POWER ELECTRONICS NEWS

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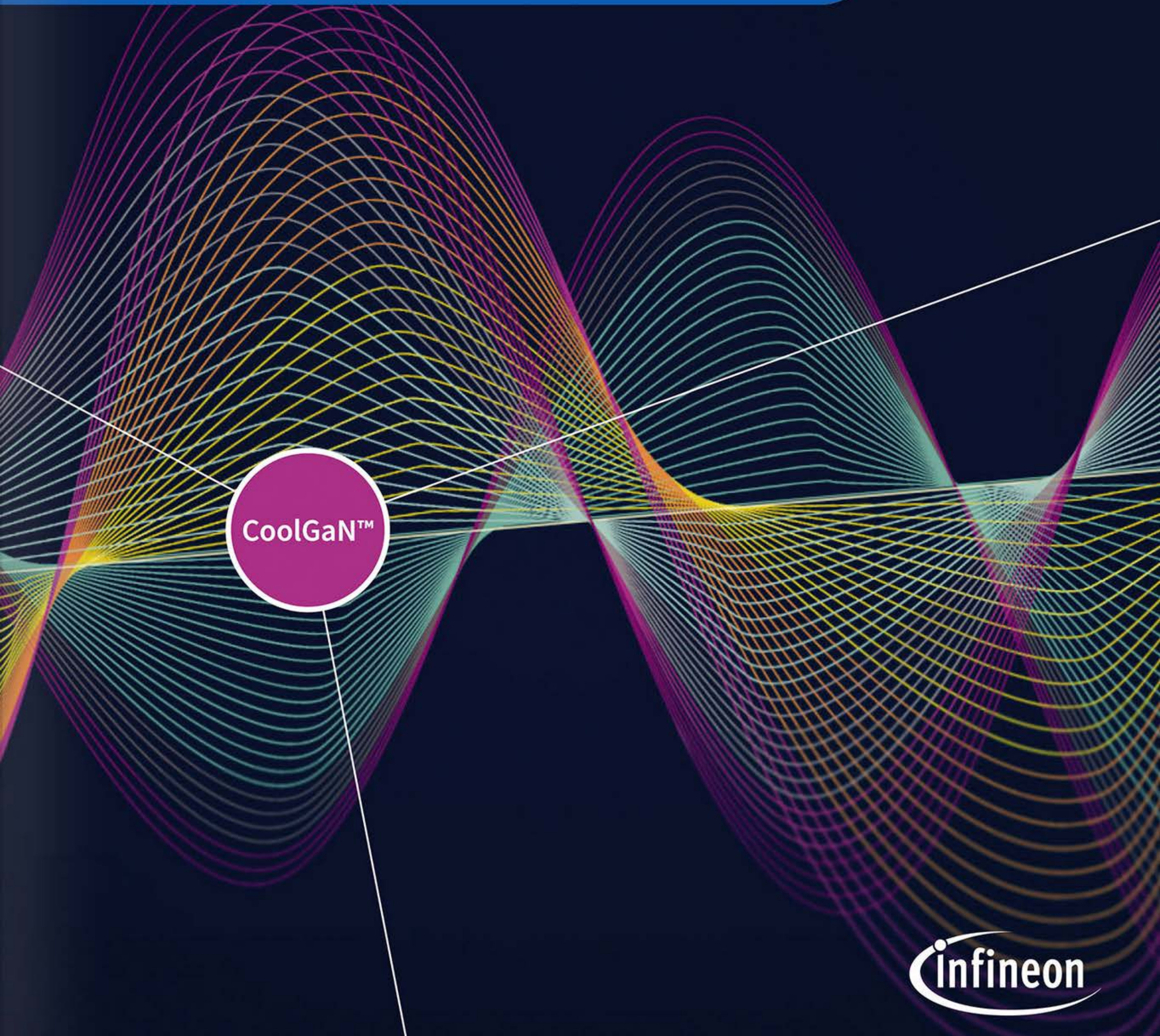

Why GaN is the future for Class D

VIDEO

CoolGaN, the new power solution – Interview to Tim McDonald, Senior Director at Infineon

Infineon's overall strategy is to integrate each of today's cutting-edge silicon technologies with a broadband counterpart. Based on the CoolSiC™ technology already introduced on the market, Infineon has introduced the new CoolGaN™ solutions, which complete the super-devices of the CoolMOS™ portfolio.
CoolGaN ensures high efficiency and reduced weight of power converters. We interviewed Tim McDonald, Senior Director, GaN Marketing & Application @ Infineon during the Power Conference.

i More info

- Technical Article
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- Power Conference Article
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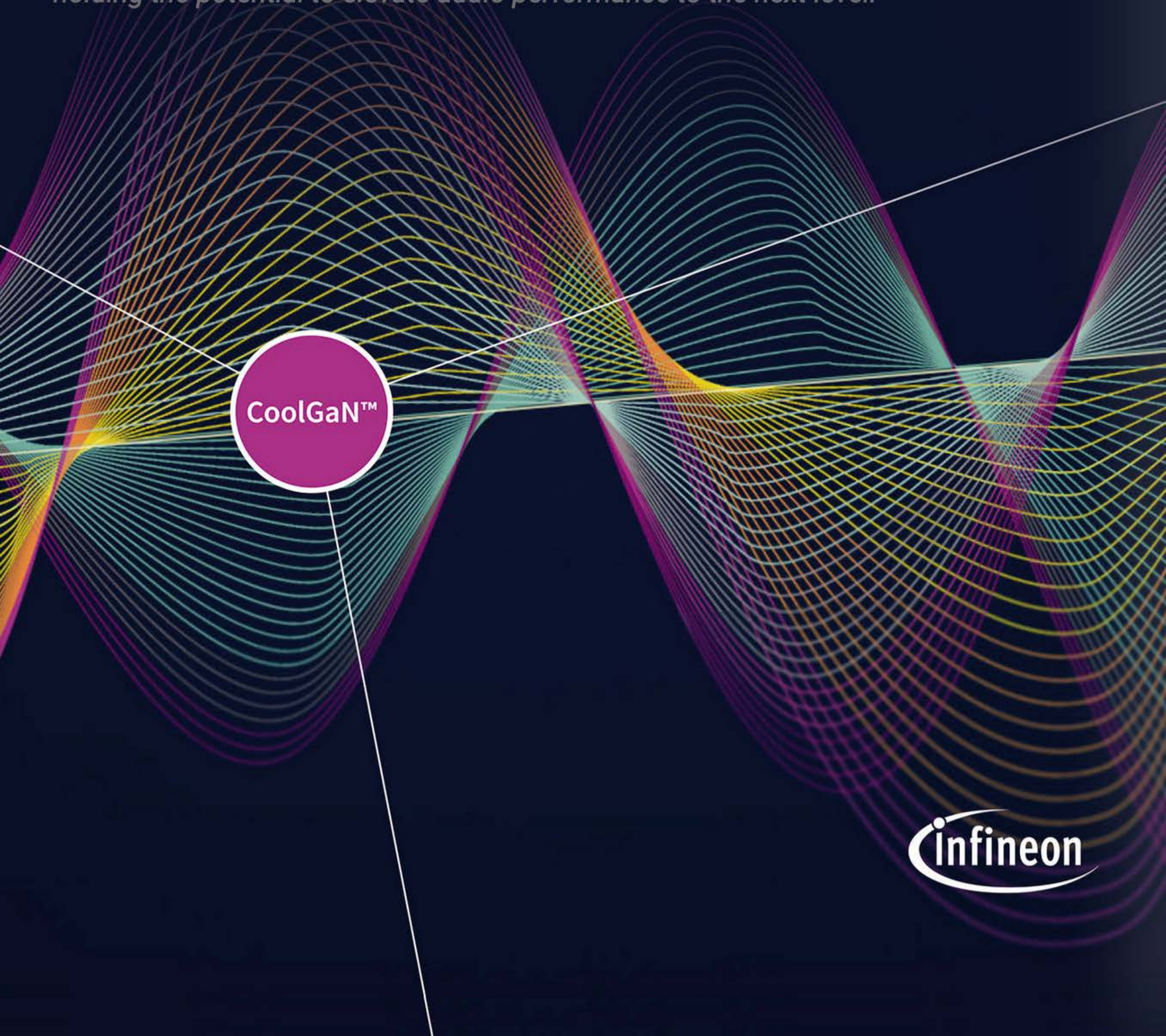
Opening up the next chapter of Class D audio amplifier performance

CoolGaN™ in audio applications

In this article, we take a closer look at gallium nitride (GaN) transistors and how this new semiconductor technology promises to revolutionize the performance of Class D amplifiers. With their very low ON-state resistance, very high and clean switching capabilities GaN devices are exceeding the performance of their silicon MOSFET counterparts. This makes them the perfect choice for high-end audio applications holding the potential to elevate audio performance to the next level.



Infineon

CLASS D – AMPLIFYING SIGNALS WITH A SWITCH

In the 1950s, a revolutionary new concept was brought to life: amplifying audio signals with active devices which are not operating in their linear gain mode but instead acting as electronic switches. The working principle is that instead of using the transistor to amplify the signal proportional to the input signal in the linear region, the analog output value is expressed by timing the ratio of the transistor being in it's on- and off-state. This generates a train of rectangular pulses, usually of fixed amplitude but with varying width and separation which then represents the amplitude[1] variations of the analog audio input signal.

Basically, the longer the on-state compared to the off-state, the higher the power it delivers to the speaker load. By making the switches alternate much faster than the audio signal frequencies, the switching operation becomes indistinguishable. Since the transistors are either fully "on" or fully "off", they spend very little time in the linear region and therefore dissipate very little power. Although Class D is the first amplifier topology that theoretically offers completely linear operation with 0% distortion and no power loss at 100% power efficiency, the commercialization of Class D audio amplifiers had to wait until the '90s when silicon (Si) MOSFETs with sufficiently good device parameters became widely available.

Ever since, the performance of Class D amplifiers has been advancing incrementally with the evolution of the Si MOSFET performance as the preferred transistor device technology.

Recently however, as GaN-based high-electron-mobility transistor (HEMT) devices with much better physical properties have become a reality, a leap in Class D amplifier performance is on the doorstep.

[1] Although modern multilevel Class D output stages can provide several levels of output amplitude.

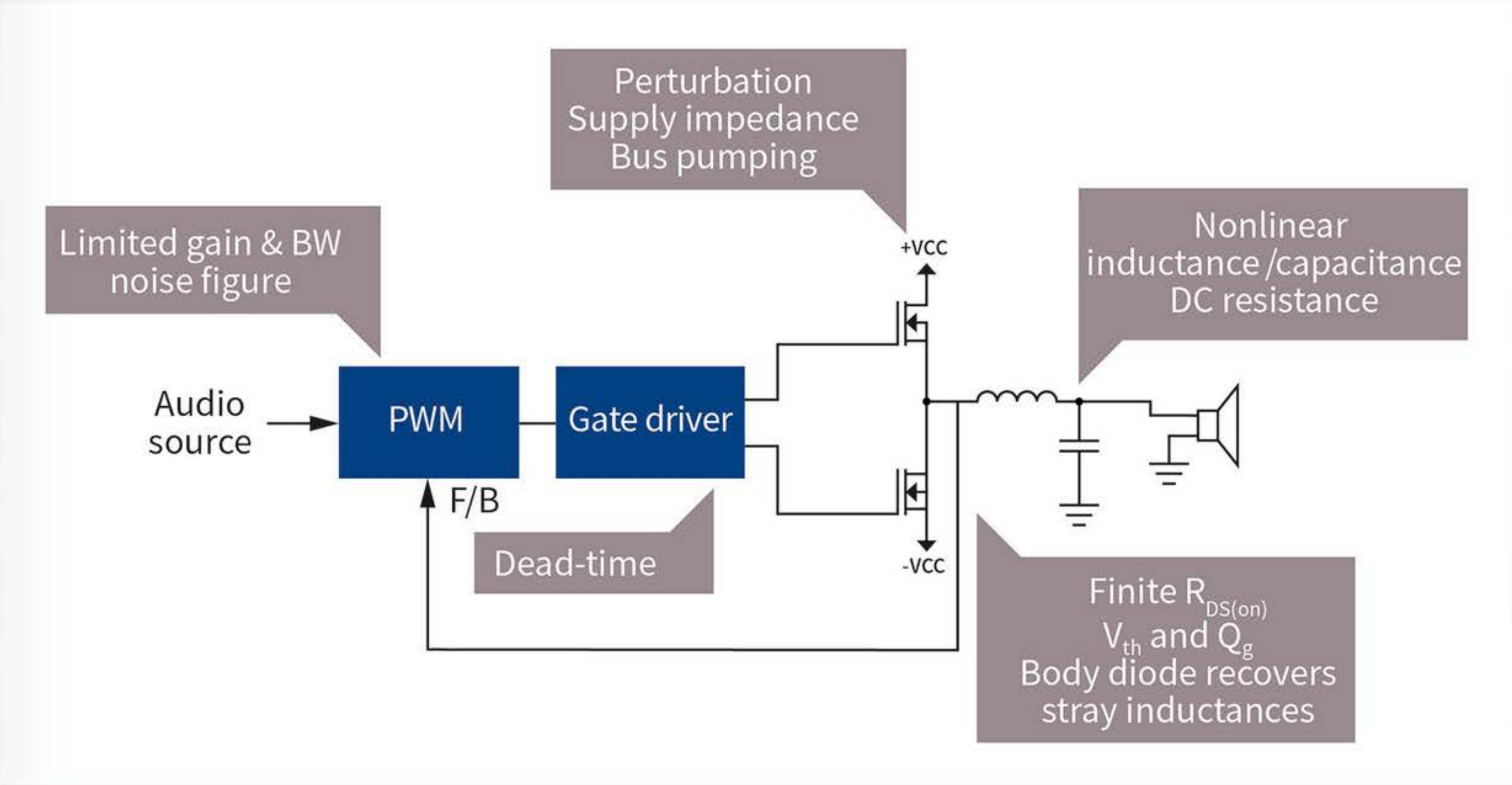


Figure 1: Ideal and practical Class D amplifier – The basic configuration of a Class D amplifier and the affecting factors. The distortion and power efficiency of a Class D amplifier relies on the accuracy and efficiency of the switching devices.

SWITCH PERFORMANCE DETERMINES AUDIO PERFORMANCE

Let's take a look at the key parameters of a power device and how these affect the switching and ultimately the audio performance of the Class D amplifier.

In contrast to traditional linear amplification classes such as Class A or AB, in terms of the device parameters a Class D amplifier exhibits no tradeoff between audio performance, size and power efficiency. In Class D, the key device parameters, such as switching speed and ON-resistance, that are needed to achieve high audio performance also help to increase power efficiency. A faster switching speed minimizes switching losses by shortening energy loss duration and a lower device resistance reduces I^2R losses (proportional to the square of current). This signifies one of the great benefits of Class D: a better figure of merit for the power switch device simultaneously enables improved audio quality and power efficiency in a smaller footprint.

The switching performance of the Class D amplifier is determined by both device parameters and operating conditions. Depending on the amplitude of the output current, the Class D amplifier power stage operates in one of two switching modes:

1. zero-voltage switching (ZVS) and
2. hard-switching

These two modes greatly influence the device switching losses (losses resulting from switching action) of a Class D amplifier.

The Class D amplifier operates in the first operation mode, ZVS, when the output power (and output current) is relatively low, typically up to only a few percent of the rated power. In ZVS operation, the transition of output switching waveform is – instead of a switch turn-on – achieved by an inductor current commutation. This commutation of the output voltage of the switch essentially eliminates any power loss that occurs during switch turn on. So in order to maximize power efficiency at idle and light load conditions, in which the amplifier operates most of the time, a short blanking time is inserted. All switches are in the off-state during this blanking time to ensure that the transition of the switching waveform completes before the start of the next switching cycle, i.e. ZVS is achieved. However, this blanking time insertion also changes the output waveform that the PWM modulator demanded, and therefore, creates distortion. The duration of the blanking time is determined by the output capacitance (C_{oss}) of the power device.

A larger C_{oss} requires a longer blanking time for the same inductor current. A much lower C_{oss} of a GaN transistor reduces the required blanking time duration and therefore decreases distortion. As discussed subsequently, a lower C_{oss} is also beneficial when a Class D amplifier is operating in hard-switching mode.

The second operation mode is hard switching (at higher output power/ current) which has two undesirable outcomes. The first unfavorable consequence of the hard-switching mode is the reverse-recovery charge (Q_{rr}) in the body diode of a MOSFET. During blanking time, all power switches are off and the body diode carries output current. The PN junction in the body diode accumulates a minority carrier charge during its conducting state. The Q_{rr} has to be discharged before the output voltage transitions to another switch side. This step, in addition to generating power loss, generates a sharp high peak in the current between the power supply rails and is the major source of electromagnetic interference (EMI) noise emission.

A GaN transistor has no body diode or minority charge effects coming from the device physics. Therefore, it exhibits zero Q_{rr} realizing much cleaner switching waveforms.

The second undesired outcome of hard switching operation is the result of switch output capacitance, C_{oss}.

The C_{oss} has to be charged and discharged to turn the switch on and off, so larger C_{oss} means greater charge/discharge energy. The energy stored in the C_{oss}, when the switch is turned off, is dissipated at the next switch turn-on. This dissipation is a significant source of power loss at high switching frequencies.

The very small C_{oss} of a GaN transistor stores much less energy and therefore reduces the switching power loss.

Similar to the switching loss, the conduction loss in power devices are also dependent on both device technology and operating conditions. The conduction loss is proportional to the device ON-resistance and to the square of the device current. GaN technology achieves lower ON-resistance in a smaller form-factor which enables a compact high-power design.

Traditionally while selecting MOSFETs for Class D amplifiers, switching and conduction power losses are in a trade-off relationship in a device technology. For example, reducing conduction loss by increasing die size for lower ON-state resistance would result in higher gate and output capacitances that slows down the switching speed, therefore, increases switching loss. A GaN transistor, a revolutionary advancement in transistor technology, achieves a lower ON-state resistance while reducing gate and output capacitances enabling remarkably lower power losses. Hence, in Class D amplifiers a GaN transistor not only enables an efficient and compact design but also achieves superior audio performance at the same time.

WHY GAN IS THE FUTURE FOR HIGH-END CLASS D

A Class D amplifier demands lower $R_{DS(on)}$ as well as faster and cleaner switching transitions for higher power ratings that are traditionally the opposing performance tradeoffs for Si MOSFETs. That's why Class D amplifiers can greatly benefit from GaN. Let's now take a look at the device operating mechanism to discover how this breakthrough performance is achieved.

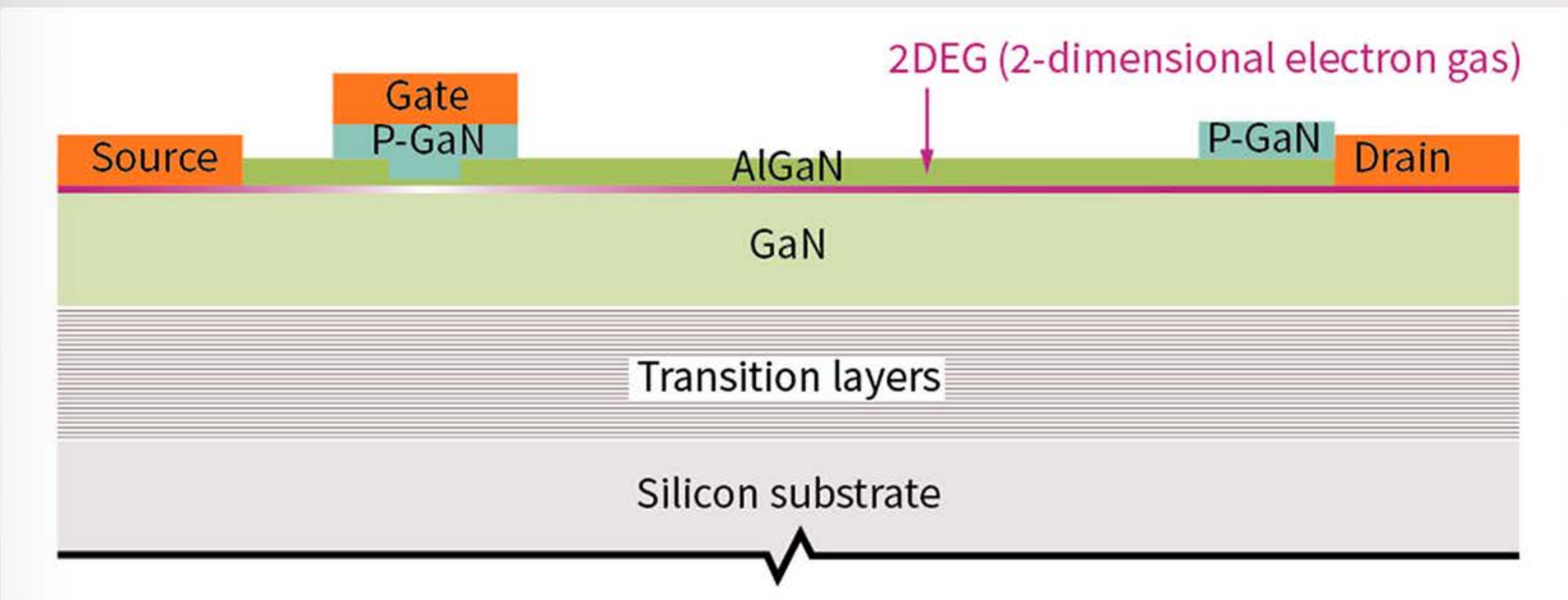


Figure 2: cross-section of Infineon's CoolGaN™ e-mode HEMTs

The basic structure of a GaN HEMT is similar to a Si MOSFET's, it includes gate, source and drain terminals. The heart of the GaN switch is a lateral two-dimensional electron gas (2DEG) layer formed in the GaN layer. The 2DEG is a pool of free electrons formed by the heterojunction between AlGaN and GaN, making a short-circuit between the source and the drain with a very low resistance.
Adding a p-GaN gate on top of the AlGaN layer makes the adjacent 2DEG depleted so the drain and source are not conducting when no gate bias is being applied (V_{GS} = 0 V). This enhancement-mode gate works similarly as in conventional Si MOSFETs. When a positive bias voltage is applied to the gate, the depletion disappears and the 2DEG forms a low resistance conducting channel.

The reverse conduction mode from source to drain is essential for Class D amplifiers during blanking time so that the switching output voltage is kept within the power supply rails.
The GaN switch is, by nature, a bidirectional device, thus it realizes reverse current as one of the on-states. When the drain voltage becomes lower than the source, the drain starts acting as source and turns on the device allowing reverse current flow. In contrast, a Si MOSFET is a unidirectional switch accompanied by an intrinsic PN junction body diode that provides a reverse current from source to drain when the device is turned off.

The absence of the body diode in GaN HEMTs is a notable feature because it eliminates the major source of switching noise caused by a PN junction body diode that is common in Si MOSFETs. Therefore, GaN HEMTs ensure much cleaner switching even at high voltages, as well as at high currents, and high-speed switching operations.

WORKING EXAMPLE – A 250 W GAN-BASED CLASS D AMPLIFIER SOLUTION

The discussed reference design example of a Class D amplifier uses CoolGaN™ (IGT40R070D1 E8220) and a 200 V Class D driver IC (IRS20957S) from Infineon.

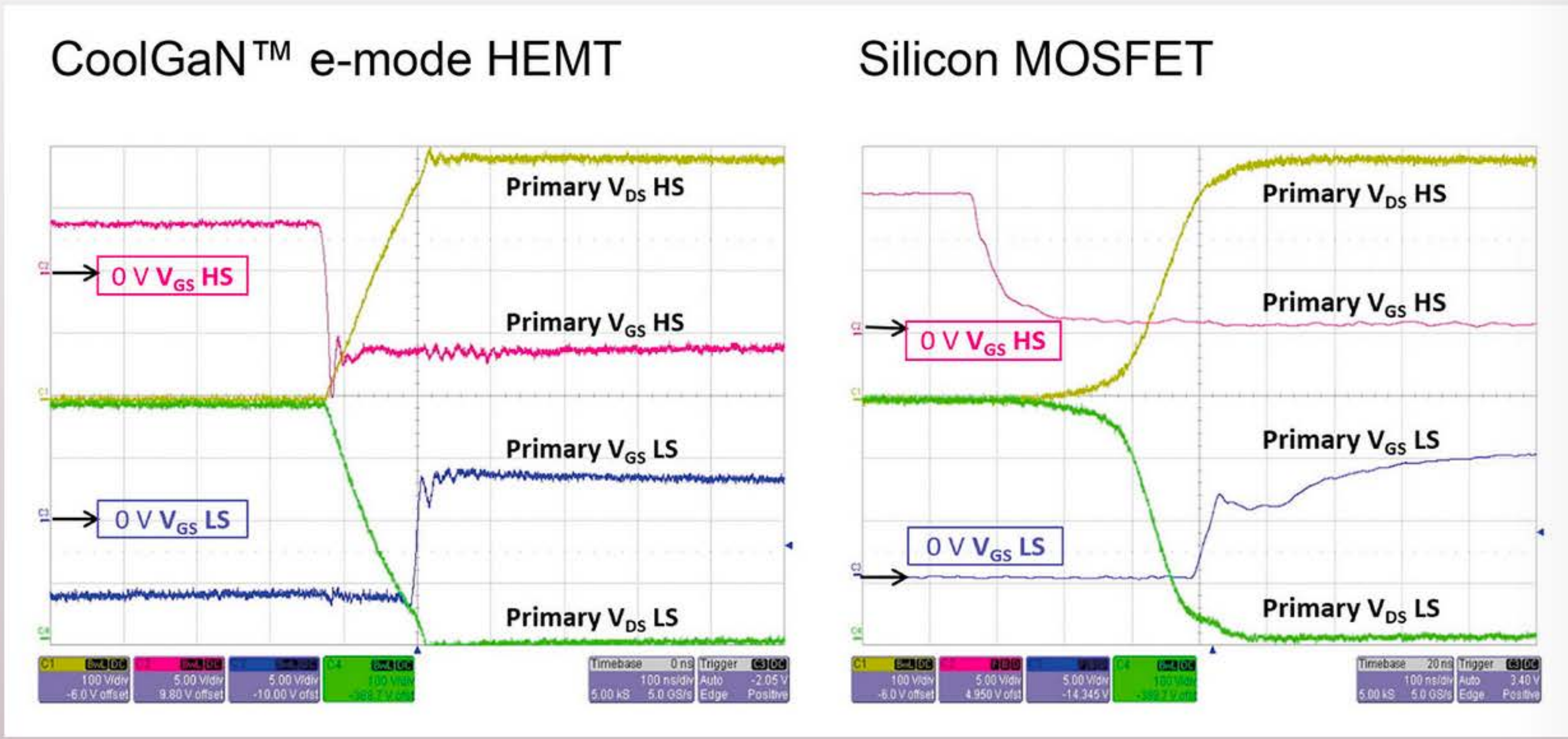


Figure 3: faster and cleaner switching waveforms with CoolGaN™ compared to a Si MOSFET

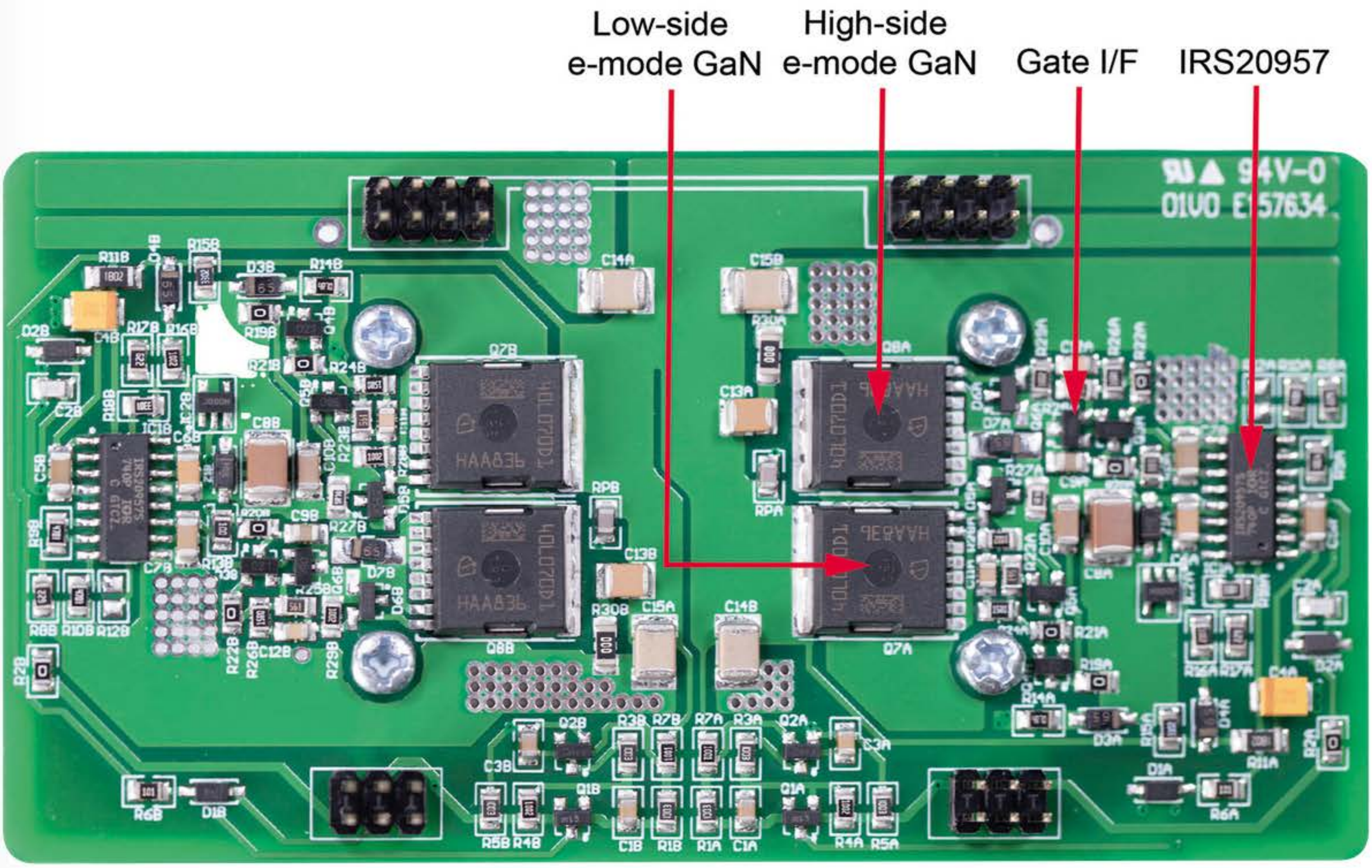


Figure 4: a 250 W + 250 W Class D design example using the 400 V, 70 mΩ audio-dedicated CoolGaN™ (IGT40R070D1 E8220) device

Using a GaN HEMT requires a different gate driving scheme. Si MOSFETs receive 0 V or 10 V gate voltage at the source to turn the switch off and - on. The gate-injection type GaN transistor, such as Infineon's CoolGaN™, is controlled in a similar fashion but with different gate-driving voltage and some sustaining DC gate bias current. In this design example, an interfacing circuit (R25, R26, R29, C12, and D6 in the low-side gate drive and identical for the high side) is inserted in the gate of the GaN HEMT.
The output from the interface circuit swings between -1 V and +3 V instead of 0 V and 10 V from the IRS20957S Class D controller IC.

Item	With heatsink	Without heatsink
Rated power @ THD+N = 1 %, 8 Ω load	250 W	160 W
Rated power @ THD+N = 1 %, 4 Ω load	220 W	N/A
THD+N, Pout = 100 W	0.008%	
Bus voltage	±72.5 V	±52.0 V
PWM frequency	500 kHz	

Table 1: design specifications of the reference design

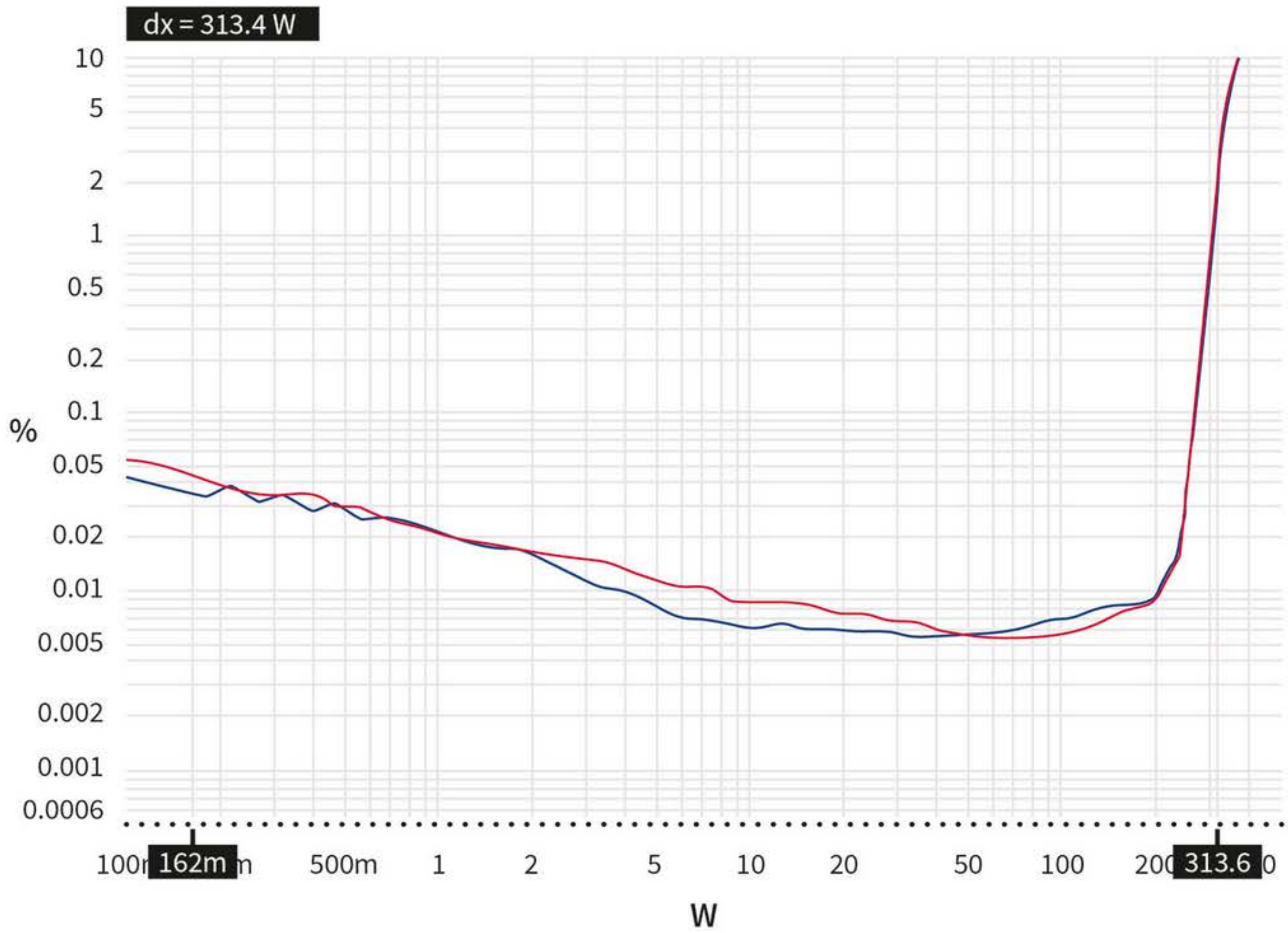


Figure 5: THD+N vs. output power at 4Ω load

The resulting audio performance is depicted in Figure 5. It shows clean switching at 500 kHz – especially if we consider that this is a 400 V, 70 mΩ $R_{DS(on)max}$ transistor. There is no visible THD+N level transition bump in the transition from soft- to hard-switching that may appear around a few Watts in high-voltage Class D amplifiers. The hard-switching region is nice and quiet.

As elaborated above, the benefits of GaN-based Class D amplifiers justify the use of this new semiconductor material. GaN devices now penetrating the audio domain mark the beginning of the next chapter of audio power amplification. And why is this especially suitable for Class D? Unlike the conventional linear topologies, the beauty of Class D is that both power efficiency and audio performance improvements can be realized, and all of these even in smaller form factors. ■

More info

- CoolGaN™ technology

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