TI *Live!* INDIA AUTOMOTIVE SEMINAR

BING LU

ISOLATED BIAS SUPPLY SOLUTIONS FOR ISOLATED GATE DRIVERS

Agenda

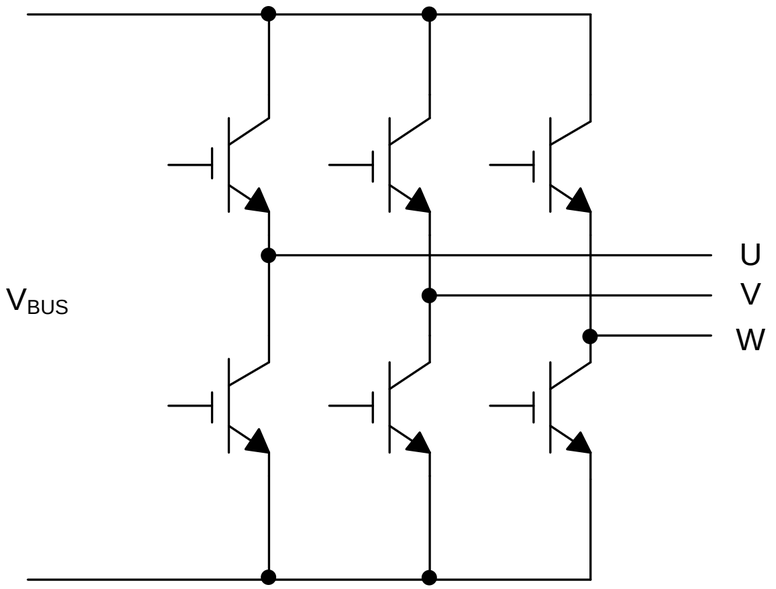
- Inverter and isolated gate driver bias supply architectures
- Different ways of creating isolated bias supply
  - Control method
  - Topology
  - Transformer
- LLC based open-loop isolated bias supply
  - Operation principles
  - Voltage regulation
- Isolated bias supply with integrated transformers
  - Power density improvement
  - Voltage regulation

Inverters in different applications

Traction inverter

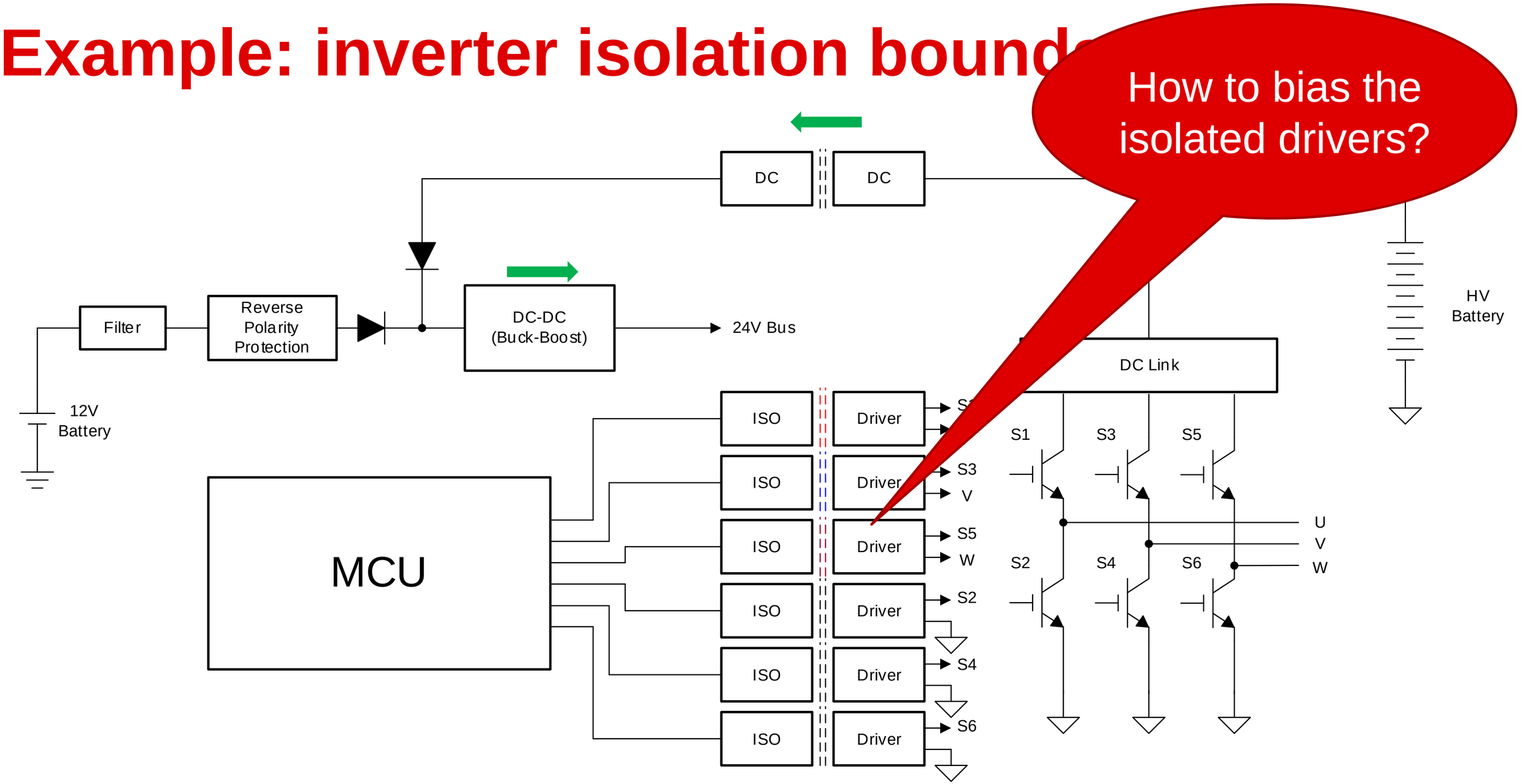
UPS

Motor drive



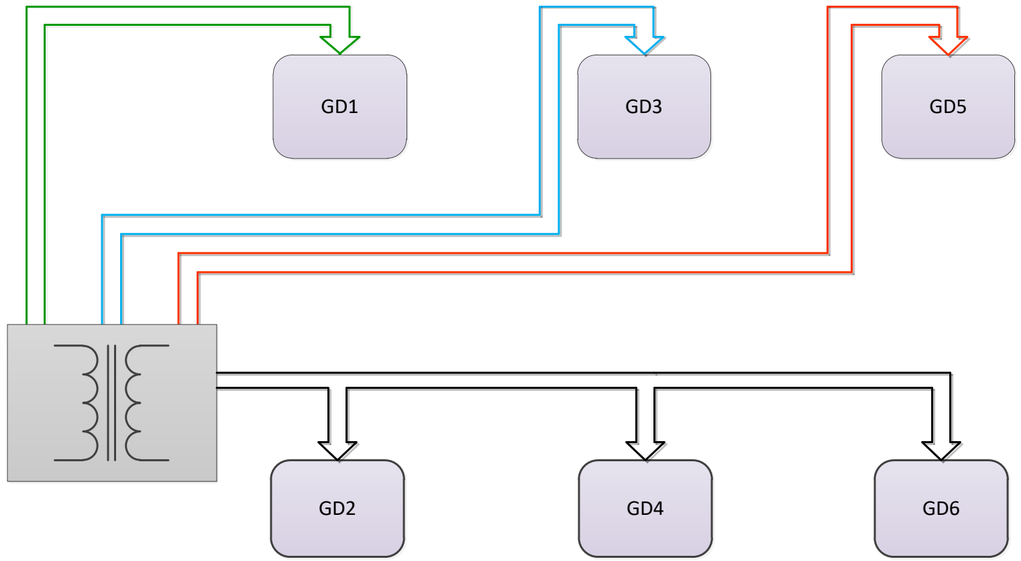
On-board charger

Example: inverter isolation bound

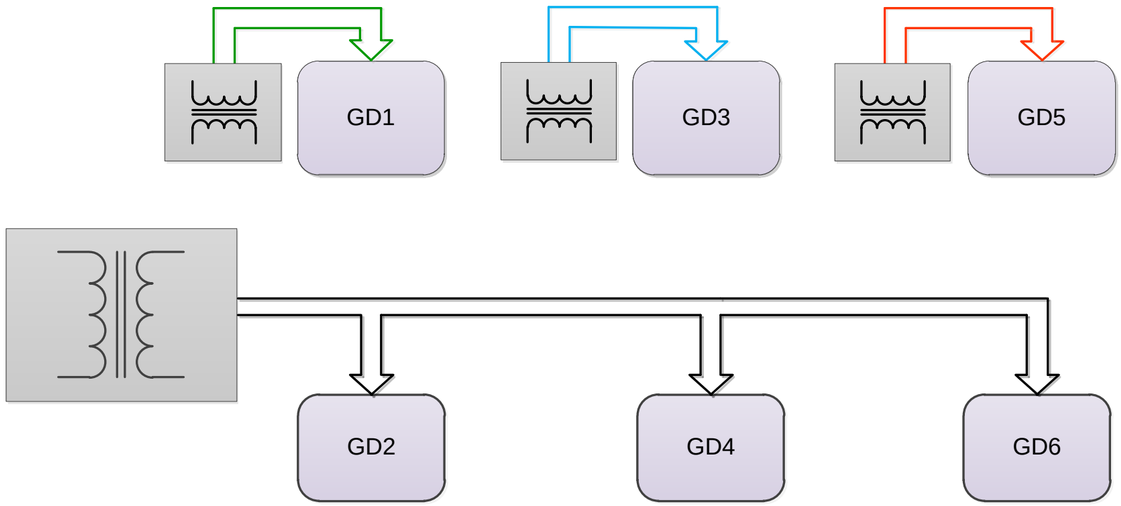


Different gate driver architectures

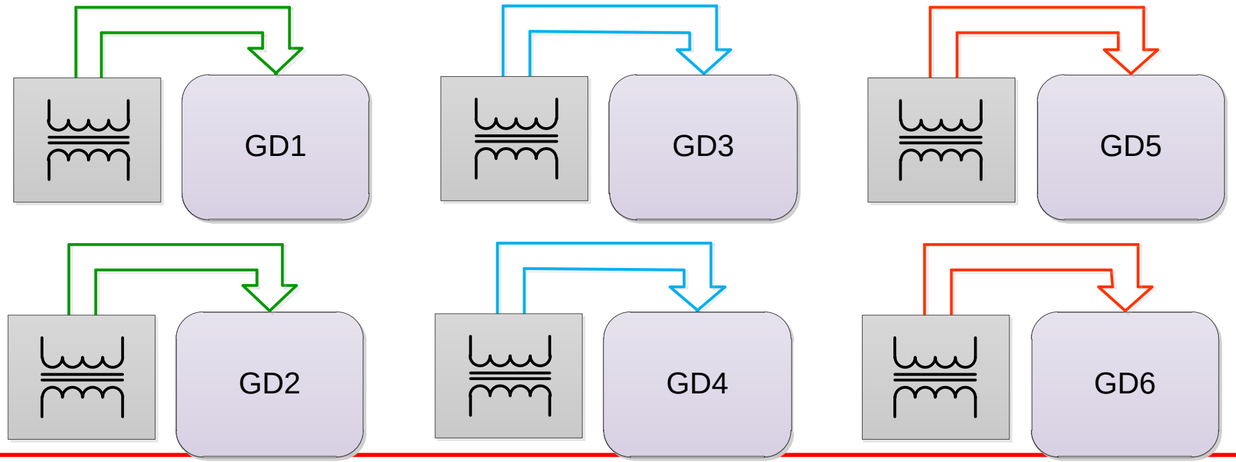
Centralized



Semi-distributed

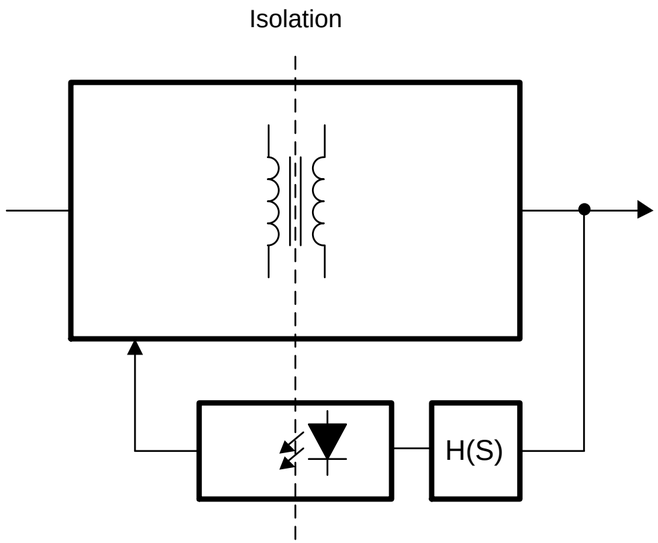


Distributed



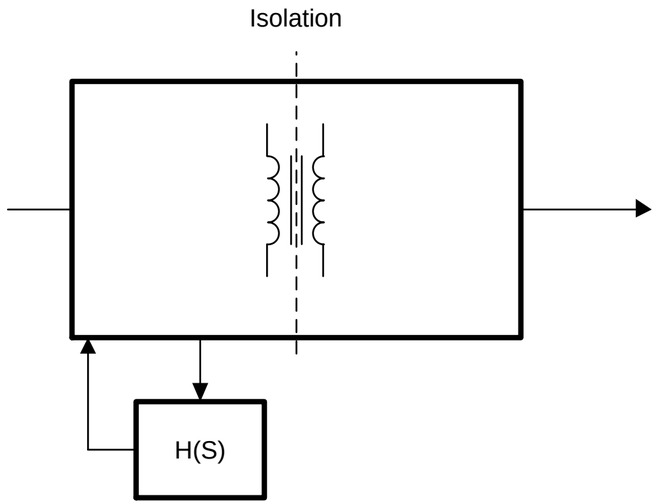
- Centralized system has lowest cost, but heavy and difficult to manage fault
- Distributed systems distribute the weight and fault, but more expensive
- Semi-distributed is somewhere in the middle

Output voltage control



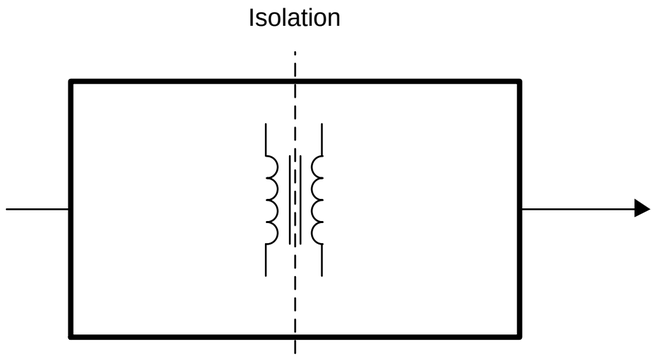
Close loop
Secondary side feedback

- Well regulated output
- No need pre-regulator
- More components
- Less reliable due to the opto coupler



Close loop
Primary side feedback

- Semi regulated output
  - Determined by cross regulation
- No need pre-regulator
- Noise sensitive due to the output voltage sampling method



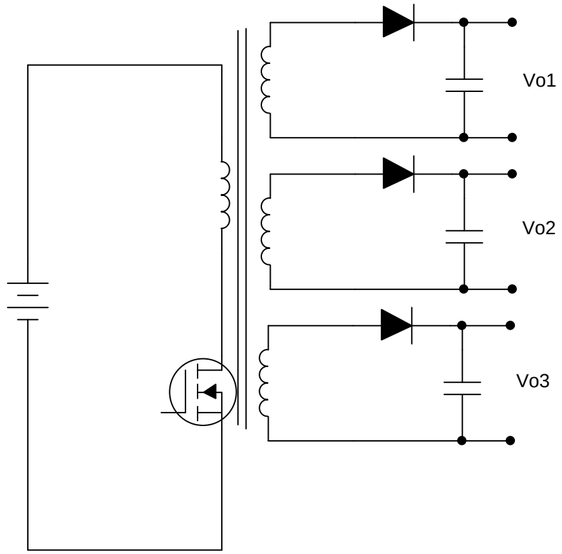
Open loop
No feedback

- No control loop, robust operation
- Less noise
  - Coupling only through the transformer
- Unregulated output, need pre-regulator

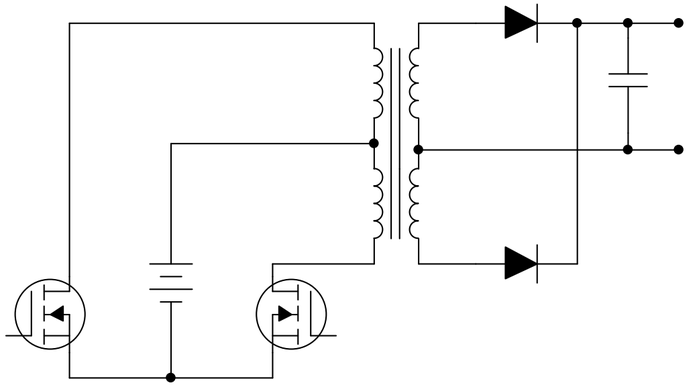
Open-loop control provides a robust solution

Topologies used for isolated bias supply

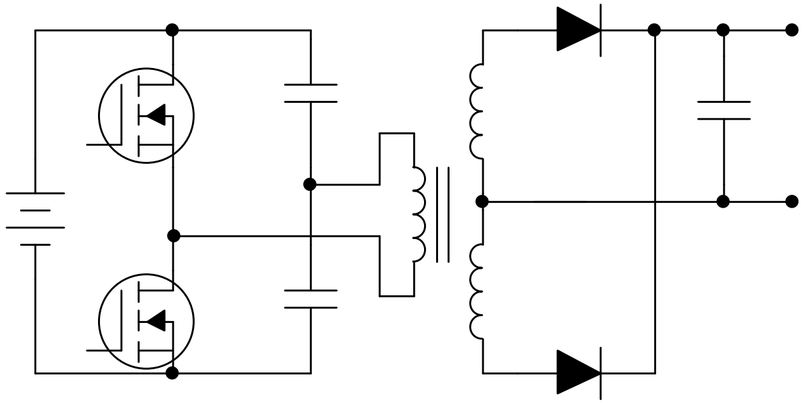
Flyback



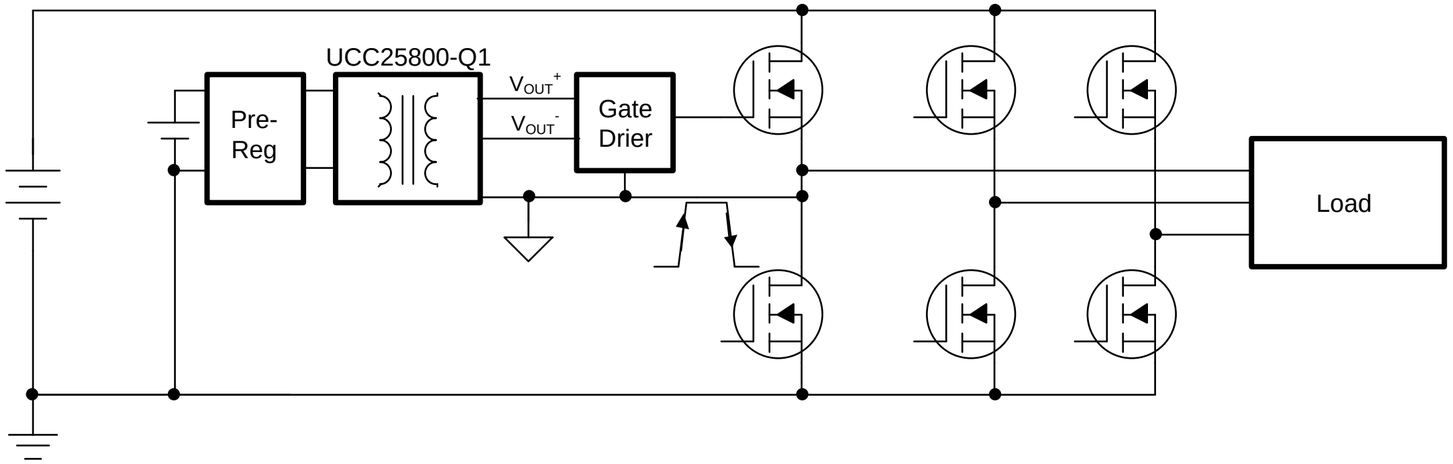
Push-pull



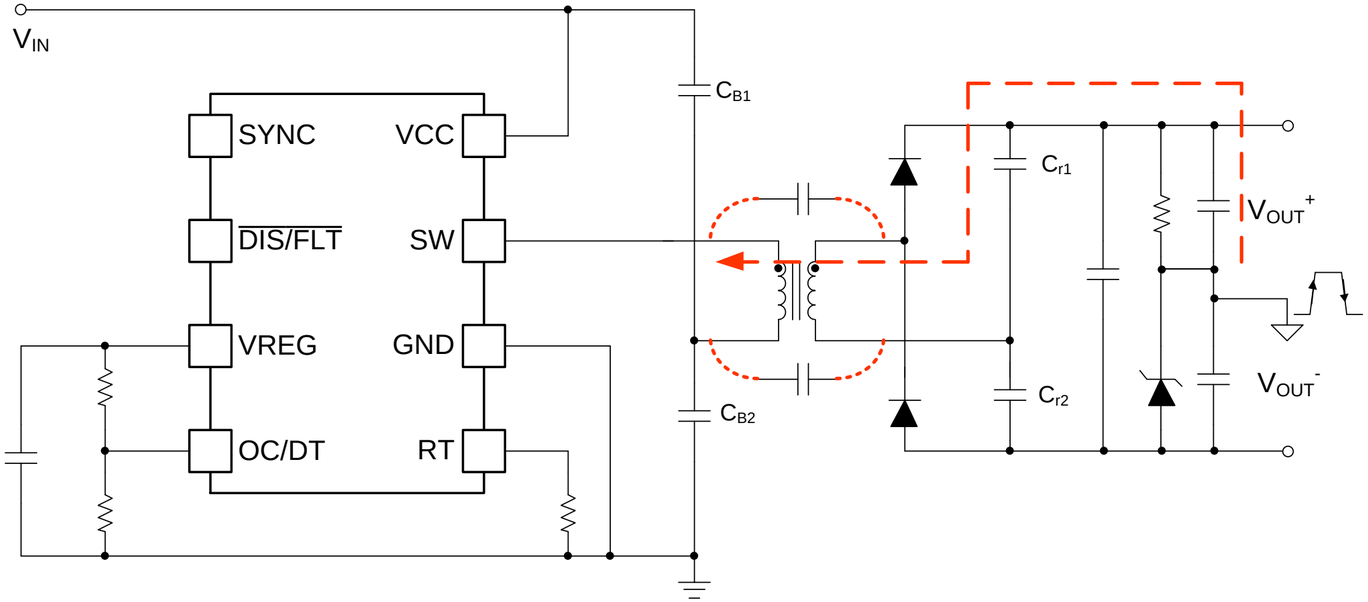
LLC



Transformer parameter impacts to system EMI

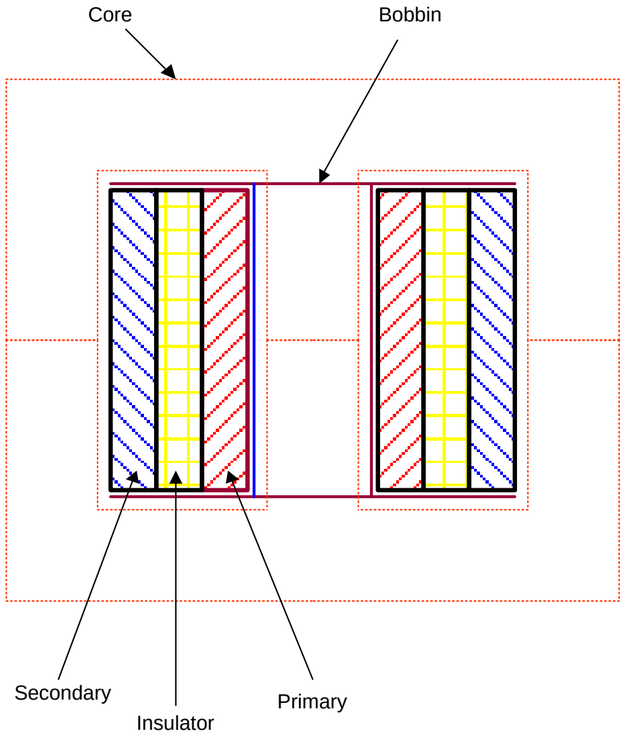


- High dv/dt couples through transformer parasitic capacitor to the primary side
- Higher EMI noise
- Extra loss
- More noise to the controller, CMTI issue
- It gets worse with SiC or GaN devices with higher dv/dt

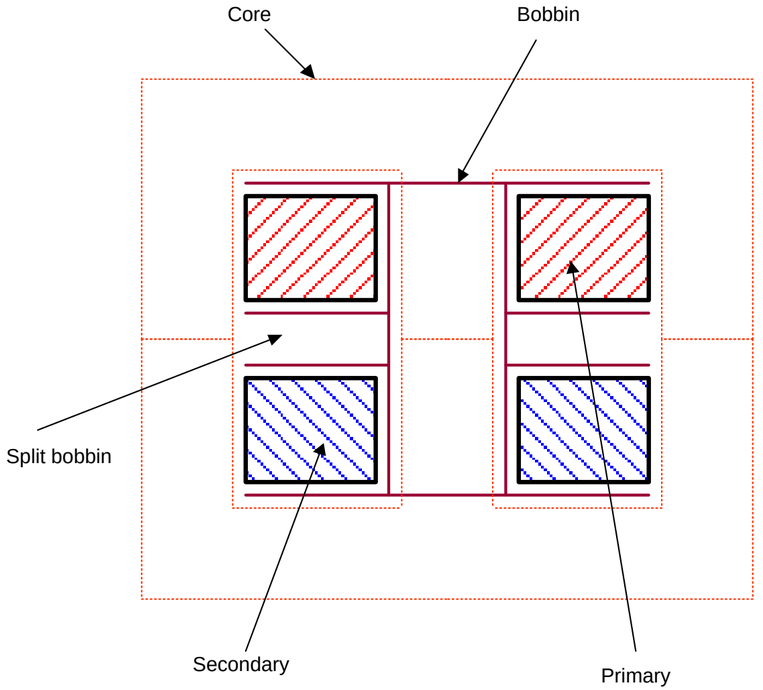


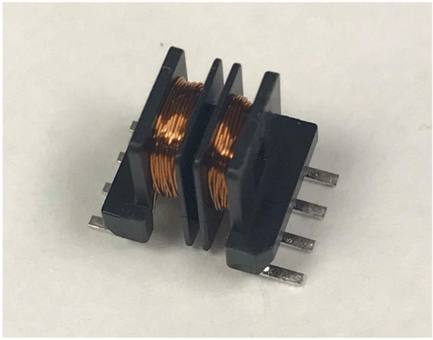
Transformer structure: less parasitic capacitance

Typical two-winding PSR Flyback transformer



Typical LLC transformer





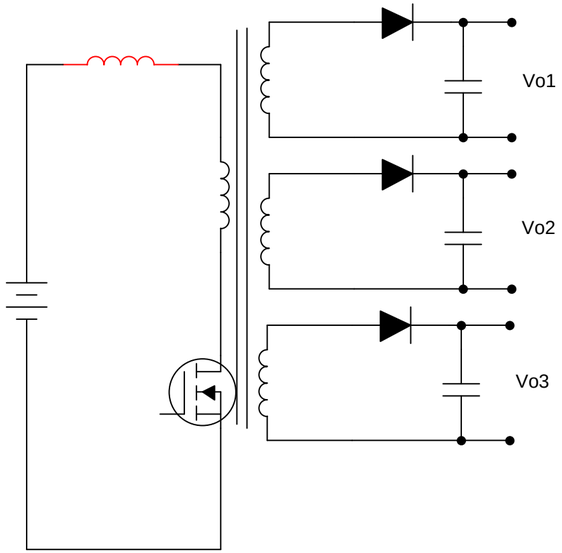
The capacitance can be reduced by increasing the insulator thickness
Less effective due to the large surface area

Split bobbin reduces the capacitance by reducing the surface area and increasing the distance
Much smaller capacitance can be achieved

Increasing the distance reduces the capacitance while increasing the leakage inductance

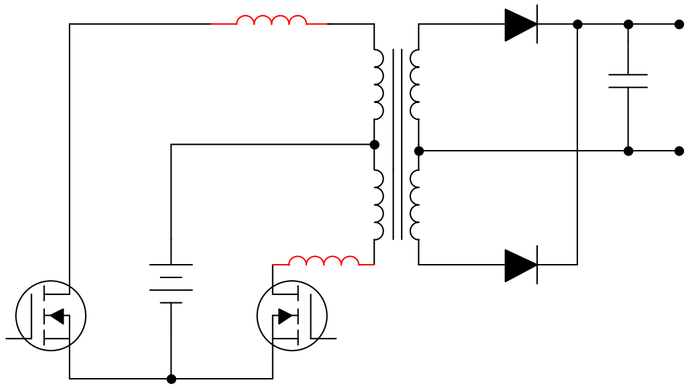
How topologies respond to leakage inductance

Flyback

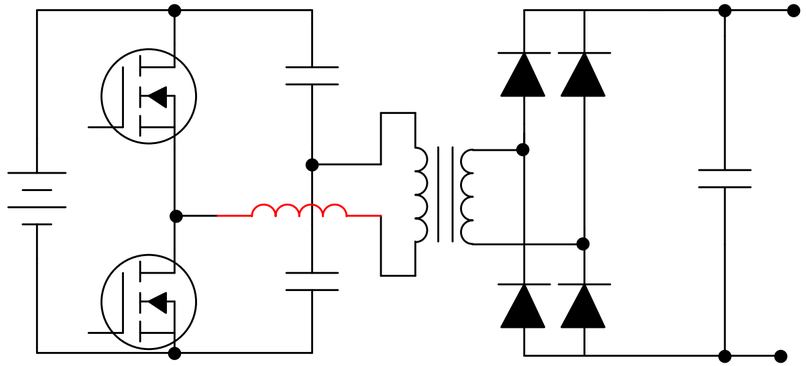


- Leakage energy can’t be transferred to secondary side
- Leakage causes
  - More EMI noise due to ringing
  - More loss
  - More device stress
- **Leakage needs to be minimized**

Push-pull

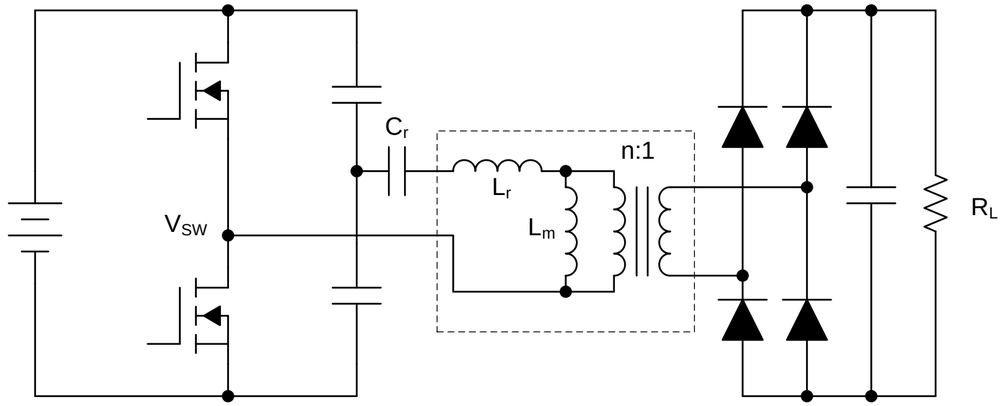


LLC



- Leakage is part of resonant circuit
- Leakage energy is fully recovered
- No extra ringing caused by the leakage
- **No limitations on the leakage inductance**

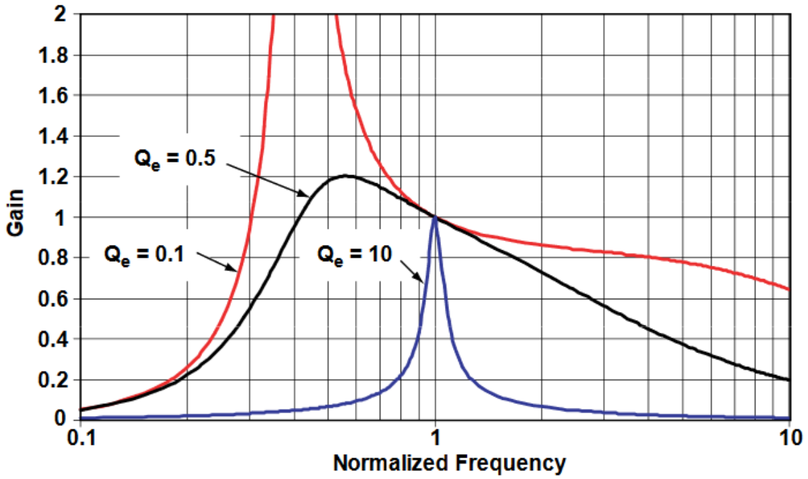
LLC converter

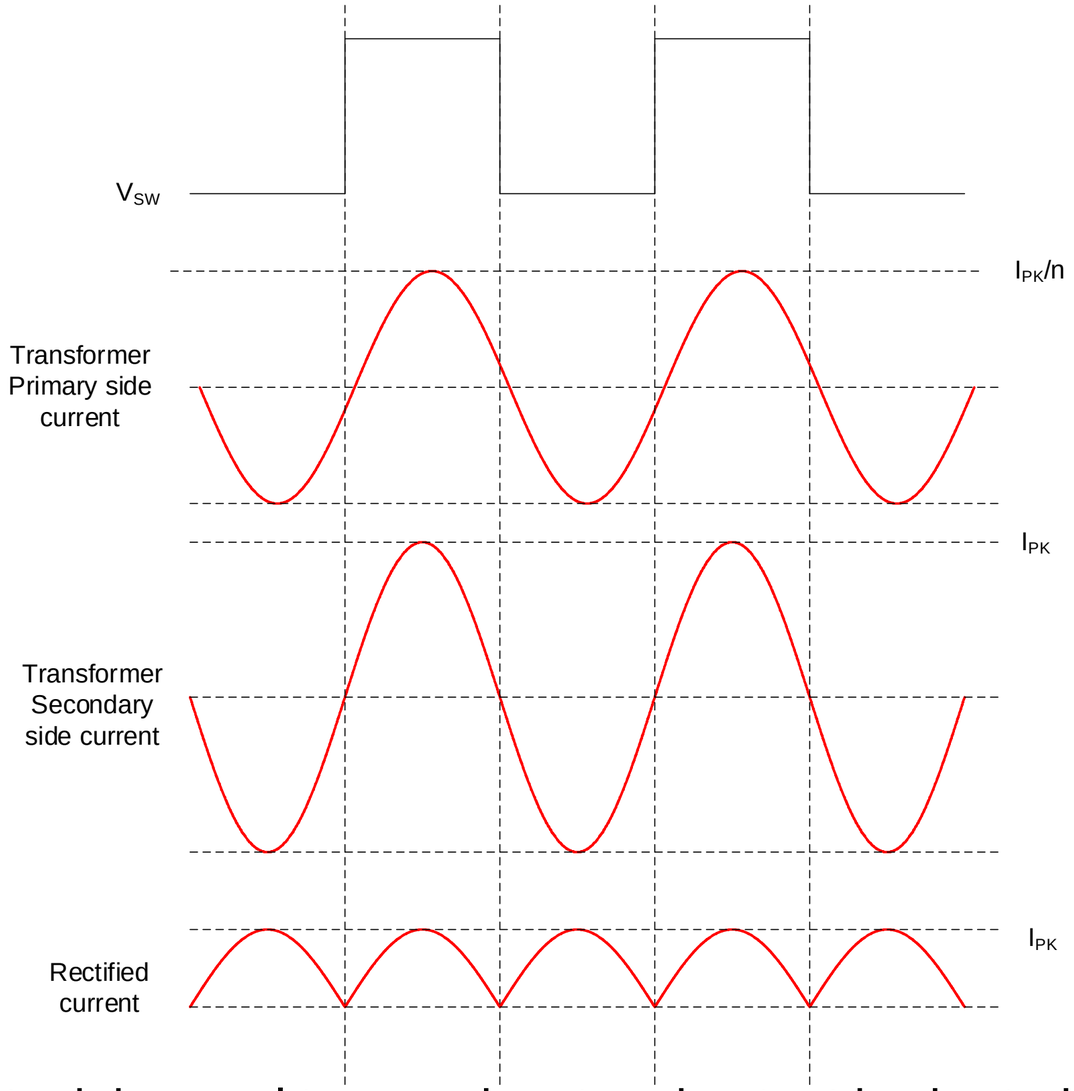


$$f_0 = \frac{1}{2\pi\sqrt{L_r C_r}}$$

$$Q_e = \frac{\sqrt{L_r/C_r}}{R_e}$$

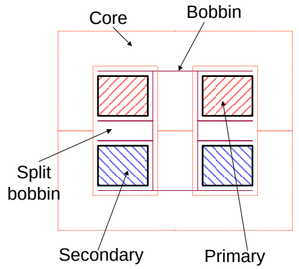
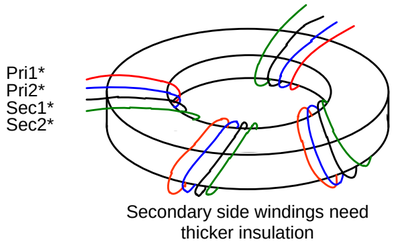
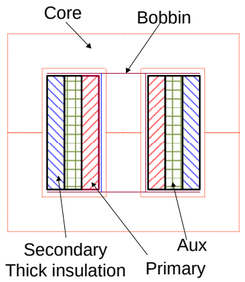
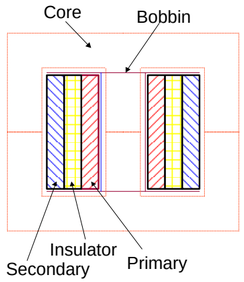
$$R_e = \frac{8n^2}{\pi^2} R_L$$





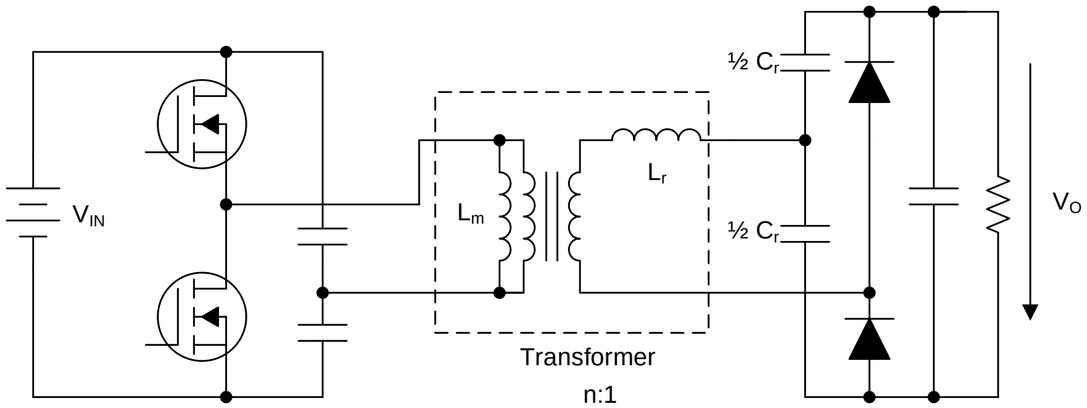
- At resonant frequency, the impedance of resonant tank is equal to zero, input and output is shorted through the transformer. Fixed frequency open-loop control is possible.
- The leakage inductance of the transformer can be used as the resonant inductor

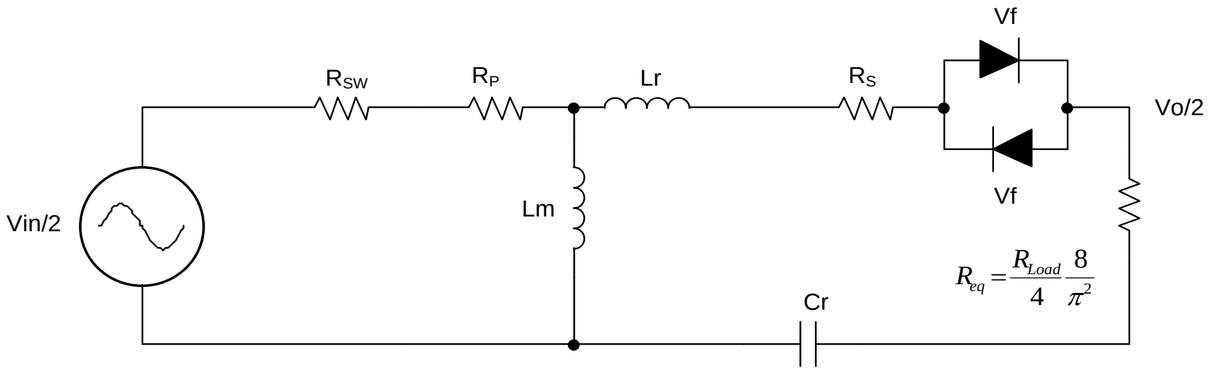
Transformers for isolated bias supply

	LLC transformer	Push-pull transformer	Three-winding flyback	Two-winding PSR flyback
				
$C_{Pri-Sec}$	**<2pF**	~10 pF	~20 pF	~20 pF
CMTI	**>150V/ns**	Worse than LLC	Worse than LLC	Much worse than LLC
Cost	**1X**	>1.15	>1.3X	>1.18X
EMI	**Best**	Good	Poor	Poor
Regulation	Good	Good	Better	**Best**

LLC converter provides an order of amplitude capacitance reduction

Open-loop LLC voltage regulation

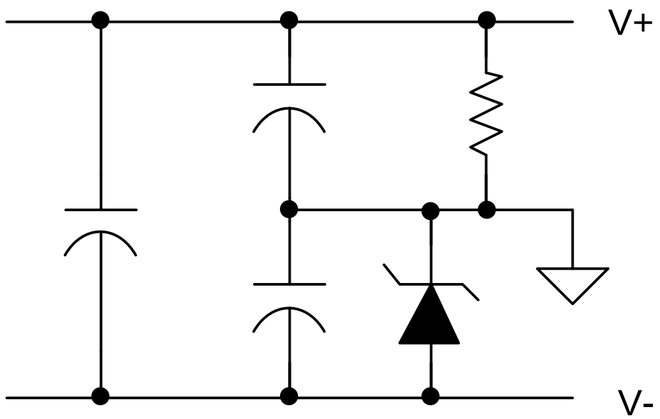




$$v_o \approx \frac{v_{in}}{n} - \frac{\pi^2}{2}\left(\frac{R_{SW}}{n^2} + \frac{R_P}{n^2} + R_S\right) \cdot I_O - 2v_f$$

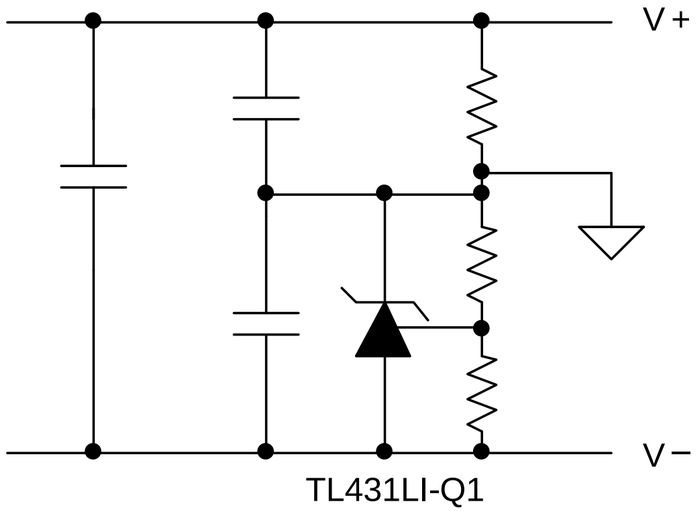
- The voltage regulation is determined by transformer turns ratio and resistive loss, as well as the diode drop
- It is critical to keep the resistive loss low to get best load regulation

Split single output voltage into dual outputs



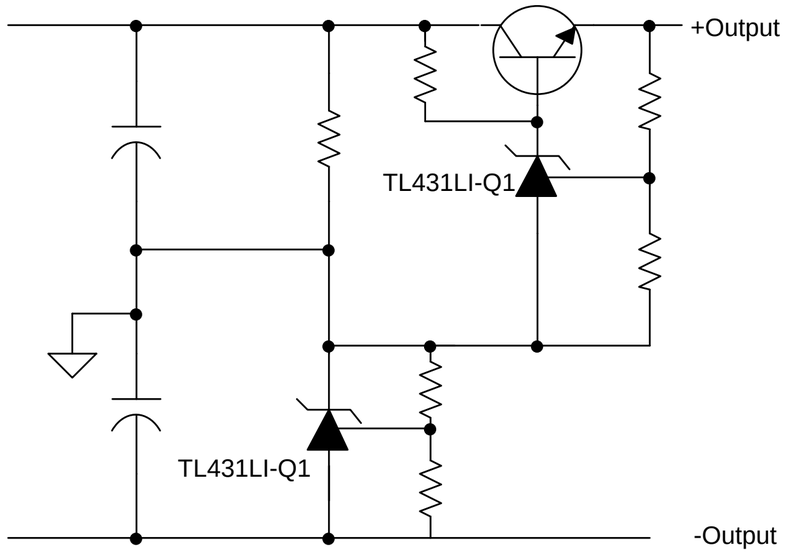
Zener split

- **Lowers cost**
- **Unregulated outputs**



Shunt Regulator

- **Higher cost**
- **Regulated negative output**
- **Unregulated positive output**



Shunt Regulator & Linear regulator

- **Highest cost**
- **Regulated output**

UCC25800-Q1

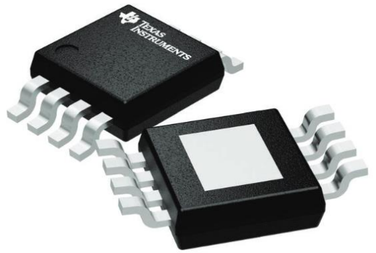
Low-cost LLC transformer driver with high performance

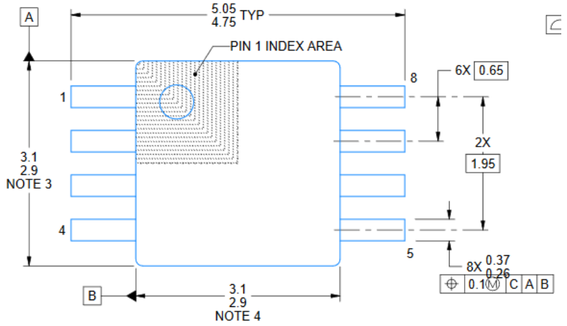
Features

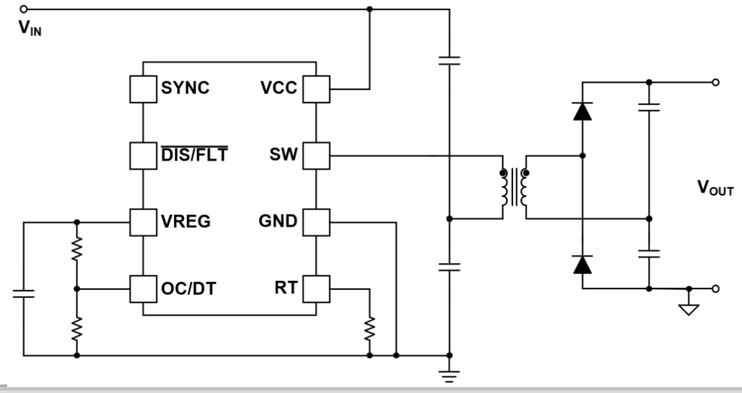
- Operation from 9 V to 34 V (40 V Abs Max)
- 6 W from 24-V input, Up to 10 W from 34-V input
- Integrated half-bridge MOSFETs
- Programmable fixed switching frequency up to 1.2 MHz
  - 1.2 MHz default, resistor settable 100 kHz – 1 MHz
  - Frequency accuracy +/-6% maximum over temperature
  - External SYNC function
- Drive multiple transformers with one UCC25800-Q1
- Automatic dead time adjustment with programmable maximum
- Integrated soft-start
- Disable pin with fault code output
- Two-level over current protection
  - Programmable via external resistor
  - UCC25800L is latched after over current
  - UCC25800R is retry after over current
- Over Temperature Protection
  - 160°C Junction
  - 10°C Hysteresis
- AEC Q100 Qualified

Benefits

- Low common mode noise due to minimal interwinding capacitance in transformer
- Simple design, highly integrated, no bootstrap capacitor
- High switching frequency for smaller size and more robustness





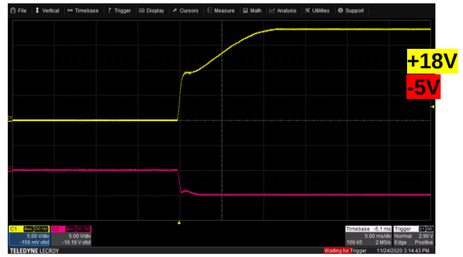


UCC25800-Q1 measurement data

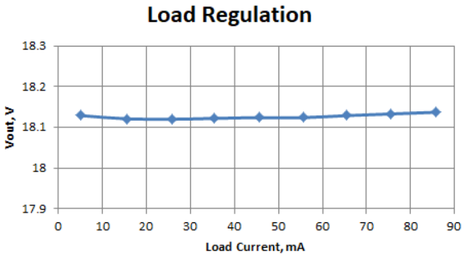
UCC25800 EVM with LM5156 pre-regulator

PARAMETER	SPECIFICATIONS
Input voltage range	6V – 26V
Output voltage and current	+18V / -5V
Switching frequency	2.2MHz and 500 kHz
Isolation	Yes, 2500 VAC (1 sec)
Topology	SEPIC + Open loop LLC transformer driver

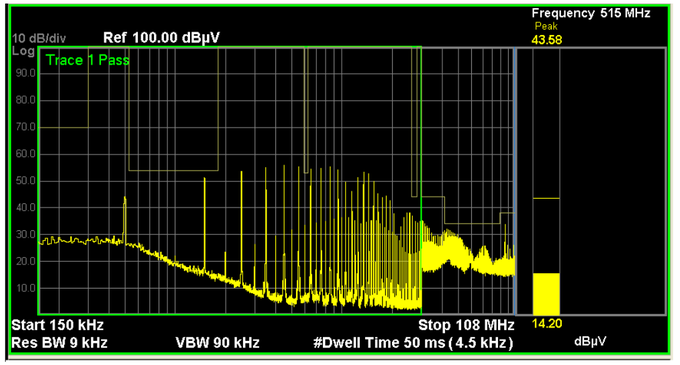
Predictable startup of +/- rails



1% Load regulation

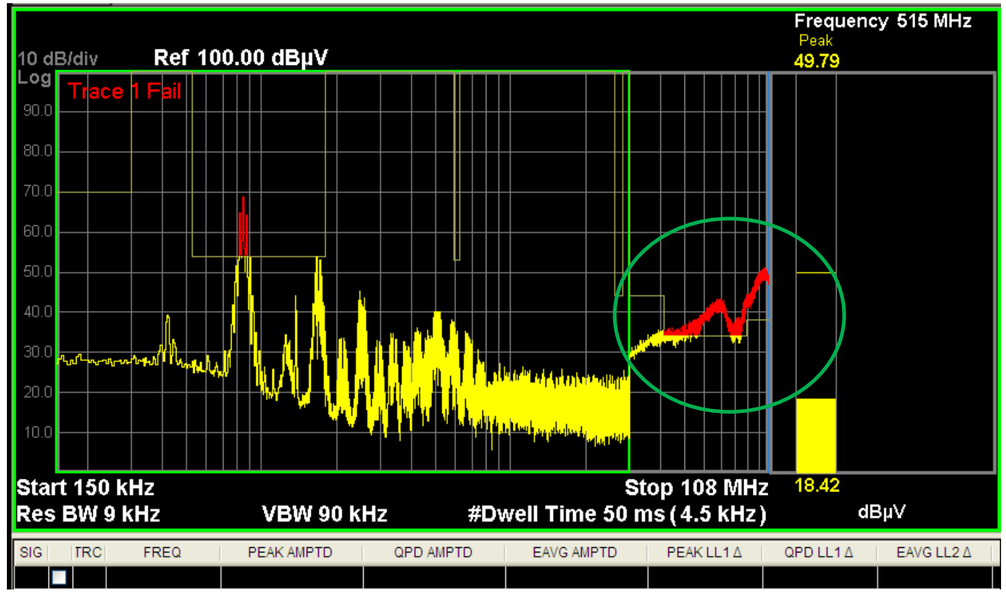


Surpasses CISPR 25 class 5 EMI standard

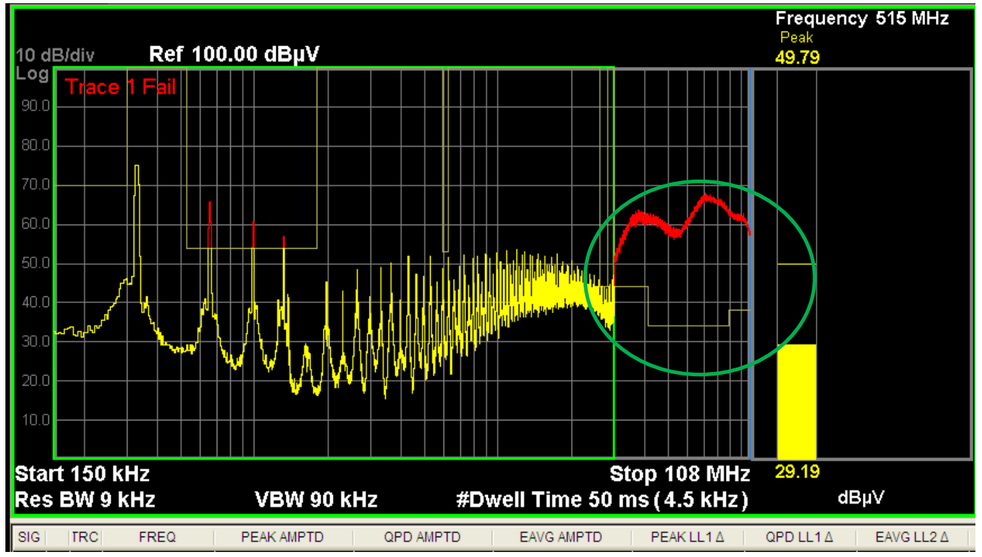


Pass - LLC Board Only with Filter

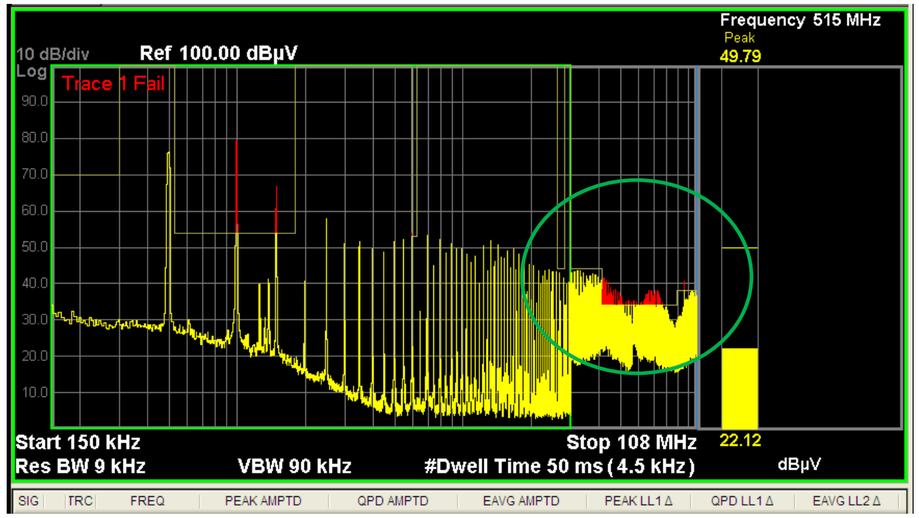
EMI noise performance comparison



5-V push-pull



24-V Flyback

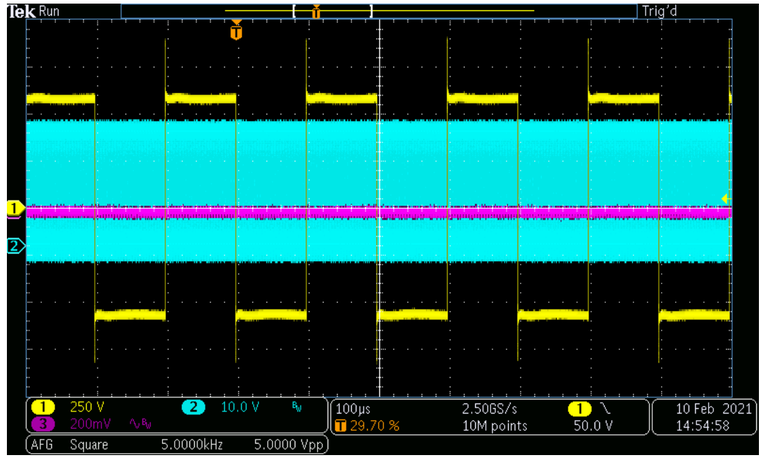


24-V LLC

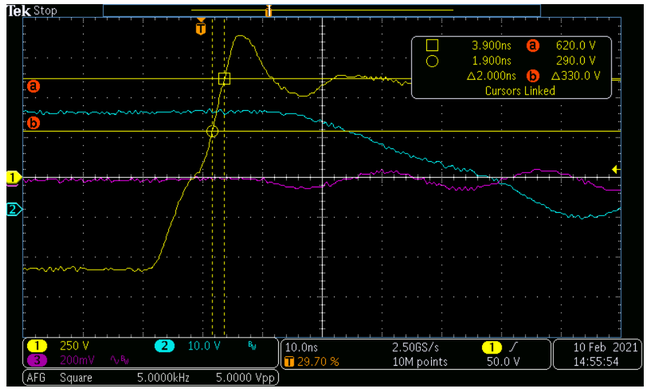
LLC has much lower high frequency EMI noise, which is the most difficult to filter out

*No EMI filter added on any topologies

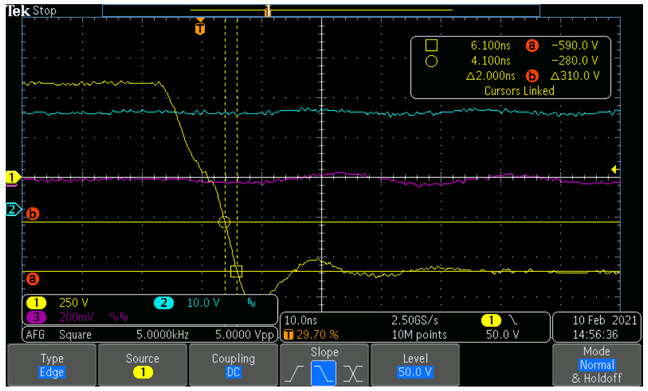
CMTI performance of UCC25800 based LLC



165 V/ns

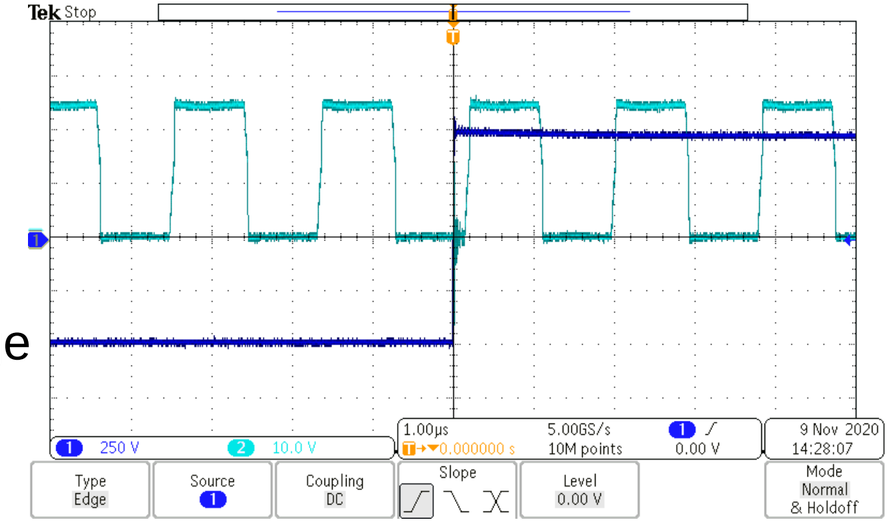


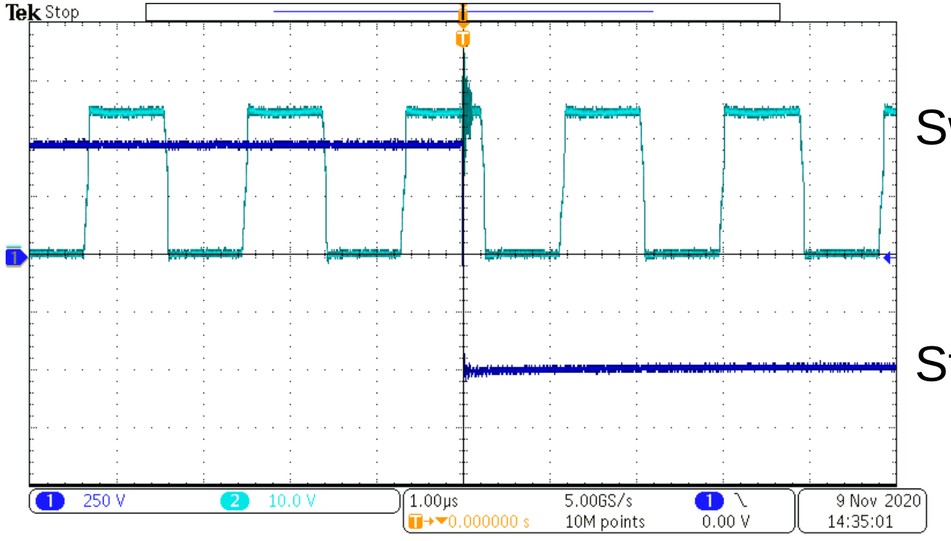
155 V/ns



Switch node

Strike voltage





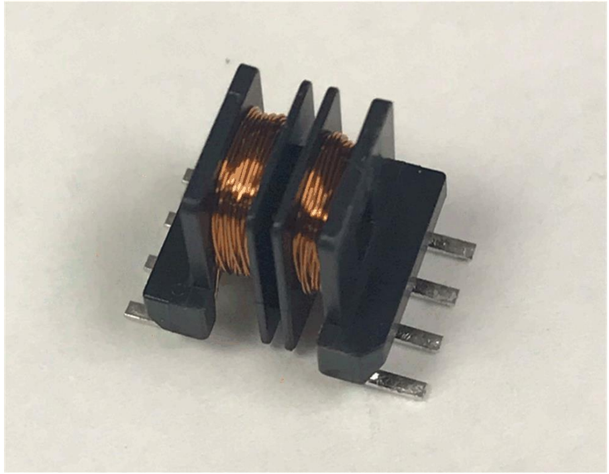
Switch node

Strike voltage

Operation is not affected by >150 V/ns CMTI

Transformer design considerations

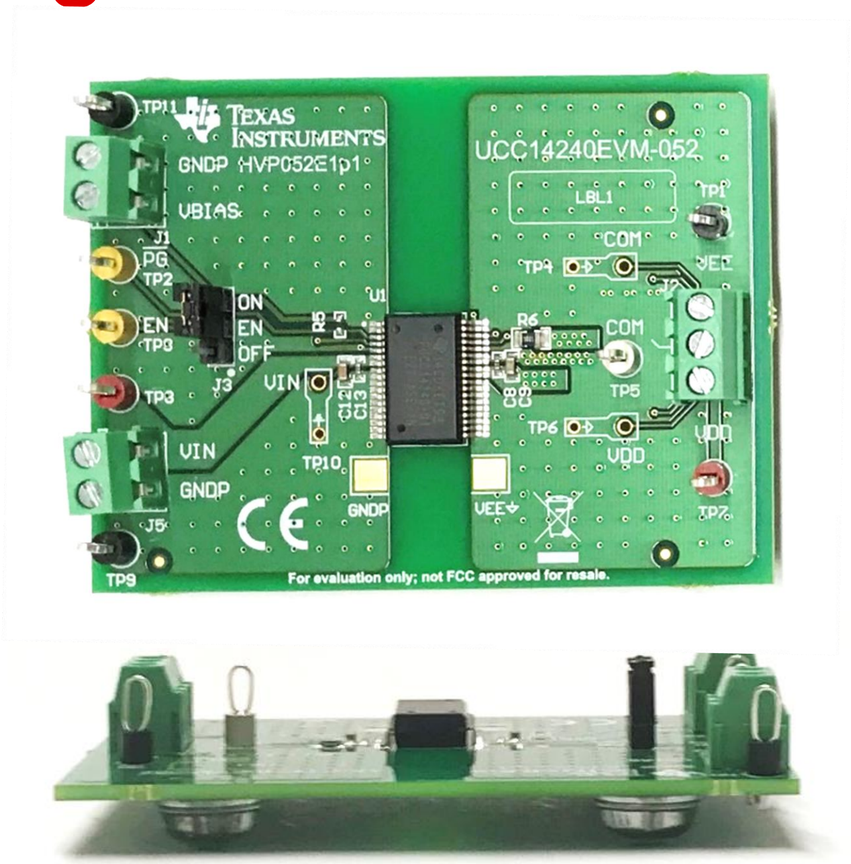
- Transformer design is simple
  - Two windings
  - Turns ratio is roughly the voltage ratio between the input and output voltage (plus the diode drop)
  - Square voltage on primary side, setting up the volt-second rating
  - Lowest Rac possible
  - No airgap
- Once the transformer is made, measure the leakage inductance from secondary side
  - Short the primary side while measuring
- Match the leakage inductance with resonant capacitor



Part number (Wurth)	Turn ratio	Leakage inductance	Input / Output
750319331	1:1	1.4 uH	24 V/24 V
750319177	1.67:1	1.48 uH	15 V/24 V
750319177	1:1.67	0.53 uH	24 V/15 V

How to further simplify the design

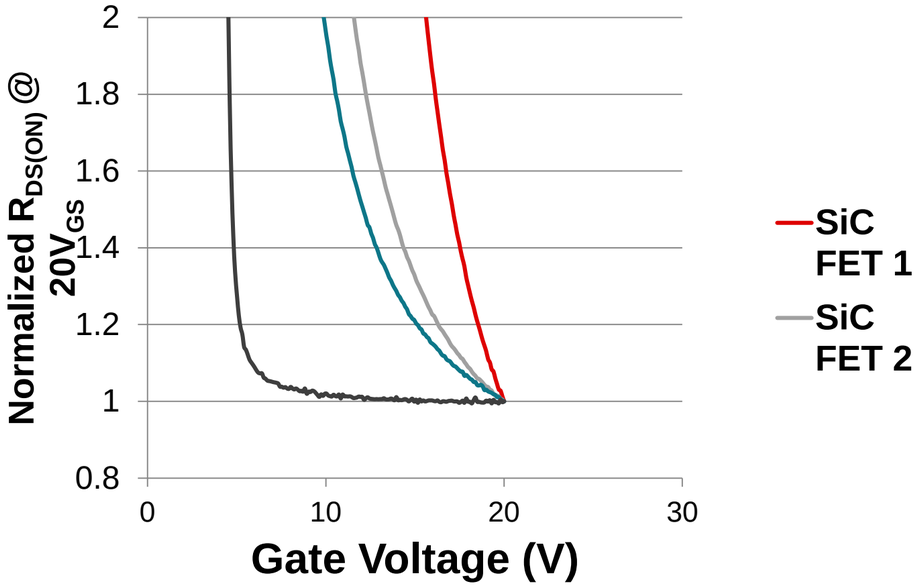
UCC25800-Q1 based open-loop LLC



UCC14240-Q1
1.5-W, high-efficiency, 3-kVRMS isolated DC/DC converter

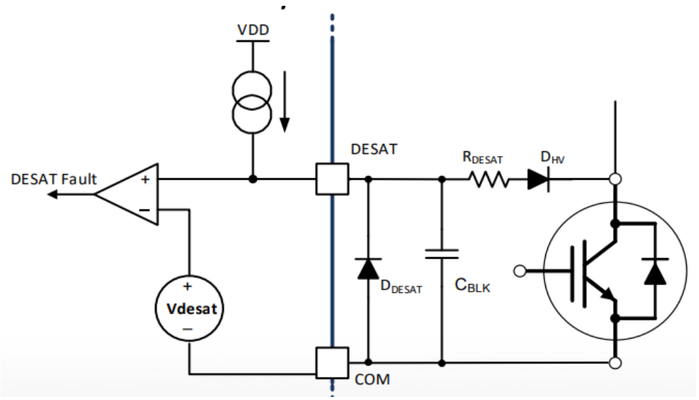
Gate driver voltage accuracy requirement

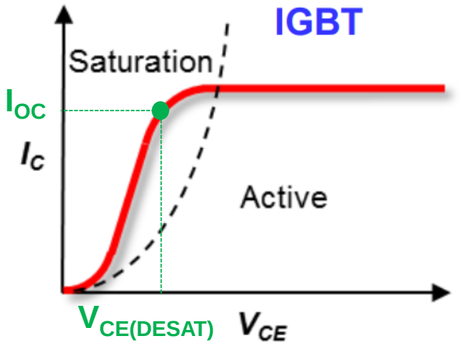
Gate voltage effect on $R_{DS(ON)}$ sensitivity

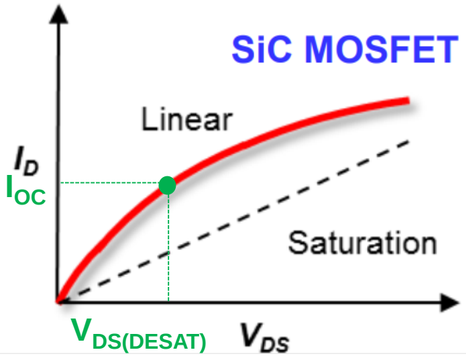


Conduction Loss = I_{RMS}^2 x $R_{DS(ON)}$

Gate voltage effect on over-current detection







V_{GS} change affects I_{OC} correlation with $V_{CE(DESAT)}$ or $V_{DS(DESAT)}$ setting

	Si MOSFET	SiC MOSFET	IGBT
Positive rail (V_P)	+12V, +15V	+18V, +20V (5%, 3%, 1%)	+15V, +18V
Negative rail (V_N)	0V	-5V, -4V, -3V	-8V or 0V

Tight bias voltage regulation improves efficiency and OCP accuracy

Isolated DC-DC module with integrated transformer

Technology shift for isolated gate driver bias supplies

Decades of **bulky transformers** …

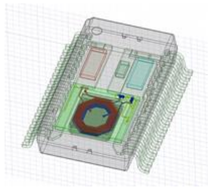
- Bulky – prone to vibrations
- High radiated EMI
- Large footprint & height
- Difficult to design

Push-pull

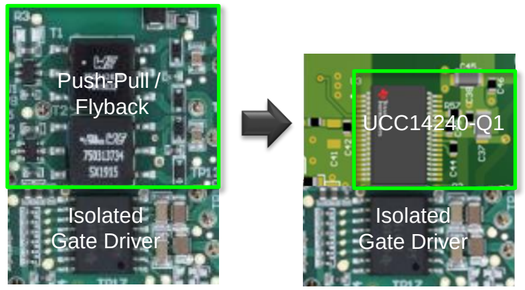
Flyback

Introducing the **UCC14240-Q1**

- 1.5W high-efficiency isolated DC/DC power supply
- Industry's smallest, most accurate & easiest-to-use
- Proprietary integrated transformer technology
- No bulky, noisy transformers

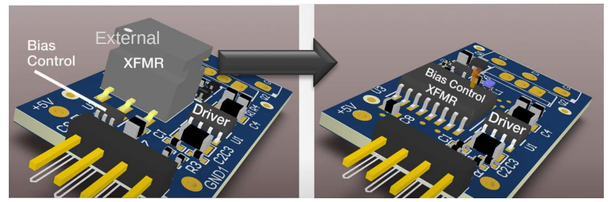


2X smaller PCB area, lower BoM



2X lower height

7.5mm Height **3.5mm Height**



TI integrated gate drive bias supply

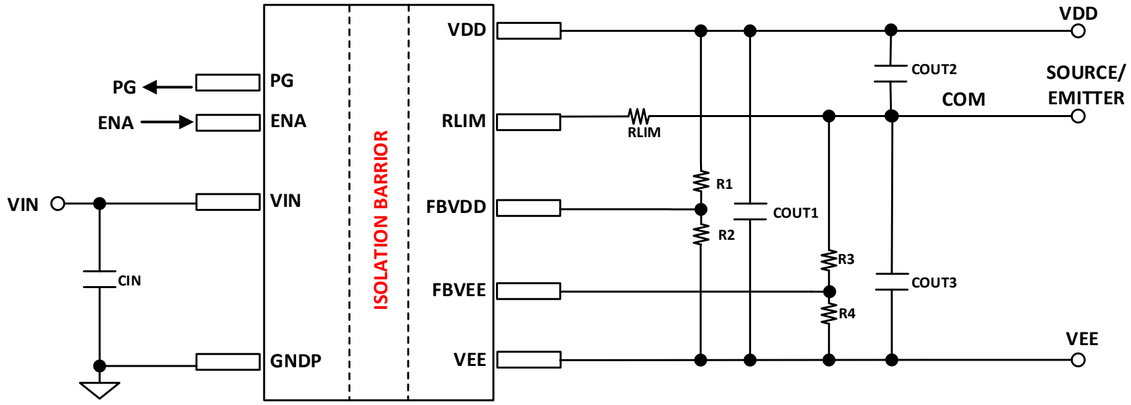
Can be configured as two outputs or single output

24 V Samples: Now

Two Outputs: $V_{POSITIVE}$ & $V_{NEGATIVE}$

VIN = 24 V or 12 V

VOUT = Both Adjustable
<1.3% accuracy

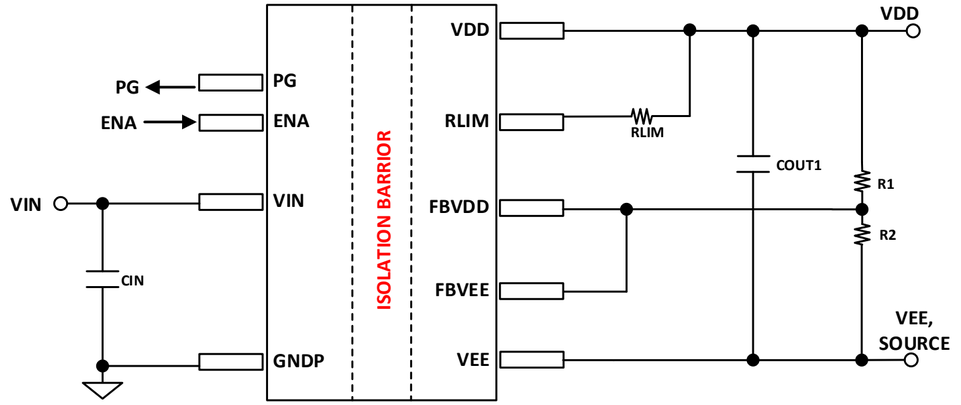


- **Higher inverter efficiency**
- **More accurate inverter current limit**

Single Output: $V_{POSITIVE}$

VIN = 24 V or 12 V

VOUT = Adjustable
<1.3% accuracy



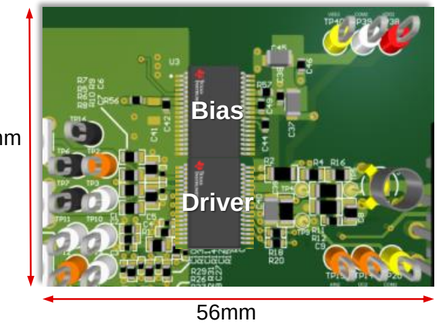
- **Higher inverter efficiency**
- **More accurate inverter current limit**

Link to datasheet Link to EVM Order Soon

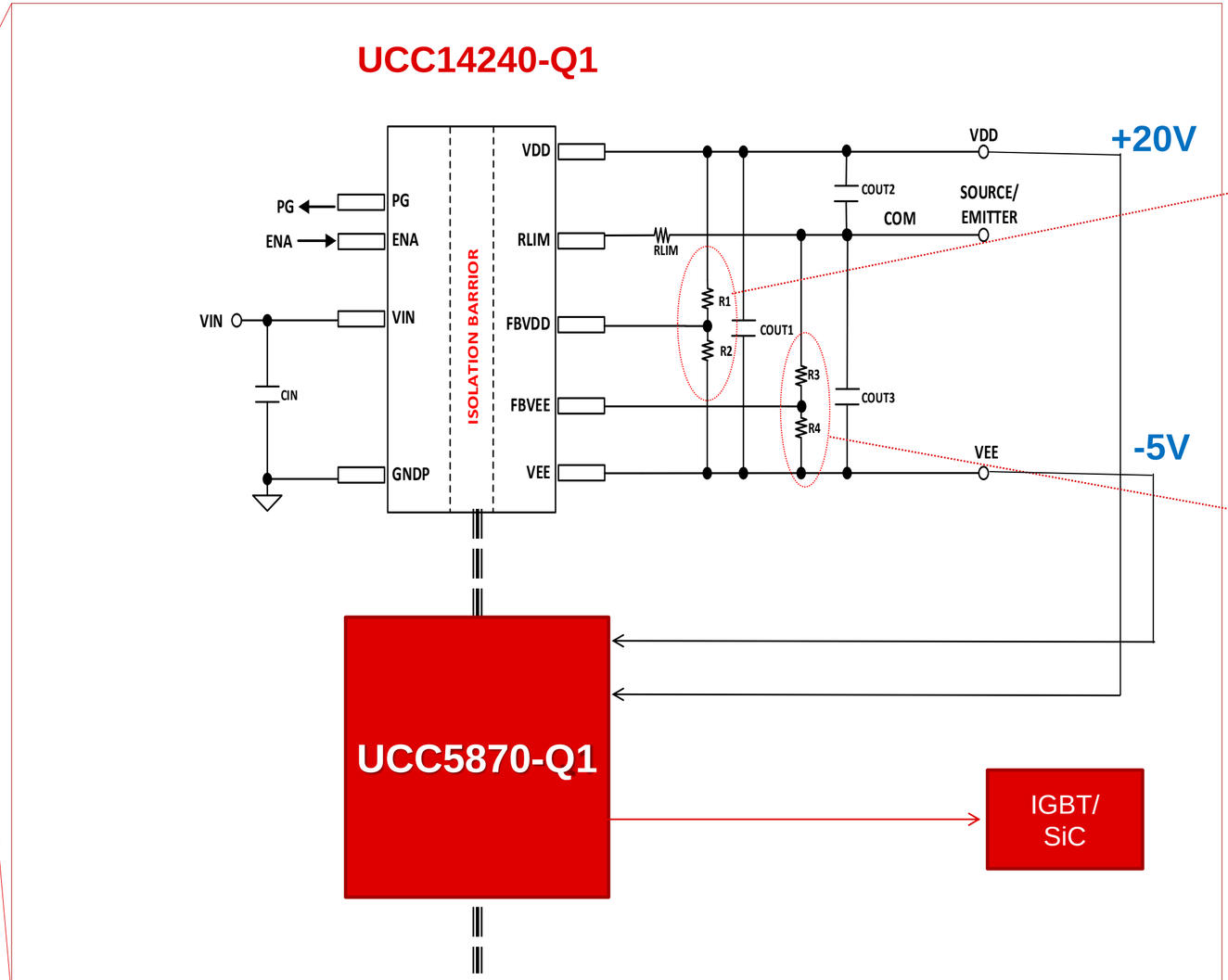
[*Disclaimer:* Specs, features & pinouts subject to change without prior notice.]

UCC14240-Q1 Best-in-class regulation

Compact PCB Implementation



- 1.3% regulation over -40°C to 150°C
- No need post regulator
- Programmable positive and negative rail outputs



R1 & R2 control the VoutΔ (18-25V)

R3 & R4 control the negative and the positive voltages

UCC14240-Q1

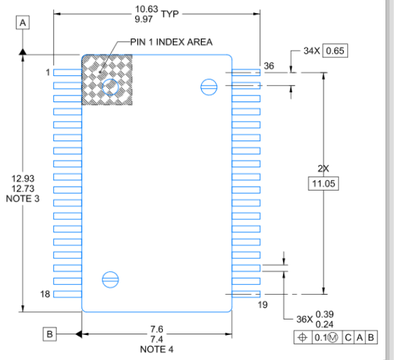
3.55 mm height dual output gate drive bias w/ integrated XFMR

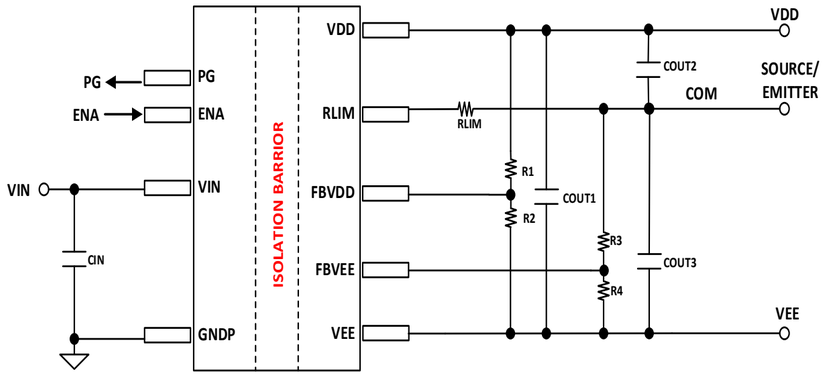
Features

- Isolated power module with integrated transformer
- 3.55 mm height, 12.8 mm x 10.3 mm with leads (8mm creepage)
- 1.5-W output power at Ta = 105°C
- Input voltage range
  - 24V nominal
  - 21V – 27V, 32V Abs,max
- Dual adjustable output voltages
  - VDD to VEE Range 18 V to 25 V, ≤ 1.3% accuracy
  - COM to VEE Range 2.5 V to VDD, ≤ 1.3% accuracy
  - ≤ 1.3% Accuracy -40°C to 150°C
- Isolated DCDC for driving: IGBTs, SiC FETs, Si FETs, sys rails
- 3.5pF primary-to-secondary capacitance with low emissions
- Wide temperature range:
  - Tj: -40 to 150°C
  - Ta: -40 to 125°C
- UVLO, OVLO, PG, soft-start, short-circuit, power-Limit, and over temperature protection, CMTI > 150kV/us
- Basic isolation
  - 3kVrms (60s)
  - 1.2kVpk working
  - 5kV surge
- AEC-Q100 auto grade

Benefits

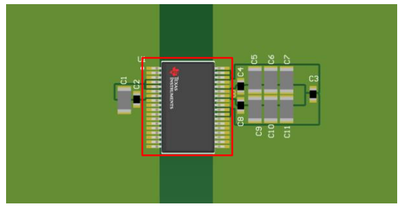
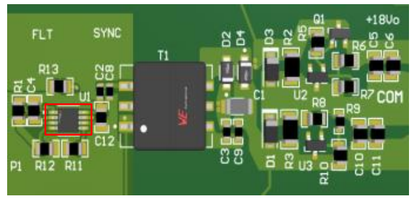
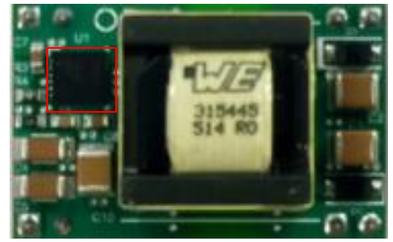
- Integrated solution enables smaller BOM, reduced board space and helps with easier system certification
- High accuracy to reduce size of IGBTs / SiC switches
- Soft start enables minimal overshoot current,
- Low EMI, high CMTI, high isolation voltage





[*Disclaimer:* Specs, features & pinouts subject to change without prior notice.]

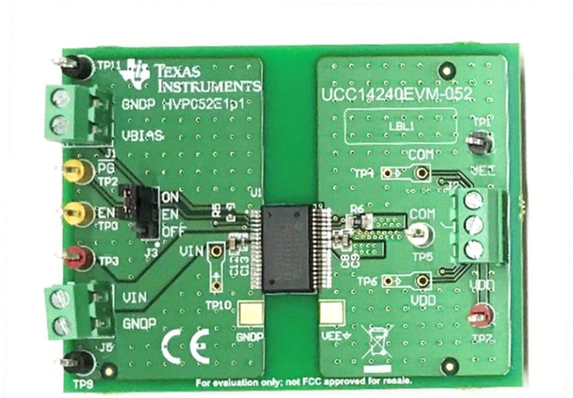
UCC14240-Q1 total solution comparison

	Integrated Transformer UCC14240	LLC Resonant UCC25800	Push-Pull SN6505	Flyback LM(2)5180	Half Bridge UCC28C42-Q1
					
	UCC14240 Product Folder	UCC25800 Product Folder	SN6505B Product Folder	LM25180 Product Folder UCC2813 Product Folder	
Total PCB Area	**220 mm²**	525 mm²	550 mm²	600 mm²	560 mm²
Maximum Height	**3.55 mm**	9 mm	8 mm	13 mm	10 mm
Vin / Power	**21V – 27V 1.5W at 105°C (Distributed Architecture)**	**9V – 34V < 10W (Centralized Architecture)**	2.25V – 5.5V < 5W	4.5V – 65V > 10W	Controller >10W
Cpri-sec	**3.5pF**	**< 1.5pF**	7pF	~20pF	~20pF

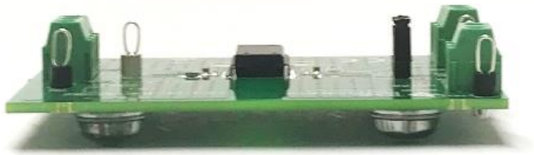
UCC14240-Q1 measurement data

UCC14240 EVM

SMALL AREA

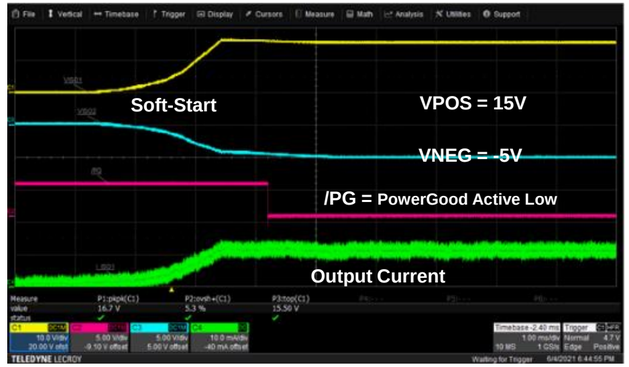


LOW HEIGHT

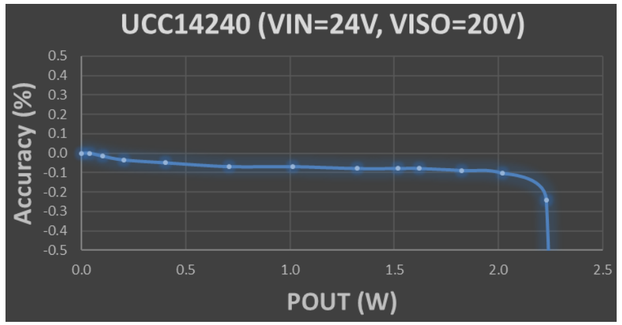


PARAMETER	SPECIFICATIONS
Input voltage range	21 V – 27 V
Dual Output voltage	+25 V / -5 V (programmable)
Regulation	≤ 1.3% accuracy
Isolation	Basic, 3k Vrms

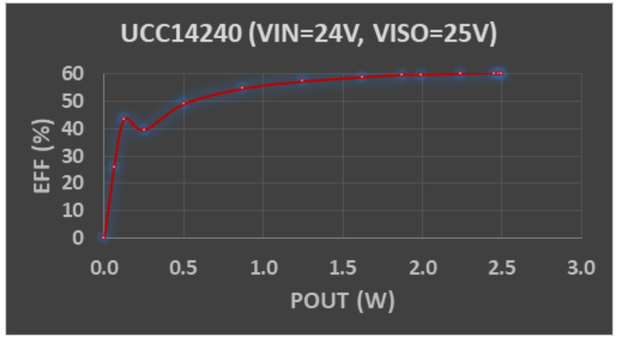
Soft startup of +/- rails



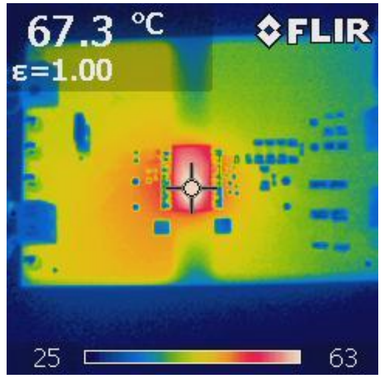
< 1% load regulation



60% peak efficiency



Cool 2-W out



Summary

- Isolated bias supply is needed for biasing the isolated gate drivers in the inverters
- The open loop LLC converter provides a simple, robust solution
  - Less EMI
  - High CMTI
  - Good voltage regulation
  - Multiple output capability
- Integrated transformer solution provides
  - Highest level of integration, minimum external components
  - Highest power density, lowest profile
  - Best-in-class regulation, no post regulator needed

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265