FOR ENERGY EFFICIENT INNOVATIONS

THINK ON.

www.onsemi.com

Solutions for High Voltage Drives

Identifying proper Gate Drivers for Power Switching

and

Differentiating Isolation techniques

December 2020

Public Information

Content and Presenters

Introduction

Powers Switches differences and why Gate Drivers are need it:

- ✓ *Differences & Similarities between IGBT's, MOSFET's, SiC MOSFET's & GaN MOSFET's*
- ✓ *Gate Drive requirements for Power Switches needs*

Gate Drivers tech features overview

- ✓ *Top Key Parameters for Gate Drivers*
- ✓ *Gate Drivers selection process*

Gate Drivers Categories/Types

- ✓ *High Side, Low Side, Dual… etc…*

Non-isolated Gate Drivers & relationship to Power Switches

Isolated Gate Driver and their Applications

- ✓ *Types of Isolation and PROS/CONS of each*
- ✓ *Why Isolate, how to Isolate and Apps*
- ✓ *Isolation Standards*

Gate Drivers Tech/Market & Applications Executive Summary

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 OPTO-coupler** technology little by little
- ✓ So far, **microtransformers** (**coreless transformers**) are the preferred digital isolation

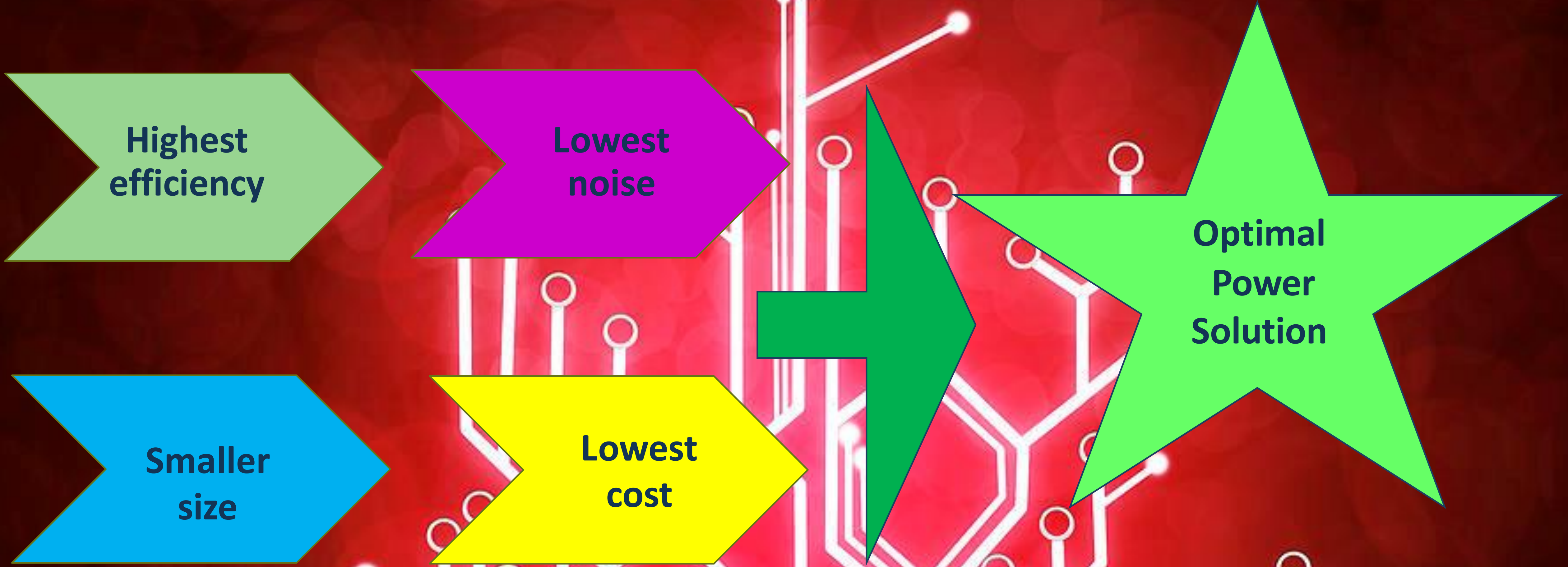
In the next 5 years, evolving industry needs will have a considerable impact on gate drivers as well:

- ✓ 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.*

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.

Driving Force in power management



Applications

For switched-mode power electronic applications involved in high-power and high-voltage conversion


Factory automation


Enterprise power & telecom


Automotive


Motor drive and control


Smart grid


Other industrials

Gate Drivers Requirements for Power Switching Devices

- MOSFET and IGBT Tech - Diff and similarities
- Required Drive Power
- Overcoming Power Switch Gate Charge
- Maximum Drive Current requirement
- Variable Output Voltage Swing
- Maximum Switching Frequency
- Maximum Operating Temperature
- ***Isolation Requirements***

Before proceed with Gate Drivers we need to understand the diff between MOSFET and IGBT

- Although both IGBT and MOSFET are voltage-controlled devices, IGBT has BJT-like conduction characteristics.

- Terminals of IGBT are known as Emitter, Collector and Gate, whereas MOSFET has Gate, Source and Drain.

- IGBTs are better in handling higher power than MOSFETs.

- IGBT has PN junctions. MOSFET does not have these.

- IGBT has lower forward voltage drop compared to MOSFET.

- MOSFETs have higher switching frequencies and hence these are preferred over IGBTs in power supplies like SMPS and small to Medium Motor Drivers

Selecting the best Power Switch (*IGBT vs. FET vs. Module*)

DISCLAMER:

- *IGBTs and HV MOSFETs are similar in many ways but differ from a performance and application perspective*
- *A "one size fits all" approach does not work*
- *The best device is the one that best meets the application needs in terms of size, efficiency and Amps/$ capability..!*

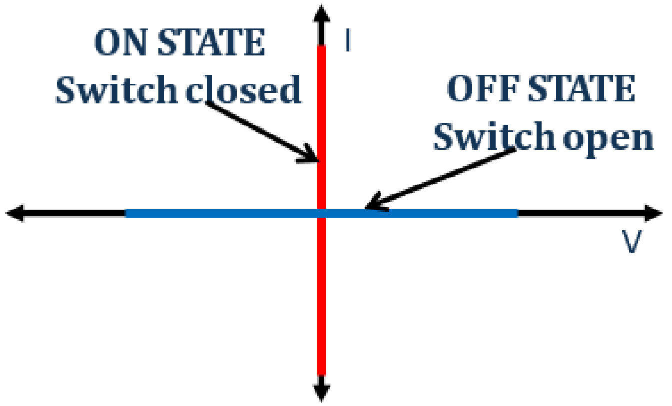
Power Switching Devices -

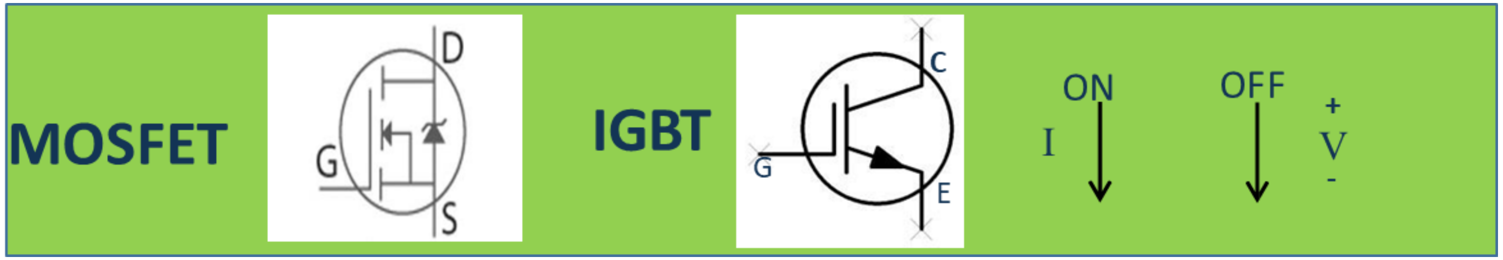
- *When comparing MOSFET and IGBT structures look very similar*
- *The difference is the addition of a P substrate beneath the N substrate*
- *The IGBT technology is certainly best Switch to use where breakdown voltages above 1000 V*
- *While the MOSFET is certainly the device of choice for breakdown voltages below 700 V*

‘Power Switch’ - *Fundamental Component in Power Electronics*

Ideal Switch

- Zero leakage in off-state
- Zero voltage in on-state
- Zero switching loss





Ideal switch:

Blocking loss, $P_{OFF} = V_{OFF} \times I_{OFF} = 0$

Conduction loss, $P_{ON} = V_{ON} \times I_{ON} = 0$

4 quadrant operation

Power Switches control flow of current in power electronic circuits by operating in 2 states (ON/OFF)

- *GATE (G) terminal controls ON/OFF status of switch*
- *Modern Power Electronics dominated by Switch Mode Power conversion*

The quick DIFF

MOSFET's:

- Improved switching speeds.
- Improved dynamic performance that requires even less power from the driver.
- Lower gate-to-drain feedback capacitance
- Lower thermal impedance which, in turn, has enabled much better power dissipation
- Lower rise and fall times, which has allowed for operation at higher switching frequencies

IGBT's:

- Improved production techniques, which has resulted in a lower cost
- Improved durability to overloads
- Improved parallel current sharing
- Faster and smoother turn-on/-off waveforms
- Lower on-state and switching losses
- Lower thermal impedance
- Lower input capacitance

IGBT vs. MOSFET

Conditions based

IGBT	MOSFET
• Low Switching Frequency (<20kHz) • High Power levels (above say 3 kW) • High dv/dt needed to be handled by the diode • High Efficiency is needed at Full load	• High Switching Frequency (>100kHz) • Wide line and load conditions • dv/dt on the diode is limited • High efficiency is needed in Light Load
IGBT Preferred	**MOSFET Preferred**

Application based

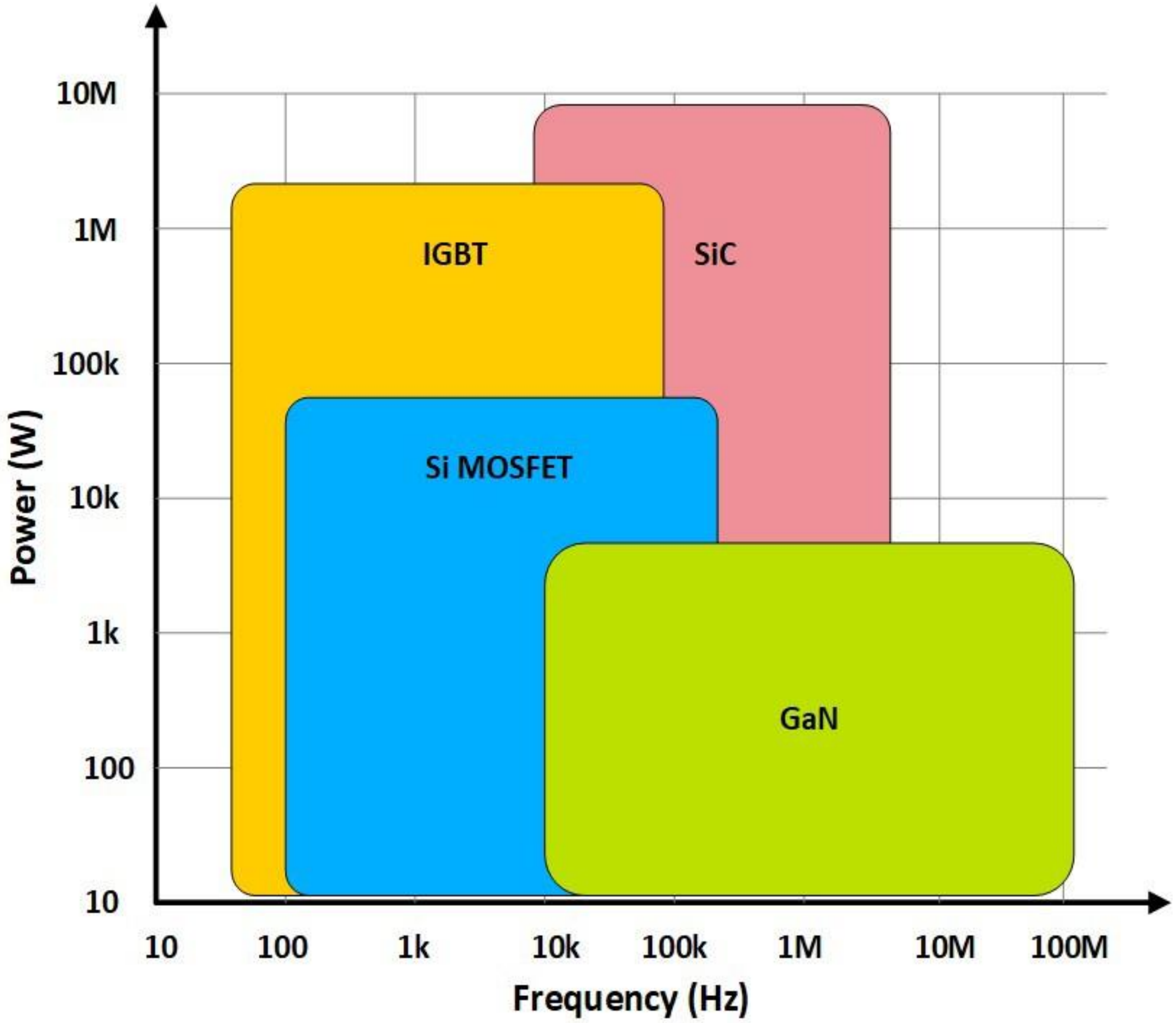
IGBT	MOSFET
• Motor Drives (>250W) • UPS and Welding H Bridge inverters • High power PFCs (>3kW) • High Power Solar/Wind Inverters (>5kW)	• Motor Drives (<250W) • Universal input AC-DC Flyback and forward converter power supplies • Low to Mid power PFCs (75W to 3 kW) • Solar Micro Inverters
IGBT Preferred	**MOSFET Preferred**

Basically all power switches need a gate driver!

Gate Driver Functions:

- Turn ON/OFF power switch
- Amplify logic signals
- Level shifting
- Protection Functions

Power Switch Apps in a nutshell (Graph)



- **Silicon MOSFET**
  - ✓ Low to mid-power applications
  - ✓ Reached theoretical performance limit
- **IGBT - Insulated Gate Bipolar Transistor**
  - ✓ Scaled for High voltage, high power
  - ✓ Least expensive per watt at high power
  - ✓ Slower but perfect for motor control
- **SiC - Silicon Carbide (breakthrough)**
  - ✓ High voltage, high current, high temperature
  - ✓ Faster switching requires gate drivers that can tolerate high dV/dt
- **GaN - Gallium Nitride (breakthrough)**
  - ✓ Low(er) voltage, high current
  - ✓ Fastest switching (higher dV/dt)
  - ✓ Narrow gate drive voltage range

MOSFET and IGBT need for Gate Drive primer

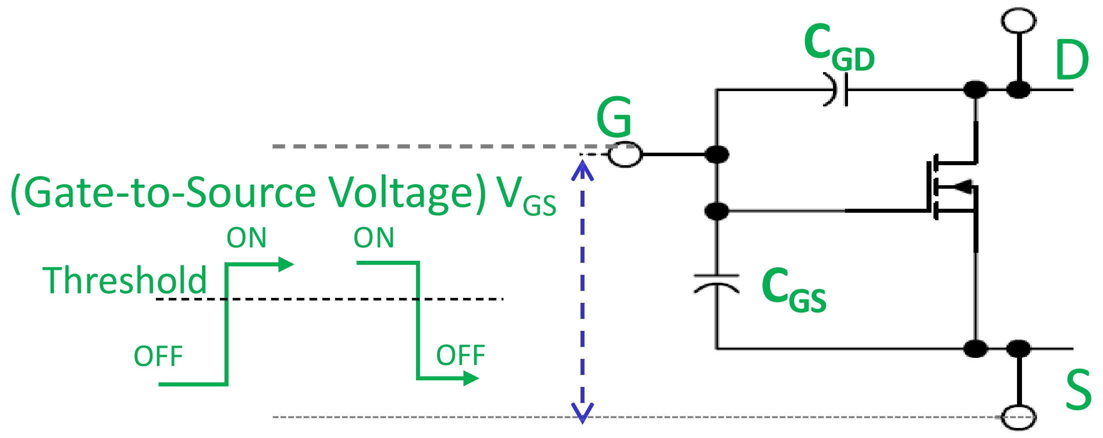
- IGBT & MOSFET is a voltage-controlled device used as a switching element in Power Switching Circuits
- The **GATE** is the electrically isolated control terminal for each device
- To operate a MOSFET/IGBT, typically a voltage has to be applied to the gate
- The structure of an IGBT & MOSFET is such that the gate forms a nonlinear capacitor that can not change its Voltage instantaneously
- The minimum voltage when the gate capacitor is charged and the device can just about conduct is the threshold voltage (VTH)
- When Higher Power IGBT/MOSFET is used, the higher Current is required to Turn ON/OFF Power Switch
- Gate Drivers are used to apply voltage and provide drive current to the gate of the power device
- Gate Drivers have fundamental parameters, such as timing, drive strength, and isolation

How does GATE terminal of a Power Switch Work ?

❖ ***Let's take example of a power MOSFET***

<u>GATE terminal controls ON/OFF state of MOSFET</u>

- V_{GS} = Voltage Between Gate & Source
- <u>To turn ON:</u> Apply a positive voltage,
- V_{GS} > Threshold level
- <u>To turn OFF:</u> V_{GS} < Threshold level
- GATE is a capacitive input, high-impedance terminal
- 2 parasitic capacitors inside MOSFET internal structure (C_{GS}, C_{GD})



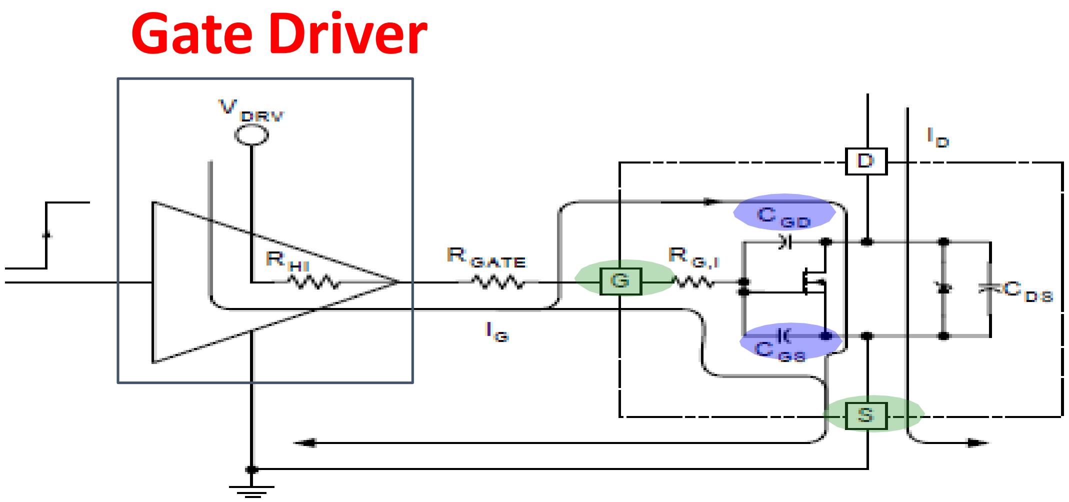
Required Drive Power

- The **Gate Driver** serves to turn the power device on and off, respectively
- In order to do so, the gate driver charges the gate of the power device up to its final turn-on voltage Vge(on), or the drive circuit discharges the gate down to its final turn-off voltage Vge(off)
- The transition between the two gate voltage levels requires a certain amount of power to be dissipated in the loop between gate driver, gate resistors and power device
- Today, high-frequency converters for low and medium-power application are predominantly making use of the gate voltage-controlled device such as power metal-oxide-semiconductor field effect transistors (MOSFETs)
- For High Power Applications best devices in use today are Isolated Gate Bipolar Transistors (IGBT's)
- Gate Drivers are not just for MOSFET's and IGBT's but also for fairly new and esoteric devise from Wide Band Gap group such as Silicon Carbide (SiC) FET's and Gallium Nitride (GaN) FET's as well

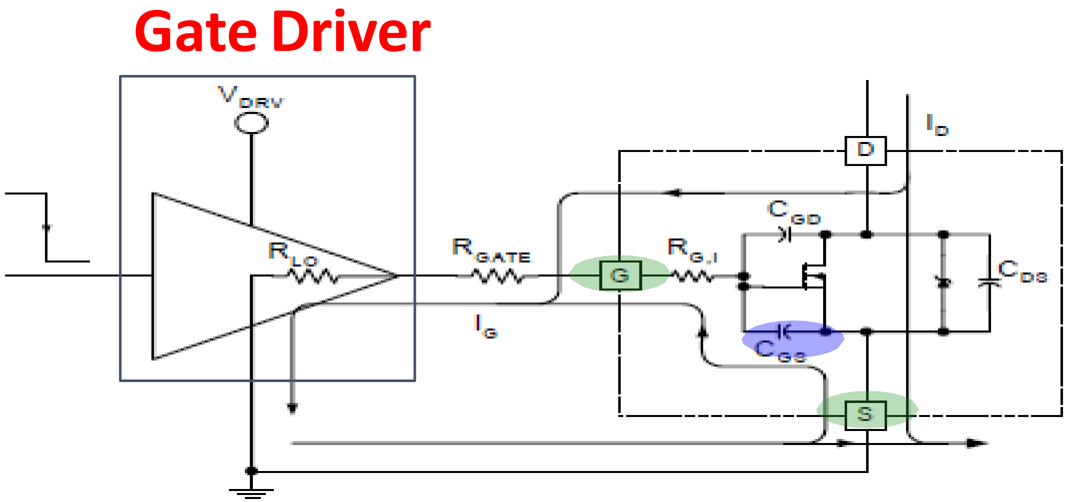
What is a Gate Driver

❖ ***It is a power amplifier that accepts a low-power input from a controller IC and produces the appropriate high-current gate drive for a power MOSFET***

- ✓ Gate Driver device applies voltage signal (V_{GS}) between Gate (G) & Source (S) of power MOSFET, while providing a high-current pulse
- ✓ To charge/discharge C_{GS}, C_{GD} QUICKLY
- ✓ To switch ON/OFF power MOSFET QUICKLY

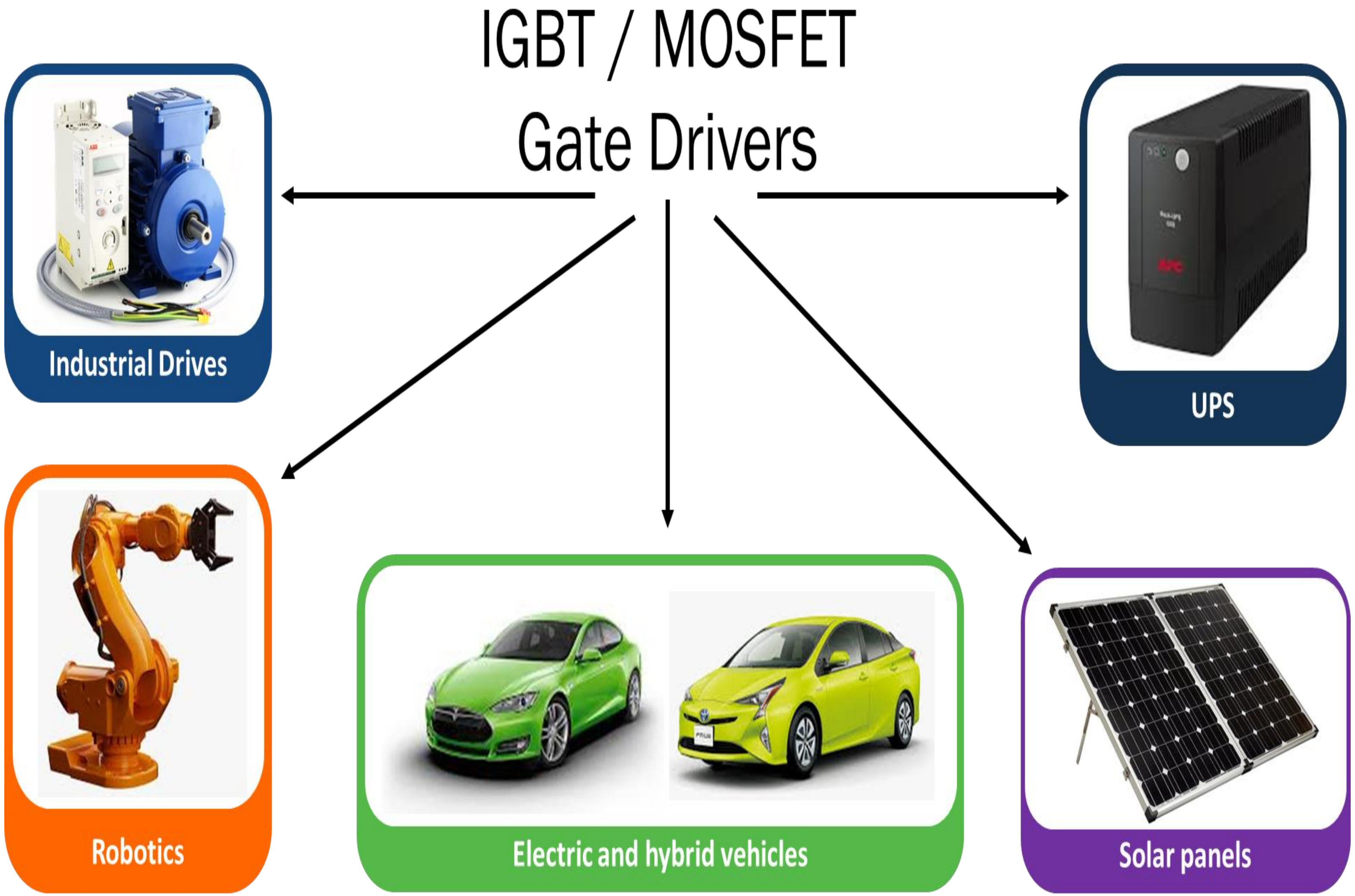


Switch Turn-On



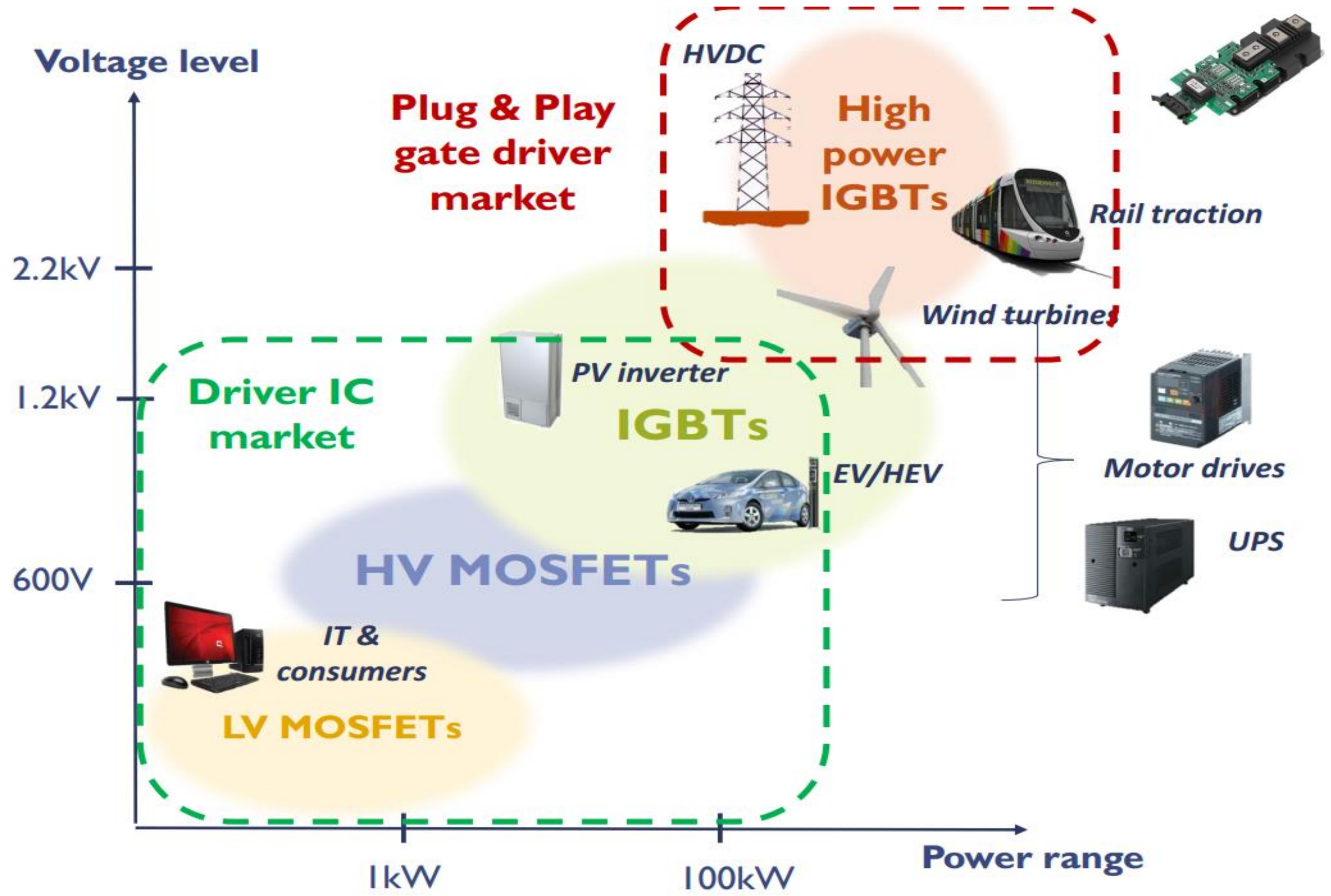
Switch Turn-Off

Gate Drivers Markets + Application Topology



- **Single & ½ Bridge**
  - ✓ AirCon, White goods
  - ✓ Pump & Motor control
  - ✓ Lighting
  - ✓ Consumer electronics power conversion.
- **Full Bridge**
  - ✓ Low/mid voltage DC-AC power
  - ✓ Inverters
  - ✓ AC/AC & DC-DC converters,
  - ✓ Motor control applications.
- **3-Phase**
  - ✓ Small BLDC motors and AC motors
  - ✓ Fluid or Air Pumps
  - ✓ Uninterruptible power supply
  - ✓ Solar inverters and other inverters

Drivers usage



Gate Drive Requirements and Considerations

- **Total Gate Charge (Qg)**

  Generally higher for HV MOSFETs (larger die compared to IGBT, for same current rating)

  - **Turn on gate resistors**

  Generally higher values used for IGBT (lower input capacitance compared to HV MOSFETs

  - **CMTI – Common Mode Transient Immunity**

  Maximum tolerable rate of rise or fall of the common mode voltage applied between two isolated circuits. The unit is normally in kV/us or V/ns. High CMTI means that the two isolated circuits, both transmitter side and receiver side will function well within the Datasheet specs

- **Gate Drive Voltage**

  Higher (15 V) preferred for IGBT, 10 V is ok for HV MOSFETs

- **Negative Gate Drive Voltage**

  Generally not needed for HV MOSFETs, sometimes used for older process IGBTs and definite need for SiC and GaN

- **Gate Driver vs. IGBT/MOSFET consideration**

  Driver that can source/sink higher gate current for a longer time span produces lower switching time and, thus, lower switching power loss within the transistor it drives.

Gate Driver Selection Questions

- How many Inputs/Outputs required from the Gate Driver
- Required Voltage Rating
- Driver Current Rating
- Gate Charge
- Maximum Switching Frequency
- Variable Output Voltage Swing
- Maximum Operation Temp
- Special Functions
- Key External Component selection
- Isolation Requirement – Yes or No

Selection

- **How many Inputs/Outputs are provided for/by Gate Driver**
  - ✓ For the inputs, It depends on the choice of the MCU and the control algorithm chosen
  - ✓ For 2 inputs, the choice is high side low side gate driver
  - ✓ For 1 input, the choice is a half bridge driver
  - ✓ Number of outputs depend on the number of half bridges that require driving
- **Voltage Rating Selection (Rule of Thumb)**
  - ✓ A conservative rule is to pick a voltage rating 3 times the operating voltage, with 1.5 times being a recommended minimum However, this depends purely on the system requirements
  - ✓ Gate drivers always work with MOSFET/IGBT, best practice is to match the voltage rating of the chosen MOSFET/IGBT

Gate Drive Current Need

➢ How much drive current is required

- ✓ Information about the required gate charge to raise the gate voltage to the desired level is essential
- ✓ Gate charge information is provided by the MOSFET manufacturer in their datasheet, usually for a gate voltage of 10 V
- ✓ Now that we know the required gate charge, we choose the drive current rating depending on the rise and fall times we are targeting.
- ✓ The equation to use is Qg = Igate * time

  - ❖ **Example: Qg = 50nc. Required Tr = 50ns and Tf = 25ns.**
  - ❖ **Igate (source) = 50/50 = 1A of source**
  - ❖ **Igate (sink) = 50/25 = 2A of sink**

- ✓ The above calculation provides us with a minimum figure. Often it is not easy to find a tailored gate driver. Best practice is to choose a gate driver with higher than the required rating and use series gate resistors to limit the source and sink currents

Gate Driver Special Functions

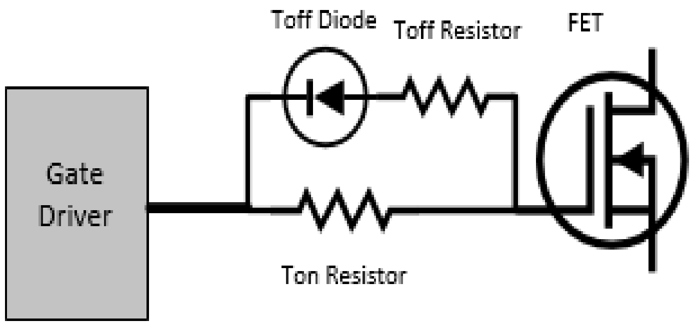
- **Special Functions**
  - **Some applications need special functions like**
    - inbuilt and/or adjustable dead time
    - enable option
    - shoot through prevention logic
    - delay matching etc. to ensure the selected gate driver comes with the required optional features

- **Key external component selection**
  - Boot-strap Capacitor Selection
  - Gate Resistor Selection
  - Layout Recommendations

External Devices Selection

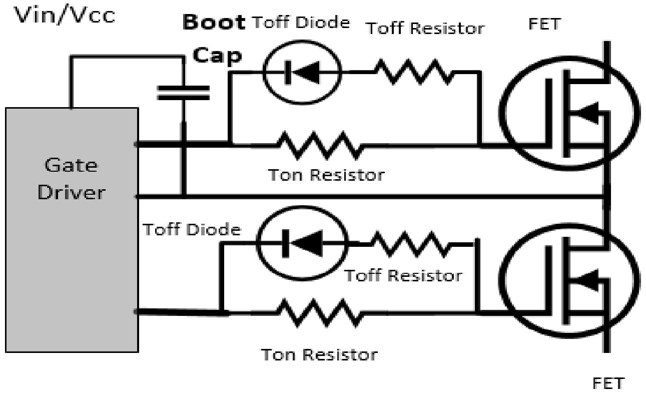
➢ Gate Resistor Selection

- ❖ A typical gate drive current control circuit needs Series Resistor with Device Gate and Optional Reverse biased Diode.
- ❖ By adjusting the Tonn and Toff resistors respectively, the rise and fall times can be controlled individually
- ❖ Reverse Biased Diode will facilitate Toff if need be



➢ Capacitor Selection

- ❖ The capacitance of the bootstrap capacitor should be high enough to provide the charge required by the gate of the high side MOSFET. As a general guideline, it is recommended to make sure the charge stored by the bootstrap capacitor is about 50 times more than the required gate charge at operating V CC (usually about 10V to 12V)
- ❖ The formula to calculate the charge in C BS to provide sufficient gate charge as follows; Q = C * V, where Q is the gate charge required by the external MOSFET. C is the bootstrap capacitance and V is the bootstrap voltage Vbs



Gate Driver Category Definition

- **Non-isolated**
  - Single - Channel
  - Multiple - Channel
- **Junction Isolated**
  - High - Side
  - High/Low
  - Half-Bridge
  - Three-Phase
- **Galvanic Isolated**
  - 1-Channel
  - 2-Channel

Non-isolated	Junction Isolated	Galvanic Isolated
• Single or multiple channel • Cheapest, simple solution for many applications where only a low-side driver is needed	• High Side, High/Low and Half Bridge • Floating HV well • From LV to 1200V breakdown voltage	• Normally needed in very high power/high voltage systems. • Three options: Optical, Inductive, Capacitive
Applications		
• Automotive • Industrial Systems • Consumer Devices	• Appliances • Consumer Devices & Power Tools • Auxiliary Automotive & Motors Drives • Offline Power	• Automotive traction inverters • Industrial Drive • Server Rack Power • Solar and Energy Storage

Products

Single - Channel	Multiple - Channel	High - Side	High/Low	Half-Bridge	Three-Phase	1-Channel	2-Channel
FAN3100/11 FAN3181 FAN312x NCD5700/1/2/3	FAN321x FAN322x	FAN73611	FAN8811 FAN7392 NCP51530 NCP5183	FAN7382 FAN73833 FAN73912 NCP5106B	FAN7382 FAN73833 FAN73912 NCP5106B	NCD57000/1 NCP5708x NCP51157	NCD57252 NCP51561

Gate Driver Considerations

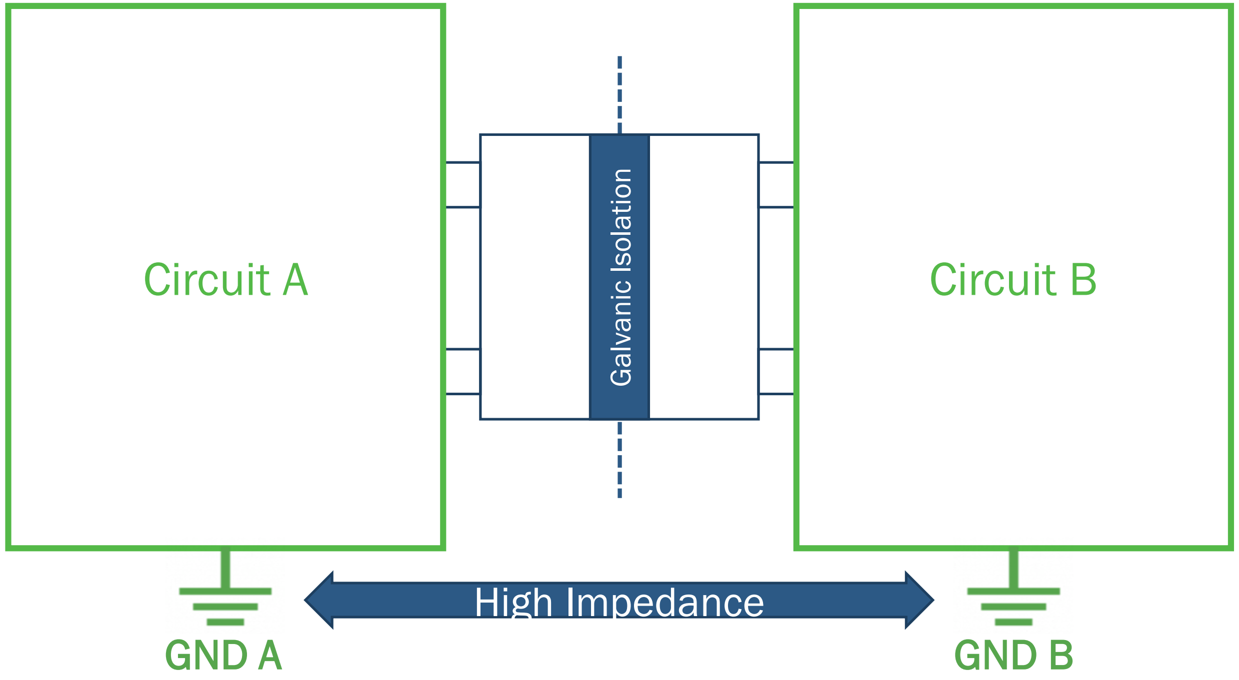
PURPOSE	EFFECT	CONCERNS
Keep PWR Switch in ON state	Minimize ON state Voltage and reduce conduction losses	Gate Voltage/Under Voltage Lockout
Keep PWR Switch in OFF state	Minimize leakage current and prevent spurious turn ON/OFF due to EXT or INT disturbances	Gate Voltage/Under Voltage Lockout
Drive SW from ON to OFF and OFF to ON	Minimize SW losses & improve EMI/EMC	Peak Source/Sink currents
Noise Immunity	Endure large GND loops & potential differences with high energy present	Separate Signal PWR GND/Reinforced
SW Protection	OCP, OTP, Shoot through, UVLO protection	Miller Capacitance Clamp/Soft Shutdown

Isolated Gate Drivers – Why, What and How Motivation in Power Management drivers to Isolation

- *Rising concern for environmental issues and energy savings is driving growth in the use of dynamic power control and inverters throughout the industrial, power, and home appliance markets*
- *In the U.S., Asia and Europe, the use of general-purpose inverters, DC Motors and BLDC Motors and AC servos is expanding rapidly, especially in the up and coming markets*
- *Most important is there has also been steady growth in the use of these devices in power-related fields like wind and solar generation, two markets that are expected to grow well into the future*
- *Pricing on MCU has dropped dramatically and current use of such Devices to control almost everything has proliferated into every aspect of Life, even Power Management*
- *IN order to separate High Voltage/Power from Logic Level Galvanic Isolation is a MUST HAVE and World Governments mandate so*

Introduction to Isolation

Galvanic isolation is a principle of isolating functional sections of electrical systems to prevent current flow.



Reasons for Galvanic Isolation

- ✓ Safety of End User
- ✓ Protecting LV circuits from HV Circuits
- ✓ Filtering of Common-Mode Noise
- ✓ Eliminating Ground Loop Noise
- ✓ Level-Shift between Power Domains

Technologies used for Galvanic Isolation

- Optically Isolated Devices
- Digitally Isolated Devices
  - Insulation with on-chip capacitors
  - Insulation with on-chip inductors
  - Insulation with off-chip capacitors

Why isolate, Summary?

- ✓ *To protect from and safely withstand high voltage surges that would damage equipment or harm humans*
- ✓ *To protect expensive controllers – intelligent systems*
- ✓ *To tolerate large ground potential differences and disruptive ground loops in circuits that have high energy or are separated by large distance*
- ✓ *To communicate reliably with high side components in high-voltage high performance solutions*

When Isolation is necessary and How to Isolate

- *Isolation is need it when there is more than One Conductive Path between two circuits creates a Ground-Loop*

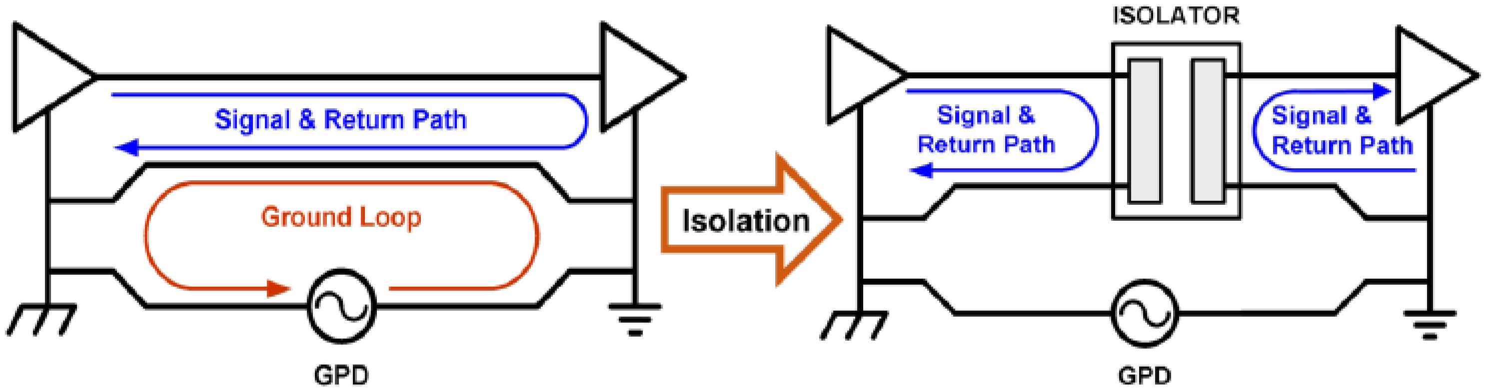
- *Multiple Ground Paths can lead to unintended compensation currents*

- *Ground Loops can be broken by:*
  - ✓ *Disconnecting the Grounds*
  - ✓ *Common Mode Chokes*
  - ✓ *Frequency Selective Grounding (Modified Tank Circuits)*
  - ✓ *Differential Amplifiers*
  - ✓ *Galvanic Isolators*

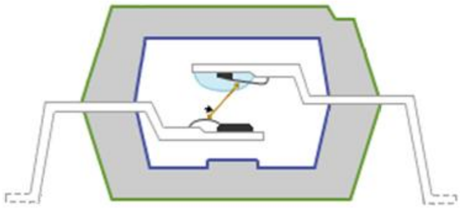
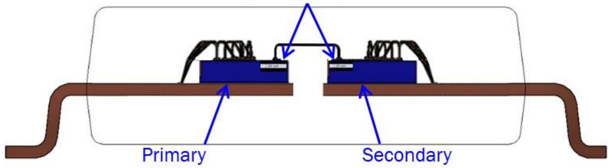
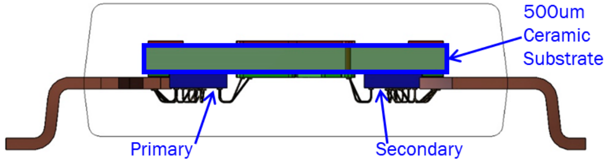
❖ ***ONLY TRUE GALVANIC ISOLATION PROVIDES PROTECTION FOR VERY LARGE POTENTIAL DIFFERENCES***

Galvanic Isolation –Reason and Methods

- ***ISOLATION*** – Means of transporting data and Power between High Voltage and a Low Voltage Circuit while preventing
  - ✓ ***Hazardous DC, AC or***
  - ✓ ***Uncontrolled Transient currents flowing between two circuits***
- To protect from and safely withstand high voltage surges that would damage equipment or harm humans
- To protect expensive controllers – intelligent systems
- To tolerate large ground potential differences and disruptive ground loops in circuits that have high energy or are separated by large distance
- To communicate reliably with high side components in high-voltage high performance solutions



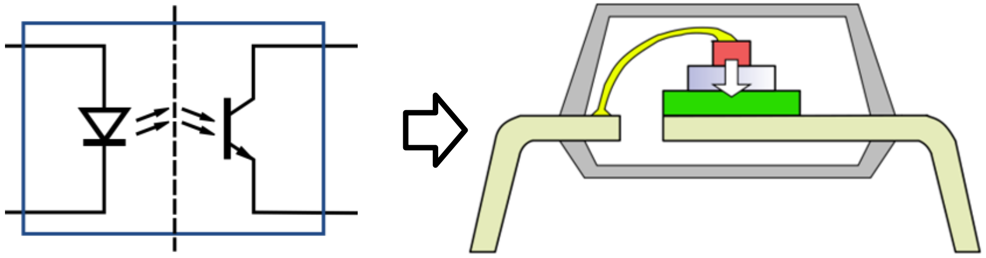
Isolation Market & Technologies

Optocouplers	Digital Isolators (DI)	Digi-Max™ (DM)
		
Technology		
Optical: LED + Photodiode	Digital: On-Chip	Digital: Off-chip with Ceramic Insulator
Benefits		
Lowest Cost EMI / EMC Immunity Isolation Reliability / Safety	Low Cost Stable over Temp & Time	EMI / EMC Immunity Isolation Reliability / Safety Stable over Temp & Time
Primary Markets		
Power Supplies Industrial HP Drives	Automotive (EV/HEV) Telecom	Industrial HP Drives
Lead Suppliers		
BROADCOM TOSHIBA ON Semiconductor	Texas Instruments Silicon Labs Analog Devices	Unique to ON Semiconductor

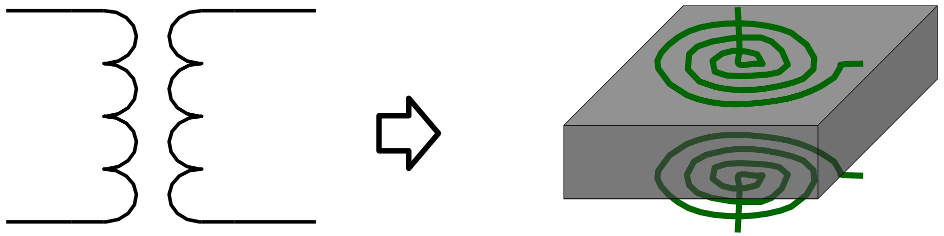
Public Information

What is the Popular Isolation methods in gate driver ?

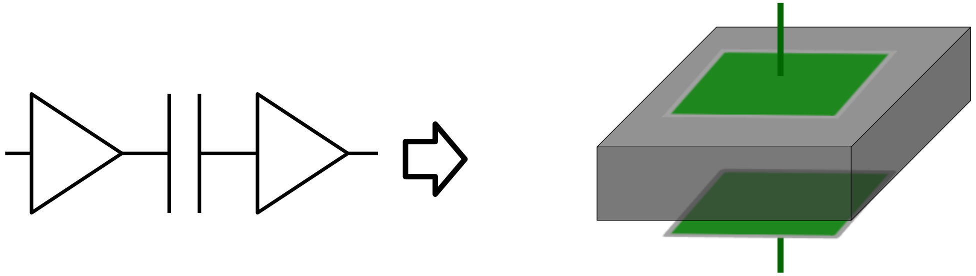
- A) **Optocoupler**
  - Signal transfer between two isolated circuits using light – LED + phototransistor, 1970s ~ (ON Semi, Avago, Toshiba and others)



- B) **Transformer**
  - Integrated micro-transformer and electronic circuitry, 2001 and on…



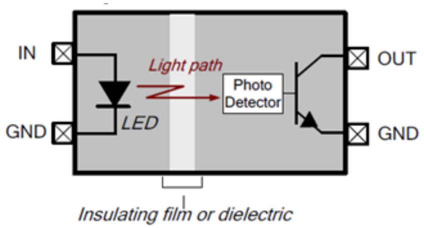
- C) **Capacitor**
  - Signal transmission through capacitive isolation with On- Off-Keying (OOK) modulation, 2007 and on…

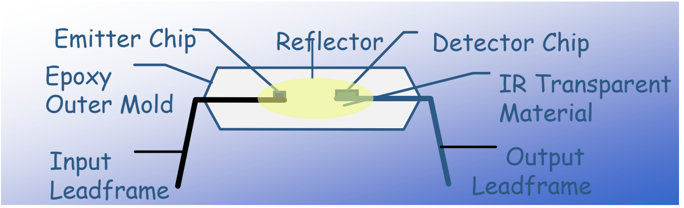


Common Isolation Techniques and Main Issues

Optical -> Optical transmission (fiber optics), optical coupling (optocoupler)

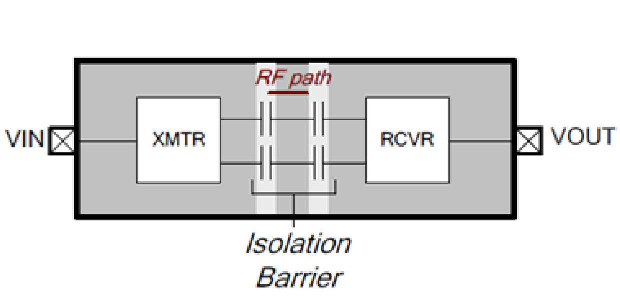
- LED degradation over time/temperature
- Slow (<25Mbit/s)
- Not economical for high-channel count

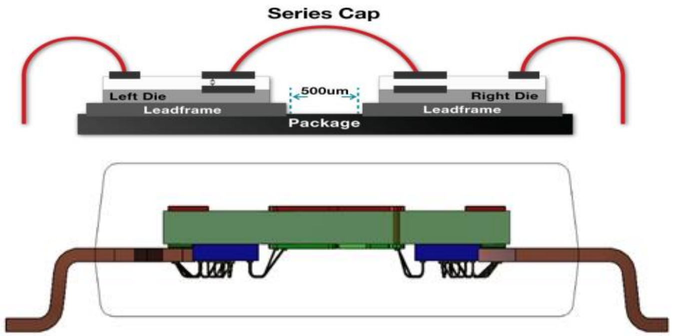




Capacitive (on-chip/off-chip)

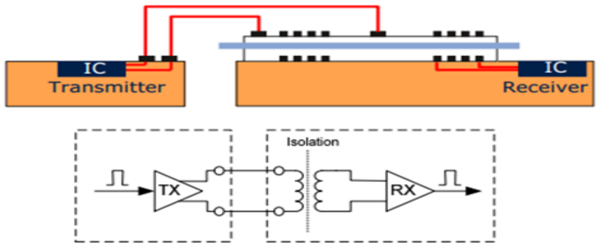
- Thin insulation barrier (on-chip)
- Insulating materials susceptible to damage from EOS/ESD (on-chip)
- Higher power consumption (off-chip)
- EMI/EMC challenges

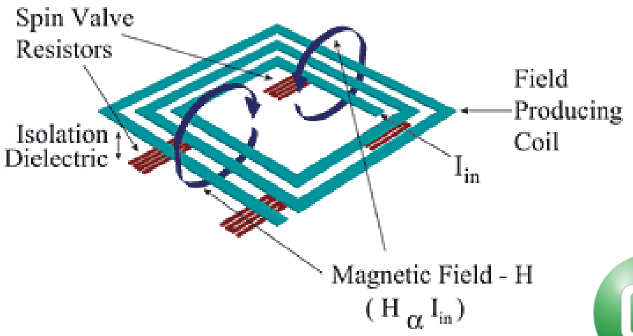




Magnetic -> Coreless transformer, magneto resistive, hall effect

- Magnetic interference
- EMI susceptibility
- Thin insulation barrier





THE importance of Integration of Driver + Isolation in single package

- ***Adding isolation is becoming mandatory as part of regulatory compliance***
  - System solutions becoming smaller in size
    - ✓ Telecom bay stations and RRUs – Higher data transactions
    - ✓ Datacenters – space limited – but more storage
- Higher efficiency
  - ✓ Switching to higher voltages
  - ✓ More intelligence to systems
  - ✓ More protection of controls
- Higher performance density
- Isolation robustness
- Availability of high voltage devices
  - ✓ Wide band gap devices – SiC, GaN

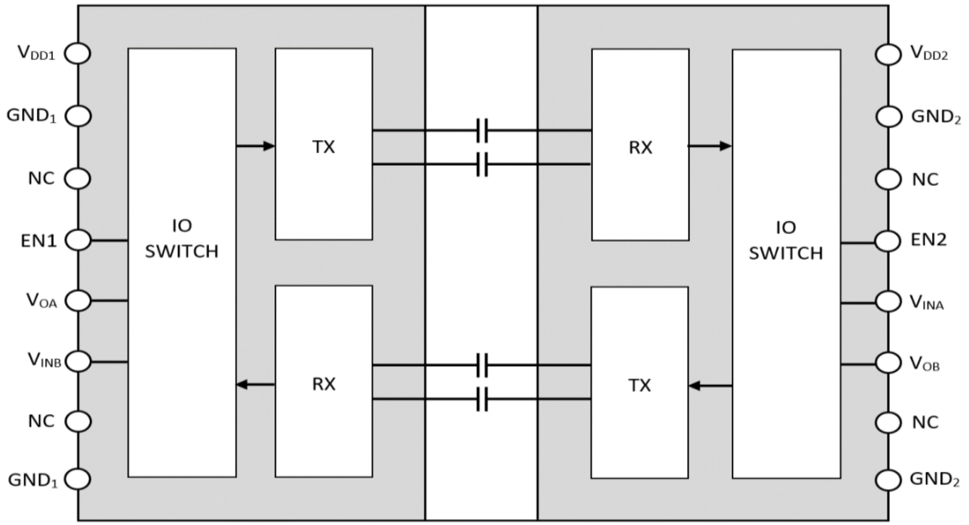
Levels of Isolation

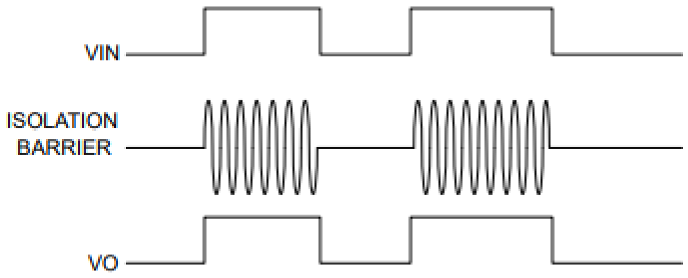
- **Functional Isolation**
  - *Functional Isolation is necessary for the proper operation of a product. There is no need for protection against electric shock*
- **Basic Isolation**
  - *Basic Isolation is single level of isolation providing basic protection against electric shock*
- **Reinforced Isolation**
  - *A single insulation system that provide electrical shock protection equal to double insulation*
- **Supplementary Isolation**
- **Double Isolation**

Comparison of Isolation Techniques

Attribute		Opto-Coupler	On-chip Magnetic	On-chip Capacitive	Digi-Max™ Off-chip Capacitive
Isolation Materials		Epoxy/Silicone gel	Polyimide	SiO_2 or equivalent	Ceramic Substrate/ Epoxy
Signal Coupling		Optical (LED +diode)	Magnetic field	Electric field	Electric field
Performance Across Temp & Time		Varies	Consistent	Consistent	Consistent
Life Expectancy		~10 Yrs	~ 20 Yrs	~ 20 Years	~20 Years
Speed		Slow	Fast	Fast	Fast
Distance Through Insulation (DTI)		> 400 µm	~20 µm	~20 µm	> 500 µm
Meets EN60950 >0.4mm DTI		Yes	No	No	Yes
Common Mode Transient Immunity (CMTI)		~25 kV/µs	> 100 kV/µs	> 100 kV/µs	> 100 kV/µs
EMI EMC	Susceptibility	Non-issue – too slow	Design techniques	Signal level dependent	Signal level dependent
	Radiation	Non-issue (light transmission)	Design techniques	Design techniques	Design techniques
Junction Temperature		Up to 125°C	Wide range (150 °C)	Wide range (150 °C)	Wide range (150 °C)
Standards		UL1577 IEC60747-5-5	UL1577 VDE0884-11	UL1577 VDE0884-11	UL1577 VDE0884-11
Modulation Method for Internal Signal Xfer		No modulation required	On-Off Keying	On-Off Keying	On-Off Keying
AEC Qualified Portfolio		Limited	Yes	Yes	Yes

Working Principles of Bi-Directional Ceramic Isolator

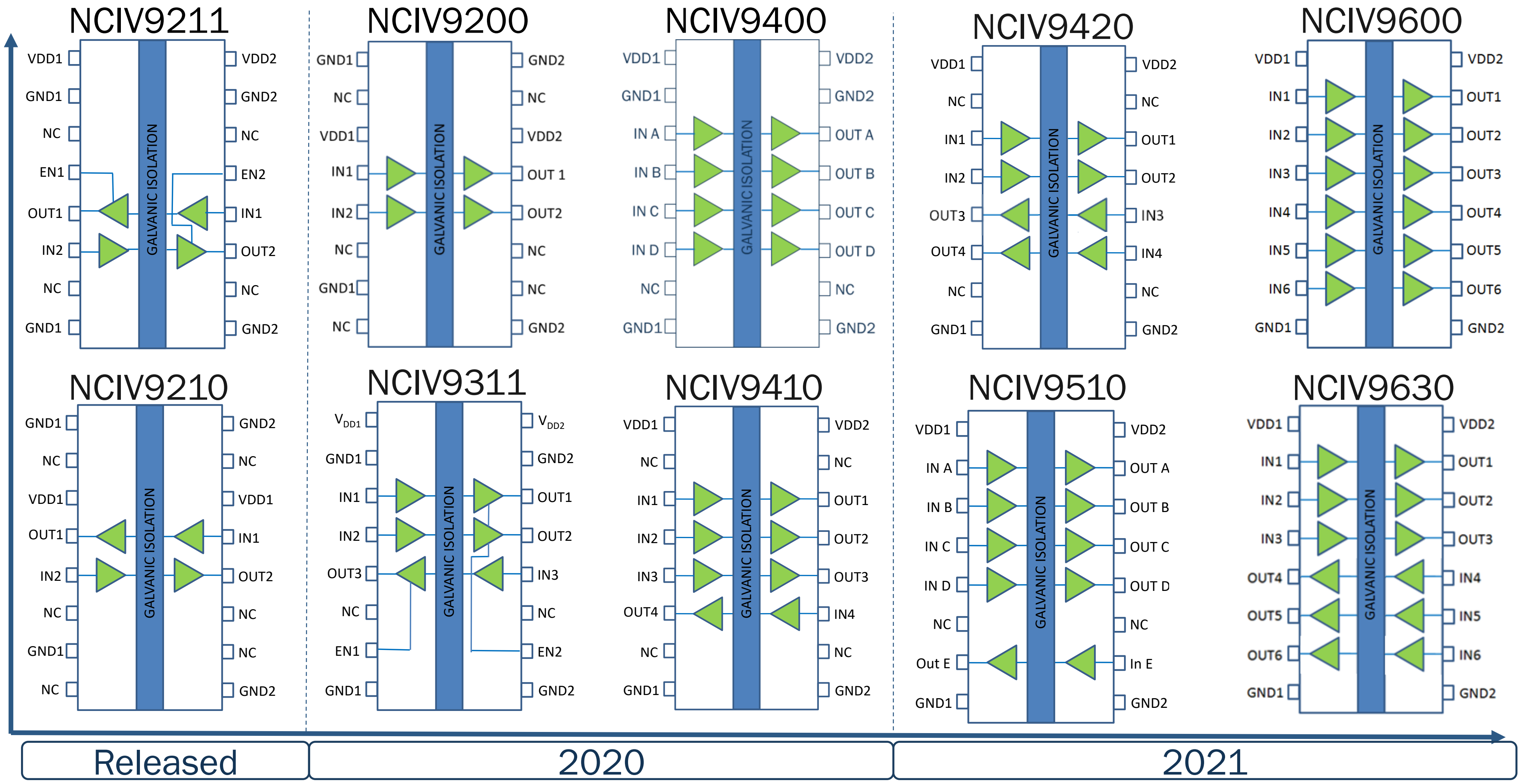


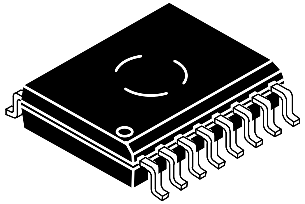


- Bi-Directional communication between two isolated circuits.
- Off−chip ceramic capacitors that serve both as the isolation barrier and as the medium of transmission for signal switching using on−off keying (OOK) technique,
- Tx, modulates the VIN input logic state with a high frequency carrier signal.
- Rx detects the barrier signal and demodulates it using an envelope detection technique.

Digi-Max™ Family of Hi-Speed Digital Logic-to-Logic Isolators

Available in Industrial (NCID) and Automotive Grade (NCIV)



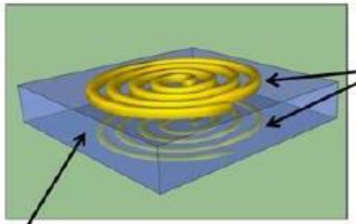


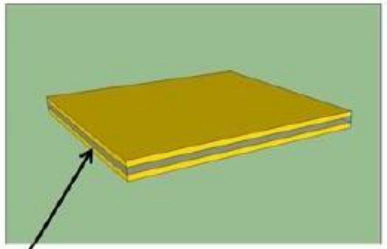
SO-16 WB Package

Other Configurations Available

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.





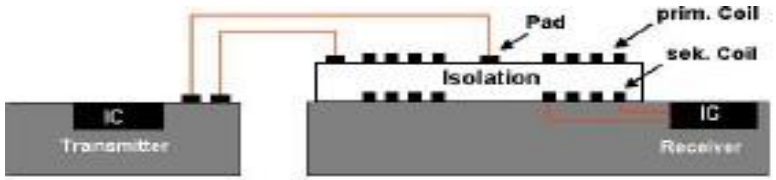
Temperatures up to 125°C

	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

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.
  - **This Tech has 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.*

Isolation Technologies (Capacitive)

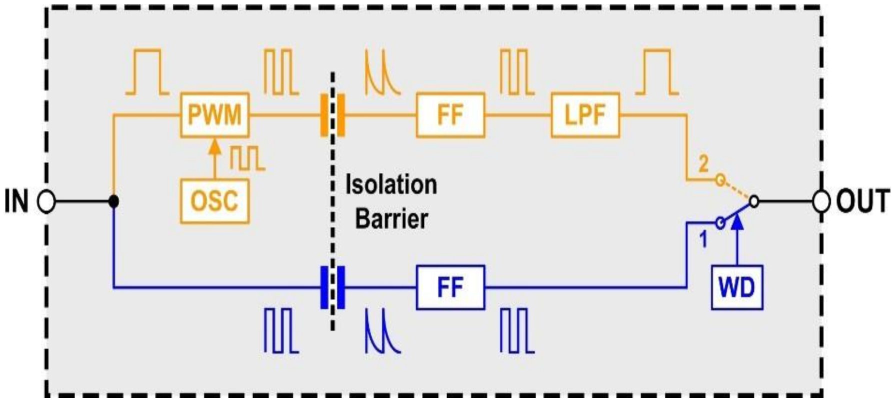


Figure 4

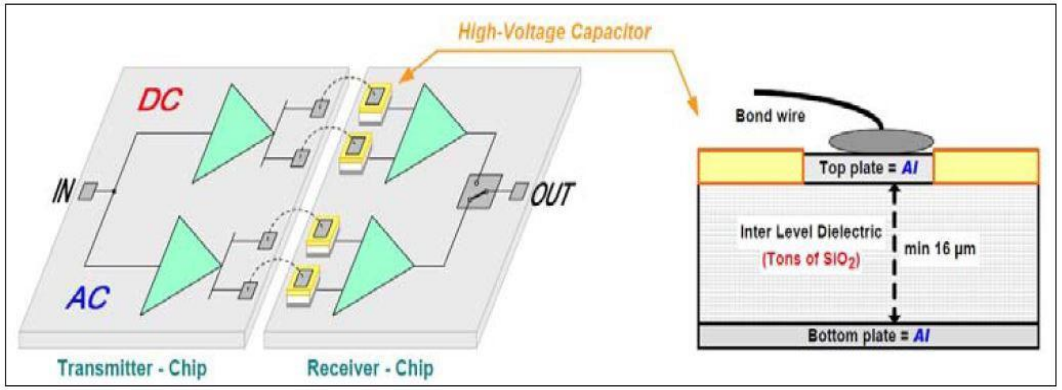


Figure 5

Advantages:

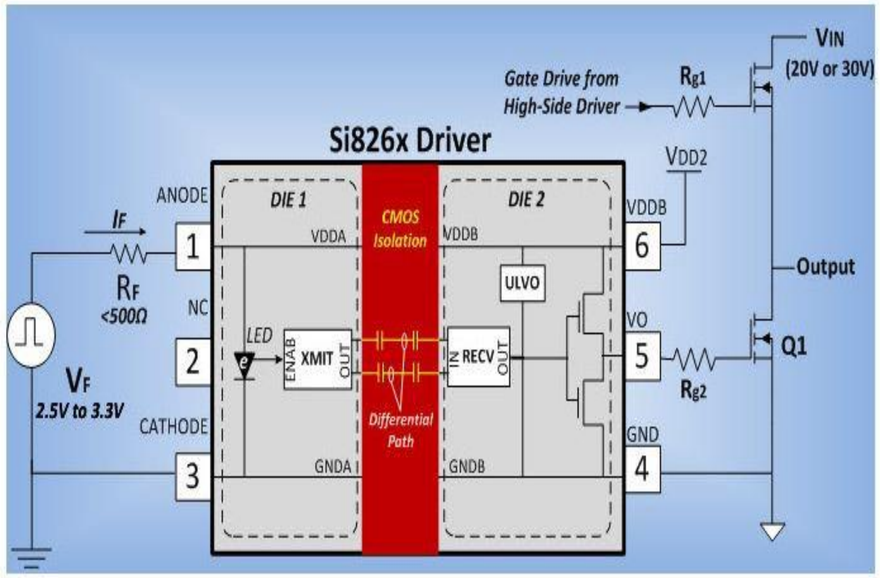
- Physical barrier utilizing dielectric insulating material
- No LED to wear out
- Total immunity to magnetic fields
- Used by Texas Instruments (developed by Burr Brown)

Disadvantages:

- Higher current consumption than transformer isolation

Honorable mention - Isolation Technologies (RF)

This RF ISO tech is used
by Silicon Labs



Advantages:

- Requires less input power than optoisolator technologies
- Lower propagation delay than optoisolators
- Total immunity to magnetic fields
- No LED to wear out

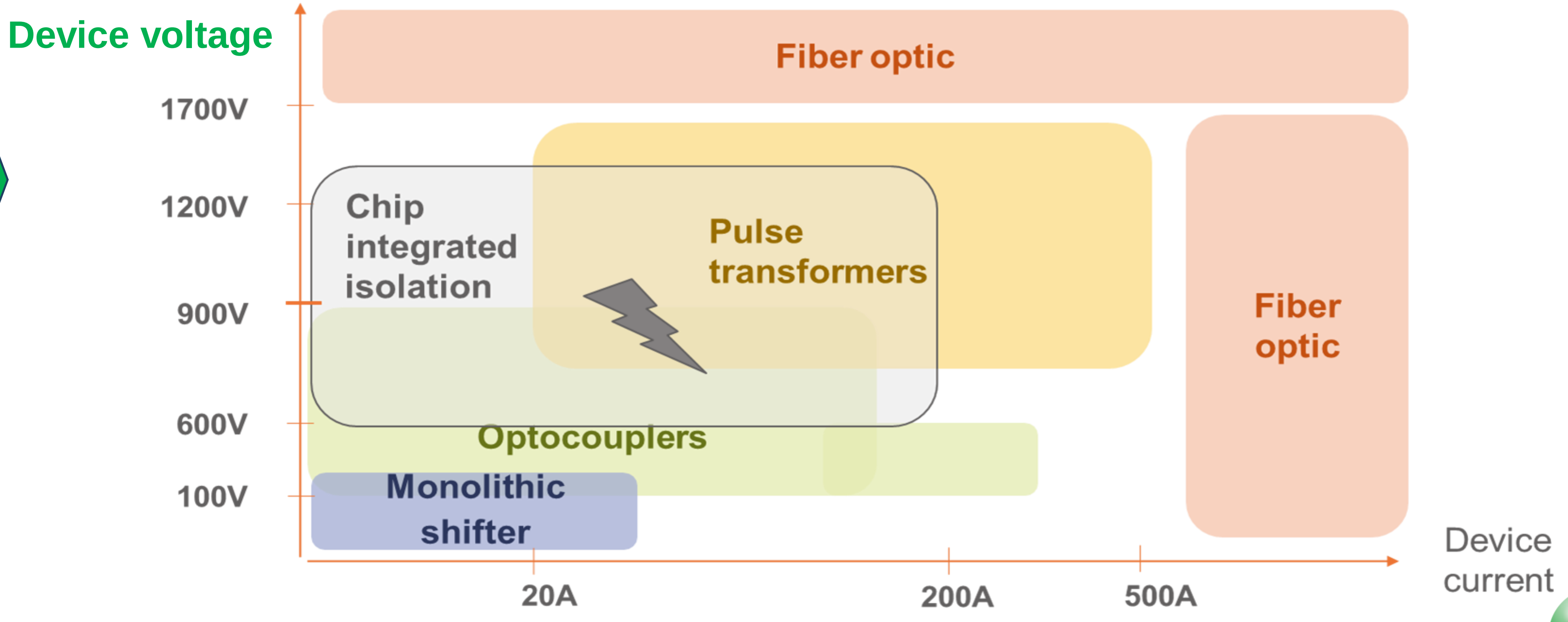
Disadvantages:

- Higher current consumption than magnetic isolation
- Carrier frequency limits pulse position accuracy

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 technologie s are penetrating the traditional optocoupler and transformer market.



Comparison between MOSFET and IGBT *Isolated* drivers

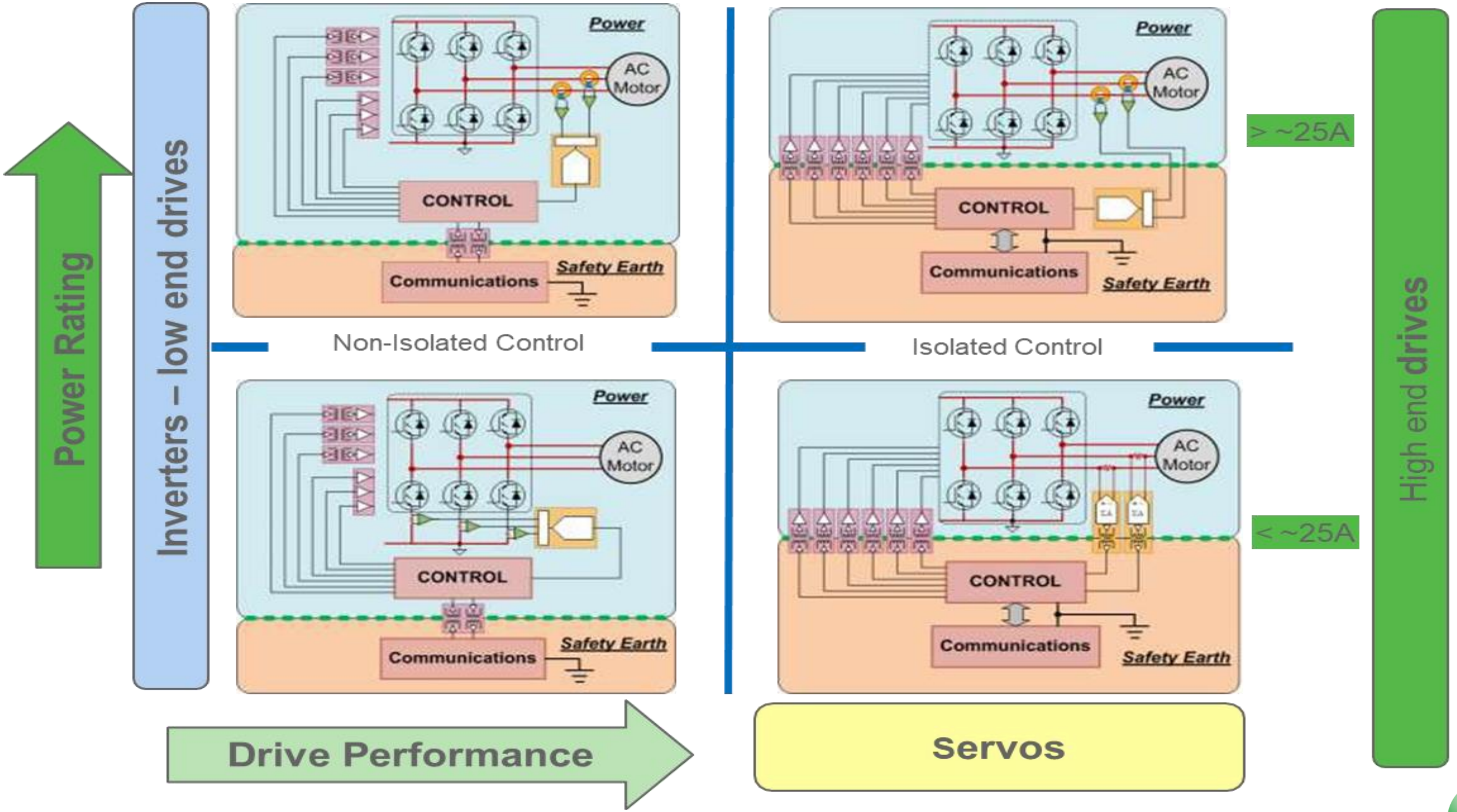
Power Switch	MOSFET	IGBT
Switching frequencies	*High (>20 kHz)*	*Low to Medium (5-20kHz)*
# Channels	*Single and Dual*	*Single*
Protection	*No*	*Yes – Desaturation, Miller Clamping*
Max Vdd (power supply)	*20V*	*30V*
Vdd range	*0-20V*	*-10 to 20V*
Operating Vdd	*10-12V*	*12-15V*
UVLO	*8V*	*12V*
CMTI	*50-100V/ns*	*<50V/ns*
Propagation delay	*Smaller the better (<50ns)*	*High (not critical)*
Rail Voltage	*Up to 650V*	*>650V*
Typical Applications	Power supplies – Server, datacom, telecom, factory automation, onboard and offboard chargers, solar u-inverters and string inverters (<3kW), 400-12V DCDC -Auto	Moto drives (AC machines), UPS, Solar central and string power inverters (>3kW), Traction inverters for auto

Comparison of SiC to MOSFET and IGBT iso drivers

Green font highlights similarities

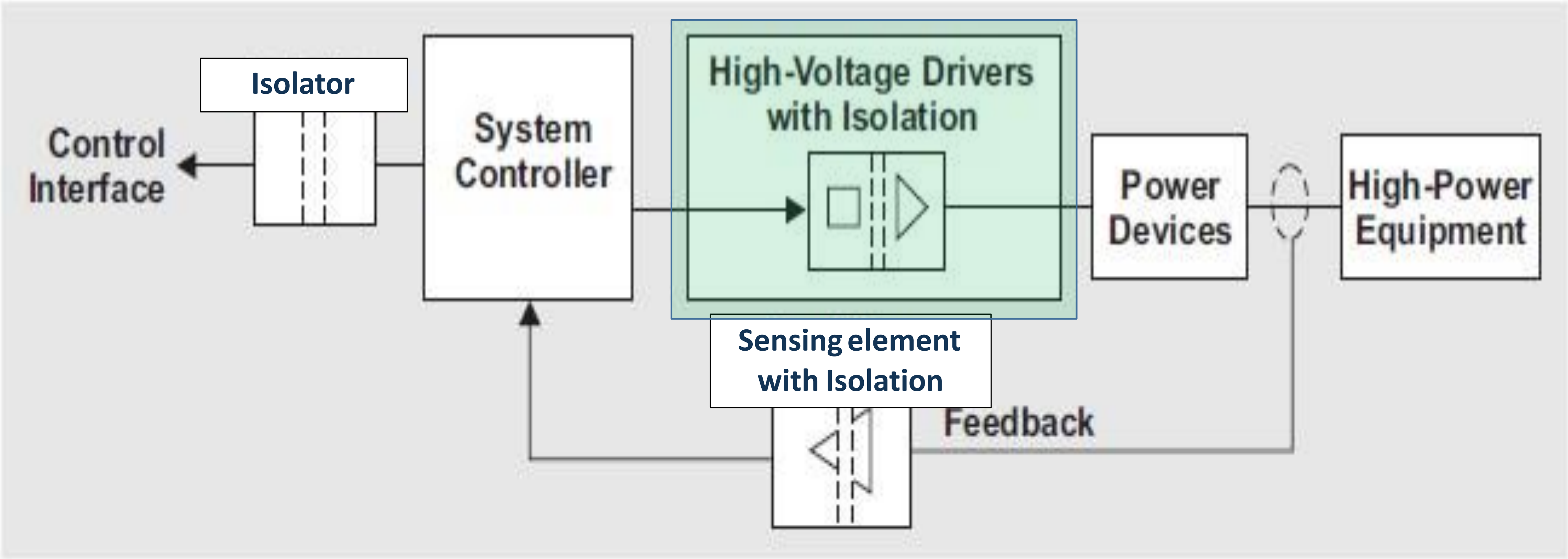
Power Switch	MOSFET	IGBT	SiC
Switching frequencies	High (>20 kHz)	Low to Medium (5-20kHz)	High (>50 kHz)
# Channels	Single and Dual	Single	Single and Dual
Protection	No	Yes – Desaturation, Miller Clamping	Yes – Current sense, Miller Clamping
Max Vdd (power supply)	20V	30V	30V
Vdd range	0-20V	-10 to 20V	-5 to 25V
Operating Vdd	10-12V	12-15V	15-18V
UVLO	8V	12V	12-15V
CMTI	50-100V/ns	<50V/ns	>100V/ns
Propagation delay	Smaller the better (<50ns)	High (not critical)	Smaller the better (<50ns)
Rail Voltage	Up to 650V	>650V	>650V
Typical Applications	*Power supplies – Server, datacom, telecom, factory automation, onboard and offboard chargers, solar u-inverters and string inverters (<3kW), 400-12V DCDC - Auto*	*Moto drives (AC machines), UPS, Solar central and string power inverters (>3kW), Traction inverters for auto*	*PFC – Power supplies, Solar inverters, DCDC for EV/HEV and traction inverters for EV, Motor drives, Railways*

Gate Driver Isolation Requirements in Motor Drivers

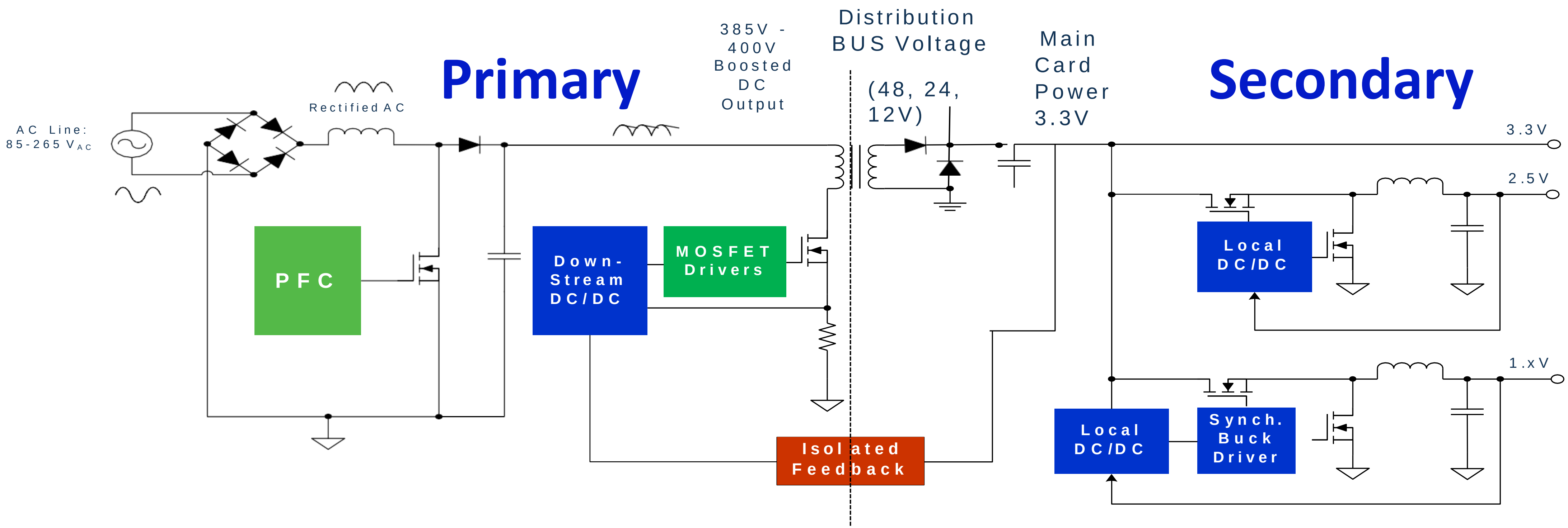


A conceptual power drive system block diagram

Electronic devices and integrated circuits (ICs) used for isolation are called isolators



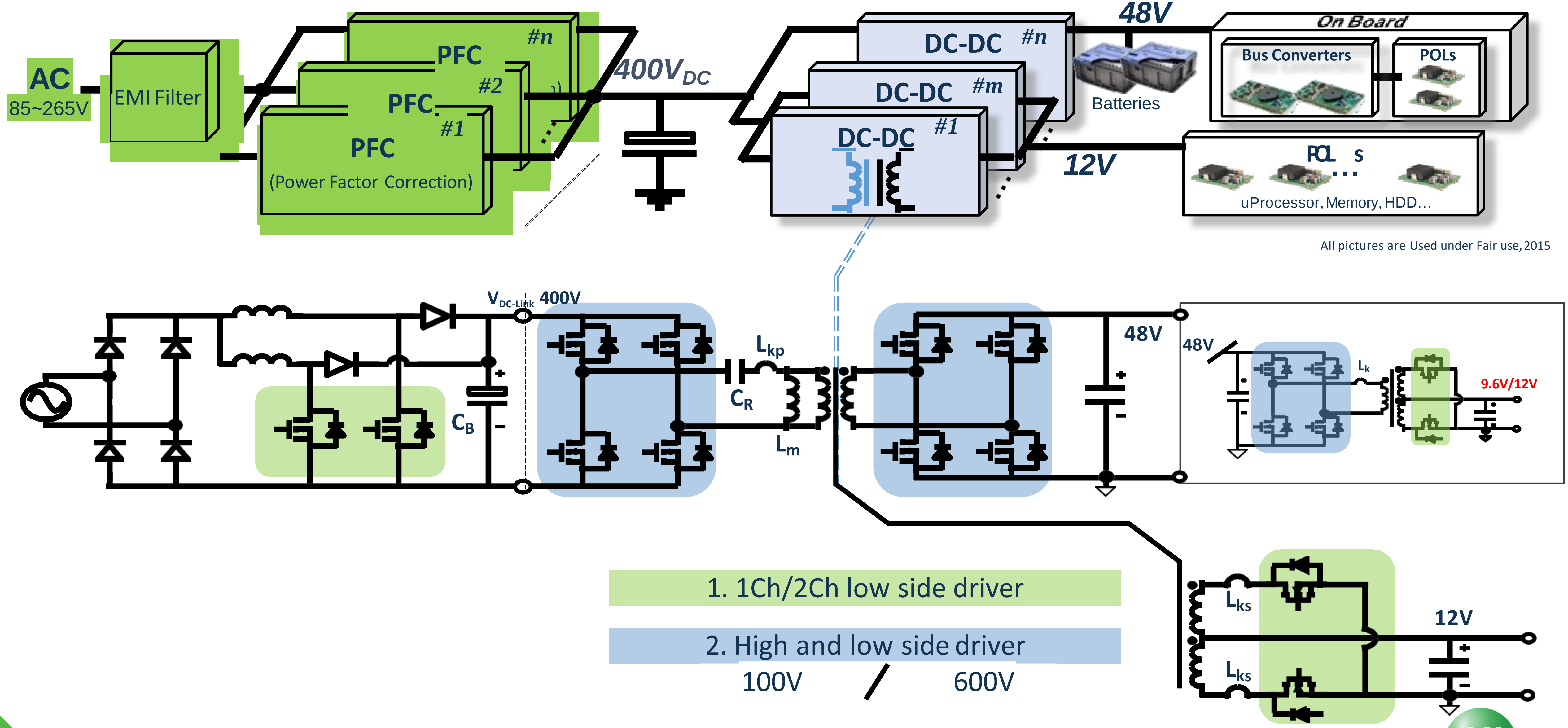
Power Supply application



There is high voltage involved on the primary side of DCDC

PFC Boost	PWM	Local POL Regulators
Reduces Harmonic Content, lowers peak current and makes load look Resistive	PWM is main loop to regulate Vo, provides proper duty cycle	PWM is main loop to regulate Vo, provides proper duty cycle

Server / Telecom Power Supply example

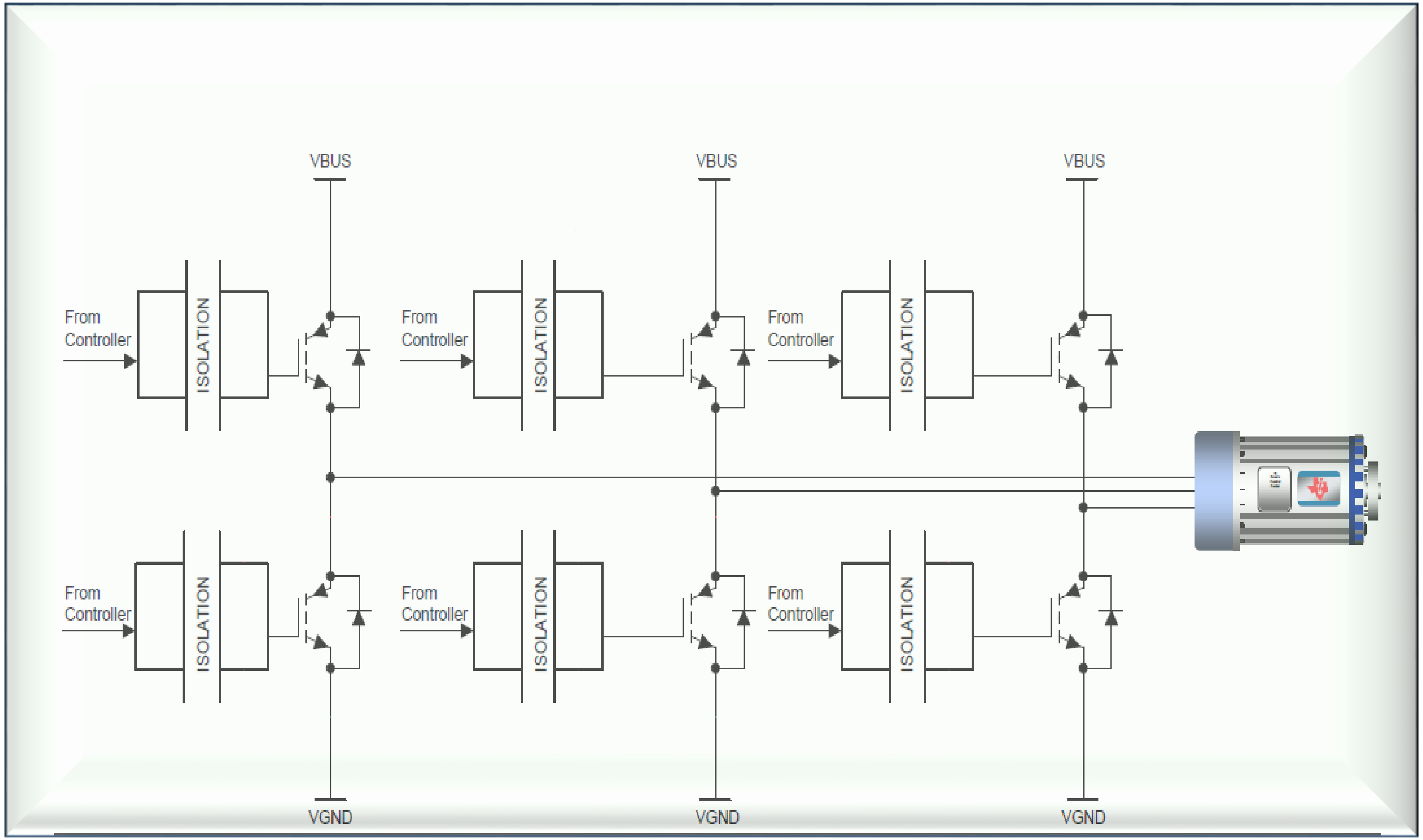


1. 1Ch/2Ch low side driver

2. High and low side driver

100V / 600V

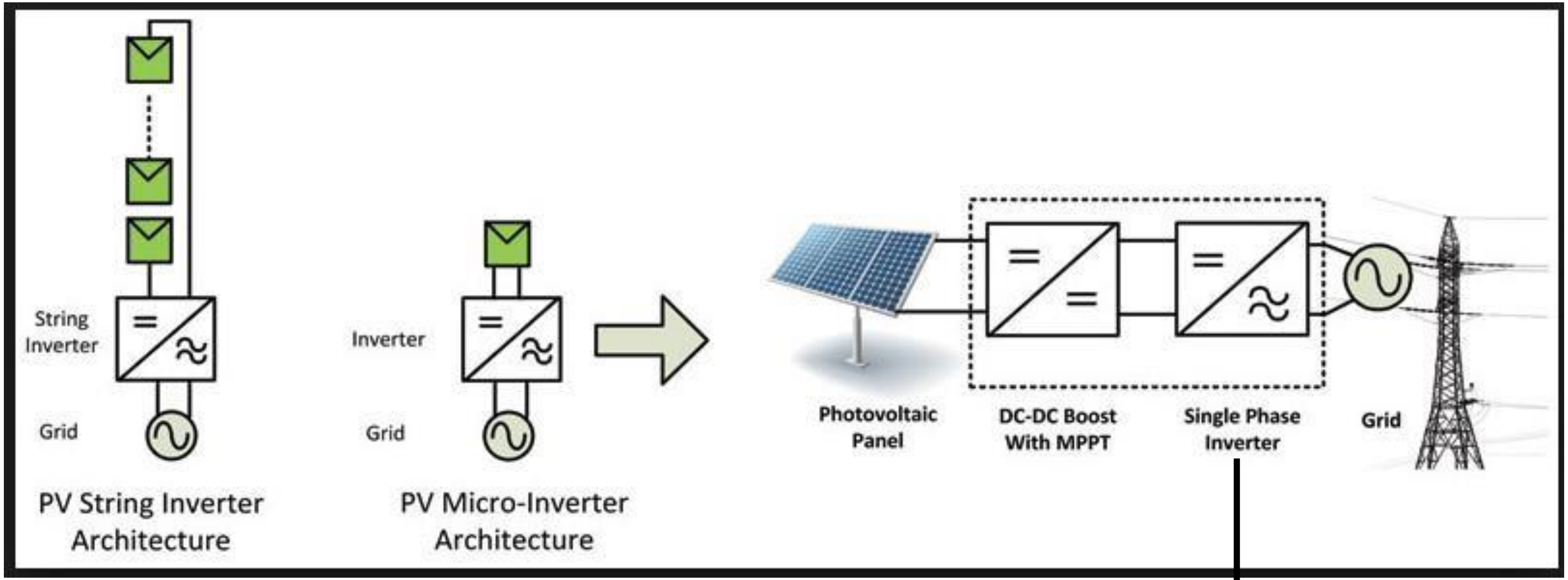
Motor drive application



Gate driver options:

- 6 single channel iso drivers with no protection (8pin) and usually reinforced
- 6 single channel iso drivers with protection (DESAT, Miller clamp or split output) (16 pin)
- 3 single channel iso drivers
  for high side only (8 or 16 pin) along with 3 non isolated drivers

Solar micro (300W)/string (<3kW) inverter



Usually MOSFET single inverters needing <u>isolated (basic or reinforced) drivers</u>

Isolation – OPTO vs. Digital

Key Article	Effect	Digital Isolators	Optocoupler
Timing performance	Enables higher throughput and efficiency for end product	Low propagation delay and skew, better part to part matching	High propagation delays and skew, worse part to part matching
Parasitic capacitive coupling	The lower the parasitics, the higher the CMTI	Less than half the parasitic coupling of optocouplers	High parasitic coupling with interdependent parameters
Reliability and high temperature operation	Longer product lifetimes	No wear out mechanisms, 60+ year operating lifetime at 125 °C at maximum VDD	Intrinsic wear-out mechanisms; 10x lower lifetime
Input current	High input current means higher power consumption	CMOS input buffers need very low input current	Requires higher input current to be competitive
Ease-of-use	Minimum external BOM needed to extract full functionality and performance	Fewer second order effects, minimum BOM required for full performance guarantee	Significant first and second order effects, temperature dependencies, imprecise current thresholds, CTR require external BOM to get stable performance
Electro-magnetic immunity and radiation	Immunity provides robustness and low radiation implies low noise generation	Capacitive-coupled devices are comparable to optos while magnetically coupled devices can be noisy and are susceptible to external EM noise	Opto are generally highly immune and have low radiation
Safety compliance	Ensures safety standards are tested and certified	General trend is new-generation isolators are on par with opto	Opto have traditionally been used for many years and are compliant

Active Standards Organizations: Keep Up-to-Date With Rapidly Evolving Requirements

IEC 60747-5-5

Optoelectronic devices

photo-couplers

VDE 0884-10 and 0881-11

Magnetic and capacitive couplers for safe isolation

Will be replaced by VDE 0884-17

IEC 60747-17

Magnetic and capacitive coupler for basic and reinforced isolation

Valid from ~ 2018 Target

→

VDE 0884-17

Magnetic and capacitive coupler for basic and reinforced isolation

Valid from ~ 2018 Target

Component level standards (component insulation capabilities)

System level standards (isolation coordination)

IEC 60664-1

Insulation coordination for equipment within low-voltage systems - principles, requirements and tests

→

IEC 61800-5-1 new UL 61800-5-1

Adjustable speed electrical power drive systems – safety requirements

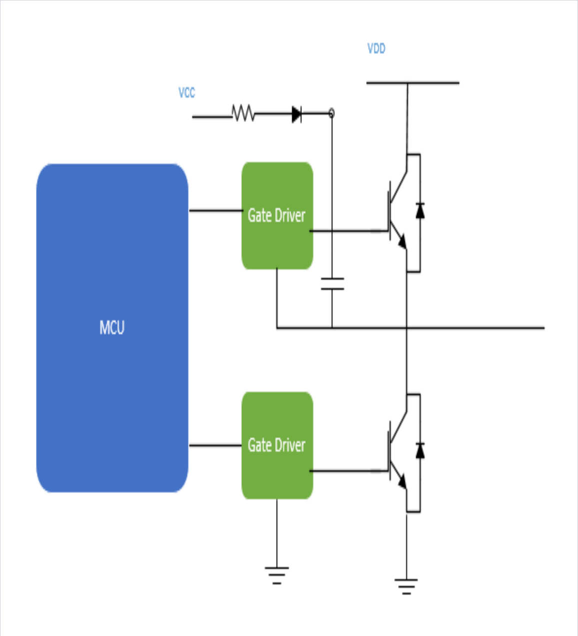
Key requirements for an isolated driver

In addition to understanding the levels of isolation…. It is important to find out about the driver functionalities:

- Propagation delay
- Common Mode Transient Immunity (CMTI)
- Rise time/fall time
- Maximum driver side supply voltage
- UVLO
- Channel to channel delay
- Protection schemes
- Dead time control and overlap
- Enable/disable features

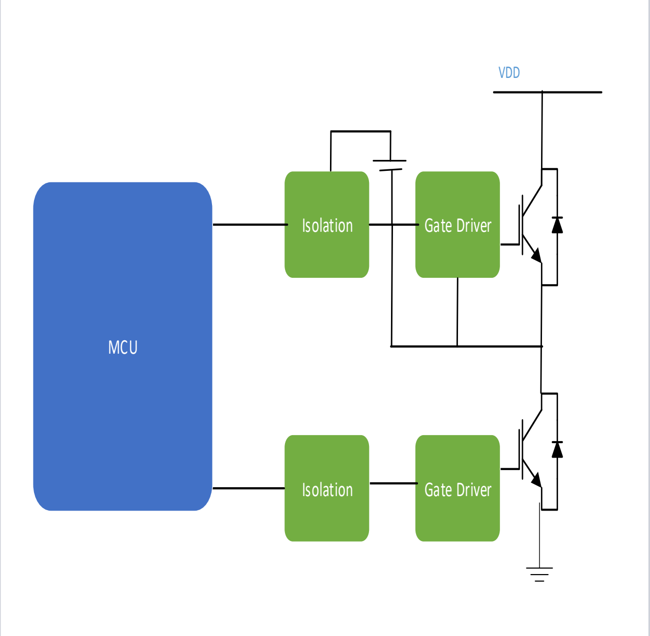
Gate Driver Topologies

Non-isolated



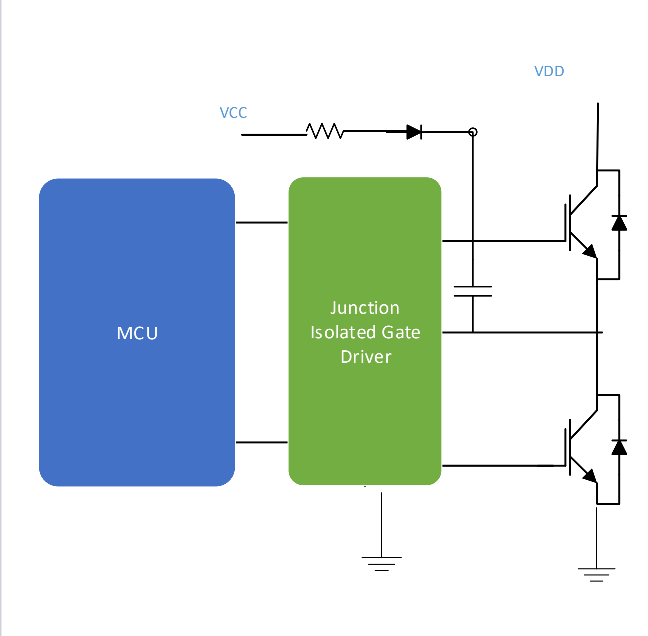
- Very simple
- Minimal features
- Layout critical to prevent crosstalk and GND currents
- May need extra Cap & Common Mode Choke to decouple noise
- APPS – Low Power SMPS with Low Cost MCU; Low drive Power

Signal Isolated



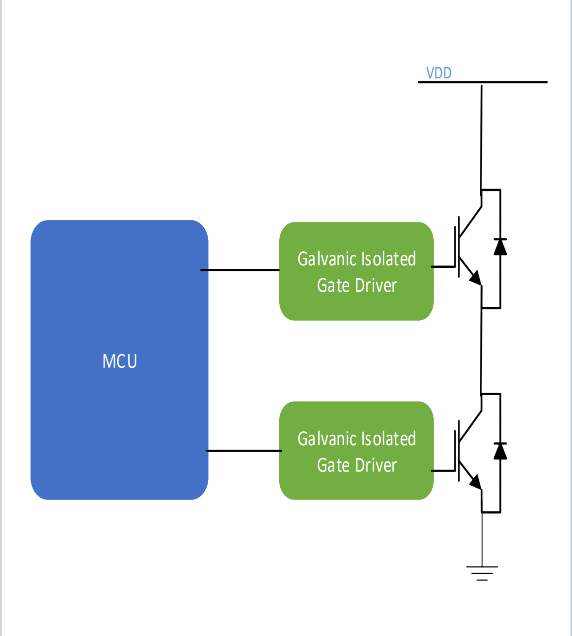
- Not commonly used
- Layout can be complex due to extra IC's
- Decoupling Caps extra cost
- GND noise Common Mode choke could be required
- APPS – Low to Med Power; Afterthought Isolation need it if long cables are used

Junction Isolated



- Low Cost
- Easy layout
- Need to select Boost Diode and Cap with care for speed/noise ratio
- Possible Cap needed for cross - coupling reduction due to NO galvanic Isolation
- APPS – DC-DC; PFC; Small-Med Motor drivers; Consumer Appliances; Med Power UPS< 3KW

Galvanic Isolated



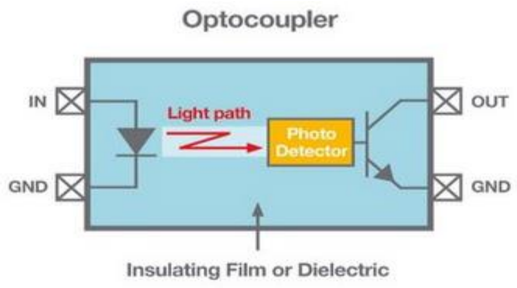
- IC is complex; all Integrated
- Full protection features
- Higher cost/Highest safety
- Ease of Layout, no extra components
- APPS – High Power AC/BLDC Motors; Industrial SMPS; Solar Inverters; High Power UPS > 3KW

Isolation Tech: OPTO, Fiber-optic & Level Shift Pros – Cons

OPTO-Coupler

Pluses:
- Simple
- Been around longest
- High Iso Capacity up to 1 KV
- Drive Speed up to 1 MHz
- Offers good response at Lower Fsw
- Very inexpensive

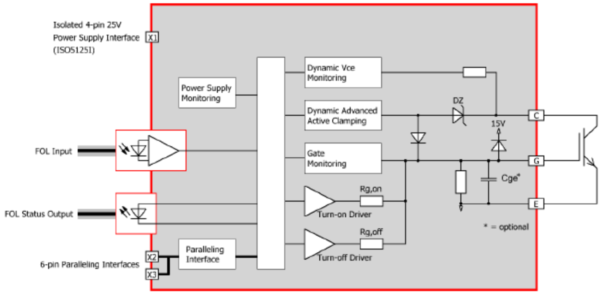
Minuses:
- LED Degradation
- Power supply required
- Slow Prop Delay
- Slow Rise/Fall times
- Frequency Response is slow
- No energy Transmission



Fiber Optics

Pluses:
- Unlimited Isolation Voltage
- Fast Response time
- Distance between points is unlimited
- Great Communication between Points

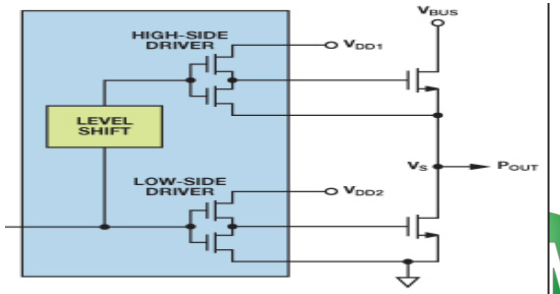
Minuses:
- Expensive
- Power Supply required
- No Energy Transmission



Level Shit/Junction Isolation

Pluses:
- High Current Capability
- Precision Analog Circuitry
- Voltage levels of 1200 V/600 V/500V/200 V & 100 V
- Configuration of 3-Phase/Half Bridge/Single Channel & more
- Best Price/Performance ratio

Minuses:
- No Galvanic Isolation
- Power Supply required
- No Energy Transmission

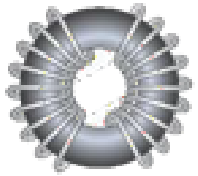


Isolation Tech: Inductive Coupling and Capacitive Pros – Cons

Transformer, Iron Core

Pluses:
- Galvanically Isolated
- Reinforced Isolation for 1700V MIN
- Fast & Accurate, low jitter/low delay
- Flexible Form Factor
- Low coupling Capacitance
- Bi-Directional

Minuses:
- Expensive
- 10% Turn ON/OFF stability issues
- Single Source
- Limited Product Portfolio, yet



Planar Core

Pluses:
- Unlimited Isolation Voltage
- Fast Response time
- Distance between points is unlimited
- Great Communication between Points

Minuses:
- Expensive
- Power Supply required
- No Energy Transmission

Coreless IC

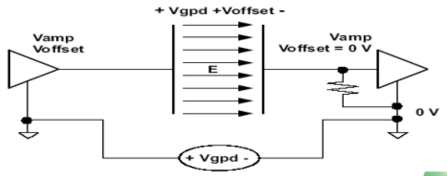
Pluses:
- High Current Capability
- Low Cost
- Very Fast
- Low coupling Capacitance

Minuses:
- Single Source
- Power Supply required
- No Energy Transmission

Capacitive Isolation

Pluses:
- Low Power Consumption
- 1700V MIN
- Fast & Accurate, low jitter/low delay
- Physical Barrier with Iso-Material

Minuses:
- Expensive
- High Current consumption



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	$$$$
Monolithic level shifter	None	50kV/µs	-	Integrated on the IC	No	-	$
Pulse transformer	Several kV	>50kV/µs	<100 ns	Bulky	No	Reliable	$
Digital isolation	Several kV	>100kV/µs	~20 ns	Integrated on-chip or driver IC package	Yes	Very reliable	$$

Comparison between Gate Drive Transformer & High & Low Side Driver with isolator

	Type A	Type B
T_{Prop}	≈20ns	≈100ns
Bias Power	NO	Yes
C_{IO}	≥10pF	≤1pF
Parasitics	Large (L_{LK})	Very small
Overshoot	Large	Small
Size	Bulky	Small

Isolation Evolution and Key Reasons behind it

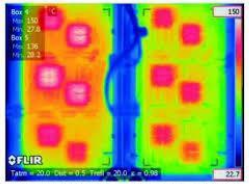
THE need for Gate Driver change

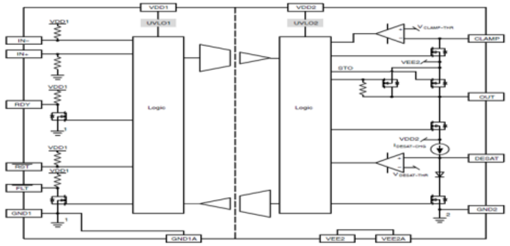
This cause-effect scenario is now principally applied by Wide Band Gap devices.

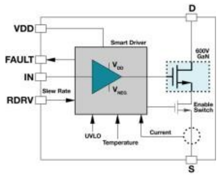
Faster switching frequency

Need for lower stray inductance

Driver IC closer to gate







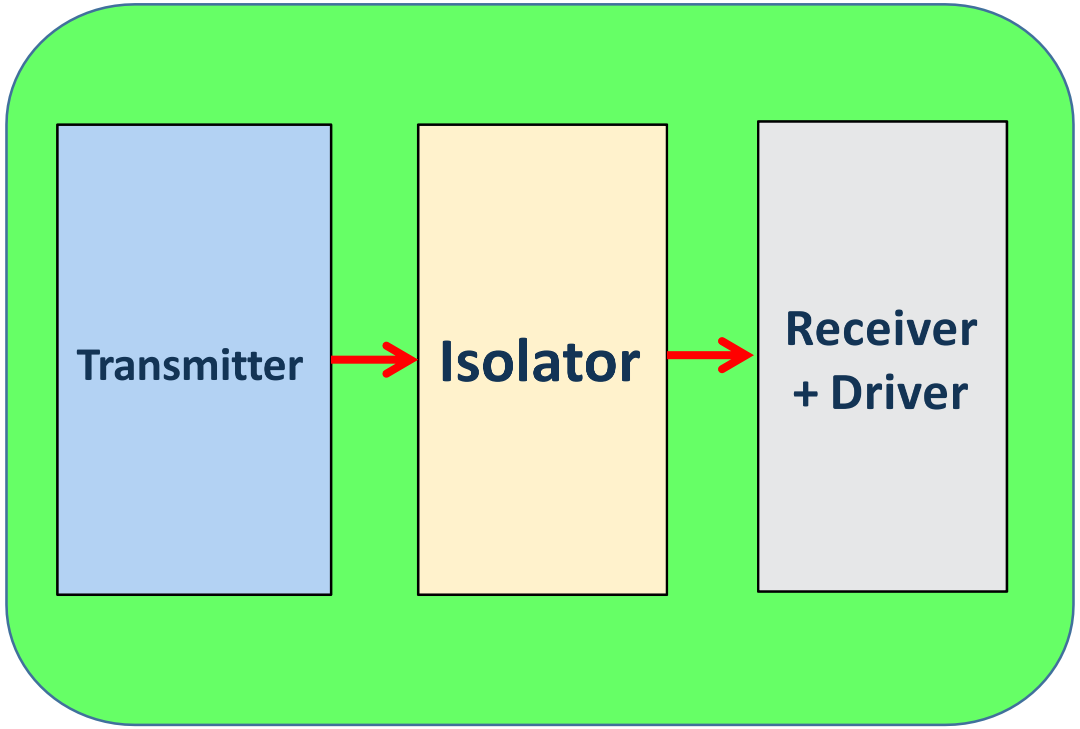
Integration of driver ICs in transistor package

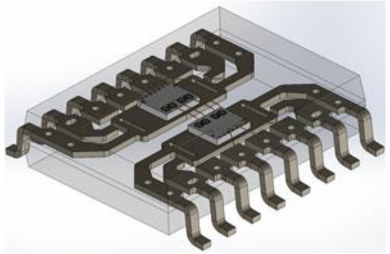
Need for on-chip integrated isolation

Higher temp. inside the power module

Construction of an isolated gate driver

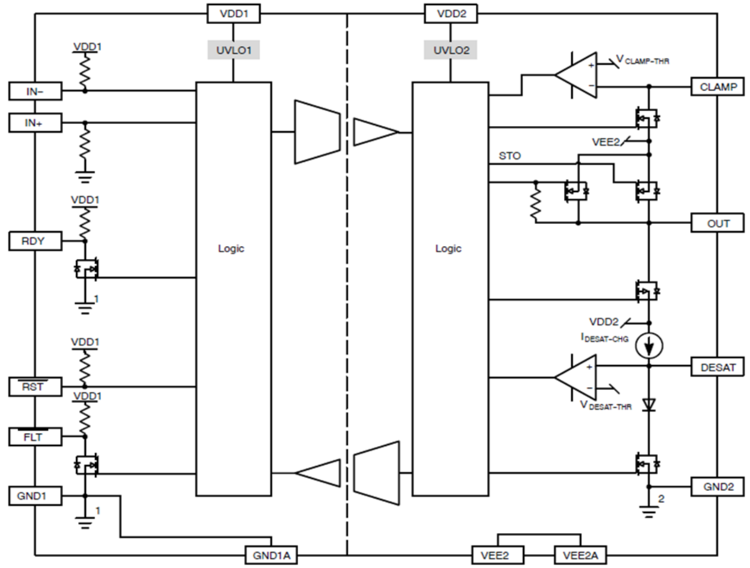
Multichip module



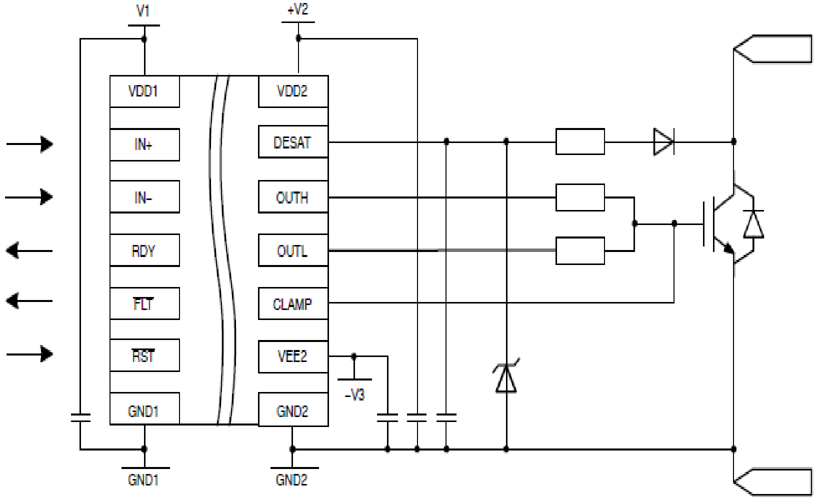


NCD57000 - Isolated Driver

Block Diagram



App Schematic

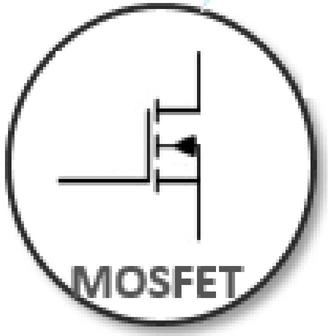


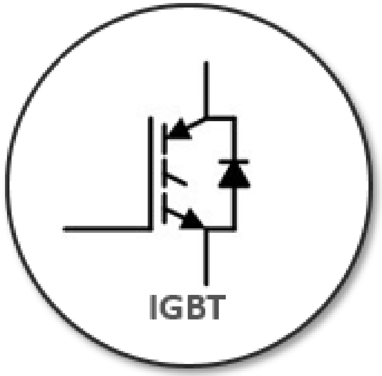
Power Switch Impact on Gate Driver Evolution

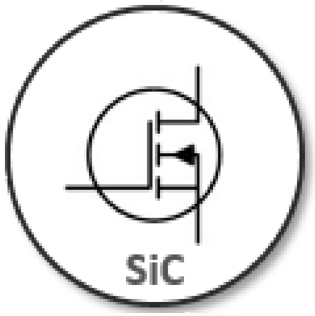
Yet even **higher**
CMTI Narrow gate
drive window

Yet even ***higher*** working voltage
Faster DSAT detection
Higher CMTI
Enhanced safety features

Higher working voltage
Miller Clamp
DSAT detection



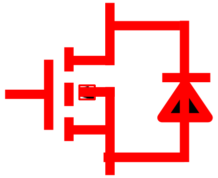
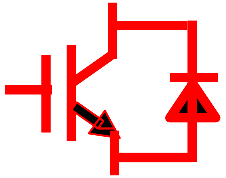
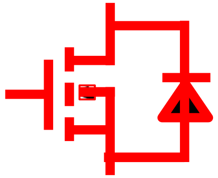
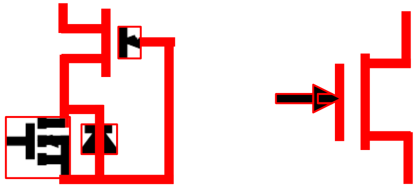


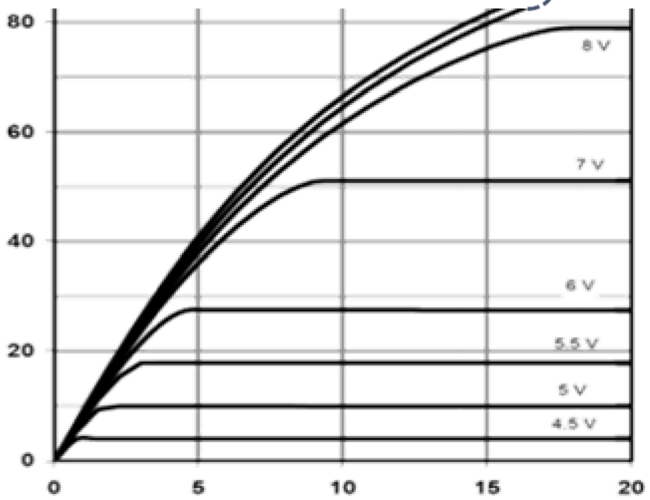


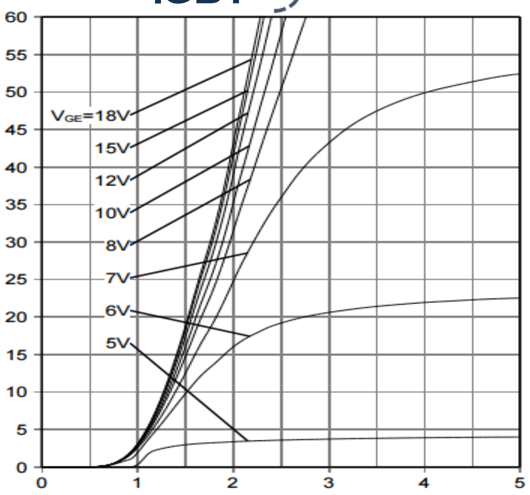
10 kW IGBT Heat Sink

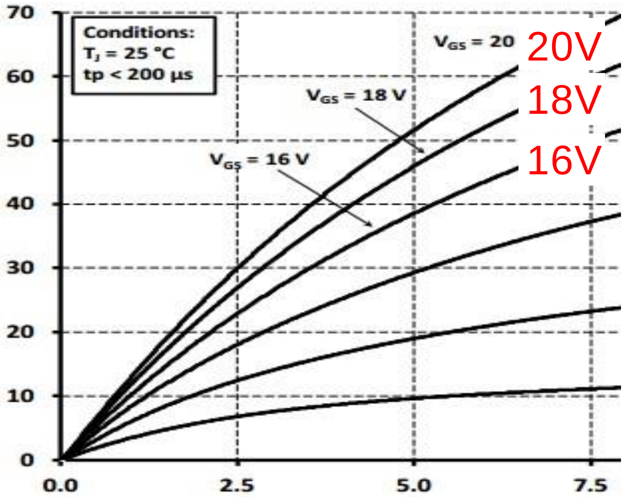
10 kW SiC Heat Sink

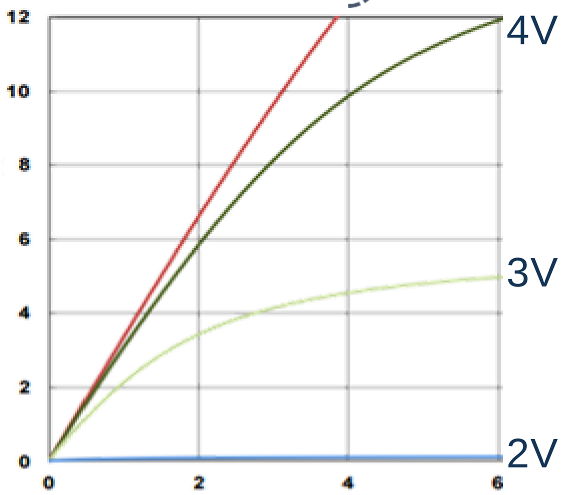
State-of-the-art Power Semiconductors (Wide Band Gap)

	Si-MOSFET	IGBT	SiC-MOSFET	GaN (Nom-ON)	GaN (Nom-OFF)
					
Voltage Ratings	20~650V	≥650V	≥650V	≤650V	
Optimal V_{GS} Max.Limit	0~15V (±20V)	-10~15V (-10~20V)	-5~20V (-5~25V)	-5~10V (±18V)	-4~6V (-10~7V)









- I-V curves are from datasheets of Infineon, CREE, EPC

Value of Silicon carbide in high voltage & high power applications

- ✓ High power density – 10x more than Silicon
  - ✓ High current density
- ✓ High breakdown voltage
- ✓ Drive higher current in a reduced footprint
- ✓ High thermal conductivity
- ✓ High mobility – ability to switch at high frequencies

Trending towards integration: Isolated gate driver

PCB Area Reduction – 76%

TYPE A

		W (mm)	L (mm)	H (mm)	Area (mm^2)	Vol (mm^3)
Type A	FAN3224/NCP81071	5	6.2	1.75	31	54.25
	GA3550-BL	17.4	24.13	10	420	4200
				SUM	451	4254

TYPE B

Type B	ISO7520C	10.5	10.6	2.65	111.3	295
	UCC27714	8.75	6.2	1.75	54.25	95
	MURS360	8.1	6.1	2.4	49.41	119
				SUM	215	509

TYPE C: ISO Driver

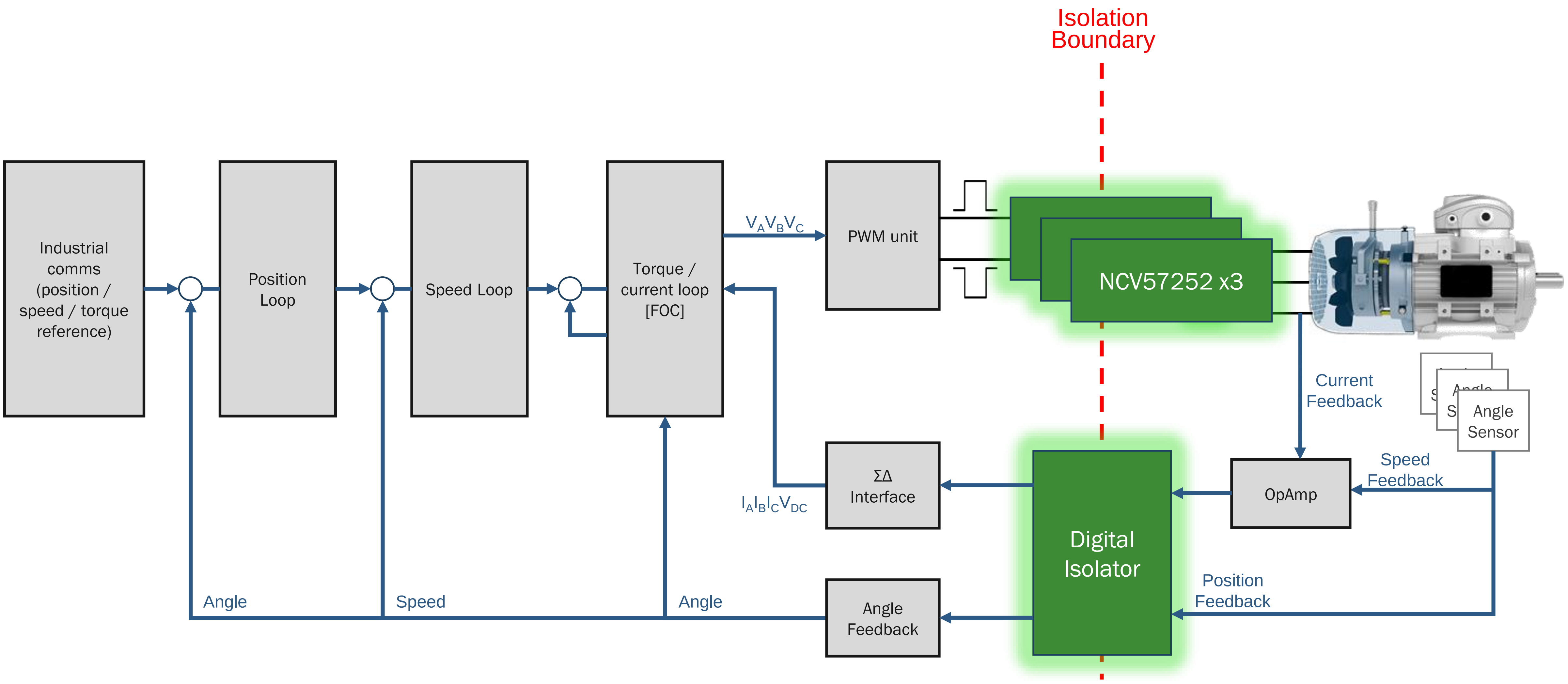
(NCD57252 & NCP51561)

- ✓ CMTI>100V/ns
- ✓ 5kVrms reinforced isolation
- ✓ T_{Prop}: 35ns Typ.
- ✓ Match./$_{TPWD}$ < 5ns
- ✓ 110mm^2

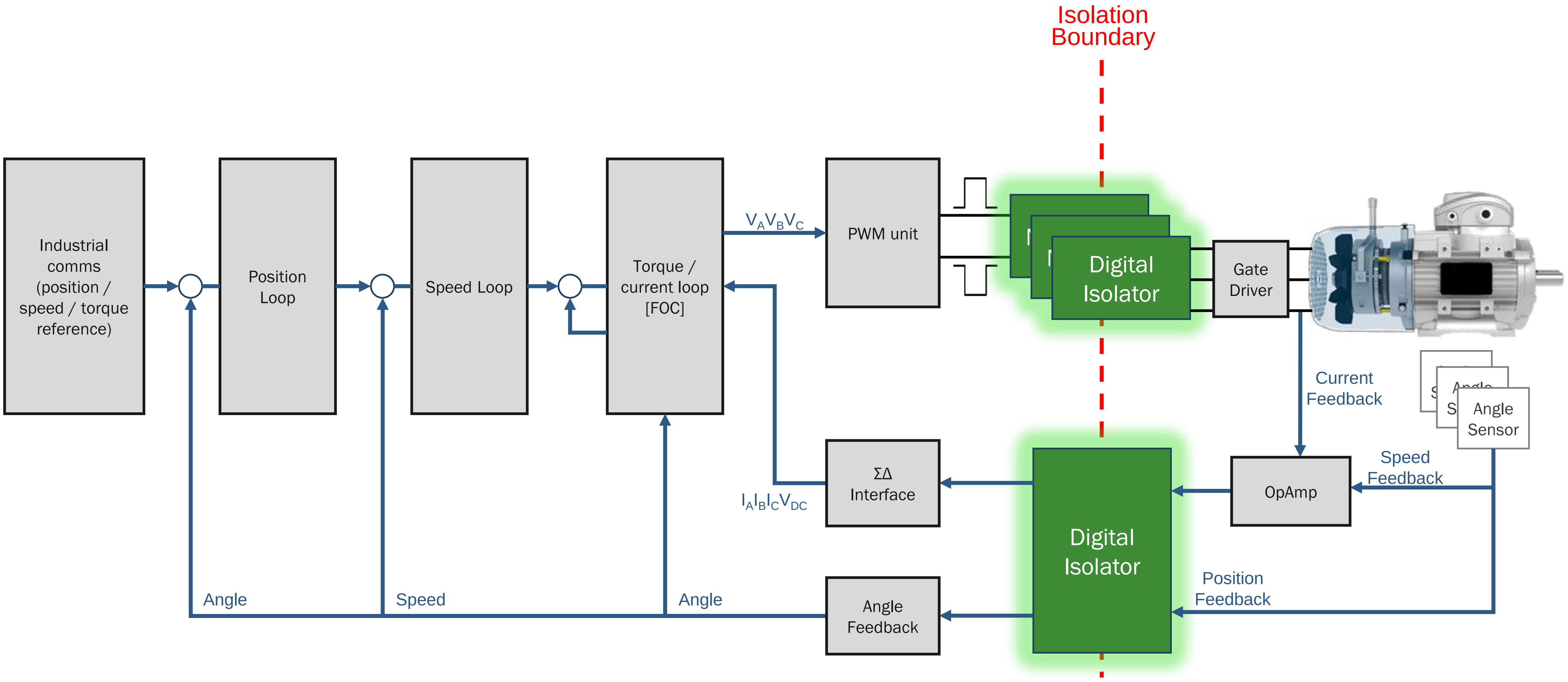
Gate Driver Key attributes

Negative Input/Output Voltage Capability	Negative Voltage result from parasitic inductances caused by switching transitions, leakage or even layout issues. Gate Driver ability to survive NEG Voltage is critical for robust, reliable solution. High Immunity to GND noise
Propagation Delay	Supports higher Frequencies, reduction in reverse recovery losses. FET needs quicker switching than IGBT and Fast Prop-Delay enables that, minimizing conduction losses in process
Delay Matching	IF FET's used in parallel then it will support Drive with MIN delay differences. Reduces issues with paralleling FET's and easily doubles Current drive output for large FET's
Wide VDD Range	Capability of using the same Gate Driver when diff Voltages are present as well as diff Power Switches (MOSFET/IGBT). Also great in low- quality PS environment. Also support Split Rail system where POS and NEG voltage present; IGBT /SiC FET's
Operating Temp Range	Very consistent performance and robustness under Extreme Temp conditions (-40 Deg C – 125 Deg C)

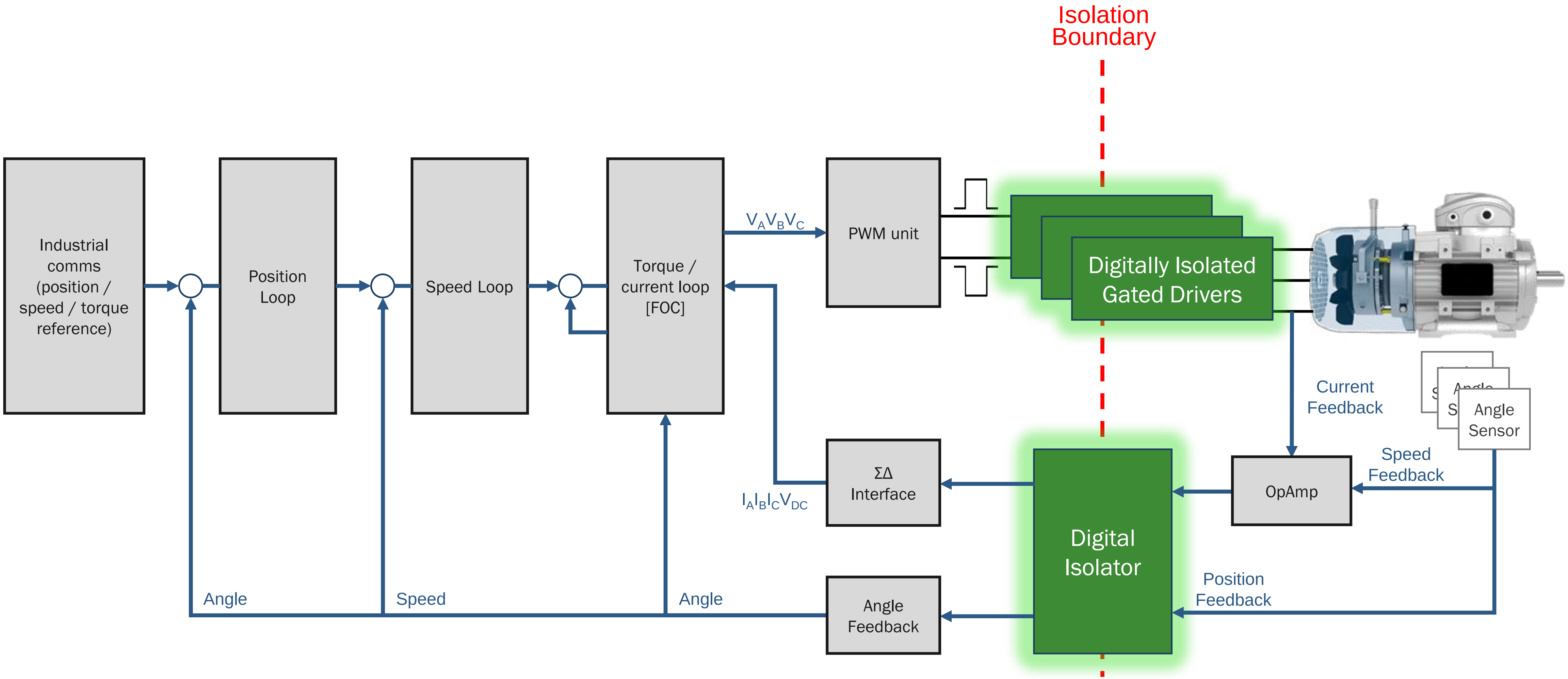
3-Phase Motor Control (Industrial Robotics / Etc...)



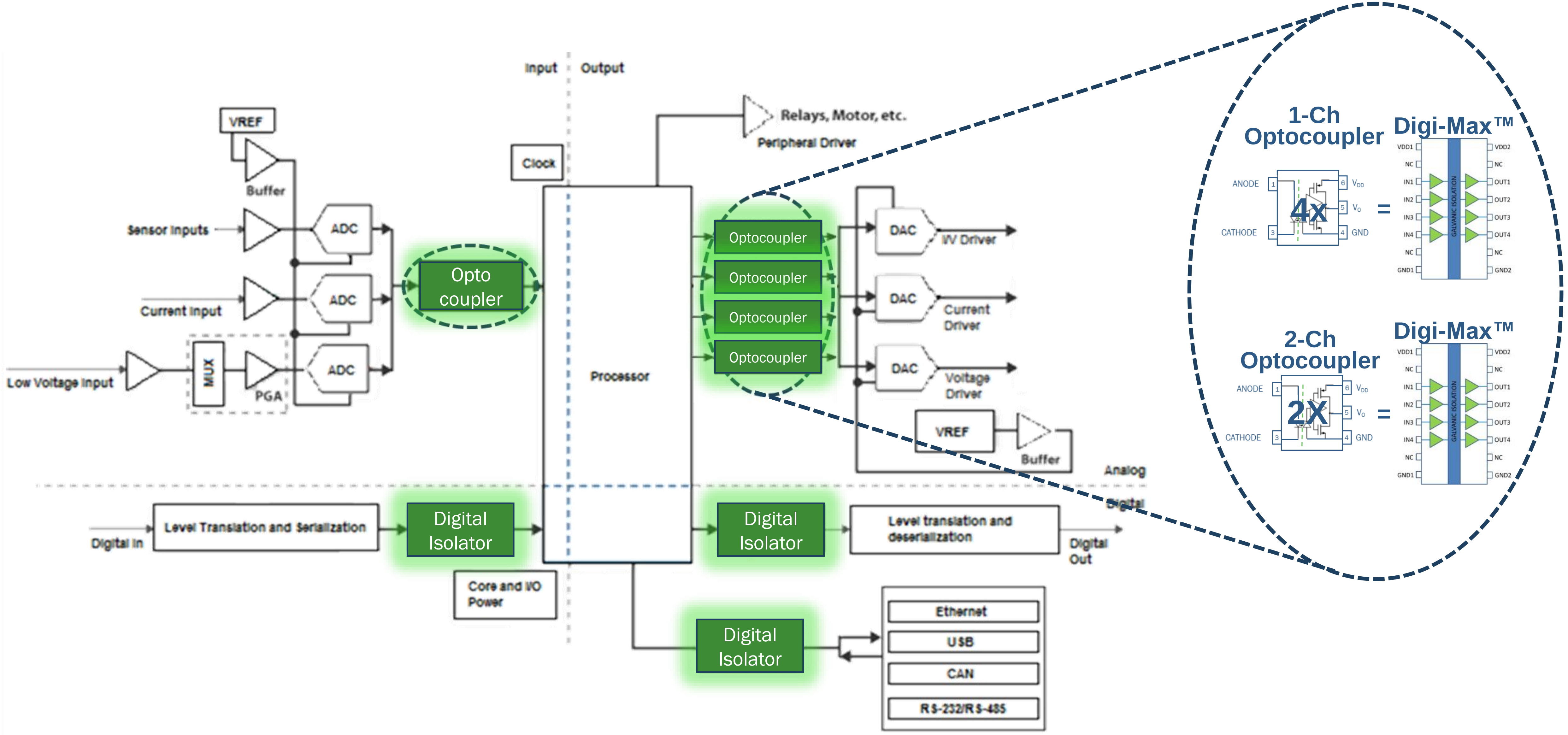
3-Phase Motor Control (Auto / Industrial Robotics / Etc…)



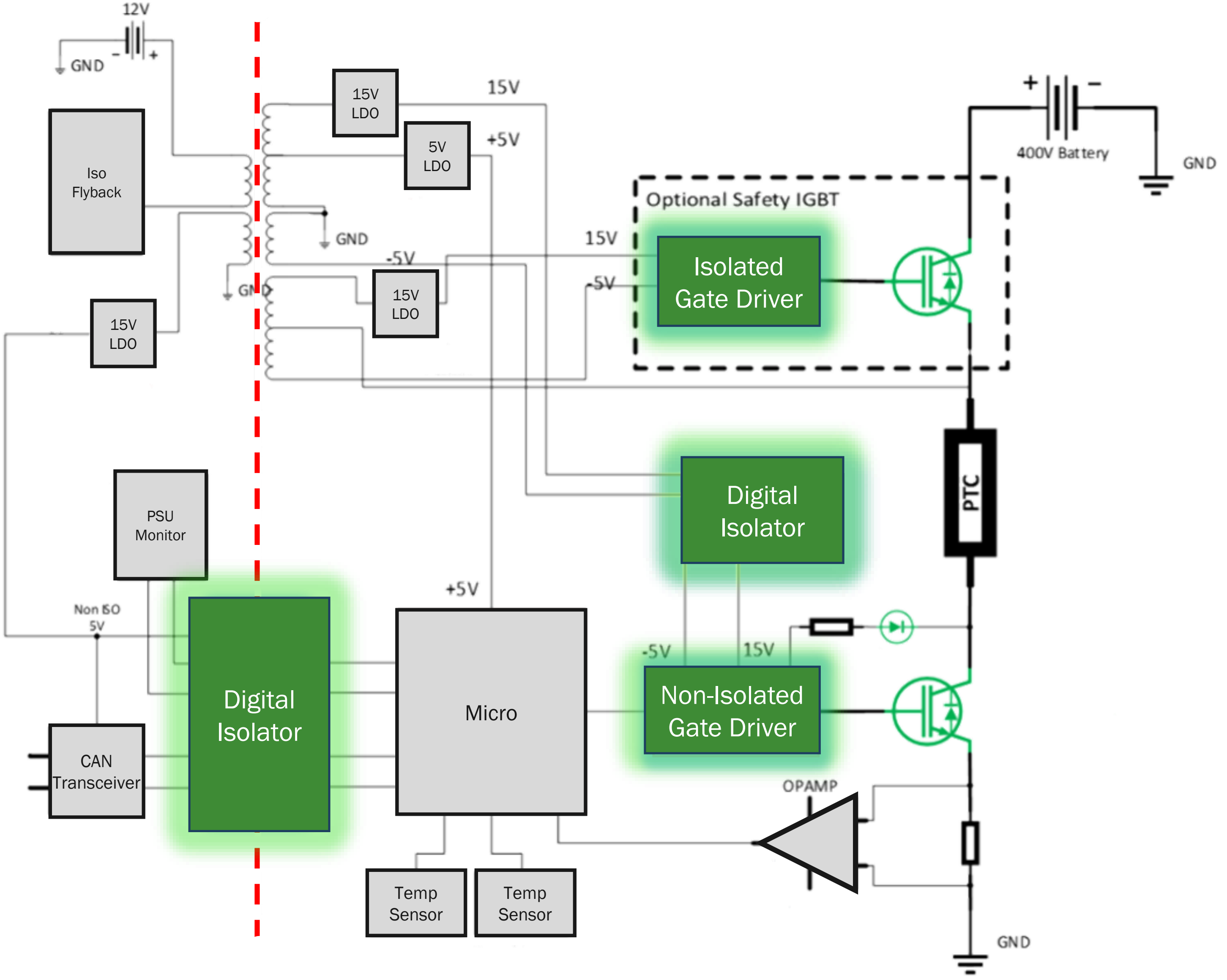
3-Phase Motor Control (Auto / Industrial Robotics / Etc...)

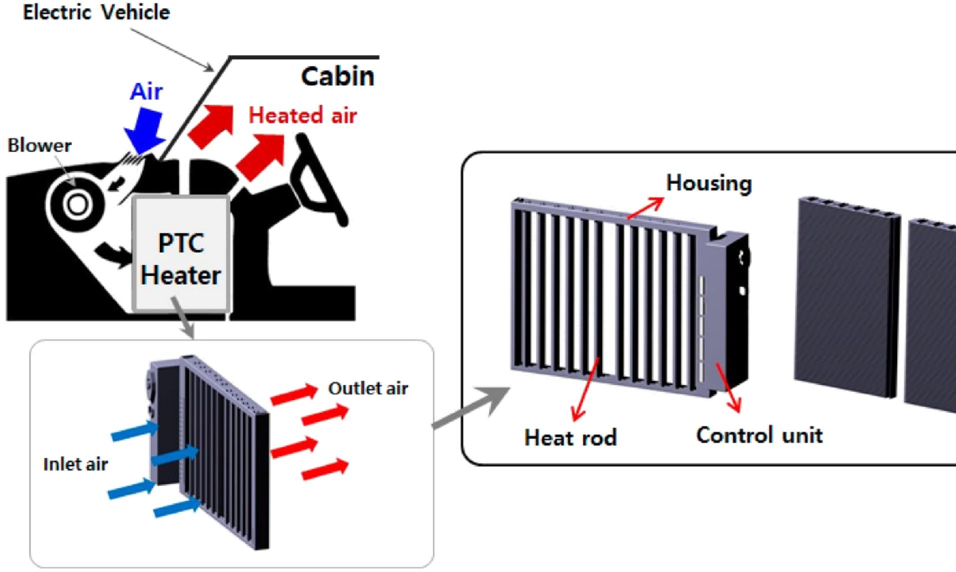


Network Communications

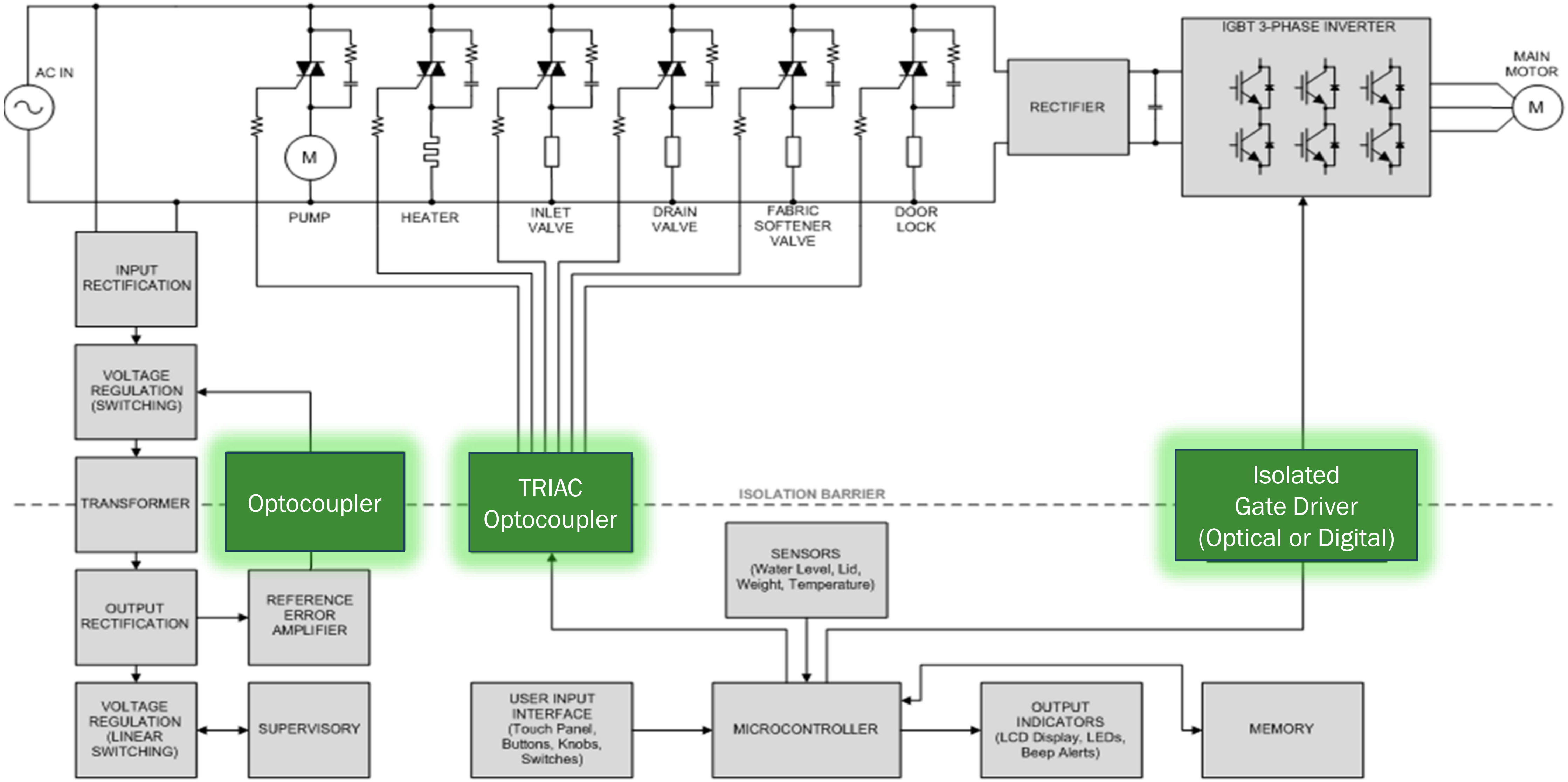


Automotive Electrification – PTC Heaters

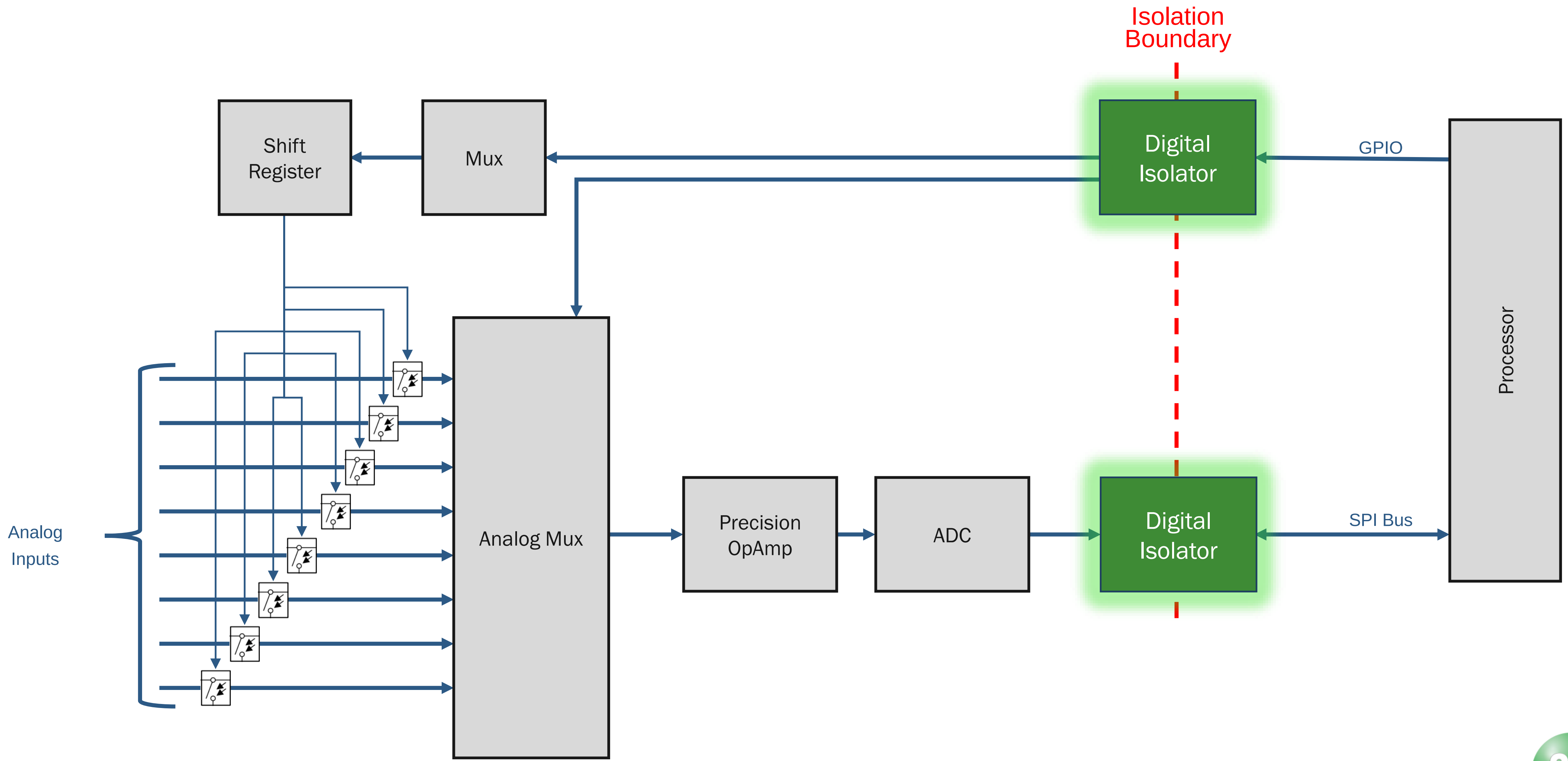




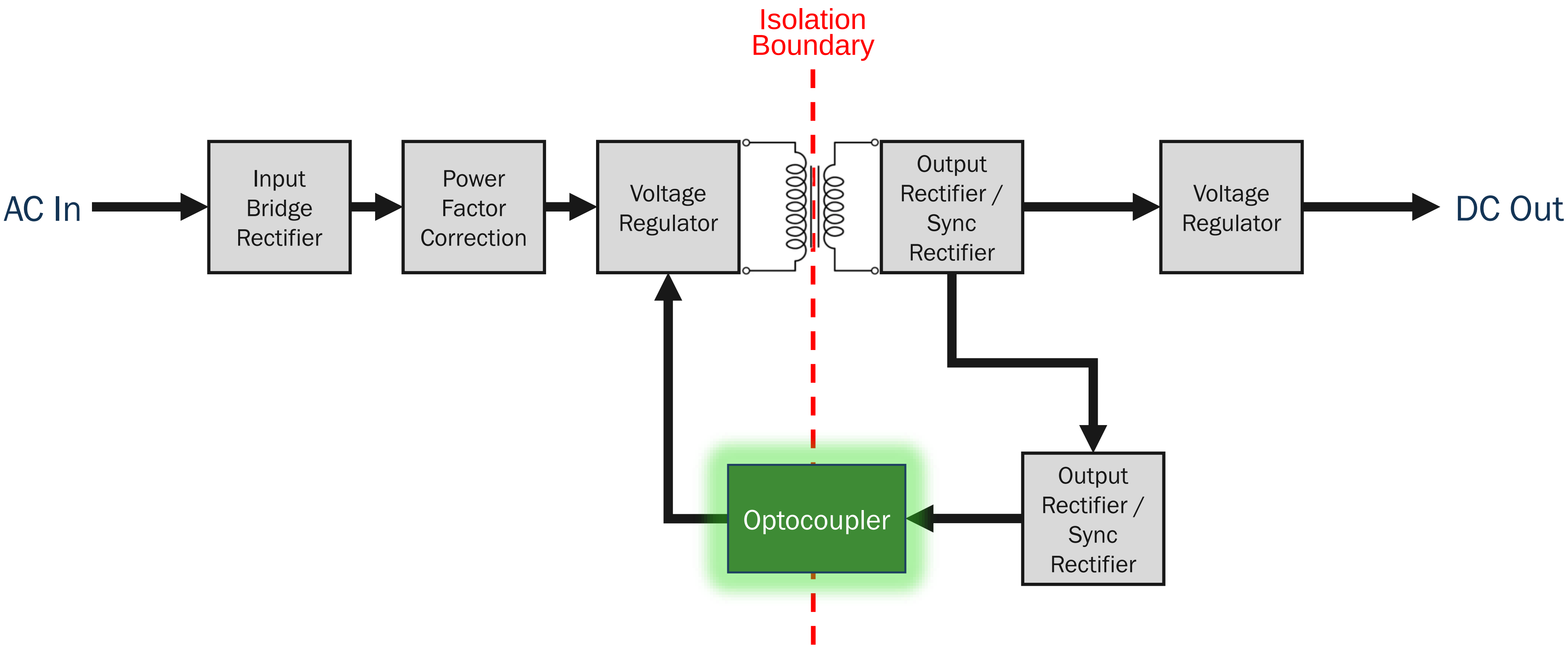
Industrial Washing Machine



Analog Input Modules



Power Supply



Thank you very much for your attention