Integrated Power Management for Automotive Solid State Relay

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Agenda

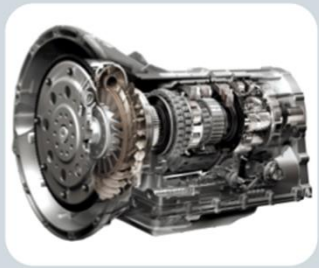
- Intro
- Electro-Mechanical Relay and its limitations in Automotive
- Solid State Relay Application scenarios in Electric Vehicles
- Solid State Relay
  - Technical approach
  - Technological options
- Solid State Relay comparison summary

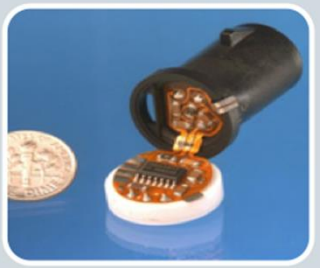
Transportation market

- Highest momentum trends
  - Autonomous operation
  - Electrification
- Impact
  - Personal transportation vehicles
  - Commercial transportation vehicles
  - Road Infrastructure
  - Fuel Infrastructure

Source: Siemens @ Sweden

Relays within HEV/EV & Powertrain





Engine Management

- Gasoline & Diesel Engine ECU
- Engine Actuators

Transmission

- Manual, Automatic, and Shift-by-Wire Transmission
- Transmission Actuators

HEV/EV

- Battery Management
- On-board Charger
- Inverter
- DC/DC Converter
- Regenerative Braking

Powertrain Sensors

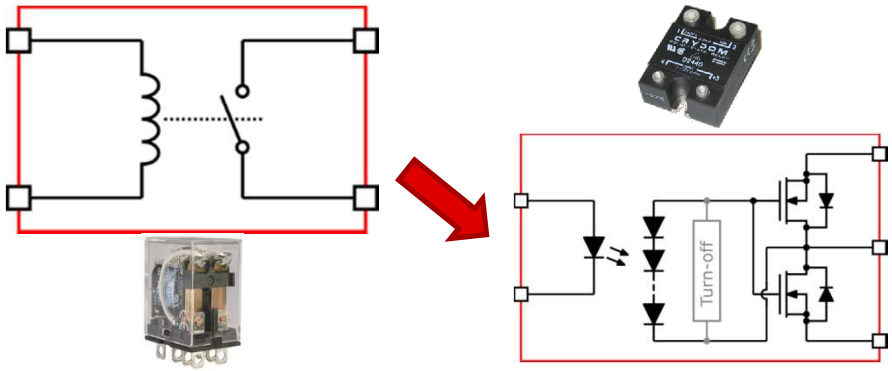
- Engine Management
- Transmission
- Electric Power Steering (EPS)
- HEV/EV

Power Steering

- Electric Power Steering
- Hydraulic Power Steering
- Steer-by-Wire

Relays and their limitations in Automotive

- Existing challenges
  - High vibration
  - Dusty and humid environment
  - Bulky device
- New challenges
  - Very large number of switching operations (e.g. monitoring)
  - Fast response required (e.g. turn-on)
  - Lower car acoustic noise
- New opportunity: **Solid State Relay**



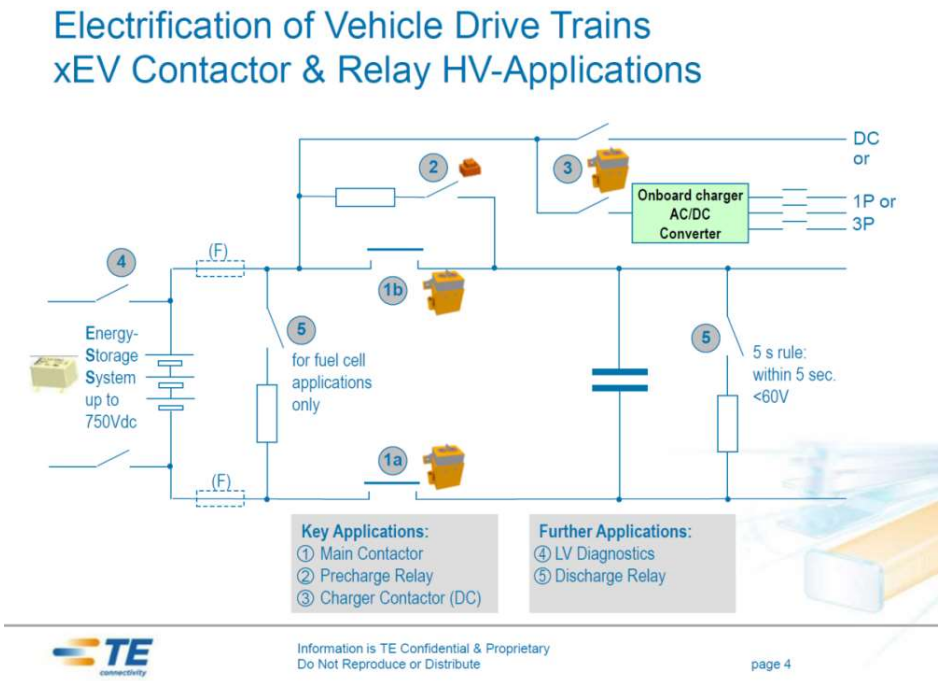
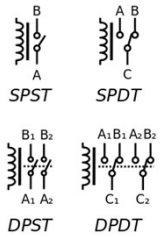
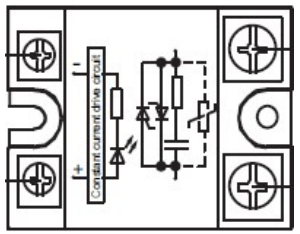


Image source: TE Connectivity

Benefits comparison





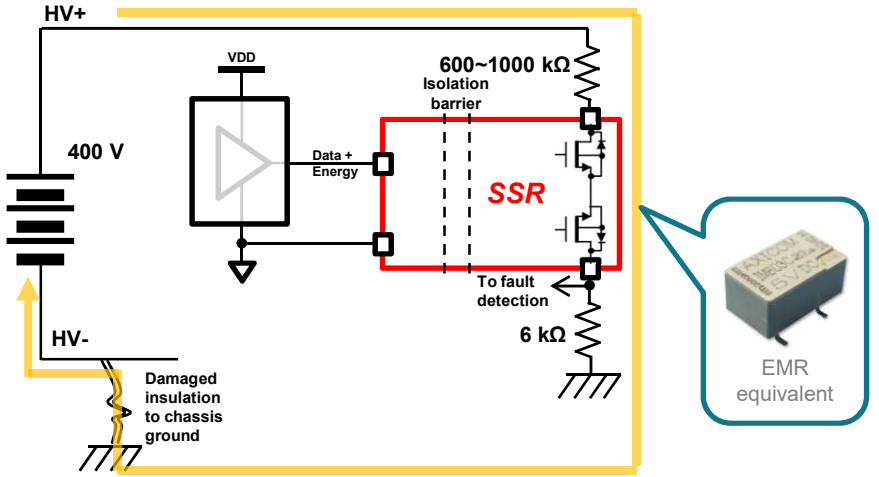
- **Low cost**
- Low contact resistance
- No off-state leakage (i.e. higher off resistance)
- Multiple contacts
- Can equivalently block AC or DC
- No heat sink required
- Tendency to fail “open”

- **Long life (>10^9 operations)**
- **No degradation of contact resistance**
- Fast switching (µs range)
- Slim profile
- More flexible input interface
- No contact bouncing
- Easier load synchronization (ZVS/ZCS)
- No acoustical noise

AUTOMOTIVE APPLICATION SCENARIOS

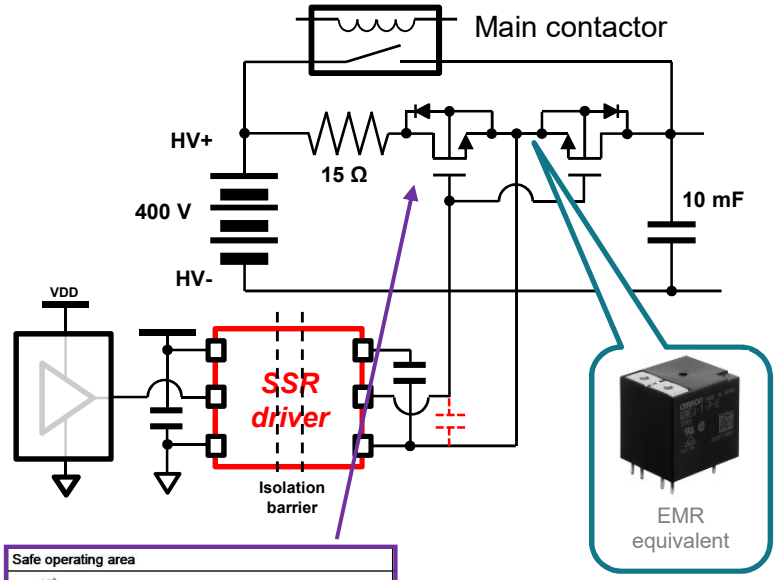
Isolation monitoring

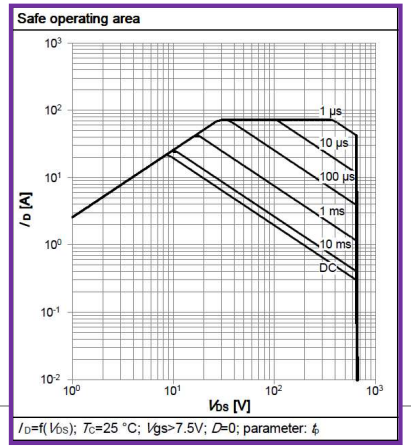
- **Need**: verify the health of the isolation between the HV battery and the chassis ground
  - This structure can be replicated multiple times in the car, need at least 2x (HV+ and HV-)
  - Need to operate reliably for a very large number of cycles, both when car is on and off
- Solid State switches can be rated for very small currents (mA range, small Q_g)
  - Opportunity for single package integration
  - Limited input energy requirements
- Hi-pot testing between HV and chassis ground requires SSR FETs to be avalanche rugged



Pre-charge

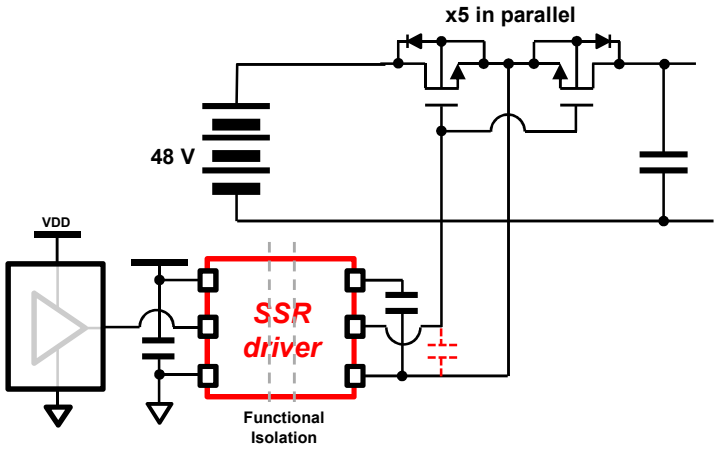
- **Need**: pre-change the dc-link capacitor avoiding extremely large inrush currents
  - Normal operation main contactor has extremely low on-resistance being rated for 250A or more
  - Appeal of SMD components
- No need for very low on-resistance due to current limiting resistor in series
  - Allows to use cost-effective FETs or other solid state devices
  - Still requires >600Vds, >20A devices (large Q_g)
- Need for high current Solid State switches gate driver, in order to avoid reliability issues

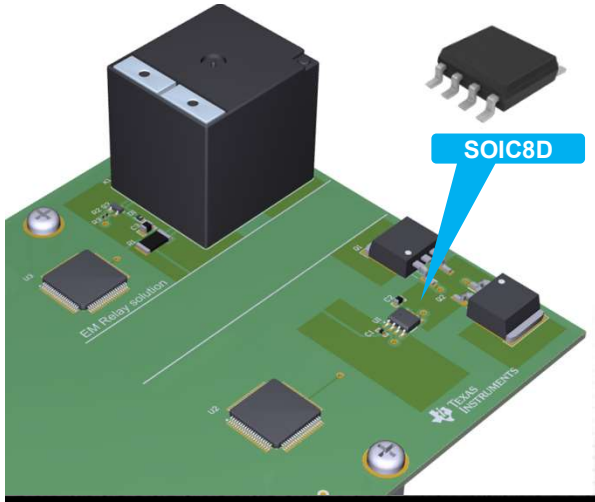


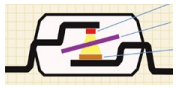
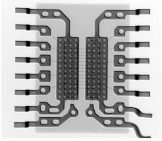
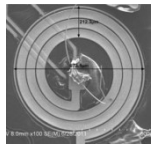


48V battery disconnect

- **Need**: compact and cost-effective solution to implement the main switch for the 48V battery
- No need for safety isolation
- Requires very large output current, could use multiple FETs in parallel (very large overall Q_g)
- Need for high current Solid State switches gate driver, in order to avoid reliability issues



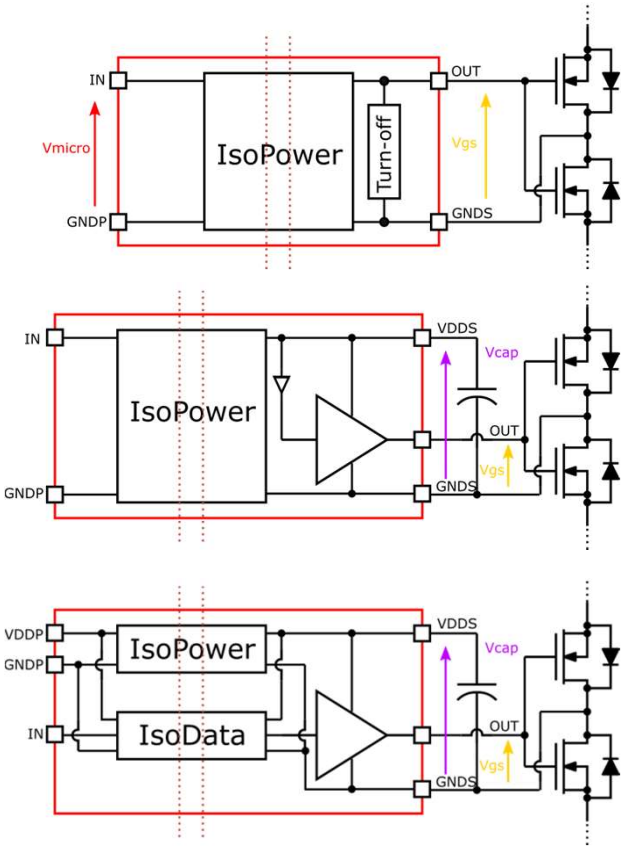


Discrete Xfmr	Opto	Silicon Caps	Integrated Xfmr
			
High Power High efficiency Large size	High Energy/bit Low data rate	Very Low Power Very Low efficiency Small size	Low Power Low efficiency Small size

INTEGRATED POWER MANAGEMENT FOR SOLID STATE RELAY
- TECHNICAL APPROACH
- TECHNOLOGIES COMPARISON

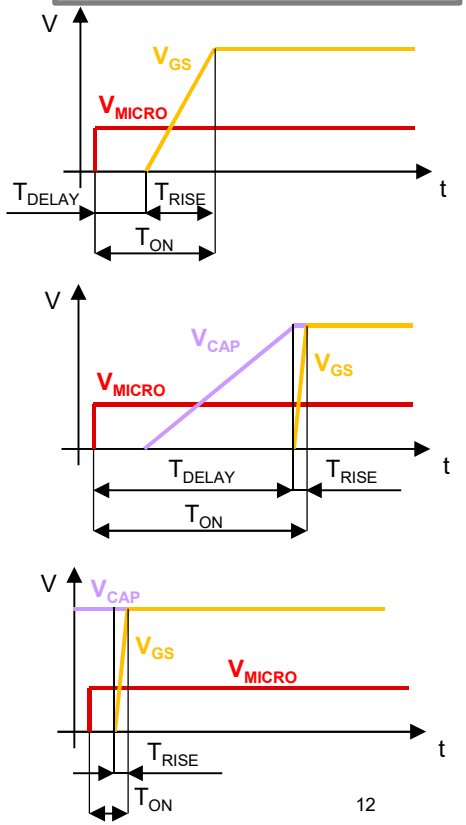
Technical approach

- **Isolated Power only, Direct Drive**
  - Need a stable output voltage source (**~10V**)
  - Direct coupling to load FETs gate
  - Not controlled and Long turn-on time (T_{RISE})
  - Power requirements dictated by T_{RISE}:
    - For 2x40nC in 10us → **80mW**
    - For 2x2nC in 1ms → **4uW**
  - Short total T_{ON} (minimum total capacitance)
  - No external cap required
- **Isolated Power, Gate Driver**
  - One external cap required (~ 5 x C_{iss})
  - Longer total T_{ON} (more total capacitance)
  - Controlled and Shorter turn-on time (T_{RISE})
- **Isolated Power and Data, Gate Driver**
  - Data rate is not very relevant, but acceptable propagation delay is ~ms or lower ➔ **1~10kbps**
    - Potential fit for Power Line Communication
  - Power requirements dictated by $\mathbf{Q_g x V_{drv} x F_{sw}}$
  - One time T_{DELAY} to charge V_{CAP}
  - Controlled and Shorter turn-on time (T_{RISE})
  - One external cap required (~ 5 x C_{iss})



Switch Q_g depends on voltage and current rating:

- 40nC for 600V / 25A
- 5nC for 100V / 15A
- 2nC for 800V / 0.2A



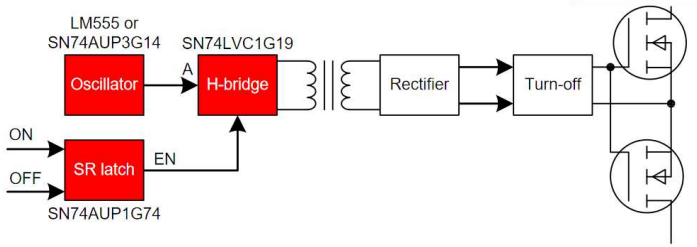
Discrete solution

- Either
  - application-specific circuits
  - packaged in industry standard EMR cases
- Mostly used for high current and voltage applications
- Application specific discrete solutions are **complex** to design
- Safety Isolation transformers are **large and bulky**
- Safety Isolation transformers are **expensive**
- Easy to achieve large output currents
  - Can achieve **small propagation delay**
  - Can drive large Q_g devices
- Easy to achieve good power transfer efficiency, hence **small input currents**

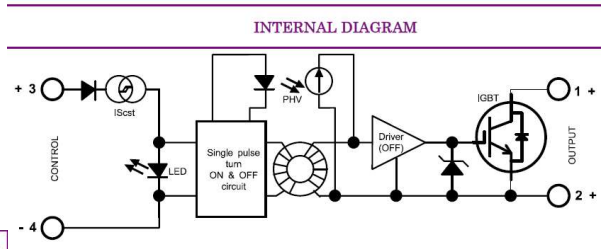
TIDA-00751

CSD19537Q3

Power MOSFETs



Control voltage range	4.5-32VDC
Max transient peak voltage	600V
Advised max. DC Mains peak voltage	(Depends on protection clamping voltage)
Max. Load Current (with heatsink)	100ADC

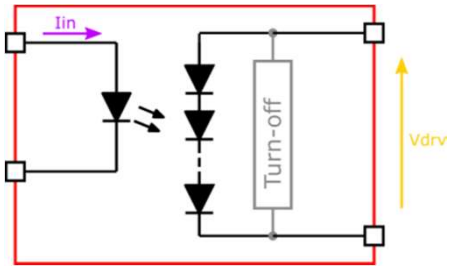


Standard EMR case

Diagram source: Celduc Solid State Relay - http://www.celduc-relais.com/wp-content/PDF/SCI0100600UK.pdf

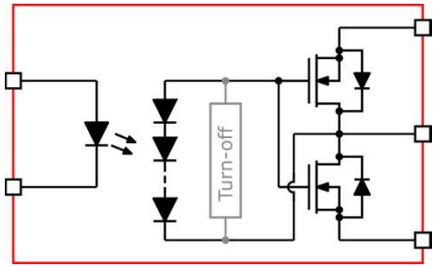
Opto based

- SSR driver solutions are typically referred to as **Photovoltaic opto-coupler**
  - **Widely available** on the market
  - Traditionally very **cost-effective** isolation solutions
  - Can optionally include integrated FET
- No need for light modulation implies **no high frequency switching noise**
- Output voltage has **wide variations** with input current and operating temperature (open loop)
- **Output power** is typically very limited (**10~100uW**)
- **Input current** is typically quite large (few mA) due to very low power transfer efficiency (**<<1%**)
- Maximum temperature rating in most of the cases is **<85~105°C**
- Some **automotive** manufacturers have reliability concerns on adopting opto-based solutions
- Some opto based SSR solutions focus on data-transfer only (on/off), assuming that gate driver supply power can be **stolen/harvested/supplied** from the load



Turn off circuit could be passive (i.e. simple discharge resistor) or active

Most often follow the **Isolated Power, Direct Drive** approach



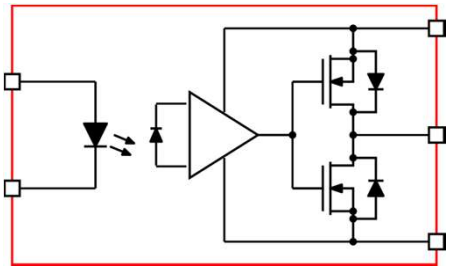
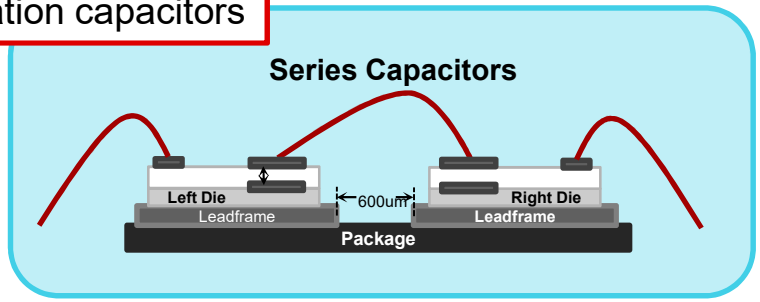


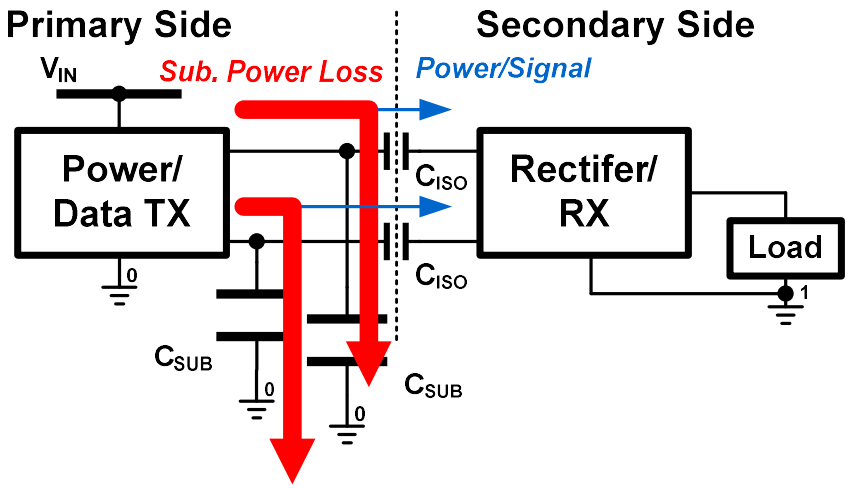
Diagram source: Toshiba

Capacitive based

- Output power is proportional to the capacitance across the barrier, so this methodology is typically preferred and **cost-effective** for low output power (**0.1~1mW** range)
- **125°C temperature range** and **automotive grade** devices are widely available
- Given limited output power capabilities, **large propagation delay** should be expected
- Integrated isolation capacitors have large amount of capacitance towards the substrate which generates substantial power losses (**1~10%** efficiency), hence **large input current**
- Could **limit process selection** hence secondary side switch integration (other than MCM)
- Some capacitive based SSR solutions focus on data-transfer only (on/off), assuming that gate driver supply power can be **stolen/harvested** from the load

TI isolation capacitors

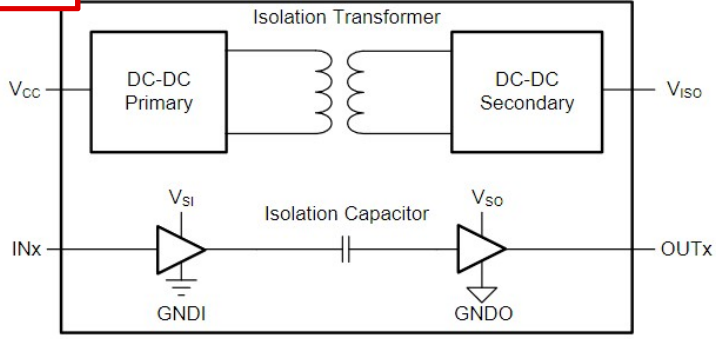




Inductive based

- No particular challenge in achieving **large output power** (**100~500mW**) for large loads with **decent efficiency** (**30~50%**)
- **125°C ambient temperature range** is feasible, but care should be given to device self-heating
- Targeting very small load FETs (0.01~0.1W) with decent efficiency requires **large inductance** transformer or **very high frequency** operation
  - VHF operation could generate **EMI/EMC** concerns
  - Large inductance could generate concerns in terms of transformer die area
  - Large inductance could generate challenges in addressing 2.5kV$_{rms}$ or lower isolation ratings with ≤4mm creepage packages
- No wide selection of **automotive grade** devices

ISOW784x



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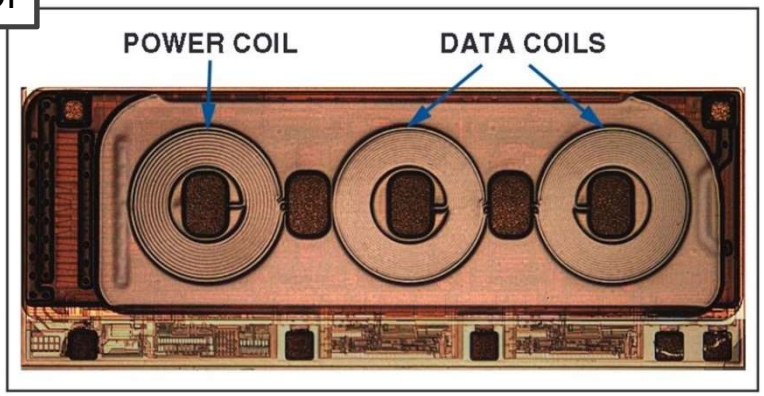

Technology Comparison Summary

Technology	Discrete components	Opto-coupler	Silicon Capacitors	Integrated Transformer
Most common approach	IsoPower only Direct or Gate driver	IsoPower only Direct Drive	IsoPower only Direct Drive	IsoPower and Data Gate Driver
Most suitable load	Large Q_g FET or IGBT 600V / 100A	Small Q_g internal or external FETs	Small Q_g (1~10nC) External FETs	Medium/Large Q_g external FETs
Cost	High (safety transformer)	Medium / Low	Medium	Medium
Market availability	Medium	Wide	Narrow	Very narrow
Automotive availability	Very narrow	Narrow	Wide	Very narrow
Operating temperature [ºC]	-40…85/100	-25…85/100	-40…125	-40…125
Propagation delay	Very small	Very large (~ms)	Large (≤ms)	Small (>us)
Input current	Small	Very large (~10mA)	Large (~1mA)	Small (<1mA)
Solution Size	 Large	 Small (thick)	 Small (thin)	 Small-Medium (thin)
Nice fit for	**48V disconnect** **HV pre-charge**	**Isolation monitoring** **HV pre-charge**	**Isolation monitoring** **HV pre-charge**	**HV pre-charge** **48V disconnect**

THANK YOU