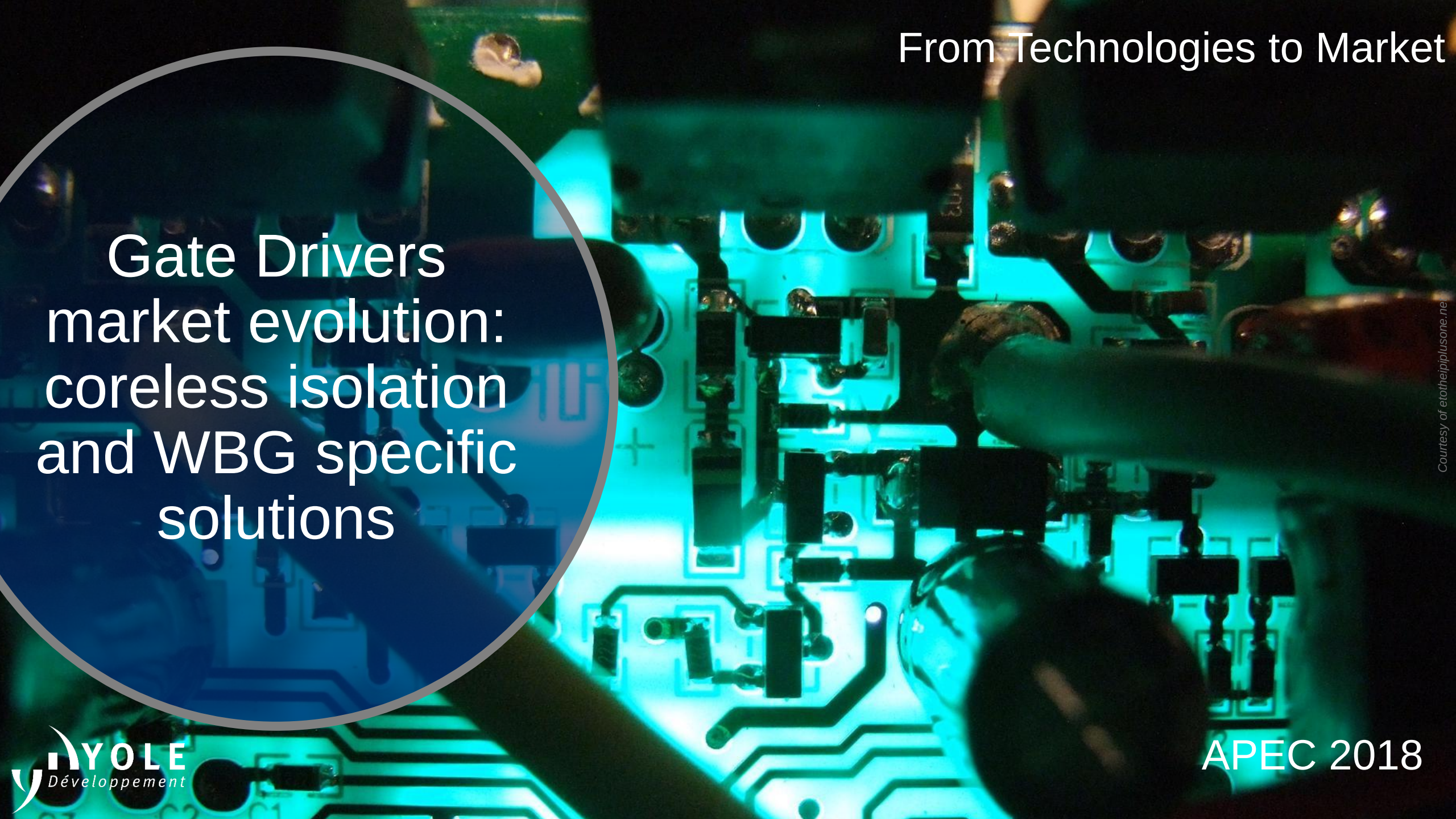
From Technologies to Market

Gate Drivers market evolution: coreless isolation and WBG specific solutions



Courtesy of etothejpjplusone.net

YOLE Développement

APEC 2018

AGENDA

- Driver IC market
- Power electronics trends
- Overview of isolation technologies
- Drivers for WBG devices
- Conclusion

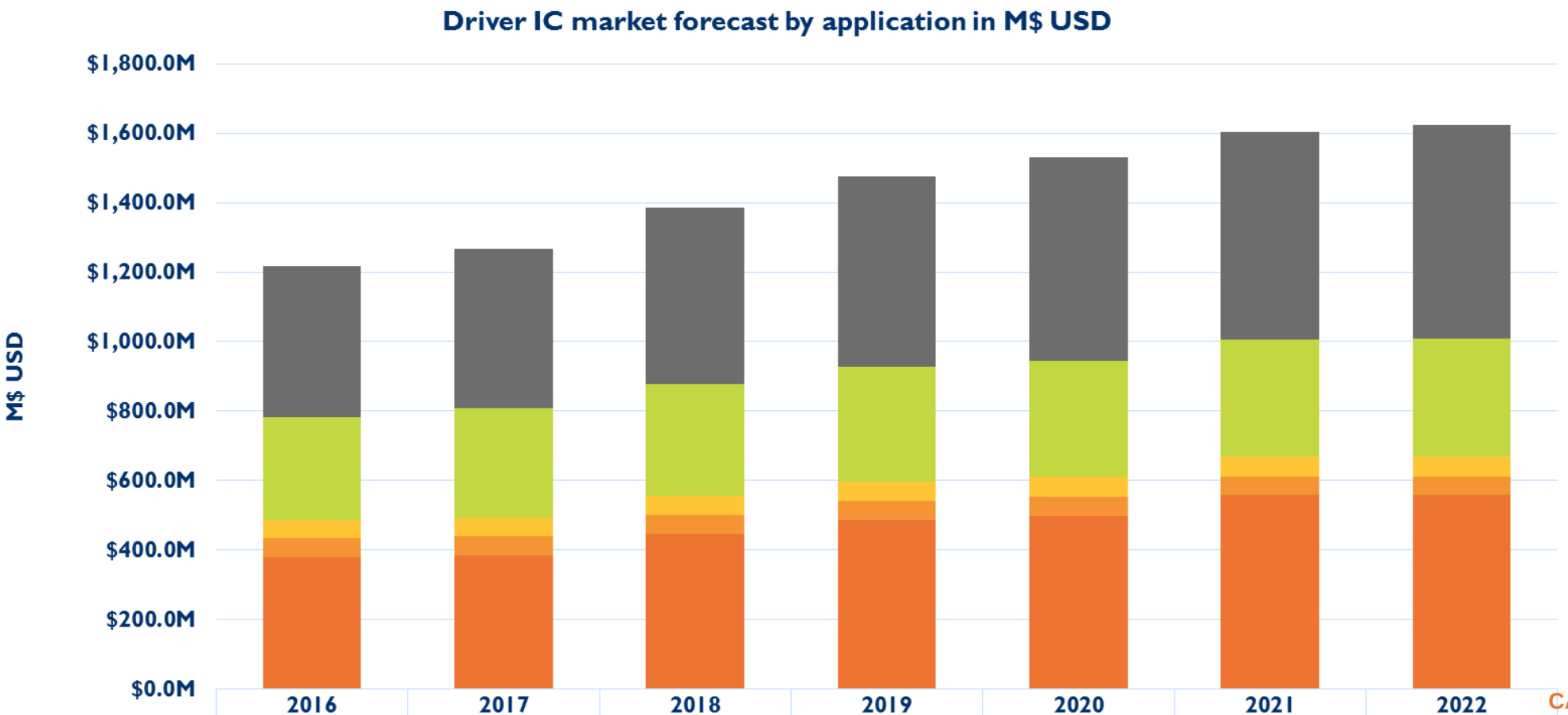
GATE DRIVER GLOBAL MARKET OVERVIEW

The global driver IC market is estimated to have been around $1.2 billion U.S. Dollars in 2016

GATE DRIVER GLOBAL MARKET OVERVIEW

Driver IC annual revenue by application

Yole forecasts gate drivers to grow at 5.1% CAGR from 2017 to 2022.



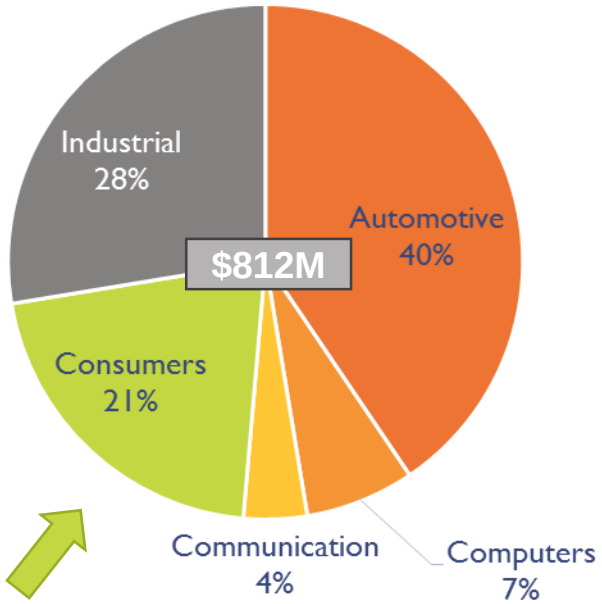
	2016	2017	2018	2019	2020	2021	2022	CAGR 16-22
Industrial	$436.6M	$459.2M	$508.7M	$548.9M	$584.3M	$597.7M	$615.4M	5.9%
Consumers	$294.3M	$315.1M	$321.9M	$329.6M	$333.9M	$336.9M	$337.0M	2.3%
Communication	$52.6M	$51.7M	$53.7M	$56.6M	$58.3M	$58.3M	$59.1M	1.9%
Computers	$55.7M	$54.3M	$54.7M	$55.0M	$54.9M	$53.5M	$52.5M	-1.0%
Automotive	$378.7M	$386.1M	$446.6M	$485.1M	$498.8M	$557.7M	$559.0M	6.7%

DRIVER IC SPLIT

MOSFET vs. IGBT gate drivers end-markets per application in 2016

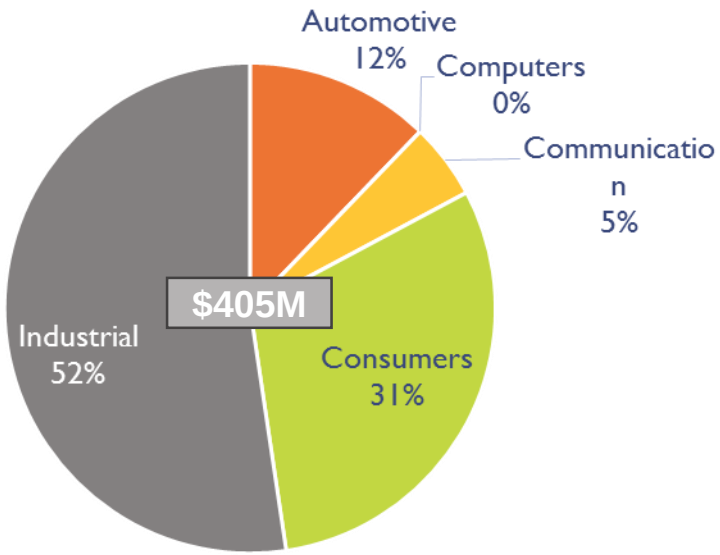
The split by application for gate drivers being used for MOSFETs or IGBTs is somewhat different in 2016.

Driver ICs for MOSFETs per application



Automotive, consumer, and industrial markets are the main ones for MOSFETs gate drivers

Driver ICs for IGBTs per application



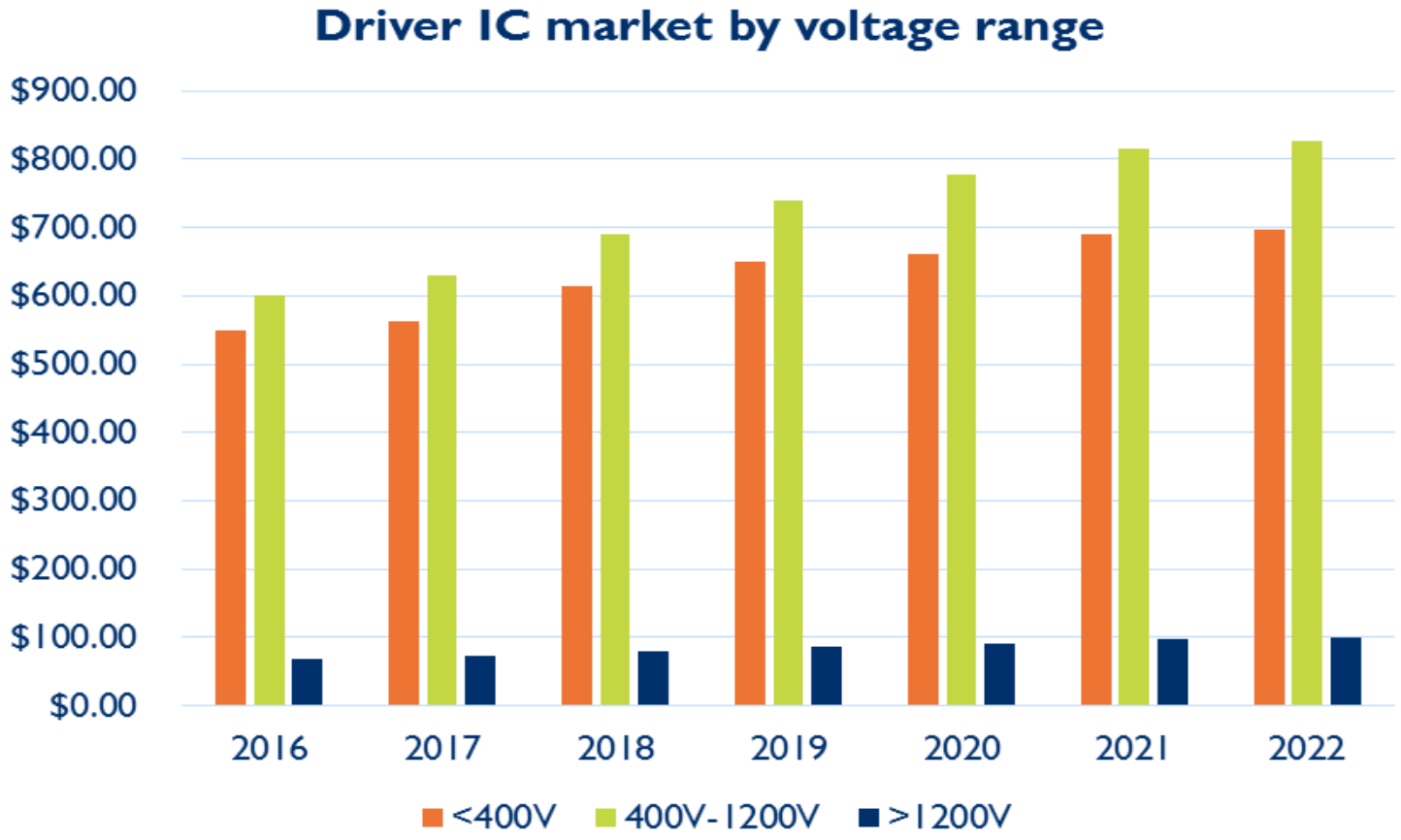
The industrial segment is the principal market for IGBT gate drivers.

DRIVER IC TOPOLOGY UTILIZATION TREND

Split by voltage of driver IC in 2016 and 2022

Medium voltage gate driver (401~1200V) market is forecast to offer the best growth potential.

- The gate driver ICs market split was primarily between the 400V voltage market and medium voltage rated between 400V-1200V.
- For applications above 1200V, designers tend to utilize IGBT modules instead of IGBTs discrete with gate drivers.

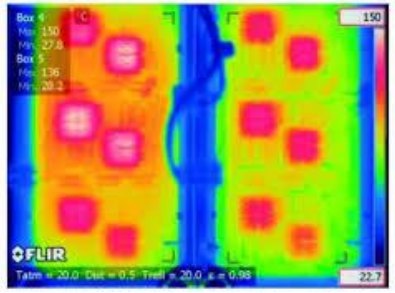


FUTURE POWER ELECTRONICS CHALLENGES

- Three main challenges in power electronics are having a great influence in the technology around the semiconductor:
  - **Higher temperature operation** of the dies
  - **Higher switching frequencies** of converters
  - **Shrinkage & integration** needs of converters in the overall systems

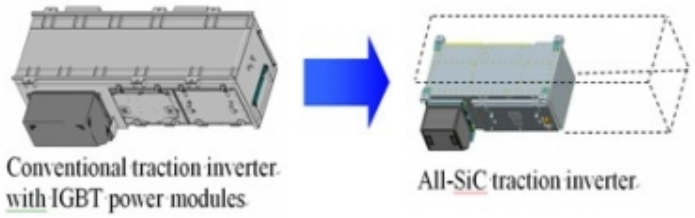
- The WBG devices, such as SiC and GaN, are already accelerating (and will accelerate even more) this process and thereby all electronics components, are obliged to adapt to the new era of power converters.

A new era of power converters is starting to emerge thanks to SiC & GaN devices benefits.



T_j : 150°C → 175°C

Switching frequency increase



Size reduction of the systems

HOW WOULD THE EVOLUTION OF POWER ELECTRONICS IMPACT DRIVER IC?

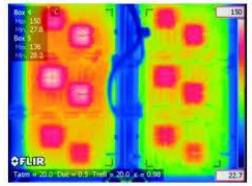
What changes for gate drivers?

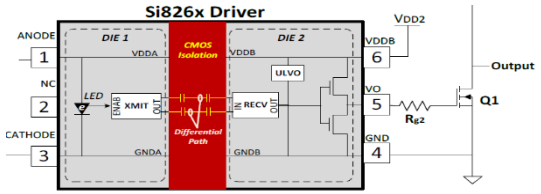
This cause-effect scenario is now principally applied by Wide Band Gap devices.

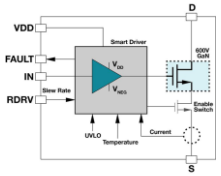
Faster switching frequency

Need for lower stray inductance

Driver IC closer to gate







Integration of driver ICs in transistor package

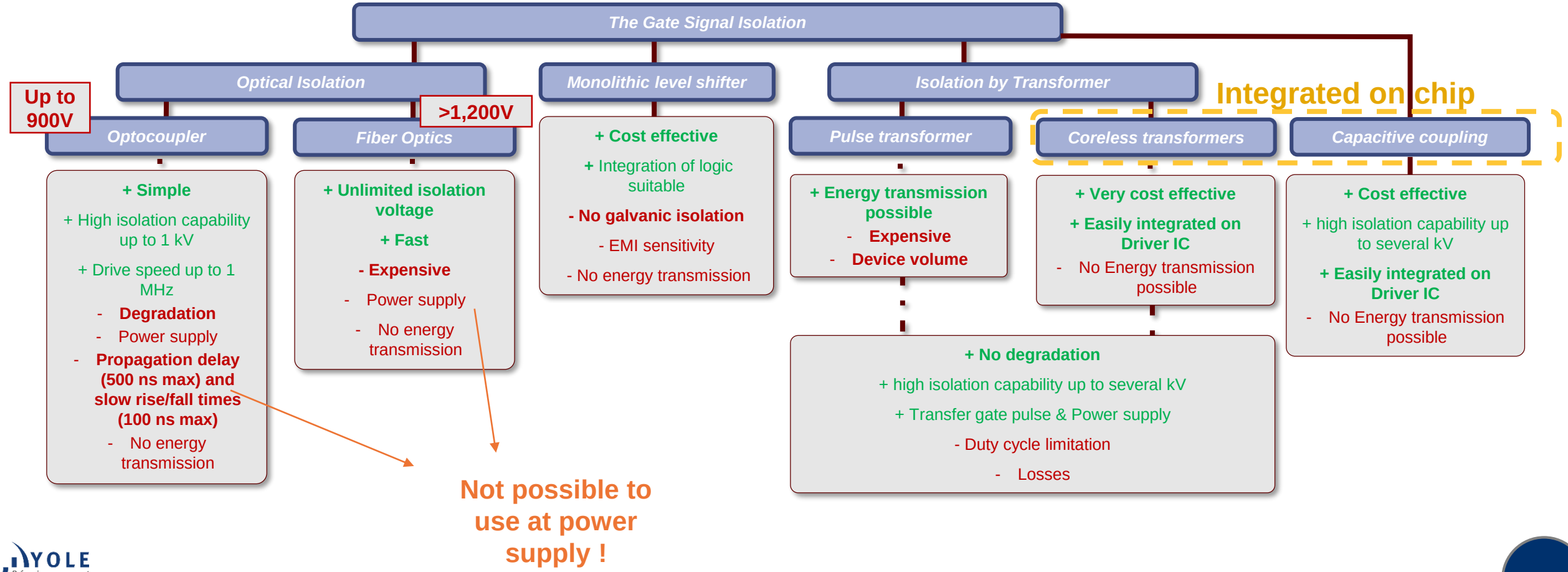
Need for on-chip integrated isolation

Higher temp. inside the power module

ISOLATION TECHNOLOGIES

Main isolation technologies used at gate drivers

- The isolation between IGBT and the controller is a challenge inside the High Voltage Gate drivers
- 3 main families of gate signal isolation are used today :



ISOLATION TECHNOLOGIES

What solution is each company using?

The Gate Signal Isolation

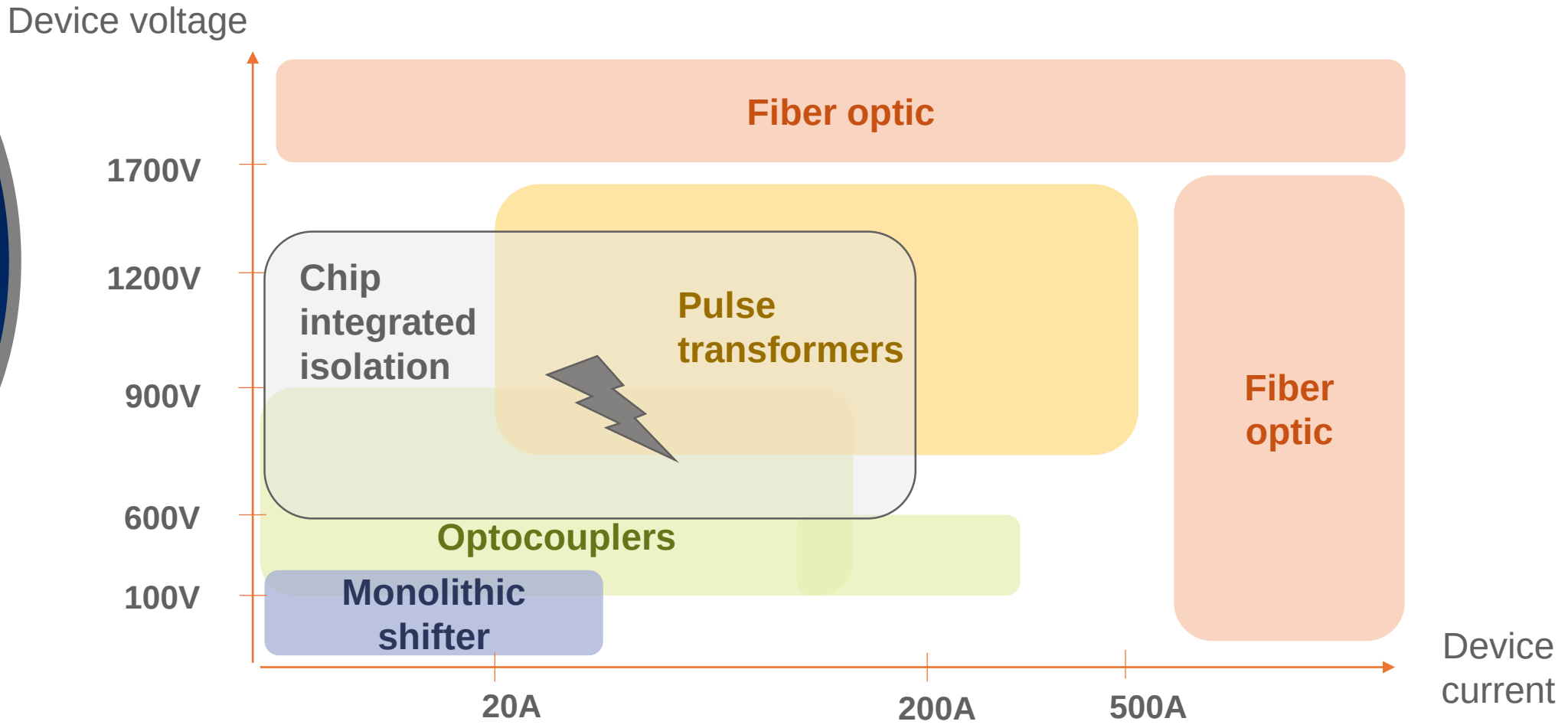
- **Optical Isolation**
  - **Optocoupler**
    - BROADCOM
    - Avago, now part of Broadcom was one of the main optocoupler manufacturers for gate drivers
    - RENESAS
    - TOSHIBA
  - **Fiber Optics**
    - BROADCOM
    - ABB
- **Monolithic level shifter**
  - NXP, ST, Texas Instruments
  - Almost all driver IC manufacturers
  - Infineon, ON Semiconductor, ROHM Semiconductor
- **Isolation by Transformer**
  - **Pulse transformer**
    - Infineon, ST, Texas Instruments, ON Semiconductor
    - Etc.
  - **Coreless transformers**
    - ROHM Semiconductor, Infineon, ST, Analog Devices
  - **Capacitive coupling**
    - Texas Instruments, Silicon Labs

Each company is positioning clearly on one of the recent digital isolator technologies

ISOLATION TECHNOLOGY PER POWER

- **Optocouplers** and **pulse transformers** have been the most used technologies to provide the galvanic isolation for gate drivers.
- **Fiber optic** remains a high-end solution, for high power applications, such as rail traction, wind turbines or the grid.
- But since a couple of years, **chip integrated isolation technologies**, such as **coreless transformers** are attacking the traditional optocoupler & pulse transformer markets.

Chip integrated isolation technologies are penetrating the traditional optocoupler and transformer market.

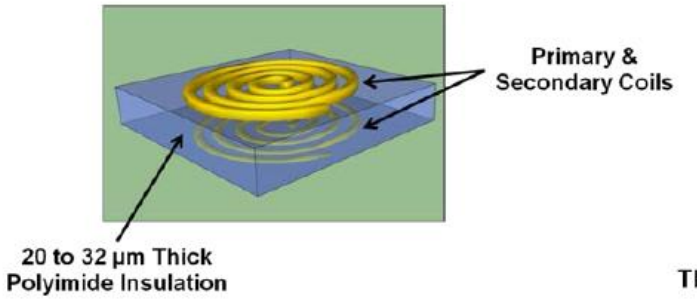


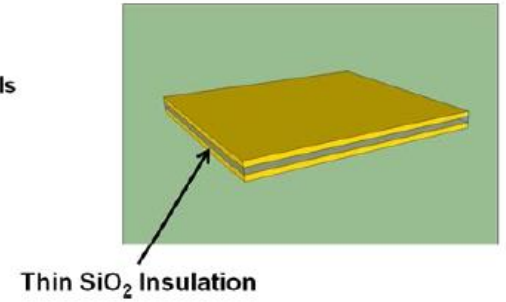
ON-CHIP ISOLATION

Micro-transformers and capacitive coupling

Polyimide & polymers are organic materials which means they show instability and degradation over time and under high temperatures. While SiO_2 is more stable.

- **A digital isolator** (also known as on-chip isolators) is used to get a digital signal across a galvanic isolation boundary.
- They serve a similar purpose as optocouplers, except optocouplers are far too slow and error prone for high speed (>1MHz) digital signals.
- Two principal technologies are being used for digital isolators: **micro-transformers** and **capacitive coupling**.
- In both cases, an insulating material separates both the primary and secondary side, such material being a **polyimide** (PI) or **a silicon dioxide** (SiO2) layer.





Temperatures up to 125°C

	Polymer-Based Optocoupler	Polyimide-Based Digital Isolator	SiO_2-Based Digital Isolator
Withstand Voltage (1 Minute)	7.5 kV rms	5 kV rms	5 kV rms
Lifetime at 400 V rms Working Voltage	25 years	50 years	25 years
Surge Level for Reinforced Insulation	20 kV	12 kV	7 kV
Distance Through the Insulation (Insulation Thickness)	400 µm	14 µm to 26 µm	7 µm to 15 µm

Isolation properties of insulating materials
Source: Analog Devices

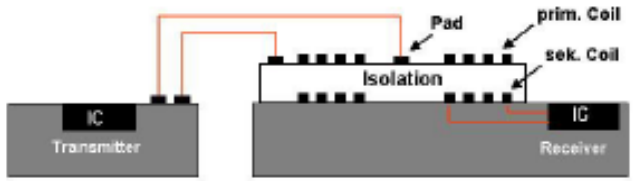
CORELESS TRANSFORMERS

Also called micro-transformers

Recent advances have brought to industrial levels the coreless technology for the insulation of control signals in an integrated driver chip.

- Coreless Transformers or Coreless Planar Transformers (CPT) were first developed as a solution for insulating the high voltage power circuit from the low voltage control circuit **allowing integration on-chip**.
- The coreless transformer technology has been **chosen by main major driver IC manufacturers** as the most adequate solution among **on-chip isolation** technologies.

- It shows several design advantages:
  - While a discrete transformer needs a core to direct the magnetic flux, the coils in an IC can be placed close enough to **save the core**.
  - The design of these transformers gives the designer **greater control in optimizing**, such as precise winding spacing and orientation when compared to traditional wire-wound magnetics.
  - **Greater stability over high temperatures**. Pulse transformers suffer from magnetic property changes and accelerated aging.
  - The pulse response of a planar transformer is typically less than 2ns, while the propagation delay is about 20ns. For optocouplers, the propagation delay is around 500ns.



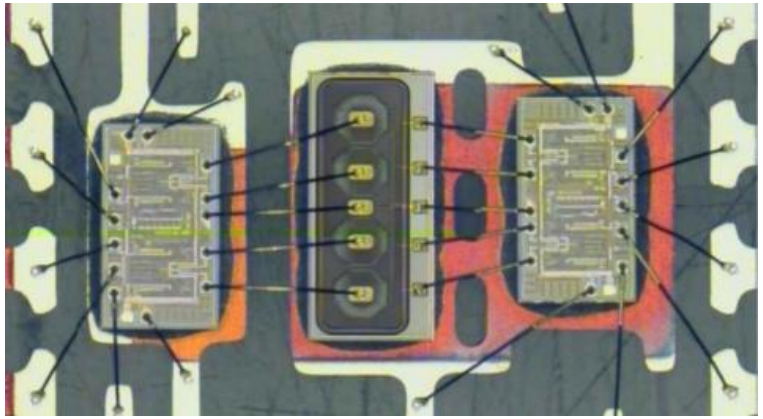
- For signal transfer, the input data is usually encoded before being transmitted to the primary data transformer. A decode is used at the secondary side to recover the signal.
- Isolation between the input and output is provided by the insulation layers between the primary coil and the secondary coil.

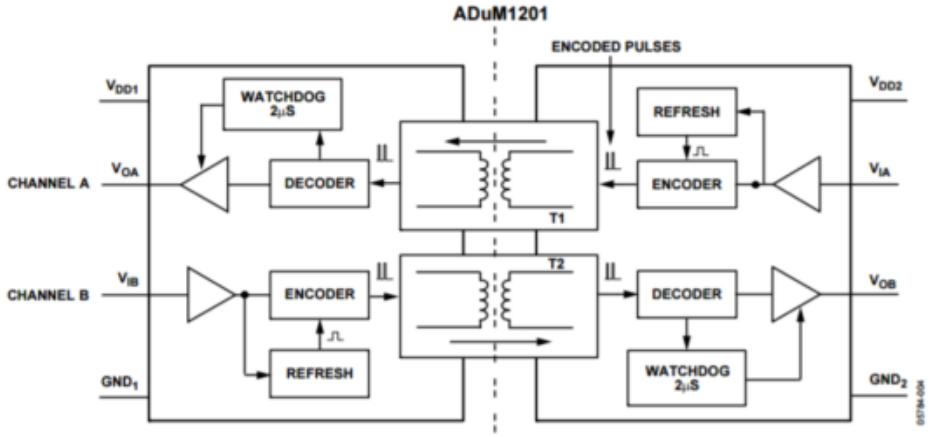
CORELESS TRANSFORMERS

Case study: Analog Devices iCoupler

iCoupler's integrated sign and power isolation capability reduces component count dramatically and improves system reliabili and lifetime.

- An **iCoupler isolation** channel consists of CMOS input and output circuits and a **chipscale transformer** (or microtransformer). In all applications, an iCoupler is powered by two separate sources which do not share a common ground.
  - An iCoupler consists of two separate channels, one for the **control signal of the gate** and the second for a **feedback signal**.





Block diagram of the ADuM1201, where an additional channel for a feedback signal is added.

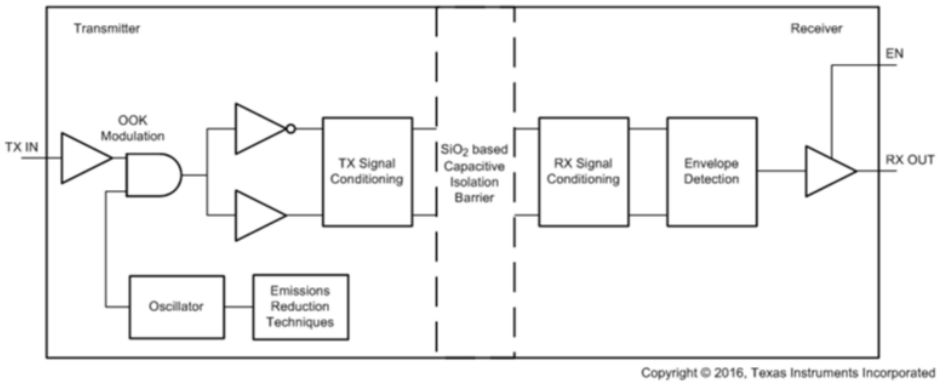
- The transformers are built on separate chips from those of the encoder or the primary chip and the decoder or the secondary chip. However, this is primarily driven for cost reasons, and **the transformers can in principle be built on top of one of the IC chips**.

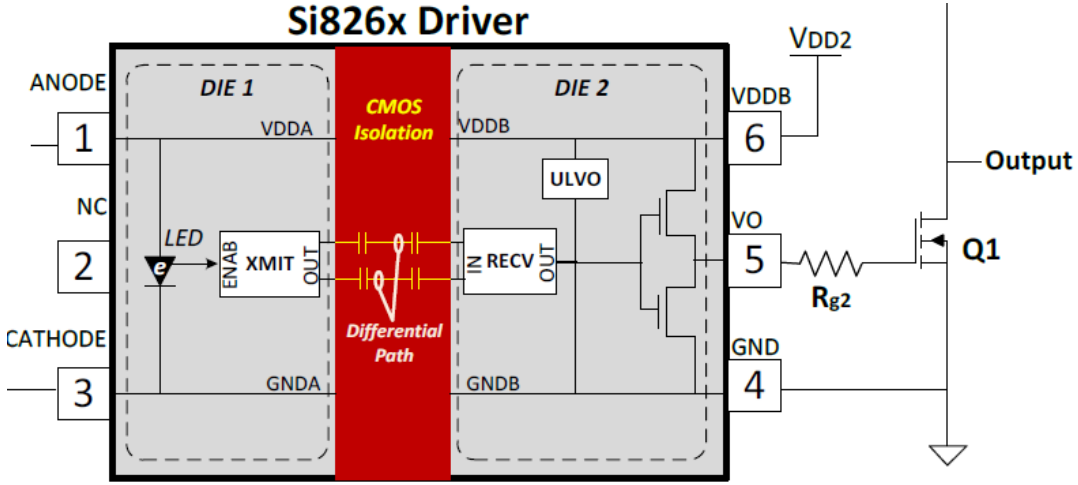
CAPACITIVE COUPLING

Case study: Texas Instrument & Silicon Labs

Today, Texas Instrument and Silicon Labs are the main companies using capacitive coupling isolation.

- The capacitive coupling is the other technology for digital isolation.
- It is a fast (8 to 10 faster than optocouplers) and reliable technology.
- **Texas Instrument** is the only big driver IC manufacturer that chose the capacitive coupling technology.
  - Other companies suggest that the isolation layer stability over time is worse than coreless transformer technology.
  - However, TI's ISO7821 digital isolator shows **>25 years life-time** and a **CMTI* > 100kV/µs**.





Silicon Labs Si856x Driver with capacitive coupling isolation

- The transmitter and receivers are **manufactured on the same chip** using the CMOS technology, separated by a silicon dioxide (SiO_2) insulation barrier.
  - The signal transmission is done by **capacitance coupling** as shown on the figure above.

Texas Instrument ISO7810 digital isolator

*CMTI: Common Mode Transient Immunity

ISOLATION TECHNOLOGY COMPARISON

	Isolation	Dv/dt immunity	Propagation delay	Integration level	Independent power supply needed at the secondary	Reliability (over time & harsh environment)	Cost
Optocouplers	Few kV	>50kV/µs	>400ns	Medium	Yes	Aging issues	$
Fiber optic	Several 10's kV	>100kV's/µs	Negligible	Medium	Yes	Good reliability	$$$$
Monolithic level shifter	None	50kV/µs	-	Integrated on the IC	No	-	$
Pulse transformer	Several kV	>50kV/µs	<100 ns	Bulky	No	Reliable	$
Digital isolation	Several kV	>100kV/µs	~20 ns	Integrated on-chip or driver IC package	Yes	Very reliable	$$

Note: evaluation on different isolation technologies, based on the best comprehension of Yole on the topic as of 02/2017

SIC & GAN DEVICE PERFORMANCES

Many efforts are still needed by power business players in order to take full advantage of SiC power devices.

SiC & GaN performance

- **High current density** → Higher Tj; High temperature packaging
- **Fast switching** → Increased EMI; Higher dv/dt; Low stray inductance packaging
- **Low Rdson** → Lower losses; Lower power consumption

Impacts or needs:

Driver IC impact

Main impact on driver ICs

- **Higher temperature environment**
- **Closer driver IC – Integration on the package**
- **Higher dv/dt isolation barrier**
- **Higher efficiency driver needed**

SIC & GAN DRIVER CHALLENGES

Comparison between SiC and GaN driver needs

	SiC	GaN
Device	• **+20V/-5V** gate voltages • Fast switching requirements: differentiate gate resistance to control turn-on & turn-off dv/dt separately	• Limited gate voltage: **+5.5V/0V** (or negative voltages) • Fast switching requirements: differentiate gate resistance to control turn-on & turn-off dv/dt separately
Driver IC	• **Galvanic isolation** required • >50kV/µs transient immunity • Short-circuit fault protection is critical	• The **monolithic level shifter** is in many cases enough • For voltages >200V a **galvanic isolation** is also required • >50kV/µs transient immunity

Package	• Integration of the **isolation on driver IC package**
	• In the future, more needs for driver IC being integrated on SiC modules for low stray inductance
	  • Higher temperature driver ICs may be needed
		• High integration between the **driver IC and the GaN switch**:
		  • Driver IC + GaN switch in the same package
		  • Monolithic solution of GaN drivr IC and GaN power switch

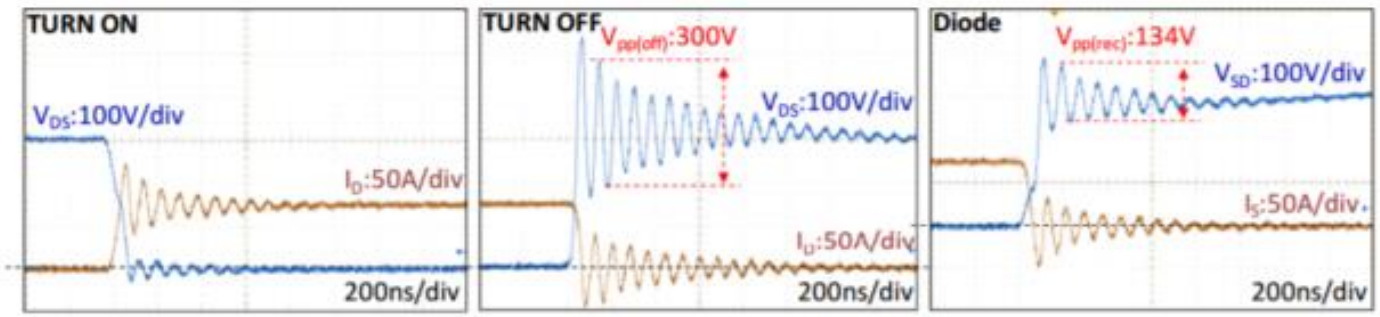
SIC & GAN DRIVING REQUIREMENTS

Very high dv/dt & di/dt consequences – SiC MOSFET example

Higher switching frequencies have some impact on how the gate needs to be driven.

- The fast switching capability is one of the key properties provided by silicon carbide devices. However SiC MOSFETs high dv/dt and di/dt may bring some challenges when driving these devices.

- Turn-off high di/dt causes V_{ds} **voltage overshoot** and **considerable voltage ringing** (figure below).



*Conditions : V_{DD}=300V, I_D=75A, Tj=25°C, Inductive load half bridge switching

**Total switching energy (Eon + Eoff + Erec) = 1.6mJ (Tj=125°C)

Fig.2 Full-SiC device switching waveforms (R_G=3.0Ω)

Faster speeds enable reducing the switching losses considerably (-70% or -80%), but increase oscillations, causing EMC issues

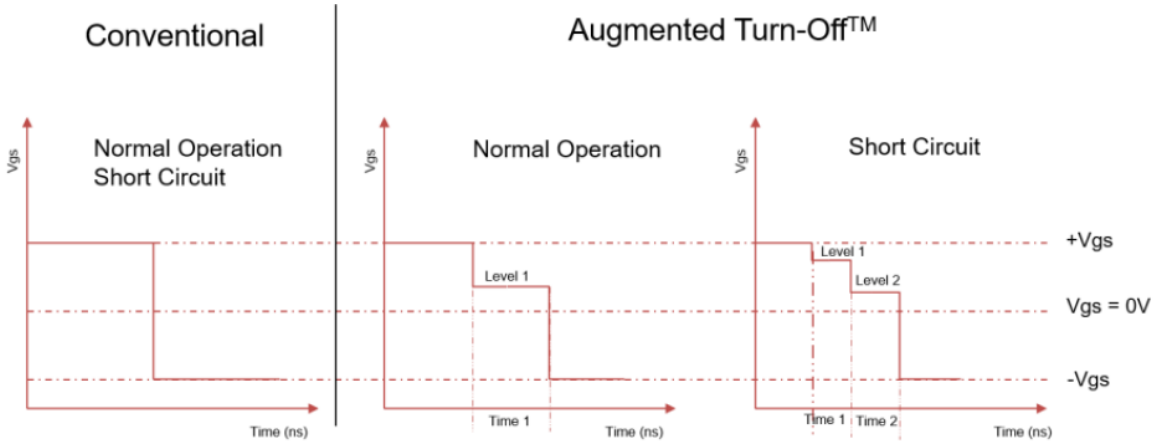
- The first solution would be to **increase R_g** (the gate resistance).
  - But that means **increasing losses** and **slowing down the response time**.
- An external **snubber circuit** can also reduce the ringing phenomenon.
  - At detriment of higher circuit complexity and higher cost.
- Otherwise, gate driver manufacturers are proposing **better suited solutions** to reduce these issues.
  - **Reducing the inductance** between the different connections (gate – driver IC) is the main trend today.

PLUG & PLAY GATE DRIVERS

Case study: Agile Switch

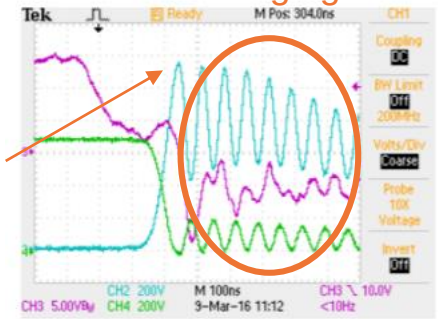
ATOff technology from AgileSwitch provide more efficient & reliable turn-off function.

- Agile Switch's **Augmented Turn-Off** technology consists on a **multi level turn-off process**.
  - It gives the flexibility to choose the inter-level voltage and its duration in order to optimize the turn-off of the gate.
  - The results are lower overvoltages and considerable reduction of the ringing phenomenon.
- A safer way of turning off the gate of SiC MOSFETs is possible by the ATOff technology, as well as saving energy losses avoiding the use of high gate resistor values.
- For short-circuit safety, two intermediate levels are used to be able to turn-off the gate faster and safer!



Ringing

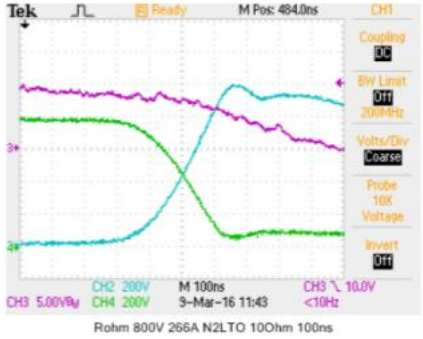
Overshoot



Rohm 700V 233A 1Ohm

R_{gate} = 1 Ohm

Higher gate resistance



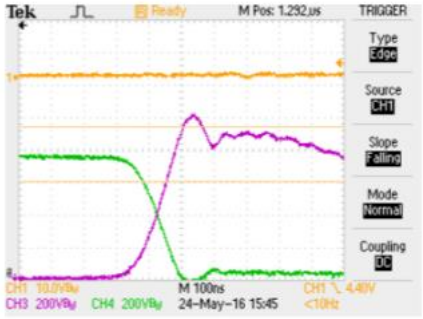
Rohm 800V 266A N2LTO 10Ohm 100ns

R_{gate} = 10 Ohm

E_{off} = 12.5mJ

Lower losses with the ATOff technology

ATOff technology



Rohm 800V 266A 4.75V 2LTO 625ns 0.5Ohm

R_{gate} = 0.5 Ohm & ATOff

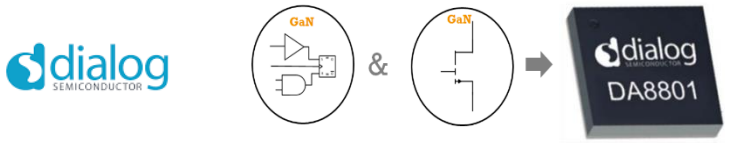
E_{off} = 7.1mJ

Measuring tests provided by AgileSwitch

GAN DEVICES: HIGHLY INTEGRATED SOLUTIONS

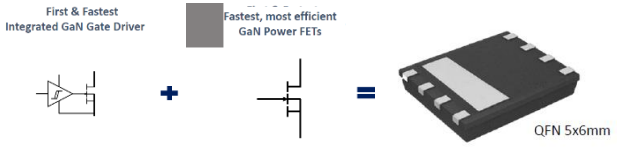
GaN device players are proposing **highly integrated solutions** between the driver IC and the GaN transistor

Monolithic solution



Power devices integrated with drivers and other analog IC functions

Navitas

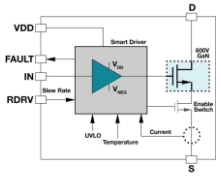


Power devices integrated with drivers in the same chip

System-in-package solution

TEXAS INSTRUMENTS

Power devices and driver IC chips in the same package



Discrete

MULTICHIP SI/GAN INTEGRATION

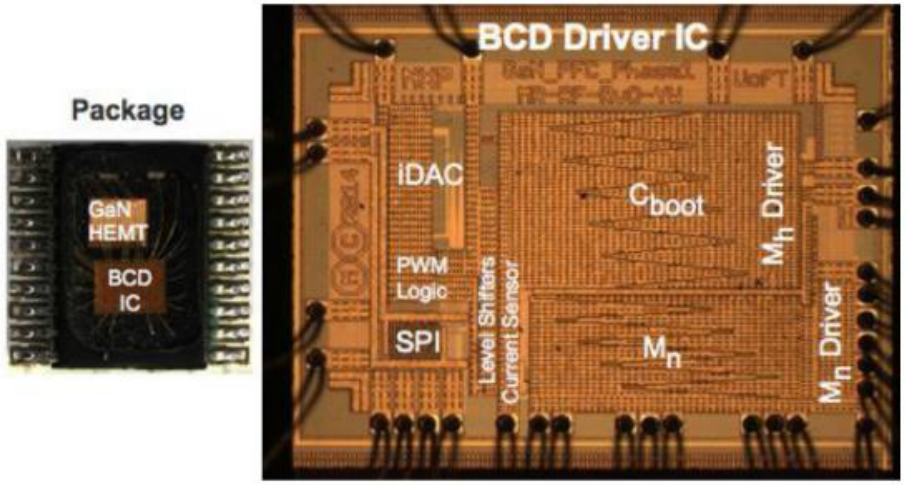
Case study: NXP system-on-package GaN solutions

The driver IC uses advanced SOI technology in order to guarantee high performance: less current leakage, better isolation, higher temp.

NXP developed an intelligent driver IC for 400V GaN-based PFC applications. The driver IC is packaged with a depletion-mode GaN HEMT to minimize the interconnect parasitic (ISPSD 2015)

- IC: 140 nm automotive BCD SOI process
- GaN HEMT and Schottky diode: Si-fab compatible GaN-on-Si process

Packaged GaN HEMT with driver IC and driver chip micrograph. The driver die measures 1.4 x 2 mm^2. courtesy of NXP

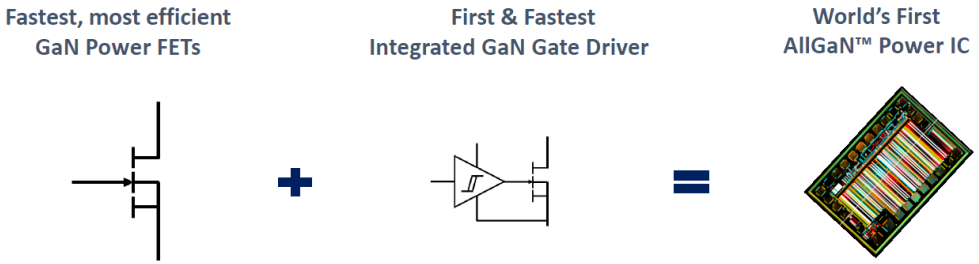


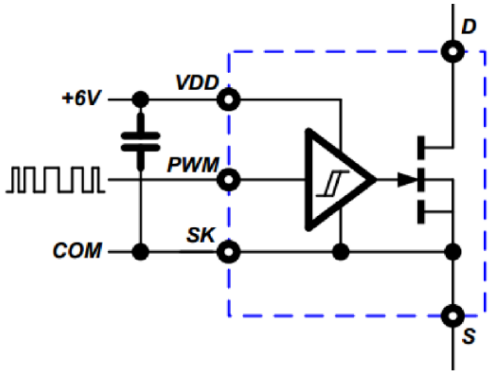
MONOLITHIC SOLUTION

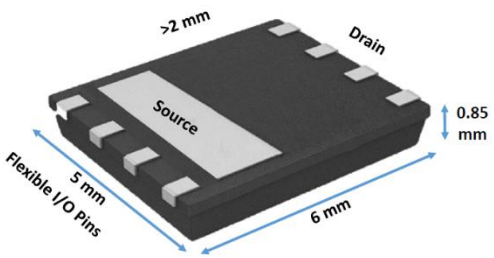
Case study: Navitas

Different companies have also explored the monolithic solution

- In 2016, **Navitas** demonstrated monolithic integration of 650V GaN IC with integrated driver circuits
- Other logic functions (hysteretic digital inputs, voltage regulation, ESD protection, sensing circuits, etc.) can be integrated as well.
- The company claims that the monolithic solution allows up to 40MHz switching, 4x higher density, and 20% lower system cost.

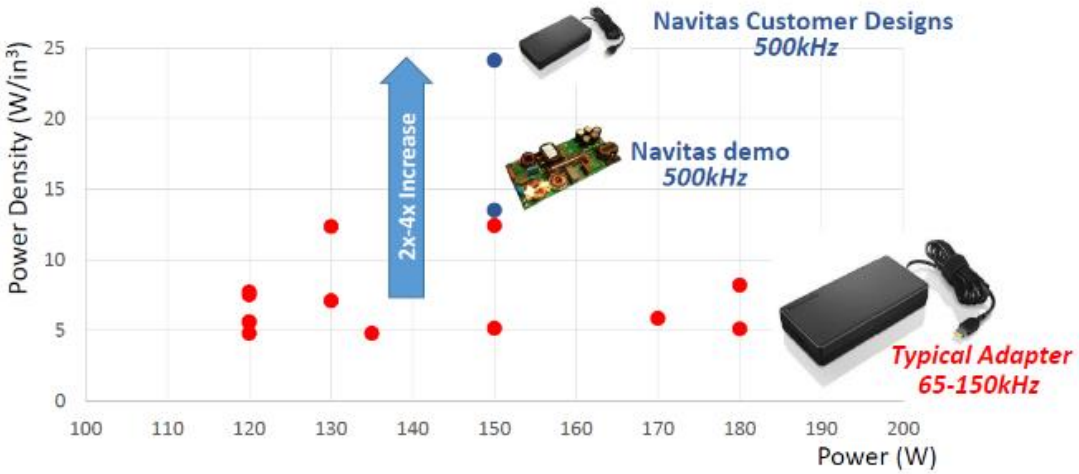






Standard QFN package (5X6 mm)

Navitas claims that their solution allow a power density increase of 2x – 4x

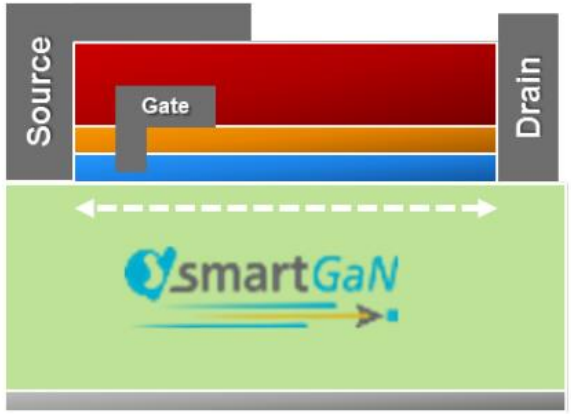


MONOLITHIC SOLUTION

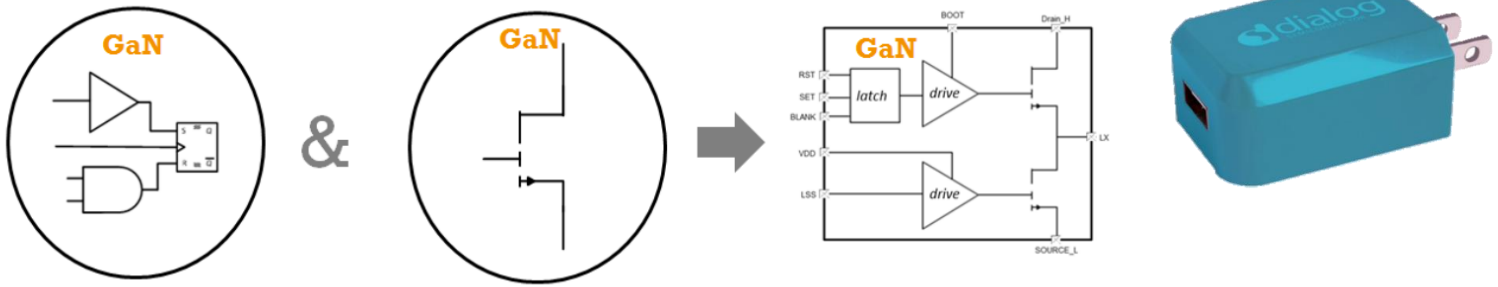
Case study: Dialog Semiconductor → GaN driver + half-bridge GaN switch configuration

Dialog Semiconductor presented in 2016 their GaN HEMT 650V monolithic solution integrating the logic driver blocks.

- In Aug. 2016, **Dialog Semiconductor** announced its first GaN power IC product offering, using Taiwan **TSMC's** 650V GaN-on-silicon process technology
- The company uses a branded SmartGaN™ that monolithically integrates GaN HEMTs with analog and logic blocks, providing a complete half-bridge solution.



- *Integrates 650V high-side and low-side power switches with analog, logic, and protection*
- *Thermally enhanced 5x5mm QFN package*
- *For 25W - 65W fast charging adapters for portable devices (i.e. smartphone, tablet)*



- *GaN based charger:*
  - *Reduces form factor by up to 40%*
  - *Cuts wasted power in half - charges phone in half the time*
  - *Over 94% efficiency for 25W adapters*

Conclusion

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CONCLUSION

Technology

Integration is one trend to help accelerate growth for gate drivers.

- Gate drivers technologies have had certain evolutions during the last decade.
  - With the arrival **of on-chip integrated isolation technologies**, isolated driver ICs have been developed by main driver IC manufacturers.
  - These digital isolators are **replacing the optocoupler** technology little by little.
  - So far, **microtransformers** (**coreless transformers**) are the preferred digital isolation.
- In the next 5 years, evolving industry needs will have a considerable impact on gate drivers as well:
  - The emerging market of **48V mild hybrid** will require **isolated half-bridge drivers**. Until now, there was no need for isolation in such low voltages. The cost of microtransformers manufactured today will decrease considerably.
  - **SiC MOSFETs** will also have an impact on the gate driver market in two ways:
    - Plug-and-Play market will enjoy a short term growth as some clients may choose to integrate SiC in their new generation converters. Customers encountering difficulties with the development of adequate drivers will prefer to purchase plug & play ones to accelerate the integration of SiC.
    - New safety and monitoring functions will be proposed by driver IC and gate driver board manufacturers in order to enhance the performance and the reliability of SiC switches.
  - **GaN transistors** will enable very high integration levels between the driver IC and the GaN HEMTs. Some companies will integrate in the same package the driver IC and the GaN switch, while others will have a monolithic solution for the integration.
- Beyond 2025:
  - In a longer term perspective, high temperature (HT) driver ICs will see a much bigger market, being driven **by integrations into high power modules**. Currently, the aerospace industry is developing HT modules, and in the coming years it will be extended to wind turbines, rail traction, electric cars, inverters, etc.
  - This integration trends will also appear on SiC IPMs, where the need to have the driver IC closer to the SiC MOSFETs will end up integrating them on the same package.

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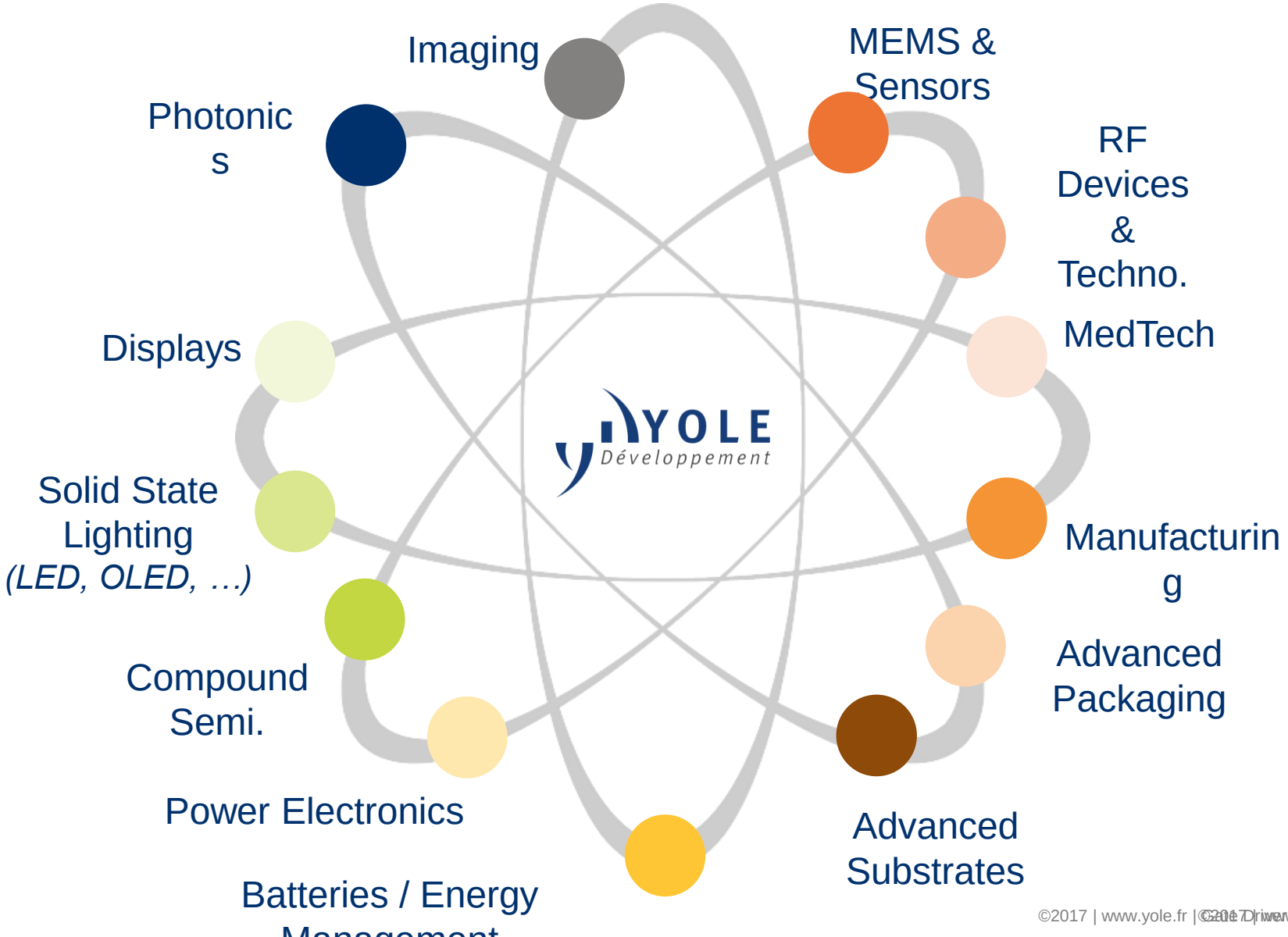

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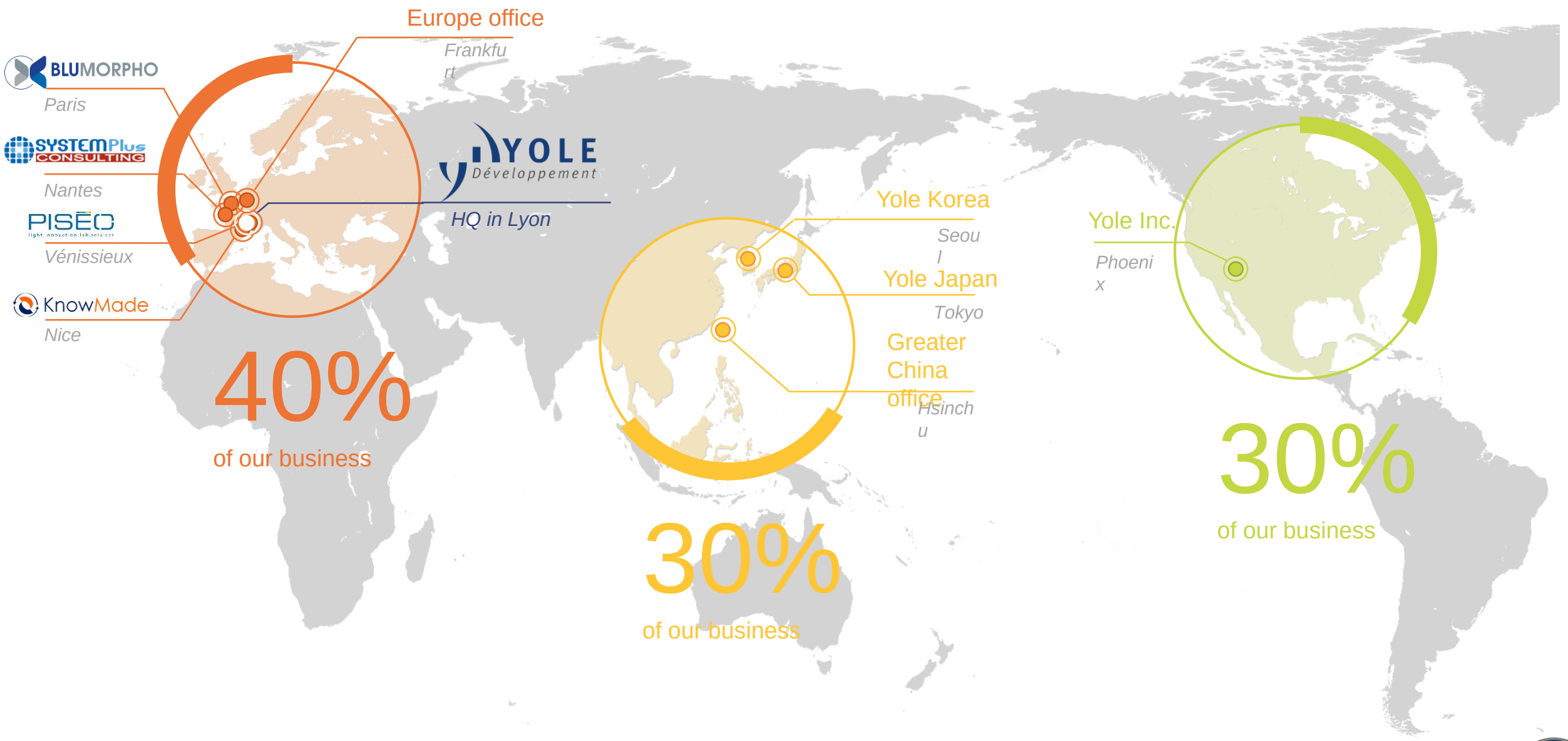

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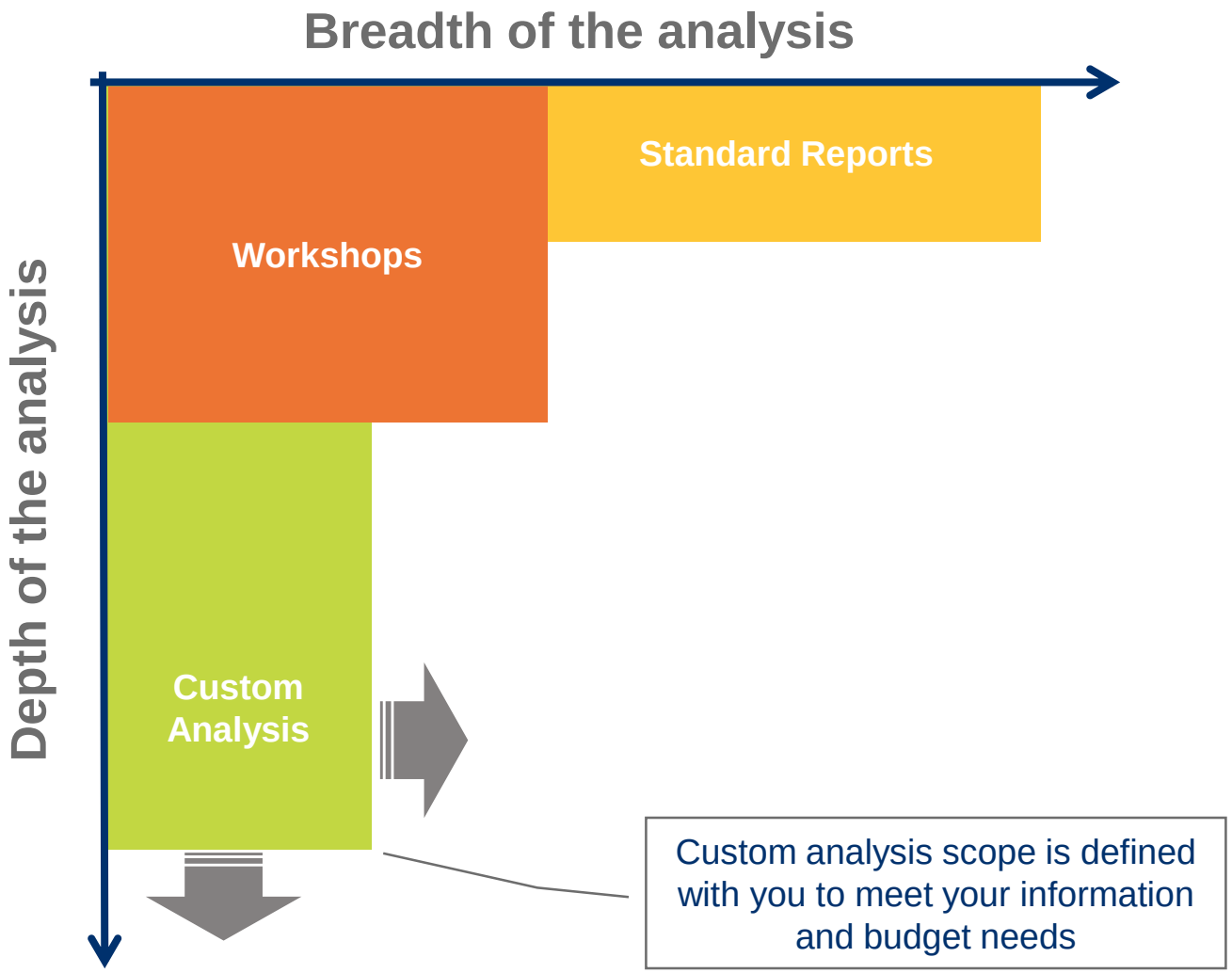

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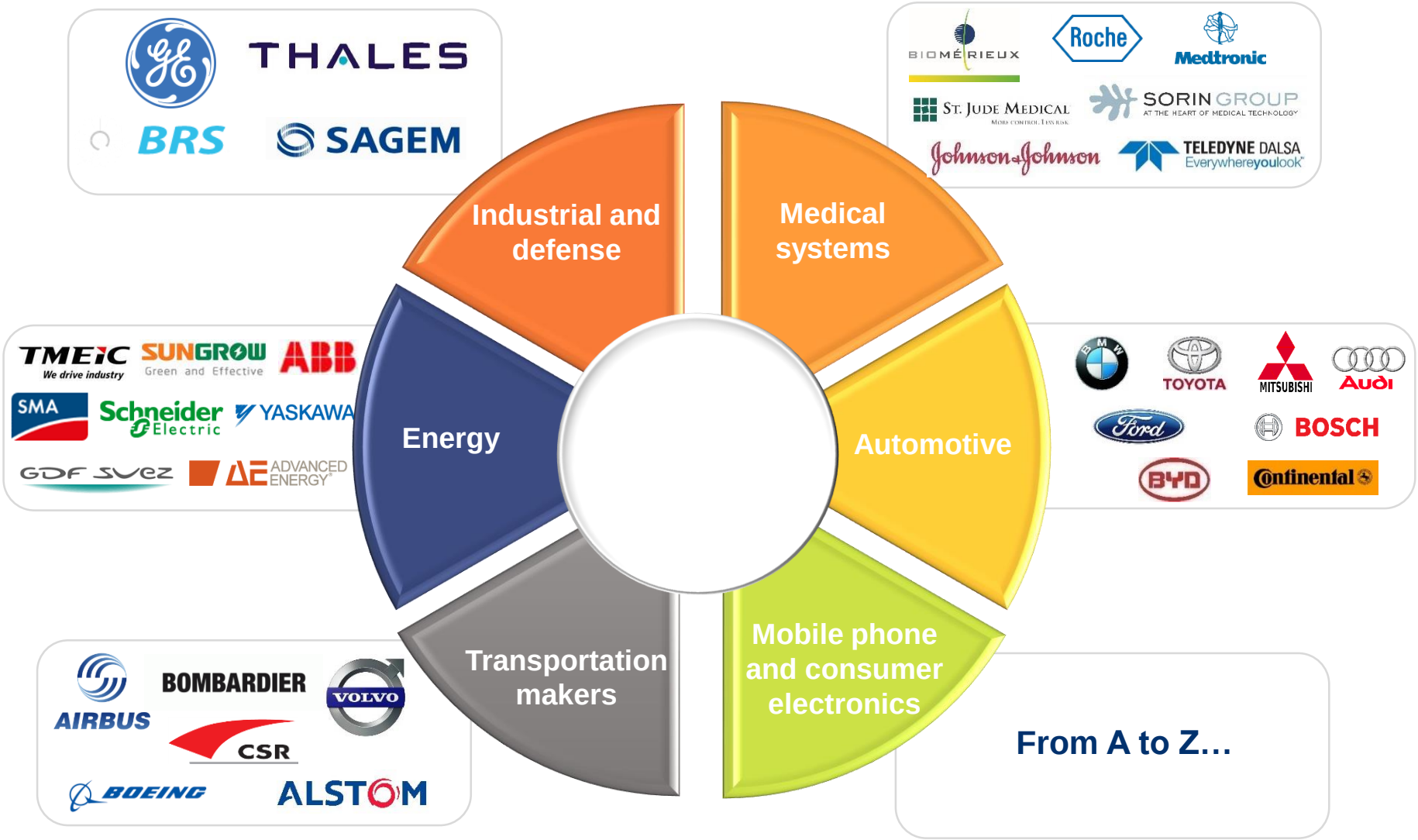

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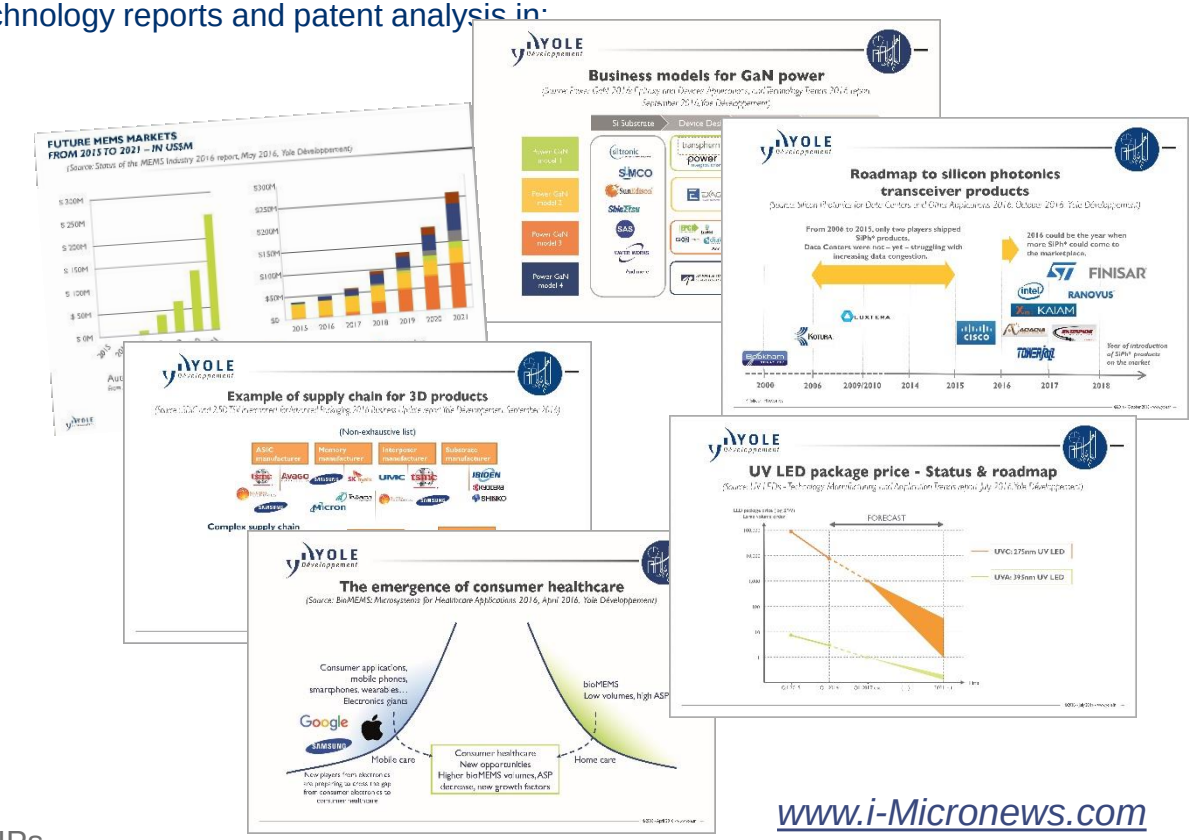

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