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- *Know-how*
- *Application*
- *Automotive*
- *Inside Rutronik*
- *System Technology*
- *Latest Components*

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Editorial

Andreas Mangler,
Director Strategic Marketing and Communication

Between “America First” and “Made in China 2025”

Dear Readers,

While one part of the world has already got its economy back up and running again, the rest continue to alternate back and forth between lockdown and loosening restrictions. This hasn’t gone unnoticed in the electronics industry. We are experiencing allocation on an unprecedented scale in both the Consumer and Industrial segments, something that even the major automotive giants are not being spared. The massive winding-down of production in the second quarter of 2020 caused shockwaves through the supply chain that are still being felt today.

But even if COVID-19 had not been a thing, the increasing pace of digitalization is still hugely driving demand for semiconductors. And while business is still largely in the hands of the major American companies, China aims to close the gap as quickly as possible with its “Made in China 2025” program. Even if it looks unlikely to achieve its goal of having 70% of its demand covered by the production of its own businesses, the government is still pumping countless billions into the program. And although Donald Trump no longer rules from the White House, marking an end to his ideology of “America First,” the USA under Joe Biden remains critical of the growing competition presented by China.

And what about Europe? It “spent years blissfully asleep at the wheel,” as Rutronik CMO Markus Krieg put it in his interview (page 14), with its share of global electronic demand dropping to around 8 percent—which basically covers Apple’s or Samsung’s needs alone. Even those lacking in imagination can conceive of what this means for the relevance of European businesses when it comes to how manufacturers prioritize supply. That said, the European Union seems to have heard the alarm bells ringing, and for its part is now putting around 150 billion euros on the table to secure local semiconductor production.

Better late than never, and hopefully in time to secure Europe’s future as a center of innovation. The numerous businesses resident in the EU and in particular in Germany need reliable local partners to remain competitive, and need to be able to produce the products they develop without having to spend months waiting for allocations of the components they need. Especially in this light, there is benefit to be found in collaborations between these European businesses and European distributors that are geared not just towards short-term gains but also the strategic importance of the home market.

As the third-largest distributor in Europe, Rutronik contributes its expertise to support the programs of the German government and the EU, because as a German company, we care deeply about the future of our home industries and of European industry. Being active globally and ensuring the independence of local businesses are not mutually exclusive—quite the opposite. Fair competition for the best innovations and the most efficient technologies is ultimately beneficial to us all.

Sincerely,

Andreas Mangler

Contents

Development trends with ceramic capacitors

Hi, we're the new guys!

There are many demands placed on ceramic capacitors: smaller construction, large temperature ranges, higher efficiency, stricter tolerances, optimized functions, and higher frequencies, not to mention the desire for application-specific versions. The manufacturers do a lot to satisfy all these requests.

BY JÜRGEN GEIER, TECHNICAL SUPPORT, AND PASCAL KUNDELIUS, PRODUCT SALES MANAGER CERAMIC CAPACITORS, BOTH AT RUTRONIK

In order to continue optimizing their ceramic capacitors, manufacturers develop new materials and mixtures as well as new approaches to the construction, engineering, and interior structure (i.e. the forms of the electrode surfaces). They also deliberately make use of certain properties such as the widely negatively viewed effect of DC bias. This effect occurs in ferromagnetic ceramic materials such as barium titanate, which is currently the material most commonly used for MLCCs (multilayer ceramic capacitors).

Alongside the more widely known designs such as high-frequency, HiQ, RF, microwave, low-inductance, and low-loss capacitors, a range of specific and novel ceramic capacitors has recently started appearing on the market that are still broadly unknown—given the current deluge of new developments, this is hardly a surprise. We introduce some of the most important features here.

Variable capacity thanks to DC bias

"Variable capacitors" do just as the name suggests—they offer variable capacitance. Using their DC bias reduces the effective capacities when a DC current is applied to their control electrodes, so they could also be referred to as VACs—voltage adjustable capacitors. These electrically trimmable capacitors are available with capacitance ratings of 33 pF to 200 pF for control voltages of up to 3 or 5 V DC, allowing them to be adjusted to up to 50% of their base capacitance. Compared to regular trimmer capacitors, this provides them with unimagined opportunities—especially given that they can not only be set to fixed values, but also used to form control loops.

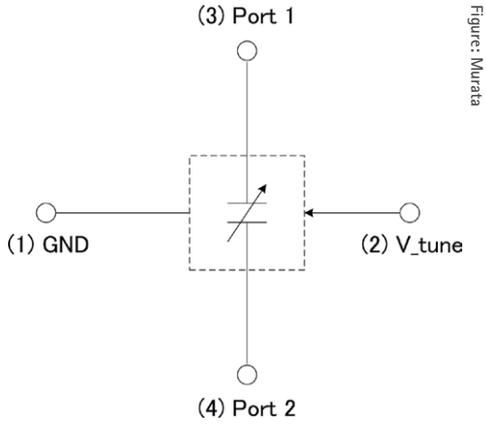


Figure: Murata

Figure 2: Substitute circuit diagram for variable capacitors.

They are available in construction sizes of 0.6 mm × 0.6 mm and 1.3 mm × 0.9 mm for working voltages of 10 V pp and 30 V pp. Applications for which these are especially ideal include NFC antenna circuits (13.56 MHz band), such as those used in smartphones and check cards, because the variable capacitors here enable frequency adjustments to be performed by simply applying the appropriate voltage in conjunction with the NFC ICs. They also compensate for variance in the antenna's L value, making f_0 adjustment easier, and also facilitate debugging during certification testing and simplify deviation adjustments during installation in the housing.

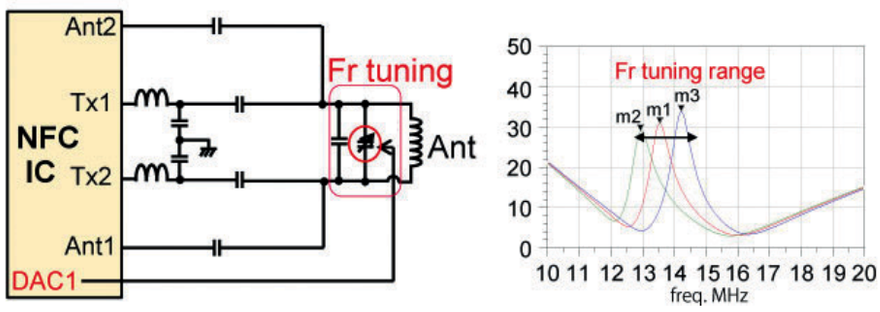


Figure: Murata

Figure 1: "Variable capacitors" offer adjustable capacitance by using DC bias.

Figure: Murata

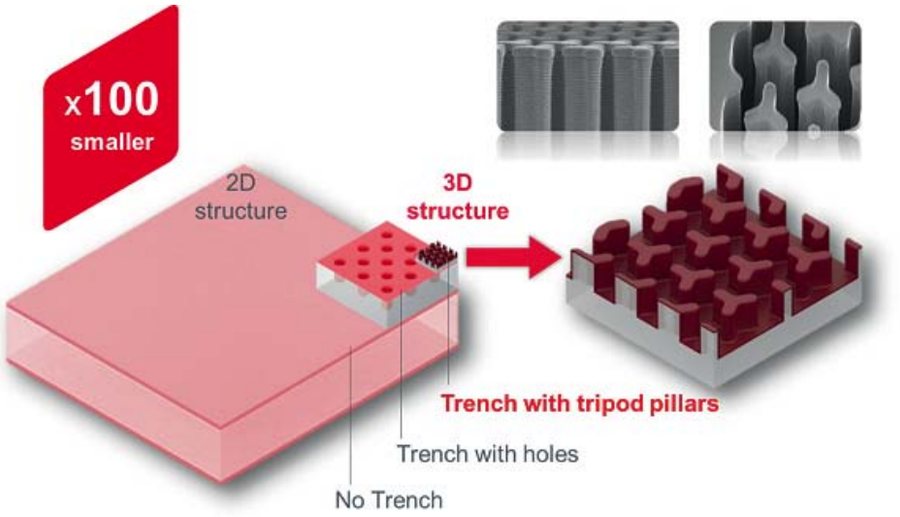


Figure 3: The 3D structure enables miniaturization by a factor of 100.

Silicon in the third dimension

For "high-density silicon" or "3D silicon" capacitors, manufacturers use the third dimension to significantly enlarge the capacitor surface—and with it the capacitance—without increasing the base surface area of the capacitor. This is how capacitance values are achieved that would require around 80 layers in MLCCs with a component thickness of 100 µm.

The Murata SiCap, for example, offers a whole 100 nF with a size of 0402 and a thickness of just 100 µm—equivalent to ten Class 1 dielectric C0Gs of size 0603 and 400 µm thickness. Thinner versions are also available from Murata on request. Capacitance values range from several pF to a few µF, and voltages range from 5 to 450 V.

Their material and construction properties make these high-density silicon capacitors especially well-suited to high-frequency applications from 10 up to 110 GHz. Their electrical characteristics are similar to the known "ceramic" type NP0 (= C0G). Unlike the C0G MLCCs, however, they can already be used as standard versions up to 150°C, and as high-temperature versions up to as high as 250°C. Thanks to their construction and thicknesses of just 50 to 400 µm, they are available not just in soldered versions, but also as bonded versions and for embedded installation. This means that there are ideal designs available for automotive, medical, RFID, high-frequency, and broadband applications, categorized as standard, high-reliability, high-temperature, and high-frequency models.

Capacitors with antiferromagnetic properties

If ceramic capacitors are used as snubber or DC link capacitors in a range of around 500 V to 900 V for working frequencies of several hundred kHz up to 1 MHz, MLCCs made of X7R ceramics (i.e. those that use the ferromagnetic barium titanate as their base material) are frequently pushed to the limits of usability. Due to their pronounced negative DC bias behavior, the necessary effective capacitance values in particular are almost impossible to achieve.

Antiferromagnetic properties are provided by the "CeraLink" capacitors from TDK. This means that they exhibit an increase in capacitance with the applied voltage, which enables much higher currents within the operating range. This is enabled by their lead (lanthanum) zirconate titanate (P(L)ZT) construction, referred to as a "ceramic."

Thanks to their extremely low ESL and ESR, CeraLink capacitors support higher switching frequencies and currents. This allows for the use of cheaper, more robust semiconductors, for example high-speed IGBTs instead of MOSFETs. This method often enables the value of the capacitor, the space on the board, the magnetic components and the heatsink to be reduced, thus also reducing the total cost.

As snubbers, CeraLink capacitors are a superb solution to reduce the risk of semiconductors being damaged by voltage spikes.

CeraLink capacitors are based on chips (7.85 mm × 6.84 mm × 2.65 mm) from which the manufacturer assembles a variety of connection options and combinations (Figure 6).

Rechargeable solid-state SMD battery with MLCC construction

The world's first rechargeable solid-state SMD battery might not be a capacitor, but the basic principles of its engineering design, constructed as an MLCC, are consistent with one. "CeraCharge" batteries offer capacitance around one thousand times that of MLCCs of comparable physical size. In other words, they have a comparably high energy density with a minimal volume. Then there are the benefits of ceramic multilayer components, namely robust safety and large-scale serial production. The use of a solid ceramic electrolyte eliminates the risks of fire and explosion, and of electrolyte leakage.

CeraCharge supports a very large temperature range of –20°C to +80°C and is therefore suitable for outdoor use.

The properties open up new opportunities for CeraCharge, in particular for IoT applications,

Figure: Murata

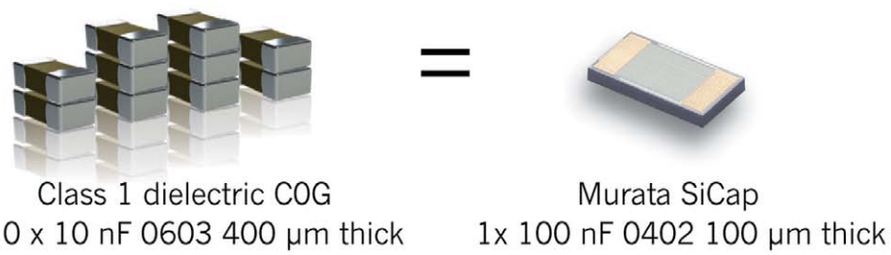


Figure 4: A SiCap from Murata offers the capacitance values of ten C0G capacitors with 100 nF.

Figure: TDK

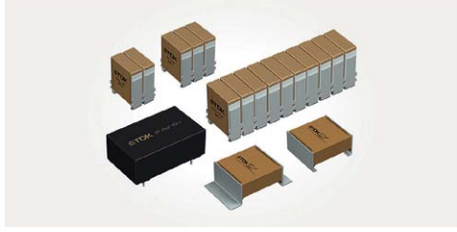


Figure 5: The compact CeraLink capacitors from TDK are suitable both for use as snubber capacitors and as DC link capacitors.

Figure: TDK

Nominal capacitance / rated voltage	Designed for 650V semiconductors	Designed for 900V semiconductors	Designed for 1300V semiconductors
Low Profile series **LP (L/J leads)**	1 µF / 500 V	0.5 µF / 700 V	0.25 µF / 900 V
Flex Assembly **FA2 / FA3**	2/3 µF / 500 V	1/1.5 µF / 700 V	0.5/0.75 µF / 900 V
Flex Assembly **FA10**	10 µF / 500 V	5 µF / 700 V	2.5 µF / 900 V
Solder Pin series **SP**	20 µF / 500 V	10 µF / 700 V	5 µF / 900 V

Figure 6: CeraLink capacitors are available in many different designs.

Figure: TDK

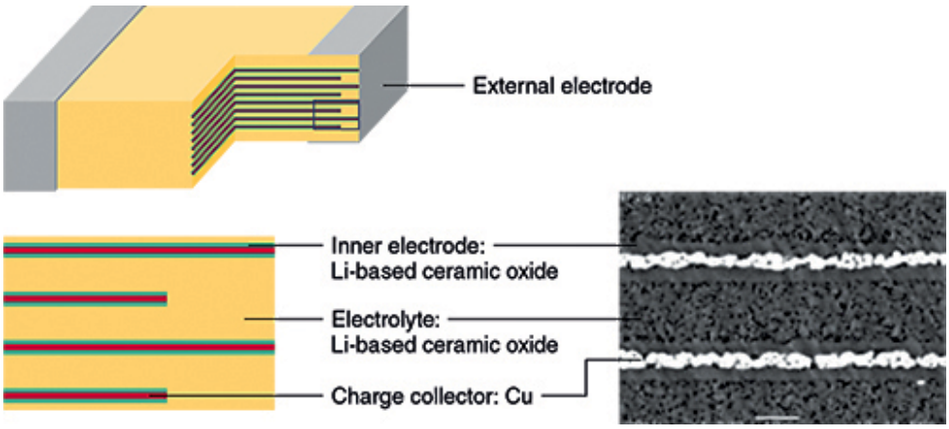


Figure 7: The construction of a CeraCharge battery is based on the design of an MLCC.

real-time clock syncing, and energy harvesting. If higher currents and/or voltages are required, these can be provided using parallel and/or serial circuits.

The CeraCharge is currently available in the size defined by EIA 1812 (approx. 4.5 mm × 3.2 mm × 1.1 mm) and offers a rated capacitance of 100 µAh and a nominal voltage of 1.5 V.

Conclusion

Even if there are many other optimized ceramic capacitors alongside the types listed here, among them MLCCs with internal copper electrodes, MLCCs with end termination for conductive adhesives, or "X2Y" versions, those illustrated here show that it is worthwhile to be a little more adventurous on occasion when there are particular requirements. This is useful for you to remain aware of your options when development is being performed at a hurried pace, and even to set new trends with product and device designs. ■

NOR flash

Safety for automotive and industrial innovations

With the advancement of artificial intelligence, machines are being entrusted to take on more and more tasks. Especially in automotive and industrial applications, sensors monitor the environment, and algorithms draw conclusions based on the compiled sensor data. These systems need to not only work correctly to ensure safety, but also need to make the right decisions—every time, all the time. Modern NOR flash memory can help achieve this.

By Adrian Elms, Senior Marketing Manager at Rutronik, and Stephan Wegstein, Senior Manager Product Marketing at Infineon Technologies

Steering, acceleration, braking and parking assistance systems, lane departure warning systems—there are more and more systems that help us to drive our cars. They offer greater performance, greater comfort, and greater safety. But in the latter case, they themselves need to satisfy strict functional safety standards. These are defined in two standards.

IEC 61508 declares four safety integrity levels (SILs) for industrial control systems (see table). ISO 26262, on the other hand, applies to safety-critical electrical/electronic (E/E) systems in automotive vehicles. It defines the safety levels ASIL A to ASIL D, where ASIL A represents the lowest risk potential, and ASIL D represents the highest. The level is determined on the basis of frequency, controllability and severity of the accident and/or damage.

ISO 26262 is based on IEC 61508, but specifically accommodates concerns specific to the automotive industry. These include in particular controllability, or the ability of a driver or other traffic participants to prevent damage or an accident in a given scenario.

NOR flash in safety-critical systems

In numerous advanced driver-assistance systems (ADAS), NOR flash memory plays a key role as part of a safety-critical system, because this non-volatile, programmable memory is robust, reliable and fast. The host processor can execute code directly from the flash memory without having to copy it to external DRAM first. This makes NOR flash memory ideal for code execution, not just in the car but also in industrial robots and other IoT machinery and devices. Another advantage is its large temperature range, allowing it to be used in a wide variety of environments and applications in the vehicle.

Common uses for NOR flash memory in automotive and industrial applications include:

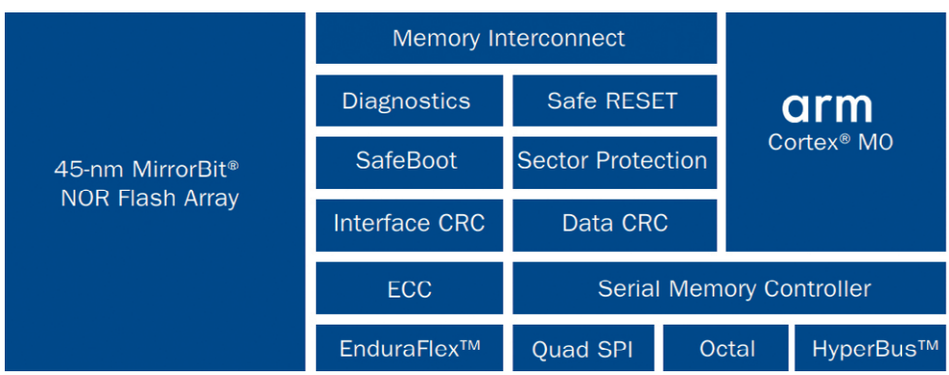


Figure: Infineon

The architecture of the Semper NOR flash memory combines an ARM Cortex-M0 with numerous safety functions.

- permanent storage of code, data and images for use during start-up,
- EEPROM emulation (i.e. storage of safety-critical data),
- continuous reading during runtime, and
- code execution directly from flash memory.

Depending on the application, the requirements for each of these workloads varies. Systems expected to satisfy high functional safety standards, however, require a new approach.

Integrity Level	Random Failure Rate	Integrity Level	Random Failure Rate
SIL 4	$\geq 10^{-9}$ to $<10^{-8}$	ASIL D	$<10^{-8}$
SIL 3	$\geq 10^{-8}$ to $<10^{-7}$	ASIL C	$<10^{-7}$
SIL 2	$\geq 10^{-7}$ to $<10^{-6}$	ASIL B	$<10^{-7}$
SIL 1	$\geq 10^{-6}$ to $<10^{-5}$		

A comparison of safety levels under IEC 61508 (SIL) and ISO 26262 (ASIL) (source: Infineon).

More than just commodity memory

Infineon has developed Semper NOR Flash specially for functional safety needs. It includes an embedded ARM Cortex-M0 as well as function blocks for diagnosis, data integrity, and reliability. They provide functions such as SafeBoot and Safe Reset, ECC (Error Correction Code) and Sector Protection. The AEC-Q100-qualified Semper NOR Flash therefore offers ASIL-B-compliant function safety with the possibility of ASIL-D support, with up to a million write cycles and 25 years' data retention even at extreme temperatures of between –40°C and +125°C. The integrated error correction support corrects single-bit errors and detects multi-bit errors (SECDED).

Long-term availability as a safety factor

The development of safety-compliant systems usually requires a large number of carefully considered, complex decisions regarding design, evaluation, testing, and certification. The product life cycles of the systems are therefore usually long, covering many years. Redesigns are usually very expensive and difficult. This makes the long-term availability of all components a critical factor. But memory in particular rarely offers availability of more than three to five years. For the Semper NOR Flash range, Infineon guarantees availability of over ten years. The range introduced here is the first generation of an entirely new platform offered by Infineon. It excels in particular in two respects. Firstly, the memory handles many processes that could not previously be covered by this component, which reduces the load on the microcontroller. Secondly, it is compliant with the JEDEC Expanded SPI Standard. This makes Semper NOR Flash memory an ideal solution for industrial and automotive applications. ■

Circuits for miniature loudspeakers

Small speakers, big sound

"Rrrring, Rrrring"—when every telephone still had a cable, that was exactly how a phone call would sound. "Ding-dong" was how the doorbell would herald the arrival of house visitors. Today, users have a choice of countless songs, sounds, and natural noises. Miniature loudspeakers with wide frequency ranges make this possible.

By Jochen Neller, Technical Support, and
Anne Santhakumar, Product Sales Manager Acoustic Components & Timing Devices, both at Rutronik

Audible communication in the form of speech or music is becoming increasingly important in human-machine interfaces (HMI), and this is also true of industrial applications. In this field, audible signals or announcements can supplement visual indications, especially when information needs to be conveyed despite a lack of visual contact with the device. There is a selection of several loudspeaker types for a wide variety of applications.

A conventional loudspeaker, also known as a dynamic or magnetic loudspeaker, basically consists of a permanent magnet mounted on a voice coil. These in turn are connected at multiple points. This structure is surrounded by a loudspeaker frame, which supports a taut diaphragm made of paper, fabric, or plastic.

Electrical signals (DC) create a magnetic field in the coil, which causes the diaphragm to oscillate. These oscillations create the acoustic signals perceived by the human ear.

The physics of this type of loudspeaker—in particular sound pressure levels (SPL)—require a certain geometry. This often makes the loudspeaker a limiting factor that prevents the device from being thinner.

Construction of a dynamic loudspeaker.

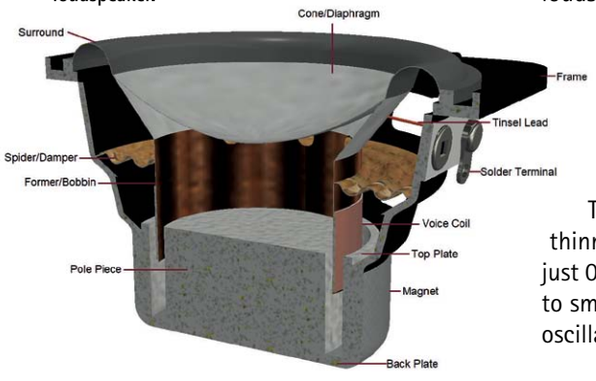


Figure: PUI Audio

Piezoelectric speakers

Piezoelectric speakers, on the other hand, are available in thin forms. They do not require a voice coil to generate sound—instead, they use the piezoelectric effect, whereby the tried and true piezoelectric ceramic material is usually bonded to a brass or nickel plate and made to vibrate by supplying it with a voltage. Unlike dynamic loudspeakers, which measure at least four millimeters in height, these are a single millimeter tall at most.

Another design is that of the multilayer piezo loudspeaker. They are constructed not just from one ceramic element, but multiple layers, with each layer filtering different frequency spectrums. This allows them to generate superior audio.

The PiezoListen from TDK is among the thinnest speakers in the world. Measuring just 0.49 mm in height, it can be glued easily to smooth surfaces, which are then made to oscillate. This is how it transforms practically any surface into a loudspeaker, be it a display, a table, a mirror, or the plastic housing of an application. The PiezoListen generates a high sound level pressure even at low voltages of 24 V p-p or less.

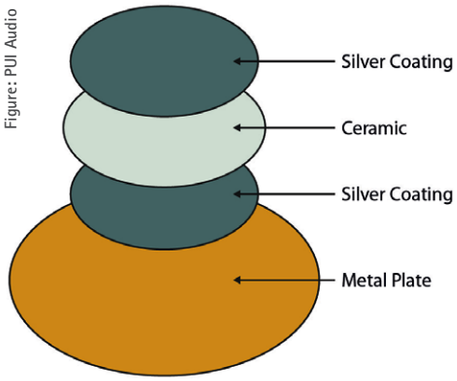


Figure: PUI Audio

Traditional structure of a ceramic loudspeaker.

Multilayer piezo loudspeakers are triggered and controlled in exactly the same way as a dynamic loudspeaker with an IC amplifier.

Amplifier circuits

Amplifier circuits for loudspeakers need to consider three factors in particular: the short-term power, the impedance, and the frequency range.

The short-term power—the load that a loudspeaker can briefly withstand from an amplifier signal without being damaged—can range from several 100 mW to several watts in miniature speakers.

The impedance of magnetic speakers is usually 4, 8, or 16 Ω. It therefore has a significant impact on music output and also plays a major role in the amplifier circuit—if a speaker with a higher impedance than is recommended is connected to the amplifier, its output may be reduced (i.e. the sound becomes quieter). On the other hand, if the impedance is too low, the quality of the sound may be impaired, or the amplifier may even shut down due to overload.

While magnetic speakers are an inductive load, ceramic speakers are a capacitive one. This means that they have a much higher impedance, which diminishes with increasing frequency. The amplifier therefore needs to supply much greater currents and cannot limit the current while maintaining the same voltage if the loudspeaker is expected to receive signals with high-frequency content.

The frequency range is divided into higher power classes, so that the signal is sent to a tweeter speaker, mid-range speaker, and bass speaker. For low power levels, a single wide-range speaker is used to eliminate the need for audio crossovers.

Dynamic speakers have a relatively low efficiency level. Their voice coil can be seen as a permanent resistor connected in series with a high inductance. It produces ohmic losses with much of the active power being dissipated in the form of heat. The amplifier must therefore provide more power—which is a disadvantage in the case of battery-powered applications in particular.

In ceramic speakers, their capacitive nature means that the reactive power plays the greater role, generating little in the way of heat. However, the amplifier circuit in the output stage requires a large amount of active power, which dictates efficiency here. Instead of conventional Class AB amplifiers, other topologies such as Class G or D amplifiers are recommended nowadays to achieve higher efficiency.

A push-pull amplifier consisting of transistors is a suitable amplifier stage for the audio amplifier. A small high-efficiency speaker only needs simple standard transistors and electrolytic capacitors to achieve an acceptable volume level.

The BCP5616 and BCP5316 complementary transistors from Diodes are well-suited for medium-level output, while something like the EEEFK1V101XP from Panasonic is ideal as an electrolytic capacitor.

Integrated circuits

Often, however, it is more effective to use integrated circuits to create simple amplifier circuits. These audio amplifier ICs control and boost the audio signal, providing a louder, cleaner, and higher-quality sound. They are available in small packages and are found in many applications such as televisions, computers, or home audio systems as digital amplifier or operational amplifier types with mono or stereo audio. Most audio amplifier ICs are specifically designed for dynamic loudspeakers (e.g. NJU8759 from JRC), although models are also available for piezoelectric speakers with integrated charge pumps (e.g. NJW1280 from JRC).

Loudspeaker housing

Once the amplified audio signal is at the voice coil or the piezo element, sound pressure waves are generated. When the diaphragm moves forward, a slight positive pressure develops on the front side of the diaphragm, while a negative pressure develops on the rear side, and vice versa.

To avoid cancellations and thus to increase the sound level significantly, the front and rear sides of the speaker should be acoustically insulated, for which the housing must be designed accordingly. Ready-to-use miniature loudspeakers complete with housings provide a convenient alternative.

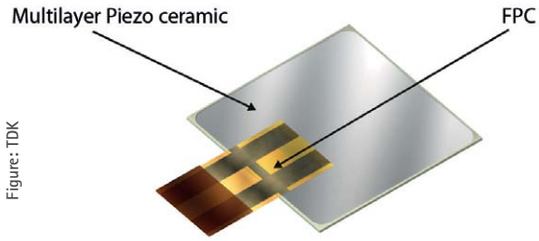


Figure: TDK

TDK's PiezoListen can use its multilayer technology to transform anything into a loudspeaker.

There is often little space available for the loudspeaker, in which case it is important to make optimum use of the available volume to achieve good audio quality with optimum sound pressure. This can be achieved with a housing that is as rectangular or cubic as possible, matching the speaker diameter to the front and rear. A horn or funnel also serves to amplify sound.

General rules for the housing structure:

- The loudspeaker diaphragm must not hit the front plate at its maximum excursion.
- Vibrations can be avoided using foam between the speaker chassis and housing. This also prevents the sound from spreading from the back to the front.
- A cavity of maximum size behind the speaker provides greater volume and superior sound quality. It is often worth having a well-designed construction to this end.

Conclusion

The choice of speaker type, the amplifier circuit, and the housing can all affect the size and audio quality of the speaker. But nowadays, there are solutions available for practically all requirements and construction size limitations. ■

Advantages and disadvantages of various speaker designs.

Ceramic piezo loudspeaker		Dynamic loudspeaker		Multilayer piezo loudspeaker	
Advantage	Disadvantage	Advantage	Disadvantage	Advantage	Disadvantage
High efficiency	High driver voltage	Tried and true, low-cost technology	Poor efficiency	No holes are required for audio output	Costly technology
Reproducible production process	Capacitive behavior	Consistent frequency behavior	Deep construction	Suitable for IP67 case	
Thin construction	Poor handling of bass tones			Ultra-thin construction	

Drive technology

Pre-charging capacitors using pulse-withstanding resistors

Electric motors are usually controlled using converters. Electrolytic capacitors are frequently used to stabilize and buffer the DC voltage in the DC link. There are a number of issues to consider with switching these capacitors in and out of the circuit.

By Bert Weiss, Technical Support at Rutronik, and Roger Renfordt, Key Account Manager at Krah

When a capacitor is charged through a resistor, the increase in voltage follows a curve in the form of a natural exponential function (Figure 1, blue line). The relevant charging current of the capacitor (green) on the other hand takes the form of a decaying exponential function.

The maximum current flows right at the start of the charging process, at which point it is 100 V/50 Ω = 2 A. After around 1.5 seconds the capacitor reaches a voltage of close to 100 V, while the current is close to 0 A.

Let's say this capacitor is charged without using a resistor, so that when the voltage is "hard switched," there is only a very low specific resistance in the supply line—estimated to be 10 mΩ—in which case there is theoretically a current of up to 10,000 A at the first moment of charging!

However, in reality, in addition to the ohmic resistance of the connecting wire, there are other elements providing resistance:

- the ohmic resistance of the capacitor estimated at around 25 mΩ
- the internal resistance of the voltage source estimated at around 20 mΩ
- the transfer resistance of the connecting terminals, switching contacts, etc. of max. 5 mΩ

This means that a realistic total resistance would be around 50 mΩ. With this, there is still a peak current of over 2,000 A (100 V/0.05 Ω = 2,000 A).

While this very high current would only be flowing for a very brief moment, you can still imagine what impact these current surges can have on other components—certainly so, when you remember that DC voltages of 800 V are commonplace in DC link solutions for converters nowadays.

Switch-on processes in consideration of wire inductance

If we consider not only the capacitance but also any wire inductance, we observe behavior such as that seen in Figure 3.

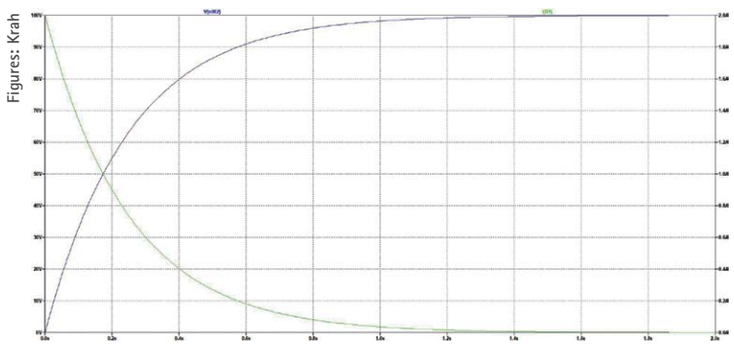


Figure 1: The voltage and charging current of a capacitor follow opposing natural exponential functions.

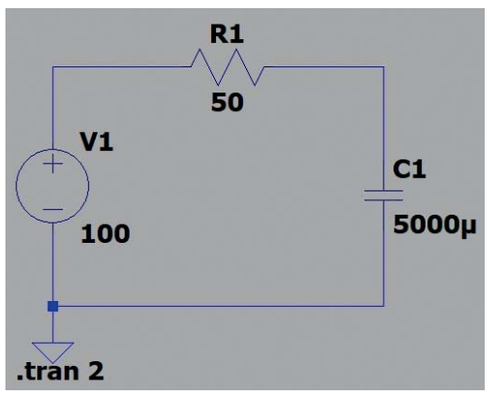


Figure 2: Charging a capacitor at 5,000 µF to a voltage of 100 V through a resistor of 50 Ω.

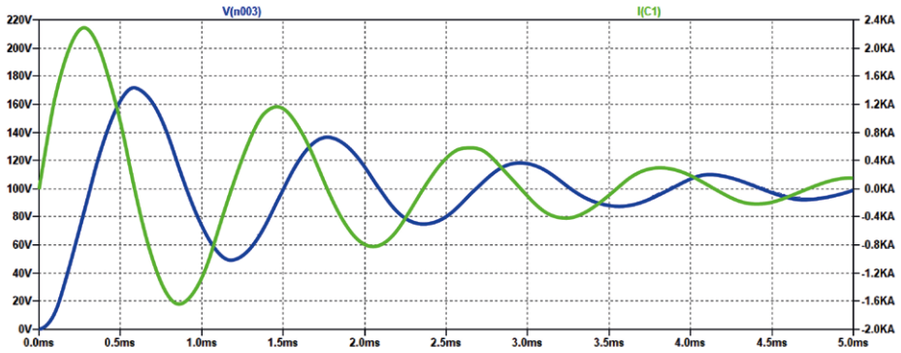


Figure 3: Behavior of a capacitor during charging, taking wire inductance into account.

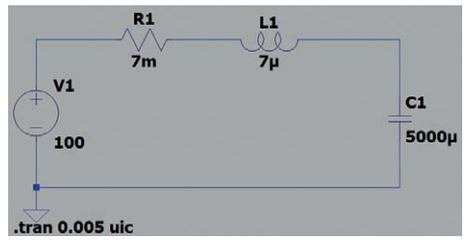


Figure 4: Charging a capacitor at 5,000 µF to a voltage of 100 V with a resistance of 7 mΩ and a wire inductance of 7 µH.

Without going into detail, the graph shows clearly that the voltage (blue curve) is no longer a natural exponential function, instead oscillating towards a value of around 100 V. Briefly, it will reach a value of up to 170 V, around 70% higher than the externally applied output voltage!

The current (green curve) also peaks at around 2,100 A just after switch-on due to the additional inductance. In other words, the current reaches very high values and overvoltages with voltage surges of up to double the externally applied voltage possibly occurring even if all ohmic resistors, inductors, and capacitors to be charged in the charging circuit are accounted for.

This is why hard-switching a capacitor should always be avoided. Pre-charging a capacitor allows the aforementioned behavior to be almost entirely prevented.

Similar behavior occurs when discharging a capacitor, which is why it is also recommended to provide a resistor for the discharging process.

Pulse-withstanding pre-charge resistors

A very simple and cost-effective approach is provided here by pulse-withstanding charge resistors, which can be connected in series with the capacitor for a certain time. All that is needed here is a pre-charge branch connected in parallel to the main switch. This branch needs to fulfill the following requirements:

- Use of the current-limiting effect of the resistor
- Two-step switch-on process:
  1. The pulse-withstanding resistor is used to pre-charge the capacitor until it has almost entirely reached the externally applied voltage level
  2. The capacitor is directly connected by bridging the pre-charge branch connected in parallel with the main switch
- A mechanical or electrical lock-out mechanism that prevents switch-on without a pre-charge

Figure 5: BR, HPRF, and VHPR series pulse-withstanding pre-charge resistors from Krah.

A wide range of pre-charge resistors is offered by Krah, the world market leader in power resistors. These include cement-coated wire resistors from 3 to 18 W and high-load resistors with aluminum housing from 60 to 560 W. Krah also offers customized solutions for special requirements. For example, increased voltage requirements, special geometric forms, and also enhanced cooling solutions can be implemented. ■

An interview with Rutronik CMO Markus Krieg

"We've overcome the crisis well"

The pandemic has raged for more than a year now, but hopes are rising of an end to it. Chief Marketing Officer Markus Krieg explains in an interview how Rutronik has performed through the ups and downs, and how the electronics markets will look in 2021.

Markus Krieg,
CMO of Rutronik

"We are taking our own patent to all of the major OEMs, one that is of particular interest for hybrid vehicles."

Despite the ongoing vaccinations, COVID-19 will be a part of our lives for a long time yet. How well is Rutronik currently coming through the crisis? How are store inventories and orders faring?
Comparing the situation to March of the previous year when the pandemic was beginning, it's fair to say that we've overcome the crisis well—both financially and as a workforce. There were few infections and no cases with severe symptoms. This shows how effective the measures within the company have been—for example, with our installation measures and home working. This is the most important thing.

But we're also performing well in terms of sales. 2020 was a challenging year in terms of sales and order receipts, because many industries had dialed back their capacities due to COVID-19. We noticed a recovery as early as the third quarter—incoming orders grew so quickly in October and November that we really struggled to meet demand. In fact, November 2020 dropped an all-time record in terms of incoming orders into our laps—and we were pleased to note that this trend continued in January and February.

The COVID-19 pandemic has accelerated the process of digitalization in many areas—including industry. How persistent will this shift be, and what does this mean for Rutronik's business model?
It's important to see this as two different trends. Firstly, there's the digitalization in personal communication, and secondly, we have digitalization in the development of applications.

The lack of opportunities for face-to-face engagement and the need to resort to video conferencing instead have shown that there are areas where digital communication is much more efficient. This is true not only of customer visits—when it comes to digital trade events, we've found that leads are qualitatively and quantitatively on the same level as at a live fair. And, last but not least, other forms of communication are becoming increasingly important, such as social media, which are a much bigger focus now. We are adapting to this and are much more active in this field than before. None of this, of course, means that we'll be neglecting personal visits, physical trade events, or traditional forms of marketing. I think a hybrid form will begin to take shape from all of this.

The other side is the digitalization of current-day applications—we definitely see a shift in this direction. Remote maintenance is playing an increasingly large role, because, of course, I can't always send technicians to every corner of the globe at a moment's notice. In terms of products, we are seeing strong growth in communication ICs—they are basically a factor in every application and offer enormous growth potential, which in turn means a massive push towards digitalization.

How can Rutronik help to overcome the COVID-19 crisis in the current situation, outside of its core business?
We are, naturally, studying the current situation and examining how we can help. With our excellent contacts with Asia and the logistics capabilities that this entails, we can help to bring rapid tests and FFP2 masks to Europe, for example, and in this way help the

government to achieve their targets of more frequent testing. In Pforzheim, we are also using our logistics capacities to support the large-scale testing center—the goal here being the "Tübingen Model," which aims to restore public life to a relative state of normality with a large number of rapid tests. We are also assisting in the development of an app that is another element of this concept.

Europe's share of the demand for global electronic components is dropping to around 8 percent—which basically covers Apple's or Samsung's needs alone. This will have consequences for the supply chain, in which European businesses risk falling behind in the medium and long term. How can Europe gain an advantage here, and how can distributors help?

To put it bluntly, the European Union has spent years blissfully asleep at the wheel, and never noticed that they are becoming technologically extremely dependent on Asia and the USA. The remaining European semiconductor manufacturers that essentially matter have developed their own production capacities in Asia or have turned to third-party producers. The consequence of this has been that, even if we develop the IP and the associated technology in Europe, it doesn't mean that we can get the production capacity for the relevant chips in Asia. The EU and the German government have now finally woken up and set up a scheme to boost Europe's own semiconductor production—for which 150 billion euros are on the table. As the third-largest distributor in Europe, Rutronik is on hand with its expertise—we are in talks with top-level representatives of the EU and the German government. But bringing production capacities back to Europe is not the end of the story—we need to ensure that European distribution channels make use of these production capacities, and that they can distribute the production output to customers in Europe. We aim to ensure that Vishay, Infineon, and the smaller manufacturers that are still in Europe are compelled to focus on Europe with their distribution channels.

Rutronik generates just under half of its sales from the automotive sector. And car manufacturers and their suppliers are also starting to feel the pinch of component allocation. How is security of supply looking for Rutronik's automotive customers?

It's worth looking at the wider picture here. In April/May 2020, the OEMs started massively dialing back their production, from VW to BMW to Audi. But if I do that, my supply chain ends up sitting on its products—and without much warning. This means masses of cancellations and delays—at one point, Rutronik had to manage and process up to 200,000 order item changes in a day. When the market regained pace, they were surprised that the supply chain had distributed the semiconductors elsewhere and the capacities were no longer available. I can't bring myself to point fingers at the supply chain or component producers here because the automotive industry did a poor job of resource management in this case. Right now, this has given rise to the problem of our being unable to purchase components as quickly as the customers are ordering them. We've been able to manage so far, or at least our customers haven't suffered a line stop just yet. To this end, we communicate closely with OEMs and Tier One and Tier Two representatives. We hope to be able to meet demand normally again by the end of Q3 or early Q4. Until then, though, we have two quarters with a lot of backlog management to handle. Our analyses have shown that the incoming orders to date are basically what wasn't ordered last year—in other words, we started at a very low backlog level, and the incoming orders are filling our books to the level that we would have expected without COVID-19 in 2020.

Are there other component groups where allocation is to be expected? And how well is Rutronik prepared for this?

In light of the circumstances described above, we basically have shortages in every area. Issues with logistics and transport capacities exacerbate the matter. The markets have recovered with a time delay—China resumed producing earlier and has exported a lot to Europe and America. This has shifted container capacities to these regions, and these capacities are now lacking elsewhere. The few available containers are currently being rented for three times the normal price, mainly from the US, meaning that we in Europe have very little in the way of transport capacity. This makes it difficult to quickly respond to shortages.

Specifically, this affects products such as displays and wireless modules. We try to keep production running by ensuring daily communication between customers and suppliers. With passive components, we occasionally experience shortages of electrolytic capacitors, which is due to the massive development of the 5G network, which requires a very large number of capacitors. The shortages are also being exacerbated by the rapid development of electromobility, which is expanding faster

than expected. This increases the demand for electrolytic capacitors, coils, and inductors—but even with electromechanical components, there are still occasional shortages, for example plug connectors for electric or hybrid vehicles, although not to the extent seen in 2018. Delivery times have also increased for ceramic capacitors and automotive-certified products, although there's no talk of component allocation just yet.

"When it comes to digital trade events, we've found that leads are qualitatively and quantitatively on the same level as at a live fair."

What is your take on the situation of German OEMs and suppliers given the upheaval caused by electromobility? How is Rutronik supporting its customers with this?
For us as a component distributor, electrification is, of course, a positive thing, because we participate in it. The share of components in the vehicle will increase in electrically powered vehicles than is already the case today, especially in terms of semiconductors for high-performance drives and power electronics. We engage with our customers closely in this regard and introduce them to innovations to enable them to keep pace with non-European competitors.

Another area relates to batteries. We are taking our own patent to all of the major OEMs, one that is of particular interest for hybrid vehicles. It allows the same distance to be covered with fewer batteries than was previously possible, which in turn helps save costs. We expect the first cars using our patent to be on the road in two years. But we're not focusing solely on e-mobility—we also have faith in fuel cells, and we have customers we're supporting in this field as well.

And what about autonomous vehicles?
As far as autonomous driving is concerned, we can see with Google or Tesla that it is already broadly possible today. The 5G network provides the requisite communication infrastructure, not only for autonomous driving but also for car-to-car communication. This is a massive opportunity for us, not only in relation to communication semiconductors, but also in power suppliers for transmission towers—the demand here is enormous.

The catch lies elsewhere, namely in legal and ethical matters—questions of "do I really want to hand decisions of how to react in a dangerous situation to a machine?" and "What's the position of insurers on this?"

How is the market performing in America and Asia, and what are the differences to Europe?
Our Asian business is performing wonderfully. Asia in general, and in particular China, overcame the crisis much sooner, which has had a positive impact on our overall net income. The first three months of this year were very encouraging—not just in China, but in South-East Asia, too. The situation in the US is rather more challenging, and we've had to cut jobs in the midst of the COVID-19 pandemic, so we're rather thin on the ground staff-wise there. We also don't yet have the resources on the ground that we wanted available at the US headquarters. This makes it difficult to develop the business in a way that allows us to achieve reasonable profitability. Mexico has also been severely hit by the coronavirus, and this is why our customers' factories were closed for weeks, if not months.

How is Rutronik Analytics performing?
We're very happy with it. The analyses that we have performed using the tool to date have been very successful. We have set up a dedicated team to offer the services offered by Rutronik Analytics now to customers as well. We are also continuously evolving on a technological level and are trying to become less dependent on a single service provider, to develop in-house software development resources, and to further improve our analysis IP.

"Our analyses have shown that the incoming orders to date are the result of what wasn't ordered last year."

Distributors' margins have been falling for years. How has COVID-19 affected this? Are there new developments in the market or within Rutronik?
To begin with, falling margins are a psychological problem. If I'm worried about losing a contract in adverse times, I can't go into negotiations with the self-confidence I need. This is why we had a drop in margins in 2020—although 2019 was itself a year that suffered partially from allocation in the passive segment. So a comparison isn't quite that simple. Higher margins are important for us because we have a high cost of ownership due to our passive and commodity portfolio. There are three key strategic points. Firstly, we must show manufacturers that they benefit from our business model, because we provide them with access to an additional customer group by delivering commodities to them. Secondly, we prepare our product marketing, sales, and FAEs even more effectively with training measures. And thirdly, we establish a very broad, balanced customer basis. Especially in the mid-range segment, there are entirely different opportunities to generate margins compared to the Tier One and Automotive segments.

Finally, let us take that ever-dreaded look into the crystal ball. How will 2021 develop for Rutronik and for the electronics industry as a whole?
I believe that two things will be important for the rest of the year. The first is availability—for responding quickly to changes, for managing existing backlogs, and thus to generate as much business as possible. The other is the matter of the impact of COVID-19—right now, many hope that the vaccines will enable us to make great strides towards normality in Q4. I'm a little more skeptical about that, not least because of the mutations and the different effectiveness levels of the vaccines. We have a close eye on developments so that we can be prepared for all eventualities. If things are looking up, we will, of course, be pleased and will help where we can. But even if things take a turn for the worse, we have learned from the past and are prepared to take the necessary steps as a company.

We managed to get through the crisis in 2020 without cutting working hours. This proves that the measures we took were the right ones—including from a financial perspective. We have created a foundation that enables us to respond appropriately to all situations. We must never forget that to profit from strong growth in business, you need the financial resources to adjust to it. We have prepared our business accordingly. ■

WE CONNECT

IN CHARGE OF TOMORROW

In the market for electric vehicles (EVs), which are expected to grow even further in the future, JAE has been working on the development of connectors for EV charging since 2010, the early adoption of vehicles.

We have already commercialized products (KW Series) that conform to CHAdeMO and CCS Type-2 standards. Currently we are developing new products that conform to CHAdeMO with the aim of further strengthening our line-up.

Technology to Inspire Innovation

JAE

Connect with JAE - and profit from innovative, reliable and responsible electric mobility solutions. Don't wait for the future, but shape it!

Logistics

More efficient procurement of C-parts

Customers ordered over 71 billion commodities from Rutronik in 2020. For the majority of these components, it is important to view the huge volumes in the context of their prices, which are often just a few cents or even fractions of a cent—these are referred to as C-parts. To generate savings potential here, it is therefore more beneficial to examine the order processes than the price of the goods themselves.

By Roman Wolf, Project Manager Supply Chain Solutions, and Patrick Krätz, Head of Supply Chain Solutions, both at Rutronik

Let's say a business needs 40,000 chip resistors each month. To keep store inventory low, an order of 10,000 resistors is sent each week. This means that four times a month a worker has to unpack the goods, check the delivery note, enter the delivery note into the inventory control system, and then shelve the goods. So as we see, components that are themselves worth just a few euros cause process costs that are at least equally as high—if not higher—than the product's actual worth. The potential to cut costs is therefore much higher in this area than with price adjustments through annual price negotiations.

Potential for optimization

To reduce process costs, delivery volumes and packaging units are effective tools for optimization. Many commodities are available in packages of 5,000 to 50,000 units, usually on a reel. The rule to consider is this: the bigger the selected unit, the lower the process costs. If the company in the above example were to

Figure: nordroden/stock.adobe.com

order 40,000 chip resistors once a month instead of 10,000 units four times a month, the required expense and effort would be reduced to just a quarter. While this increases store inventory, the low value of the C-parts means that this is not usually a relevant factor.

With optimizations such as these, Rutronik has been able to drastically reduce the number of delivery note items for numerous customers whose annual order volumes number in the billions of units (see image), or has managed to keep these items consistent while volumes rise. And each item removed from the delivery note represents process costs saved.

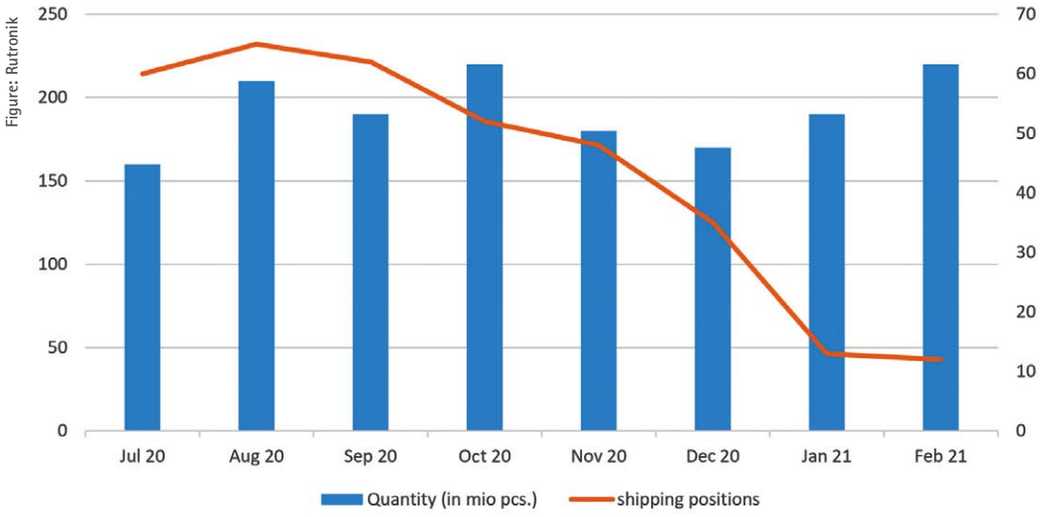


Figure: Rutronik

Optimized procurement allows for drastic cuts in the number of delivery note items—and with these, a reduction in the effort and expense required for the receipt of incoming goods.

Security of supply with low storage costs

If the main concern is a low stock value, a consignment store is a good way to keep this value low. The goods are stored near to the company's production facilities, ready to be collected as needed. They are only billed when collected. This is how a consignment store offers not only low storage costs but also optimized management of goods flows, as well as security of supply.

To make procurement processes generally as efficient as possible, Rutronik had taken steps years ago to digitalize the entire process, from order to forecast to shipping notification to invoicing. In addition to standardized file formats such as EDIFACT, VDA, or SAP IDOC, Rutronik can also handle other formats, such as Excel or text files, enabling as many customers as possible to benefit from electronic data interchange and, with it, the ability to automate procurement processes. This results in an improvement in data quality, basically as a by-product.

This is true both of conventional procurement processes with order submissions and order confirmations as it is of dynamic delivery systems involving rolling, long-term forecasts. The latter in particular also contributes significantly to security of supply, because the more familiar the distributor is with the long-term needs of its customers, the better they can take account of these needs in the event of sudden market changes in the manufacturer backlog—a situation that is extremely common, whether due to adverse weather conditions in regions with large numbers of production sites, the impact of the COVID-19 pandemic, or demand surges resulting in allocation, as was the case in 2018.

Logistics is much more than just ordering the right goods at the right time to be delivered to the right place. It is also an essential element of optimizing cost structure and of the performance of the company. For C-parts, efficient delivery processes play an especially important role in keeping logistics and processing costs as low as possible, even as volumes rise. This is why a customized, smart delivery strategy makes more sense here than a just-in-time delivery system. ■

FAE support

Field application engineers without the field

Sitting at a table with developers feels like a thing of the past. Design-in support is another thing that the coronavirus pandemic has largely relocated into the digital realm. What can still be achieved with it? And what form will it take in the post-corona era? Carsten Steiner, Director FAE/BDM Global at Rutronik, provides the answers.

Mr. Steiner, what can be achieved with digital FAE support?
Carsten Steiner: I'll start with what it can't achieve—it doesn't let us test components under real conditions with our customers. And the intuitive hands-on experience is also lacking, especially with many electromechanical components. Displays are something that you need to have seen in person before you choose to buy them—even the glossiest brochures, websites, and data sheets won't suffice here. This is why we have a comprehensive warehouse with demo products that our customers can borrow and test in their application.

And the personal aspect of face-to-face meetings is also missing. Digital meetings are simply not a full-blooded substitute for them.
But everything else works just as well online—some of it even better, in fact. We keep discovering that we are often able to answer our customers' questions more quickly in Web meetings than we can during on-site appointments. In this regard, our FAEs prepare for every meeting even more intensively than they ever have. In the future, we aim to make use of other communication methods and tools such as messaging services, ticketing systems, and virtual/augmented reality solutions. This is how we aim to engage with our customers on an even more individual level—a beginner and a digital native simply has different expectations and preferences to a veteran with decades of experience.

If everything is done online anyway, can't a developer or purchaser simply use Google, search through an online shop, or ask in forums? I mean, you can find everything online these days.
That's not quite true. Sure, you might be able to find a lot of information, but it can easily take hours to find what an FAE could answer in a few minutes. Not only that, but you need to be able to understand the context of the information, which takes knowledge and experience. Each of our customers is an absolute expert in their field, no doubt about that! But their core expertise is not in the continuous and intensive observation of the component market. This is a time-consuming task that our FAEs perform by actively engaging with the component manufacturers and with the collaboration of our product and line managers.

This is in part time-consuming because the diversity of product models and the complexity of the components has massively increased in recent years, while life cycles continue to be ever shorter. It's not enough to be familiar with the latest components—the manufacturers' road maps are also important. Being unaware of these may result in a component being incorporated into a design, even though it has already been discontinued when serial production starts. Our FAEs always have an eye on this, and on delivery times. To avoid unpleasant surprises, they also recommend alternative components as a second source—and not just with focus components, either. C-parts are just as prone to causing production stoppages, as recent months have shown time and time again. It is also important to be able to assess the opportunities and limits of components, which takes experience, and also knowledge of the latest technologies. These often enable entirely different solutions for certain requirements.

You can't just google all of this. And what's more, we often notice how component decisions have focused on the same components for years, even though these components have since ceased to be technologically relevant or have ceased to represent a major cost factor. Others end up left unnoticed, with the same components being used again and again, even though there is considerable optimization potential for the solution as a whole. With an outside perspective and backed by a comprehensive product portfolio, our FAEs can take a holistic perspective of the solution and consider the total cost of ownership.

Carsten Steiner, Director FAE/BDM Global at Rutronik

"Ultimately, the goal is always to develop a competitive final product."

And there's another very important aspect: time to market. The points that I mentioned all help to ensure a rapid market launch. We also support our customers with in-house-developed development kits, demo boards, and complete solutions, for example with an MCU platform for AI-based edge applications.

You mentioned short development cycles. Which product segments are seeing the most dynamic performance?
I would say that everything in the Wireless segment is among them. The new wireless

technologies such as 5G, Wi-Fi 6 and the Bluetooth developments provide entirely new opportunities for networking, which as we know is a key element of IoT and Industry 4.0. Also, ideas that were too expensive, too complex, too large, or too power-hungry a couple of years ago are now often becoming feasible. When it comes to semiconductors, the wide-bandgap materials such as SiC and GaN are providing considerable momentum, but the passive and electromechanical components are also enjoying a lot of movement thanks to the new types of rechargeable batteries and supercaps.

While we're on the topic of products—how do component manufacturers benefit from working with a distributor?
First of all, many customers don't have the volumes to enable a manufacturer to serve them all directly. This is where we like to serve as the long arm of the manufacturer in order to grow their customer base. And because Rutronik has a worldwide presence, we can reach additional regional markets, not to mention vertical market segments—it often happens that we recommend a module for a medical engineering application even though it's actually designed for automotive applications, simply because the features are a perfect match.

Ultimately, the goal is always to develop a competitive final product. The more successful our customer's application, the more components they need, and that's ultimately what everyone involved wants—device manufacturers or development institution, component manufacturers, and distributors.

It's precisely where these interests meet that a distributor traditionally does their best work. What changes are you observing here?
Flexibility has become more important than ever. The pandemic has once again shown that, even with state-of-the-art planning tools, there is no such thing as absolute planning certainty or absolute security of supply. In general, even the largest European OEMs don't enjoy priority handling in component delivery from component manufacturers—compared to the needs of American and Asian manufacturers, they simply represent too small a share. As a distributor, we have more sway due to how we bundle demand and with our close partnerships of many years with the manufacturers. And we have the expertise and the solutions to withstand component shortages. The closer customers work with us and the more they share their plans, the better this works.

Finally, let's take a look in the crystal ball. How will the work of the FAEs change as a result of the rise of digitalization?
The traditional "field" aspect with personal on-site consulting will cease to exist in its established form in the future. Instead, a mix of analog and digital communication methods, varying from customer to customer, will take root. New tools will be used for this purpose, allowing us to respond more quickly and more precisely—I've already named a few examples. There will almost certainly be more to come—it'll be interesting to see how this goes!

5G campus networks

Private cellular networks for the smart factory

Digitalization as a buzzword may not be new anymore, but in reality, digitalization as a real phenomenon is starting to pick up pace. It forces businesses to develop continuously to remain relevant in the market. 5G campus networks help them to be more agile, more efficient, and more digital.

By Anja Schaal, Team Leader Product Marketing Wireless, and Manuel Fischer, Work/Study-Student, both at Rutronik

5G campus networks are local, geographically limited 5G networks that are inaccessible to the general public. They are of particular interest for industrial use, as 5G technology offers precisely the features needed for networked production—high reliability, large range, low latency, and high bandwidth alongside energy efficiency. These features require higher frequency ranges, however. Instead of the 2.2 GHz used for previous cellular standards, 5G campus networks depend on frequencies between 3.7 and 3.8 GHz. With 5G, we refer to band n78.

What makes 5G campus networks so special?

5G technology enables wireless real-time communication between humans, machines, sensors, and other end devices. The 5G network beats its 4G predecessor with enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC) and ultra-reliable and low-latency communications (URLLC).

Latency values with URLLC drop from around 15 to 80 milliseconds under 4G to less than 1 millisecond. This enables machinery, robots, and autonomous transport systems to be controlled without any perceptible lag.

With eMBB, data transfer speeds can reach up to 10 Gbit/s with 5G—with a capacity of 10 Tbit/s per km². By way of comparison, 4G technology reached its limit at 1 Gbit/s. This makes 5G around ten times as fast as 4G. Videos can be transmitted live in very high resolution. In these times of the coronavirus pandemic, this allows overseas developers to view even the smallest details and give their comments on them.

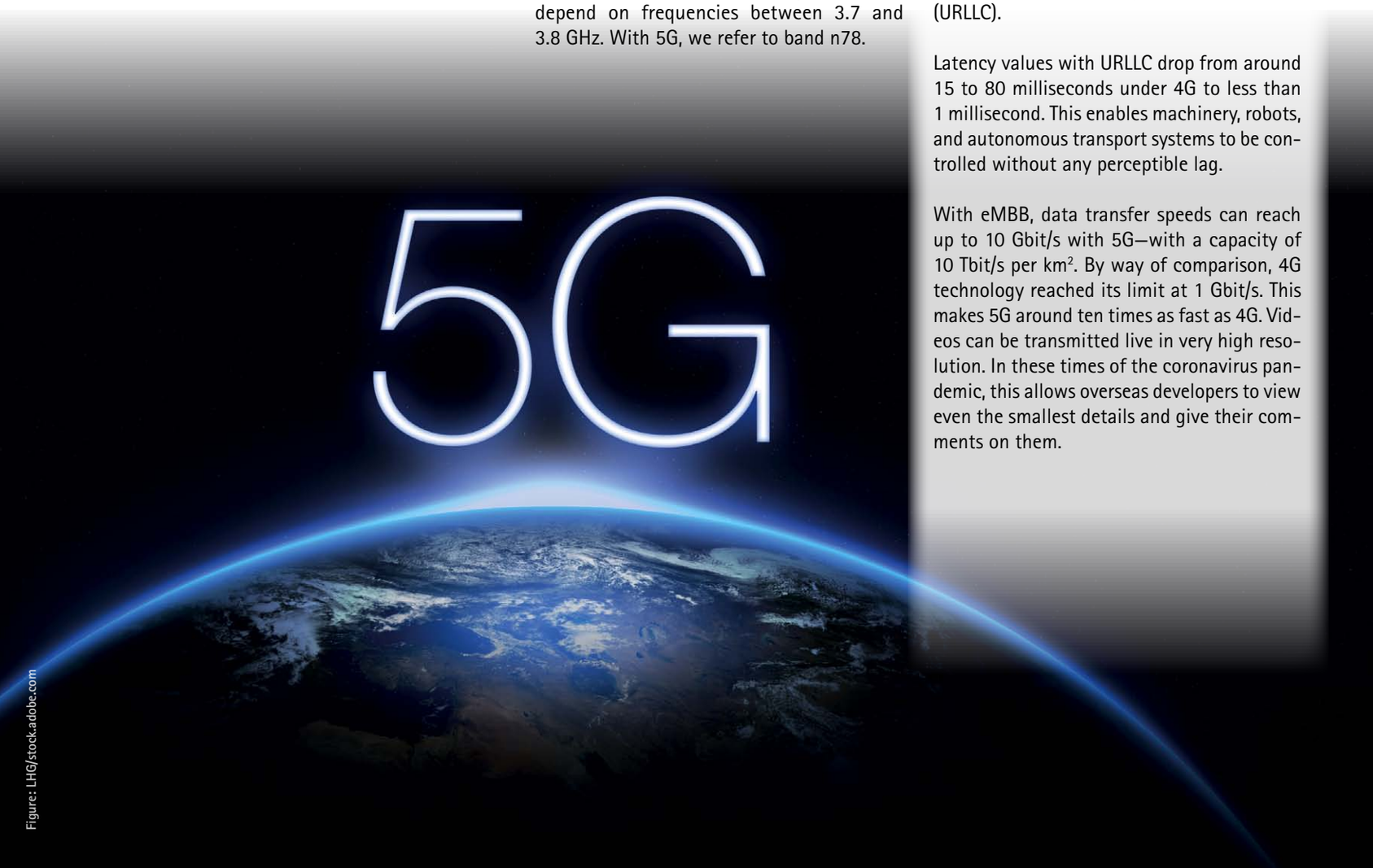


Figure: LHG/stock.adobe.com

Of particular interest is the immense connection density enabled by mMTC of up to one million end devices per km^2, all while minimizing energy consumption, which is just around 10% of the consumption of LTE systems, while the connection density of 4G is barely around 200 end devices per km^2. mMTC is of particular benefit for applications in large warehouses, car park management systems, and major events in sold-out stadiums.

Not only that, but thanks to the smart "network slicing" technology, it is possible for several virtual networks to operate concurrently on the same physical network infrastructure. This allows data for every application type (eMBB, mMTC, and URLLC) to be transmitted over its own virtual cellular network, which in turn can be individually optimized for each application. Campus networks also beat public networks in terms of reliability and availability, as their operation is not dependent on a cell provider.

What can 5G do better than Wi-Fi 6?

Campus networks are in and of themselves nothing new. But right now, most of them are based on Wi-Fi technology. Wi-Fi 6, also known as Wi-Fi AX, is the latest generation of Wi-Fi, and was announced almost at the same time as 5G technology. Like 5G, it brings numerous improvements to the table, among them more bandwidth per data stream, lower latency, and higher data rates of up to 6 Gbit/s. This is enabled by new modulation methods such as OFDMA (orthogonal frequency-division multiple access) and 1024-QAM (quadrature amplitude modulation). Because Wi-Fi 6 is backwards compatible, user hardware does not need to be replaced—a major advantage for private networks in office buildings in particular.

As the number of networked machines, systems, as well as mobile applications such as robots and autonomous transport systems rises, so, too, do the needs placed upon the private network. Many industrial and production installations also need a campus network that covers not only indoor spaces but also outdoor areas, because, for example, transport systems cover the entire area of a production facility. Due to the low frequency between 3.7 and 3.8 GHz (compared with 5 GHz for Wi-Fi), 5G covers a greater range while still offering comparable data transfer rates to Wi-Fi. With Wi-Fi and even Wi-Fi roaming, it was possible that an autonomous transport system would have to stop for a moment when changing cells, and could only start moving again when there was a connection with the new cell or gateway. This is especially the case with any mobile application dependent on a continuous data stream. Under 5G, the cell has a larger range, latency times are lower, and the transition between cells is seamless. So when it comes to mobile systems and applications used in automation for industrial systems and production facilities, 5G has the advantage.

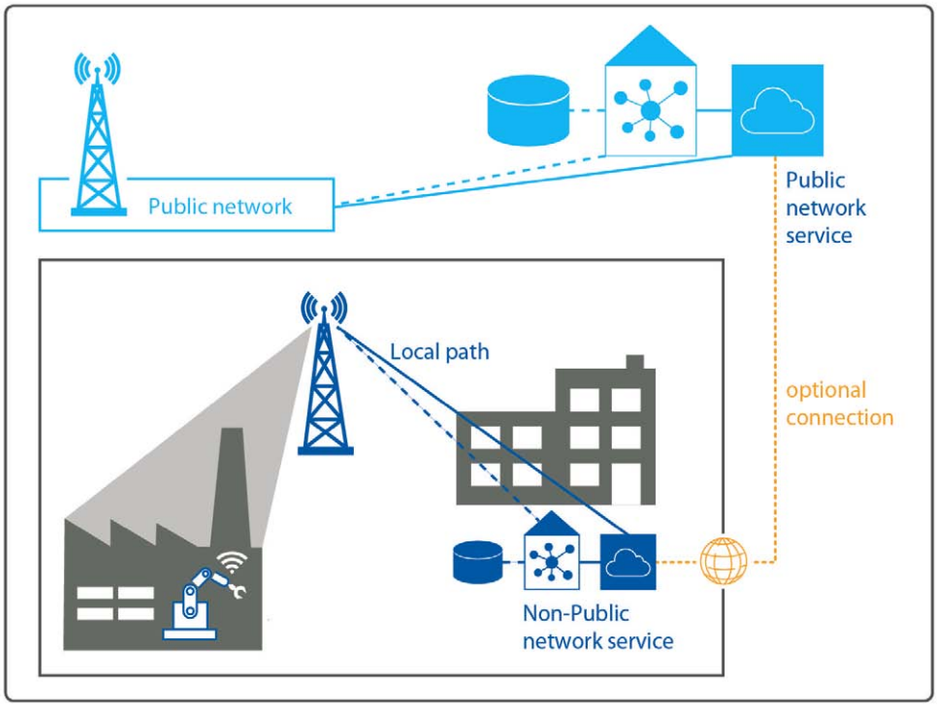


Figure: Rutronik

5G campus networks are not publicly accessible, which means that they provide a high level of data security.

How can businesses get a 5G campus network?

Businesses in Germany can obtain licenses for 5G frequencies by submitting an application to the Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway. The Federal Network Agency has approved a 100 MHz band in a frequency range of 3.7 to 3.8 GHz for local networks for this purpose. Frequency blocks can be awarded for one or multiple properties.

The fee for the license is calculated based on the requested bandwidth (B) in MHz (which must be specified as an increment of 10 between 10 and 100 MHz), the license term in years (t), and the area to be covered by the cell network in square kilometers. The area to be covered can be categorized as "built environment and transport" (a1) or "other" (a2). Industrial and commercial areas are categorized as a1. The formula applied for the calculation is:

$$\text{Fee in €} = 1{,}000 + B \cdot t \cdot 5 \cdot (6 \cdot a1 + a2)$$

For a production facility with an effective area of 0.2 km², a contract term of ten years and a full bandwidth of 100 MHz, the license fee is € 6,000—equivalent to an annual fee of € 600.

Which hardware is required?

The necessary hardware, ranging from 5G cards and modems to antennas, servers, and power supply units, is available from Rutronik. One example is the FN980-5G-M.2 card from Telit, one of the first 5G products available on the market. It supports the LTE and 5G sub-6GHz bands used worldwide (i.e. also the n78 band, covering 3.3 to 3.8 GHz), which is needed to establish a campus network in Europe.

With a form factor of 30 mm × 50 mm and a temperature range of –40 to +85°C, the 5G-M.2 card is ideal for industrial applications. It is based on Qualcomm's Snapdragon X55 5G chipset. The FN980 is shipped with proprietary Telit software and can be configured using AT commands. The FN980m model also supports the new mmWave frequency bands.

Advantech is now also offering a 5G-M.2 card in the form of the AIW-355DQ family—like Telit's solution, it, too, is based on the Snapdragon X55 5G chipset. Unlike Telit, however, Advantech is gearing towards regionally specific versions for Europe, North America, and Japan with the AIW-355DQ range. It measures 52 mm × 30 mm, and the temperature range of –10 to +55°C is not quite as expansive as the Telit card.

Both 5G-M.2 cards—from Telit and from Advantech—offer multiple 5G and GNSS antenna sockets. Rutronik offers suitable antennas from the manufacturers 2J, AVX, and Pulse.

One of the portfolio highlights is the 2JW1683 Katana from 2J. As one of the smallest 5G monopole antennas, it supports sub-6 GHz frequency bands for a campus network and is also backwards compatible with its support for 4G, 3G, and 2G bands. Thanks to the articulated plug, antenna positions of 45° to 90° angles are possible. With an ultra-compact size of just 10 mm × 80 mm, it makes very small devices possible and can still transmit through buildings and heavily built-up, urban areas—making it perfect for covering production facilities.

When it comes to 5G polymer adhesive antennas, the manufacturer 2J offers the 2F0283P, 2JF0383P, 2JF0483P, and 2JF0583P versions—the difference between these is solely in the size of the ground plate. They optimize signal strength and signal quality in the entire sub-6 GHz range using an omnidirectional transmission pattern. They support not only 5G but also legacy 4G, 3G, and 2G frequency bands.

Suitable cables and connectors in all lengths and colors are available from Rutronik's wireless team, and technical support is provided by the large team of field application engineers and product specialists. ■

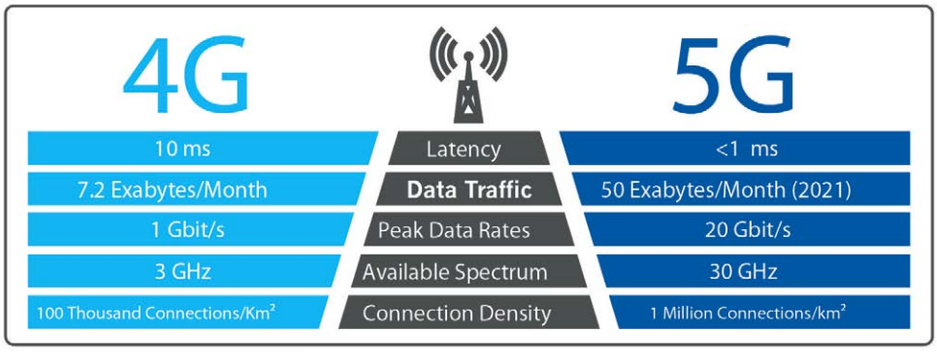


Figure: Rutronik

A direct comparison clearly shows that 4G and 5G are worlds apart.

Alternatives for ToF applications

How VCSELs can be best put to use

VCSELs (vertical-cavity surface-emitting lasers) are superior to LEDs when it comes to short switching times and a narrow optical spectrum—making them the best choice for time-of-flight (ToF) applications. To make the best use of the abilities of VCSEL chips, however, the packages need to be optimized for them.

By Alain Bruno Kamwa, Product Sales Manager Opto at Rutronik, and Markus Oberascher, Senior FAE at Lextar

Figurer: Lextar

A brief look at the ToF principle can help better judge the benefits of VCSELs. ToF uses the speed of light to measure distances or—with a ToF camera—to capture three-dimensional images. There are two methods for this: the direct and the indirect ToF method.

Direct ToF measures the time between the sending of an optical pulse and the arrival of the reflected light pulse.

Indirect ToF sends bursts comprising multiple pulses with a high modulation frequency (measured in MHz) and measures the phase shift between the transmitted signal and the received, reflected light signal. Figure 1 shows how this method employed by ToF cameras is used to capture 3D images.

Rising modulation frequency requires low-inductance design

The first important aspect of a VCSEL is the modulation frequency. The higher it is, the better the depth resolution and short-range detection of the ToF camera. Currently, modulation frequencies of up to 100 MHz are used, which corresponds to a period length of 10 ns. With a duty cycle of between 30 and 50%, this means that the VCSEL has a turn-on time of just 3 ns to 5 ns. In other words, the rise time and fall time of the light source must be much shorter than the turn-on time—typically under 1 ns for a modulation frequency of 100 MHz. VCSEL chips offer rise and fall times of well under 1 ns, making them far superior to LEDs, which usually only achieve around 10 ns.

However, a special low-inductance design is required for the package to prevent deterioration in the superior switching behavior of the VCSEL chip. The substrate design here is critical.

Field of view: Making a circle a square

The second key aspect is the light output curve. The field of view (FoV) or lighting range is expressed as a vertical and horizontal angle,

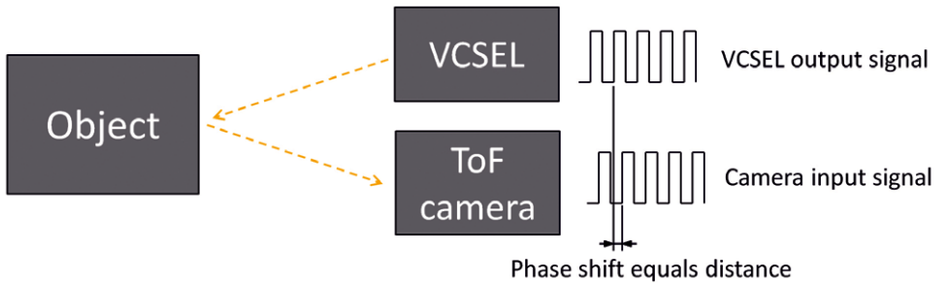


Figure 1: A ToF camera uses the indirect ToF method.

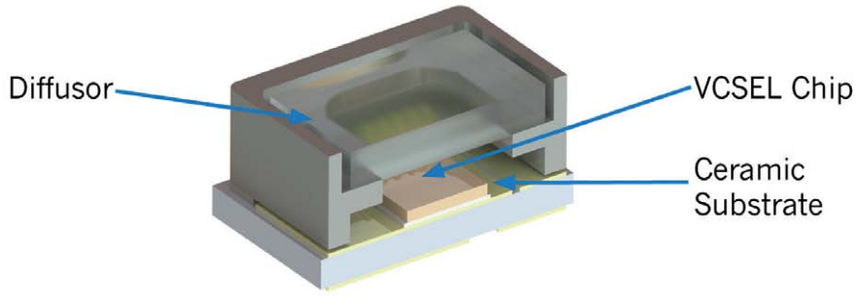


Figure 2: Cross-section of a VCSEL in its ceramic package.

usually measured at full width at half maximum (FWHM). This describes the illuminated area—which is almost rectangular—to illuminate the field of view of the camera as optimally as possible. However, a naked VCSEL chip has a ring-shaped beam pattern with a beam divergence (i.e. the further away you get from the source, the wider the beam becomes) of around 15° to 25°. A diffuser lens reshapes the beam into its rectangular form (Figure 3).

But the form is not the only important factor—the light distribution within the FoV is also key. Figure 4 shows the horizontal and vertical beam diagram for a VCSEL from the manufacturer Lextar. The maximum beam intensity here is not in the middle (at 0°), but at the outer edges. This bathtub-shaped pattern ensures that the area is evenly lit. This is shown in Figure 5, where the light distribution is visible on a flat surface. The light intensity is distributed evenly over a large angle—meaning that the FoV of the ToF camera is also evenly illuminated. VCSELs also have an advantage over LEDs here, the latter having a circular light pattern with the maximum value at the 0° axis.

Eye safety

If the laser beams from a VCSEL strike the eye, they can cause serious damage. This is especially dangerous in applications such as driver monitoring or person counting if the VCSEL lens has been damaged or detached as a result of excessive mechanical stress, as this can change the beam pattern, which may intensify the radiation significantly.

To prevent this, Lextar has integrated a monitoring diode in the VCSEL package alongside the VCSEL chip (Figure 6). It uses part of the radiated light, which is reflected back to the photodiode through the lens. A damaged or detached lens would change or lose the light

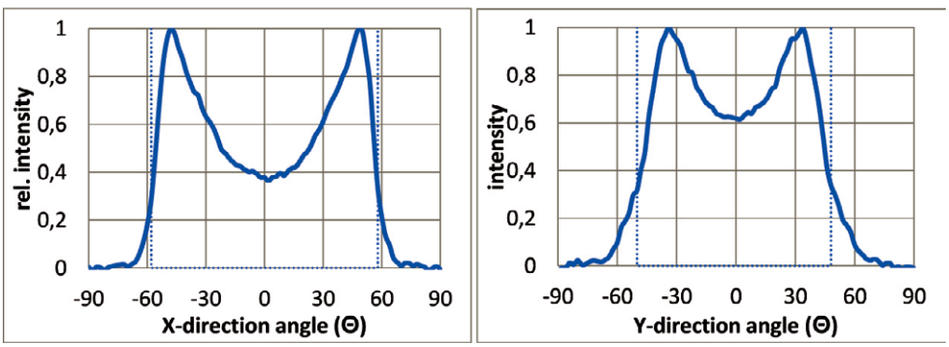


Figure 4: Bathtub-shaped beam pattern of VCSELs.

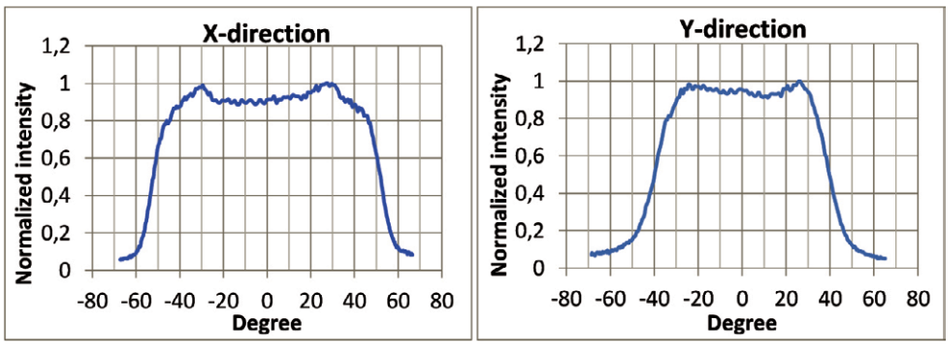


Figure 5: Light from a VCSEL hitting a flat surface will cause that surface to be evenly illuminated.

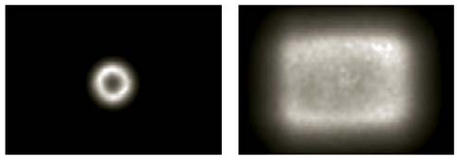


Figure 3: Beam pattern of a VCSEL without (left) and with (right) diffuser lens.

reflection to the photodiode and thus change the photocurrent. If an anomalous photocurrent is detected, the VCSEL can be disabled immediately, thus preventing harmful laser radiation emissions.

Heat management for large ranges

For a ToF camera to achieve large ranges, VCSELs are operated with high currents measuring several amperes. This requires effective heat management design in the package substrate to enable efficient heat dissipation. Ceramic packages and silver-rich die-bonding pastes are used for this purpose.

VCSEL chips with a good package provide a light source with superb properties in relation to radiation intensity, modulation frequency and optical properties, allowing more powerful ToF systems compared to LEDs.

For a variety of applications, Lextar offers VCSELs with two typical ToF operating wavelengths of 850 and 940 nm. 940 nm is invisible to the human eye, while 850 nm VCSELs have a visible red dot on the VCSEL—especially apparent in the dark. At 850 nm, the camera sensitivity is 50 to 100% higher than at 940 nm. This means that the signal-to-noise ratio (SNR) is better at 850 nm than at 940 nm. In terms of sunlight rejection, however, 940 nm models are often the better choice, as the intensity of sun radiation is much lower in this range.

Optimized driver circuit improves the system as a whole

A complete lighting unit requires not only the VCSEL but also the driver, which should be selected in consideration of the following technical parameters:

- Short delivery time: The most important components of a driver circuit include a field-effect transistor (FET) gate, the gate driver, and passive components. These are usually immediately available, enabling a prototype for a lighting unit to be developed within a short time.

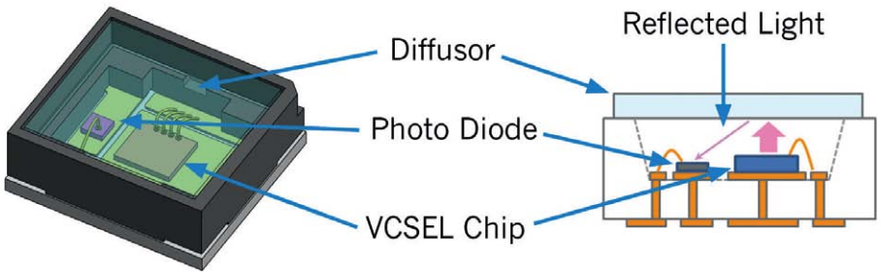


Figure 6: A VCSEL with an integrated photodiode helps to ensure eye safety.

- Design flexibility: A trigger circuit with discrete components offers more flexibility and can be adapted to a variety of design requirements (e.g. peak currents, pulse forms, adjustable rise times).

- Power: GaN-FET switches generally have a lower resistance (RDSon) compared to corresponding silicon-based products. This enables the driver to handle higher current spikes, which can increase the efficiency of the overall lighting unit.

- Scalable driver parameters: Ideally, the driver electronics will support modulation frequencies of up to 100 MHz or even more.

IC-Haus, for example, offers the iC-HG 6-channel laser driver, which enables spikeless switching of VCSELs with properly defined currents at CW (continuous wave) frequencies of up to 200 MHz. The channels can be paralleled for full 3 A CW operation and a total of 9 A of pulsed current. TTL or LVDS inputs enable the VCSEL to be activated or deactivated with ease or different current levels to be selected; these currents are defined by the voltages at the control inputs. The integrated thermal shutdown mechanism protects the iC-HG from damage caused by overheating. The iC-HG30 even allows for a frequency of 250 MHz and 6 A CW operation/30 A pulse current. It is also clocked for AEC-Q100 qualification.

Numerous potential applications

A ToF camera in the car can help to enhance comfort and driving safety, for example by monitoring the driver, passenger, and objects in the passenger seats. They can be used to detect if the driver is distracted or tired before there is an accident. Interior space monitoring also enables head and body positions to be detected, for example to optimize airbag control. It can also be used for gesture control. Outside the vehicle, a ToF application can support assisted and autonomous driving.

Melexis has developed a demo kit for infrared lights in ToF applications, specially for monitoring vehicle interiors. The demo board has powerful onboard processing capabilities for hand gesture recognition and high image resolution for object classification. This makes it suitable not only for gesture recognition and driver monitoring, but also skeletal tracking, person and obstacle detection, and traffic monitoring.

The demo board is equipped with a Lextar PV85Q series VCSEL, which offers high efficiency and a narrow spectral bandwidth (1.8 nm). Its various optical power options allow for the detection of multiple objects, 3D depth assistance, and presence detection. This VCSEL includes a photodiode to ensure eye safety. The fully integrated MLX75027 VGA (640 × 480) optical ToF image sensor is delivered with DepthSense pixels measuring 10 µm × 10 µm.

But VCSELs are not limited to ToF applications. 2D vision systems and other new applications such as optical data communication can also benefit from the higher modulation rate and intensity of the VCSELs. ■

Machine learning

Components for machine learning on the edge

Machine learning directly in the device has the potential to revolutionize countless products, whether it be the categorization of objects from an imaging sensor, gestures from an accelerometer, or sentences from an audio stream. However, to achieve this, the algorithms must be run on embedded components.

By Zibo Su, Product Manager Digital at Rutronik, and Daniel Fisher, Senior FAE EMEA at Gowin Semiconductor

The development of applications based on machine learning requires management of multiple technical disciplines, but most businesses only have some of these disciplines represented in-house. Data scientists, machine learning engineers, and software developers are then hired to develop, train, fine-tune, and test models for machine learning. The catch here is that these models usually do not run on embedded hardware or mobile devices, because most machine learning engineers have never used models on embedded hardware before and are unfamiliar with the resource limitations. For trained models to be used on mobile SoCs, FPGAs and microprocessors, the model needs to be optimized and quantized.

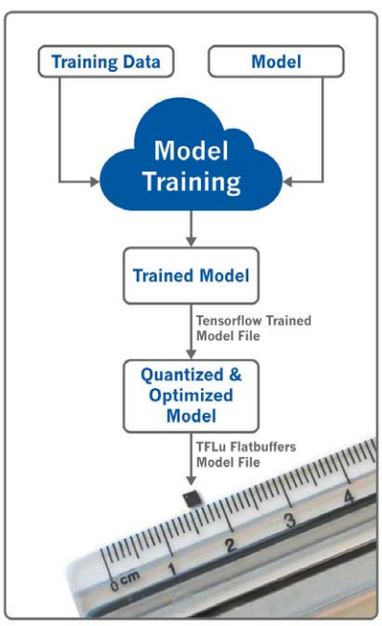
Semiconductor manufacturers in turn are faced with the task of developing products that satisfy new requirements in relation to performance, cost and form factor—all with strict time-to-market demands. Flexibility is required for interfaces, inputs, outputs and memory usage so that the products can cater to a variety of applications.

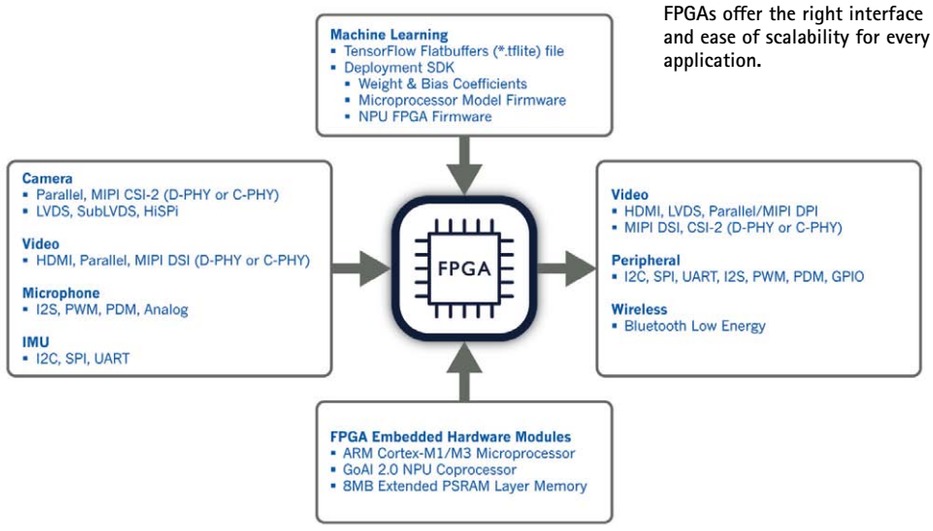
Optimization and quantization

This has become somewhat easier in recent years thanks to Google's TensorFlow Lite. This open source platform for machine learning now also includes scripts that can be used to optimize and quantize machine learning models in a "FlatBuffers" file (*.tflite). It uses parameters configured for a certain application environment.

Ideally, an embedded hardware product should be able to import FlatBuffer files directly from TensorFlow without having to use proprietary or hardware-specific optimization methods outside of the TensorFlow ecosystem. This enables software and hardware engineers to easily use the quantized and optimized FlatBuffer file on FPGAs, SoCs, and microcontrollers.

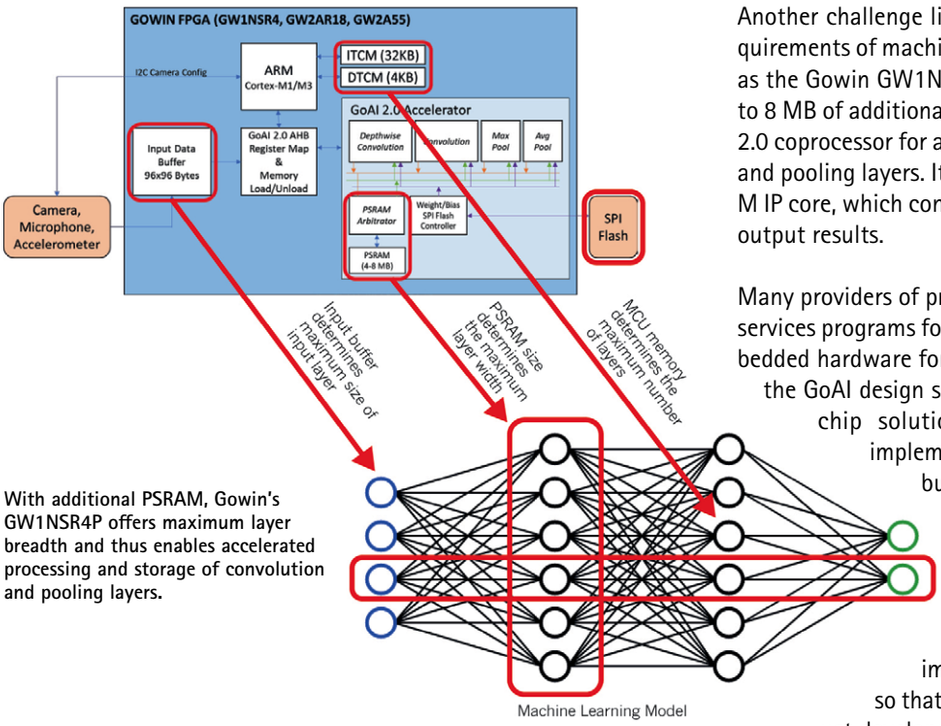
To enable machine learning to run on embedded hardware, models must be quantized and optimized.





FPGAs offer the right interface and ease of scalability for every application.

Figures: Gowin Semiconductor



With additional PSRAM, Gowin's GW1NSR4P offers maximum layer breadth and thus enables accelerated processing and storage of convolution and pooling layers.

Another challenge lies in the substantial flash memory and RAM requirements of machine learning models. New hybrid µSoC FPGAs such as the Gowin GW1NSR4P satisfy these requirements by embedding 4 to 8 MB of additional PSRAM. The GW1NSR4P provides a special GoAI 2.0 coprocessor for accelerated processing and storage of convolution and pooling layers. It is used in conjunction with its hardware Cortex-M IP core, which controls the layer parameters, model processing, and output results.

Many providers of programmable semiconductors also provide design services programs for steeper learning curves for customers using embedded hardware for machine learning. Gowin is no exception here—the GoAI design services program helps users searching for a one-chip solution for classification or for assistance with implementation for tested, trained models "off the shelf," but who don't know how they should communicate with the embedded hardware.

Suppliers provide these kinds of programs to help businesses use fewer resources in relation to embedded machine learning and on implementations on embedded hardware (TinyML) so that they can concentrate more actively on their product development. ■

A comparison of SoCs, MCUs, and FPGAs

Embedded hardware platforms only have limited resources, are not especially great for development purposes, and are complicated to use. But they do offer low power consumption, low costs, and modules with small dimensions as a reward. What do SoCs, microcontrollers, and FPGAs offer?

SoCs offer the highest performance and many standard interfaces, but also usually have the highest power consumption. The interface-specific inputs and outputs mean that they consume a lot of chip space, which makes them relatively costly.

The advantage of microcontrollers is their very low power consumption and small form factor, but they are often highly limited in terms of machine learning performance and modeling capacity. Models at the high end of the product range usually only offer specialist interfaces, such as for cameras or digital microphones.

FPGAs cover a broad segment between microcontrollers and SoCs. They are available with a wide selection of packages and flexible inputs and outputs. This enables them to support any interface required for a given application without having to waste chip space. The configuration options also enable cost and power consumption to be scaled with performance and allow additional functions to be integrated. The problem with the use of FPGAs for machine learning is their lack of support and integration for SDK platforms such as TensorFlow Lite.

Machine learning FPGAs

To overcome this flaw, Gowin Semiconductor provides an SDK on its GoAI 2.0 platform that extrapolates models and coefficients, generates C code for the ARM Cortex-M processor integrated in the FPGAs, and generates bitstreams and firmware for the FPGAs.

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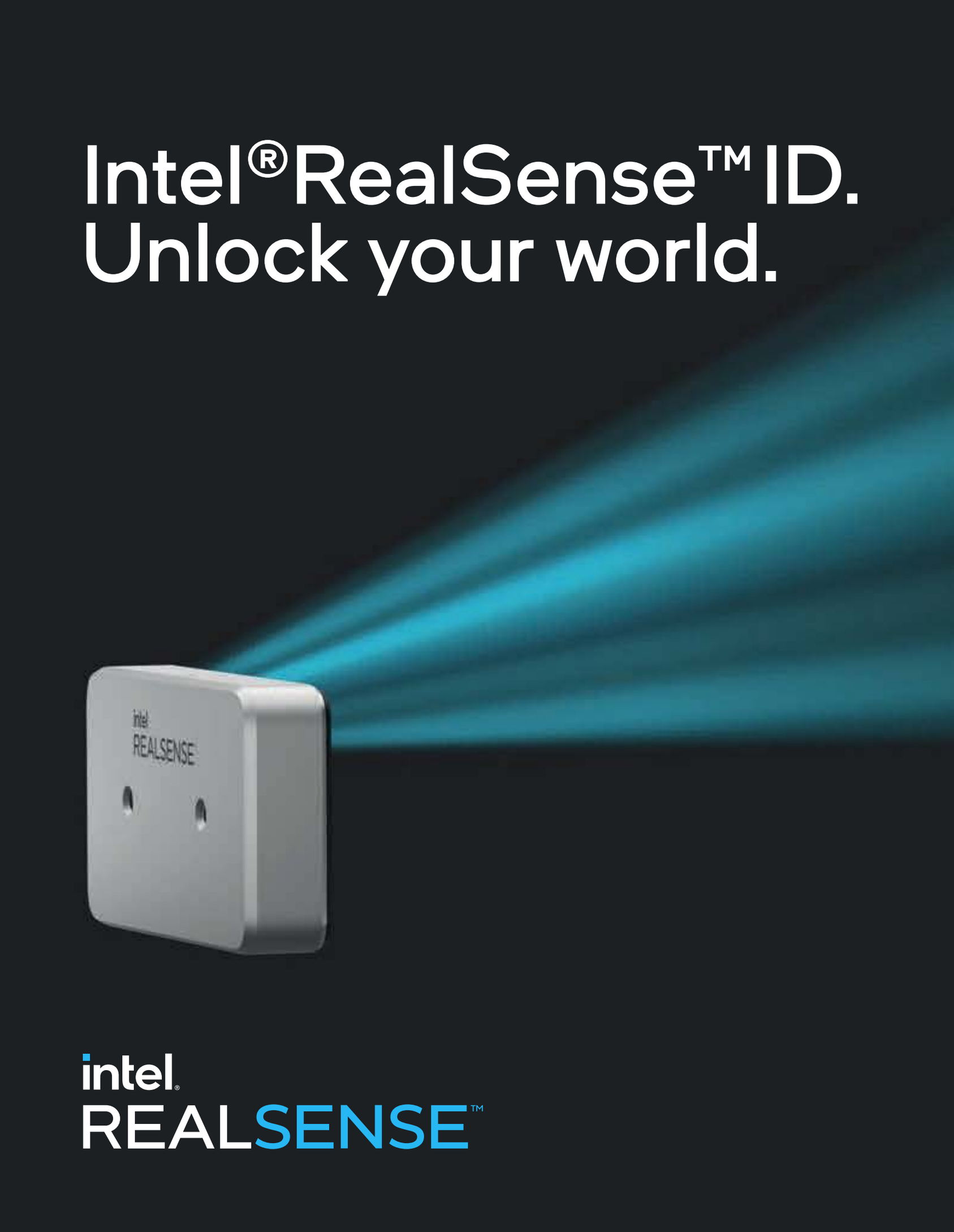

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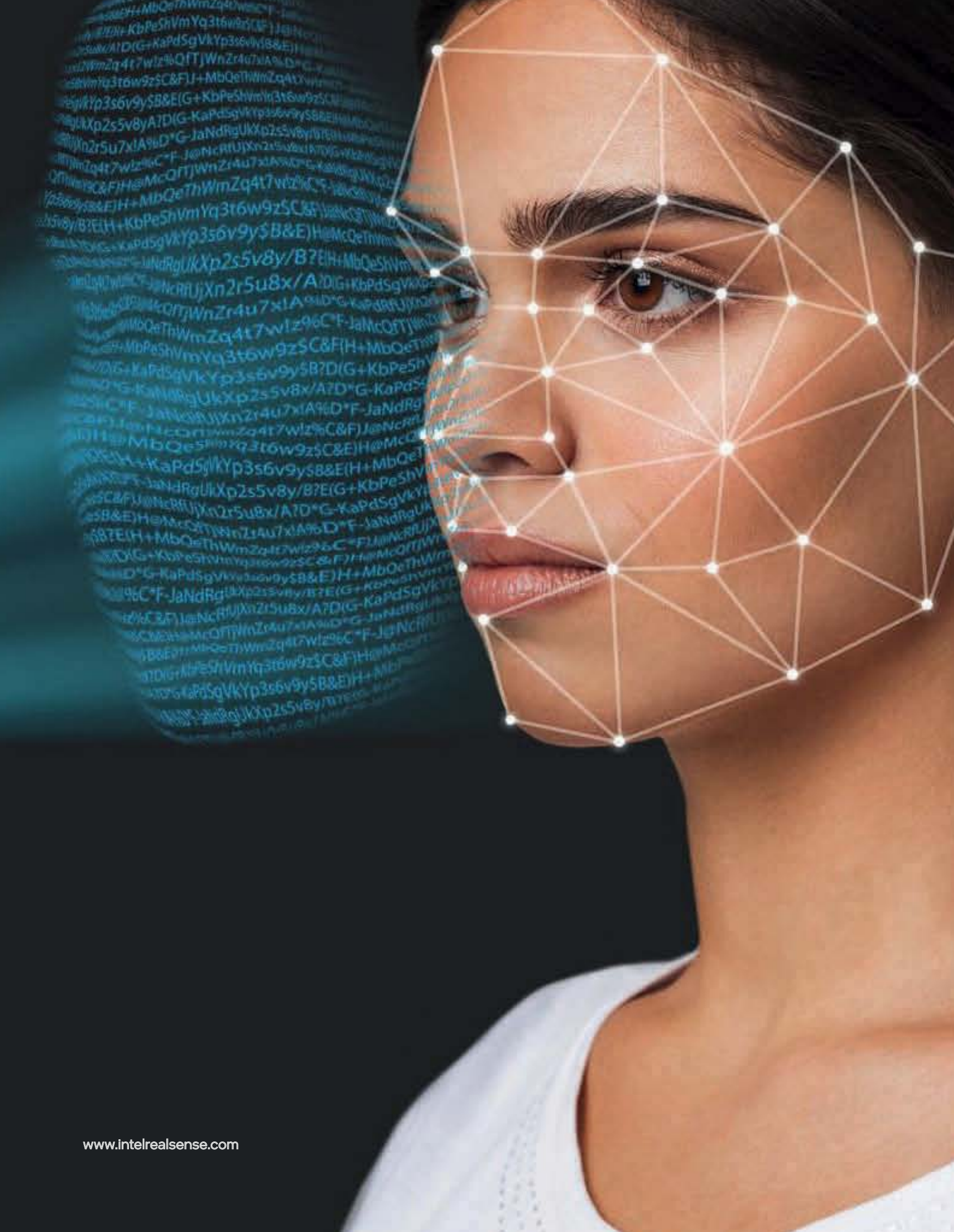

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5G and TSN

For the industrial automation of the future

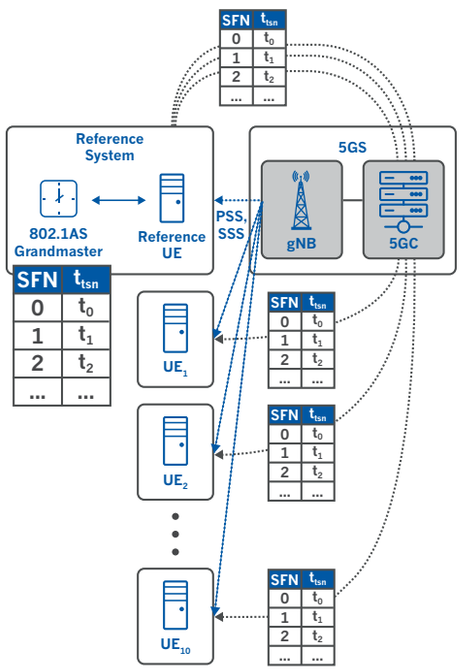
There are numerous fieldbus standards aimed at ensuring real-time support, but none of them provide a manufacturer or platform-agnostic networking solution. An answer has been provided in the form of Time-Sensitive Networking (TSN). But mobile applications using consistent real-time communication are possible when combined with 5G.

By Andreas Mangler,
Director Strategic Marketing and Communication
at Rutronik

The Fraunhofer Institute for Production Technology (IPT) and a number of mechanical engineering, robotics, and network engineering companies have recognized the potential to combine TSN with 5G. Together, they have developed a capable communication infrastructure with the aim of creating a high-availability, reliable, and secure communications solution for sensors and actuators with cloud support. TSN provides real-time communications for wired communication, while 5G cellular technology handles all mobile and cloud connections.

One potential application would be the precise control of a robot and a tool, or of two robots working together during live production. Data processing can be outsourced to the cloud using this infrastructure, with the results sent back to the system. This enables robots in highly dynamic production systems to be controlled adaptively and flexibly without them needing to be connected directly to one another. This works with devices from a multitude of manufacturers, even using existing machinery and installations. There are numerous other scenarios that can also benefit from this combination, and some that perhaps may only be feasible with this constellation—among them autonomous driving, transport applications and remote surgery.

Figure 1: Concept for distribution of TSN time in a 5G network.



TSN for real-time Ethernet

Let's first consider TSN, an evolution of standard Ethernet. Ethernet provides data communication services between devices from different manufacturers for IT purposes, namely in office environments. Industrial Ethernet is a more robust solution that is suitable for harsh environments. Special protocols such as EtherCAT, Profinet, and Modbus TCP also provide a more deterministic environment—in other words, data packets are transmitted or received at predictable times, and the risk of data loss is eliminated.

But what Industrial Ethernet does not guarantee is real-time support. To this end, the IEEE 802.1 Task Group has developed a range of sub-standards referred to as Time-Sensitive Networking (TSN). These standards define protocols for timing and time synchronization (IEEE 802.1AS) and for the configuration (IEEE 802.1Qcc in particular) and control of data traffic (Traffic Shaping and Scheduling, IEEE 802.1CB, 802.1Qbu, 802.1Qbv among others).

Figures: Rutronik, based on M. Gundall, C. Huber, P. Rost, R. Halfmann, and H.D. Schotten: "Integration of 5G with TSN as Prerequisite for a Highly Flexible Future Industrial Automation: Time Synchronization based on IEEE 802.1AS". In: 2020 IEEE 46th Annual Conference of the IEEE Industrial Electronics Society (IECON), IEEE, 2020.

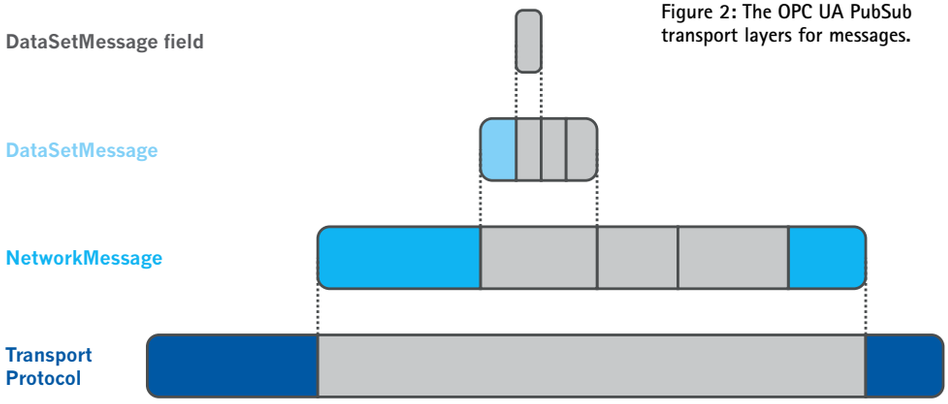


Figure 2: The OPC UA PubSub transport layers for messages.

This means that there is a common plan that defines when data packets are forwarded in a prioritized fashion.

TSN does not cover all seven layers of the OSI model for network protocols, in which each layer defines how two systems communicate with specific tasks and functions. TSN addresses Layers 1 and 2 and the real-time aspect, which covers the entire vertical length of the model. This means that more protocols are required for the higher layers. Businesses can continue to use their existing standards here, for example OPC UA. TSN provides the benefit of guaranteed real-time support without the need to adapt standards.

Interoperability and IT/OT convergence

Thanks to open standards, TSN enables manufacturer and platform-agnostic interoperability between different devices, machines, and installations, similar to how standard Ethernet works in office IT. These standard Ethernet components can be integrated into TSN, allowing TSN to establish a consistent link between IT (information technology) and OT (operational technology) components. Critical and noncritical systems with different traffic classes can operate in the same network.

With bandwidths ranging from 10 Gbit/s to 400 Gbit/s—compared to the 100 Mbit/s commonly seen in Industrial Ethernet networks—TSN also caters to the demands of increasingly large data volumes.

To date, only some of the TSN sub-standards have been ratified—others are still a work-in-progress. Even so, the existing standards can be implemented right away—they already guarantee real-time communication and can be adapted to future standards.

What does real-time mean?

To guarantee real-time support in a network, the following features are required:

- Each device requires a precise internal clock so that each data packet can be timestamped.
- All devices in the network need to be time-synchronized.
- Data packets are transmitted with very low latency, meaning that they are bound by a very strict time limit. Time-critical applications require ultra-low latency (ULL) of just a few milliseconds or even less than a millisecond, end-to-end—i.e. from the time transmission starts until it has been fully received.
- Low jitter: Latency is always related to time variations referred to as "jitter." Some industrial control applications prohibit jitter from exceeding a few microseconds, while others can handle delays of up to a millisecond.

Jitter and latency are also the most important parameters for the quality of service (QoS) of a ULL network.

Solution provider for TSN and 5G

All products required to create a TSN and 5G infrastructure are available in Rutronik's portfolio. Application engineers, product managers, and line managers are on hand to assist with the implementation.

Processors and boards with TSN support

Intel's 10 nm Atom x6000E processor and N- and J-series Pentium and Celeron product ranges have 2.5 GbE MACs with TSN functions integrated. Compared to the previous generation, they have 1.7 times the single-thread performance, up to 1.5 times the multithreading performance, and also twice the GPU performance. The UHD graphics allow for a resolution of up to 4kp60 on up to three displays concurrently. Their Programmable Services Engine (PSE) with an ARM Cortex-M7 microcontroller offers independent processing power with low DMIPs and I/Os for IoT applications. They also feature a network proxy, embedded controller, and sensor hub. For remote monitoring and administration and for remote firmware and software updates, the processors offer in-band support via Wi-Fi or Ethernet; alternatively, out-of-band administration over wired Ethernet is also possible.

There are numerous boards from a variety of manufacturers available from Rutronik based on these Intel processors. The SMC-93 from Seco is the first SMARC module specially developed for functional safety in safety-critical systems.

Advantech offers a SMARC 2.1 module with up to four cores and 40% better CPU performance as well as improved GPU performance compared to previous models. The SOM-2532's features include two GbE LAN interfaces for TSN PHY for real-time device communication as well as USB 3.2 Gen2 and PCIe Gen3. With CAN FD, much higher data transfer rates are possible, achieving user data transfer speeds that are ten times faster—an interesting feature for data-rich applications. The WISE-DeviceOn software from Advantech ensures that IoT devices operate with stability and can be conveniently administered remotely. The SOM-2532 is therefore particularly recommended for applications in automation, medical engineering, and transportation.

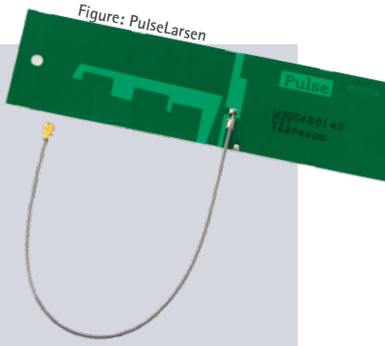
The MIO-5152 3.5" SBC (single-board computer) from Advantech is also equipped with the latest Intel processors and Advantech's WISE-DeviceOn. It comes fitted with 32 GB of DDR4-3200 and offers numerous interfaces, including HDMI 2.0/DP/LVDS, Dual GbE, four USB 3.2 sockets, four USB 2.0 sockets, six UART interfaces and TPM support.

Kontron also offers a SMARC 2.1 module (SMARC-sXEL (E2)), as well as two COM Express models with TSN support (COMe-mEL10 (E2) COM Express mini Type 10 and COMe-cEL6 (E2) COM Express Compact Type 6). All three are available as versions with the Intel Atom x6000E, Pentium, or Celeron, and offer numerous interfaces.

A comparable board with a Thin Mini-ITX form factor is available from DFI and is based on the Intel Atom X6000 series.

Kontron has developed a ready-to-use TSN system—the KBox C-102-2 TSN Starter Kit includes the IPC KBox C-102-2 and the PCIe-0400-TSN Gigabit Ethernet interface card with TSN support. The four network interfaces with switching function are based on standard Ethernet as specified by IEEE 802.3 and make it possible to develop deterministic control applications in convergent networks from OT to IT without the need for additional switches. The system is shipped with Realtime Linux and a network management tool for rapid setup of a TSN network. Upgradeable hardware and software open up the solution for new and evolved TSN standards. The target applications include deterministic industrial control computers and servers, convergent networks for critical and noncritical traffic, and security solutions to protect deterministic traffic against malicious attacks.

Figure: PulseLarsen



Whether for 5G, 4G, 3G, or 2G, with support for GNSS, Wi-Fi, Bluetooth, and more, the W3554 ultra-wideband dipolar antenna from PulseLarsen can do it all.

5G cards, modems, and antennas

The Rutronik product portfolio also includes a selection of hardware components for developing a 5G campus network, including 5G cards and modems as well as antennas. This includes one of the world's first available 5G solutions—the FN980 5G-M.2 card from Telit, which supports LTE and 5G sub-6 GHz bands worldwide. With a form factor of 30 mm × 50 mm and a temperature range of –40 to +85°C, it is also suitable for use in industrial applications. The FN980m model also supports the new mmWave frequency bands above 30 GHz. Telit's cards are based on the Snapdragon X55 5G chipset from Qualcomm, as are the 5G-M.2 modules of the AIW-355 family from Advantech. Unlike Telit, however, Advantech is gearing towards specific versions for Europe, North America, and Japan with the AIW-355 range. At 30 mm × 52 mm, it has a slightly larger form factor, and a reduced temperature range of –10°C to +55°C. The 5G-M.2 cards from both manufacturers have multiple 5G and GNSS antenna sockets.

Rutronik offers various 5G antennas from 2J, AVX, and PulseLarsen. The compact W3415 5G SMD antenna from PulseLarsen supports all sub-6 GHz bands (4G and 5G), and measures just 40 mm × 7 mm × 3 mm. The W3554 series ultra-wideband dipolar antenna from PulseLarsen with a frequency spectrum of 698 to 6,000 MHz is suitable for 5G applications and also for 2G, 3G, 4G, GNSS, Wi-Fi, Bluetooth, Bluetooth Low Energy, Zigbee, and the 868, 915, 2,400, and 5,000 MHz ISM bands. The PCB antenna measures just 30 mm × 120 mm × 0.2 mm.

For developing an internal campus network, Rutronik also supplies special 5G network components from FSP. These are suitable for supplying base stations, access networks, data centers, or individual network devices.

Real-time support now available wireless thanks to 5G

5G enables real-time support to be expanded globally to wireless networks through TSN. 5G enables not only ultra-low latency (ULL) and precise time synchronization, but also massive increases in reliability, range, and bandwidth compared to its predecessor technologies, all with superior energy efficiency.

5G also enables the creation of private networks that are inaccessible to the public. They provide another substantial boost in performance, data protection, and network security, as well as guaranteed quality of service (QoS). This is how 5G is laying the foundations for secure communication between a variety of machines and installations, robots, and components—ranging from sensors and actuators to cloud services. When developing a TSN network, it is therefore recommended to consider integrating 5G support to ensure that you have a future-proofed, scalable solution.

More detailed information on developing a 5G campus network is provided in the article on page 22.

Integrating 5G into a TSN network

A concept of the Research Group of the German Research Center for Artificial Intelligence (DFKI), the Technical University of Kaiserslautern, and Nokia Bell Labs shows how TSN time synchronization (IEEE 802.1AS) can be integrated in compliance with 5G standards (Figure 1). The 5G system comprises a 5G base station (gNB) and a 5G core network (5GC) as well as multiple end devices (UE). One of these end devices (Reference UE) is connected to the wired TSN network as part of the reference system. This device must support IEEE 802.1AS so that it can be synchronized with the TSN clock via the Grandmaster.

The 5G system also has its own synchronization mechanism, where each 5G base station (gNB) synchronizes the end devices networked with it using the primary (PSS) and secondary (SSS) synchronization signals. The end devices use these signals to identify their wireless cell and radio frame; using specific synchronization algorithms, they can adjust for frequency and time differences. Each incoming System Frame Number (SFN) is also paired with the current time of the reference end device and transmitted to each connected end device. If OPC UA PubSub is used for distribution, all end devices connected to the base station can be synchronized.

The synchronization between the base station and connected end devices means that only the offset relative to the corresponding TSN time needs to be identified.

Figure 2 offers an illustration of the message layers. The User Datagram Protocol (UDP) in combination with Multicast is used as the transport protocol so that every device in the Multicast group receives the subscribed messages.

As shown by Figure 3, the research team successfully used this arrangement with a synchronization interval of 31.25 ms to achieve synchronicity of 350 ns between an evaluation kit and an Intel NUC Mini PC.

Conclusion

TSN raises standard Ethernet to a new level of real-time communication. It allows for the consistent and manufacturer-agnostic connection of IT and OT devices. 5G allows this opportunity to be expanded to mobile connections. Combining both technologies provides the foundations for collaborative robotics and the reliable control of highly dynamic production systems, including mobile robots, and also for goods transport systems, assisted and autonomous driving, remote surgery, and augmented and virtual reality applications. ■

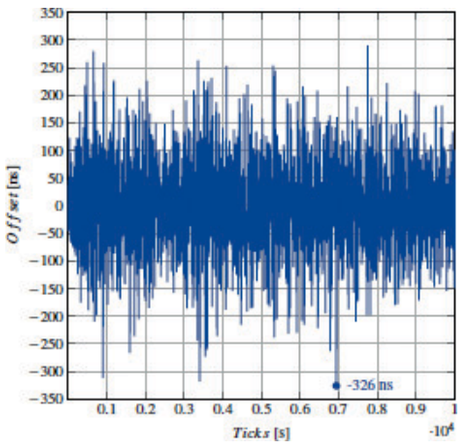


Figure: Michael Gundall, Christopher Huber, Peter Rost, Rüdiger Halfmann, Hans D. Schotten

Figure 3: The maximum offset in synchronization between the TSN evaluation kit and an Intel NUC Mini PC was 350 ns with a synchronization interval of 31.25 ms.

Automotive MOSFETs

A package deal that's worth it

The rise in the use of MOSFETs in applications such as LED drivers, power supply units, or battery chargers, and as substitute relays and fuses ensures that they will continue to enjoy strong growth. MOSFETs with further optimizations to cater to many more applications excel with reduced space requirements, lower power loss, greater efficiency, and low costs. How are manufacturers pursuing these optimization objectives?

By Ralf Hickl,
Product Sales Manager Automotive
Business Unit at Rutronik

As a general rule, the more efficient components become, the smaller, lighter, longer-lasting, and cheaper the end products become, and the less likely they are to heat up. Some applications are not even possible until components reach a certain degree of efficiency. As a result, with greater efficiency comes greater demand for relevant components, providing further growth.

System efficiency is king

Switches – usually MOSFETs – are key components that play a defining role in efficiency. Their conductivity and switching losses are critical in determining heat loss. The "figure of merit" parameter (ON resistance R_{DSon} × gate charge Q_{gate}) allows us to evaluate static (electrical conductivity losses) and dynamic (electrical switching losses) performance.

Tweaks for smaller figures of merit or higher efficiency in MOSFETs can be performed using semiconductor materials with superior properties such as SiC or GaN. These materials offer reduced dynamic losses by means of faster switching and lower thermal resistance compared to conventional silicon MOSFETs. This is especially true at higher voltage levels. But MOSFET systems consist of more than just a semiconductor chip. The package and connection technology also play an important role.

Reduce power loss by reducing overall resistance

If we consider the distribution of the ohmic resistance of a MOSFET-on-chip with its contacts and package, we notice how the resistance values of package $R_{Package}$ and the resistance of the die are connected in series (Figure 1).

So it is not enough to simply keep developing better and better MOSFET chips. The package technology also needs to keep pace with these optimizations. The following methods are available to achieve this:

- **Surface contacts instead of bond wires:** The larger contact and cross-section area helps reduce the thermal and electrical resistance of the package (Figures 2, 3, and 4).

Figure 1: Schematic representation of layers in an n-channel trench MOSFET alongside the resistance model

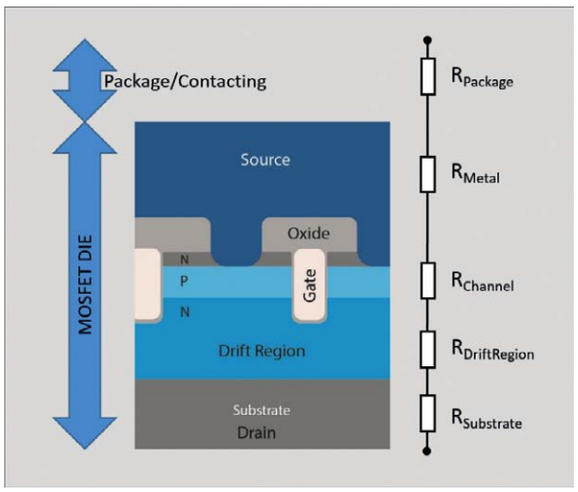


Figure: Rutronik

Figure: Rutronik

Figure 2: MOSFET from Diodes in PowerDi1012 package (TOLL)

Figure: RichTphoto/stock.adobe.com

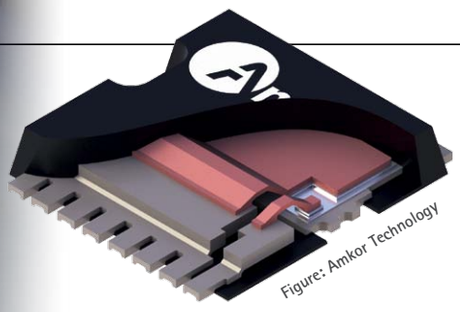


Figure 3: View of the inside of a MOSFET TOLL package with copper clipping

Manufacturer	Series	Type	I_{DC}/A	$R_{DSonmax}$/mΩ@25°C	R_{thjc}/°C/W	Package
Vishay	TrenchFET GenIV	SQJQ140E	701	0.53	0.25	PowerPAK 8x8L
Infineon	DirectFET	AUIRF8739L2	545	0.60	0.44	DirectFET2 L-Can
Infineon	OptiMOS-6	IAUA250N04S6N006	250	0.64	0.60	sTOLL
Toshiba	U-MOSIX-H	TKR74F04PB	250	0.74	0.40	TO-220SM(W)
Diodes	-	DMTH4001SPSQ	100	1.00	0.80	PowerDI5060-8

Table 1: Comparison of several packages with their properties

An extra bonus is that the strip-like form of the contact clip also reduces the parasitic inductance of the connection.

- **Thinner dies:** Thinner dies offer two advantages. The first is that the overall electrical resistance is reduced because the length of the path of the current through the chip is reduced overall. Additionally, the channel is closer to the surface, which further reduces thermal resistance.

- **Source-down packages:** A source-down package has the channel, where the heat loss is generated, positioned closer to the cooling surface. This provides the component with better electrical and thermal properties. Infineon has introduced the first MOSFETs with a 3.3 × 3.3 mm² PQFN package and inverted die, and refers to this technology as "source-down" technology.

Improved usage of the die

This shows how improved heat dissipation to the environment allows for greater heat loss without causing the component itself to overheat. The aforementioned surface contact of the chip helps in this regard. But there are several additional measures that can be taken.

Cooling from above

In conventional packages, the MOSFET chip is located with the drain facing down on the metallic contact surface. This drain connector is soldered to the PCB and represents the main path for heat dissipation into the board.

However, the PCB itself has to be cooled. This is why the heat energy is often conducted to the other side of the PCB using thermal vias. The PCB and its vias add extra heat resistance on the route from the MOSFET to the environment. In this case, the rear of the PCB can be fitted with a heat sink.

However, if the cooling surface is located on the upper side of the MOSFET package, a heat sink can also be connected upon it directly. The heat resistance generated by the PCB and its vias then ceases to be a factor.

Cooling from above and below (dual side cooling, DSC)

This special package has not yet been broadly adopted, so developers are limited in their choice of types and manufacturers and there are hardly any second sources available.

Table 1 lists the standard packages of various manufacturers and their properties. It clearly shows that the largest packages do not automatically offer the smallest thermal resistance values.

Conclusion

To allow the latest MOSFETs to fully benefit from their package advantages, manufacturers have also provided innovations in package technology. Recent dies in packages with surface contacts using copper clipping provide a remarkable improvement in electrical and thermal properties. This provides a path to smaller, lighter, longer-lasting, and cheaper applications, and may even facilitate entirely new ones. ■

Table 2: Comparison of a number of MOSFETs

Manufacturer	Brand Name	JEDEC	Leads	Size/mm	PCB Area/ mm²	Current/A	R_{thJC}/ K/W	Misc.	Example Type
Diodes, Infineon	TOLL, HSOF-8, PowerDi1012		no	10×12	120	300	0.35		IPLU300N04S4
Infineon	TOLG, HSOG-8		yes	10×12	120	300	0.4		IAUS300N04S4
Infineon	TOLT	MO-319A	yes	10×12	120	300		Top Side Cooling	
Vishay	Reverse TO-252, Reverse DPAK		yes	6.5×10	65	>100	1.1 … 1.4	Top Side Cooling	„SQR40020R SQR40N10-25“
Vishay	PowerPAK 8×8L		yes	8×8	64	701	0.25		SQJQ140E
Vishay	Reverse PowerPAK 8×8L		yes	8×8	64	400	0.25	Top Side Cooling	SQJQ184ER
IFX	sTOLL, HSOF-5	MO-319	no	7×8	56	250	… 0.6		IAUA250N04S6006
Vishay	PowerPAK SO8L	„similar MO-235“	yes	5×6	30	300	0.3		SQJA36EP
Diodes, Toshiba, Infineon	PowerDI56, SO8-FL, SOP-adv, TDSON, HVSON, SSO8	MO-240 AA	no	5×6	30	150	0.8 … 0.9		TPHR7904PB
Toshiba	DSOP-adv		no	5×6	30	120	1.13‖1.5	Dual Side Cooling	TPW1R104PB
Infineon, Diodes, Vishay	S308, PowerDI33, TSON8-FL, TSON-adv, PowerPAK 1212-8SLW, TSDSON, miniHVSON	MO-240 BA	no	3×3	10	123	0.76		SQS140ENW

Ambient lighting

Light: the new chrome

Anyone who considered themselves to have had class back in the day would have had a car with shining chrome. Today, light is the new chrome, turning vehicles into status symbols. LED technology has made it possible. But new technical developments also present designers with new challenges.

By Bernd Wondratschek,
Field Application Engineer ABU at Rutronik

Figures: Elmos

Modern LEDs provide a variety of opportunities for ambient lighting in the car.

Countless specks of light in the Rolls-Royce Phantom make you feel like you're driving beneath a sky of stars, conveying a sense of luxury and exclusivity. Unlike chrome, light can perform many more functions. Inside vehicles, it can influence the occupants' emotions depending on the brightness and color—they feel at ease, comfortable and less stressed, or cheered up and encouraged. Cognitive abilities can also be improved with light, preventing the driver from tiring as quickly and helping them to better concentrate.

But colors can also have negative effects. This is why an additional HMI system may be useful to ensure that the color of the lighting matches the physical and emotional condition of the driver. These usually employ what are known as "themes," which involves various parameters being preconfigured. Such a system can contain several microcontrollers and up to 300 RGB modules, comprising LED chips and drivers.

Out of the comfort zone

While interior LED lighting was initially only used in luxury models, and purely as a comfort factor, they are now commonly being used in mid-class vehicles. The main objective here is to establish LEDs as a functional feature for enhancing safety. The selective use of light makes it easier for the driver to find their way around the vehicle interior, and control elements or indicators can be highlighted or hidden as needed. Warnings, for example when an object is too close, are more readily noticed when shown in red light. Information on the status of the vehicle or on incoming phone calls can also be elegantly communicated via LEDs to be quickly interpreted by the driver.

But it is essential to avoid overkill—the light must not dazzle or distract the driver or other people. And when too many lighting elements are used, their impact is lost.

Ever smaller LEDs edging ever closer together

Technical evolutions offer up even more artistic and application opportunities. For example, LED strips can be integrated on flexible PCBs designed for challenging conditions along the edges of the roof and in the seating upholstery.

	E521.38	E521.39
MCU	ARM Cortex-M0, 32-bit µC	16 bit (H430 µC)
LEDs to Control	4 (6 with multiplexing)	1 (RGB/W)
Current Sources	12 × 60 mA	3 × 40 mA
PWM Generators	12 × 16 bit (up to 1000 Hz @16 bit)	4 × 16 bit, 48 MHz (up to 700 Hz @16 bit)
Supply Voltage (max.)	20 V	40 V
Memory	32 kB flash	32 kB flash
Cust. NVM	256 byte	128 byte
RAM	2 kB	1.25 kB
SysROM	SysROM for re-flash available	24 kB
Bus	differential bus with auto-addressing	LIN (V2.2a) auto-addressing + - bus shunt method
Safety (ISO 26262)	ASIL B	–
AEC-Q100	125°C	125°C
Package	DFN18L5040	SOIC8

Specifications of the new Elmos LED drivers.

Components are also getting smaller and smaller, with recent LED modules measuring just 8 × 18 mm². This is necessary, because the space available to install electronic components also shrinks with every development cycle. This means that in smaller modules, the diffusor gets closer and closer to the light source, the LED chip.

If the distance between the LED or LED module and the diffusor is reduced, they need to be fitted more tightly together to generate a consistent light surface. As a general rule, the distance between the LED and diffusor should be equal to the distance between two LEDs, which means that more LEDs need to be fitted.

For small light strips, an optical fiber cable can be illuminated from both ends. However, this only works up to a length of around 15 to 20 cm—beyond that, the light is not strong enough in the middle of the cable to ensure a consistent, homogeneous color. This is why, with roof lighting for example, it is necessary to place a series of LEDs or LED modules at regular distances.

LED drivers for limited space

For applications such as the center console, a multi-channel driver such as the E521.38 from Elmos is recommended. This can control four LEDs, even six when using multiplexing, allowing it to help satisfy strict installation space requirements. Developed in accordance with ISO 26262 for ASIL-B applications, it can also be used for functional safety systems. Its DFN18 package with wettable flanks help make inspections easier. The differential digital interface makes it the leading choice for dynamic ambient lighting, because—unlike other bus systems and large bus arrangements—it doesn't cause lag effects resulting from insufficient data transfer rates. This means that consistent color displays and movements are guaranteed.

For smaller LED modules, the E521.39 LIN-RGB/W driver is ideal. It is designed for ambient lighting, which, at present, is usually static in nature. Unlike its predecessor, it has flash memory to enable the module to receive software updates in the vehicle. It can withstand a supply voltage of up to 40 V and has a low maximum idle current draw of 30 µA. The robustness and low consumption of the module make it perfect for use in battery-powered vehicles. Thanks to the 12-bit ADC, it also offers high-resolution temperature measurement by reading the internal temperature sensors and using a differential measurement of the forward voltage. The LED driver can use this to have the software compensate for aging and temperature effects.

The E521.38 multi-channel driver uses an integrated pulse width modulation generator to generate a (PWM) frequency of 1,000 Hz with full 16-bit pulse width resolution. The E521.39 provides up to 700 Hz with the same resolution. This puts them well above the requirements of the automotive OEMs, which specify 500 Hz in their respective standards to ensure an absence of flickering in interior lighting. This provides reserves to meet even stricter requirements.

The LED driver's PWM system enables not only flicker-free light but also considerable capacity for soft color transitions. A further benefit is that, given that OEMs keep specifying increasingly strict color spaces for LEDs, this allows for more LED binning and reduces costs when selecting LEDs.

The Elmos LED drivers will soon be launched on the market and will then be available from Rutronik, as will other ICs from the manufacturer that can be used to create optical applications for HMIs, such as non-contact gesture control systems. Rutronik can also supply all other components needed for innovative ambient lighting, from white and RGB LEDs with top or side LED form factors to power supply chips, to passive components such as capacitors and inductors. The Rutronik Automotive Business Unit (ABU) provides manufacturer-agnostic technical support specifically for automotive applications. ■

Current measurement in the drive unit of electric vehicles

More compact inverters require more precise shunts

As for many other devices and applications, smaller and smaller components are required for electric cars. In the case of inverters for the control unit of the electric motor, miniaturization entails higher switching frequencies. This increases the influence of parasitic inductance. Low-inductive shunts offer the highest precision for measuring the drive current.

By Jasmin Asi,
Product Sales Manager Resistors
at Rutronik, and
Nico Pathé,
Field Application Engineer
at KOA Europe

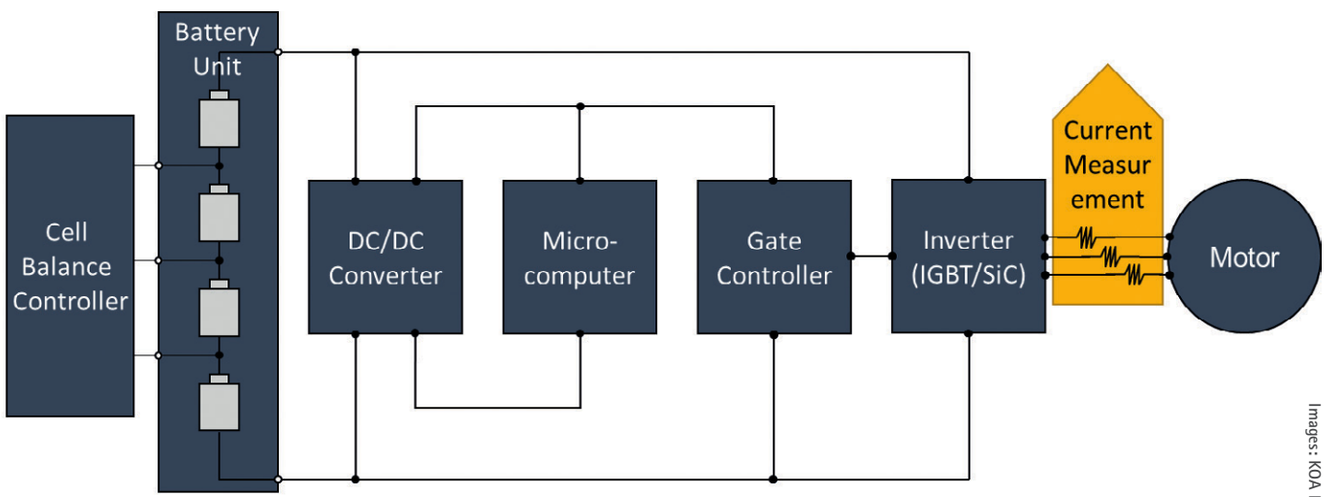
Battery-powered electric vehicles are currently regarded as the basis for future mobility. The concept is as easy, as it is old: A battery stores the electric energy that is used to run an electric drive, which sets the car in motion. The objective of modern technology is a drive unit as efficient as possible, which in the end will help to increase the driving range. At the same time, the charging time should be kept as low as possible.

Mainly brushless three-phase motors are used in current e-cars, because they are maintenance-free, nearly free from wear, and highly effective. Power electronics are needed to control the motor, as the battery provides direct current. Figure 1 shows the schematic description of such a drive unit.

The shown power electronic consists of an inverter module, which transforms the direct current into three phases. So far, this was mainly done with IGBTs, which are silicon-based insulated-gate bipolar transistors. As an output filter an inductor, which is adapted to the inverter, is used.

Approaches to miniaturization

In the course of increasing the driving range, as much weight as possible should be cut down. With higher battery voltages for example it is possible to use a smaller wire cross section. To shrink the whole electric system, silicon carbide (SiC) technology offers the possibilities of higher switching frequencies and lower switching losses together with a smaller architecture. The higher switching frequencies also offer the advantage that smaller passive components can be used, including a smaller coil in the output filter.



Images: KOA Europe

Figure 1: Schematic description of a drive unit for a battery electric vehicle.

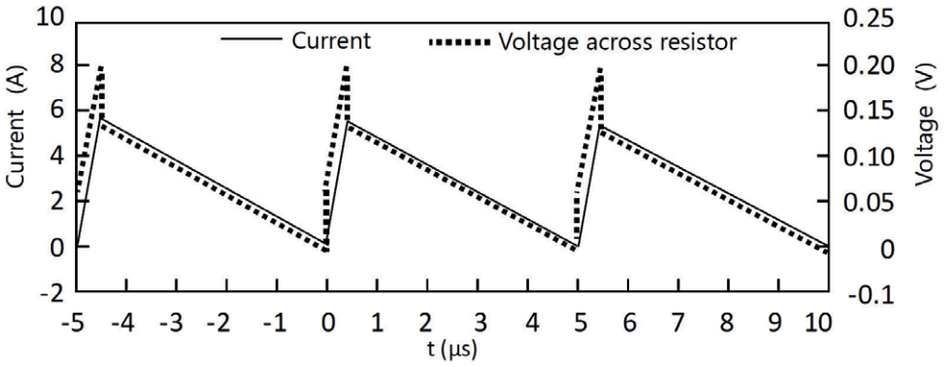


Figure 2: Voltage and current across a shunt with 50 mΩ and 10 nH.

In order to properly control the drive current, the motor control unit needs to have the actively flowing current as an input parameter. Thus, the current needs to be measured continuously. The most accurate results are obtained with a current-measuring resistor (shunt). So-called metal plate shunts in the milliohm to microohm range are most frequently used here. They normally consist of an alloy and are suitable for particularly high currents. The principle of measurement is quite simple: If a current is flowing through a resistor, there will be a measurable voltage drop. As the ohmic value of the resistor is known, the flowing current can be measured with these two values by using Ohm's law.

In practice, many factors can influence the measurement and lead to a false measuring result if not taken care of. For high frequency currents the parasitic inductance has the biggest influence. Having a change in the amount of flowing current, it induces an electromotive force (EMF). The stronger the current change in a certain time period or the shorter the time period of a certain current change is, the bigger the EMF will be. Figure 2 shows a typical current and voltage across a resistor with high parasitic inductance.

As the voltage is meant to be measured with the shunt, the induced EMF needs to be kept as low as possible to reduce the error in measurement. The higher the switching frequency will be, the higher the influence of the parasitic inductance will turn out. That is why, especially for SiC inverters, shunts with particularly low parasitic inductance should be used to guarantee a precise measurement of the current.

Another possibility is to choose a higher ohmic value, so that the influence of the parasitic inductance will be smaller compared to the voltage drop, as the measured signal will be much higher. On the other hand, this will lead to higher electric losses due to the higher energy consumption. Therefore, it is more advantageous to look out for a shunt with especially low parasitic inductance from the beginning. First and foremost, very flat SMD (surface-mount device) metal plate shunts offer a very low parasitic inductance, due to their structural shape and material.

Figure 3: The PS and TLR series from KOA include especially low inductive shunts.

As an initial tolerance for current sensing resistors a value of ±1% was established. To reach this value during production, the resistor needs to be trimmed. Special trimming processes, that work without cutting into the resistive element, offer the best solution here. With the TLR and PS series from KOA Europe, Rutronik offers two particularly low-induction shunt series.

For the TLR series KOA has implemented a trimming process completely without cutting into the material, which leads to parasitic inductance values in the range of 0.1 nH. The PS series is designed for much higher currents, up to 244 A. These values are a bit higher, but significantly below 1 nH. Therefore, these parts are perfectly suited for current measurement in the drive unit of electric vehicles, especially when SiC-based or other high-frequency inverters are used. ■

Haptic feedback systems for touchscreens

Using touch applications without visual contact

Touchscreens have already replaced many switches and dials in the car. But the sleek, flat surface is also the problem—controls cannot be felt, so the driver has to look. This can be dangerous at high speeds and in dense urban traffic. Haptic feedback systems provide a solution here.

By Edgar Schäfer,
FAE Automotive Business Unit
at Rutronik

If a touchscreen is fitted with active haptic feedback, it provides the operator with a similar feedback to a mechanical key. There are three types of actuators for such haptic feedback systems: piezo elements, vibration motors and linear haptic actuators.

Linear haptic actuators: enough power even for large displays

Linear haptic actuators are defined by the very strong feedback that they provide. This enables them to provide very noticeable haptic feedback even with large touchscreens or displays—comparable with a keypress. The feedback is provided quickly with a trigger delay of no more than 3 to 5 milliseconds.

Linear haptic feedback actuators work with an operating voltage of between 9 and 16 V, and their only drawback is their installation height of 16 mm.

Vishay offers such an actuator based on a solenoid coil—the IHPT-1411 combines very compact construction with powerful oscillation of 6g with a mass of 0.5 kg and a trigger voltage of 12 V, enabling it to simulate a keypress on a touch display, for instance. Its standard connectors have been immersed in 100% solder, and customized connectors are also possible on request. The IHPT-1411 has also been available with AEC-Q qualification since recently.

Vibration motors: easy to control

Vibration motors move a weight, such that they vibrate instead of emitting the "click" feedback of actuators. However, they suffer from relatively substantial lag with a trigger delay of between 20 and 50 ms, which makes the feedback seem somewhat artificial. They require a trigger voltage of under 12 V—most models can run with just 3 V—and are easy to trigger. Vibration motors are only suitable for

Figure: Vishay

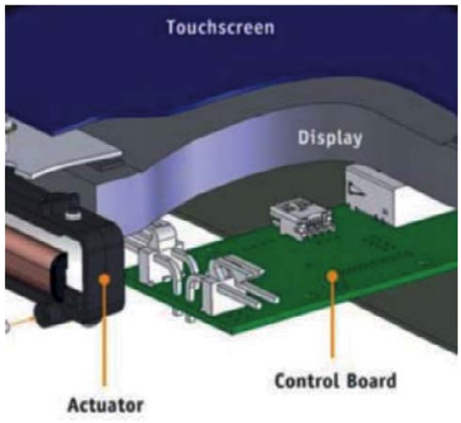


Figure 1: Construction of a touchscreen with haptic feedback actuator.

Figure: Vishay

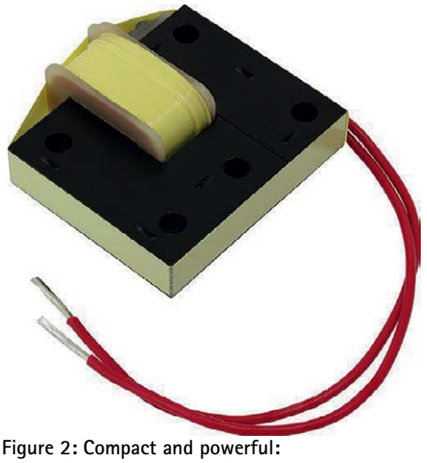


Figure 2: Compact and powerful: the IHPT-1411 actuator from Vishay.

Figure: TDK

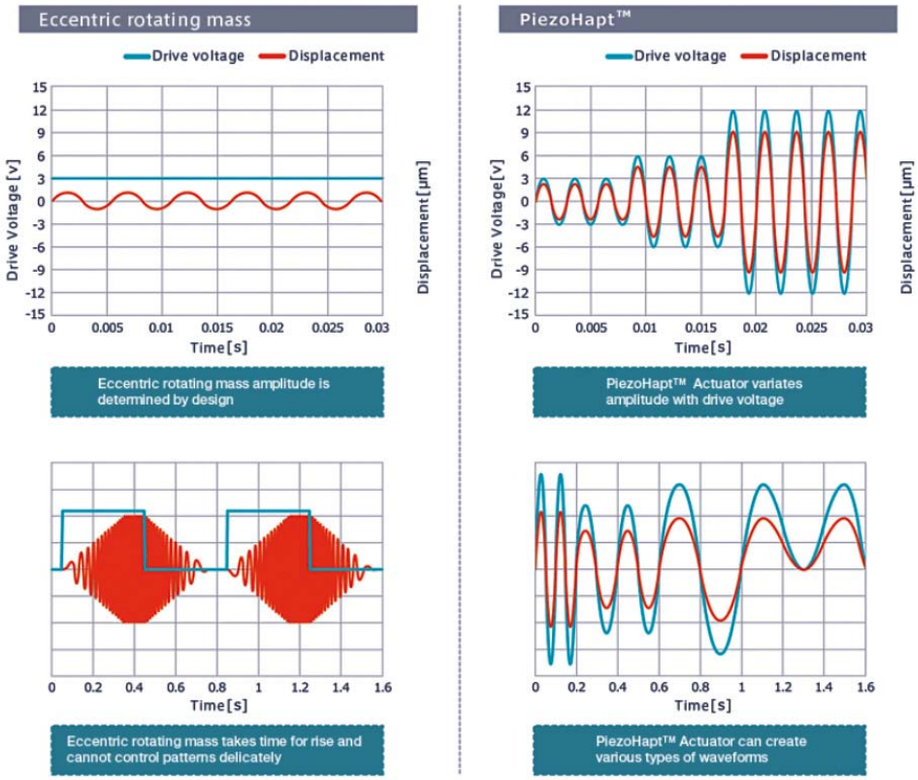


Figure 3: A comparison with vibration motors shows that piezo elements respond much more quickly and flexibly.

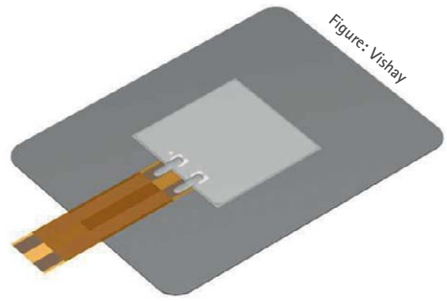


Figure: Vishay

Figure 4: The PiezoHapt-L from TDK is just 0.35 mm thin and is ideal for adding haptic feedback to a single button.

smaller displays, however. This is because, for example, a display that is as large as a tablet and is screwed to the vehicle would have to have a vibration motor that is very large and respond with a great deal of lag.

Piezo elements: flat and pressure-sensitive

At 0.25 mm, piezo elements are extremely flat. They are also pressure-sensitive, which means that greater pressure on a given position of the display generates a greater voltage than lighter pressure. The feedback from the piezo element varies depending on the voltage, and the actuator can also trigger different types of feedback within different waveforms. This opens up other control opportunities—for example, you could have the volume of a sound system increase faster the harder you press. However, the feedback is less pronounced than with the other two technologies.

Piezo elements have no moving parts whatsoever and this makes them very long-lasting. However, they do have the disadvantage of a high trigger voltage of at least 24 V.

The PiezoHapt-L (PHUA8060-35A-33-000) from TDK is a suitable solution for providing a small element such as a single button with haptic feedback. It uses a multi-layer piezo element, which means it can handle a minimum voltage of 24 V, and can generate greater oscillation than a single-layer element of the same thickness.

The PiezoHapt actuator has a unimorph structure—in other words, it consists of an active and a non-active layer. The active, piezoelectric element with electrodes on both sides is bonded on one side to a non-active metal plate. If an alternating current is applied to the electrode, the piezoelectric element alternately expands and contracts, which causes the bonded metal plate to move accordingly (Figure 5). The alternating current creates alternating peaks and troughs that produce a vibration. This is done very efficiently thanks to the unimorph structure.

Depending on the amplitude and frequency of the applied voltage, the PiezoHapt-L can generate a variety of vibration patterns; it is incredibly responsive with a reaction time of 4 ms. The vibration plate on which the piezo element is mounted measures 80 mm × 60 mm and is barely 0.35 mm tall.

Surfaces with feeling

Touch displays aren't the only thing that can be fitted with haptic feedback—any smooth surface can become a touch-sensitive solution that replaces conventional buttons and switches on the dashboard and in the door panel. The IHPT-1411 actuator from Vishay is ideal for this. And with this, there's absolutely no excuse not to keep your eyes on the road! ■

Figure: TDK

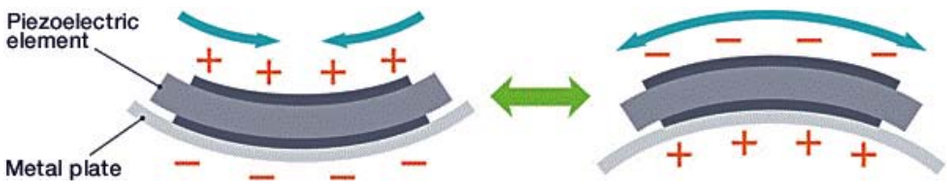


Figure 5: The PiezoHapt actuator from TDK is very efficient thanks to its unimorph structure.

Current sensing solutions

Concepts for measuring direct current

The growth of electrification is unyielding. And where devices used to be powered from mains grids and thus by AC currents, today they are often battery-powered. And all the while, the electrical power levels required are getting larger and larger. Efficient and precise current measurement requires suitable sensors – especially for DC currents.

By Ralf Hickl, Product Sales Manager Automotive Business Unit at Rutronik

Three methods are available to measure pulsed currents from power supplies with DC components.

Method 1: shunts

Shunts measure current directly on the basis of Ohm's law. Current flowing through a resistor causes a voltage across that resistor to drop in proportion to the current. This linear correlation makes it especially simple to process the analog signal into a measurement. A current sensing amplifier processes the measurement voltage so that the input voltage range of the analog/digital converter (ADC) is properly utilized in the microcontroller.

Suitable shunts are available from suppliers such as Vishay, Rohm, KOA, and Panasonic. They range in size from chip resistors to massive metal arches with screw connectors and power losses of up to tens of watts.

If the layout and signal pickup is compliant with the handling conditions stipulated by the manufacturer, the imprecision of the

Figures: Rutronik

Construction of a current sensor using shunts, including signal processing.

Magnetic field sensors are also suitable for measuring large currents, but require expertise on the mechanics.

Current sensor ICs and modules are very easy to use.

measurement will be dependent on the tolerances of the components used in the signal chain. The information in the data sheets makes it relatively easy to evaluate the precision of the system as a whole.

Advantages with the use of shunts for current measurement are:

- High bandwidth
- Low sensitivity to interference
- Large and diverse range of products
- Can be integrated into busbar (power rail)

Vishay offers current measurement resistors optimized for PCB assembly in a sample kit.

Disadvantages:

- Measurement principle with power loss proportional to R and I^2
- No galvanic isolation between measurement current and measurement signal
- Expertise in analog signal processing required

Rutronik24.com provides a useful list of suitable shunt resistors under Passive Components > Resistors > Precision Chip Resistor.

Method 2: magnetic field sensors

This method involves the magnetic field sensor being placed on the electrical conductor. A cylindrical magnetic field forms around the straight, energized conductor. According to Ampère's law, the strength of the magnetic field is dependent on the current and the distance from the conductor. A user constructing a current sensor based on this principle must therefore control the mechanical production tolerances and the mechanical stability of the structure as a whole.

The advantages of using magnetic field sensors are:

- Galvanic isolation of measurement current and measurement signal
- Practically zero power loss in measurement
- Digitalization already performed in the magnetic field sensor
- Suitable for measurement of large currents

Disadvantages:

- Potentially sensitive to stray fields
- Mechanical expertise required of user, geometry, and production tolerances reflected in transfer function
- Low bandwidth

Magnetic field sensors are available on the market from suppliers such as Infineon, Micronas, and Melexis, and can be found at rutronik24.com under Semiconductors > Sensors > Current Sensors.

Method 3: ready-to-use current sensor ICs or current sensor modules

The use of prefabricated current sensor modules or ICs is much simpler than using magnetic field sensors, as manufacturers will have already solved the mechanical design issues. The transfer curve is known and is shown in the data sheet. Current sensor ICs for soldering onto PCBs where the conductor is fed through the IC package are widespread. For higher currents, there are modules with package (through-)holes through which the power conductor is looped once or several times. Varying the loop count provides a simple method of adjusting the sensitivity of the measurement system.

The advantages of using ready-to-use modules and ICs are:

- Ease of use with curves as described in the data sheet
- Galvanic isolation of measurement current and measurement signal
- Practically zero power loss in measurement
- Digitalization already performed in the sensor module

Disadvantage: few suppliers

The manufacturers of current sensor ICs and modules include Infineon and BYD. The products are available at www.rutronik24.com: Semiconductors > Sensors > Current Sensors.

Conclusion

As battery-powered devices become more widespread and electrification progresses, there are ever more DC currents to be measured. Depending on the current level and the frequency range of a superimposed AC component, there are various sensors available: shunt resistors, current sensor modules/ICs, or proprietary developments with magnetic field sensors.

Shunt resistors are especially ideal for low voltages due to the lack of galvanic isolation and for low currents due to the unavoidable power loss, which increases in proportion to the square of the current.

Even so, they are used in some electric vehicles with currents of several hundred amperes and voltages of 400 V for the purpose of detecting battery currents.

Because shunt resistors have a low self-inductance, the frequency range is large and is dictated broadly by how analog signals are processed downstream.

Current sensors using magnetic fields are especially well-suited to large currents, as they experience practically no power loss, and are ideal for high voltages as they offer galvanic isolation. The bandwidth is usually limited by the sensor anyway, and less so by the downstream electronics.

Current sensor modules and ICs are ideal for projects requiring a shorter time-to-market. ■

AUTOMOTIVE HIGH CAP. MLCC

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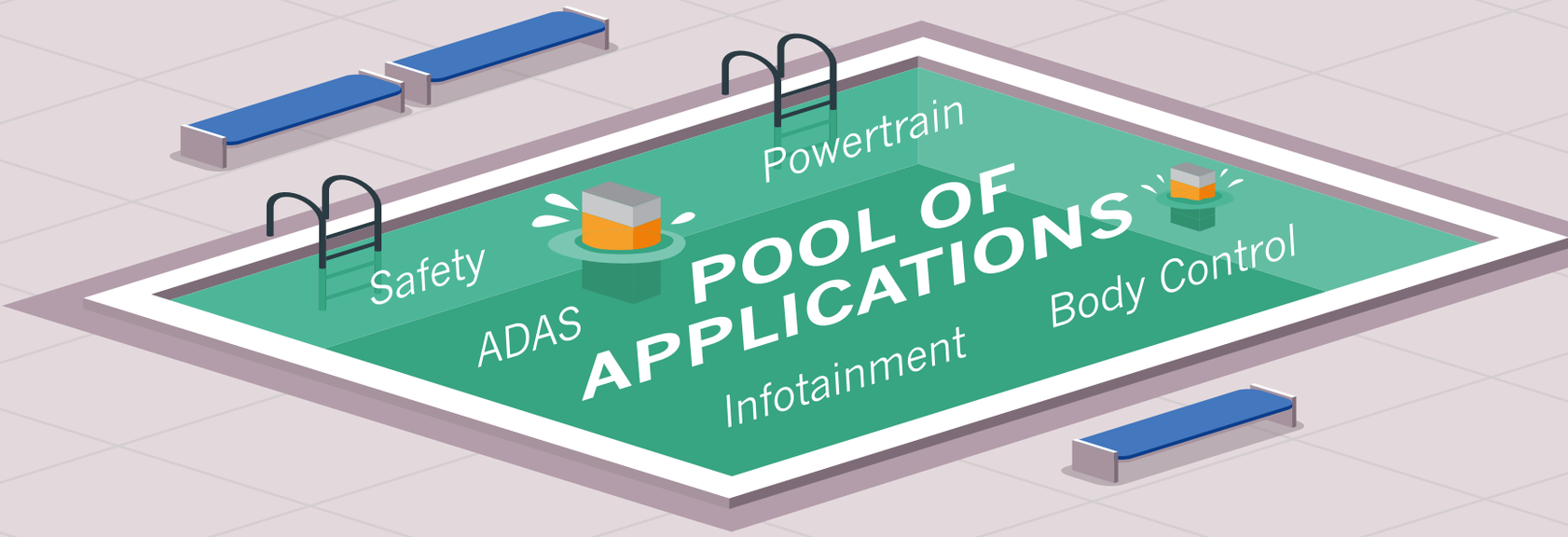

AEC-Q200 — **PREMIUM QUALITY** — **VW80808**

Voltage	Application	Size	X7R/X7S Standard - PN Series	X7R/X7S 5mm Bending - PJ Series
100V	xEV 48V Battery Line	1210” 1206” 0805”	**4.7μF:** CL32Y475KCIVPNE **2.2μF:** CL31Y225KCHVPNE **1μF:** CL21Y105KCYVPNE	**4.7μF:** CL32Y475KCIVPJE **2.2μF:** CL31Y225KCHVPJE **1μF:** CL21Y105KCFVPJE
50V	ICE 12V Battery Line	1210” 1206” 0805”	**10μF:** CL32Y106KBJ4PNE **10μF:** CL31Y106KBKVPNE **1μF:** CL21B105KBFVPNE	**10μF:** CL32Y106KBJVPJE **10μF:** CL31Y106KBKVPJE **1μF:** CL21B105KBFVPJE
25V		1210” 0805”	**22μF:** CL32Y226KAVVPNE **4.7μF:** CL21Y475KABVPNE	**10μF:** CL32B106KAJVPJE **4.7μF:** Coming Soon
16V	DC Block EMI Filter Power Supply	1210” 1206” 0805”	**22μF:** CL32B226KOJVPNE **10μF:** CL31B106KOHVPNE **10μF:** CL21Y106KOQ4PNE	**22μF:** CL32B226KOJVPJE **10μF:** CL31B106KOHVPJE **4.7μF:** CL21B475KOQVPJE
6.3V		1210”	**47μF:** CL32Y476MQVVPNE	**47μF:** CL32Y476MQVVPJE

Voltage	Application	Size	X8L - Up to 150°C High Temperature Standard - PN Series
25V	ICE 12V Battery Line	1206” 0805” 0603”	**2.2uF:** CL31E225KAH4PNE **470nF:** CL21E474KAF4PNE **220nF:** CL10E224KA84PNC

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Si vs. SiC MOSFETs

Exchange technology–but correctly!

Silicon-carbide-based (SiC) MOSFETs allow for much greater efficiency levels compared to silicon-based (Si) versions, although it is not always easy to decide when this technology is the better choice. We explain which criteria are to be considered here.

By Hannah Metzner, Product Sales Manager Power at Rutronik, and René Mente, Senior Staff Engineer PSS Division at Infineon

For voltages over 1000 V, IGBTs were usually the solution of choice. But the superb properties of SiC now enable fast-switching, unipolar components that can be used in place of bipolar IGBTs. They enable applications that were previously only feasible at lower voltages (<600 V) to now be implemented at higher voltages. Compared to bipolar IGBTs, these SiC-based MOSFETs offer power loss reductions of up to 80%.

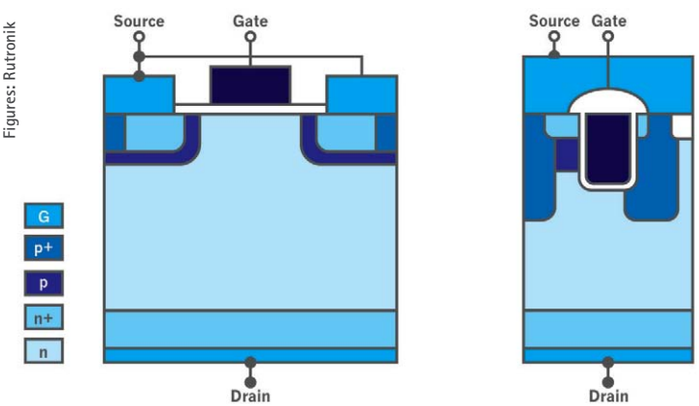
Infineon has further optimized the already beneficial properties of SiC—with CoolSiC Trench Technology, MOSFETs with especially high threshold voltages (V_{th}) and low Miller capacitance are possible. This makes them more resilient to undesirable parasitic turn-on effects compared to other SiC MOSFETs. In addition to the 1,200 V and 1,700 V models, Infineon has since expanded its portfolio to include 650 V CoolSiC MOSFETs, which can also be used in 230 V mains applications. Their higher system efficiency and robustness and their lower system costs enable them to be used in applications such as telecommunications, servers, charging stations for electric vehicles, and battery packs.

If the choice is generally between the tried-and-true Si-based MOSFETs and the more recent SiC-based MOSFETs, there are various criteria to consider.

Efficiency and power density of application

Compared with silicon, the R_{DSon} of silicon carbide is less prone to volatility in the operating temperature range. With a SiC-based MOSFET, R_{DSon} only moves by a factor of around 1.13 between 25°C and 100°C, while with a typical Si-based MOSFET such as the CoolMOSTM C7 from Infineon, it changes by a factor of 1.67. This means that the operating temperature has much less of an impact on power loss and can therefore be much higher. As a result, SiC-based MOSFETs are ideal for high-temperature applications or can make do with simpler cooling solutions to achieve the same efficiency levels.

Figures: Rutronik



SiC-based MOSFETs have fewer conductivity losses and up to 80% fewer switching losses compared to IGBTs—in this case using the example of the 650 V CoolSiC MOSFET from Infineon.

Drivers

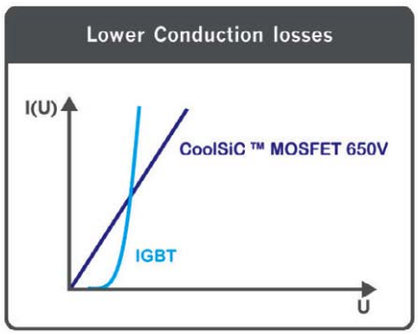
When switching from silicon to silicon carbide, there is also the question of suitable drivers. If Si-based MOSFET drivers generate a gate turn-on voltage of up to 15 V, they can generally continue to be used. However, a gate turn-on voltage of up to 18 V allows for a significant further reduction in the resistance R_{DSon} (by up to 18% at 60°C), such that a change in driver might still be worthwhile.

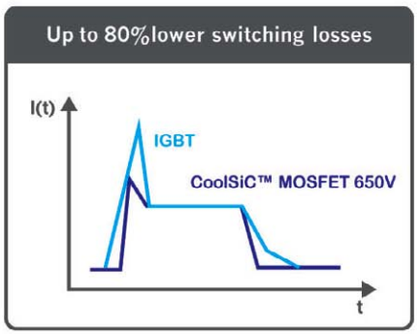
It is also recommended to avoid negative voltages at the gate as these can cause a shift in $V_{GS(th)}$, such that R_{DSon} increases with prolonged operation. The voltage drop across the source inductance in the gate drive loop results in a high di/dt, which may cause a negative $V_{GS(off)}$ level. An even bigger challenge is posed by a very high dv/dts, which is caused by the gate drain capacitance of the second switch in a half-bridge configuration. This problem can be avoided with a lower dv/dt, but at the expense of reduced efficiency.

The best way to limit negative gate voltage is to use a separate power and driver circuit by means of the Kelvin source concept and to integrate a diode clamp. Positioned between the gate and source of the switch, a diode clamp limits the negative voltage present at the gate.

Reverse recovery charge Q_{rr}

Especially with resonant topologies or designs that use continuous hard commutation of the conducting body diode, it is important to also consider the reverse recovery charge Q_{rr}. This is the charge that has to be removed from the





Trench Technology minimizes losses in use and provides maximum reliability in operation.

integrated body diode—present in all diodes—when the diode is no longer conductive. Various component manufacturers have made great efforts to reduce this charge as much as possible. The "Fast Diode CoolMOS" family from Infineon is one example of the fruits of these efforts. These feature faster body diodes and can reduce Qrr by a factor of 10 compared to their predecessors. Infineon's CoolSiC family even gets one up on this—compared to the latest CoolMOS components, these SiC MOSFETs achieve a further 10× improvement.

CoolSiC technology allows for the development of systems with fewer components and reduced magnetic elements and heat sinks, making them simpler, smaller, and cheaper. Thanks to Trench Technology, these components also guarantee the lowest losses in usage and the highest reliability in operation.

Power factor correction (PFC)

The focus of the industry is currently on increasing system efficiency. To achieve efficiency values of at least 98%, more efforts are being directed towards power factor correction (PFC). SiC-based MOSFETs with improved Qrr help to achieve this. These now enable hard-switched half-bridge/full-bridge topologies for PFC. For its CoolMOS technology, Infineon had previously recommended a "Triangular Current Mode" approach, but with SiC it is possible to implement a continuous conduction mode totem pole PFC.

Output capacitance C_{OSS}

In a hard-switched topology, the stored energy E_{OSS} must be dissipated; this energy is typically greater than with the latest CoolMOS version. Compared to the turn-on losses of a totem pole PFC, however, it is still relatively low and thus negligible, at least initially. The lower capacitance means that it is possible to benefit from faster switching speeds, but this can also lead to drain source overshoot (V_{DS}) during turn-on.

With Si-based MOSFETs, this can be compensated for using an external gate resistor to reduce the switching speeds and achieve the required voltage derating of 80% at the drain source. The disadvantage of this solution is that, especially during turn-off, the increase in current results in greater switching losses.

While the output capacitance with SiC-based MOSFETs is greater than with comparable Si-based power semiconductors across a 50 V drain source voltage, the C_{OSS}/V_{DS} relationship is much more linear. The result of this is that SiC-based MOSFETs allow a lower external resistor to be used in the same circuit compared to Si-based models without exceeding the maximum drain source voltage. This can be advantageous in some circuit topologies, for example in LLC resonant DC/DC converters, in which it is possible to omit the additional gate resistor.

Conclusion

Although silicon carbide technology has many advantages, the obsolescence of Si-based MOSFETs is by no means a given. This is in part due to the much higher threshold voltage of the body diode—simply replacing a Si-based MOSFET with a SiC-based model would result in four times the power loss in the body diode, essentially sacrificing the efficiency gains. To actually benefit from the greater efficiency of SiC-based MOSFETs, the boost function of a PFC must be used across the MOSFET channel and not in the reverse direction across the body diode. Dead times must also be optimized to fully leverage the benefits of SiC-based MOSFETs. ■

A comparison of electromechanical and MOSFET relays

Analog technology in the digital age

The world is changing at an ever-faster pace—and so, too, are electronics. Components are expected to provide ever more performance while offering smaller, more compact constructions, and need to satisfy ever more sophisticated technical specifications to boot. So that means with relays, we will be going with MOSFETs in the future instead of electromechanical designs—right?

By Burak Duman,
Technical Support at Rutronik

Much like other so-called "dinosaurs," electromechanical relays have long been declared to be obsolete. But they're still hanging around—they still have their advantages, just like the MOSFET relays that were meant to replace them. So the choice is dependent on the individual circumstances—we need to compare the most important parameters. A relay's key parameters include service life, trigger current, switching speed, electrical isolation, and, of course, price.

Service life

MOSFET relays have a longer service life than electromechanical designs, as they are not switched mechanically—they are activated by a light signal (LED) that is converted into an electrical voltage. The LED is the only factor here that limits the life of the relay.

In an electromechanical relay, on the other hand, applications involving high inrush currents for switching purposes can result in the contacts melting, which can cause the contact tabs to be fused. To prevent this, some manufacturers have developed special high-inrush relays. The G5RL from Omron, for example, can handle trigger currents of up to 100 A. This is achieved in part by the use of silver tin oxide ($AgSnO_2$) as a contact material. At the same time, it must be noted that inrush surges are not prevented by the use of high-inrush relays. The relay is only capable of handling these peak currents.

Trigger current

MOSFET relays can be triggered by a current as little as 0.2 mA, for example the G3VM from Omron (high-sensitivity types). With battery-powered applications, this ensures a long service life, and when using multiple MOSFET relays, it prevents mains overload. Electromechanical relays require a trigger current of at least 5 mA.

Switching speed

In terms of switching speed, MOSFET relays clearly have the advantage, needing barely 0.2 ms while electromechanical relays require all of 5 ms.

Noise levels

MOSFETs switch entirely silently as they are triggered by a light signal. In electromechan-

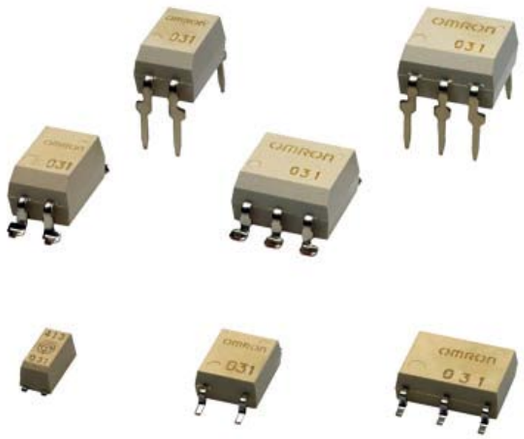
Figure: Scanrail/stock.adobe.com

ical relays, switching is performed—as the name suggests—mechanically. This results in a clicking sound. For applications where noise levels are a factor, however, there are low-noise relays available. The G5RL from Omron, for example, doesn't exceed 30 dB.

Electrical isolation

Both relay types are electrically isolated, albeit with a difference—a MOSFET is only electrically isolated on the load terminal, while an electromechanical relay is isolated on both the load and trigger terminals. This might be a critical argument in safety-related applications in favor of an electromechanical relay.

Figure: Omron



The high-sensitivity relay G3VM from Omron is ideal for battery-powered applications or where multiple MOSFETs are being used.

Price

Electromechanical relays are currently cheaper than MOSFET models. But if we incorporate the service lives into cost-of-ownership analyses, they will be more expensive in some applications due to the addition of maintenance costs.

Conclusion

Electromechanical relays continue to have a purpose, especially in safety-critical and cost-sensitive applications such as solar power generation products, energy storage facilities, and electromobility. Where other requirements play a key role, MOSFET relays have the advantage. This is why both technologies tend to supplement one another than compete against each other. The most important thing is to be aware of their respective advantages and disadvantages in order to make optimum use of the components. ■

CO_2 sensors based on new measurement principle

Time to clear the air

Aside, perhaps, from H_2O for water, there's barely a chemical component that is so well-known as CO_2 for carbon dioxide. CO_2 sensors measure carbon dioxide concentrations in the air so that action can be taken if limits are exceeded. The latest models are smaller and cheaper than their predecessors.

By Marcel Saffert, Product Sales Manager Analog & Sensors, and Markus Balke, Senior Manager Product Marketing Analog & Sensors, both at Rutronik

CO_2, the base substance for all organic compounds, is a colorless, odorless gas consisting of carbon and oxygen. Plants use photosynthesis to convert it to oxygen together with water.

CO_2 is produced by cellular respiration and by the decay of animal and plant organisms. In human civilization, it is also produced by the combustion of fossil commodities in industry, when heating buildings, or in vehicle combustion engines. This is causing the concentration of CO_2 in the Earth's atmosphere to rise, which drives the greenhouse effect and provokes climate change.

Impact on humans

In small quantities, carbon dioxide is perfectly safe for human beings. At higher concentrations, however, it can prevent the lungs from taking in oxygen and can cause a variety of symptoms, depending on the amount of CO_2 in the air. With CO_2 of between one and three volume percent in the air, concentration may be impaired, fatigue may develop, and there may be an increase in heart rate or blood pressure. CO_2 content of five volume percent upwards may cause dizziness, headaches, shortness of breath, and ultimately unconsciousness.

This is why DIN EN 13779 defines four categories of indoor air quality based on carbon dioxide concentration. It classifies CO_2 levels below 800 ppm (parts per million) as good, levels up to 1,000 ppm as being of medium-good quality and levels of 1,000 ppm upwards as medium. When CO_2 exceeds 1,400 ppm, the air quality is deemed to be poor. At the workplace, employees must not be exposed to more than 5,000 ppm of CO_2 over eight hours.

CO_2 and coronavirus

In the midst of the coronavirus pandemic, studies have examined whether there is a direct link between the concentration of CO_2 and aerosols, which could be a trigger for COVID-19 infection when containing a viral payload. Based on current knowledge, there is no such link. Even so, a higher CO_2 content is indicative of poor indoor air, which also commonly entails elevated aerosol concentrations—so there certainly is an indirect link between CO_2 and aerosols. There are therefore two good reasons to be consistent in employing ventilation measures: improved well-being and greater performance as well as a reduced risk of infection by coronavirus.

Not only that, but coronavirus control measures such as home working and homeschooling as well as business and restaurant closures are causing most people to spend more time at home. Because buildings are increasingly being better insulated to satisfy modern energy efficiency standards, there is very little ventilation taking place. This is why it is more important than ever to take note of the CO_2 content of indoor air.

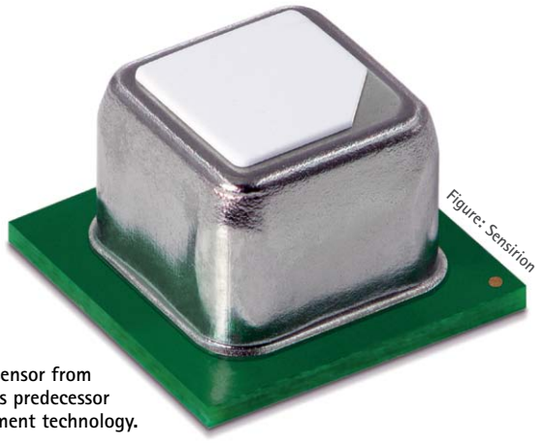


Figure: Sensirion

Figure 1: The SCD4x CO_2 sensor from Sensirion is much smaller than its predecessor due to its new measurement technology.

Avoiding stuffy air

Suitable sensors are used to measure CO_2 concentrations, for example for CO_2 warning lamps. In classrooms, they can be used to provide a simple, visual indication when concentrations are too high and the windows should be opened. In smart home systems, they provide values that are used to automatically trigger ventilation measures or warning signals.

This sensor data can also be used for other information, for example to determine how many persons are currently present in a room. An algorithm is used here to compare the average increase in CO_2 levels generated by human respiration against the measured increase in CO_2 concentration.

In the food industry and food logistics, controlled regulation of CO_2 concentration can actively affect product quality, because CO_2 can speed up or slow down the natural aging processes of fruit and vegetables. CO_2 content also has an effect on plants and animals. By detecting and adjusting this value, producers can use this to their benefit.

NDIR measurement technology

The SCD30 sensor from Sensirion is a proven solution for measurements of this type. It detects CO_2 concentrations using NDIR measurement technology (nondispersive infrared spectroscopy) with a high precision of ±30 ppm +3% of the measurement value in a measurement range of up to 40,000 ppm.

NDIR measurements are based on an infrared radiation source and two optical filters placed opposite one another with two detectors in a tube. The radiation source emits a wavelength that is solely absorbed by CO_2 molecules. Air flows into the tube through an opening, and the CO_2 molecules present therein absorb part of the radiation. The opposite detectors measure the resultant change in radiation intensity. The second detector provides a reference measurement to minimize the impact of contamination such as dirt or dust.

This principle results in comparatively large sensors—Sensirion's SCD30 measures 35 mm × 23 mm × 7 mm—but due to the high precision of its measurements, it has still been a key product in CO_2 detection for many years.

Photoacoustic system

Sensirion has now introduced a successor—the SCD4x—which satisfies all requirements relating to miniaturization and reduction in power consumption. It is based on the new photoacoustic sensor technology, which does not require a minimum distance between the radiation emitter source and the sensor. This means that the SCD4x measures just 10 mm × 10 mm × 6.5 mm and is still cheaper than its predecessor. However, the other measurement technology reduces the precision to ±50 ppm +5% of the measurement between 400 and 2,000 ppm (SCD40) or ±40 ppm +5% of the measurement between 400 and 5,000 ppm (SCD41). As with its predecessor, the SCD30, the measurement range is 0 to 40,000 ppm.

Infineon has also announced a CO_2 sensor based on photoacoustic measurement technology. Measuring 14 mm × 14 mm × 7.5 mm with a precision of ±30 ppm +3% of the measurement, the manufacturer reports that it will be available from mid-2021.

The small size and superior value for money make these new sensors especially compelling for applications in the smart home, IoT, automotive, HVAC, food, and consumer goods fields.

Photoacoustic measurement technology is based on narrow-band light that matches the absorption bands of CO_2 molecules. This means that it has precisely the wavelength range in which its electromagnetic radiation is absorbed by CO_2 molecules. The light is emitted into the measuring cell of the sensor, and the CO_2 molecules absorb part of the light. The energy that this produces causes oscillations in the CO_2 molecules, which increases

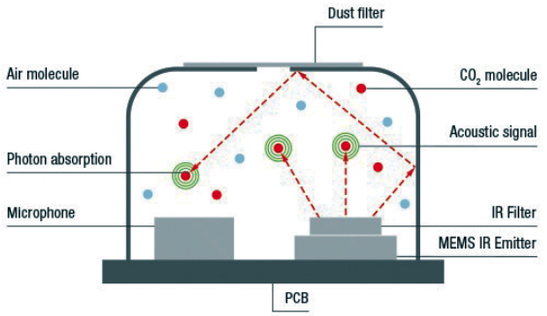


Figure: Sensirion

Figure 2: How photoacoustic measurement technology, which is used as PASens technology in the new SCD4x CO_2 sensor from Sensirion, works.

the pressure in the measuring cell. A microphone measures this pressure difference, which enables conclusions to be drawn on the number of CO_2 molecules present in the measuring cell and thus on the CO_2 concentration in the air.

With this measurement technology, the low drift of the detector signal in common measurement ranges offsets the reduction in measurement precision. As the CO_2 concentration rises, so, too, does the drift. With NDIR technology, the exact opposite is true—the drift of the detector signal is more pronounced particularly where CO_2 concentrations are low (Figure 3).

Conclusion

It has never been as important as it is now to be aware of CO_2 concentrations in the air, because it not only affects the well-being and health of people, but can also help to contain the spread of coronavirus infections. The food production industry and logistics sectors as well as animal and plant breeding activities can actively influence the quality of their products using CO_2 levels. Tried-and-true CO_2 sensors benefit from high measurement precision. More recent models cater to demands for smaller sensors and lower costs, although measurement precision does suffer as a result. ■

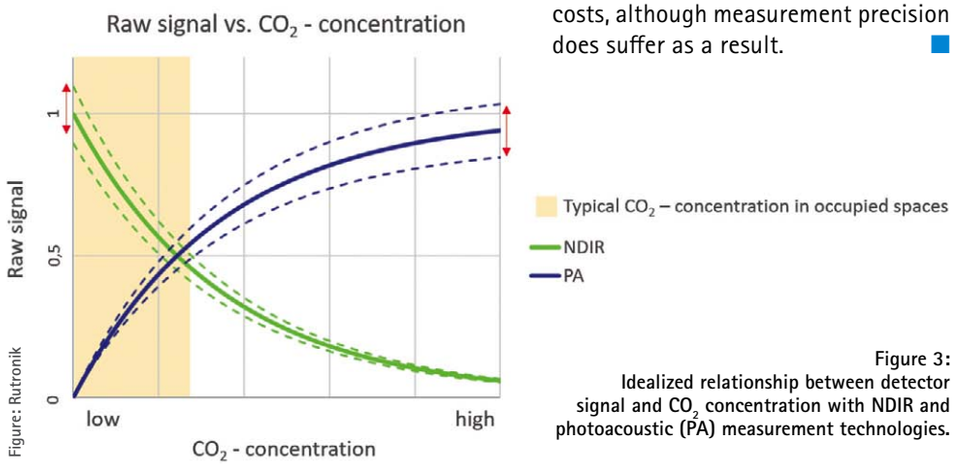


Figure: Rutronik

Figure 3: Idealized relationship between detector signal and CO_2 concentration with NDIR and photoacoustic (PA) measurement technologies.

Reference designs, dev kits, and more

Off-the-shelf is fine, but nothing beats customization

Application notes, user guides, development kits, and evaluation boards aim to help developers achieve results with even shorter times-to-market to meet ever more stringent requirements. To satisfy these demands, there are a few aspects that need to be considered from the outset.

By Martin Dossmann,
Product Sales Manager Inductors
at Rutronik

Figure: yurygolub/stock.adobe.com

The leading semiconductor manufacturers were quick to recognize that it is not just the performance and quality of their products that affect their market performance. Extensive documentation is also a competitive advantage that should not be underestimated, because this makes it easier for product developers to implement the components.

Manufacturers are providing more and more extensive tools on their websites for this purpose. They range from entire circuit diagrams with parts lists, including all necessary passive and electromechanical components, and even tools to integrate all product data for peripheral components into the simulation tools.

Semiconductor suppliers often develop these reference designs jointly with manufacturers of electromechanical and passive components. The boards that this process produces serve superbly as test environments and as a starting point for in-house development. But they are not optimized according to the same criteria as an application for serial production. The reasons for this are obvious. Production numbers for test boards are very low, so it is often not worth performing unit cost optimization, which entails longer development times and higher development costs. The layout and space requirements of the boards are also not bound by any restrictions as the boards are not designed to be used in real environments. There are also the operating conditions of the semiconductor component to consider. These can vary greatly in a variety of applications, and this can have an impact on the requirements of all a circuit's components.

This means that the reference design can be relatively costly and still not meet the requirements of the application in terms of dimensions and weight, or in terms of other parameters such as temperature. This is why it is worth not taking the suggestions from the reference design on simple faith.

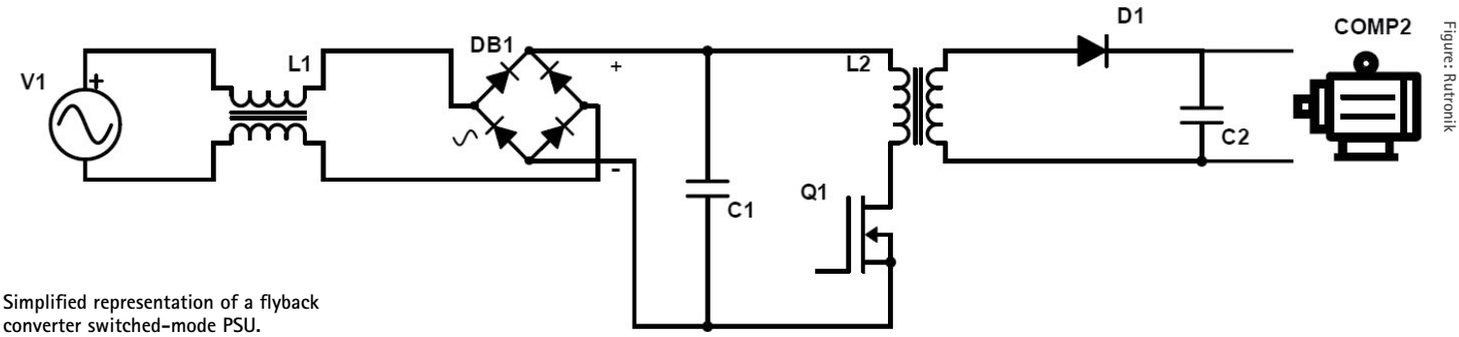


Figure: Rutronik

Simplified representation of a flyback converter switched-mode PSU.

Simplifying the time-consuming search for ideal components

The search for components that (better) meet requirements can be somewhat time-consuming. You need to consider in your specific circumstances how much time and effort you wish to invest in your search for alternatives.

The 80/20 rule provides a rough but helpful guideline here: 80% of the optimization potential can be realized with 20% of the effort. For optimizing cost, it is therefore usually advisable to focus on the high-value components in the circuit.

Best practice experience and external resources can help provide greater efficiency in development, for which broadline distributors are ideal—their application engineers and product managers are intimately familiar with the entire range of components, from semiconductors to passive and electromechanical elements to displays, boards, and systems as well as storage, memory, and wireless technologies, providing non-partisan advice on any and all manufacturers.

Example: power supply units

A key example here would be power supply units, as there are just a handful of circuit constructions that have become established in this area in practice. These topologies are used time and time again in similar arrangements. This allows a considerable wealth of knowledge from previously and successfully executed projects to flow into new designs.

Sure, the requirements of specific circuits can vary greatly, but the following example shows that experience gained in the field of power supplies can be very beneficial.

The flyback converter topology is well-established in galvanic isolation-based switched-mode power supply designs for industrial applications. The starting point of development in this example is usually the choice of a suitable converter for the power class in question. The associated BOM for the reference design usually contains 40 to 60 items. Some of these items are featured several times on the board. The image shows a simplified version of a typical circuit for a flyback converter AC/DC PSU. It focuses on the main cost-driver components, which need to be selected with care, especially when producing at large volumes.

The converter, pulse transformer, common-mode choke, and the two capacitors in the diagram already account for the bulk of the cost-driver components in this application. This is why attention should focus on the choice of components.

The prioritization in this example can be applied to a variety of development projects to save costs and enable more efficient complete solutions. ■

Text to speech

Look who's talking!

Talking and listening are the most natural ways for humans to communicate with one another—writing didn't come until much, much later. With human–machine communication, the trend is heading very much back to the roots. These days, high-quality audio files can be created in many languages with absolute ease.

Figure: wabeno/stock.adobe.com

By David Werthwein,
Product Manager Digital
at Rutronik

A device or a machine that can talk provides massive benefits in a great many applications. It provides accessibility for people with impaired vision. It is no longer necessary to have the device in question in sight, which is a massive safety boost when driving a car, for example. And it can also be very helpful when people are in a different room, for example when nurses in a hospital are audibly alerted to a dangerous situation, even if they are currently not actually with the patient. Similar warnings can be valuable in production facilities as well. Speech output can also make the operation of ever more complicated equipment much simpler.

Applications with bidirectional communication—i.e. those that can not only "speak," but also "listen," such as Siri, Cortana, and so on—take this a step further, although speech output is often wholly adequate. This offers the benefit of keeping hardware and software requirements much lower and eliminates the need for complex infrastructure with Internet connectivity.

Generating speech with ease from text files

Previously, text had to be recorded in each desired language to support speech output. This meant hiring a recording studio and professional voice actor or setting up your own studio—an expensive and time-consuming solution. To drastically reduce development time and costs, Epson has developed the ESPER2 Voice Data Creation PC Tool. This PC-based development environment can be used to create high-quality audio files, currently for up to twelve languages.

To do this, pre-worded sentences can be imported into the tool as a CSV file or entered directly into an editor form. The tool is used to generate a language file. ESPER2 also analyzes the text's sentence structure to achieve a proper and natural pronunciation and emphasis, and it also has an extensive dictionary. The pronunciation of product names, proper names, and invented words that are not in the dictionary can be defined as desired using the edit function. This makes it possible to have audio files generated of such quality that it is difficult to tell them apart from the natural spoken word of a human being.

If voice and audio files are already available in WAV format, these can also be used with ESPER2. The WAV files can be easily imported into the development environment, where they are joined with the files generated by ESPER2.

For further editing, sentences can be exported from the tool in CSV format for use in Excel.

Be understood everywhere in the world

ESPER2 currently supports 12 languages: US and UK English, French and Canadian French, German, Italian, Russian, European Spanish and Latin American Spanish, Chinese, Japanese, and Korean. To accommodate language-specific features, it is possible to adjust the tone and speed of the voice.

However, the tool does not have a translation function, which means that the text needs to be entered into ESPER2 in each desired language.

Epson has already announced a library containing audio files with common units such as currencies, weights, and similar values, as well as basic noises that can be used to add flourishes to human speech.

Minimal storage space and high voice quality

To enable efficient transfer and storage, ESPER2 uses Epson's proprietary EOV codec format (Epson Own Voice). Compared to the standard compression format ADPCM (adaptive differential pulse-code modulation), EOV shrinks file sizes by up to 66%—all while preserving superb speech quality at bitrates of 16 kbit/s to 40 kbit/s.

The .eov file consists of a lookup table combined with the audio files. To keep the countless sentences in multiple languages manageable for developers, they can assign the same ID in the lookup table to a sentence in several languages. This means that they then only need to reference one ID and the language is played in all languages.

To save even more storage space, it is possible to combine expressions that are frequently used with other expressions by joining them with a slash (/). For example, the days of the week would look like this:

ID number 1: "Today is/Monday."

ID number 2: "Today is/Tuesday."

ID number 3: "Today is/Wednesday."

The generated voice units here are: "Today is," and "Monday," "Tuesday," "Wednesday."

Storage and speech output with integrated ...

To store and output the generated voice files, Epson offers an integrated and a discrete solution. The integrated solution comprises a 32-bit ARM Cortex-M0+ microcontroller with an integrated voice and audio hardware processor (SoC) that enables the audio to be output simultaneously over two channels with a sample rate of 15.625 kHz each.

This is currently the only integrated solution on the market that can output text and audio at the same time. The unique feature here is that the individual volumes can be adjusted independently of one another. This can be used, for example, to reduce the volume of music as soon as the speech output begins. The pitch and voice speed are managed at a hardware level, and speed can be adjusted in 5% increments between 75% and 125%.

Figure: Rutronik

Rutronik's Arduino-compatible adapter board allows for fast creation of high-quality speech output.

The IDs of the generated voice and audio files are written to a register in the processor, which then plays the relevant audio files. This eliminates the need for special program code to link the audio files. Once the audio output starts, no additional CPU resources are required, freeing up the CPU entirely to handle other tasks or go into sleep mode.

... or discrete solution

The discrete solution combines a module from the S1V30xxx speech output IC range from Epson with an external host microcontroller. This is ideal for existing designs where the microcontroller cannot or should not be replaced. Any microcontroller with an integrated serial interface is suitable for this method.

The first module in this series, the S1V3G340, has just one audio channel, which means that it can output either speech or music. According to the manufacturer, all new speech output ICs should be fitted with two discrete channels, like the integrated solutions. Currently, the S1C31D50 microcontroller is available with two channels; the mix-play function allows these to be mixed together, for example as voice output with discreet background music. The S1C31D51 model also offers a sound generator to achieve speech output via a piezoelectric or electromagnetic buzzer. Special applications based on keywords to be recognized can be supported by the S1C31D50 or S1C31D51 microcontrollers in conjunction with a microphone connected to an A/D converter input.

Various evaluation tools from Epson can be used by developers to test the quality of the speech output—via a loudspeaker using the S5U1C31D50T1200 and S5U1C31D51T1100 evaluation board, or using the S5U1C31D51T2100 buzzer board via a piezoelectric or electromagnetic buzzer in conjunction with the S5U1C31D51T1100 evaluation board. All of the evaluation tools offer extensive testing software available in different languages, and the desired language can be selected using a DIP switch. Once the free ESPER2 software is installed and licensed, it is also possible to create your own sentences, modify them as you wish, and export them to the evaluation board.

Short sevelopment times thanks to Rutronik adapter board

If you need even shorter cut development times for high-quality speech output, you are best served by the Arduino-compatible RutAdaptBoard-TextToSpeech adapter board (Arduino Shield) from Rutronik, which can be plugged into any standard microcontroller evaluation kit with an Arduino interface. However, it is at its most convenient when combined with the RutDevKit Development Kit, because the appropriate software drivers are already available free of charge. As an alternative to the STM32L5 software driver, Rutronik has developed a driver for the Infineon/Cypress PSoC microcontroller.

The S1V3G340 sound IC from Epson is the heart of the RutAdaptBoard-TextToSpeech. It is controlled by the host microcontroller and can play back previously defined speech stored in the external NOR flash memory as binary data. The USB to SPI bridge converts the data from the USB protocol to a serial protocol during the flash process. The speech is first generated as a ROM file using the ESPER2 Voice Data Creation PC Tool for this purpose before it is then exported to the external NOR flash memory of the adapter board. Rutronik has developed a special PC software tool specifically for this that allows all previously generated speech data to be tested by outputting it on the PC alongside the flash process before it is actually written to the flash memory.

The speech is output to any external loudspeaker via an audio amplifier and 3.5 mm jack. Optimum audio output can be achieved with a loudspeaker with an impedance of 8 Ω or more.

RutAdaptBoard-TextToSpeech and RutDevKit are available at www.rutronik24.com. Rutronik's specialists are on hand to provide implementation support and advice, including for questions regarding additional components for the application such as audio amplifiers, NOR flash memory, or loudspeakers. ■

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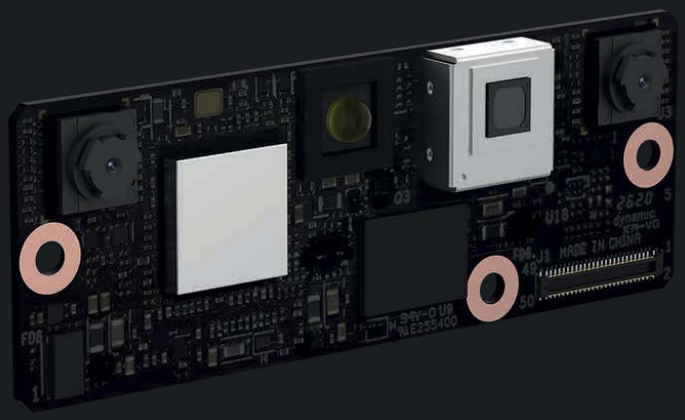

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