Holding AB, from Sweden. The founders of Audio Bricks, Patrik Boström and Lars Press Petersen were well-known to ICEpower. Boström had founded Anaview in Sweden in 2001, only two years after ICEpower was founded in Denmark. And, Petersen held the position as Innovation Manager at ICEpower from 2003 to 2007. Bringing both men on board created a strong ICEpower management team, together with Kjeld Lindegaard Andersen and Mads Emil Solgaard, which gave ICEpower considerable knowledge of Class-D amplifier development and cutting-edge ideas, unique among Scandinavian companies. **Photo 1** shows Boström and Solgaard at ICEpower's new temporary lab facilities.

ICEpower was once again able to act with the speed and the agility of a small company, while being able to leverage its unique market position and strong reputation to its advantage, combining a mature portfolio of technology and products in consumer, professional, automotive, and mobile audio applications, with real market knowledge. It also gained some of the most recent amplifier technology platforms.

ICEpower Innovations

ICEpower has developed low-power Class-D chips for mobile audio applications (e.g., phones and laptop computers), for which it developed more than 12 ASICs (see **Photo 2**). That development provided ICEpower with a solid foundation for in-house chip development, which it then manufactured for companies such as Samsung, Sanyo, and Toshiba. The first ICEpower Class-D chipset to be used for ICEpower's own amplifier products, the ICCx chipset, was developed 15 years ago (2002). Already a very advanced chipset, the ICCx has served ICEpower for many years, shipped in millions of amplifiers, and is still in use for many products.

Many years of accumulated insight lead to the recent development of a totally new chipset generation, the ICEedge, which consists of a dual-channel controller IC and two driver ICs. During the development of this chipset, which took seven years, a string of research projects were initiated leading to the filing of an additional six patents. The aim was to simultaneously provide truly outstanding high-end audio quality and flexibility. ICEpower also focused on protection features, giving the amplifiers containing these chips a nearly unbeatable product reliability at a reduced product cost. ICEpower regards the ICEedge chipset as the most advanced Class-D chipset in the world. With this technology platform, amplifiers with a range of 50 to 7,000 W can be built.

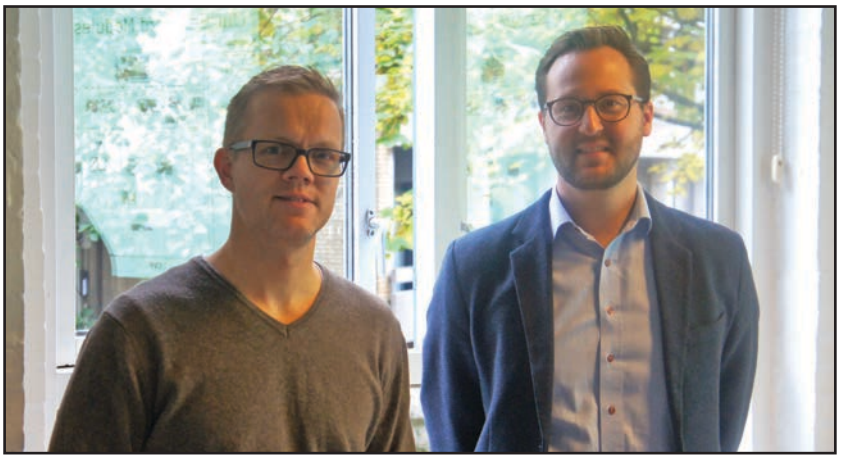


Photo 1: Patrik Boström and Mads Emil Solgaard welcomed audioXpress to their temporary lab facilities, after separating from Bang & Olufsen.

Instead of trying to put everything on one chip, the ICEdge chipset was deliberately split into a driver part and a controller part, enabling the use of a low-noise process for all the sensitive analog parts in the signal chain (e.g., high-quality audio op-amps and comparators). This way, extremely low noise levels, which normally are only achievable with discrete analog audio components, could be reached.

The gate drivers feature a high breakdown voltage, a high voltage, and current slew rates. The method—a silicon on insulator process—enabled a gate driver design capable of up to ±150 V supply voltage with a low propagation delay of just 110 ns.

Photo 2: ICEpower developed more than 12 ASICs for mobile audio applications (e.g., laptops) used by many of the large volume manufacturers.

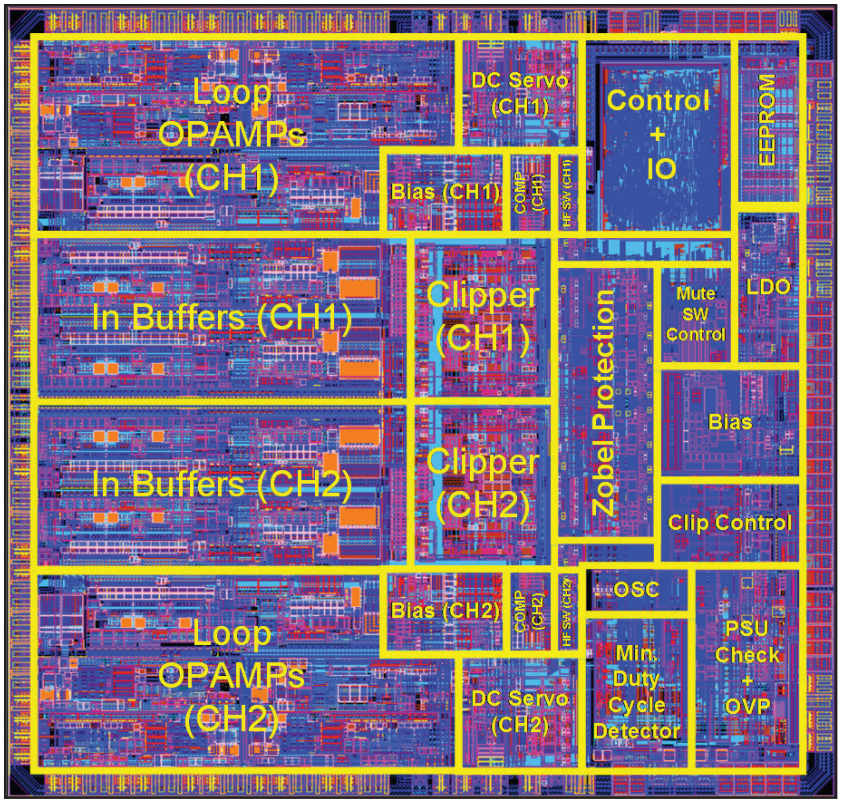


Photo 3: In the ICEedge controller, ICEpower used a dual-mono design, with the two channels being completely separated and with the physical layout being fully identical.

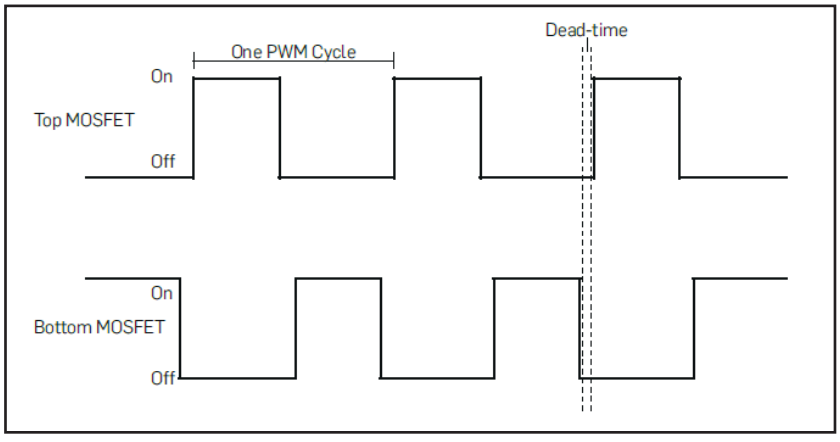


Figure 1: A small delay is introduced by the ICEedge Driver in the MOSFET gate drive timing, ensuring that one MOSFET is turned off before the opposite MOSFET is turned on. This prevents a momentary short circuit of the power supply and increases efficiency. This delay is shown in the figure as dead-time.

The ICEedge Controller is a fully integrated pulse-width modulation (PWM) modulator and a system controller for dual-channel self-oscillating Class-D switching amplifier applications (see **Photo 3**). The controller has a fast communication interface for two ICEedge drivers. All passive loop components are external, allowing flexibility, precision, stability, and linearity.

The controller includes 16 high-performance audio op-amps and two high-speed comparators, high impedance fully balanced audio inputs, and DC servos for a low DC offset voltage at amplifier outputs. In terms of protection features, the controller combines a precision clipper and supply voltage surveillance circuits, overcurrent protection, thermal management, over/undervoltage, a modulation index, and Zobel protection. The design allows controlled pop reduction during start up and shut down, simple pin control and diagnostic information, with no microcontroller required for full operation and it features an I^2C interface for control and system programming.

The ICEedge driver IC is a fully integrated gate driver for Class-D switching amplifier applications using discrete external MOSFETs. The design uses high voltage technology for amplifiers with up to ±150 V power supply voltage, which enables up to 7 kW into 4 Ω and features a high-speed (110 ns) 2.2/1.5 A driver for direct drive of MOSFETs. The drive capability can easily be extended with the addition of an external active drive circuit and the design allows for continuous dead-time compensation, ultra-fast cycle-by-cycle output current limit, and optimized dead-time compensation for both low- and high-side drive.

There's also a built-in high-speed measurement system for accurate MOSFET temperature measurement and amplifier protection, temperature diagnostic information including the possibility of early warning for fan control, and the ability to implement an active anti pop system during amplifier start up. The design also allows both single and split supply for the lowest system cost. A few features are very interesting and deserve a closer look.

Special Features

Continuous Dead-time Compensation (CDC). To get a high efficiency and low distortion it is necessary to have a switch behavior of the power MOSFETS as ideal as possible. In Class-D output stages, the two output MOSFETs can, if controlled incorrectly, short circuit the power supply at each output transition. This will cause increased losses and electro-magnetic interference (EMI) and also

possible amplifier failure. Unfortunately, a MOSFET's switching-on and switching-off behavior is not symmetrical. The result is the need for a rather large so called "dead-time," the time needed to ensure no cross conduction (i.e., both Mosfets conducting at the same time) occurs. (see **Figure 1**).

The solution is a small delay introduced by the ICEedge Driver in the MOSFET gate drive timing, ensuring that one MOSFET is turned off before the opposite MOSFET is turned on. This prevents a momentary shortcircuit of the power supply and increases efficiency. However, to keep distortion at the lowest possible level, very accurate timing is required.

Fortunately, the ICEedge Driver's dead-time setting is very accurate, leaving only minute variations in production and across applications. But since the dead-time for the total power stage also depends on the switching behavior and the timing of the power MOSFETs introduced by complex speaker loads, dead-time related distortion still exists, especially in high power amplifiers.

To compensate for this phenomenon, the ICEedge Driver provides an ICEpower proprietary CDC mechanism that adds small continuous compensating adjustments to the gate driver output timing derived from the previously measured PWM switch timing. In other words, based on the actual timing of the power stage MOSFETs, the ICEedge Driver will maintain the optimal timing of the full power stage and thus provide optimum low distortion properties.

*Switching on...*The driver chips have an on board pre-bias setting system avoiding switch-on pops. Before the amplifier is released the bootstrap capacitor for the upper MOSFET is pre-charged by a current source. This has to be done correctly, otherwise the PWM sequence would not be starting at 50% resulting in an audible pop at the start-up sequence (see **Figure 2**).

*And switching off...*A nice feature is the amplifier's controlled switch-off behavior. If you perform an abrupt shut-down of the amplifier, the PWM cycles will stop in the middle of one cycle. This most likely results in a pop noise. The solution used here is switch-off frequency sweep. When the amplifier is shut down, a high frequency sweep with a predefined switch stop time is activated. By sweeping the PWM to a high frequency, the remaining "pop-energy" gradually reduces to nothing and ensures a pop-free switch-off of the amplifier (see **Figure 3** and **Figure 4**).

Temperature... check! ICEedge measures the temperature in eight zones and gives an early warning before the temperature limit is reached.

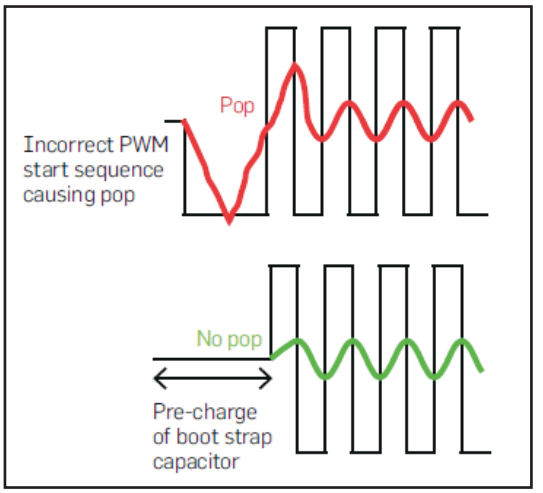


Figure 2: Some designs make no prevention against pop noise. This results in a pop at the beginning of the PWM cycles. ICEedge implements an advanced solution to eliminate pop noise.

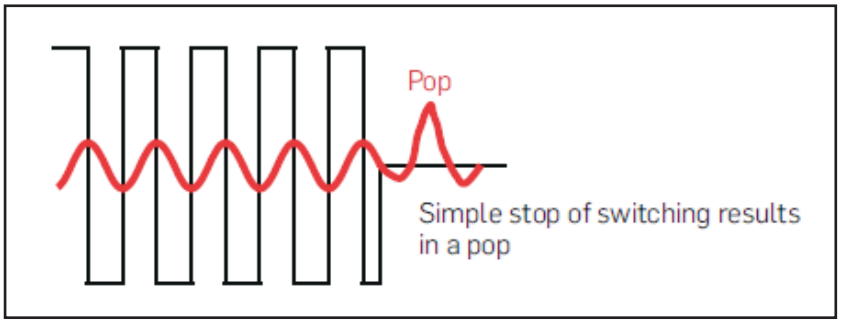


Figure 3: An abrupt shut-down of the amplifier causes the PWM cycles to stop in the middle of one cycle, likely resulting in a pop noise.

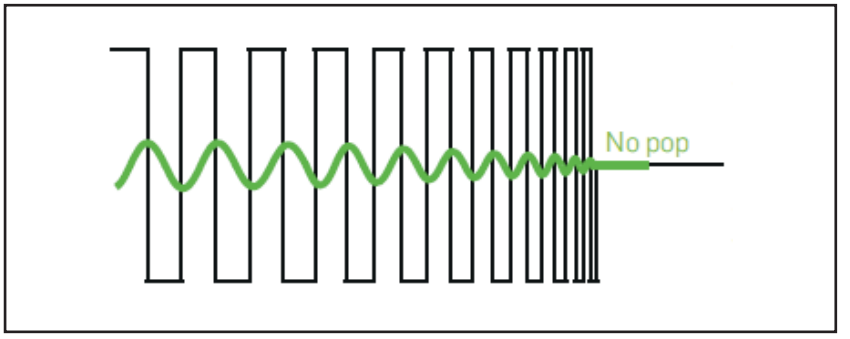


Figure 4: ICEedge eliminates pop noise.

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.

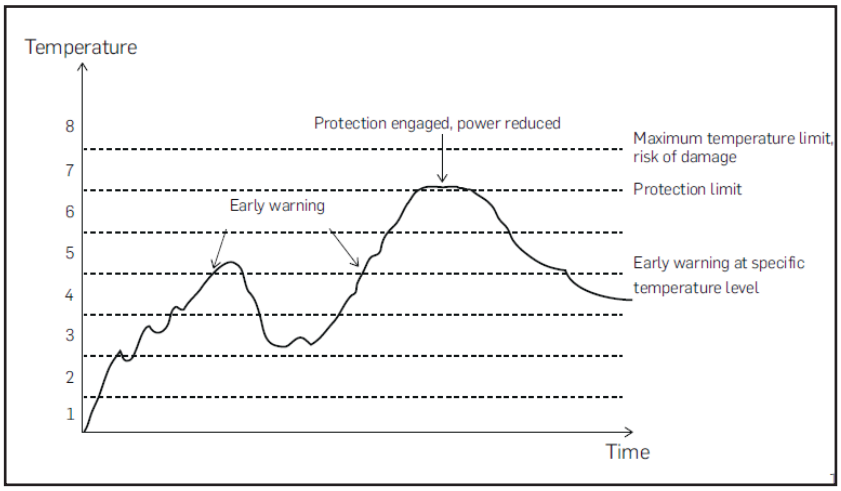
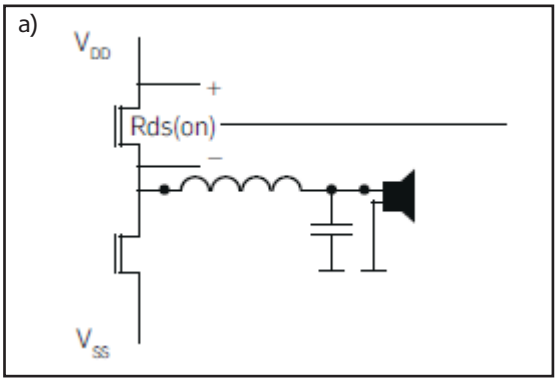
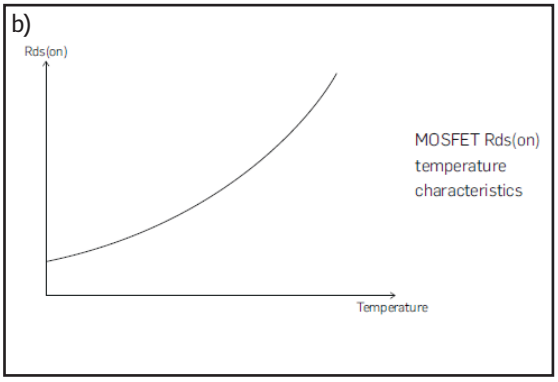


Figure 5: This is an early warning temperature capture.

Figure 6: ICEedge measures the current by monitoring the voltage drop across the MOSFET Rds(on) to avoid damage and keep the music playing (a). However, Rds(on) is highly temperature dependent (b).





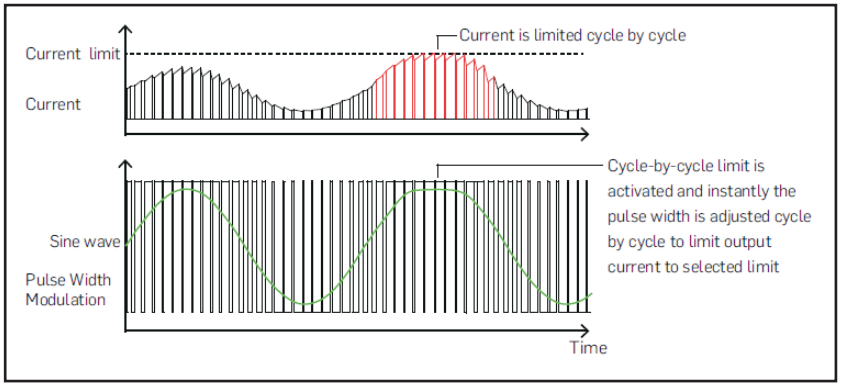


Figure 7: ICEedge has a Temperature-Compensated Cycle-by-Cycle Current Limit (TCCCL).

At a certain temperature, the system will send a warning about the rising temperature. This way, there is time to react and limit the power before any risk of shutdown or damage. Should the temperature keep rising, a protection system will activate and gradually turn down the power until the temperature has reached safe operating levels. Most important is that by organizing temperature control this way an amplifier will not break down from overheating, thus ensuring its continuous service (see **Figure 5**).

Of course, this depends greatly on where and how you measure temperature... Usually the MOSFET temperature measurement does not correspond to the actual die temperature and is delaying the actual temperature of the die itself as it is not measured there. There is the risk that an over-temperature warning comes too late and damage to the MOSFETS is already done.

ICEedge is capable of measuring the temperature directly at the MOSFET's drain terminal with no electrical isolation. This means that the actual temperature information is available with the most minimal delay possible, giving the shortest reaction time of the temperature control system.

Current Limiting. MOSFETs are rather sensitive to overcurrent. If the limit is exceeded, a MOSFET will be damaged. Continuously monitoring a MOSFET during operation is a good idea. In principle, that can be done rather easily by monitoring the voltage drop across the MOSFET Rds(on), which can be seen in **Figure 6a**. However, this Rds(on) is highly temperature dependent (see **Figure 6b**). The ICEedge Temperature-Compensated Cycle-by-Cycle Current Limit (TCCCL) measures the temperature and compensates for the changing Rds(on), which can be seen in **Figure 7**.

Monitoring the current cycle-by-cycle and the actual temperature of the MOSFET die enables a direct response if the current limit is reached by lowering the current to ensure that the amplifier will not be damaged. In this way, it is also possible to use better specified MOSFETs with lower current ratings or filter coils with more desirable specifications. Of course, this can also be used to save costs as you can integrate the parts at a lower price point without risk of damage.

The Possibilities

Marketwise, implementing ICEpower amplifiers provides a range of choices from existing and new platforms with different form factors and solutions for higher volumes, higher quality, and more power ratings. Current amplifier modules, from small to large sizes, allow a choice of single-channel, dual-

channel and multichannel solutions, with or without power supply.

ICEpower's AS Series includes a range of full-featured amplifiers from 100 to 1,200 W with universal mains and ErP/Energy Star compliant standby (see **Photo 4**). The ASX Series features power options from 25 to 700 W, ideal for more cost-focused products with less need for features. The ASP Series features ICEpower's most powerful Class-D modules. The recent 1200AS1 module features a power rating of 1 × 1,200 W in 4 Ω and the 1200AS2 includes two 1,200 W channels in 4 Ω (see **Photo 5**). The company has also introduced the new ICEtheater7, a one-board seven-channel high-quality amplifier, leveraging its newest Class D DualLoop3, topology (see **Photo 6**).

ICEpower also offers the newly developed, full featured 100AS1 and 100AS2 modules (see **Photo 7**). The modules, a one- and two-channel 100 W amplifier, enable high performing and high volume applications, which together with the 1200AS1/2 modules completes the requirements for 100 to 1,200 W at a highly competitive price point. These new models feature DualLoop3 Class D topology, universal mains, a standby functionality, a regulated power supply, PFC, monitoring, diagnostics, a comprehensive protection scheme, and several more features.

With the newly acquired Audio Bricks product range, ICEpower offers a second option that enables designers to incorporate an Audio Brick module into a manufacturer's own design.

Since the merger with Audio Bricks, ICEpower has decided to integrate its products and technology as ICEpower products, under the ICEbricks series.

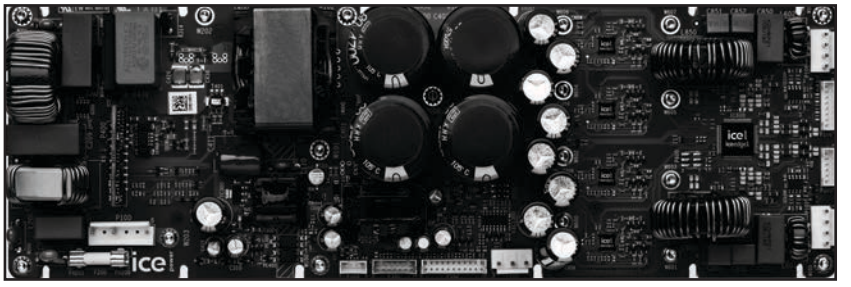


Photo 4: An example of an AS module from ICEpower, with a power output of 2x 1200 W in an ultra-compact and lightweight package.

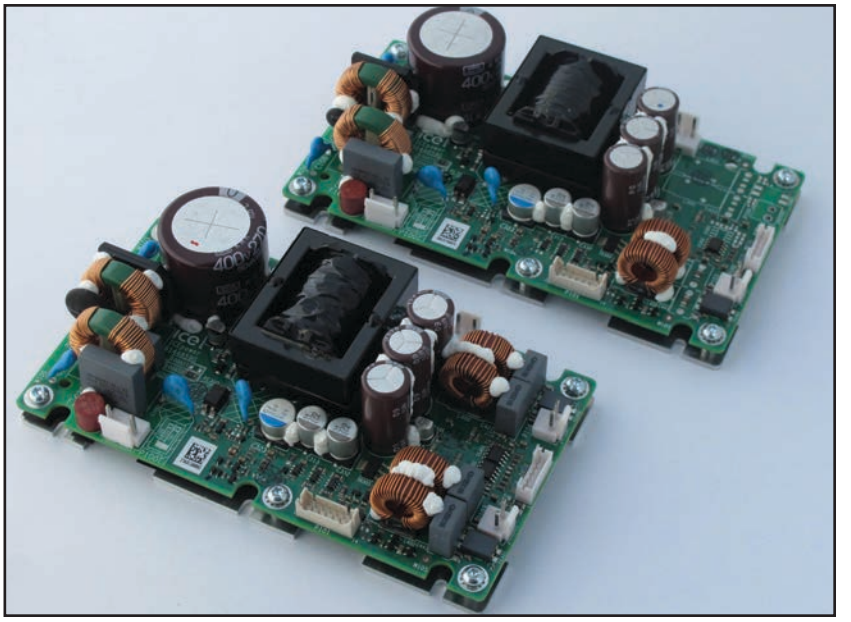


Photo 5: The recent 1200AS1 module features a power rating of 1 × 1,200 W in 4 Ω and the 1200AS2 includes two 1,200 W channels in 4 Ω.

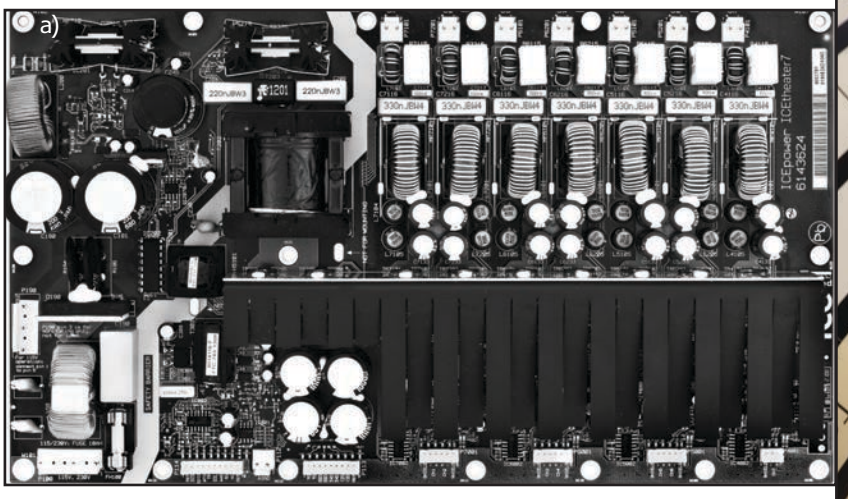


Photo 6: The new ICEtheater7, a seven-channel high-quality amplifier using the newest Class-D DualLoop3 topology (a) and a custom OEM 16 channel amplifier, using ICEmatch modules, which was on display at the NAMM Show 2017 (b).

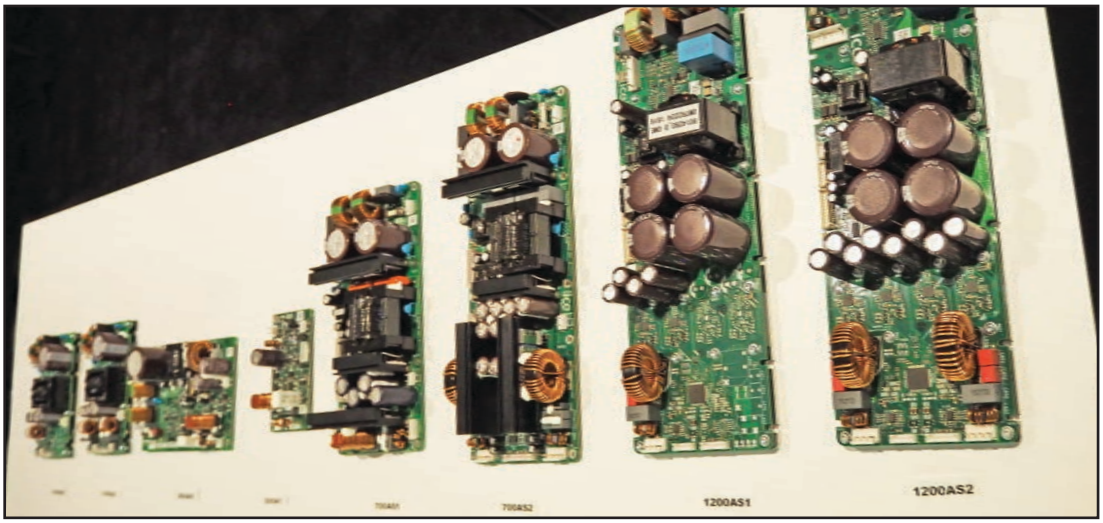


Photo 7: These are the A1 and AS1/2 modules, which are the newest generation of ICEpower modules and were on display at the NAMM Show 2017.

Photo 8: ICEpower has set up in temporary headquarters until it moves to a permanent location in Copenhagen, Denmark.

Photo 9: This new coffee machine now powers ICEpower's temporary premises.

We will explore the possibilities with ICEbricks in a future issue of *audioXpress*.

ICEpower also offers a third option for manufacturers to use the ICEedge chipset and design their own products. A prerequisite is that the manufacturer be willing to invest in its Class-D knowledge on a much larger scale.

How does this technology work in practice? In a future article in this series, *audioXpress* will take a closer look at the new ICEpower flagship: the 1200AS2 module. This is a 2x 1,200 W in 4 Ω amplifier with a built-in power supply that can be used as a pro audio workhorse or potentially in high-end amplifier applications.

Its separation from Bang & Olufsen has forced ICEpower to move to a (temporary) new building, which *audioXpress* visited. While the company prepares to move to a completely new location in Copenhagen, Denmark, we found a company deeply focused on continuous research with no lack of ideas and aspirations. The move means that a lot of test equipment has to be relocated and the current laboratory was showing a happy relocation atmosphere (see **Photo 8**). As some of our photos document, development and testing continues as usual.

One of the most successful tests was already the new coffee machine, which we found was the center of attention in the lab (see **Photo 9**). While the old one stayed behind in the division of joint property with Bang & Olufsen, the new one is already supporting ICEpower with new fresh ideas.

For more information about the ICEedge Class-D chipset visit www.ICEpower.dk.

A New Audio Amplification Powerhouse

On May 1, 2016, Keld Lindegaard Andersen, CEO, and Mads Emil Solgaard, VP of Sales & Marketing, together with the private equity fund, Industry Development (Industri Udvikling), acquired ICEpower A/S from Bang & Olufsen A/S. The ICEpower management team had 50% of the company and Industri Udvikling another 50%. At the time of the separation from Bang & Olufsen, the ICEpower management team and Industri Udvikling stated their intention was to develop ICEpower further and consolidate its position as a leader in Class-D audio power conversion.

In September 2016, Danish company ICEpower, now independent from Bang & Olufsen, announced the decision to merge with Audio Bricks, and to acquire its holding company, Bolecano Holding AB, from Sweden. While ICEpower is highly recognized in the market as one of the leading brands in audio amplification, Audio Bricks was a relatively new company, created in 2014 by Patrik Boström and Lars Press Petersen. Boström and Petersen have now become partners and shareholders of ICEpower, respectively holding the position of CTO of Amplification and CTO of Research and SMPS at ICEpower.

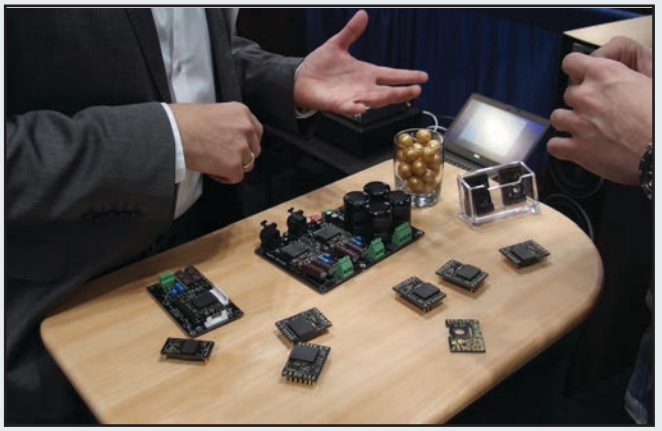
The two founders of Audio Bricks are both familiar with Class-D power electronics. Boström was one of the founders of Anaview AB, in Sweden, while Petersen was Innovation Manager at ICEpower from 2003 to 2007.

Boström has a BSc in Electrical Engineering and developed amplifiers and power supplies for OEM automotive, high end, consumer, home theater, and sound reinforcement applications. Boström started his electronics career at Ericsson in Stockholm designing switch mode power supplies for Telecom applications. In 2004, he founded Anaview, which became a well-known supplier of complete high-quality powered Class-D modules. Boström is the inventor of several patents within the field of Class D and loop design.

Petersen holds a PhD in Power Electronics from the Technical University of Denmark. In 2014, he started Audio Bricks with Boström. Petersen is an innovator and power supply specialist. Prior to that, Petersen worked for ICEpower from 2003 to 2008 and was deeply involved in the research of new topologies and system designs. Between 2008 and 2011 he headed a start-up business, Upcon Technology, which specialized in switch mode power supplies focusing on high efficient telecom and server power supplies. From 2012, he worked as a senior advisor and researcher at the Technical University of Denmark, in the field of switch mode electronics. Petersen has participated in more than 30 scientific papers and patent applications.

"We share the same ideas on development of quality sound by technology and combining technologies to reach our goals. Already in the early zeroes we worked together, became friends and discussed how we could join forces. The timing is right for all of us now," stated Keld Lindegaard Andersen, ICEpower's CEO.

For more information, visit ICEpower or Audio Bricks at www.ICEpower.dk and www.a-bricks.com.



The Audio Bricks modular audio amplification platform was introduced in 2015, at the 139th International Audio Engineering Society (AES) Convention in New York.

Even though Audio Bricks has continued to exist as a separate entity, ICEpower displayed its new ICEbricks designation for the Audio Bricks modules—Engine-400, AUX-plant, and Motherboard-1— at the NAMM Show 2017.