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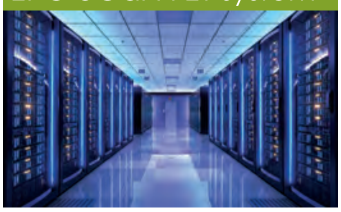
Off-grid energy management system

GaN HEMTs operating at high voltage

The energy innovation opportunity

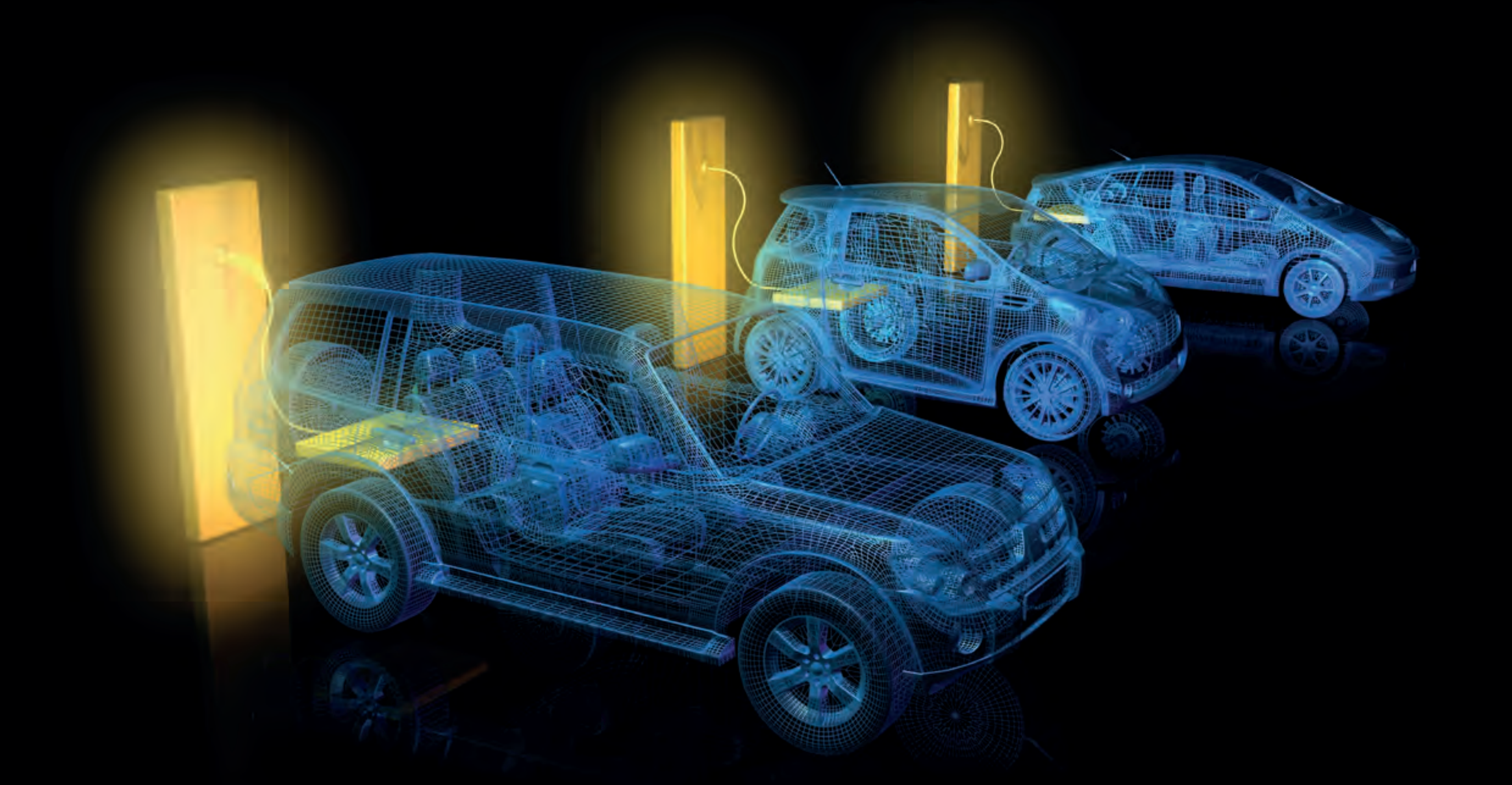
EV, industrial and telecom boost

Monolithic Power uses EPC eGaN FET system



Developing new GaN decade bandwidth MMIC power amplifiers

By Qorvo



AIXTRON
AIXTRON

editor'sview

By Mark Andrews, Technical Editor

Powering into a new year has never felt better

ACCORDING TO LEADING ECONOMISTS and industry analysts speaking at the SEMI Industry Strategy Symposium in January, the global economy will return to pre-pandemic growth levels in 2021.

How quickly our personal economies and life around us see a rebound is still open ended as vaccine makers ramp production and medical researchers strive to make certain what is going into eager recipients' arms is effective against the latest viral variants.

In a very real sense, our view of how the world fares depends very much on what happens to us individually. It has been with macabre irony that as people get sick in one place, they are healed elsewhere. Today's hot spot may be tomorrow's safe zone. Things we can't do today will soon enough be doable once more. Yet the power electronics industry and other IC sectors are surging along, setting 2020 sales records for everything from controllers to IGBTs to SiC-enabled inverters to the wide world of wideband tech.

According to SEMI experts still reconciling 2020, the year saw robust chip sales growth in the high single digits; manufacturing equipment sales increases ran at roughly double the IC percentages. The ISS experts said that while seasonality is having its usual effects on first quarter numbers, easing pandemic conditions are expected to spark expansions across broad semiconductor sectors following 2020's robust performance.

As EV sales and everything needed to give a vehicle its 'go' turned into a 2020 bright spot for power electronics makers, 2021 may be even better. In this edition, we examine how new insights into powering medical devices by researchers at imec are laying the groundwork for future technologies that will make diagnosing illnesses faster, more accurate, and potentially even life extending.

We also take an in-depth look at Qorvo's development of 2-20 GHz decade bandwidth GaN amplifiers that take the 'compromise' out of wideband design. We also examine hybrid power solutions from Wärtsilä Energy; high voltage HEMTs from Integra Technologies and we look at ways industry leaders like ON Semiconductor are growing and diversifying their product lineup to address 21st century challenges.

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CONTENTS

14 COVER STORY
Qorvo develops new GaN Decade Bandwidth MMIC power amplifiers

Gallium Nitride (GaN) power amplifiers are emerging for commercial applications in greater quantities than ever before

24 Reliable off-grid energy management system reduces electricity costs

A large gold mining operation in southwest Mali (Africa) required a hybrid energy system including fossil fuelled generators, a 30MW solar power plant, and energy storage. Wärtsilä's GEMS advanced energy management system has proven essential to achieving sustainable reliability and efficiency.

28 New wireless charging solutions for implantable, insertable and ingestible medicaldevices

Researchers from imec presented a novel, new system for wireless medical device communication and power at the 2020 ISSC conference. The devices, 30 times smaller than today's start-of-the-art systems, considered system power requirements alongside medically relevant data communication

32 DC's – the energy innovation opportunity

DCS recently hosted a virtual roundtable, sponsored by energy transformation company, ENEL-X, which brought together a range of experts to discuss ideas and technologies around sustainability and energy efficiency as they relate to the data centre

34 EV, industrial and telecom gave a boost to the 2020 power electronics market

Yole Développement examined the 2020 power electronics market to assess how the COVID-19 pandemic impacted core market sectors

38 Disrupting markets with high-voltage GaN HEMTs

GaN HEMTs operating at high voltage up to 150 V outperform vacuum tubes by combining high performance with greater reliability, longer lifetime and lower operating costs

41 Product Showcase

GTAT's Pure Play on Silicon Carbide Crystal Company rapidly increasing the supply of SiC

news

06 Denso Adopts SDK SiC epi-wafers for EVs

07 EnergyHub and Enel X partner to expand EV charging as a grid resource

08 ITRI and DuPont inaugurate new semiconductor materials Lab

09 GaN Systems launches novel GaN power stage

10 Monolithic Power Systems uses EPC eGaN FETs

11 EV Group establishes state-of-the-art customer training facility

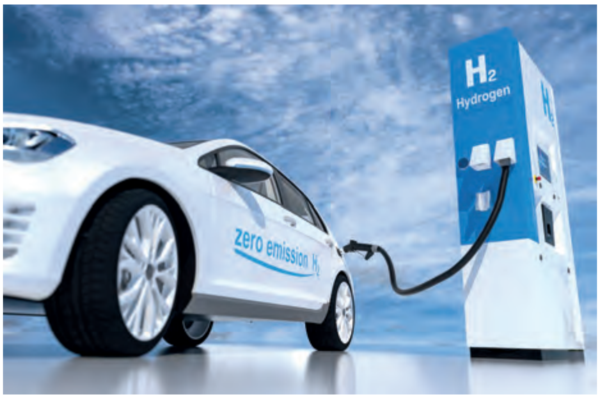
12 Tektronix releases TekDrive, groundbreaking data collaboration software

Denso Adopts SDK SiC epi-wafers for EVs

SiC EPITAXIAL WAFERS, the main material for power semiconductors, with a diameter of six inches (150mm) and manufactured by Showa Denko, have been adopted by Denso Corporation for its latest booster power modules for fuel cell electric vehicles (FCEVs).

SDK's SiC epi-wafers, launched in 2009, have been adopted by electronic device manufacturers for various devices including power supply for servers of cloud computing systems, quick charging stands for EVs, and railcars. DENSO adopted SDK's SiC epi-wafers for its next-generation power modules recognizing the track record of adoption by device manufacturers, highest-grade epi specifications, low density surface defects, and low frequency of basal plane dislocation.

When compared with current mainstream silicon-based semiconductors, SiC-based power semiconductors can operate under high-temperature, high-voltage, and high-current conditions, while substantially reducing energy loss. These features enable device manufacturers to produce smaller, lighter, more energy-efficient power control modules. SiC power semiconductors are already used in on-board battery chargers and quick charging stands for EVs, and railcars. Demand for SiC power semiconductors is expected to grow, with full scale use in power control units (PCUs) for EVs in and after 2025.



The Showa Denko Group aims to contribute to the solution of SDGs-related issues through its business activities and become "a social contribution company" that contributes to the creation of society where affluence and sustainability are harmonised. The size of the market for SiC epi-wafer, which realises efficient use of energy, is expected to be about 100 billion yen in 2025, and will grow further because of the start of its full-scale use as parts of PCUs.

As the largest independent manufacturer of SiC epitaxial wafers, and under a motto of "Best in Class," SDK will continue coping with rapid expansion of the market for SiC epitaxial wafers and providing the market with high-performance and highly-reliable products, thereby contributing to the spread of SiC-based devices.

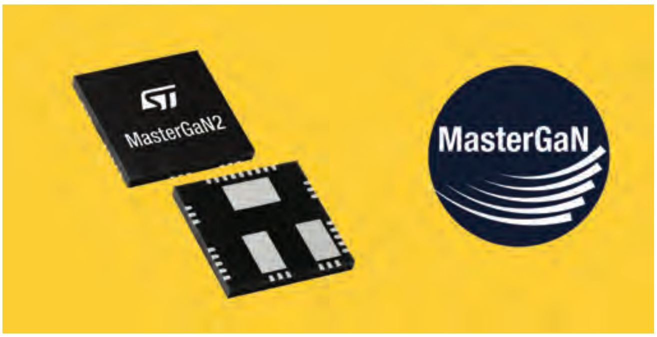
STMicroelectronics introduces MasterGaN2

BUILDING upon the advantages of STMicroelectronics' MasterGaN platform, MasterGaN2 is the first in the new family to contain two asymmetric GaN transistors, delivering an integrated GaN solution suited to soft-switching and active-rectification converter topologies.

The 650V normally-off GaN transistors have on-resistance (RDS(on)) of 150mΩ and 225mΩ. Each is combined with an optimised gate driver, making GaN technology as easy to use as ordinary silicon devices. By combining advanced integration with GaN's inherent performance advantages, MasterGaN2 further extends the efficiency gains, size reduction, and weight savings of topologies such as active clamp flyback.

The MasterGaN power system-in-package (SiP) family combines the two GaN HEMTs and associated high-voltage gate drivers in the same package with all necessary protection mechanisms built-in. The designer can easily connect external devices including Hall sensors and a controller such as a DSP, FPGA, or microcontroller directly to the MasterGaN device. The inputs are compatible with logic signals from 3.3V to 15V, which helps simplify the circuit design and bill of materials, permits a smaller footprint, and streamlines assembly. This integration helps raise the power density of adapters and fast chargers.

GaN technology is driving the evolution toward fast USB-PD adapters and smartphone chargers. ST's MasterGaN devices enable these to become up to 80 percent smaller and 70 percent lighter, while charging three times faster compared to ordinary silicon-based solutions.



The built-in protection comprises low-side and high-side under-voltage lockout (UVLO), gate-driver interlocks, a dedicated shutdown pin, and over-temperature protection. The 9mm x 9mm x 1mm GQFN package is optimised for high-voltage applications, having over 2mm creepage distance between high-voltage and low-voltage pads.

MasterGaN2 is in production now, priced from $6.50 for orders of 1000 pieces.

EnergyHub and Enel X partner to expand EV charging as a grid resource

ENERGYHUB has partnered with Enel X, the Enel Group's advanced energy services business line and EV charger manufacturer and service provider, to expand the availability of smart electric vehicle (EV) charging stations as a flexible distributed energy resource (DER) for utilities. Through the partnership, utilities can now manage customer-owned Enel X smart EV charging stations through EnergyHub's Mercury DERMS platform, expanding the breadth of EnergyHub's EV charging solution and increasing the EV charging resources available for utilities to manage. Utilities including Baltimore Gas & Electric (BG&E) and Eversource are the first to leverage the partnership and enroll customers with JuiceBox residential smart charging stations, with more to come.

Preparing for transportation electrification has emerged as a top priority for utilities. Bloomberg New Energy predicts EVs will account for the majority of passenger car sales by 2040. According to the same research, smart EV charging technology, which encourages customers to charge at optimal times, is estimated to save grid operators 30 to 70 percent of electrical infrastructure upgrade costs, representing hundreds of millions to billions of dollars a year in savings.

"We see managed EV charging as an important and growing piece of our DER portfolio, which we leverage not just during the hottest days of the year, but to manage demand year round," said Michael Goldman, Director of Energy Efficiency for Eversource. "We're glad to be able to allow more customers to participate by offering incentives to our customers with JuiceBox EV chargers."

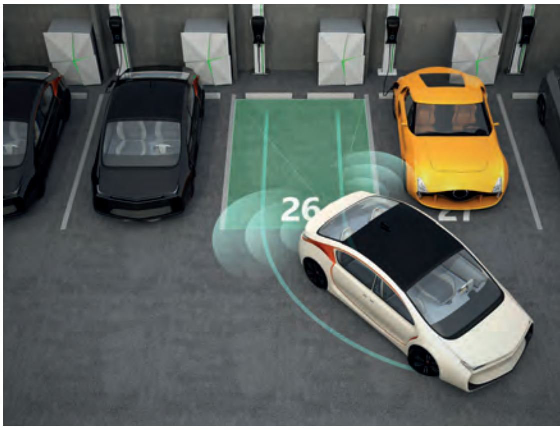
The partnership with Enel X, with over 60,000 consumer charging stations deployed nationwide, expands the ecosystem of EV chargers that utilities can manage with EnergyHub's Mercury DERMS.

"Working with EnergyHub and Enel X allows us to partner with our customers to manage flexible EV charging load, preparing us for the future of transportation electrification, while also supporting the grid as whole" said Kristy Fleischman Groncki, manager of strategic programs at Baltimore Gas and Electric. "Our EV Smart program managed with EnergyHub rewards customers for contributing to the grid while using their preferred EV charging equipment."

EnergyHub and Enel X are working with electric utilities to harness the benefits of EV adoption and smart charging for the grid. The partnership enables utilities to grow their DER portfolios deployed with EnergyHub by managing enrolled Enel X JuiceBox smart charging stations in a service territory. Through the integration of EnergyHub's Mercury DERMS platform with Enel X's cloud-based JuiceNet smart EV charging software, utilities can forecast load, intelligently instruct, and monitor load results from customer-owned Enel X charging stations.

"Preparing for mass adoption of electric vehicles and EV charging infrastructure is one of the most critical steps utilities should be taking today to lead the energy transition," said Giovanni Bertolino, Head of e-Mobility, Enel X North America. "Enel X's expanded partnership with EnergyHub adds to over thirty utility programs we have underway and further demonstrates the ability of our product portfolio and JuiceNet software platform to seamlessly integrate with third-party platforms to deliver best-in-class solutions and added grid flexibility to utilities everywhere."

Utility time-of-use (TOU) rates incentivize EV owners with Level 2 smart charging stations to utilize off-peak charging, generating bill savings for the customer and reducing strain on the grid during peak periods. In Maryland, where the state has a goal to deploy 300,000 EVs by 2025, the Public Utilities Commission authorized local utilities to install a network of 5,000 residential, workplace, and public charging stations. To best support the rollout, BGE deployed EnergyHub's Mercury DERMS to implement an EV-TOU rate that incentives



off-peak charging, through the gathering and analyzing of charging data. This charging data is provided at a 15 minute granularity from customers' Level 2 charging equipment, including Enel X JuiceBox smart chargers.

Matt Johnson, VP of Business Development at EnergyHub said, "Integrating with a leader in EV charging and clean energy solutions like EnelX demonstrates our commitment to providing a comprehensive EV managed charging solution to utilities. We're excited to partner with Enel X to enhance our ability to deploy a comprehensive grid-edge management solution that optimizes the value of customer-owned distributed energy resources for our clients."

The integration of EnergyHub's Mercury DERMS plaform with Enel X's JuiceNet smart EV charging software platform is enabled by JuiceNet, which optimizes the energy consumption of the JuiceBox EV charging station to align with grid conditions, while ensuring customer mobility requirements are met. EnergyHub's Mercury DERMS platform allows utilities to monitor, coordinate, and orchestrate EV charging in concert with other DERs. EnergyHub works with utilities on multiple types of EV management solutions: time of use (TOU) enablement, peak management, and dynamic load shaping. EnergyHub and Enel X previously partnered to provide utilities with access to certain portfolios of Enel X commercial and industrial demand response assets.

ITRI and DuPont inaugurate semiconductor materials Lab

INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE (ITRI) and DuPont Electronics & Imaging have celebrated the opening of a new semiconductor materials laboratory in Hsinchu, Taiwan.

DuPont established the laboratory to stay close to the semiconductor industry in Taiwan. DuPont will conduct, in collaboration with ITRI, semiconductor material research, development and enhancement, and accelerate pilot testing and commercial viability to support DuPont's customers as they pursue the next generation of semiconductors in Taiwan.

The evolution of 5G and Artificial Intelligence (AI) has spurred development of key technologies for the next generation of semiconductors, including materials to support heterogeneous integration, advanced manufacturing processes, and high-end packaging. Taiwan plays a leading role in the semiconductor industry and has an integrated semiconductor supply chain.

Chih-I Wu, VP and general director of ITRI's Electronic and Optoelectronic System Research Laboratories, stressed that ITRI has long invested in semiconductor research and development and has a solid foundation in the fields of electronics and optoelectronics, advanced packaging processes, chemistry and materials. With the support from AI on Chip Program of Department of Industrial Technology (DoIT), Ministry of Economic Affairs (MOEA), ITRI will expand investment in advanced equipment and technology, heterogeneous integrated packaging experiment platforms and diversified design, manufacturing processes and prototype production services.

"Bringing together ITRI's semiconductor-related technical strength and DuPont's expertise in materials, this laboratory in ITRI's vicinity will enable closer exchanges between the two organisations to bring more innovative solutions and meet the immediate needs of Taiwan's semiconductor and IC substrate industries," he said.

"DuPont has been conducting business in Taiwan for more than 50 years and has grown alongside Taiwan's industrial development, especially in the electronics industry. Our investment in semiconductor technology and manufacturing centres in Taiwan serves as our hub in Asia Pacific to promote advanced semiconductor technologies globally," said Dennis Chen, DuPont Taiwan president.

"Over the years, we have made efforts in strengthening technological breakthroughs, terminal applications and supporting the strategic technology roadmap in Taiwan. The inauguration of this laboratory marks another important milestone as we continue to enhance innovation and R&D capabilities in Taiwan."

JEDEC publishes guidelines for SiC power conversion devices

JEDEC Solid State Technology Association has announced the publication of JEP183: Guidelines for Measuring the Threshold Voltage (VT) of SiC MOSFETs. The publication addresses the critical topic of accurately measuring the threshold voltage (VT) of SiC MOSFETs, addressing the unique behaviour of SiC MOSFETs.

The threshold voltage test methods provided in JEP183 can be used as a common industry guideline for measuring VT of SiC power devices, focused on N-channel vertical structure MOSFET technologies, providing a common baseline for the SiC MOSFET market.

For flexibility, three test methods are offered which may be applied for datasheet, process control, technology development, final tests and other usage. Threshold voltage is a key parameter in the evaluation of changes in the characteristics of physical stimulus such as voltage and/or temperature stress. Without accurately measuring VT, it is not possible to monitor how device characteristics are changed by the stress applied to a device. SiC/SiO2 interface of SiC MOSFET is more complex than the Si/SiO2 interface, which requires careful handling of traps in the device with regard to the change monitoring of characteristics.

"JEP183 recommends approaches for precise and repeatable measurements of SiC MOSFET VT, which will help ensure successful implementation of SiC devices in automotive and industrial markets," noted Jeffrey Casady, Power Die Product marketing engineering manager, Wolfspeed and the chair of the JC-70.2 subcommittee.

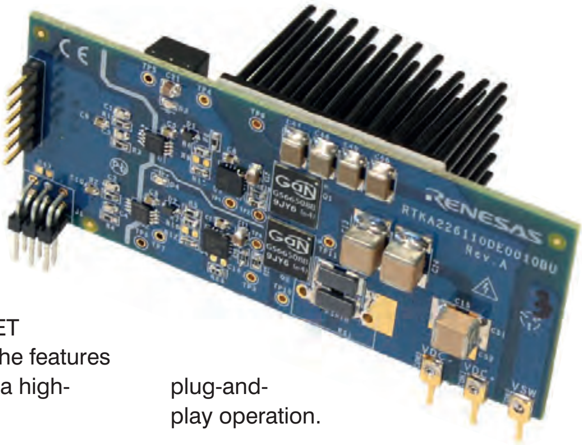
GaN Systems launches novel GaN power stage

GaN SYSTEMS has released two 650V half-bridge daughter cards (30A and 60A), which provide a versatile platform to evaluate GaN drivers and transistors. The evaluation cards are available in two power levels, up to 3kW (GS-EVB-HB-66508B-RN) and up to 6kW (GS-EVB-HB-66516T-RN) and include the Renesas RAA226110 low-side GaN FET driver.

These cards are thought to be the industry's first to provide programmable overcurrent protection with adjustable thresholds and programmable source current for adjustable turn-on slew rate.

"GaN transistors have established themselves as a fundamental building block in power electronics. The introduction of Renesas' low-side GaN FET driver with its best-in-class features and performance are a confirmation that GaN transistors have become the preferred tool of choice for power design engineers," said Paul Wiener, VP of strategic marketing at GaN Systems.

"Renesas is committed to the development of innovative power products that support GaN transistors," said Philip Chesley, VP of the Industrial and Communications Business Unit at Renesas. "One example is our new RAA226110 low-side GaN FET driver, which provides all of the features customers are looking for in a high-performance driver."



These power stage designs can be used in a wide range of applications from enterprise 1U power supplies (up to 5kW), high-power density bridgeless totem pole PFCs, PV inverters, energy storage systems, motor drives, and automotive DC/DC converters and onboard chargers. The evaluation board operates with a GaN Systems' motherboard for easy setup and plug-and-play operation.

The evaluation card also features integrated VGS regulation at 2MHz fSW and one-of-a-kind functions such as programmable over current protection with adjustable thresholds of 40mV/80mV/120mV and differential current sensing as well as programmable source current for adjustable turn-on slew rate (0.3A, 0.75A, or 2A).

AEG power solutions equips the Microgrid laboratory emulator of Paderborn University

AEG POWER SOLUTIONS, a provider of power supply systems and solutions for industrial, critical infrastructure and innovative power electronic applications announced its selection to deliver the power electronics for the power research emulation environment of the new microgrid laboratory of the University of Paderborn. Microgrids are local networks consisting of energy sources, storage facilities and consumers in various sectors. Their advantages: the energy consumption share of renewable energy can be increased and the peak power required at the grid connection point can be reduced. They represent an important solution component to ensure a secure, clean, efficient and cost-effective energy supply in the future.

The Competence Center for Sustainable Energy Technology (KET) at Paderborn University, under the leadership of the Department of Power Electronics and Electrical Drive Technology (LEA), is developing the infrastructure with which the behavior of power system such as battery storage systems, wind turbines, photovoltaic systems or combined heat and power plants can be emulated in the laboratory.

In combination with control and component modelling, the microgrid laboratory offers a highly flexible and modular development and validation platform on which a wide range of questions on local grids can be investigated and solutions developed.

The microgrid emulator will provide a test environment to emulate up to 16 energy system components. These can act as power source or consumer and will be programmed individually asrectifier or inverter via a rapid control prototyping system (RCP).

The whole system can emulate a total power of 2 MVA. External loads can also be integrated in the setup to study their behavior under certain grid conditions.

Paderborn University and AEG PS worked closely together – trusting AEGPS' expertise to engineer and customize the systems for the emulator project. The reliability of the systems is key for the project to achieve accurate simulation results. The solution delivered comprises 8 customized UPS systems based on the reliability proven Protect UPS series. The added rapid control prototyping systems will let each UPS system behave as inverter and/or rectifier to emulate up to 16 different components. Further AEGPS' flexible Convert SC Flex - usually used as storage converter with onand off-grid capabilities – will connect the emulation environment to the public power grid.

The systems have been delivered in December 2020 while commissioning of the emulation environment is planned in Q1 2021. The project is financed by 50% from the European regional fond, by 40% from Northrhine-Westphalia and by 10% from Paderborn University.

Monolithic Power Systems uses EPC eGaN FETs

MONOLITHIC POWER SYSTEMS has announced the launch of a new family of 48 V – 6V digital DC-DC power modules for 48 V data centre solutions, using eGaN transistors from Efficient Power Conversion (EPC). These power modules target applications for high density computing and data centres, artificial intelligence, machine learning, and multi-user gaming.

The MPC1100-54-0000 is the first in the new product family that will include modules in an LLC topology that use eGaN FETs to achieve an overall efficiency above 97 percent in a footprint of only 27 mm x 18 mm x 6 mm for 48 V – 6 V conversion. A key advantage of 48 V – 6 V front-end conversion includes the enabling of a high frequency secondary stage that is small enough to be placed much closer to the xPU/ASIC/GPU to reduce the power distribution loss by 4x compared to the commonly used STC topology for 48V – 12V conversion.

For high-density server applications, record power density and efficiency can be achieved with simple, low cost topologies such as an LLC DC-DC converter. eGaN FETs are well suited for LLC converters due to their combined low gate charge with 5 V gate operation that yields very low gate power consumption, ultra-low on-resistance, and low output capacitance charge.

With power levels ranging from 300 W to 1000 W, these modules are scalable to accommodate a range of high current and high power applications. Customers can add up to three modules to address higher power requirements, or scale down to one or two modules for lower power requirements.

"The 48 V – 6 V module family offers an extremely powerful and versatile solution set for high-performance computing, high-density data centres, and artificial intelligence systems migrating to the 48 V power distribution architecture," said Maurice Sciammas, SVP marketing and sales, MPS. "With the EPC devices inside our modules, we can increase power density significantly to meet the demanding requirements of these advanced applications."

"Advanced computing applications are putting higher demands on power converters, and silicon-based power conversion is not keeping pace," said Alex Lidow, CEO of EPC. "We are delighted to work with MPS, a leader in this space, to implement GaN into their modules, allowing customers to increase the efficiency, shrink the size, and reduce system cost for 48 V power conversion."

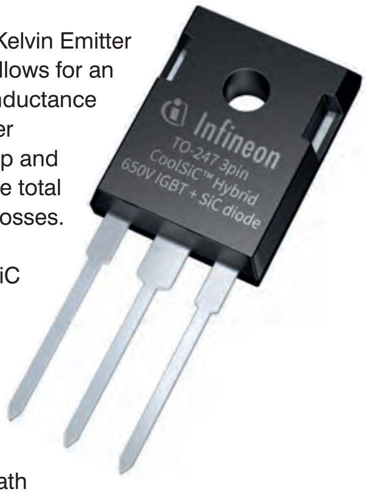
Infineon announces 650VCoolSiC range

INFINEON TECHNOLOGIES has launched a 650 V CoolSiC Hybrid IGBT portfolio in a discrete package with 650 V blocking voltage. The CoolSiC hybrid product family combines benefits of the 650 V TRENCHSTOP 5 IGBT technology and the unipolar structure of co-packed Schottky barrier CoolSiC diodes.

With superior switching frequencies and reduced switching losses, the devices are especially suited for DC-DC power converters and power factor correction (PFC). These can typically be found in applications like battery charging infrastructure, energy storage solutions, photovoltaic inverters, uninterruptable power supplies (UPS), as well as server and telecom switched-mode-power supplies (SMPS).

Due to a freewheeling SiC Schottky barrier diode co-packed with an IGBT, the CoolSiC Hybrid IGBTs perform with significantly reduced switching losses at almost unchanged dv/dt and di/dt values. They offer up to 60 percent reduction of E on and 30 percent reduction of E off compared to a standard silicon diode solution. Alternatively, the switching frequency can be increased at least by 40 percent with unchanged output power requirements. A higher switching frequency will allow reducing passive components size and thus lower bill-of-material cost. The Hybrid IGBTs can be used as a drop-in replacement for TRENCHSTOP 5 IGBTs allowing an efficiency improvement of 0.1 percent for each 10 kHz switching frequency without redesign efforts.

The product family creates a bridge between pure silicon solutions and high performing SiC MOSFET designs. Even more, in comparison to pure silicon designs, Hybrid IGBTs can improve electromagnetic compatibility and system reliability. Because of the unipolar nature of Schottky barrier diodes, the diode can switch fast without severe oscillations and risk of a parasitic turn-on. Customers can choose between a TO-247-3 or a TO-247-4 pin Kelvin Emitter package. The fourth pin of the Kelvin Emitter package allows for an ultra-low inductance gate-emitter control loop and reduces the total switching losses.



The CoolSiC Hybrid discrete IGBT family follows the success-path of earlier released CoolSiC Hybrid IGBT EasyPACK 1B and 2B modules with IGBT chip and CoolSiC Schottky diode. The discrete portfolio can be ordered now. It comprises 40 A, 50 A, and 75 A 650 V TRENCHSTOP 5 ultra-fast H5 IGBTs co-packed with half-rated CoolSiC Gen 6 diodes, or medium speed S5 IGBTs co-packed with full-rated CoolSiC Gen 6 diodes.

EV Group establishes state-of-the-art customer training facility

EV GROUP (EVG), a supplier of wafer bonding and lithography equipment for the MEMS, nanotechnology, and semiconductor markets, has announced that it has established the EVG Academy, a training facility for customers that provides technical training on all classes of EVG equipment as well as on EVG's CIM Framework software platform in an optimized environment.

Established at EVG's headquarters in Austria, the EVG Academy comprises a new 800-square-meter facility created in tandem with the recently completed Cleanroom V expansion project. By attending in-depth, tiered training classes at the EVG Academy, customers can be qualified to perform basic repairs as well as preventative maintenance on EVG equipment without the need to contact EVG customer support – providing customers with greater flexibility for tool maintenance. The new training facility also serves as the education and training hub for EVG's global organization.

The EVG Academy builds on EVG's existing training facilities at its headquarters, doubling the amount of training space and technical trainers. It includes eight individual training areas – one for each major class of EVG equipment -- as well as four classrooms and a dedicated workshop area for electrical and mechanical training. Thanks to the additional floorspace, the EVG Academy has also expanded the number and type of tools available for training, including EVG's fully automated HVM platforms, such as the GEMINI® FB automated production wafer bonding system with SmartView® NT3 bond aligner and the BONDSCALE® automated production fusion bonding system.

"The EVG Academy was purpose-built with the goal to enable in-depth customer training on all EVG platforms utilizing the latest equipment and technologies, including our most advanced fully automated high-volume manufacturing (HVM) tools," stated Helmut Pfeifer, vice president of customer support. "EVG has made significant investments in updating our training infrastructure, and we are extremely proud of this world-class facility, which sets new standards for knowledge transfer in our industry. The new EVG Academy will greatly enhance the learning experience for both our customers and our international customer support teams."

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The EVG Academy is now open for training. Customers interested in learning more can contact EVG at **academy@evgroup.com**

Tektronix releases TekDrive, groundbreaking data collaboration software

TEKTRONIX, INC. announced the availability of TekDrive, the first native oscilloscope-to-cloud software solution to facilitate global data collaboration directly on an oscilloscope, PC, phone or tablet.

Created to enable ultimate ease and accuracy in data accessibility and collaboration, TekDrive provides engineers the ability to instantaneously share and recall data directly on an oscilloscope, eliminating the need for cumbersome data-sharing practices.

TekDrive allows for data to automatically become accessible, usable and shareable across teams and partners, making remote work easier—all with industry-leading security practices built in.

In addition, TekDrive is the first general purpose test and measurement file system with scope-like data visualizations. The software provides ultra smooth visualization and analysis capabilities that support any modern browser, including options to view, zoom, pan, measure, decode and analyze full test and measurement data on any device without the need for any additional software.

"This technology is a game changer for teams," says Tami Newcombe, president of Tektronix. "Clients tell us about insecure data-sharing practices that are awkward and unreliable, and now with TekDrive, data sharing is secure and lightning fast. Launching TekDrive today marks a major expansion of our Tektronix vision to focus on relevant and cutting-edge software solutions that directly correspond to the latest industry needs."

Seventy percent of oscilloscope users have the need to transfer data off scope. Through TekDrive, data updates are instantly saved in globally-accessible shared folders in which owners can manage secure access and permissions at a granular level.

"I joined Tektronix to help inspire the next wave of innovation in electronics engineering, and projects like this will do exactly that," says David Sulpy, chief information officer at Tektronix. "Engineers needed their own workspace in the cloud to securely manage complicated, real-time data from their oscilloscopes. TekDrive fulfills that need, whether they are working in the lab or at home."

TekDrive was built with the engineer in mind, and boasts a clean, easy-to-use interface for file organization, management, search, upload and download. It's also architected for ease-of-integration with secure vendor-agnostic REST APIs for scripting, automation and analysis.

Tektronix provides SDKs and examples in multiple languages, such as Python, Matlab and LabVIEW. The TekCloud Developer Program also provides a secure way for third party developers to add native TekDrive capability to their devices, instruments and software applications. With a quick integration, any vendor of hardware or software can unleash the ecosystem of TekCloud storage, streaming, visualization and analysis into their products.

"Aggregating data from various instruments has always been a challenge. Engineers often use unsecured USB sticks, or worse, snap photos of the instrument's screen with a phone," says Siddharth Deliwala, director of laboratory programs at University of Pennsylvania. "Being able to share data directly from instruments via TekDrive is a breakthrough for engineering teams in the commercial and academic space to learn and innovate efficiently."

TekDrive is now available in many regions worldwide and will be released globally over the coming months.

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Qorvo develops new GaN decade bandwidth MMIC power amplifiers

Gallium Nitride (GaN) power amplifiers are emerging for commercial applications in greater quantities than ever before. GaN has become a key wide bandgap technology serving numerous power electronics applications. While renowned for its power density, ruggedness, high voltage handling and PAE, developing devices that employ GaN technology is not without challenges. Qorvo is a leader in high frequency GaN as part of its extensive RF and mixed signal device portfolio for mobile, infrastructure, defense and commercial applications including 5G, the IoT/IIoT, smart home, automotive and broadband systems. The company recently detailed how its designers created a novel 2-20 GHz GaN power amplifier with world class performance during the Angeltech Live II conference in late 2020. Power Electronics World has prepared a summary of Qorvo's presentation including key performance plots and device images. Contact information is provided at the end of the article.

BY MICHAEL ROBERG, INFRASTRUCTURE & DEFENSE PRODUCTS, QORVO

MY NAME is Michael Roberg and I work for Qorvo in the Infrastructure and Defence Products Business Unit. This feature will discuss recent advances in decade bandwidth high power MMIC amplifiers. I want to start by giving you an outline of my talk to provide information about what motivated this work, while offering some context about why we would want to be designing things like this.

The introduction will be followed by a description of some different things that we've developed in the last couple of years that we've introduced into industry through the International Microwave Symposium (IMS) 2019 and 2020; In 2019 we talked about a novel biasing technique for bandwidth enhancement of multi-stage distributed power amplifiers.

I'll follow that up by reviewing a 10 watt, 2-20 GHz NDPA, which is a non-uniform distributed power amplifier that uses a novel broadside coupled output transformer. Following that I will show you how we get to 20 watts using a 2-20 GHz, non-uniform distributed power amplifier employing a decade bandwidth power combiner. And finally, I'll summarize this work.

To introduce this topic, why would you want something like a 2-20 GHz power amplifier in the first place? Well, there are many wideband commercial and military systems that desire to work over this bandwidth. Examples of systems that use 2-20 GHz amplifiers can include rack mount power amplifiers for test equipment, for evaluating different parts of all different bandwidths. And you want just one large, rack mount power amplifier to be able to test devices with different frequency ranges.

There's also additional wideband test equipment that would certainly want to have something like a 2-20 GHz power amplifier. And certainly, there are other commercial and military systems that desire being able to work over this bandwidth. These can include radars, electronic warfare systems, communication systems, et cetera. So in order to meet the 2-20 GHz bandwidth requirement, a non-uniform distributed power amplifier is quite necessary in order to meet the customer need with a single monolithic chip.

Now, with these designs, customers continuously want to increase performance. They always want more bandwidth. They want to push the output power higher. They want more gain, more power and efficiency, et cetera, to enable them to develop next generation systems. They also desire the simplicity of use where they don't want to have off chip bias tees and all sorts of components required to get amplifiers of this type to work. They want them to be relatively simple to work in their system with maybe some off chip bypassing capacitance. But other than that, they just want a device to be kind of a one stop shop from an amplifier perspective. Why? It is simpler; there is not a lot of work to be able to use a device designed to fit these customer requirements.

The thing with these non-uniform distributed power amplifiers that enables these systems is they present many unique design challenges, even though they are system enabling. And just to highlight further, customers always want more power. I've never heard a customer say they want less power. It's always more power. And so we're continuously trying to find ways to design these things and push the power higher while enabling these system applications. So what are some of the design challenges that you run into when you try to design a non-uniform power distributed amplifier? (See Figure 1).

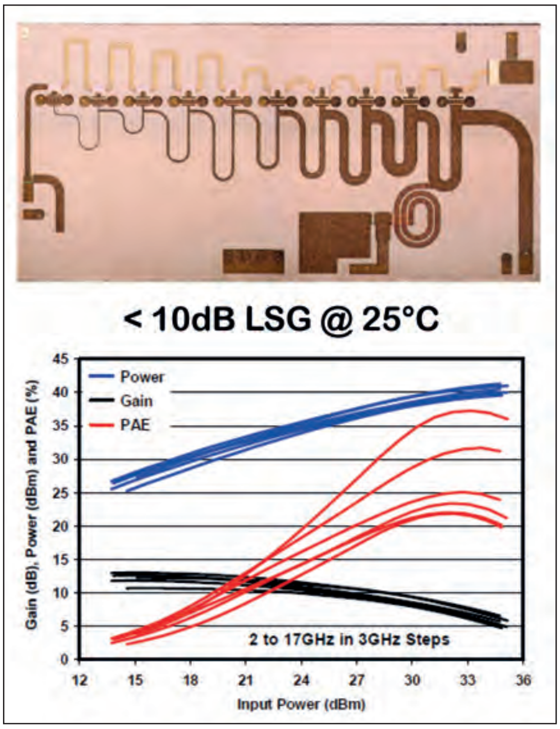

Figure 1: Example layout and performance of a traditional single stage NDPA

You have output power limitations. Typically, you're limited by the power that you can deliver into 50Ω by the device technology of traditional design techniques. That's a very big limiter. That's why most of the commercially available, non-uniform, distributed power amplifiers that operate over this bandwidth that you've seen up to this point have been pretty much limited to around 8 watts; designers haven't seen much beyond 8 watts that are commercially available. And that's due to the fact that they're trying to deliver power to 50Ω.They have a device technology that only allows them to use so much active device periphery and that really limits the power.

Another additional challenge to performance is power added efficiency. Wide bandwidth non-uniform, distributed power amplifiers inherently operate at low power added efficiency relative to what you could get out of a single device perfectly matched at an individual frequency. And that's because there's a lot of outphasing going on within the amplifier itself in order to achieve the bandwidth. Another challenge with performance that we will address in this presentation is large signal

gain. A single stage typically provides far less than 10 dB of large signal gain at room temperature. And that's typically not enough for the customers when they want to buy these power amplifiers. They'd certainly like at least 10 dB of large signal gain and would take as much as you could give them while maintaining stability. So we will address that in a minute.

There are challenges with the implementations of these devices. Obviously, we have to design them to be robust and reliable. So we have to handle the DC current that they need when they're operating in a saturated fashion without electro migrating the conductors. That's very important. It is necessary to DC block all of the RF ports to make it a monolithic solution and also have to have the DC biasing integrated in the chip to minimize the off chip components. And what that really means is they don't want to go purchase a very expensive, off chip series blocking capacitor that operates over this band if they want that monolithically integrated.

All of those challenges with implementation create a performance challenge, which is bandwidth. And so we need to find a way to address these challenges while still maintaining the 2-20 GHz bandwidth that we would like to achieve. (See Figure 2).

We'll talk first about the gain challenge. How do we deal with that? Well, the easiest way to increase the gain of a non-uniform distributed power amplifier is to put two back to back – cascade two of them. So you get the gain of the first stage and the gain of the second stage; that's a very straightforward way to do this. Now, what's the issue with that? The issue

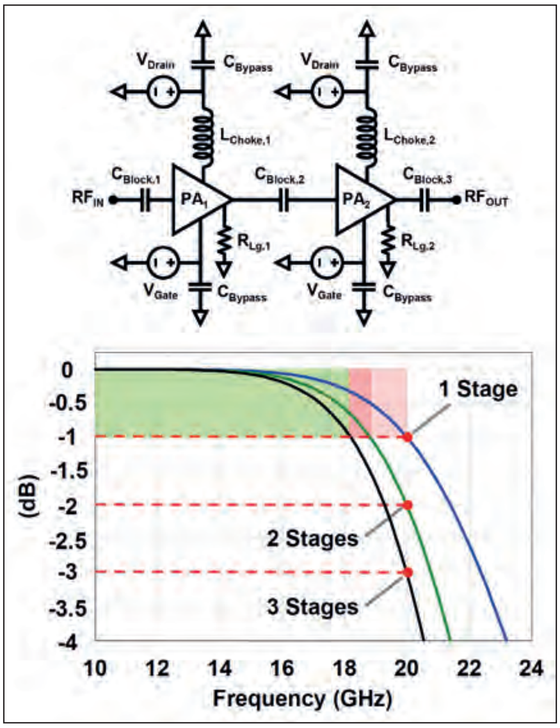

Figure 2: Distributed PA Design Challenges

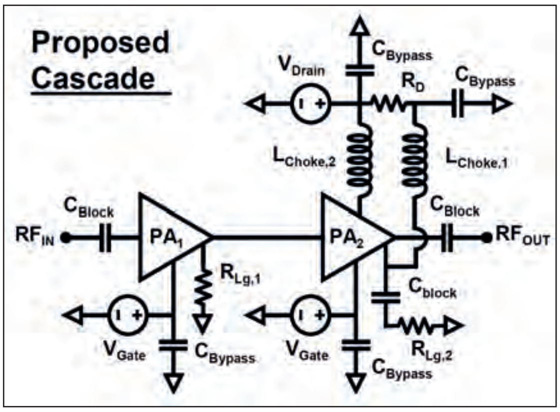

Figure 3: Proposed Cascading & Bias Technique

becomes the bandwidth, which is limited due to the on chip DC blocking and biasing; just cascading multiple stages makes the problem worse.

Referring to Figure 2, what happens when each stage, say, rolls off by 1 dB at 20 GHz? Well, if you cascade 3 of those, obviously you're going to roll by 2 dB at 20 GHz and 3 dB makes the problem even worse. So basically, you start off with a 2-20 GHz amplifier that maybe has 1 dB roll off at the high end and if you're pushing the limits, you're going to end up with 2 dB roll off at the high end if you cascade two of them. That's problematic. What we want to do is find a way to eliminate that issue where we can maintain the performance up at 20 gigahertz in terms of gain.

There is actually a relatively straightforward way to approach this problem that doesn't really require a lot of effort and is quite elegant. I won't go into the extreme details in this presentation because we don't have a lot of time. But you could look at the IMS 2019 paper that I presented, and basically the idea is to recognize that the gate termination of the output stage is typically a low impedance. And so what you can do is use that as a point to deliver the current into the prior stage by blocking that gate termination resistance from ground and just feeding the current through the gate line (See Figure 3).

The nice thing about that approach is because it's low impedance, the choke inductor that you need to use in order to basically block RF from traveling down is much smaller. And so what you can do is make sure you designed that driver stage such that it is not a key bandwidth limiting element of the design. That's a key concept in that the DC current is now riding down the gate line of the output stage PA, which is perfectly fine because typically you're using coupling capacitors between the devices in the gate line anyhow.

This approach provides a very elegant location in order to place the bias tee for the first stage, in order to make sure you're doing a good job biasing the first stage in enhancing the bandwidth of that stage so you don't see any roll off at the high end.

In order to demonstrate that technique, here's a die that was developed (See Figure 4) which is basically a two watt driver amplifier that operates over 2- 20 GHz. The die size I'm showing is 2.74 x 2.74 millimetres, so it's rather compact. It is a two-stage die. The RF input is on the upper left-hand side while the RF output is on the opposite side; it has single VD and VG connections. A key point to point out is where the driver choke attaches to the output gate line. It is labeled as number 2 in red in the top middle of the die. The driver choke feeds the bias current into the first stage, traveling all the way down the output stage gate line prior to arriving in the first stage. So it's a rather elegant solution for biasing in that it provides enhanced bandwidth.

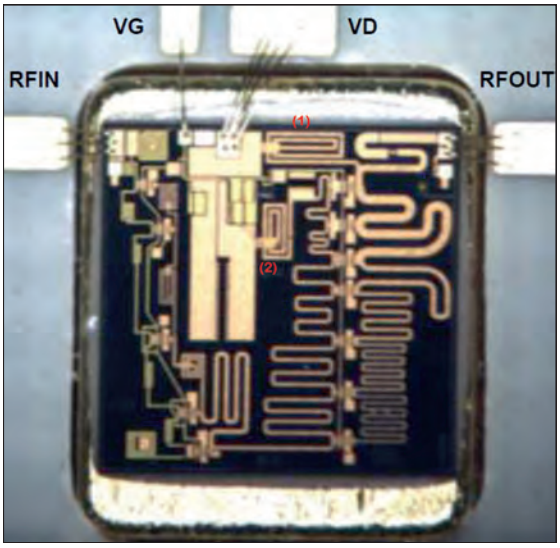

Figure 4: Die layout

Here's some measured performance on this die (Please see Figures 5 & 6). I'm showing the scattering parameters where the solid traces are measured and the dash lines are simulated at a bias point of 18 volts, 330 mA at 25° C and you can see that we got a little bit more gain, especially up at the high end than we did at the simulation. Quite nice performance. We're barely seeing any roll off at the 20 gigahertz point. And so clearly this is working well in order to provide us very nice 2-20 GHz broadband performance from an S parameter perspective.

But S parameters aren't the only thing we care about with amplifiers of this type. We also care about the power and the power added efficiency. So this is showing the measured versus modeled comparison again, the solid line is measured and dashed is a

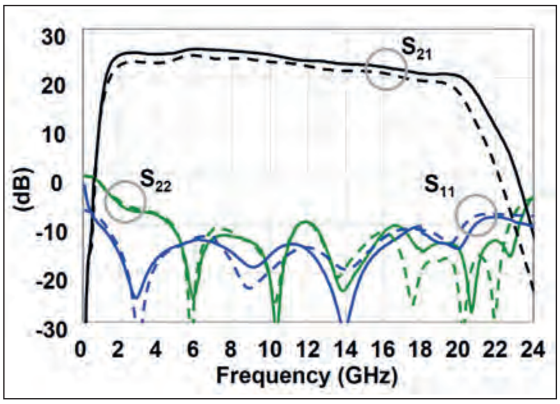

Figure 5: Measured Performance--S Parameters
*Solid Traces: Measured. Dashed Traces: Simulated. 18V, 330mA. 25°C Measurement

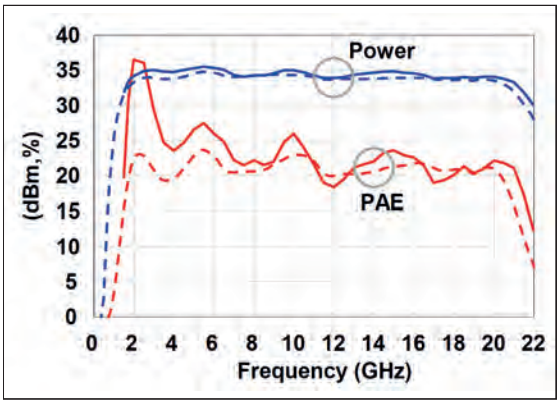

Figure 6: Measured Performance--Power / PAE
*Solid Traces: Measured. Dashed Traces: Simulated. 18V, 330mA. 25°C Measurement, Pin = 18dBm

Reference (#)	Frequency (GHz)	Technology	Circuit Topology	Large Signal Gain (dB)	Output Power (W)	PAE (%)	Die Size (mm^2)
[6]	1 - 17	CMOS SOI	Stacked DA	11 - 14.1	0.08 - 0.13	12.2 - 19	1.14
[7]	1 - 20	SiGe HBT	Stacked DA	6 - 10.5	0.04 - 0.09	10 - 28	2.54
[5]	4 - 18	GaAs	2-Stage NDPA	16.3 - 17.5	4.3 - 5.6	19 - 31	38.35
[5]	4 - 18	GaN	Balanced NDPA	7 - 9.4	2.5 - 4.4	≤15.6	7.22
[8]	2 - 15	GaN	NDPA	6.4 - 8.4	4.3 - 6.9	20.6 - 32	10.06
[2]	1.5 - 17	GaN	NDPA	7.5 - 9.8	9 - 15	20 - 38	15.35
[3]	2 - 20	GaN	NDPA	8 - 11.1	9.6 - 21.6	15.3 - 35.7	38.25
[4]	1 - 8	GaN	2-Stage NDPA	23.7 - 25.2	9.3 - 13.1	29 - 46	11.38
[9]	2 - 12	GaN	NDPA	5.4 - 9.3	3.5 - 8.9	18 - 35	4.32
This Work	**2 - 20**	**GaN**	**2-Stage NDPA**	**15.8 - 17.5**	**2.4 - 3.5**	**18.4 - 36.5**	**7.5**

Figure 7: Performance Comparison Table

model. We get a nice boost in efficiency at the low end. Sometimes it's very difficult to properly model the impact of the harmonics with the device model. And so we got quite an additional bump in performance down low and up at the high end. We're quite close. You can see that we have quite good performance well over 2 watts of output power with an input power of 18 dBm. So very, very good; a nice 15 dB+ large signal gain in a 2-20 GHz amplifier (See Figure 7).

Just to compare some of that performance with what has been previously done in literature, our solution compares very well, and has very nice large signal gain. It doesn't have as much output power as some of the others, but that was not the intention. We'll talk about getting to those levels of output power soon. It does have a very nice efficiency over that full bandwidth; very good performance in a nice compact die size. That's a technique that we'll use moving forward into the higher power amplifiers that we intend to develop (See Figure 8).

The next thing we want to talk about is getting to a higher power. We want to get to 10 watts. What's typically been done in industry is that the voltage is pushed to the limit of the GaN technology to get the output power as high as possible, because 50 Ohms is the limitation, especially over a decade bandwidth. And so the question becomes, OK, is there a better way to do that? And one of the better ways to do that is to consider the case where, let's say, I'm not delivering power into 50 Ohms.

Instead – let's say I'm delivering power into 12 and a half Ohms, so what can I do? Looking at Figure 8, you can see a graph were the black trace is showing the power you could theoretically deliver into 50 Ohms in the GaN technology that I'm talking about. And then in the green trace, you also see the power you could deliver at 12 and a half Ohms. What becomes

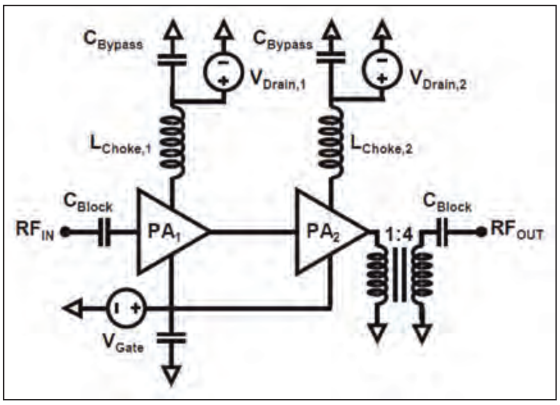

Figure 9: Proposed Design Architecture

immediately clear is that you could deliver significantly more power in 12 and a half Ohms because you can use four times as much periphery. What's also clear is that for the same level of power you could deliver into 50 Ohms, you could use a much lower voltage to deliver it into twelve and a half Ohms.

As we can see, with a 12 and a half Ohms design, there are some attractive advantages because you're not stressing the device. You're not pushing the dissipation within a specific device higher. There are a lot of advantages to being able to deliver the amount of power you need using a lower voltage because you're trading current for voltage in that case. So the discussion becomes, why haven't people done this before? Well, they haven't figured out a way to realize a decade bandwidth transformer that does a four to one impedance transformation. Here is where we get to talk about the way we found to do just that. The proposed design architecture is shown in Figure 9. We're going to use a two stage PA using that bandwidth enhancement technique for the driver stage and the outputs that I previously discussed.

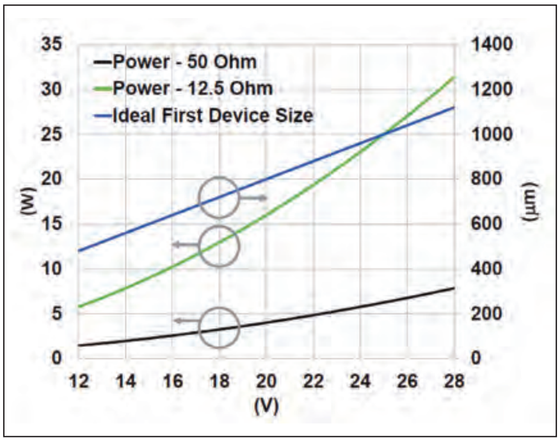

Figure 8: Distributed PA Design Challenges. Power capability in a 50W vs. 12.5W system vs. VD. Assumes Rp = 80W·mm and Pdensity = 2.5W/mm @ 20V. Ideal first device size assuming 100W max. transmission line impedance

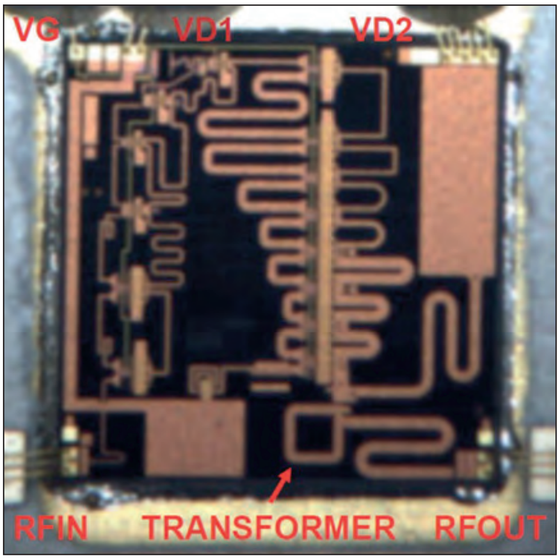

Figure 10: Chip Layout (3.24mm x 3.24mm)

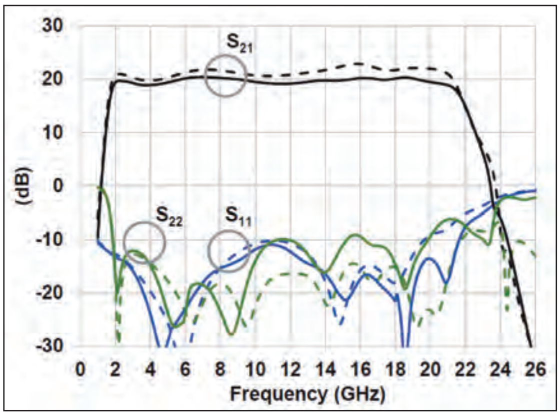

Figure 11: S-Parameters Modeled vs. Measured
*22V / 1680mA / 25ºC

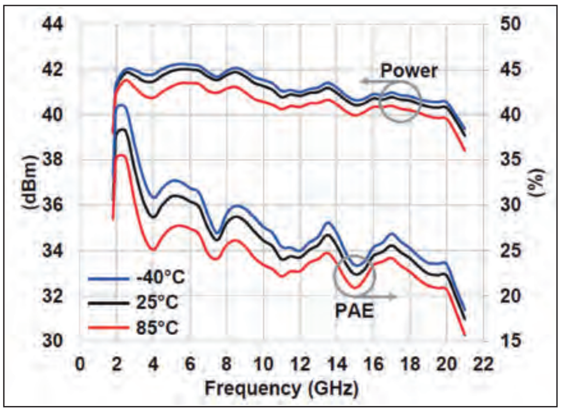

Figure 13: Power / PAE vs. Temperature
*22V / 1680mA / 25ºC / Pin = 27dBm

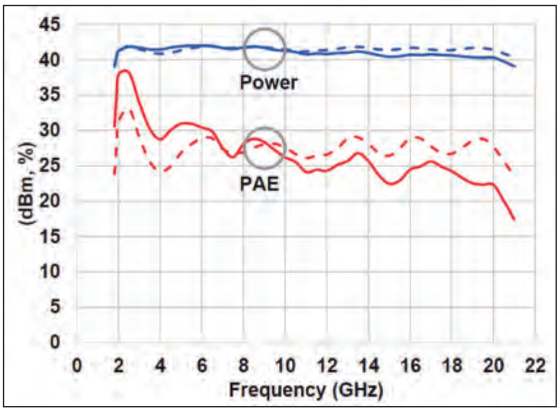

Figure 12: Power / PAE Modeled vs. Measured
*22V / 1680mA / 25ºC / Pin = 27dBm

The stage is going to be designed to deliver power into a 12 and a half Ohm impedance rather than a 50 Ohm impedance. To do that we're going to need a one to four transformer as shown in Figure 9 to deliver that impedance back to the system impedance of 50 Ohms.

To do that, we use a novel broadside coupled transformer with a little bit of matching wrapped around it, which was discussed in our IMS 2020 talk. I'm pointing out the transformer at the red arrow in Figure 10. This is all done on a GQaN15ES process – the die size is 3.24 mm by 3.4 mm – not significantly larger than the two watt amplifier that I have previously shown. Again, everything's monolithically integrated. All of the blocking and biasing is done on chip. The only thing you would have off-chip would be some bypass capacitance on these supply lines in order to ensure your part is stable with improved linearity (See Figures 10 & 11).

Figure 11 shows S parameters that were modelled versus what was measured at a 22 volt bias point. And so you can see again, we get a little bit more gain out of the part than we simulated and very well matched across the band, approximately 10 dB or better. Figure 12 Shows the power and power efficiency model versus measure. We again get a little bit of a boost at the low end of the band.

For the same reasons that I previously mentioned, it does tail off a little bit at the high end of the band, but the point is, at 22 volts, we did maintain easily over 10 watts of power from 2-20 GHz, which is the first time that a commercially available part has ever been offered to do anything like that. And in addition, we offer several more dB of gain because we have two stages. This performance is at an input power of only 27 dBm.

If you look at many of the parts currently available prior to this part in industry, you'd see they would be

Reference (#)	Frequency (GHz)	Circuit Topology	Large Signal Gain (dB)	Output Power (W)	PAE (%)	Die Size (mm^2)	Supply Voltage (V)
[2]	1.5 - 17	1-Stage NDPA	7.5 - 9.8	9 - 15	20 - 38	15.35	30
[3]	2 - 20	1-Stage NDPA	8 - 11.1	9.6 - 21.6	15.3 - 35.7	38.25	30
[4]	2 - 19	Stacked NDPA	12 - 15	5.5 - 12.3	22 - 49	4.7	28
[5]	2 - 18	Stacked NDPA	19 - 21	9.1 - 15.8	18.3 - 38.1	7	28
[6]	1 - 8	2-Stage NDPA	23.7 - 25.2	9.3 - 13.1	29 - 46	11.38	28
[8]	2 - 20	2-Stage NDPA	15.8 - 17.5	2.4 - 3.5	18.4 - 36.5	7.5	18
This Work	**2 - 20**	**2-Stage NDPA**	**13.3 - 15**	**10.7 - 15.8**	**22.3 - 38.2**	**10.5**	**22**

Figure 14: Benchmark Comparison

driven well past two watts of input power just due to the large signal gain. Figure 13 shows performance vs. temperature; performance doesn't degrade substantially at 85° C, you're barely dropping below 10 watts at 85° C carrier plate backside carrier plate backside. We have an excellent level of performance; even up to an 85° C backside temperature, PAE is staying above 20 percent, which is an absolutely world class level of performance.

Figure 14 shows the benchmark comparison with other amplifiers that are available that we see in current literature; you'll see that even as the output power level, efficiency is definitely world class. It has the highest minimum amount of output power over that full band that has been achieved to date in a very nice compact form factor. It uses a 22 volt voltage supply where all the other parts that even try to get to this level of power are using 28 to 30 volts.

So I believe we have proved the point that you can use this four to one impedance transformer in order to be able to achieve the level of performance we have demonstrated over the 2-20 GHz band. But customers don't want to stop there. They don't just want 10 watts, they want 20 watts, and they'll want 40 watts next week. So we need to figure out a way to take these type of amplifiers and make more power. And so what I've come up with here is a concept with some results shown that allow you to take two amplifiers and combine them so that you can double the power (See Figure 15).

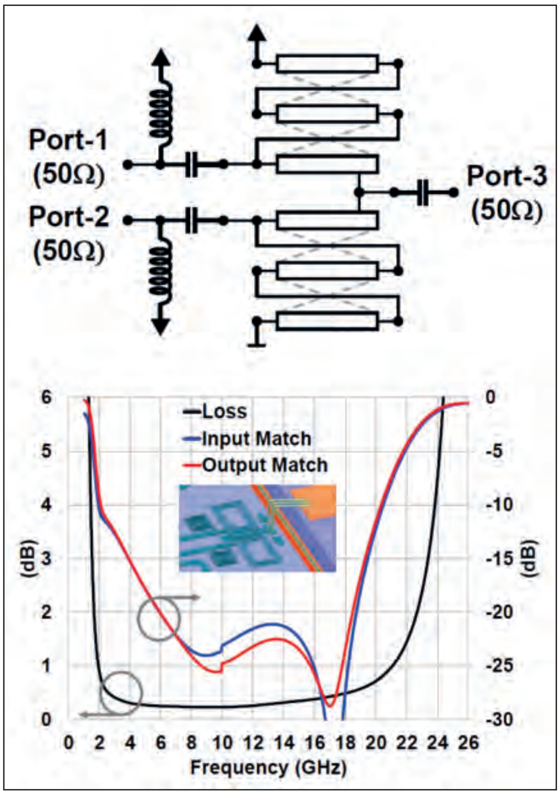

Figure 15: Combined Amplifier Concept

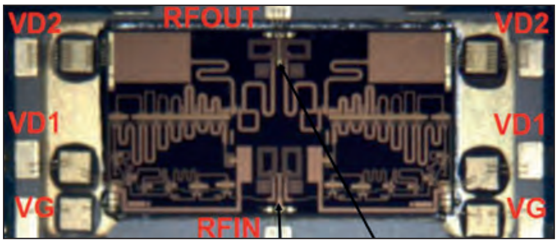

Figure 16: Chip Layout (3.69mm x 6.99mm)

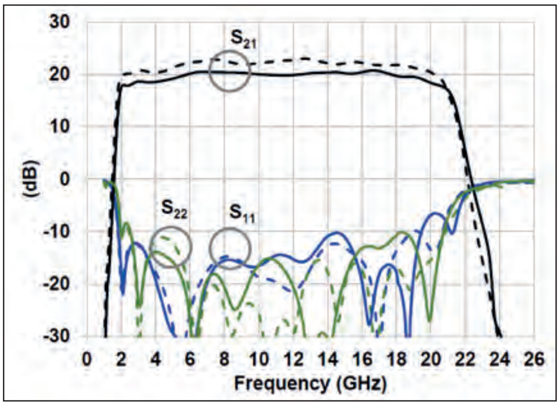

Figure 17: S-Parameters Modeled vs. Measured
*22V / 3360mA / 25°C

This sounds like a very simple concept in general. But the problem is no one's found a way up until this point to be able to implement such a power combiner over a decade of bandwidth, specifically at 2-20 GHz. Figure 15 shows a way to do just that. This concept uses two, tri-filar transformers; these individual circuits transform from 50 to 100 ohms at this point; you put those in parallel.

We have created a 50 ohm combiner with all three ports matched at 50 ohms. We also have a little matching section of the circuit that allows you to improve the low end performance. Put together, this does a very good job at being a broadband power combiner (See Figure 16).

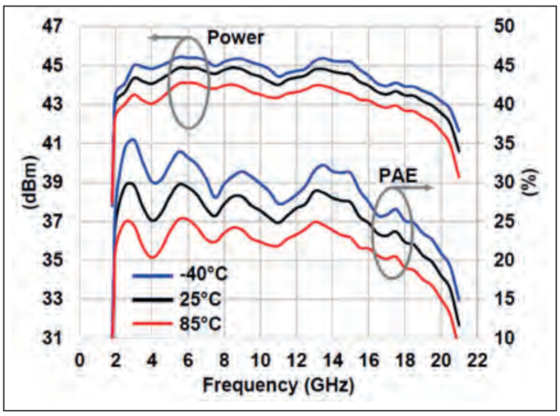

Figure 18: Power / PAE vs. Temperature
*22V / 3360mA / 25°C / Pin = 31dBm

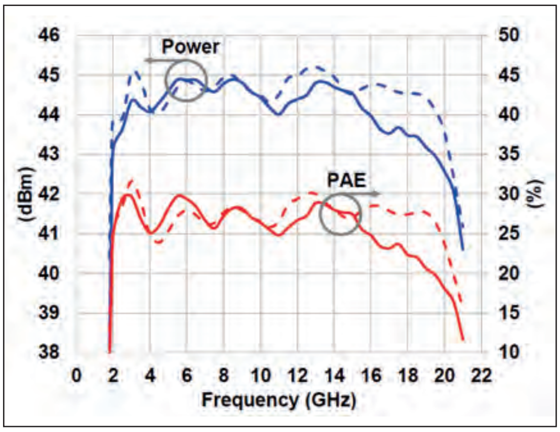

Figure 19: Power / PAE Modeled vs. Measured
*22V / 3360mA / 25ºC / Pin = 31dBm

Figure 17 shows the simulated performance of such a power combiner over the 2-20 GHz bandwidth, and it's quite clear that it works very well over that bandwidth. You're looking at approximately 0.5 dB to 0.6-0.7 dB of loss. In a best case scenario over the bandwidth, the minimum loss approaches approximately a quarter to two-tenths of a dB. We used this concept on the amplifier I previously showed you to combine two in parallel on-chip.

This is a rather large chip. It's approximately 3.7 by 7.0 millimetres. But the internal amplifier is effectively identical to the previously presented 10W design. It's just the combiner, input splitter and two of the 10W core PAs. Figure 18 shows some measured versus modelled performance of this amplifier. This is also at 22 volts. So, again, a little bit more gain than we had simulated, but still well-matched. Figure 19 shows model versus measured – you can see it deviates in certain locations quite substantially.

But again, we maintained performance as we passed 20 watts, up to approximately 19 GHz. We developed an amplifier covering 2-19 GHz, at 20 watts, power added efficiency from 2-19 GHz of approximately 20 percent. It does dip a little bit at the high end. We think that could probably be improved with a better design of the combiner. But this just really shows the concept. This is the first time you've ever seen a commercially available part that offered this level of output power with this level of gain ever, so despite some minor limitations, this is quite world class performance.

Referring again to Figure 18, we can see performance vs. temperature, it doesn't completely fall off a cliff as you heat it up, which is very nice. At 18 GHz, it's dipping to just below 20 watts at 85° C backside – it still offers a very nice level of performance.

Figure 20 shows that our part delivers a benchmark level of performance versus all the other parts in existence that attempt to meet these specs. You'll find a list of the parts I discussed today at the close of this article. You can see that the output power of our part pretty much blows away anything else that has been discussed in literature or in industry with excellent power added efficiency. The die size is rather large due to the fact that we're combining two amplifiers. But again, as mentioned when discussing the previous amplifier, as well as this amplifier, we're doing this at only 22 volts while everyone else is using 28 to 30 volts to try to get to even half the power. It's a very impressive result.

In summary, I presented a new cascading design technique for a two stage distributed power amplifier that was shown in IMS 2019. Please feel free to look for that paper. We created a very nice amplifier that shows that we can improve the bandwidth of the driver stage so that the cascaded bandwidth does not suffer. We also showed a higher power distributed power amplifier using this novel decade bandwidth approach by creating a 1:4 impedance transformer to show that you can achieve 10 watts at 22 volts without issue.

And finally, I have shown a decade bandwidth, monolithic power combiner that you can use to combine amplifiers in a 50 Ohm system and basically almost double the power. We effectively achieved 20 watts over that 2-20 GHz bandwidth from a single chip, which is certainly world class performance.
I should mention, these are all commercially available parts; you can buy them now; they are in production and listed on the Qorvo website, www.qorvo.com

The two watt amplifiers are available in both die and packaged form. The QPA2213D, the die-level device,

Reference (#)	Frequency (GHz)	Circuit Topology	Large Signal Gain (dB)	Output Power (W)	PAE (%)	Die Size (mm^2)	Supply Voltage (V)
[2]	1.5 - 17	1-Stage NDPA	7.5 - 9.8	9 - 15	20 - 38	15.35	30
[3]	2 - 20	1-Stage NDPA	8 - 11.1	9.6 - 21.6	15.3 - 35.7	38.25	30
[4]	2 - 19	Stacked NDPA	12 - 15	5.5 - 12.3	22 - 49	4.7	28
[5]	2 - 18	Stacked NDPA	19 - 21	9.1 - 15.8	18.3 - 38.1	7	28
[6]	1 - 8	2-Stage NDPA	23.7 - 25.2	9.3 - 13.1	29 - 46	11.38	28
[9]	2 - 20	2-Stage NDPA	13.3 - 15	10.7 - 15.8	22.3 - 38.2	10.5	22
[10]	2 - 20	2-Stage NDPA	15.8 - 17.5	2.4 - 3.5	18.4 - 36.5	7.5	18
This Work	**2 - 20**	**2-Stage NDPA**	**11.6 - 13.9**	**18.0 - 30.8**	**18.0 - 29.7**	**25.8**	**22**

Figure 20: Benchmark Comparison

and the QPA2213 is the surface mount package part. The 10 watt die part is the TGA2962, and the QPA2966D is the 20 watt product, currently only available in die form; the packaged parts are coming very soon. I anticipate them being available in the first half of 2021.

For more information about the products discussed in the AngelTech Live II Conference (https://onlinesummit.angel-tech.net), please contact: Paul Prudhomme, Marketing Director at Qorvo: paul.prudhomme@qorvo.com, or visit the company's website: www.qorvo.com

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ADDITIONAL PRODUCT INFORMATION

All products on Qorvo's website www.qorvo.com and in production

- QPA2213D / QPA2213: 2-20 GHz 2W Amplifier
  - Die and package part available
- TGA2962: 2-20 GHz 10W Amplifier
  - Die only, packaged part coming very soon
- QPA2966D: 2-20 GHz 20W Amplifier
  - Die only, packaged part coming very soon

Contact:
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for additional product information

Dennis Ralston
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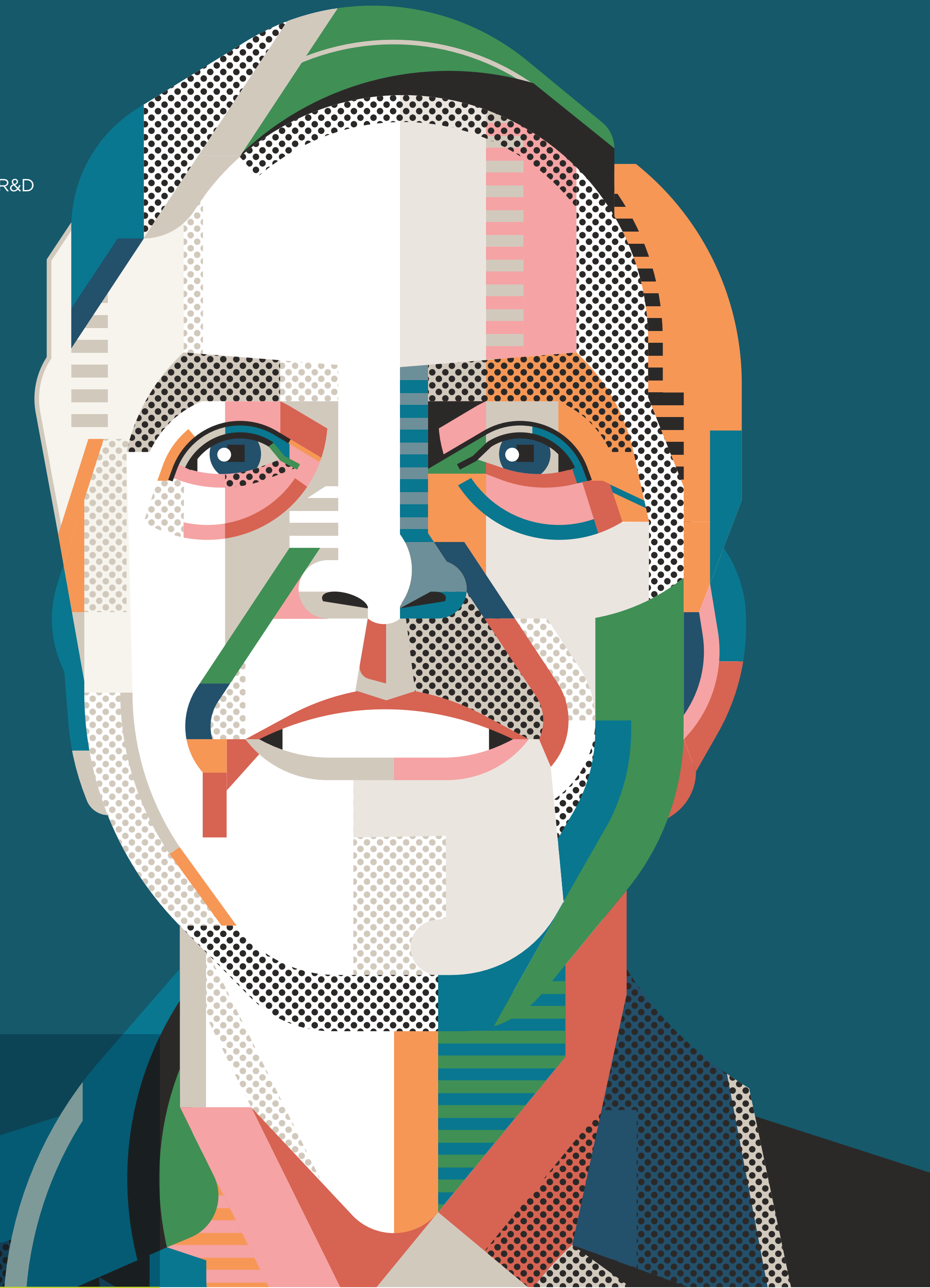
Government Relations and Cooperative R&D
KLA



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Reliable off-grid energy management system reduces electricity costs

A large gold mining operation in southwest Mali (Africa) required a hybrid energy system including fossil fuelled generators, a 30MW solar power plant, and energy storage. Wärtsilä's GEMS advanced energy management system has proven essential to achieving sustainable reliability and efficiency.

BY LUKE WITMER, GENERAL MANAGER, DATA SCIENCE, WÄRTSILÄ ENERGY STORAGE AND OPTIMIZATION

SINCE B2GOLD first acquired the Fekola gold mine, located in a remote corner of southwest Mali, exploration studies revealed the deposits to be almost double the initial estimates. A recent site expansion has just been completed, and while the existing power units provide enough power to support the increase in production, the company sought to reduce its energy costs, cut greenhouse gas emissions, and increase power reliability. The addition of a 35MWp solar photovoltaic (PV) plant and 17MW/15MWh of energy storage to the existing 64MW thermal engine plant was decided. This new energy mix is anticipated to save over 13 million litres of fuel, reduce carbon emissions by thirty-nine thousand tons per year, and generate a payback in just over four years.

Such an elaborate hybrid configuration needs a powerful brain to deliver on all its potential: Wärtsilä's GEMS, a proprietary advanced software and controls platform for energy management, has been set up to control the energy across the fleet of power sources, thermal, renewable, and battery storage. The integration, control, and optimization capabilities provided by GEMS allow the thermal units to be run at the most efficient rate and enable the battery storage to handle the large load step changes and volatility of the solar PV generation assets.

GEMS is a critical requirement, as it makes decisions in fractions of a second, utilizing large amounts of data from multiple streams that cannot be comprehended quickly enough by a human to perform the required actions manually. As renewables ramp up and down, GEMS continuously performs calculations to ensure that enough spinning reserves are provided, ensuring security of supply of electricity to manage any contingency events such as generator faults and equipment failures. In addition, the renewable forecasts are constantly changing, requiring different engine setpoints.

GEMS conducts the orchestra of all of the equipment to ensure the reliable operation of the grid in the least cost possible. The complexity and scale of the Fekola mining operation mandated the use of a highly advanced system like GEMS—operating the grid completely by human control would have been impossible.

Integrated Hybrid Energy Solution

In the context of the Fekola mine, which is an off-grid electrical island, the battery is performing a lot of different services simultaneously, including frequency response, voltage support, shifting solar energy, and providing spinning reserves. The energy load is very

Fekola gold mine in Mali, Africa. Mine operators use a hybrid energy system composed of fossil fueled generators, a 30MW photovoltaic (PV) array, and 15MWh of energy storage. The hybrid plant relies on the Wärtsilä GEMS proprietary advanced software and controls platform to automatically balance load and generation 24/7 for optimal electricity efficiency across mine operations.
Photo provided by Wärtsilä Energy Storage and Optimization; Photo credit: Wärtsilä Energy

flat, with a steady consumption rate around 40MW as the mining equipment is operating consistently, 24/7. However, if an engine trips offline and fails, the battery serves as an emergency backstop. The controls reserve enough battery energy capacity to fill the power gap for the time it takes to get another engine started, and the software inside each inverter enables the battery to respond instantaneously to any frequency deviation.

The reciprocating engines operate most efficiently at 85-90 percent of their capacity, this is their 'sweet spot.' But if there is a sudden spike in demand, if a little more power is needed, or if mining equipment is coming online, then another engine needs to be run to meet the extra load. With the battery providing spinning reserves, the engines can be kept running at their sweet spot, reducing the overall cost per kilowatt hour. Moreover, with the solar plant providing power during the day, three to four engines can be shut down over this period, providing a quiet time to carry out preventive maintenance. This really helps the maintenance cycle, ensuring that the engines operate in a more efficient manner.

Solar PV volatility can be intense. On a bright day with puffy clouds passing by a solar farm of this size can easily see ramps of 25MW over a couple of minutes.

The software is constantly analysing the data and running the math to solve the economic dispatch requirements and unit commitment constraints to ensure grid reliability and high engine efficiency

This requires intelligent controls, dynamically checking the amount of solar that can be let into the grid without causing an issue for the engine loadings or without overloading the battery.

Conducting the orchestra

The GEMS intelligent software provides the optimization layer that controls all the power sources to ensure that they work together in harmony. The user interface (UI) gives access to all the data and presents it in a user-friendly way. Accessible remotely, all operations are simulated on a digital twin in the cloud to verify the system controls and simulate the most efficient operating scenarios to lower the cost of energy. This is an important software feature, both during and after commissioning as it allows operators to train on the platform ahead of time and familiarise themselves with the automated controls and dynamic curtailment of renewables. The UI provides the forecast for renewables and the battery charge status at any given moment, it can provide push email or phone notifications for alerts; telling operators when to turn off an engine and when to turn it back on.

The software is constantly analysing the data and running the math to solve the economic dispatch requirements and unit commitment constraints to ensure grid reliability and high engine efficiency. Load forecasting integrates the different trends and patterns that are detectable in historic data as well as satellite

Author Luke Witmer, Data Science General Manager for Wärtsilä Energy Storage and Optimization, stands outside one of the company's containerized energy storage and management units at the Fekola mine in Mali, Africa. Photo provided by Wärtsilä Energy Storage and Optimization; Photo credit: Wärtsilä Energy

based solar forecasting to provide a holistic approach to dispatching power. The Fekola site has a 'sky imager'—a cloud tracking camera with a fisheye lens that provides solar forecasts for the next half hour in high temporal resolution.

To ensure that operators really understand the platform, and have visibility over the advanced controls, the UI provides probability distributions of the solar forecast. Tracking the forecast errors enables operators to see whether the solar is overproducing or under producing what the forecast was expecting at the time, providing visibility on the key performance indicators to the operators. This feedback is an important part of the machine/human interface and provides operators with insight if an engine is required to be turned on at short notice.

Automated curtailment enables the optimization of the system providing a reactivity that people cannot match. By continually monitoring the engine loadings and battery, the system is ready to clamp down on solar if it gets too volatile or exceeds some spinning reserve requirement. For example, if a large, unexpected cloud arrives, the battery is dispatched to fill the gap while the engines ramp-up. Once the cloud disappears, the engines remain committed to operating for a few hours, and the solar power is transferred to recharge the battery.

Over time, as load patterns shift, the load forecasting algorithm will also be dynamically updating to match the changing realities of the load. As mining equipment hits layers of harder rock, increasing the power load, the system will adjust and dispatch the engines accordingly.

Hybrid solutions will become the new gold standard for off-grid heavy energy users

The Fekola mine project incorporates the largest off-grid hybrid power solution in the world, demonstrating the growing case for clean energy and its sustainable and economic potential for mines in Africa and beyond.

As the cost of batteries and solar panels continues to become more competitive, hybrid solutions are proving to be a realistic and effective means for increasing energy reliability and lowering operating costs in any context. This frees up resources to improve the human condition; whether through cheaper materials and gainful employment, or by providing broader access to reliable electricity for healthcare, education, and improved quality of life.

Imec offers new wireless charging solutions for implantable, insertable and ingestible medical devices

Researchers from imec presented a novel, new system for wireless medical device communication and power at the 2020 ISSC conference. The devices, 30 times smaller than today's start-of-the-art systems, considered system power requirements alongside medically relevant data communication. As Mark Fichman, team lead for medical device development at imec explains, the new approach is designed to make diagnoses and treatment less invasive, more reliable and easier to administer.

IMEC has built a unique toolset for wirelessly communicating and powering implantable devices including those close to the skin surface or deeper in the body as well as for 'smart pills'. This toolset allows the development of customized solutions for medical device companies in a relatively short period of time.

In February 2020, imec presented an ultra-small radio chip at the renowned ISSCC conference in San Francisco. The chip – 30 times smaller than today's state of the art systems performing the same functionality – can be used to set up a wireless link with a wide variety of medical devices (e.g. smart pills [ingestibles], or small implantables and insertables [devices close to the skin], to exchange data.) The presentation highlighted one example of the work that imec is doing in the field. Mark Fichman, team lead for medical device development, explains how such chips can be used for both communication and for charging. The latter can enable more user-friendly rechargeable implants or even battery-less devices.

Safety and longevity are key for implantables

Implantables, insertables and ingestibles typically consist of several building blocks: a sensing module, an actuation or stimulation module, a communication module, a power source, and – typically – a programmable component orchestrating all operations. Additionally, implantable devices require encapsulation technology to survive within the human body for long periods of time. For this, imec relies on its CMST research group at Ghent University. This group is developing a unique multicoating technology for a.o. implantables.

The requirements for all these building blocks are extremely stringent. "It's like sending a part to space. When you implant a device, nothing can go wrong. You don't want to put the patient through an extra surgery procedure just because some electronic part is failing," said Fichman.

"The same goes for the power source. You don't want to operate on the patient every year to replace the battery. Single-use or primary batteries are used in devices such as pacemakers. After a lifetime of 5 to 7 years, the batteries need to be replaced. But because the main pacemaker device is situated relatively close to the skin surface, this is considered a localized invasive procedure.

Another small drawback is the fact that the battery is relatively large (to guarantee the long lifetime) and that the patient will 'feel' where it is located. A similar approach is taken for ingestibles or smart pills. Because the lifetime of the device is only one gastrointestinal cycle, primary batteries are the choice in this case."

Other medical implants are powered by so-called secondary batteries, as Fichman explains: "These are rechargeable batteries, typically used for devices that are implanted deeper in the body, such as neurostimulators. A patient with such a device needs to recharge it, typically at home. This implies that the charger should be attached for some time, up to a few hours. For some specific applications, there are also more advanced solutions available, like the charging belt for spinal cord stimulators of Boston Scientific."

"At imec, we believe that new technologies can change the life of patients with implants. We are developing radio chips and systems for wireless communication with the implantable or insertable. These could be used to make recharging much easier and more user-friendly, or to even make devices that don't require any battery. Also, low-power system design is an essential part of this research."

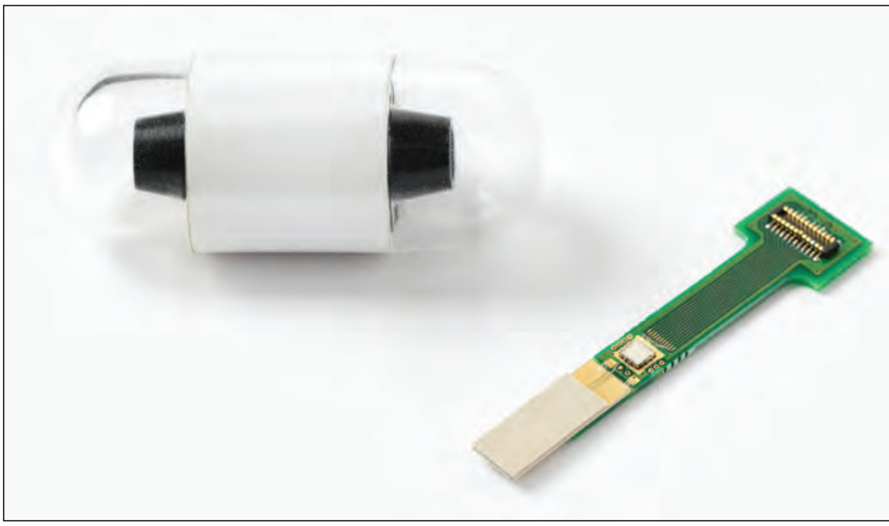
In the latter case – the battery-less implant – the patient would wear an external device like a patch or belt with a battery, a radio chip and an antenna that sends wireless signals to power the implanted device for a short period of time to do the necessary sensing and actuation. The implant would afterwards be depowered.

Which wireless technology to choose?

Imec has a lot of expertise in all kinds of wireless communication technologies. For each application, a perfect match must be found to meet all requirements. According to Fichman, "The most common wireless communication technology is RF-based. A tradeoff needs to be made between signal penetration in the body, size of required antennas, and data rate requirements.

If you use high-frequency radio signals, you can use small antennas (beneficial for the size of the recharging wearable) but the signal will not penetrate deep in the body. Low-frequency radio signals on the other hand are less absorbed by the soft tissue of the body but require larger antennas. Inductively coupled communication has the benefit of almost no tissue absorption, but tends to have limited data rates and requires good alignment between transmitter and receiver. Finally, there are other techniques like ultra-sound, but these also have their specific benefits and drawbacks."

"We believe that every application has different requirements when it comes to wireless communications with an implant (for exchanging sensor data and actuation instructions, for



Mock-up of an ingestible pill (left) with prototype transceiver (right). The small rectangular chip is imec's ultra-small 400MHz radio (including antenna) for communication with the ingestible. It is pictured here on a green test board.

reprogramming, etc.). For the wireless charging, we are investigating inductive coupling, RF signals and ultrasound technologies."

"Inductive wireless powering is the most used technique for powering implants because the magnetic permeability of the body is almost equal to that of air. Because of that, the path losses in human tissues are close to insignificant. Another important advantage is the relatively large power density safety limit, up to $100mW/mm^2$. In addition, since energy is not transferred via wave propagation, no energy is lost because of reflections by the skin and between tissues with different properties. However, inductive powering suffers from strong sensitivity to misalignment between the power transmitting coil outside the body and the implanted receiving coil. This limits its adoption to cases in which the location of the implant is known in advance."

"Wireless powering using mid-field or far-field radio frequency electromagnetic waves on the other hand is less sensitive to misalignment. However, radio frequency power transmission suffers from significant path losses in human tissue. Additionally, safety limits are 1,000 times lower. Also, since the energy transfer happens via wave propagation, significant reflection occurs at the interface between air and skin. Finally, since the body is not a homogeneous medium, multi-path reflections will occur also inside the body, further reducing the effectiveness of this technique."

"Wireless power transfer can also occur via mechanical means, via ultrasound pressure waves. Given that the body is mostly composed of water, the propagation of sound waves is very effective and path losses are low while the safety power limits are reasonable. The main challenge with ultrasound

power transfer is the reflection coefficient between air and skin, which is as high as 99.9%. In order to mitigate this loss, good acoustic coupling must be ensured in the whole path from transmitter to receiver.

This implies the use of acoustic gels and the implant must remain in close contact with the tissue in order to receive power. Even then, good acoustic coupling cannot be guaranteed throughout the body; for example due to the presence of bone tissue. So again, every application has different requirements and a different optimal technological solution."

"Thanks to our expertise in IC design, system design and integration, it is possible to make very compact radio solutions that support different radio technologies for wireless communication and charging. For every specific application, a customized solution may work. Because we have a long track record in building radio solutions with a variety of technologies, this development can be done in a relatively short period of time. For quick iterations, we can start with discrete component-based solutions but also go all the way to make custom chips for the application"

Multiple implants tightly in synch

Making a customized solution for communicating with and charging your medical implant, has an extra, unique advantage. The radio chip, present in the patch or belt worn by the patient, can also be used to synchronize the operation of several implants in the body. This can be an extremely interesting feature for certain applications, Fichman remarked.

"Think for example of a localized stimulation that is used for pain relief in a certain part of the body. The stimulus triggers a chain reaction that passes through many neurons, both to the targeted spot and to the brain.

The latter causes a typical sensation with the patient, which is a well-known side effect of this treatment. What if a second stimulation site could be used to prevent the stimulus from going all the way to the brain? This would certainly make the solution much more pleasant for the patient," he stated.

Implanting a dialysis machine in the patient's body

What if radio chips could be so small that they could be worn unobtrusively by the patient, while communicating with, charging and synchronizing the implants that the patient has inside its body? Fichman believes the technology has far reaching possibilities.

"For sure, this innovation paves the way for many new medical solutions and treatments. Medical device companies can probably imagine what this feature could mean for their specific application. One application that imec is focusing on is the artificial kidney. Indeed, as an active member of the Kidney Health Initiative (KHI), which (in cooperation with the

FDA) is stimulating the development of technologies for future dialysis methods, imec wants to contribute to this noble goal. In fact, we even helped writing the KHI innovation roadmap."

"We envision that our radio chips could be used in external wearables (such as patches) in which the main function is to communicate with and power an implanted artificial kidney (IAK). The patient would wear a patch with an integrated antenna and radio chip, attached to a small rechargeable battery. To guarantee a secure wireless link, imec has developed very robust anti-hacking technology, based upon physically unclonable features (PUFs)."

"Depending on the energy consumption and internal battery of an IAK, charging of the IAK by the patch could be done intermittently, while the IAK would dialyse in a continuous way. To save on energy, the IAK can be connected between an artery and a vein, without the need for any energy-guzzling blood pumps. Instead, it would run on the body's internal blood pressure while the artificial urine from the IAK would be dumped via the bladder in the natural way. And, by focusing on ultra-low-power system design, the internal electronics for monitoring and control would only consume very little power."

"An IAK would be an enormous improvement compared to today's big bed-side dialysis machines that usually require three hospital visits per week (with 4 hours of treatment each). Dialysis patients would gain much more freedom to go where they like and when they like, just like patients with a pacemaker, or an implanted electronic nerve stimulator for pain relief."

With small radio chips integrated in a patch, it would be possible to power an artificial kidney and extract its data and send it to the cloud.

Taking passive implants to the next level

When thinking of implants, most of us think of pacemakers and neurostimulators. These are active devices, performing an active function inside the body, like sending out a pulse. Next to this, there are also passive implants such as screws, stents, hip replacements, stomach reduction staples, etc. Fichman explained how next-generation technology can benefit these types of implants as well.

"Passive devices can sizably benefit from our implantable technologies. One could add sensors or actuators to these passive devices to check for certain parameters. These 'upgraded' implants would not need to have any batteries. Instead, they would only get activated if the patient puts an external powering device close by. Then, the sensor would wake up for a short period of time, do some sensing or actuation, and send its data to the external device."

"Or take the example of the stomach reduction staples. By 'smartifying' the staples, one could get sensing info from the implanted staples. Information collected from such smart staples can be paramount in the post-surgery follow-up and through the recovery program. Because imec's technology allows data collection from multiple sensors with respect to each other, this could provide some useful information on the functioning of the reduced stomach."

Conclusion

Imec has long-standing expertise in wireless radio technologies, miniaturization and design for ultra-low power consumption. These capabilities can be extremely interesting for medical device companies to innovate in the field implantables, insertables and ingestibles, according to Mark Fichman.

"We have an extensive toolset ready to mix and match our knowledge and our technological building blocks to make a dedicated solution for each specific application. With dedicated radio-enabled external units (incorporated in a wearable, patch, belt, etc.), one could readout an implanted device, send instructions, synchronize readout or activation of several devices, or power a rechargeable or battery-less (active and passive) device."

"The long track record of IMEC in the development of wearable solutions (including regulatory approved medical devices both in the US by the FDA and Japan's PMDA) strengthens the system level proposition, being able to offer both implants and external wearable solutions to power them. The possibilities are enormous, and, together with medical device companies with much more experience on the application-end, we can make true innovations happen. The cross-fertilization between technology and application knowledge is key in this."

About Mark Fichman

MARK FICHMAN is a senior engineer and team leader at imec. His background is primarily as a hardware engineer; he has spent most of his career in the area of active implantable medical devices working for a number of start-ups for 20 years. He is product-oriented, seeking solutions in the most challenging environments that often require multi-discipline abilities, with extensive knowledge of standards within that area as well as for wearable devices. Mark joined the connected health solutions group at imec in 2017 to lead the implantable program, working on next-generation implantable devices intended for diagnosis and therapy.

Data centres: The energy innovation opportunity

DCS recently hosted a virtual roundtable, sponsored by energy transformation company, ENEL-X, which brought together a range of experts to discuss ideas and technologies around sustainability and energy efficiency as they relate to the data centre.

This article gives you a flavour of the debate.

THE DATA CENTRE INDUSTRY'S sustainability record to date was the initial focus for the discussion. There was a general consensus that the data centre industry has already achieved a fair amount in terms of improving its energy efficiency and, to a certain extent, reducing its carbon footprint. But there was also agreement that there's much more work to be done – mainly in ensuring that, whatever power is consumed provides the maximum productivity when it comes to the IT infrastructure housed within a data centre.

A crucial objective, bearing in mind that we are now very much in the data (digital) age. More and more devices are producing more and more data, hence the growth in requirement for more and more data centres, where the storage, networks and compute can live (all of which are much more efficient in terms of useful output/power consumed than only a few years ago) – the 'plumbing' that supports applications and data. Moving forwards the debate has to focus on the interaction of data centre facilities and IT infrastructure. A data centre might be the most energy efficient in the world, but if it houses power-hungry servers and storage hardware, then that's of limited value. The good news is that both individual companies and both the data centre and IT industries are receptive to the new ideas and technologies which can help to address the sustainability challenges of the digital age.

An additional challenge is trying to meet the massively increasing digital data demand at the same time as reducing data centre/IT infrastructure energy consumption levels. Hence, the data centre industry needs to be open and honest enough to tell folk: 'If you want to carry on using all of your digital devices, then understand that this comes at an environmental cost, part of which is the building and running of more and more data centres'.

And the pandemic has accelerated the digital transformation process and, happy to report, the data centre industry, and the IT infrastructure it supports – whether that be on-premise, colo, cloud and managed services – has met the challenge spectacularly well. Indeed, one roundtable participant suggested that, after the health sector, the IT sector should be recognised as a 'hero' of the pandemic.

The roundtable discussion moved on to consider the issue of sustainability as it applies to the IT equipment – with the point made that there's a finite amount of resources left to be dug out of the ground. So, there's a balance to be struck between sweating IT assets to the 'maximum' and acquiring newer, more efficient servers, for example. In many cases, older IT hardware, especially if refurbished, can provide a level of performance and energy efficiency that matches all but the very latest, fastest products – more than sufficient for most companies and IT users. There's also work to be done when it comes to data centre operators and their customers working together to help achieve a degree of energy usage optimisation. Traditionally, colos do well out of guaranteeing an agreed amount of power for their customers and then supplying (usually rather less!) actual power. A more enlightened approach, where data centre operators help their customers to reduce their power footprint, or at least to optimise it, is seen as a positive way forward.

Moving on to the data centre facility innovation, the discussion looked at ideas such as liquid cooling, waste heat re-use and the growing usage of lithium-ion batteries. There was a general consensus that all such innovations had a role to play in addressing the sustainability challenge, but considerations such as data centre location and customer profile mean that there can be no one size fits all solution. The sustainability challenges for data centres located in, say, London, Oslo and Singapore are very different.

Waste heat re-use depends on the proximity of enclosed spaces/buildings which are able to take the heat and use it effectively; liquid cooling appears to have a sweet spot for the highest density, high performance computing applications and the business case for its use in a general purpose data centre is maybe not so compelling at the current time; and, in the case of lithium-ion batteries, there's only so much lithium waiting to be mined. Apologies to readers who might be fed up hearing the same conclusion for many of the questions debated at the roundtable, but 'balance' would seem to be the watchword when it comes to data centre facility technology innovations.

And we also have to return to the need for the data centre and IT disciplines to work more closely together. As a couple of participants highlighted, it may well be that what might seem right now as some fairly exotic technologies that promise to revolutionise storage, networks and compute will have just as big an impact on data centre design, and sustainability success, as any power or cooling innovations. In simple terms, these developments fall into one of two categories: heat-free/heatless IT; smaller and smaller devices processing/handling/storing ever larger data quantities.

These IT developments may well be a few years away, but they do promise to make a significant, positive contribution when it comes to improving energy efficiency. Data centre operators and their customer would do well to take note.

Of course, we couldn't have a discussion about energy innovation and sustainability without looking at renewable energy and alternative energy sources. Wind and solar appear to be the favourites – although one participant pointed out that the manufacture of huge wind turbines might not be that environmentally friendly in terms of both the large amount of metals required, along with the coatings. The impact of huge offshore windfarms on the natural world was not mentioned, but it's just a further point to be considered when balancing the sustainability pros and cons of a renewable energy source. And someone mentioned the world 'nuclear'.

Clearly, there's a serious debate to be had around the clean energy it provides, operating safety issues and nuclear waste disposal…

Readers can make up their own mind as to whether serious debate is something of which UK politicians are capable of right now, but there's no doubt that the data centre industry, as with so many other sectors, can be granted a large degree of self-regulation when it comes to environmental issues, or government can intervene and set targets and impose penalties. Balance between the two is everything – especially when it comes to the ambitious promising of apparently impressive targets, but with only the vaguest ideas as to how to achieve them. One suspects that the COP26 summit later this year will give a better indication of those countries which are committed to turning sustainability talk into firm actions, and those who remain caught up in the sound bites and rhetoric.

But the data centre industry itself, driven by existing regulations, and, increasingly, customer demand, is aware that sustainability and energy innovation are no longer optional 'nice to haves', but essential business drivers. The roundtable concluded with each participant being invited to imagine that they were the Minister for Data Centres for the day – what would they do?

The responses include:
Consulting with a range of experts from across the sector, to produce a series of best practice guides, and to encourage essential collaboration; encouraging stronger collaboration between data centre operators and the energy grid operators; promoting a better understanding of the data centre's essential role in, for example, smart cities and Big Data; to promote a better understanding of the link between the data centre, the data, and society; less focus on regulation, more focus on ensuring that every data centre company has a sustainability programme; promotion of the mission-critical aspect of the data centre; along with encouraging collaboration across all industry sectors to share ideas and solutions.

EV, industrial and telecom gave a boost to the 2020 power electronics market

Yole Développement examined the 2020 power electronics market to assess how the COVID-19 pandemic impacted core market sectors. Yole found that while some sectors suffered from supply chain disruptions, electric vehicle (EV), industrial and telecom applications grew. Yole Technology and Market Analyst **Ana Villamor** interviewed **Ali Husain,** Senior Manager for Strategy and Corporate Marketing at ON Semiconductor about 2020's bright spots amidst a very challenging year.

IT IS NOT SURPRISING that the last year has been filled with anxiety for power semiconductor players as a result of the COVID-19 pandemic and its impact on the market and supply chain. However, even though we are living in difficult times in some segments such as automotive, the global power electronics market was still worth about $17.8 billion in 2020. As shown in the Status of Power Electronics Industry 2020 report performed by Yole Développement, the power electronics market is expected to reach $22.7 billion by 2025, with electric vehicle (EV) applications being a driving force of the market due to very aggressive targets set by major countries world-wide.

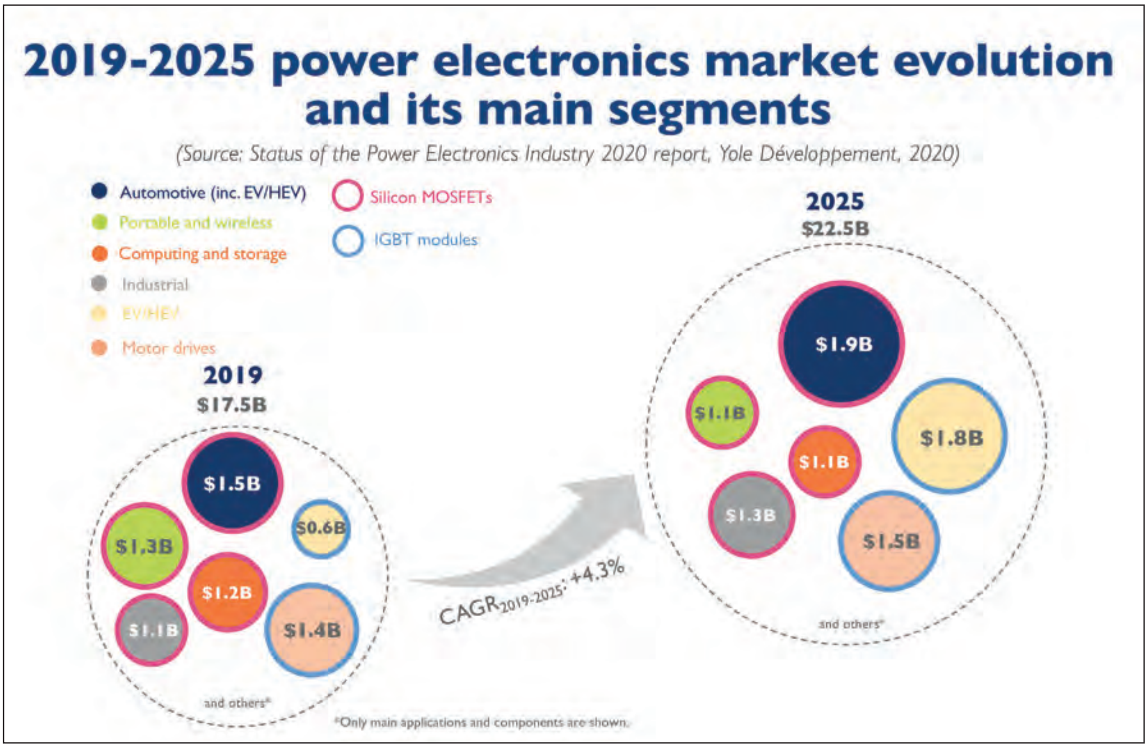
Moreover, we cannot ignore big revenue applications in the industrial sector (being automated/electrified) or telecom applications, both of which were pushed during the pandemic.
Ana Villamor, Technology & Market Analyst at Yole Développement (Yole) interviewed Ali Husain, Senior Manager for Strategy and Corporate Marketing at ON Semiconductor, one of the global semiconductor leaders, to know more about their products and future trends for power electronics.

Ana Villamor (AV): *Please briefly introduce yourself and your activities at ON Semiconductor?*

Ali Husain (AH): I am Ali Husain, Senior Manager for Strategy and Corporate Marketing. I focus on power electronics and industrial systems.

AV: *Can you tell us what the main power electronics products developed by ON Semiconductor are?*

AH: ON Semiconductor develops the full range of power electronics products; our solutions range from Watts to 10's of kilowatts, from low voltage



2019-2025 power electronics market evolution and its main segments by Yole

to grid voltage, from discrete devices to highly integrated modules, from diodes and power switches to controllers, drivers and protections, and from traditional silicon to new wide bandgap devices. ON Semiconductor's product portfolio can address nearly every application or topology.

AV: *What is the added value of ON Semiconductor's products?*

AH: ON Semiconductor's power electronics have best-in-class efficiency, with different versions that trade off switching loss and conductor loss in order to optimize for a variety of power conversion requirements.

AV: *Which are the main applications that ON Semiconductor will be targeting in the coming years to ensure the success of the power semiconductor division?*

AH: Automotive markets are the biggest long-term market for power electronic market growth. ON Semiconductor has solutions for traction inverters, OBCs, DC-DC conversion and auxiliary motors for the electrification of the automobile (for both 48V and high voltage systems covering MHEV, PHEV, BEV and FCEV).

ON Semiconductor is also highly focused on Industrial markets, where there is strong adoption of power electronics into automation, robotics and energy generation and storage. The other markets that we are targeting is cloud and telecom power, which have been growing faster during this pandemic period.

AV: *What has been the impact on power semiconductor market of the COVID-19 crisis? In this context, do you see the supply chain reshaping in this industry?*

AH: The pandemic has brought challenges and opportunities for power semiconductors. There is already greater demand for cloud power solutions, and there will be increased demand for robotics and factory automation as all companies harden and add redundancy to their supply chains.

AV: *What impact do you see especially from the EV market on the different activities of ON Semiconductor?*

AH: The EV market will drive new solutions for low weight and high efficiency at all power conversion points. These requirements have been driving innovation within ON Semiconductor for several years and will continue to do so for many years in the future. One example is our single and double side cooled traction inverter modules. We worked closely with the cooling system design in order to create compact, efficient and easy-to-use solutions for traction drive.

AV: *Can you share with us the related roadmap for the next five years for ON Semiconductor's EV products?*

AH: Vehicle electrification is one of ON Semiconductor's focus investment areas in automotive. We are developing solutions to help consumers spend less time charging and more time driving their vehicle. We are addressing these needs by releasing one of the most extensive and complete portfolio of power solutions for EVs covering all needs for traction inverters, OBC, DC-DC and HV auxiliary

On Semiconductor image of power module overlaying an industrial scale PV plant array)

applications using a 400V or 800V battery. For example, we will be extending our VE-TRAC™ family of traction inverter power modules with more than 15 new part numbers in the next 18 months covering applications from 80 to 250+kW in 400V or 800V battery systems with IGBTs and SiC MOSFETs.

AV: *At Yole, analysts see several changes in the supply chain for EV manufacturing: OEMs encroaching on Tier1s for the power module and making the inverter themselves, and discrete players jumping into module assembly. How does this impact leading semiconductor manufacturers, such as ON Semiconductor?*

AH: ON Semiconductor's wide portfolio of power solutions can address the needs arising from this industry transformation. ON Semiconductor is not only offering products but also tools to help application engineers achieve their design targets. Simulation models and application support are only a couple of examples of these tools. Our extensive portfolios allow the customer to develop a scalable solution that can cover wide application ranges. So, regardless if the design customer is moving away from a Tier1 towards an OEM, ON Semiconductor can support every player's needs with a wafer, discrete or integrated solution.

VE-Trac™ Dual module overlaid against a vehicle in motion; image by On Semiconductor)

AV: *There have been several announcements relating to the use of 300mm production lines for power electronics. Yole is aware of the transfer of GlobalFoundries New York (USA) 300mm fab to ON Semiconductor and the announcement of the sale of two 200mm fabs. It seems that everything is ready for big production changes in throughput. How do you see production evolving in power electronics components in the coming five years?*

AH: Power electronics demand will continue to grow as automobiles, the electric grid and climate control become more electrified. Increased wafer size will be key to meeting this demand and keeping parts cost effective for new applications. Another trend for the next five years and beyond will be packaging innovation and greater integration, especially for WBG materials.

AV: *What short-term and long-term impacts do you foresee in the semiconductor industry from the push in China for local power semiconductor manufacturing?*

AH: There will be price pressure on all non-China producers in order to maintain market share. Existing power device vendors will need to differentiate their quality, reliability, delivery and support.

AV: *What is the status of the technology for wide bandgap (WBG) mass production? Which are the more promising markets for SiC and GaN in the next 2-3 years?*

AH: Silicon carbide will continue to grow share for industrial power and energy generation, and we will see it in automobile traction inverters growing rapidly. Gallium nitride is starting to prove itself in consumer power supply apps, but it will take more than three years to gain significant share in more demanding applications.

AV: *What can we expect from the ON Semiconductor power semiconductor division in the next two to three years?*

AH: Increasing portfolio of SiC devices and modules for EV traction inverters, solar systems, and EV charging. We will continue to lead with improved technologies for IGBTs, MOSFETs, gate drivers and more. We also will keep developing novel packaging and thermal management solutions to increase power density.

For more information about Yole Développement's Status of Power Electronics Industry 2020 report, please visit: https://www.i-micronews.com/products/status-of-the-power-electronic-industry-2020/

Disrupting the tubes market with high-voltage GaN HEMTs

GaN HEMTs operating at voltages of up to 150 V outperform vacuum tubes by combining high performance with greater reliability, longer lifetime and lower operating costs

BY GABRIELE FORMICONE, JEFF BURGER, JAMES CUSTER AND JOHN WALKER FROM INTEGRA TECHNOLOGIES

INVENTED PREDOMINANTLY in the first half of the twentieth century, vacuum electron devices (VEDs) have a long history as a critical component enabling satellite communications, radar systems, high-energy particle accelerators, and other applications requiring high output power, wide operating bandwidth and high efficiency. VEDs include traveling-wave tubes and klystrons.

While VEDs are an accepted technology, they suffer from multiple weaknesses, many of which can be addressed by semiconductor-based solid-state amplifiers, which have become the mainstream technology in the lower power, lower frequency VED market. Semiconductor-based solutions deliver longer lifetime, superior ruggedness, and higher reliability, and reduce overall system size, weight, and costs. Yet despite all this success, solid-state sources have yet to penetrate the high end of the market for high power, multi-kilowatt applications.

Modernization of high-power RF communication and data transmission systems will push the requirements of what traditional VEDs can deliver. In addition, system architects are demanding more efficient power sources to meet green requirements while driving down operating costs over the system life. Thanks to the pioneering work of our team at Integra Technologies Inc., a market leader in RF and microwave high power devices, we have achieved a breakthrough by pushing the operating voltage for this class of device to a new high, raising the bar for high efficiency GaN-on-SiC technology. These efforts draw on our long heritage of silicon bipolar and GaN/SiC RF high power expertise at 28 V and 50 V, with our latest success representing yet another milestone in our advancements in green technology, which date back to 2013. The ground-breaking progress that we have made enables high-voltage GaN/SiC-based HEMTs to offer a compelling commercial alternative to the VED.

The foundation for our advanced R&D activity is our portfolio of proprietary epitaxial structures. They are specifically developed for high-power RF applications, and benefit from decades of refinement, realised through close collaborations with our high-power customers.

Leveraging this field-proven IP, we have developed new epitaxial structures specifically designed for high-voltage operation. In addition to this advance, we have introduced and then patented innovated circuit and thermal management techniques specifically for high power operation. Benefiting from all this progress, our devices can now operate at voltages of up to 150 V, resulting in a dramatic improvement in output characteristics.

Our latest generation of high-voltage GaN/SiC devices, which produce pulsed power densities up to more than 20 W/mm, enables the production of solid-state devices with an output power of several kilowatts. Critical to the performance of the next high-power-generation green platforms, our HEMTs deliver sufficient gain, efficiency, and reliability to enable these systems to fulfil their performance targets. Our devices are manufactured in a mainstream wafer fabrication foundry, using commercially available, production-ready materials.

Increasing power and dynamic range

At last year's International Microwave Symposium, our company demonstrated the incredibly high output powers that can be produced by RF GaN/SiC transistors operating at elevated voltages of between 100 V and 150 V. We reported 2 x 50 mm gate periphery die yielding 1.2 kW when operating in CW mode at 100 V, and producing 2.3 kW when driven at 145 V using 100 μs-wide pulses and a 5 percent duty cycle. Plots of power gain and drain efficiency versus output power for these devices, which have a drain efficiency of 80 percent when operating in both modes, are shown in Figure 1. Two key features

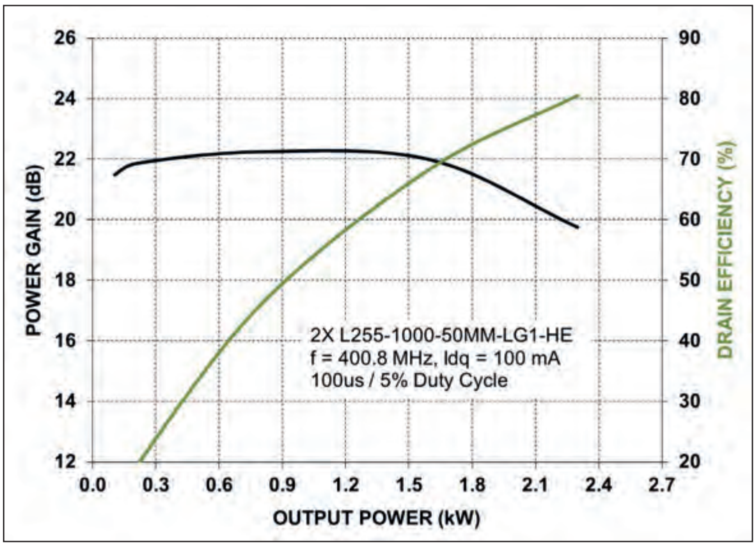


Figure 1. Measured RF power gain and drain efficiency versus output power at 145 V bias and 400.8 MHz. Quiescent current is 100 mA. 6 Ω series gate resistors help to stabilise the transistor with 20 dB gain at 2 dB compression and 2.3 kW saturated power. Drain efficiency peaks at 80 percent. In CW operation at 100 V bias, saturated power is 1.2 kW with the same 80 percent peak drain efficiency.

of this amplifier's design are harmonic tuning, used to realise high efficiency, and patented thermal enhancement techniques that help mitigate heat dissipation in such high-power density transistors. We have designed the devices and circuits to operate at 400.8 MHz. This is the frequency employed in today's largest particle accelerators, and also a frequency of interest for long-range, early-warning radar systems.

Our technology enables a single transistor to produce a CW power level of 2 kW and a pulsed output of 4 kW at an efficiency greater than 70 percent. With this level of performance, megawatt power levels can be realised with fewer combiners and lower related losses. By comparison, off-the-shelf 50 V RF technology would require massive power combiners

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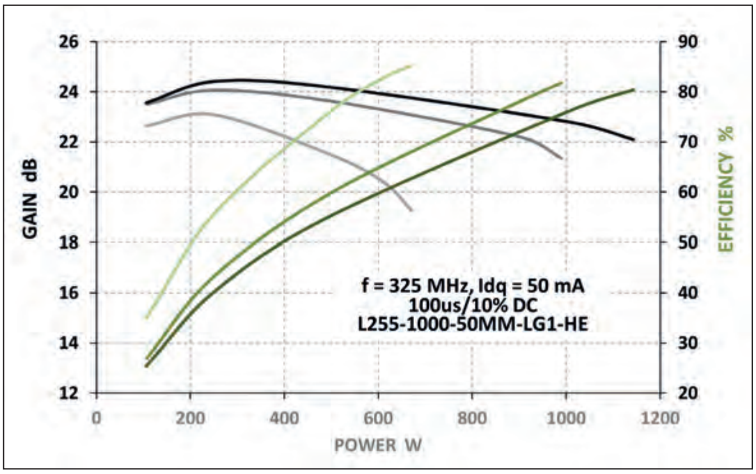

Figure 2. Measured RF power gain and drain efficiency versus output power for a 50 mm die with a signal of 100 µs pulse width and 10 percent duty cycle at 325 MHz. The device is characterized at 100 V, 125 V and 145 V DC bias demonstrating a 3 dB power dynamic range. By reducing operating bias to 50 V a 6 dB dynamic range is achieved.

to achieve similar performance, degrading system efficiency, while increasing the complexity of heat extraction. We also showcased the design flexibility of this technology by increasing the operating voltage to 150 V at the 2020 European Microwave Week. In this forum, we reported a single 50 mm gate periphery die that produced a 3 dB power dynamic range when modulating its operating bias from 100 V to 125 V and then on to 145 V (see Figure 2).

This amplifier's devices and circuits are designed to operate at 325 MHz, targeting large particle accelerators. Our single semiconductor die delivers a 1.1 kW peak power at 145 V with 80 percent peak efficiency. The peak power decreases by about 3 dB at 100 V bias.

Going to even lower voltages can offer additional benefits. When we dial back the bias to 50 V, peak power can be modulated by around 6 dB while still preserving 80 percent peak efficiency; and we can realise additional dB of dynamic range by reducing the operating bias towards 28 V or 32 V. We have obtained similar results, also announced at European Microwave Week, with a power amplifier designed to operate at 650 MHz.

Such a great dynamic range is a key enabler in high-power RF systems. It allows multi-use or functionality, and it also enables older systems to be upgraded to combine legacy performance with additional state-of-the-art capabilities. For the high-power devices we reported at the most recent International Microwave Symposium and European Microwave Week, the peak channel temperature is only around 150 °C. Such low temperatures are realised from proprietary techniques that enhance heat flow from the hottest spots of the active region.

Our R&D activities have extended to considering the bandwidth associated with the higher power densities and higher load impedances at 100 V and 150 V. Power-over-bandwidth is a 'hot button' in several applications, with requirements that may be strictly application-specific and not discussed in the public domain. What we can say, nonetheless, is that broadband high-power applications are destined to reap huge benefits from our 100 – 150 V amplifier technology.

System-level benefits

As mentioned earlier in this article, the higher voltage GaN transistors can achieve power densities of more than 20 W/mm, thus allowing for reduced circuit complexity for the same relative power level. As an example, two 1 kW transistors running at 50 V could be replaced by a single 2 kW transistor operating at 100 V. This eliminates one transistor and the combining structure required for the lower voltage solution.

Another advantage of a higher voltage is evident in a simple load-line analysis. While a 50 V device will provide a 25 W output power with just a 50 Ω load, a 100 V device will provide four times this power.

For broadband applications, higher voltage GaN HEMTs can also be an advantage, considering that the device impedances increase with higher voltage operation and the capacitance-per-Watt are reduced. Lower voltage solutions require larger impedance transformations to achieve bandwidth, while a higher voltage solution can eliminate these transformers or reduce transformation ratios and their complexity. When utilizing 100 V GaN, the matching structure size can be reduced by a factor of two or more by removing transformers over a 50 V GaN solution for the same RF output power.

There is no doubt that much is to be gained from increasing the operating voltage of the GaN HEMT. There are benefits for the device itself, including an increase in output power, plus plenty of advantages at the circuit and system level. Our company is in talks with several VED's users to commercialize our high-voltage GaN/SiC green technology.

Further reading

G. Formicone et al. "A 2.3 kW 80% Efficiency Single GaN Transistor Amplifier for 400.8 MHz Particle Accelerators and UHF Radar Systems", IEEE-MTTS International Microwave Symposium, 2020.

G. Formicone et al. "A GaN/SiC UHF PA for Particle Accelerators with 100-145V Quasi-Static Drain Modulation," European Microwave Week, 2020.

G. Formicone et al. "Targeting radar with 150 V RF GaN HEMTs" Compound Semiconductor magazine, March 2016.

GTAT's PURE PLAY ON SILICON CARBIDE CRYSTAL

Company rapidly increasing the supply of SiC

EVERYWHERE YOU LOOK, the 'electrification of everything' is happening. Reliance on fossil fuels is, little by little, ebbing. While the shift is not a swift one, there is widespread agreement that 'clean' power is the direction the world is headed. Worldwide, more than 25 countries have announced a phase-out of internal combustion vehicles in the next few years as they invest in clean technology systems. In the United States, California, Massachusetts, and New Jersey are heading in the same direction.

It is against this backdrop that foundational developments are taking place at GT Advanced Technologies (GTAT). One of these is the emergence of advanced semiconductor materials and devices that can handle the kind of power needed to efficiently drive applications ranging from electric vehicles to massive data centers. Semiconductors have traditionally been built upon silicon wafers. Silicon chips make sense for mobile phones, watches, and televisions where cost and performance factors lend themselves to that material. But the electrification of cars, trucks, trains and other 'power electronics' applications (where voltages and currents exceed what silicon can efficiently handle) point to advanced semiconductor materials such as silicon carbide (SiC).

First, it is extremely efficient with minimal losses and high switching speeds (transitioning from an 'ON' state to 'OFF'). Second, chips made from SiC run at higher temperatures that enable minimal cooling requirements. Third, devices made from SiC can be smaller and therefore lighter. Using the electric vehicle as an example, SiC provides smaller and lighter powertrains, faster charging, and better range. Complementary to this, charging stations based on SiC technology will quicken the process to fully charge a vehicle.

GTAT's role here is to make the SiC crystal that others downstream use to make wafers and devices. This is an important supply chain distinction because what the market demands is a rapidly growing supply of SiC crystal at affordable prices. "That is what the market is signaling," says GTAT President and CEO Greg Knight. "There are many superb companies around the world that are very adept at wafering and device fabrication, and the goal is to put our CrystX® SiC at their doorstep at competitive prices and in high volume." Over the past year, GTAT has signed long-term supply agreements with three of the largest global makers of wafers and devices.

Producing SiC is much more involved and challenging than making silicon crystal, and the material is not defect-free. While the technical benefits of SiC are well understood, producing the crystal in volume and at a cost and quality level that markets demand is challenging. "Our business model gives every company wishing to get into SiC a way to immediately do so," said Knight. "They don't need to invest in the capital and complex knowhow, because we've already done that." The result is a much more rapid 'path forward' for SiC across growing markets that need the material. Wafer producers with strength in silicon can now offer SiC, which is a valuable portfolio position to

Figure 1: A portion of GTATs production area at its Hudson, New Hampshire facility

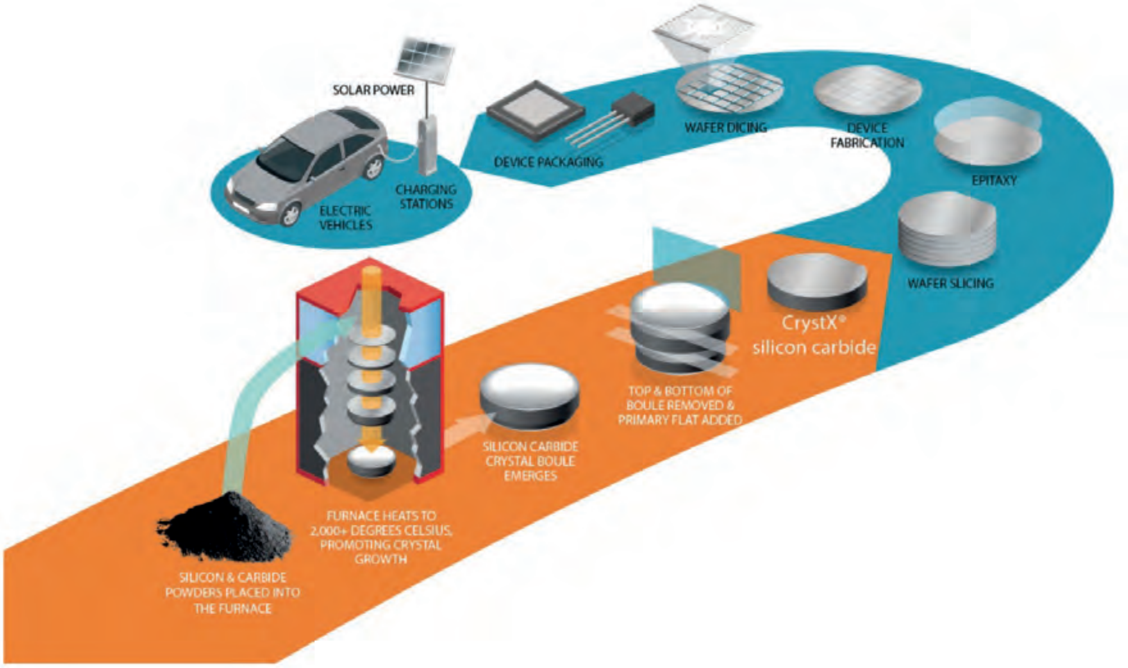

Figure 2: As a ‘pure play’ producer of silicon carbide, GTAT is able to provide ‘pucks’ to downstream makers of wafers and semiconductors.

have as applications transition from one material to the other.

GTAT’s heritage as a crystal-growth equipment and technology provider puts it at a distinct advantage as demand accelerates for affordable SiC wafers. “There is a tremendous amount of knowhow we’ve brought to bear here,” said Knight. “We design equipment to enable the most robust and repeatable crystal growth process while minimizing capex and cost of ownership. We excel at building crystal-growth equipment and can scale very rapidly, and we have a strong and fundamental understanding of the science needed to drive material quality to the highest levels.”

Indeed, a mere 18 months after beginning production of CrystX® SiC, GTAT has achieved quality levels leading to long-term supply agreements with Global Wafers, ON Semiconductor and Infineon. “These are the companies that are highly invested in making the ‘electrification of everything’ a reality, and they are coming to us for their crystal material,” Knight said. GTAT produces its CrystX® SiC at 150mm diameter now and is driving toward 200mm to achieve a 1.8x increase in the number of devices that the larger surface area makes possible. GTAT’s quality levels are always being driven higher, which is the major focus point for the Company. One of the major benefits of GTATs overall process is the ability to deliver very precise resistivity values for its SiC. While the standard industry range of 19-22 Ω-cm for SiC is very attainable, GTAT meets customer specifications with the tightest distribution across the crystal.

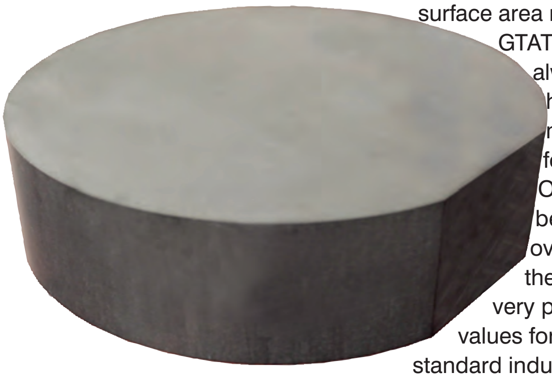

Figure 3: A 150mm diameter CrystX® ‘puck’ ready for wafering

The deliverable from GTAT is a CrystX® SiC ‘puck’ that users slice into very thin wafers. The goal for customers is to achieve the highest amount of yield from each puck. In addition to transitioning from 150mm diameter to 200mm, usable height of the puck is also meaningful. GTAT is now producing the largest SiC pucks available in the market, with a roadmap that continually improves on that. This results in more wafers and more devices from a single puck.

Product quality levels are important, but an even more meaningful benchmark is GTAT’s overarching quality program that touches every aspect of the business. Here, GTAT is demonstrating a level of competence and speed unmatched in the industry. “We obtained ISO 9001:2015 certification very rapidly,” said Knight. “In less than a year, we equipped our facility, reached volume production, and achieved ISO certification. I cannot think of any other company in our industry that has been able to accomplish these milestones faster.” While the technical specifications for CrystX® SiC are industry-leading, customers are also very invested in seeing GTAT managed and operating in a quality-driven way.

In addition to ISO, IATF 16949 is a quality standard for the automotive industry. Since SiC is a fundamental part of the overall EV supply chain, GTAT is now meeting customer-driven requirements of this important global standard.

While the acceleration of the worldwide electric vehicle industry is a catalyst for GTATs growth, it is important

Figure 4: While the EV industry is the obvious driver for SiC adoption, several other application areas will call upon the material.

to recognize that SiC is going to be useful in many other areas. One application area is renewable energy, where electricity requires additional power conversion before it can be fed to the grid. For example, a wind turbine produces electricity that must be converted from AC to DC, then back to AC for the grid. For solar energy, which produce DC power only, a SiC inverter turns power into alternating current the grid needs. The key to driving rapid adoption of all these applications is to grow the global supply of SiC and at affordable price points, which are the two focus points for the Company.

As wind- and solar-produced power sources form the basis for our global push toward renewable energy, managing that electricity becomes crucial. Energy storage systems help smooth the inevitable discrepancy between supply and demand, and these can be made smaller and easily scalable when using SiC-based modules and devices. Other applications for SiC are also increasing from industrial equipment and 5G telecom, where size and weight advantages of the material will match its electrical superiority.

The transition to renewable and clean energy sources is unquestionably accelerating, which means that efficient semiconductors designed to power this future are needed now. GTAT plays a vital role in this overall ecosystem by providing a high-volume supply of affordable SiC crystal upon which these advanced circuits are produced. As a 'pure-play' producer of SiC crystal, GTAT has forged a business model that is already proving advantageous on a worldwide scale.

To learn more about GTAT's SiC capabilities, please visit **www.gtat.com**

GT ADVANCED TECHNOLOGIES

About GT Advanced Technologies
GT Advanced Technologies is a manufacturer of high-performance crystal materials including silicon carbide (SiC) and sapphire. GTAT's corporate headquarters in Hudson, New Hampshire also serves as the Company's primary manufacturing facility for its CrystX® silicon carbide. This material is fundamental to the production of semiconductors used in electric vehicles and other power electronics applications.

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https://gtat.com/products/silicon-carbide