Gate Drivers market evolution: coreless isolation and WBG specific solutions
• Driver IC market
• Power electronics trends
• Overview of isolation technologies
• Drivers for WBG devices
• Conclusion
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.

<table>
<thead>
<tr>
<th>Year</th>
<th>Industrial</th>
<th>Consumers</th>
<th>Communication</th>
<th>Computers</th>
<th>Automotive</th>
<th>M$ USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>$436.6M</td>
<td>$294.3M</td>
<td>$52.6M</td>
<td>$55.7M</td>
<td>$378.7M</td>
<td>$1,800M</td>
</tr>
<tr>
<td>2017</td>
<td>$459.2M</td>
<td>$315.1M</td>
<td>$51.7M</td>
<td>$54.3M</td>
<td>$386.1M</td>
<td>$1,600M</td>
</tr>
<tr>
<td>2018</td>
<td>$508.7M</td>
<td>$321.9M</td>
<td>$53.7M</td>
<td>$54.7M</td>
<td>$446.6M</td>
<td>$1,400M</td>
</tr>
<tr>
<td>2019</td>
<td>$548.9M</td>
<td>$329.6M</td>
<td>$56.6M</td>
<td>$55.0M</td>
<td>$485.1M</td>
<td>$1,200M</td>
</tr>
<tr>
<td>2020</td>
<td>$584.3M</td>
<td>$333.9M</td>
<td>$58.3M</td>
<td>$54.9M</td>
<td>$498.8M</td>
<td>$1,000M</td>
</tr>
<tr>
<td>2021</td>
<td>$597.7M</td>
<td>$336.9M</td>
<td>$58.3M</td>
<td>$53.5M</td>
<td>$557.7M</td>
<td>$800.0M</td>
</tr>
<tr>
<td>2022</td>
<td>$615.4M</td>
<td>$337.0M</td>
<td>$59.1M</td>
<td>$52.5M</td>
<td>$559.0M</td>
<td>$600.0M</td>
</tr>
</tbody>
</table>

**CAGR 16-22**
- Industrial: 5.9%
- Consumers: 2.3%
- Communication: 1.9%
- Computers: -1.0%
- Automotive: 6.7%
The split by application for gate drivers being used for MOSFETs or IGBTs is somewhat different in 2016.

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

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

• 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.

Medium voltage gate driver (401~1200V) market is forecast to offer the best growth potential.
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<sub>j</sub> : 150°C → 175°C

Switching frequency increase

Size reduction of the systems
What changes for gate drivers?

- Faster switching frequency
- Need for lower stray inductance
- Driver IC closer to gate
- Higher temp. inside the power module
- Need for on-chip integrated isolation
- Integration of driver ICs in transistor package

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

1. Optical Isolation
   - Optocoupler
   - + Simple
   - + Unlimited isolation voltage
   - + Fast
   - - Expensive
   - - Power supply
   - - No energy transmission

2. Monolithic level shifter
   - + Cost effective
   - + Integration of logic suitable
   - - No galvanic isolation
   - - EMI sensitivity
   - - No energy transmission

3. Isolation by Transformer
   - Pulse transformer
   - + Energy transmission possible
   - - Expensive
   - - Device volume

4. Capacitive coupling
   - + Cost effective
   - + high isolation capability up to several kV
   - + Easily integrated on Driver IC
   - - No Energy transmission possible

Not possible to use at power supply!
ISOLATION TECHNOLOGIES

What solution is each company using?

Avago, now part of Broadcom was one of the main optocoupler manufacturers for gate drivers.

TOSHIBA

Almost all driver IC manufacturers have adopted one of the recent digital isolator technologies.

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

Optical Isolation
- Optocoupler
- Fiber Optics

Monolithic level shifter

Isolation by Transformer
- Pulse transformer
- Coreless transformers
- Capacitive coupling
• **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.

---

**Device voltage**

- **1700V**
  - Fiber optic
- **1200V**
  - Chip integrated isolation
  - Pulse transformers
- **900V**
  - Optocouplers
- **600V**
  - Monolithic shifter
- **100V**
  - Monolithic shifter

**Device current**

- **20A**
- **200A**
- **500A**
ON-CHIP ISOLATION

Micro-transformers and capacitive coupling

- **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.

<table>
<thead>
<tr>
<th></th>
<th>Polymer-Based Optocoupler</th>
<th>Polyimide-Based Digital Isolator</th>
<th>SiO₂-Based Digital Isolator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Withstand Voltage (1 Minute)</strong></td>
<td>7.5 kV rms</td>
<td>5 kV rms</td>
<td>5 kV rms</td>
</tr>
<tr>
<td><strong>Lifetime at 400 V rms Working Voltage</strong></td>
<td>25 years</td>
<td>50 years</td>
<td>25 years</td>
</tr>
<tr>
<td><strong>Surge Level for Reinforced Insulation</strong></td>
<td>20 kV</td>
<td>12 kV</td>
<td>7 kV</td>
</tr>
<tr>
<td><strong>Distance Through the Insulation (Insulation Thickness)</strong></td>
<td>400 μm</td>
<td>14 μm to 26 μm</td>
<td>7 μm to 15 μm</td>
</tr>
</tbody>
</table>

Polyimide & polymers are organic materials which means they show instability and degradation over time and under high temperatures. While SiO₂ is more stable.

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Temperature s up to 125°C
CORELESS TRANSFORMERS

Also called micro-transformers

- 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

• 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.

iCoupler’s integrated signal and power isolation capability reduces component count dramatically and improves system reliability and lifetime.

• 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.

Block diagram of the ADuM1201, where an additional channel for a feedback signal is added.
CAPACITIVE COUPLING
Case study: Texas Instrument & Silicon Labs

- 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 lifetime and a CMTI* > 100kV/µs.

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

- The transmitter and receivers are **manufactured on the same chip** using the CMOS technology, separated by a silicon dioxide (SiO₂) insulation barrier.
  - The signal transmission is done by capacitance coupling as shown on the figure above.

*CMTI: Common Mode Transient Immunity

**Texas Instrument ISO7810 digital isolator**
# ISOLATION TECHNOLOGY COMPARISON

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

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

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
- +20V/-5V gate voltages
- Fast switching requirements: differentiate gate resistance to control turn-on & turn-off dv/dt separately
- Galvanic isolation required
- >50kV/µs transient immunity
- Short-circuit fault protection is critical

### GaN
- Limited gate voltage: +5.5V/0V (or negative voltages)
- Fast switching requirements: differentiate gate resistance to control turn-on & turn-off dv/dt separately
- The monolithic level shifter is in many cases enough
- For voltages >200V a galvanic isolation is also required
- >50kV/µs transient immunity

### Package
- 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
- 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
SIC & GAN DRIVING REQUIREMENTS

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

• 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).

• 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

• 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!

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

R_{gate} = 10 Ohm
E_{off} = 12.5mJ
Lower losses with the ATOff technology

R_{gate} = 0.5 Ohm
\& ATOff
E_{off} = 7.1mJ

Measuring tests provided by AgileSwitch
GaN devices are highly integrated solutions between the driver IC and the GaN transistor. 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.
- **System-in-package solution**: Power devices and driver IC chips in the same package.
- **Discrete**: Power devices and driver IC chips in separate packages.

**GAN DEVICES: HIGHLY INTEGRATED SOLUTIONS**

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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 mm². courtesy of NXP
MONOLITHIC SOLUTION

Case study: Navitas

- 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.

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

Different companies have also explored the monolithic solution.
MONOLITHIC SOLUTION

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

- 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.

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

- 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
CONCLUSION

Technology

- 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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