Attracting Tomorrow TDK

Bridgeless Isolated PFC

Using GaN FETs and Digital Control

November 7, 2017

Jin He, Ph.D.
TDK-Lambda Americas
A TDK Group Company
Power Systems Business Group

Outline

- TDK at a Glance
- Why AC-DC Power Modules
- Traditional PFC vs. Bridgeless PFC
- Minimize Conduction Loss
- Totem-Pole Bridgeless PFC
- Use of Wide Band-gap Devices
- Synchronous Rectification
- Digital Control and Simulation
- PMBus and GUI
- Thermal Consideration
- Specification and Efficiency Curves
- Droop Load Share
- EMI
- Survive AC Line Surges
- Summary

TDK at a Glance

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Synergies with TDK's core technologies

2017 TDK
Global Sales
~ **$11.7 Billion**

TDK Company established Dec 7, 1935
80+ years serving customers

Capacitors	Inductors (Coils)	EMC Components
RF Components and Modules	Voltage / Current / Temperature Protection Devices	Sensors and Sensor Systems
Ceramic Switching / Heating, Piezo Components, Buzzers and Microphones	Transformers	Ferrites and Accessories
Noise Suppressing / Magnetic Sheet	Anechoic Chambers and Radio Wave Absorbers	Power Supplies
Magnets	Flash Storages	Wireless Power Transfer
FA Systems	Transparent Conductive Film	Micro Modules (Substrates with Built-in ICs, Products Utilizing with SESUB)
Solar cells	Biosensor	Application Specific IC (ASIC) Development and Supply

88,000+ employees
in 60+ countries

TDK · TDK-Lambda · EPCOS · InvenSense Sensing Everything · MICRONAS · ATL · Chirp · Faraday Semi

TDK was founded in Japan in 1935 as the world's first company to commercialize a magnetic material called Ferrite

TDK-Lambda Global Operations

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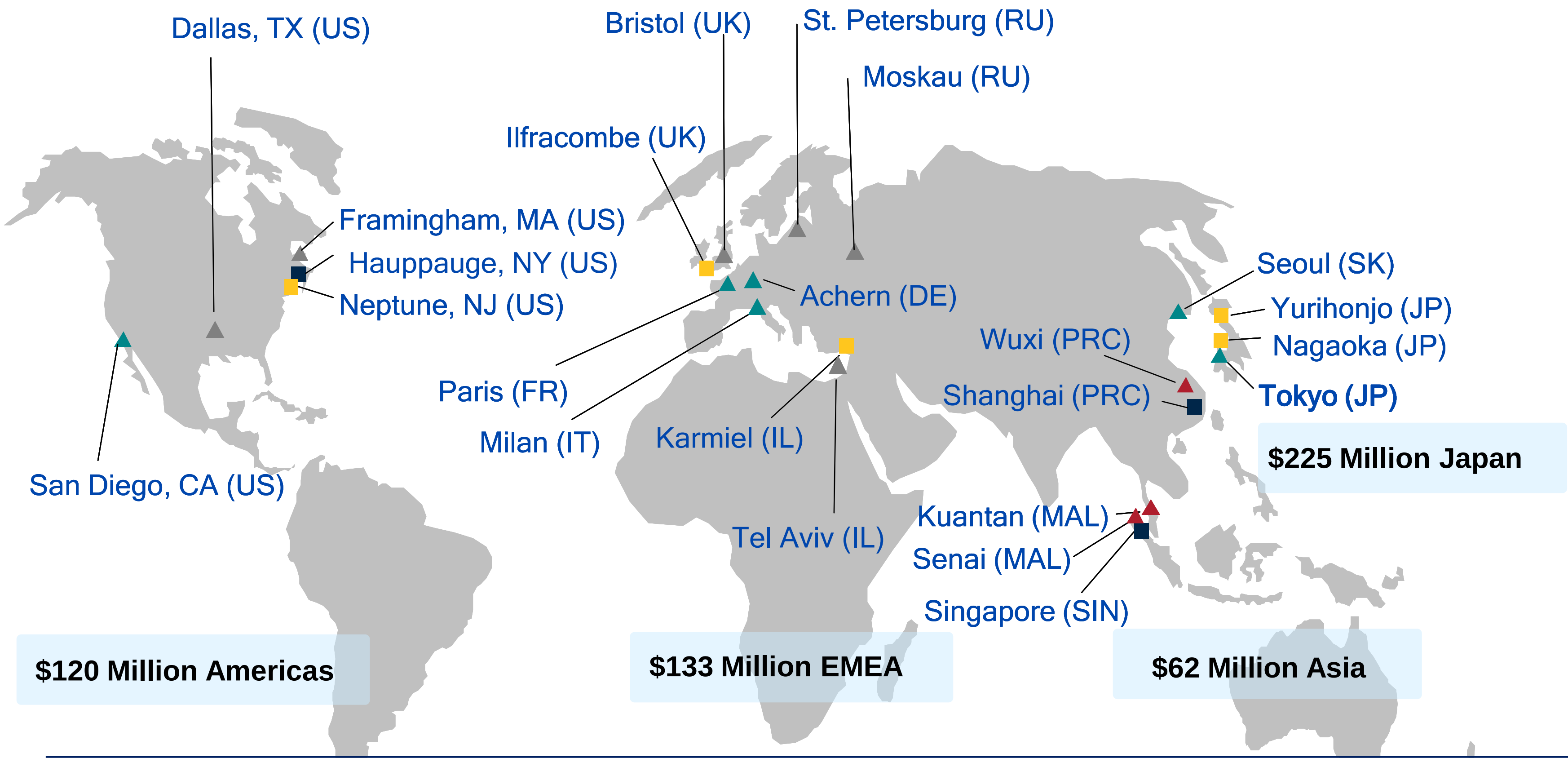
- Global Full-Functional Network
- Solutions for R&D, Manufacturing, Sales, & Service

$540 Million Global Sales



Regional HQ
- ▲ Manufacturing
- ▲ R&D
- ▲ Commercial
- ■ Manufacturing, R&D, Commercial
- ■ R&D, Commercial


San Diego (America)


Neptune (America)


Ilfracombe (U.K.)


Karmiel (Israel)


Kuantan (Malaysia)


Senai (Malaysia)


Wuxi (China)


Nagaoka (Japan)

Diversified Market Segments & Broad Offering

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- TDK-Lambda offers over 5,000 Standard Products

Medical
Ultrasound
Hospital Beds
X Ray
Chemical Analyzers
Surgical Tools & Instruments
MRI
Lasers

Test & Measurement
Instruments
Oscilloscopes
Burn-in & Test
Disk Drive Testers
Board Testers
Data Acquisition

Industrial & Automation
Material Handling
Factory Automation
Process Control
Simulation Equipment
High End Printers
Semiconductor Equipment

LED Signage

Communications
Wireless Base Station

Gaming & Vending
Robtics

Military

#1 Global Supplier of Industrial Power Supplies

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AC-DC Industrial

AC-DC Modular / Configurable

AC-DC & DC-DC Power Modules

DIN Rail AC-DC & Filters

Programmable

EMI Filters

#2 Global Supplier of Medical Power: Meeting 60601 Std

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QM5/7/8 700-1500W
12-18 channel output
Low noise

Vega & Vega Lite
450/650/900W
10ch output

NV 175/300W 5ch output
350/700W 8ch output

EFE300M 3"x 6"
EFE400M 3.5"x 6.5"

CFE400 7"x4"

CSS 40-500W

CM4 600W Conduction

SWS1000L

HWS-A/ME 30-150W
HWS/ME 300-1500W

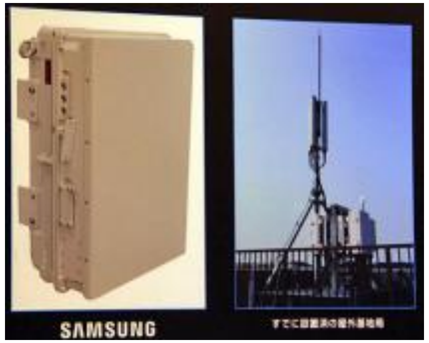
RWS1000B/ME
RWS1500B/ME
1000-1500W

DT 50-**300**W
Energy efficiency V,VI

CUS-M
30-350W
(Ultra-low profile)

Why AC-DC Power Modules ?

- Low profile, small size, conduction cool, MIL-STD 810G S&V
- Many Ruggedized Applications:
- LTE and RF Amplifiers
- Hand Radio Chargers
- Signage and Displays
- Street Security Cameras
- Industrial Vacuum Pumps
- Military Communications and Ground Vehicles
- Airborne Radar and Satellites









Smart City Installation

Traditional PFC with High Conduction Losses

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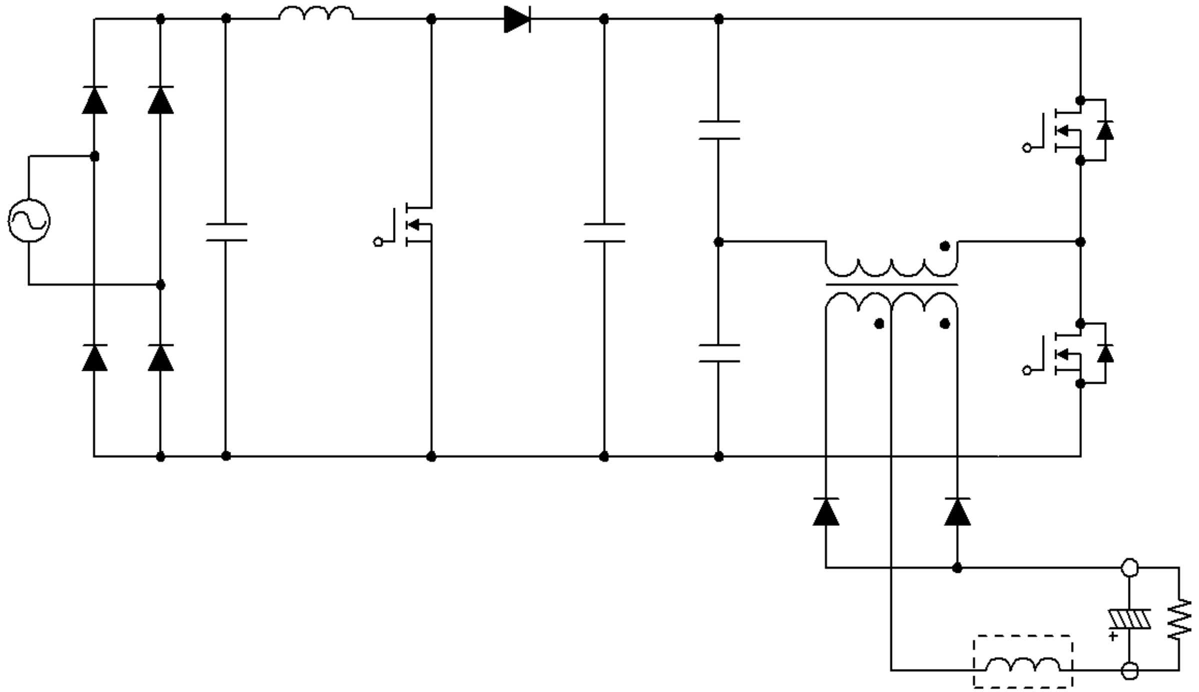
Traditional PFC: High Conduction Loss

- Boost Switch ON: 2 Diodes plus 1 FETs Conducting
- Boost Switch OFF: 3 Diodes Conducting
- Any moment: 2 ~ 3 diodes conducting
- High conduction loss, worst at low line input
- More conduction losses in DC-DC secondary
- Something needs to be done to reduce P_cond



Bridgeless PFC Reducing Conduction Losses

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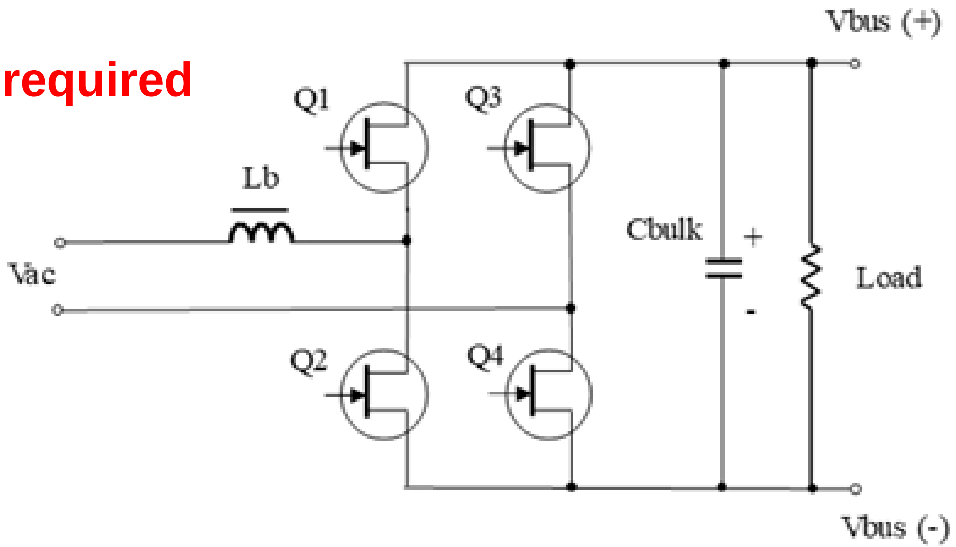
- Totem-Pole Bridgeless PFC:
- Use of Two Fast Switches (Q1 and Q2)
- Also Use Two Line Frequency Switching Devices (Q3 and Q4)
  - Boost Switch ON: 2 FETs Conducting (Synchronous Mode), No Diodes
  - Boost Switch OFF: 2 FETs Conducting (Synchronous Mode), No Diodes
  - Any moment: 0 diodes conducting
  - No diode conduction loss at any line inputs
  - For CCM: FETs Reverse Recovery, Wide Band-gap Devices required



Traditional PFC vs. Bridgeless PFC

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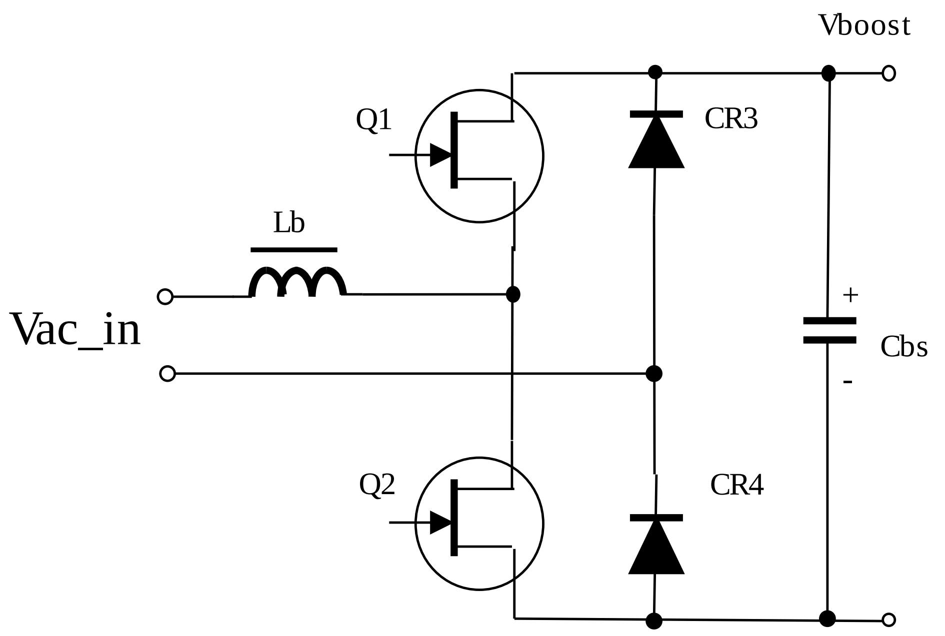
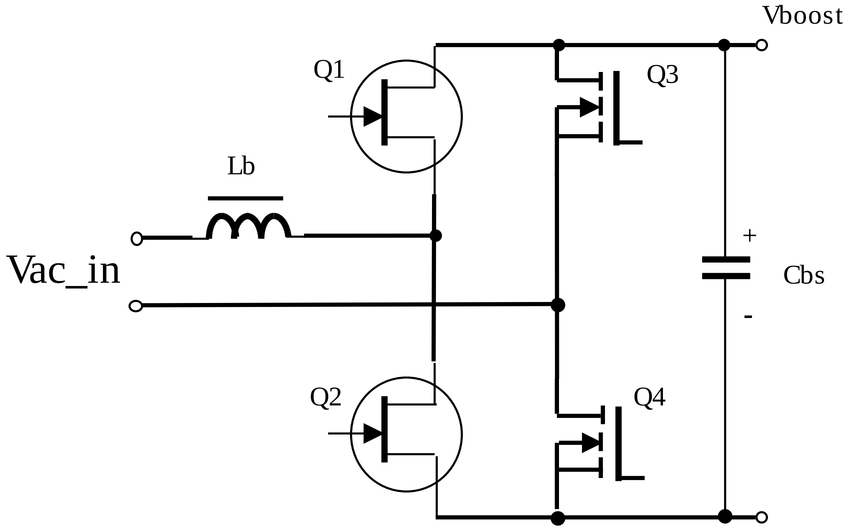
- Simplified Totem-Pole "Bridgeless" PFC
- Use of Two GaN Devices: Q1 and Q2 plus Two Rectifier Diodes
- Low Conduction Loss
  - Boost Switch ON: 1 GaN + 1 Diode Conducting
  - Boost Switch OFF: 1 GaN (sync-mode) + 1 Diode Conducting
  - Any moment: 1 diode conducting
  - Reduced conduction loss
  - Simplified Driving Scheme
  - Save Board Space, especially useful for Power Module



Use of Wide Band-gap Devices

- Why Wide Band-gap Devices such as Gallium- Nitride (GaN) or SiC FETs ?
- For Boost Converter, DC Bus Voltage is always higher than the peak of AC line
- For DCM Operation:
  - Use of FETs is OK, no body diode reverse recovery, but too much peak current
- For CCM Operation: 390V Bus will discharge thru Q1 when Q2 turns on due to reverse recovery of Q1
  - Use of GaNs is required since both Q1 & Q2 will experience body-diode reverse recovery if FETs used
- Wide Band-gap Devices (GaN or SiC FETs) w/o reverse recovery needed
- Q3 & Q4 conduct every half line cycle, low frequency switching
- Additional Driver + AC Line Zero-Crossing Detection Needed for Q3/Q4, i.e. more board space



Age of GaN is Coming

- Compare the performance of a full featured TDK PFE500F (500W) AC-DC Modules
- New Generation TDK PFH500F Module Performance Gains are significant (see below table)
- Board Space Savings Allow PMBus Monitoring / Programming features
- More & More Power Semiconductors Vendors Launched GaNs + Supporting ICs (drivers)
- Production Volumes Continue to Increase, and Price Starts to Drop
- The Age of GaN is coming

Power efficiency	Up to 92% (5% increase)
Power density	100W/cubic inch (30% increase)
Size reduction	28%
Thermal impact	Waste heat reduced by 38% (makes it easier to cool)
Space savings	Savings mean that PMBus™ monitoring and programming (read/write) can be included

Synchronous Rectification, SR, (for PFC and/or DC-DC)

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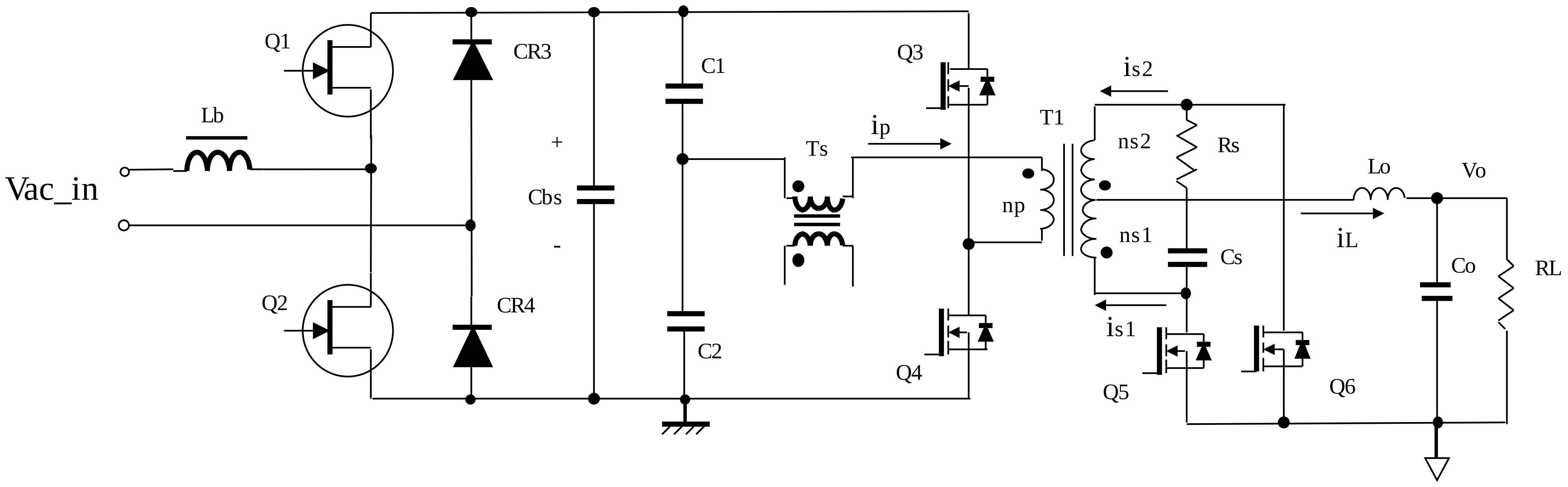
- Simplified Totem Pole “Bridgeless” PFC + Half Bridge DC-DC with SR Operation
- SR Operation further reduced conduction losses in DC-DC converter secondary side



Digital Control (with Analog Speed)

- PFH Module: Small Form Factor (4”x2.4”x0.52”) & Diversity of Features (PMBus Requirement)
- Use Digital Controller(s) with Small Foot-print (40 pins) and Analog Speed Makes Senses:
  - Functional, Real-time PWM Control, and Communication Tasks
  - Two ARM7 Core based Micro-controllers used for PFC and DC-DC Converters
  - Hardware based PID Controller and Hardware Supported PMBus Interface
  - These HW Features Free Up Significant Computational Bandwidth
  - PID Controller Peripherals Execute Independently, Triggered by ADC Module of Controller
  - State-Machine Based Firmware Architecture, Developed in C++
  - Firmware Operates with a Background Loop(s)
  - Executes All Functional Tasks Corresponding to Individual States of the State Machine
  - The Loop Is Clocked by a Timer, Allows the Control of the Loop Execution
  - The Loop is Interrupted by Time Critical Tasks For Safe Operation of the Module

MATLAB Simulation Model for PFC

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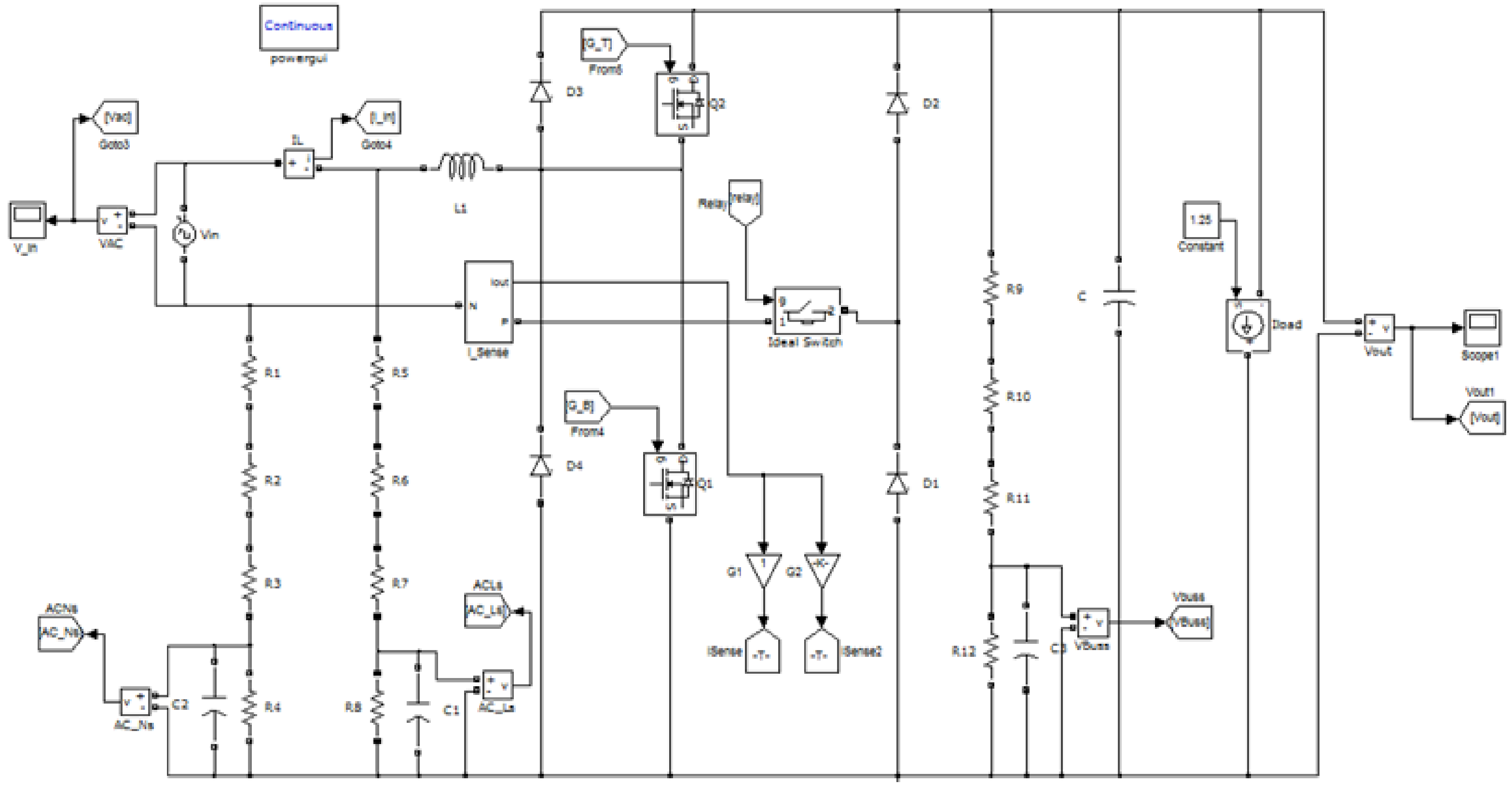
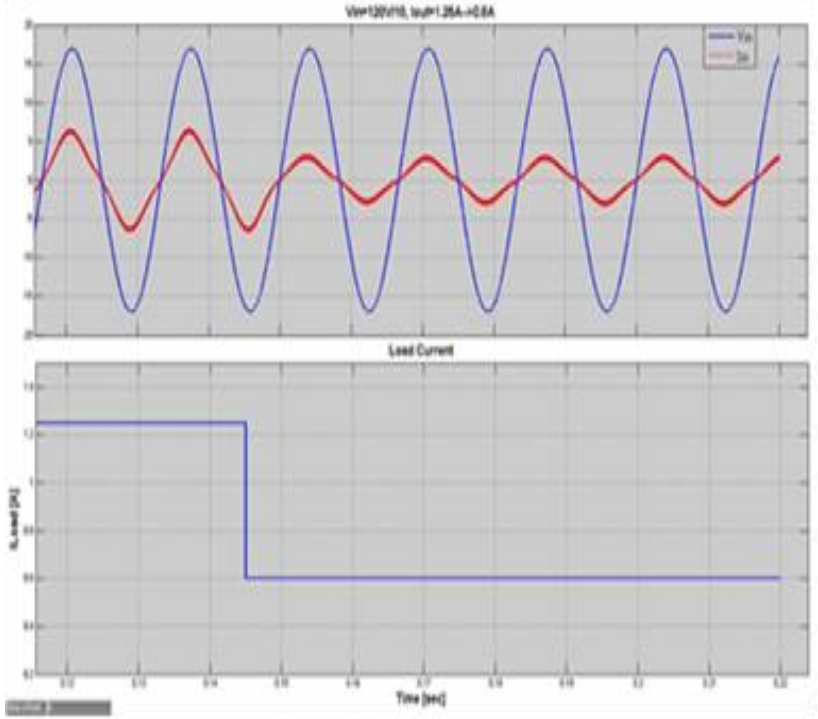
- Digital PID Controller Design Starts with MATLAB / SIMULINK Model (Shown PFC Converter Below)
- Explore the effects of time discretization and quantization errors





PMBus

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Functionality	Parameter	Read & Write
Output Voltage	Output Voltage Set-point	Read & Write
	Internal DC-DC High Voltage Set-Point	Read
	Output Voltage Droop Rate	Read
	Vout Mode	Read
	Operation	Read
Fault Management	Over Current	Read & Write
	Under Voltage	Read & Write
	Over Voltage	Read & Write
	Over Temperature	Read & Write
Status	Alert Mask	Read & Write
	Status	Read
	Manufactures Status	Read
	Output current	Read
	Input current	Read
	Input voltage	Read
	Internal Temperatures	Read
Manufacturing record	ID, Model, Rev, Location, Release Date, Support	Read
System Commands	Restore Manufactures Default	Read
	Save User Data	Write
	Restore User Data	Read

- **Supports up to128 different PMBus Addresses**
- **Supports 31 Commands**
- **Supports PMBus Alert function**
- **Supports 100KHz / 400KHz clock rates**

PMBus

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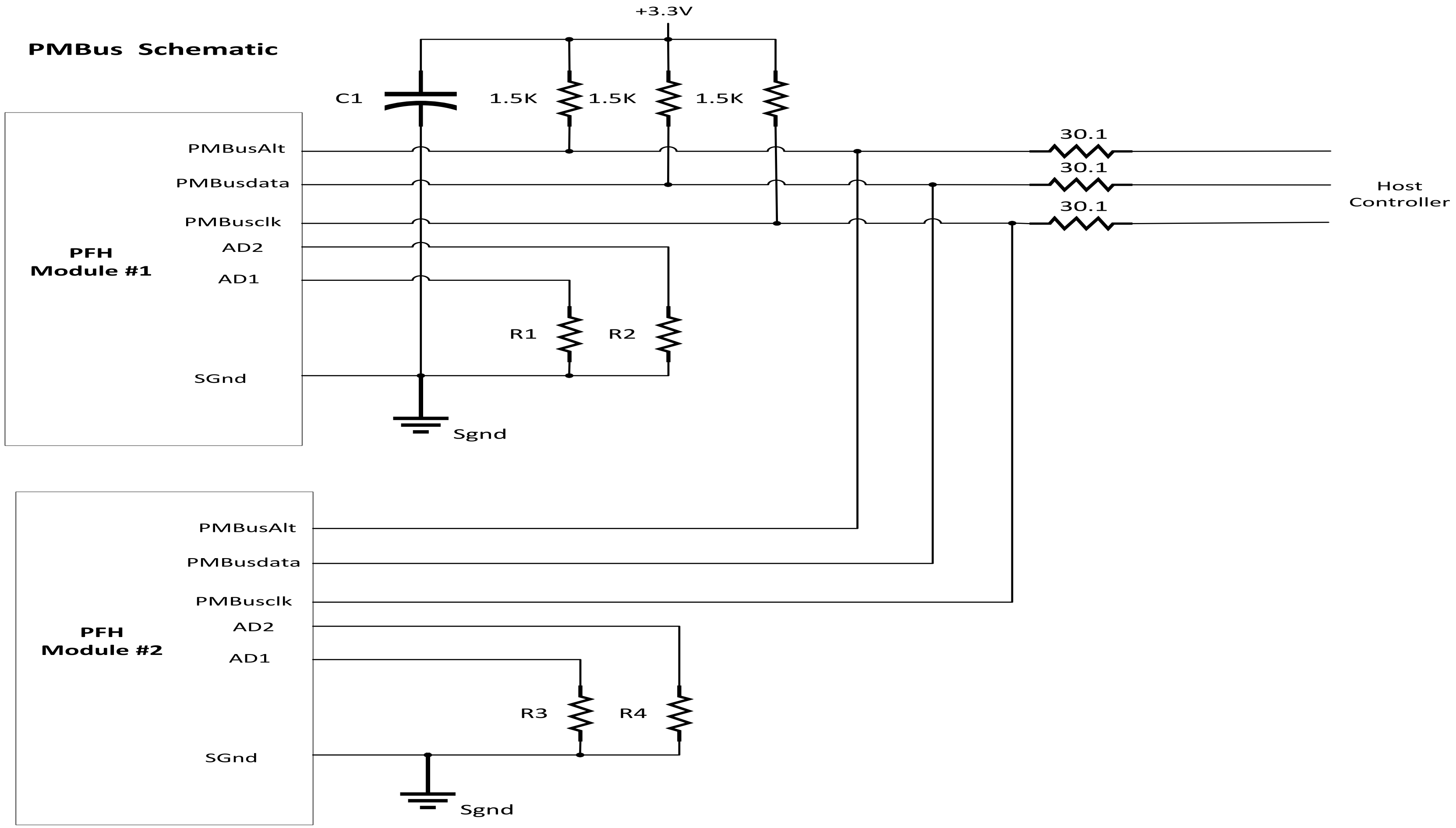
- Use of External Rs on AD pins to set PMBUs address
- Use of 7-bit address to identify devices on the bus



PFH GUI Screen-shot

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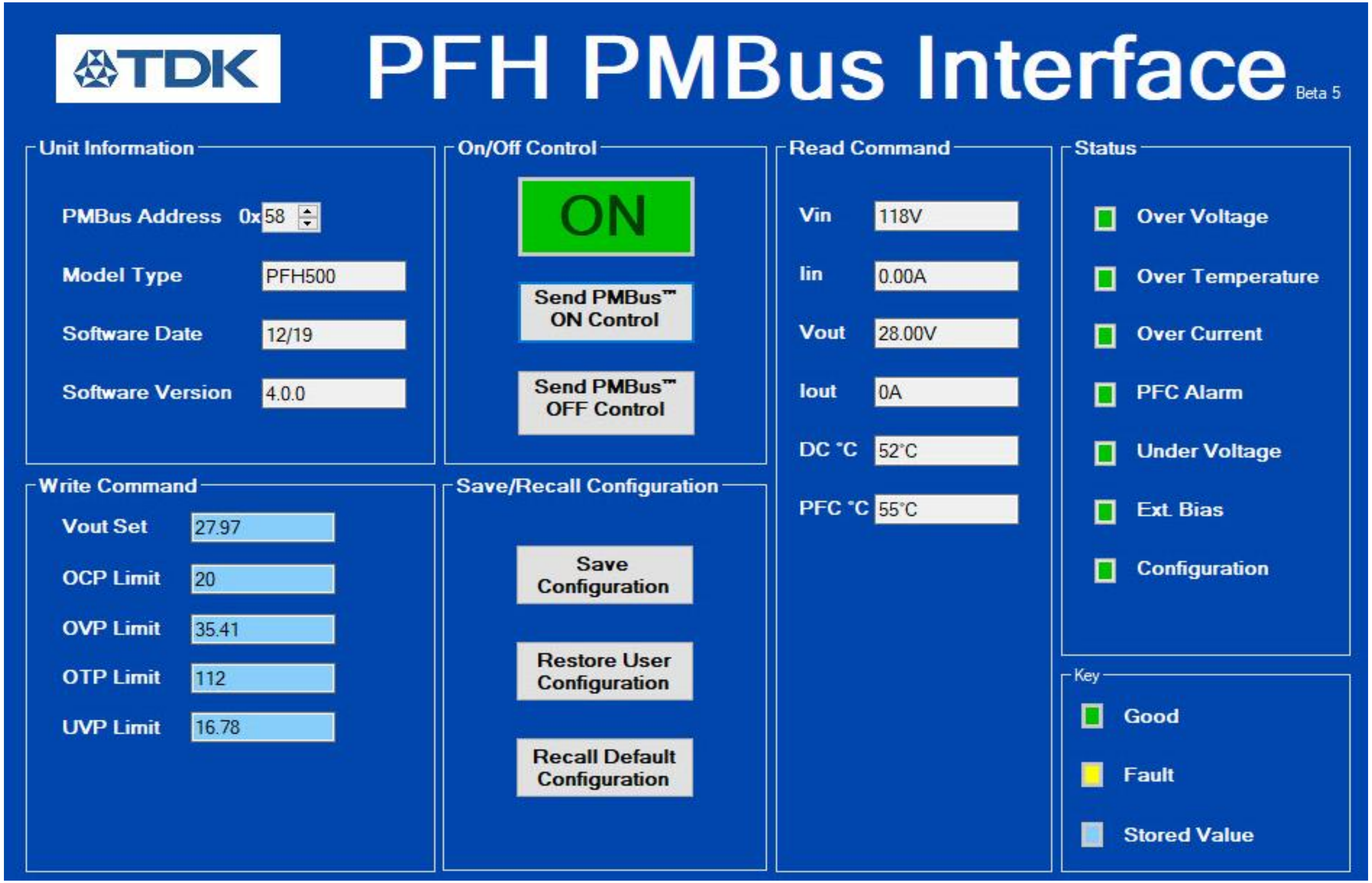

Thermal Consideration and Design

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- Original TDK PFE Power Module has a two-board design: Insulated Metal Substrate + Control board
- Eliminating IMS Board Helps to Improve Common Mode Noise Generation (Parasitic Cap)
- Hurts Heat Transfer Efficiency (Power Devices plus Magnetics Mount on FR-4 board)
- FR-4 Board UL Temp Limit is 130C (PCB Board for Transformer & Inductor Windings)
- Smaller PFH Module Foot-Print Further Reduces Surface Areas for Heat Transfer
- Use of Potting Material to Assist the Reinforced Safety Isolation Requirement (Pollution I or II)
- Potting Material is NOT a Very Desired Heat Transfer Thermal Interface Material (TIF)
- Potting Process and Curing Process Add Manufacturing Complexity and Labor Cost
- Potting Material Expansion May Cause Components Solder Joints Reliability Issue
- Different CTE (Cu, FR-4, Case, Potting Material) Can Add High Mechanical Stresses to Internal Parts
- To Achieve High Density: High Efficiency, Good Package Design with Good Heat Transfer are the Keys
- Good Mechanical Package Design, Potting Process, and Assembly Process: Keys for Reliability

PFH Thermal Images and De-rating Curves

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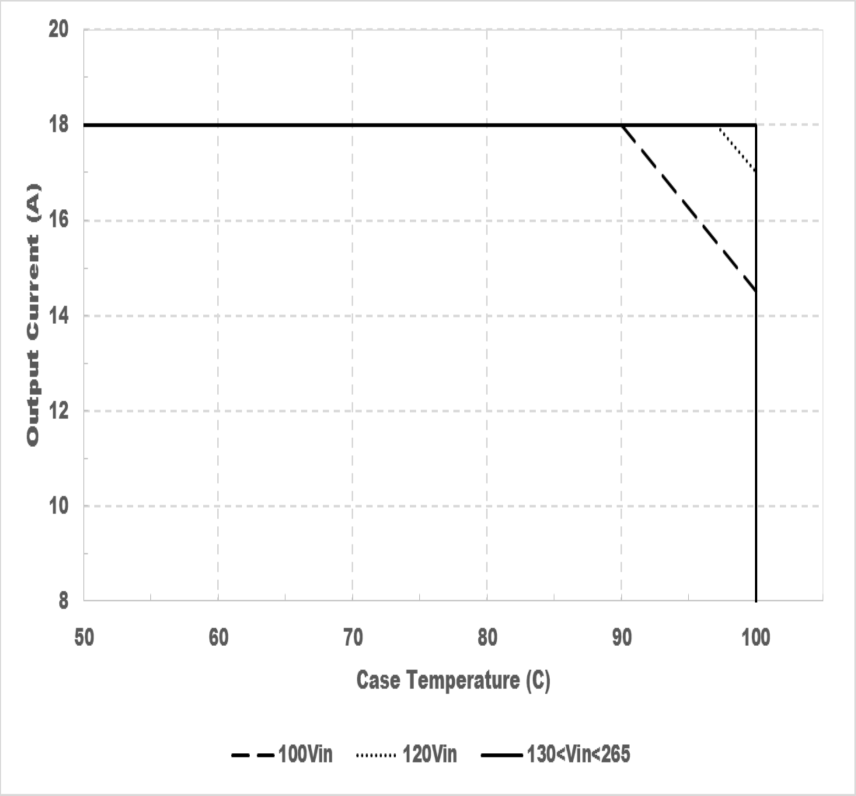
Open Frame Module, Tested in Socket

Vin=230Vac, Io=18A, Vo=28V, Po=504W



PFH Specification

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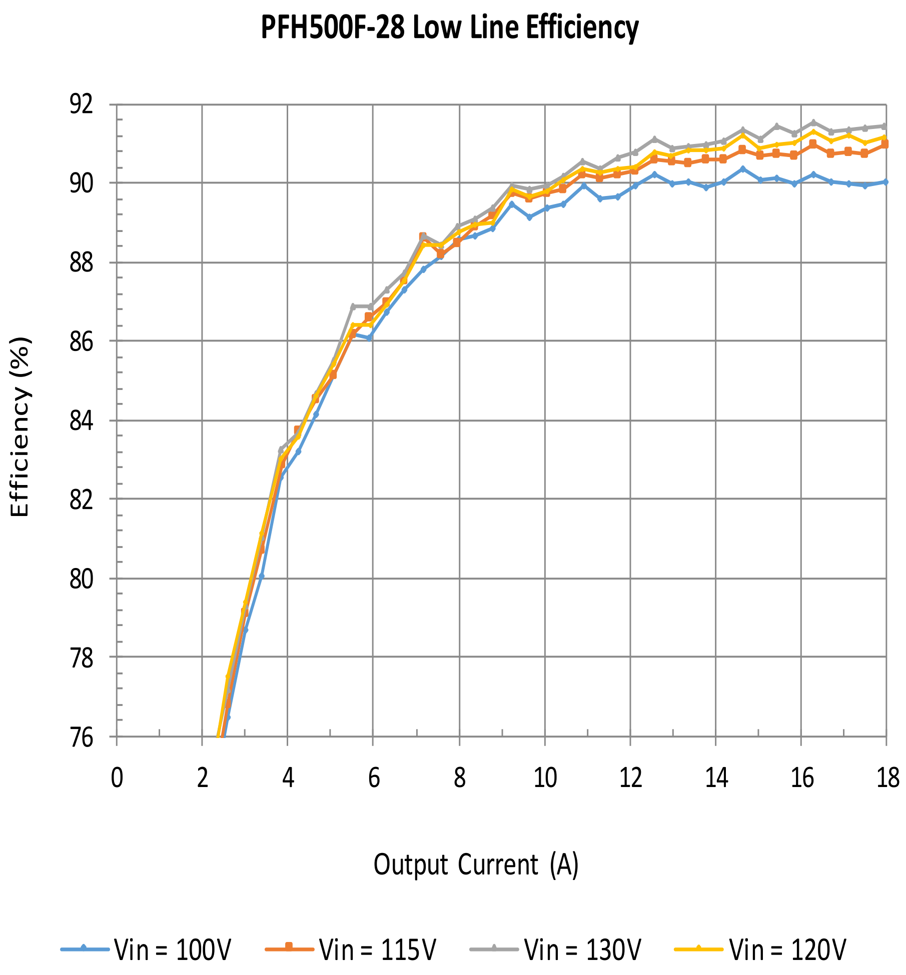
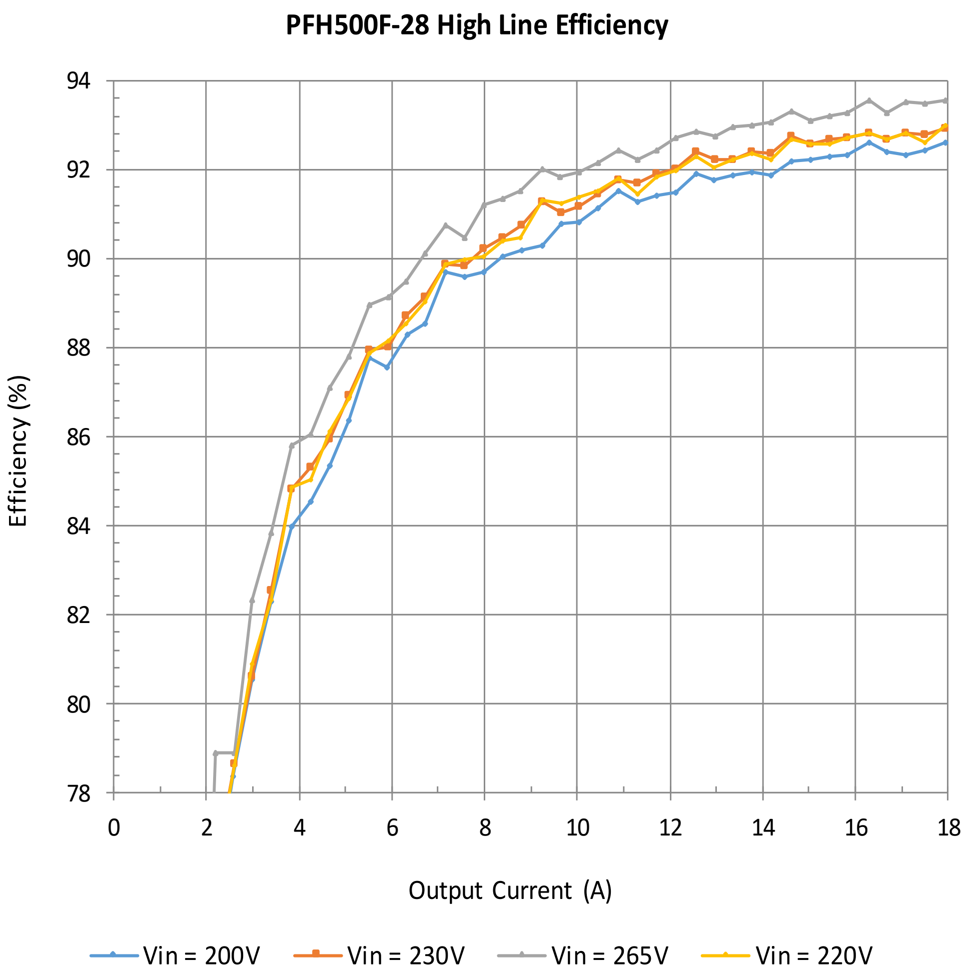
Parameter	PFH500F-28-100
Input voltage	85-265VAC (47-63Hz, 400Hz option)
Power Factor	0.95 minimum
Efficiency (115V/230VAC)	90% / 92%
Vo nominal	28V
Vo adjustable range	± 20%
Remote Sense	Possible
Power good	200mA Max, (low active)
Remote on/off	Negative (pull low to enable)
Auxiliary supply	12V, 200mA
Parallel operation (optional)	Droop mode
Interface	Digital (PMBus)
Protections	OVP (latch), OCP (non latch), OTP (Latch)
Operation temperature	-40 – 100C
Cooling	Conduction cooled
Withstand voltage	3KVAC (In-Out), 2.5KVAC (In-case), 1.5KVdc (Out-case)
Size	4.0 x 2.4 x 0.51 (101.6 x 61 x 12.9)

Typical Efficiency Curves





Droop Load Share

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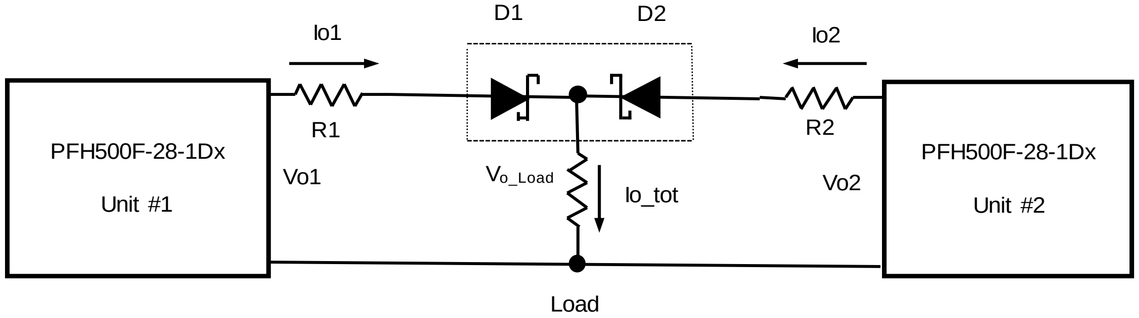
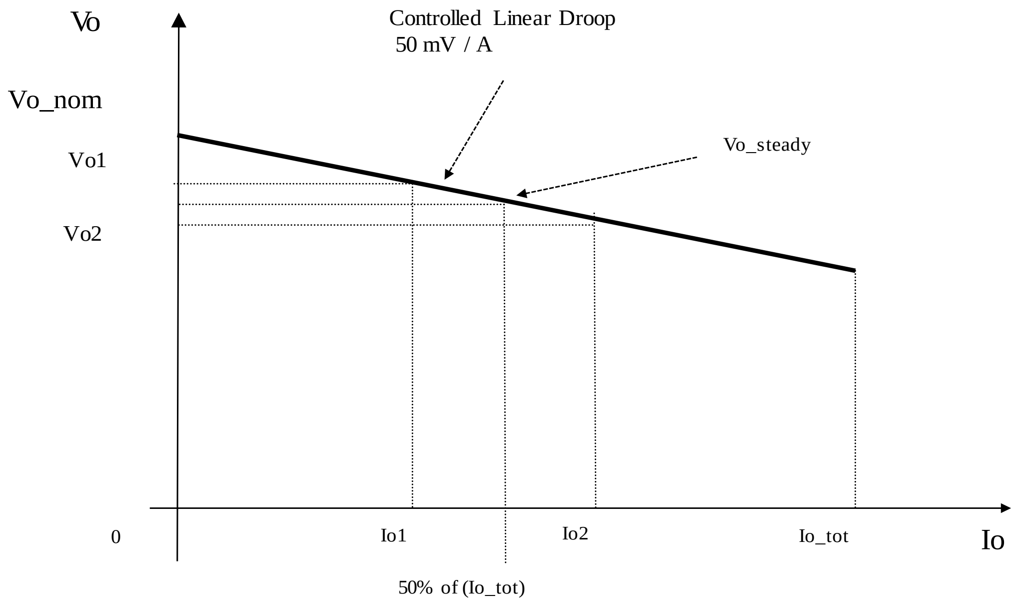
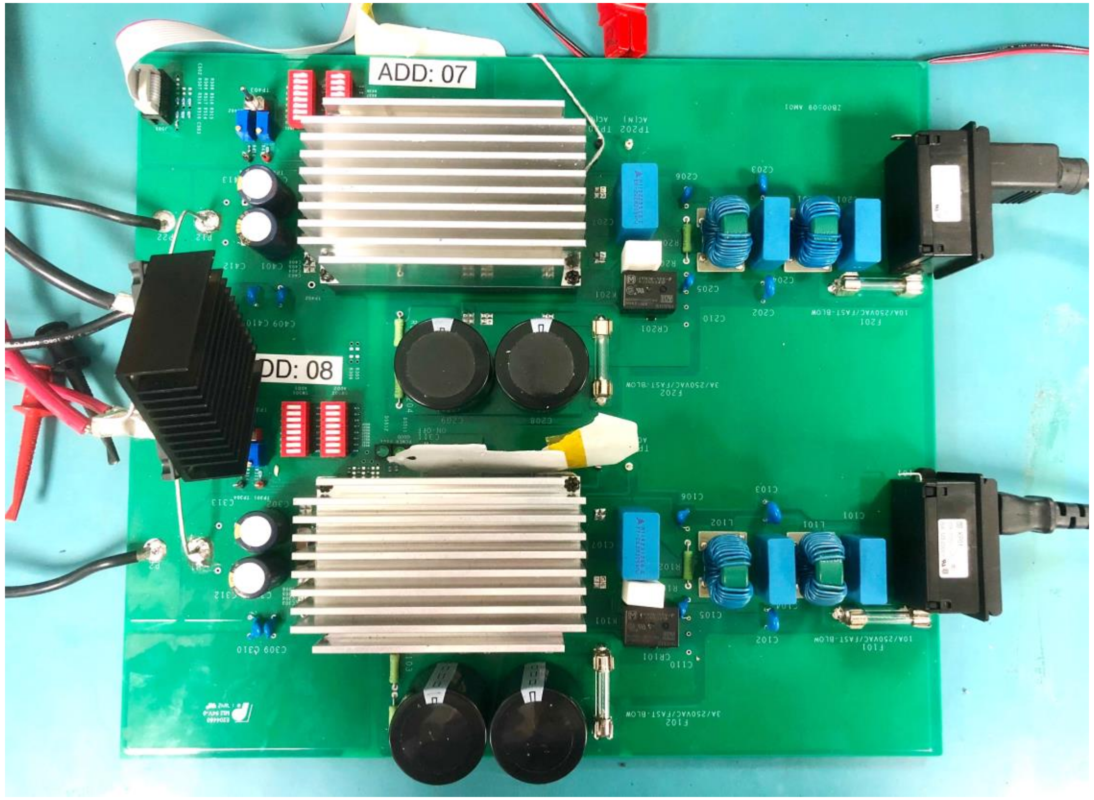
- PFH500 Uses Droop Load Share Method
- Sensing Load Current, Reducing Vref
- Output Voltage Drops as Load Increases
- SR Operation: Fast No Load to Heavy Load Transient
- Oring FETs or Oring Diodes Needed for Redundancy
- Initial Vo Setting + Load Sensing Accuracy: Keys
- Wiring Impedance / Oring Device Drops Balance
- Parallel More Than 3: Possible
- Two PFHs Can Also be Connected in Series



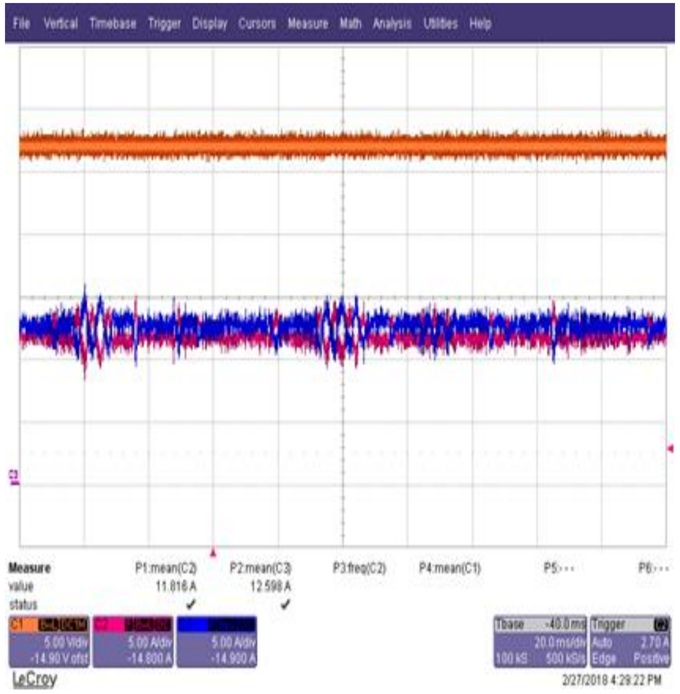


Load Share Test Set-up

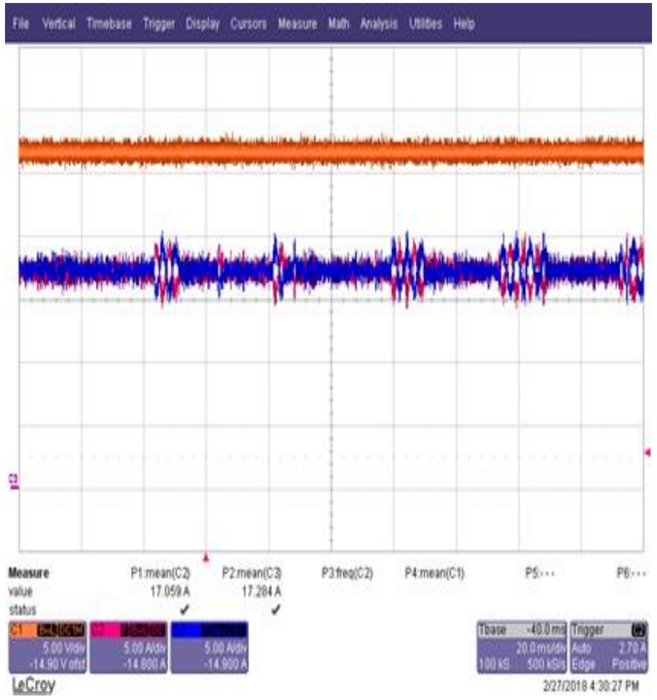


Static Load Share

25A Total Load



35A Total Load



Ch.1 Vout Ch. 2 Io1 Ch.3 Io_2

Dynamic Load Share

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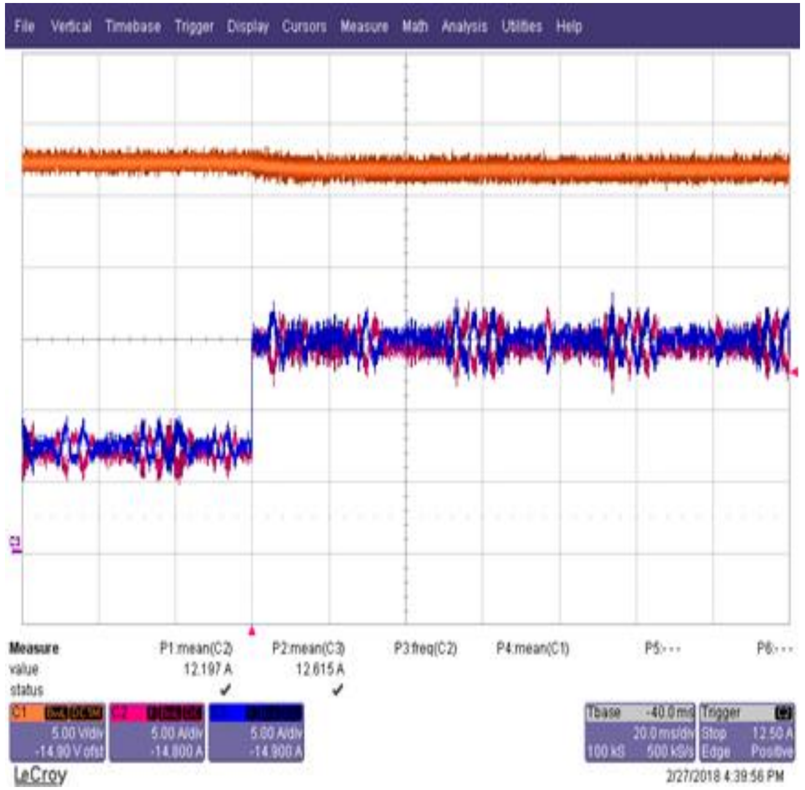
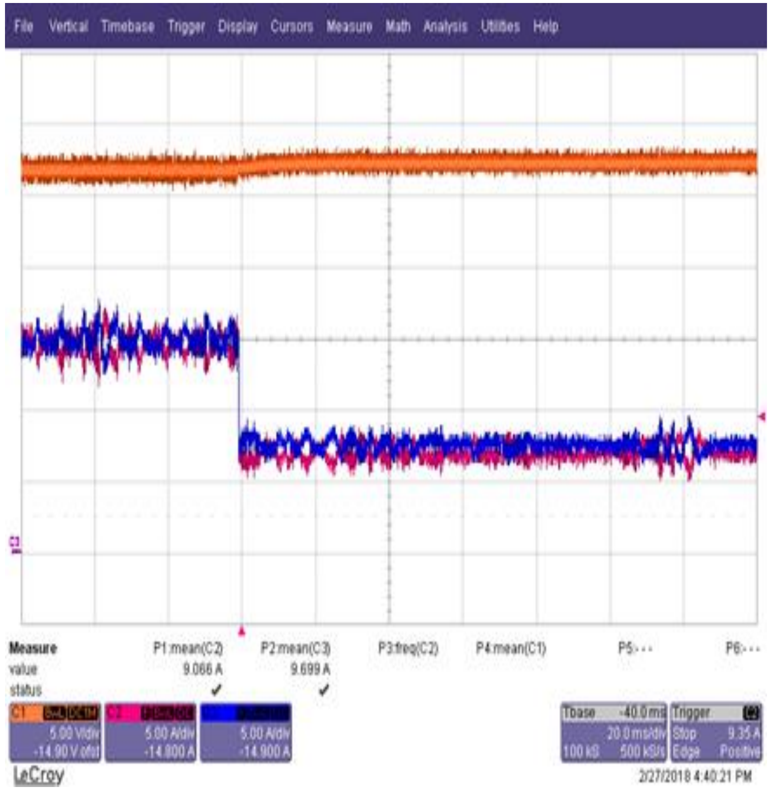
Transient Load Step (load step 50%, 1A/us slew rate)

Ch1 = Vout Bus   Ch2 = Iout Unit 1   Ch3 = Iout Unit 2



15A to 30A



30A to 15A

Dynamic Load Share

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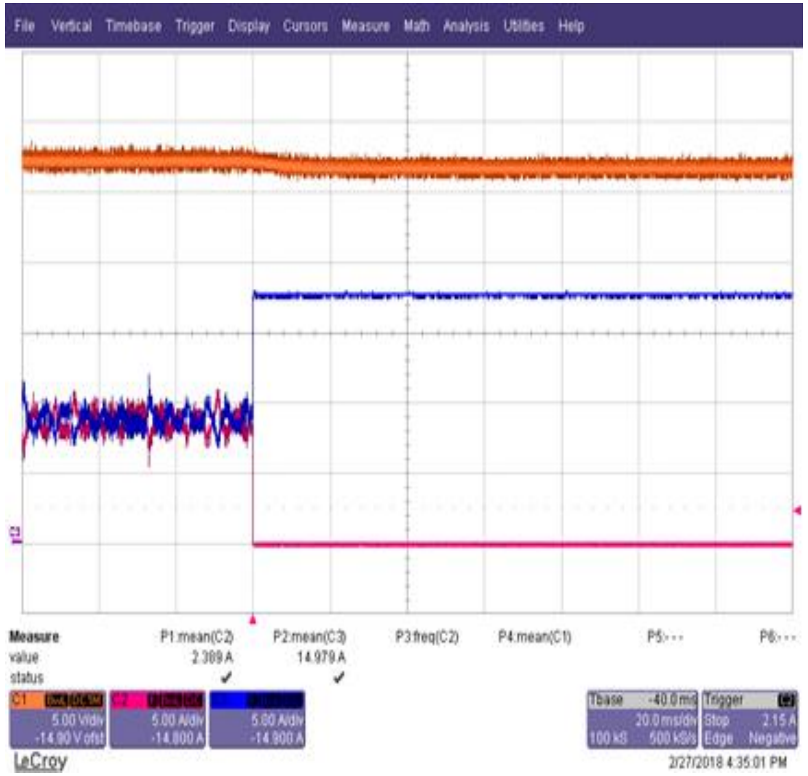
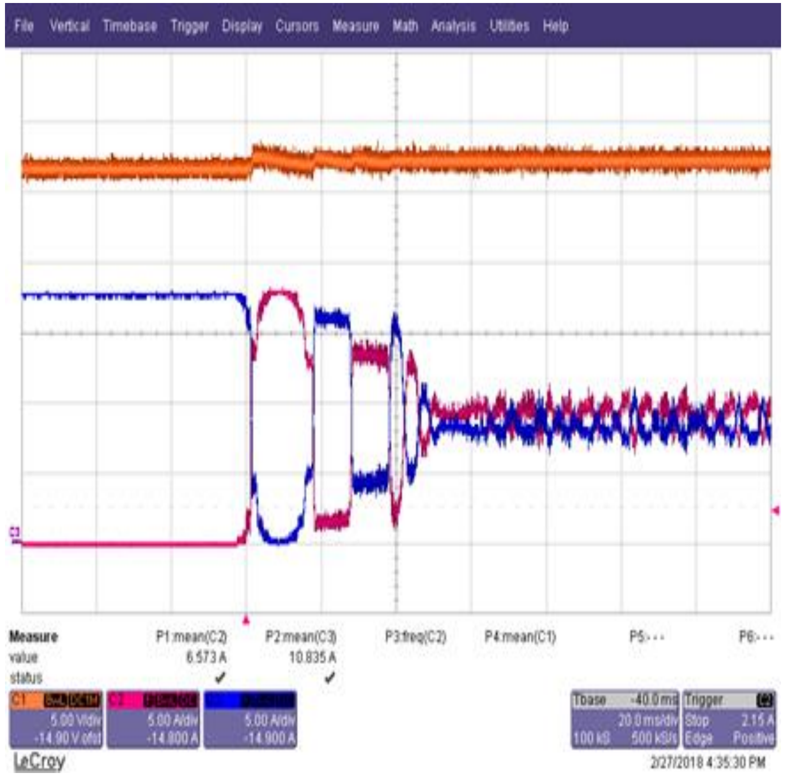
2 units running, 1 unit shutdown



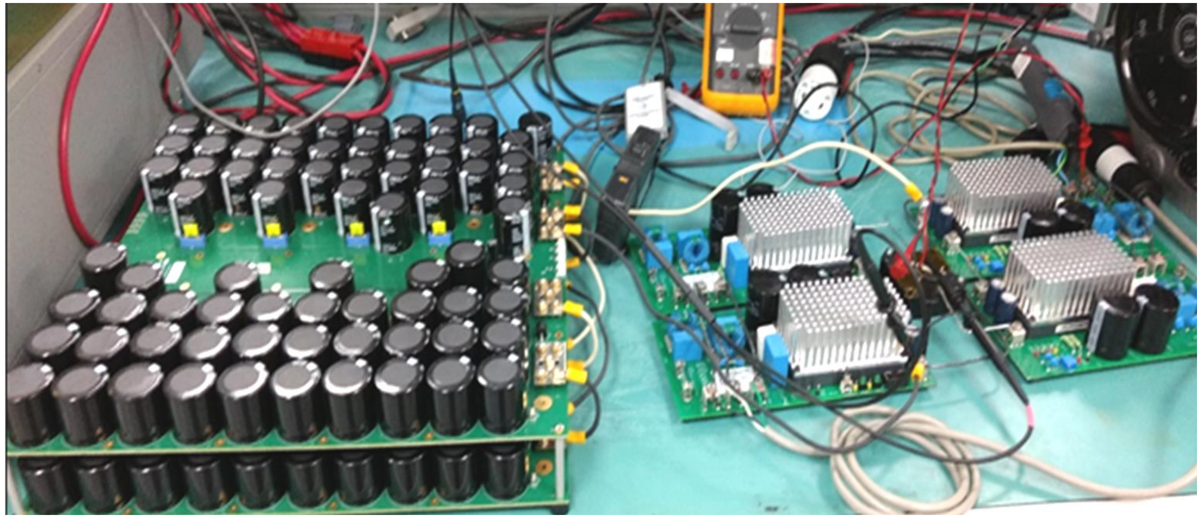
1 unit running, 2nd unit turning on

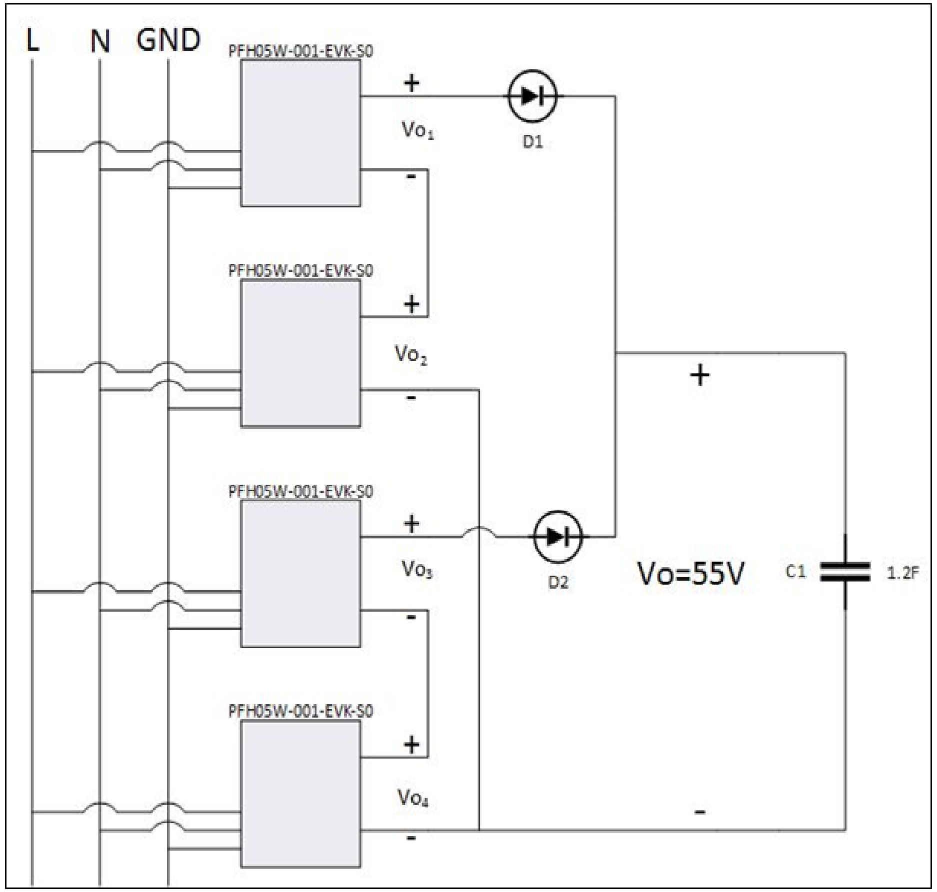


Ch1 = Vout Bus Ch2 = Iout Unit 1 Ch3 = Iout Unit 2

Load Share with Large Capacitive Load Application

- 2 Modules in Series for 1kW,
- 2 Series Branches in Parallel (for total 2kW)
- Tested Load Capacitance > 1F





EMI

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- Single Board Design Mitigates Common-Mode Noise (no parasitic common-mode caps)
- 5 Sided Metal Case Helps the Radiated Noise Emission
- Passing Class B for both Conducted and Radiated Emission even with fast switching GaN

Conducted Emission Test Set-up

Radiated Emission Test Set-up

EMI: Conducted Emission Test

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CONDUCTED EMISSIONS

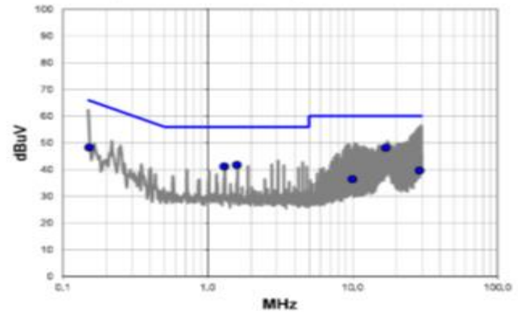
element

Work Order:	TDKL0022	Date:	1-May-2019
Project:	None	Temperature:	22.1 °C
Job Site:	TX01	Humidity:	53.4% RH
Serial Number:	None	Barometric Pres.:	1017 mbar
Tested by:	Marty Martin		
EUT:	PFH 500F-28V-100-R Module		
Configuration:	Unknown		
Customer:	TDK-Lambda Americas Inc.		
Attendees:	Shuhui and Michael		
EUT Power:	110VAC/60Hz		
Operating Mode:	16.9 amp Load		
Deviations:	None		
Comments:	Heatsink tied to EGND		

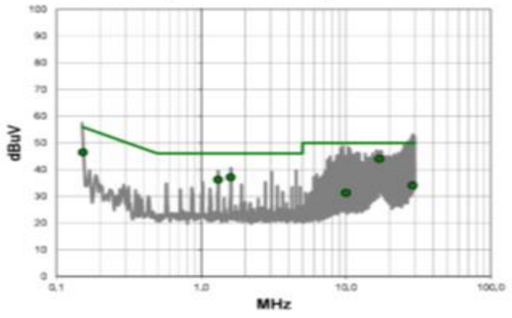
Test Specifications	Class B	Test Method
EN 55032:2012/AC:2013		CISPR 32:2015

Run #	20	Line:	High Line	Ext. Attenuation:	0	Results	Pass

Quasi Peak Data - vs - Quasi Peak Limit



Average Data - vs - Average Limit



Quasi Peak Data - vs - Quasi Peak Limit

Freq (MHz)	Amplitude (dBuV)	Factor (dB)	Adjusted ()	Spec. Limit ()	Compared to Spec. (dB)
16.994	27.2	20.9	48.1	60.0	-11.9
0.153	27.9	20.3	48.2	65.9	-17.7
1.595	21.6	20.1	41.7	56.0	-14.3
1.306	21.0	20.1	41.1	56.0	-14.9
28.997	17.7	21.9	39.6	60.0	-20.4
9.997	15.9	20.5	36.4	60.0	-23.6

Average Data - vs - Average Limit

Freq (MHz)	Amplitude (dBuV)	Factor (dB)	Adjusted ()	Spec. Limit ()	Compared to Spec. (dB)
16.994	23.1	20.9	44.0	50.0	-6.0
0.153	26.1	20.3	46.4	55.9	-9.5
1.595	17.0	20.1	37.1	46.0	-8.9
1.306	16.1	20.1	36.2	46.0	-9.8
28.997	12.1	21.9	34.0	50.0	-16.0
9.997	10.7	20.5	31.2	50.0	-18.8

CONDUCTED EMISSIONS

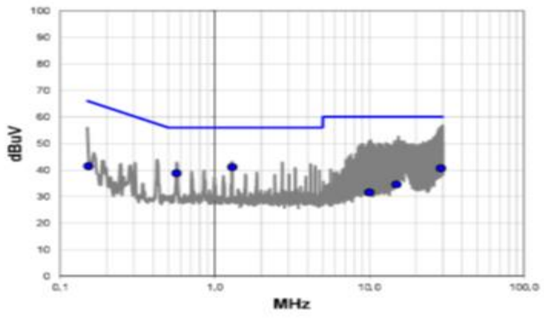
element

Work Order:	TDKL0022	Date:	1-May-2019
Project:	None	Temperature:	22.1 °C
Job Site:	TX01	Humidity:	53.4% RH
Serial Number:	None	Barometric Pres.:	1017 mbar
Tested by:	Marty Martin		
EUT:	PFH 500F-28V-100-R Module		
Configuration:	Unknown		
Customer:	TDK-Lambda Americas Inc.		
Attendees:	Shuhui and Michael		
EUT Power:	230VAC/50Hz		
Operating Mode:	16.9 amp Load		
Deviations:	None		
Comments:	Heatsink tied to EGND		

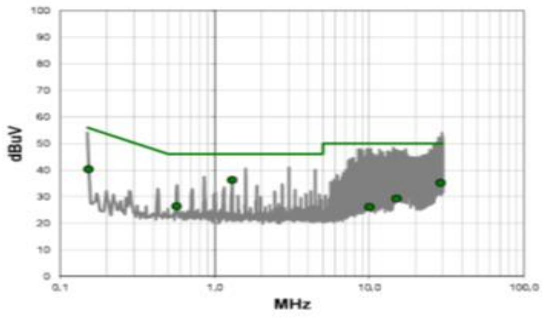
Test Specifications	Class B	Test Method
EN 55032:2012/AC:2013		CISPR 32:2015

Run #	23	Line:	High Line	Ext. Attenuation:	0	Results	Pass

Quasi Peak Data - vs - Quasi Peak Limit



Average Data - vs - Average Limit



Quasi Peak Data - vs - Quasi Peak Limit

Freq (MHz)	Amplitude (dBuV)	Factor (dB)	Adjusted (dBuV)	Spec. Limit (dBuV)	Compared to Spec. (dB)
1.296	21.1	20.0	41.1	56.0	-14.9
28.992	18.8	21.9	40.7	60.0	-19.3
0.566	18.7	20.1	38.8	56.0	-17.2
0.153	21.2	20.3	41.5	65.9	-24.4
14.997	13.9	20.7	34.6	60.0	-25.4
9.995	11.1	20.5	31.6	60.0	-28.4

Average Data - vs - Average Limit

Freq (MHz)	Amplitude (dBuV)	Factor (dB)	Adjusted (dBuV)	Spec. Limit (dBuV)	Compared to Spec. (dB)
1.296	16.3	20.0	36.3	46.0	-9.7
28.992	13.3	21.9	35.2	50.0	-14.8
0.153	20.0	20.3	40.3	55.9	-15.6
14.997	8.6	20.7	29.3	50.0	-20.7
0.566	6.3	20.1	26.4	46.0	-19.6
9.995	5.6	20.5	26.1	50.0	-23.9

EMI: Radiated Emission Test

Attracting Tomorrow TDK

RADIATED EMISSIONS

EUT:	AC/DC Power Supply	Work Order:	TDKL0004
Serial Number:	None	Date:	09/14/2017
Customer:	TDK-Lambda Americas Inc.	Temperature:	23.9°C
Attendees:	Michael Lawrence	Relative Humidity:	46.1%
Customer Project:	None	Bar. Pressure:	1014 mb
Tested By:	Marty Martin	Job Site:	TX02
Power:	230VAC/50Hz	Configuration:	TDKL0004-1

TEST SPECIFICATIONS

Specification: Equipment Class B	Method:
EN 55032:2012/AC:2013	CISPR 32:2015

TEST PARAMETERS

Run #:	9	Test Distance (m):	10	Ant. Height(s) (m):	1 to 4(m)

COMMENTS

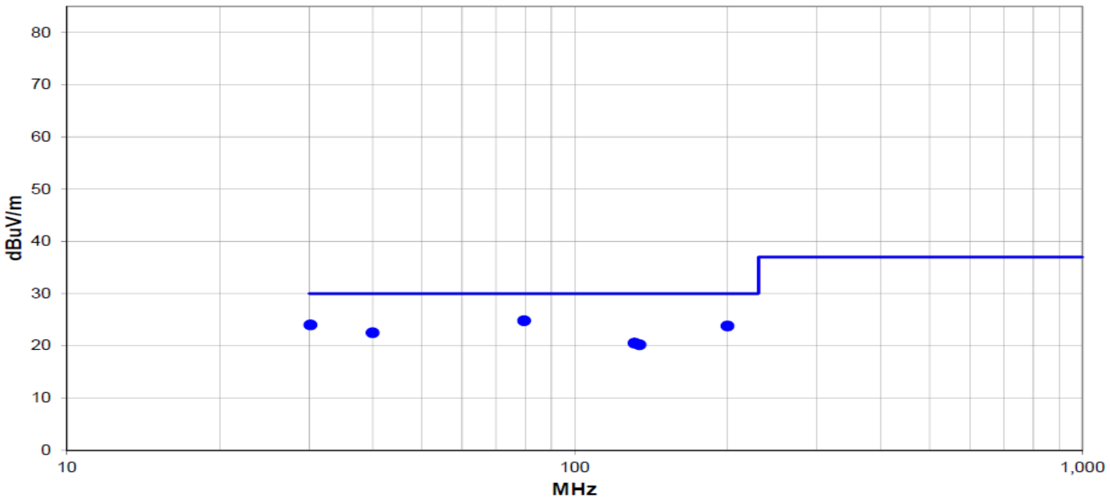
This is eval data only. 230VAC, Full load [internal], 6T-31. Added grounding strap.

EUT OPERATING MODES

Typical Operating Mode

DEVIATIONS FROM TEST STANDARD

None



Run #: 9 PK AV QP

RADIATED EMISSIONS

EUT:	AC/DC Power Supply	Work Order:	TDKL0004
Serial Number:	None	Date:	09/14/2017
Customer:	TDK-Lambda Americas Inc.	Temperature:	23.9°C
Attendees:	Michael Lawrence	Relative Humidity:	46.1%
Customer Project:	None	Bar. Pressure:	1014 mb
Tested By:	Marty Martin	Job Site:	TX02
Power:	120VAC/60Hz	Configuration:	TDKL0004-1

TEST SPECIFICATIONS

Specification: Equipment Class B	Method:
EN 55032:2012/AC:2013	CISPR 32:2015

TEST PARAMETERS

Run #:	10	Test Distance (m):	10	Ant. Height(s) (m):	1 to 4(m)

COMMENTS

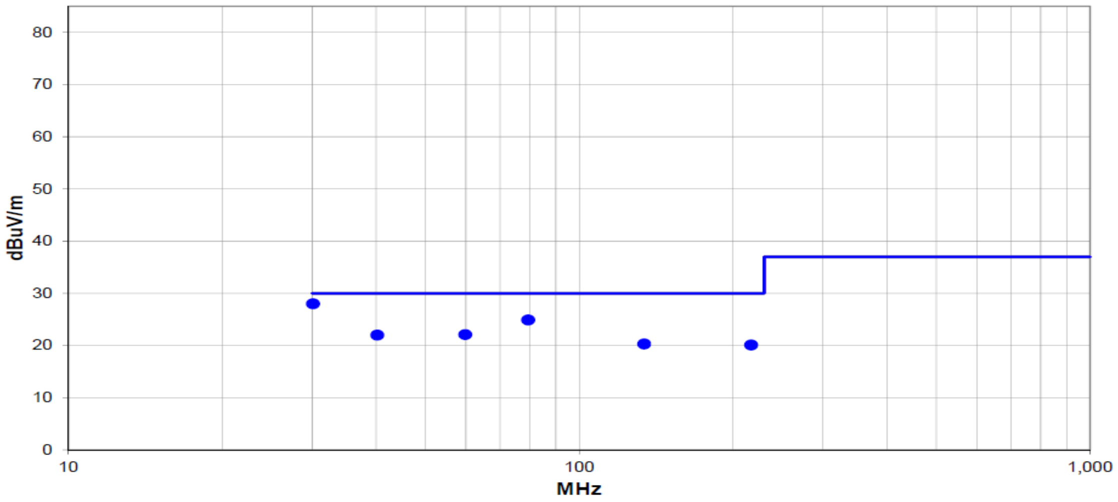
This is eval data only. 120VAC, Full load [internal], 6T-31. Added grounding strap.

EUT OPERATING MODES

Typical Operating Mode

DEVIATIONS FROM TEST STANDARD

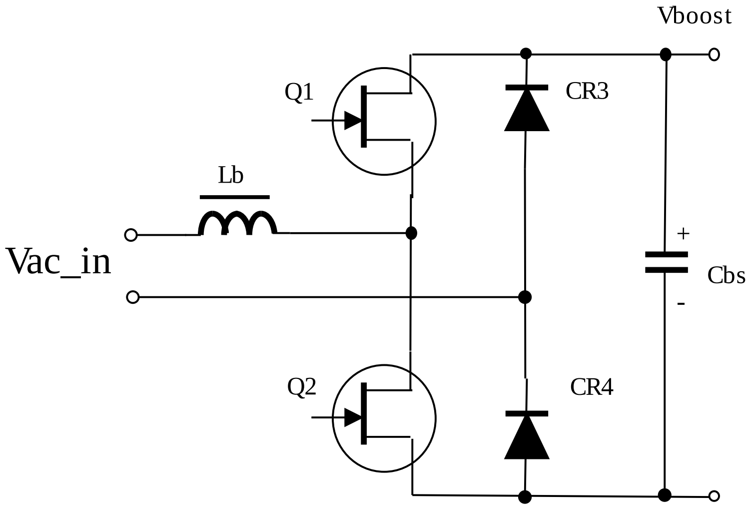
None



Run #: 10 PK AV QP

Survive AC Line Surges

- Half Bridge Switch Formation in Totem-Pole PFC
- AC Line Voltage Zero-Crossing Detection: Critical
- Turning-on Wrong Devices can Cause Failure
- Power Module Small Size Limits Boost Inductance Value
- Lower Peak Current Capability: GaN vs. Super Junction FETs

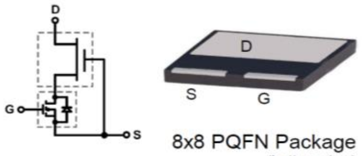


Product Summary (Typical)	
V_{DS} (V)	600
$R_{DS(on)}$ (Ω)	0.15
Q_{rr} (nC)	54

GaN Power
Low-loss Switch

Features
- Low Q_{rr}
- Free-wheeling diode not required
- High-side Quiet Tab™ for reduced EMI
- RoHS compliant
- High frequency operation

Applications
- Compact DC-DC converters
- AC motor drives
- Battery chargers
- Switch mode power supplies



8x8 PQFN Package
(bottom view)

Absolute Maximum Ratings (T_C=25 °C unless otherwise stated)

Symbol	Parameter	Limit Value	Unit
$I_{D25°C}$	Continuous Drain Current @T_C=25 °C	17	A
$I_{D100°C}$	Continuous Drain Current @T_C=100 °C	12	A
I_{DM}	Pulsed Drain Current (pulse width:100 μs)	60	A
V_{DSS}	Drain to Source Voltage	600	V
V_{TDS}	Transient Drain to Source Voltage [a]	750	V
V_{GSS}	Gate to Source Voltage	±18	V
$P_{D25°C}$	Maximum Power Dissipation	96	W
T_C	Operating Temperature Case	-55 to 150	°C

650V CoolMOS™ C7 Power Transistor

IPL65R070C7

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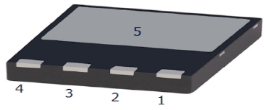


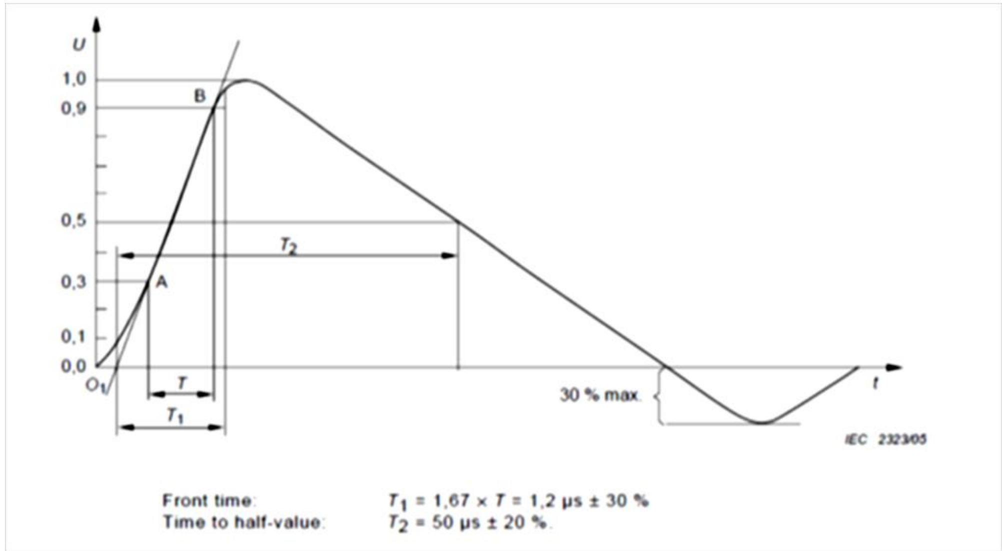
Table 1 Key Performance Parameters

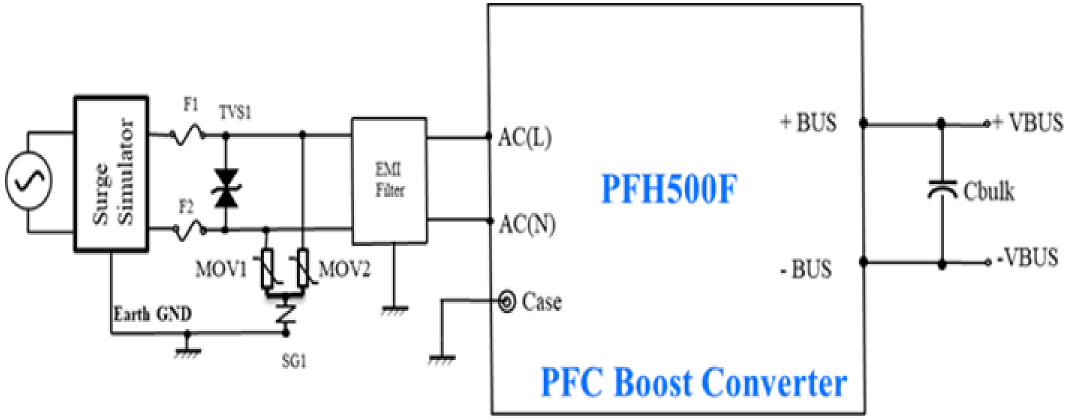
Parameter	Value	Unit
V_{DS} @ $T_{j,max}$	700	V
$R_{DS(on),max}$	70	mΩ
$Q_{g,typ}$	64	nC
$I_{D,pulse}$	145	A
E_{oss}@400V	8	μJ
Body diode di/dt	60	A/μs

Survive AC Line Surges

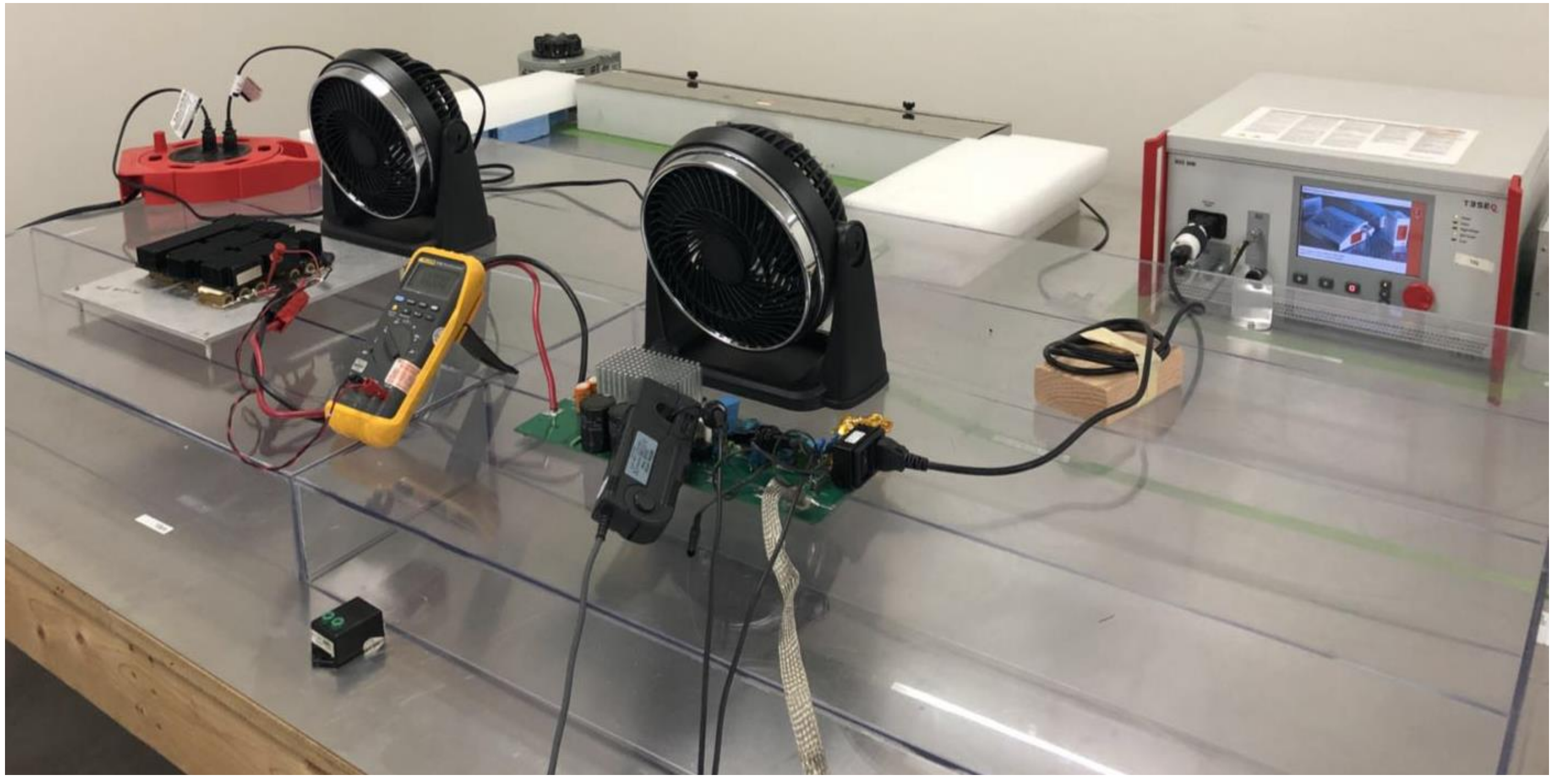
Attracting Tomorrow TDK

- For IEC61000-4-5, Level 4:
- Differential Mode Surge: +/-2kV (2 OHM Impedance)
- Common Mode surges: +/-4kV (12 OHM Impedance)
- Peak Surge Current can reach 1kA
- AC Line Voltage may be distorted during the surges
- Designed for Criteria: B
- External Protection Devices Needed
- Fast Power TVS device + MOVs and SG used
- Fast Input OVP & Input OCP detections Needed
- PFH500F passed IEC61000-4-5, Level 4





IEC 61000-4-5 Line Surges Test Set-up



IEC 61000-4-5 Line Surges

Attracting Tomorrow TDK

EUT:	PFH Module	Work Order:	TDKL0008
Serial Number:	PFH041732M0014	Date:	03/19/2018
Customer:	TDK-Lambda Americas Inc.	Temperature:	23.4°C
Attendees:	Shuhui Mi	Relative Humidity:	35.8%
Customer Project:	None	Bar. Pressure:	986 mbar
Tested By:	Jonathan Kiefer	Job Site:	TX07
Power:	Input: 110VAC/60Hz, Output: Vo = 28VDC, Io = 14A	Configuration:	TDKL0008-1

TEST SPECIFICATIONS

Specification:	Method:
IEC 61000-4-5:2014	IEC 61000-4-5:2014

TEST PARAMETERS

Open Circuit Voltage, Risetime:	1.2 us ± 30%	Short Circuit Current, Risetime:	8 us ± 20%
Open Circuit Voltage, Time to ½ Value:	50 us ± 20%	Short Circuit Current, Time to ½ Value:	20 us ± 20%
Time Between Successive Pulses:	60 seconds		

COMMENTS

Evaluated according to IEC 61000-4-5 Level 4 per customer requirements. 77% Load.

EUT OPERATING MODES

Supply Constant Output 28VDC

DEVIATIONS FROM TEST STANDARD

None

EUT FUNCTIONS MONITORED

Monitoring the Fluke multimeter and the Oscilloscope for any glitches or anomalies.

RESULTS

5 Surges Each Setting

	COMMON MODE LOW LINE TO GROUND (12Ω IMPEDANCE)				COMMON MODE HIGH LINE TO GROUND (12Ω IMPEDANCE)				DIFFERENTIAL MODE HIGH LINE TO LOW LINE (2Ω IMPEDANCE)			
kV	0°	90°	180°	270°	0°	90°	180°	270°	0°	90°	180°	270°
+2.0	3	3	3	3	3	3	3	3	1	1	1	1
-2.0	3	3	3	3	3	3	3	3	1	1	1	1
+4.0	1	1	1	1	1	1	1	1	3	3	3	3
-4.0	1	1	1	1	1	1	1	1	3	3	3	3

OBSERVATIONS

Item	Observation
1	Output shut down, returned to normal operation in less than 1 sec. Manufacturer identifies this as criteria B.
2	Not Required
3	Not Tested

CONCLUSION

Meets Element Performance Criteria	B

The EUT exhibited a change in performance when operating as specified by the manufacturer, the EUT self-recovered.

FOR REFERENCE ONLY

IEC 61000-4-5 Line Surges

Attracting Tomorrow TDK

EUT:	PFH Module	Work Order:	TDKL0008
Serial Number:	PFH041732M0014	Date:	03/19/2018
Customer:	TDK-Lambda Americas Inc.	Temperature:	23.4°C
Attendees:	Shuhui Mi	Relative Humidity:	35.8%
Customer Project:	None	Bar. Pressure:	986 mbar
Tested By:	Jonathan Kiefer	Job Site:	TX07
Power:	Input: 230VAC/50Hz, Output: Vo = 28VDC, Io = 14A	Configuration:	TDKL0008-1

TEST SPECIFICATIONS

Specification:	Method:
IEC 61000-4-5:2014	IEC 61000-4-5:2014

TEST PARAMETERS

Open Circuit Voltage, Risetime:	1.2 us ± 30%	Short Circuit Current, Risetime:	8 us ± 20%
Open Circuit Voltage, Time to ½ Value:	50 us ± 20%	Short Circuit Current, Time to ½ Value:	20 us ± 20%
Time Between Successive Pulses:	60 seconds		

COMMENTS

Evaluated according to IEC 61000-4-5 Level 4 per customer requirements. 77% Load.

EUT OPERATING MODES

Supply Constant Output 28VDC

DEVIATIONS FROM TEST STANDARD

None

EUT FUNCTIONS MONITORED

Monitoring the Fluke multimeter and the Oscilloscope for any glitches or anomalies.

RESULTS

5 Surges Each Setting

	COMMON MODE LOW LINE TO GROUND (12Ω IMPEDANCE)				COMMON MODE HIGH LINE TO GROUND (12Ω IMPEDANCE)				DIFFERENTIAL MODE HIGH LINE TO LOW LINE (2Ω IMPEDANCE)			
kV	0°	90°	180°	270°	0°	90°	180°	270°	0°	90°	180°	270°
+2.0	3	3	3	3	3	3	3	3	1	1	1	1
-2.0	3	3	3	3	3	3	3	3	1	1	1	1
+4.0	1	1	1	1	1	1	1	1	3	3	3	3
-4.0	1	1	1	1	1	1	1	1	3	3	3	3

OBSERVATIONS

Item	Observation
1	Output shut down, returned to normal operation in less than 1 sec. Manufacturer identifies this as criteria B.
2	Not Required
3	Not Tested

CONCLUSION

Meets Element Performance Criteria	B

The EUT exhibited a change in performance when operating as specified by the manufacturer, the EUT self-recovered.

FOR REFERENCE ONLY

Tested By

Summary

Attracting Tomorrow TDK

- PFH: Smaller Size, Highest Power Density (> $100W/in^3$) Isolated AC-DC Power Module
- Successful Use of Bridgeless Totem-Pole PFC with GaN Devices and Digital Controller
- Use of Synchronous Rectification for PFC and DC-DC Capable of Load Share
- Full Digital PWM Control with Analog Speed and PMBus Feature Set
- Single PCB Board Design with Metal Case and Potting
- High Efficiency: 90% at low line nominal and 92% at high line nominal
- Good thermal design with minimal thermal de-rating with smaller size (4” x 2.4” x 0.52”)
- Meet Reinforced Isolation Requirement (I/O: 3,000 Vac; I/C: 2,500Vac; O/C: 1,500Vdc)
- Passed IEC61000-4-5, Level 4 Surges
- Passed EMC EN55032-Class B EMI
- Offering: 12V, 24V, 28V, and 48V Models
- Option for 400Hz Operation (Tested for MIL-Std 704)
- Released for Mass Production