

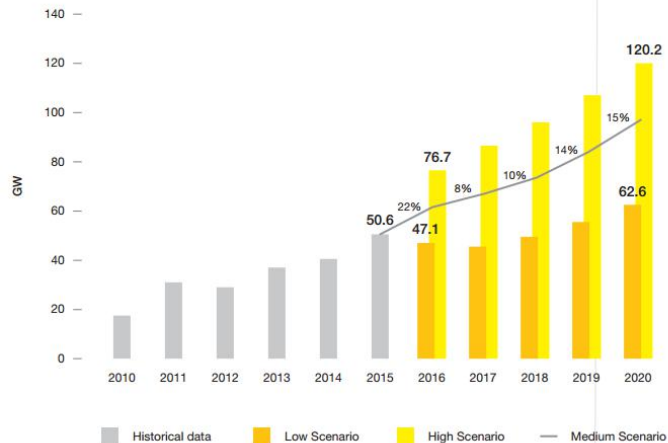
TI 10KW High efficient/small size solar inverter new solution

Texas Instruments

April, Y18

WW Solar Trends

FIGURE 8 GLOBAL ANNUAL SOLAR PV MARKET SCENARIOS UNTIL 2020



- China is expected to install 30+GW in 2017
- 570+GW of Cumulative growth by 2022
- 5%+ growth CAGR 2017-2022

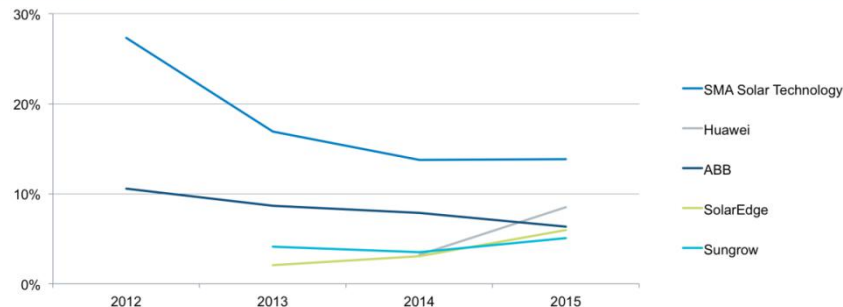
<http://www.greentechmedia.com/articles/read/huawei-and-sma-lead-gtm-researchs-2015-global-pv-inverter-rankings>
<http://press.ihs.com/press-release/technology/sma-retains-top-ranking-global-pv-inverter-market-competitors-are-gaining-i>

FIGURE: Top 10 Global PV Inverter Vendors by Shipments and Revenue, 2015

Ranking by Total PV Inverter Shipments (MWac)		Ranking by Total PV Inverter Revenue (\$M)	
Rank	Company	Rank	Company
1	Huawei	1	SMA
2	Sungrow	2	Huawei
3	SMA	3	Sungrow
4	ABB	4	ABB
5	Sineng	5	SolarEdge
6	TMEIC	6	TMEIC
7	TBEA	7	Enphase
8	Schneider Electric	8	Schneider Electric
9	Power Electronics	9	Omron
10	SolarEdge	10	Tabuchi

Source: GTM Research's Global PV Inverter and MLPE Landscape

2012 - 2015 global market share (% of \$M) of five largest PV inverter suppliers



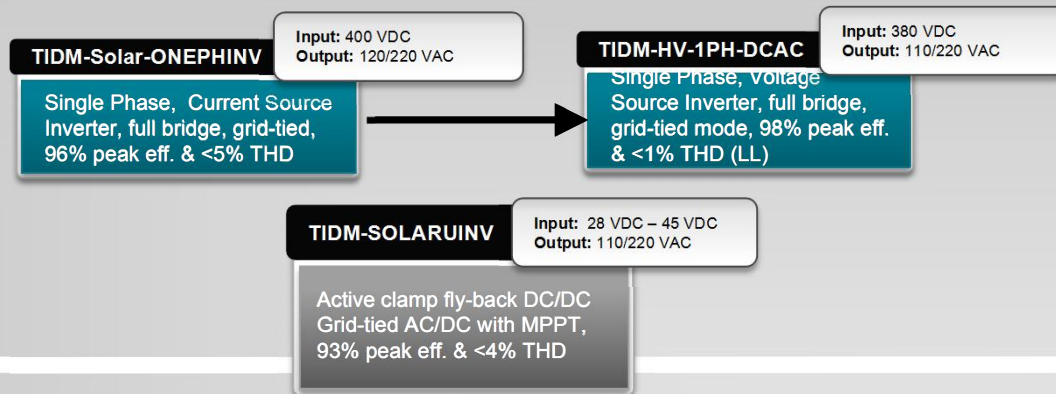
Notes: Market share not shown where it is less than 2%. Suppliers shown are five largest in 2015.
Source: IHS

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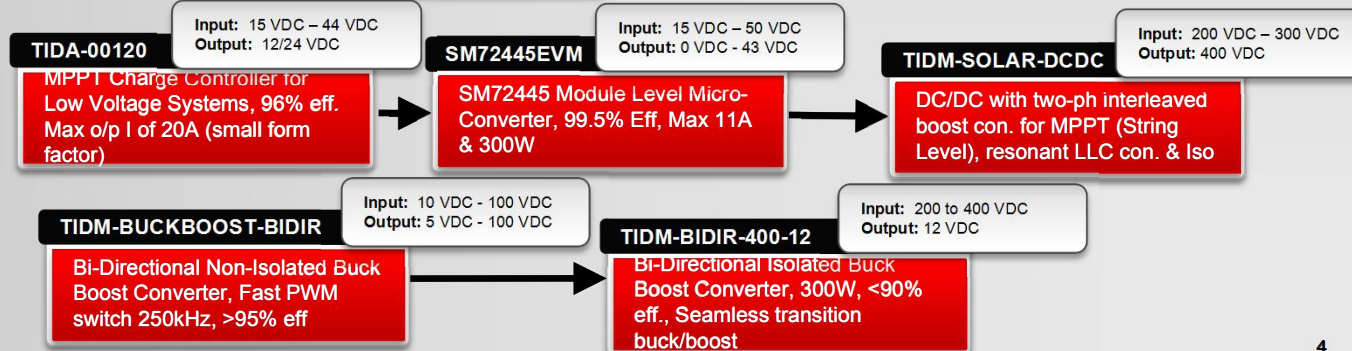
TI Design map for Solar Inverters and Renewable Energy Storage

TI Designs – Power Conversion Stages

DC/AC



DC/DC



Gate Drivers

PMP9455

3 A, Dual Ch, Non-Isolated,
Prop Delay 22 ns, Matching
Delay 1 ns, Dual Half Bridge
MOSFET Driver

Gate Driver for 800VA to
3kVA Inverters (SM72295),
Integrated current sense +
buf

TIDA-00448

4 A, Single Ch, Isolated,
Prop Delay 40 ns, IGBT
Driver

Flexible High Current IGBT
Gate Driver with Reinforced
Digital Isolation (ISO7842)

TIDA-00638

2 A, Single Ch, Reinforced
Isolation, Prop Delay 76 ns,
IGBT Driver

Isolated Gate Driver for 100V
to 400VAC inverters (SN6505
& ISO5451)

In-Design

TIDA-00195

2.5 A, Single Ch, Isolated,
Prop Delay 76 ns, IGBT Driver

Isolated IGBT Driver
Evaluation Platform for 3-
Phase Inverter (1200V IGBT &
50-200A)

PMP9461

DC/DC: 3A, Dual Ch, Non-Isolated, Prop
Delay 22 ns, Matching Delay 1 ns, Dual
Half Bridge MOSFET Driver
DC/DC: 7A, Single Ch, Non-Isolated, Prop
Delay 25 ns, MOSFET Driver

Complete Micro-inverter
design using SM72295 full
bridge driver with int. I sense

Full system design

HMI

TIDEP0044

Supports Wi-Fi, CAN, RS-232,
USB, Display, Industrial
Ethernet, and PLC

Solar Inverter Gateway
Development Platform
(AM3358)

TIDEP0015

Supports Ethernet, RS-485,
CAN, and Display

Capacitive Touchscreen
Display (Sitara AM4376)

TIDM-CAPTIVATE-64-BUTTON

Single and multitouch
detection, 100sps and 10ms
typical delay

64-Button Capacitive Touch
Panel With TI Microcontroller
With CapTIvate Technology

TI Designs – V & I Sensing

Shunts

Non-Isolated

TIDA-00528 (OPA333/INA226)

40 to 400 V Uni-Directional
Current/Voltage/Power
Monitoring

Max Voltage: 400 V
Max Current: 8 A

TIDA-00639 (OPA333/INA226)

600 V Uni-Directional
Current/Voltage/Power Monitoring
for Smart Combiner Box

Max Voltage: 600 V
Max Current: 15 A

Isolated

TIDA-00555 (AMC1100)

I&V Sense using fully diff.
Isolation Amp, 3 I&V
Channels, <0.5% Acc

Max Voltage: 300 V
Max Current: 40 A

TIDA-00080 (AMC1304)

I&V Sense using fully diff.
Isolated DS Mod, and F2837XD
Dual-Core Delfino Board, 3 I&V
Channels, <0.5% Acc

Max Voltage: 1 kVAC
Max Current: 200 A

TIDA-00601 (AMC1304)

I&V Sense using fully diff.
Isolated DS Mod, and
MSP430F67641

Max Voltage: 1 kVAC
Max Current: 90 A

TIDA-00738
(AMC1304/OPA188)

Wide Input Current Using
Shunts and Voltage
Measurement

Max Voltage: 300 VAC
Max Current: 60 A

Hall

TIDA-00218 (DRV5053)

AC Current Measurement with
Hall Effect Sensor

Max Current: 12 A

TIDP184 (DRV441)

±100 A Closed-Loop Current Sensor
Reference Design Using Bi-Polar
Supplies

Max Current: ± 100 A

Fluxgate

TIPD196 (DRV421)

±15 A Current Sensor
Using Closed-Loop
Compensated Fluxgate
Sensor

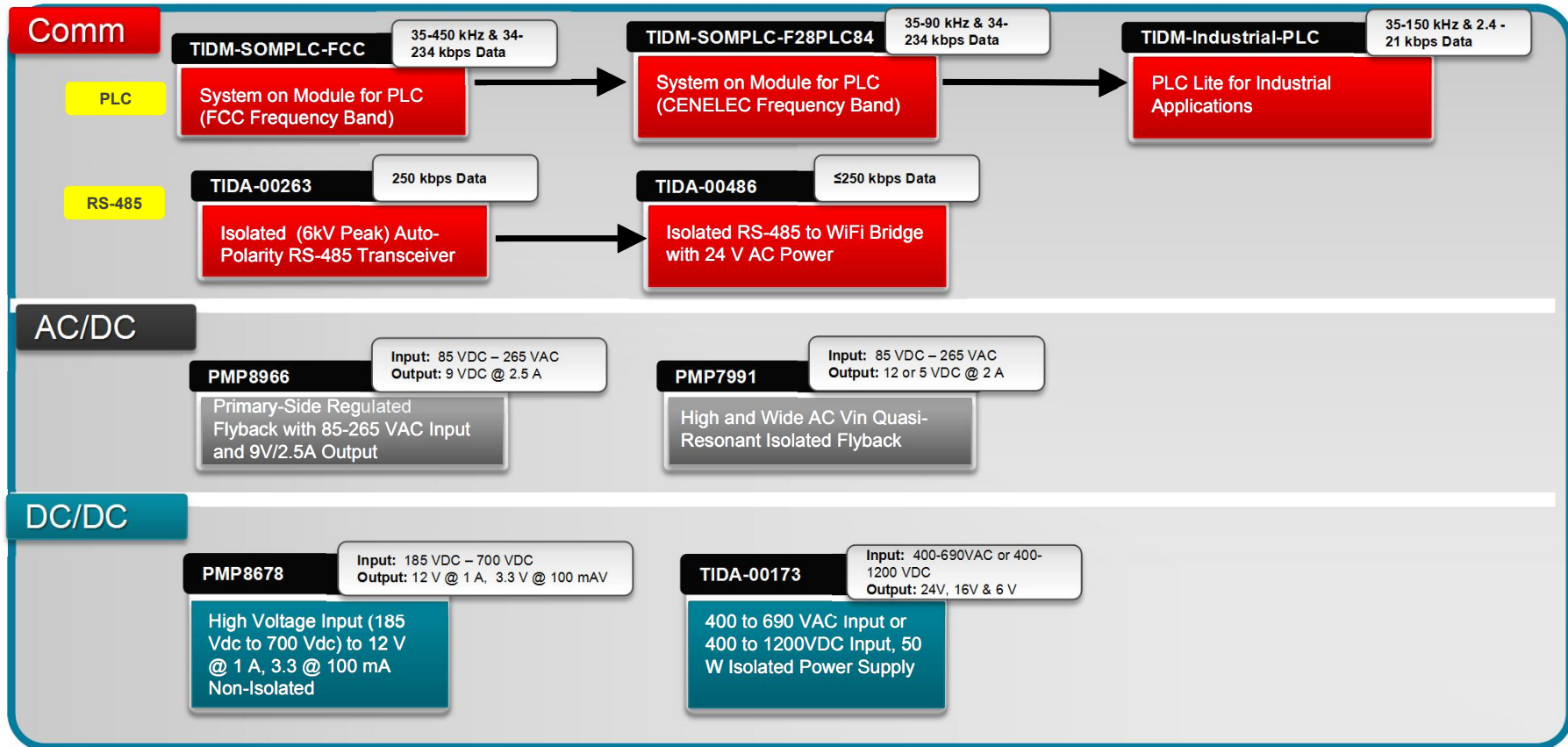
Max Current: 15 A

TIPD205 (DRV425)

±100 A Bus Bar Current
Sensor using Open-Loop
Fluxgate Sensors

Max Current: ± 100 A

TI Designs – Communication & Power Supply



TI 10KW Solar Inverter Design(TIDA-01606)

TIDA-01606

10kW 3-Phase 3-Level Grid Tie inverter reference design for solar string inverter

Design Features

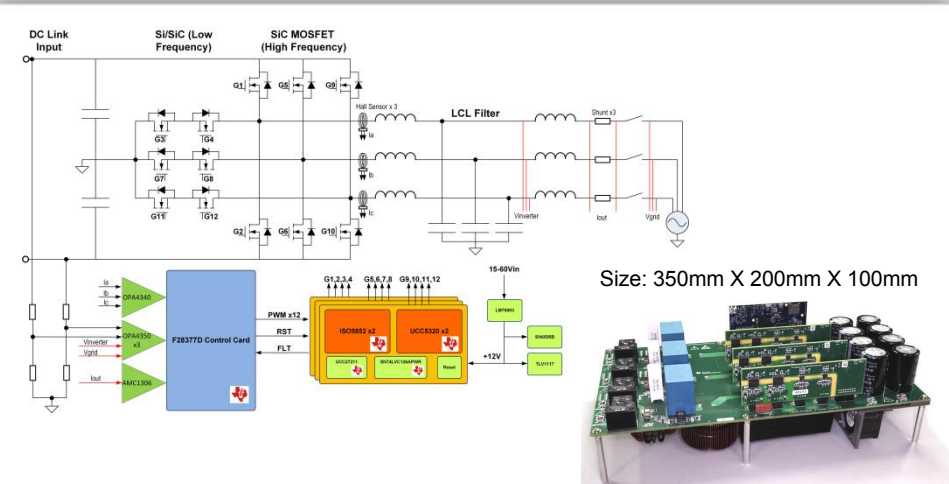
- 10kW 3-Phase 3-Level inverter using SiC MOSFETs
- System Specifications:
 - Input : 800V/1000V
 - Output : 400VAC 50/60 Hz
 - Power : 10KW/10KVA
 - Efficiency : > 99% peak efficiency
 - PWM frequency : 50kHz
- Uses ISO5852, UCC5320 gate driver & C2000 MCU controller
- Uses Littelfuse LSIC1MO120E0080 1200V 80mOhms SiC MOSFETs
- Reduces output filter size by switching inverter at 50KHz
- Isolated current sensing using AMC1306 for load current monitoring
- Differential voltage sensing using OPA4350 for load voltage monitoring
- Targets less than 2% output current THD at full load

Tools & Resources

- **TIDA-01606 Tools Folder**
- **Test Data/Design Guide**
- **Design Files:** Schematics, BOM and BOM Analysis, Design Files
- **Key TI Devices:** UCC5320, ISO5852, AMC1306, SN6505, TMS320F28379D, OPA4350, OPA350, LM76003, PTH08080WAZT, UCC27211

Design Benefits

- 3-Level T-type inverter topology for reduced ground current in transformer-less grid-tie inverter applications
- Reduced size at higher efficiency using low Rdson SiC MosFET and higher switching frequency (50kHz) at higher power (10kW)
- Platform for testing both 2-level and 3-level inverter by enabling or disabling middle devices through digital control.



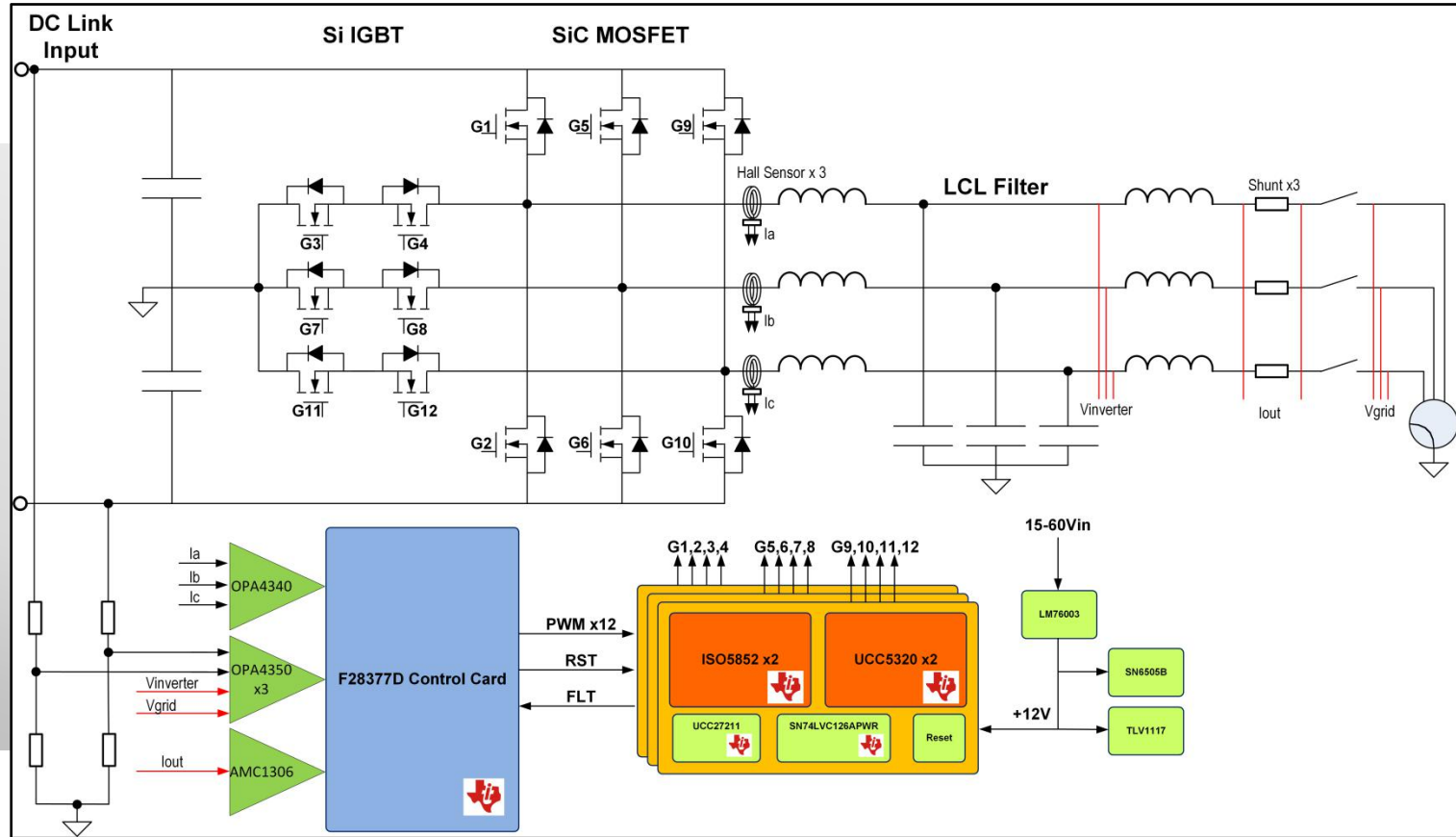
Specifications

AC Output	Power (KW/KVA)	10/10
	PF rated/adjustable	1/0.7lag to 0.7lead
	Grid Voltage (L-L)	400V \pm 20%
	No of Phases	3
	Frequency	50/60Hz \pm 5Hz
	Current (Max)(A)	18
DC Input	Nominal Voltage (V)	800
	Rated Min/Max Voltage (V)	600/1000
Performance	Efficiency (peak/European)	98.5%
	Output current THD	<2%
Other Specs	Off Grid operation	No
	Operating temperature	-25°C to +60°C
	Thermal management	Forced air cooling

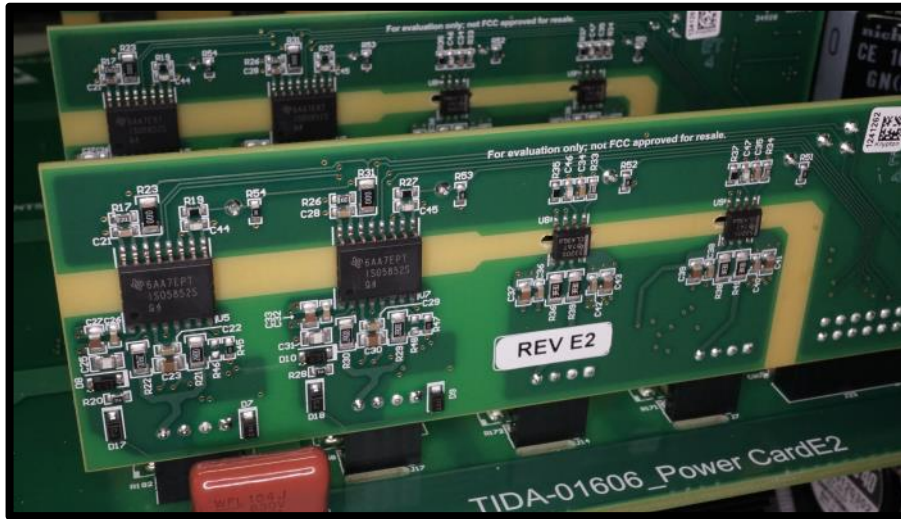
Target End Equipment's

String Inverters – Residential/Commercial

Topology & System Architecture

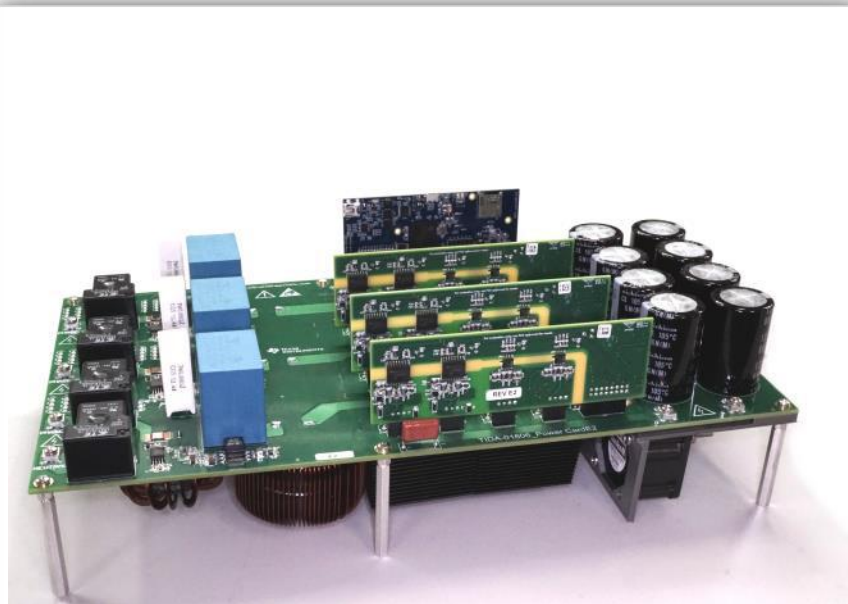


10kW Three Level Inverter Hardware



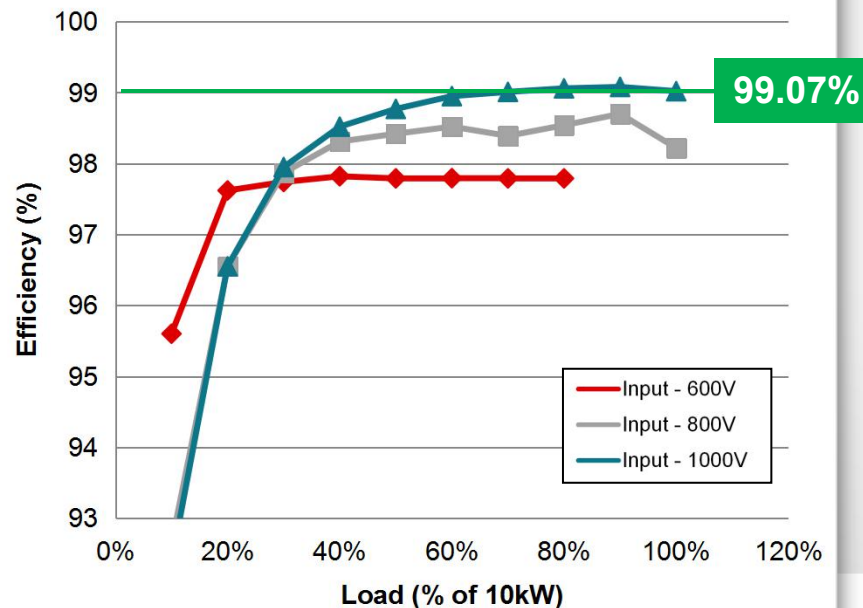
Total Size: 350mmx 200mm x 100mm

10kW Three Level Inverter Measurements



Measured Efficiency (vs) Load

99.07% Peak Efficiency

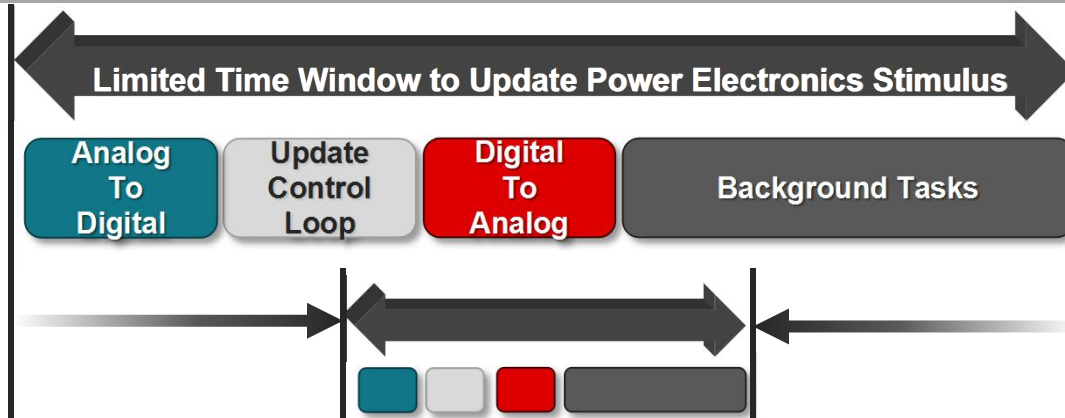
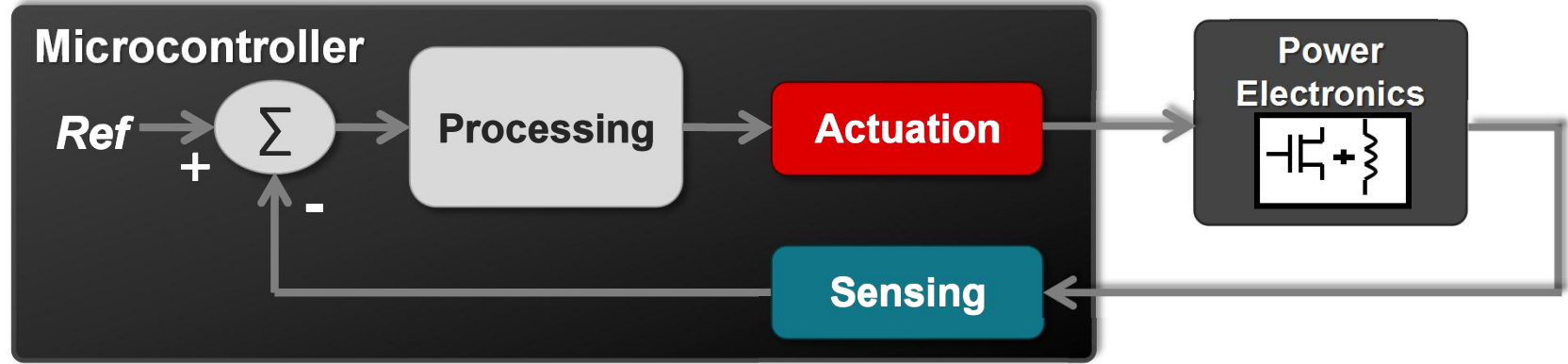


10kW Three Level Inverter Summary

- 99.07% Peak Efficiency at 8kW
- 99.02% Efficiency at 10kW
- 1.4kW/l

Measured Results Summary	
SYSTEM PARAMETER	VALUE
Input Voltage	600-1000Vdc
Output Voltage	400VAC 50/60Hz
Maximum Power	10kW
PWM Frequency	50kHz
Efficiency (Peak)	99.07% @ 8kW
Efficiency (Full Load)	99.02% @ 10kW
Size	350mm x 200mm x 100mm

C2000 - Essentials of Real-time Control



C2000 - The Real-Time Control Portfolio

Production

Sampling

Delfino™

F2833x/23x

C2834x

F2837xS

F2837xD

100 MIPS ↔ 800 MIPS
12 PWM ch., Type 1 ↔ 24 PWM ch. Type 4
1x 12-bit, 2 S/H ↔ 4x 12/16-bit, 4 S/H
12.5 MSPS ADC ↔ 3.5/1.1 MSPS per ADC

Piccolo™

F2802x

F2803x

F2805x

F2806x

F28004x

F2807x

40 MIPS ↔ 240 MIPS
8 PWM ch., Type 1 ↔ 24 PWM ch. Type 4
1x 12-bit, 2 S/H ↔ 3x 12-bit, 3 S/H
2 MSPS ADC ↔ 3.1 MSPS per ADC

Delfino™ TMS320F2837xD

Features

- **800MIPS** real-time performance of dual C28x core with dual CLA co-processors to run parallel control loops
- 4 differential **16-bit ADC**, 1MSPS each and 3x 12-bit DAC
- **Trigonometric Math Unit (TMU)** - 1 to 3 cycle SIN, COS, ARCTAN instructions
- Direct memory access through dual EMIFs (16bit/32bit)
- **Protection** with 8x Windowed Comparators and X-Bar
- **8 Sigma Delta Decimation Filters** to enable sensing across the isolation boundary

Tools



[TMS320F28379D Experimenter's Kit](#)

Part Number: TMDXDOCK28379D

Software



[Digital Power SDK
& powerSUITE](#)



[controlSUITE™
Software](#)



[SafeTI](#)



[Code Composer Studio
\(CCS\) IDE](#)

TMS320F2837xD

Temperatures

105C

125C

Q100

Sensing

ADC1: 16-bit, 1.1-MSPS
12-bit, 3.5 MSPS

ADC2: 16-bit, 1.1-MSPS
12-bit, 3.5 MSPS

ADC3: 16-bit, 1.1-MSPS
12-bit, 3.5 MSPS

ADC4: 16-bit, 1.1-MSPS
12-bit, 3.5 MSPS

8x Windowed Comparators w/
Integrated 12-bit DAC

8x Sigma Delta Interface

Temperature Sensor

3x eQEP

6x eCAP

Processing

**C28x™ DSP
core**
200 MHz

FPU

TMU

VCU-II

**CLA DSP
core**
200 MHz
Floating-Point Math

6ch DMA

Processing

**C28x™ DSP
core**
200 MHz

FPU

TMU

VCU-II

**CLA DSP
core**
200 MHz
Floating-Point Math

6ch DMA

Memory

Up to 512 KB
Flash

Up to 102 KB
SRAM

2x 128-bit Security Zones

Boot ROM

2x EMIF

Memory

Up to 512 KB
Flash

Up to 102 KB
SRAM

Action

12x ePWM Modules (Type 4)
24x Outputs (16x High-Res)

Fault Trip Zones

3x 12-bit DAC

Connectivity

4x UART

2x I2C (w/ true PMBus)

3x SPI

2x McBSP

2x CAN 2.0

USB 2.0 OTG FS MAC & PHY

uPP

Power & Clocking

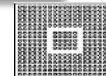
2x 10 MHz OSC

Ext OSC Input

Debug

Real-time JTAG

Packages



Package	Dimension
176-pin HLQFP	24x24mm²
337-pin NFBGA	16x16mm²

UCC53xx Family

0.5/2/4/6A/10A Isolated IGBT/SiC Gate Drivers with High CMTI

Features

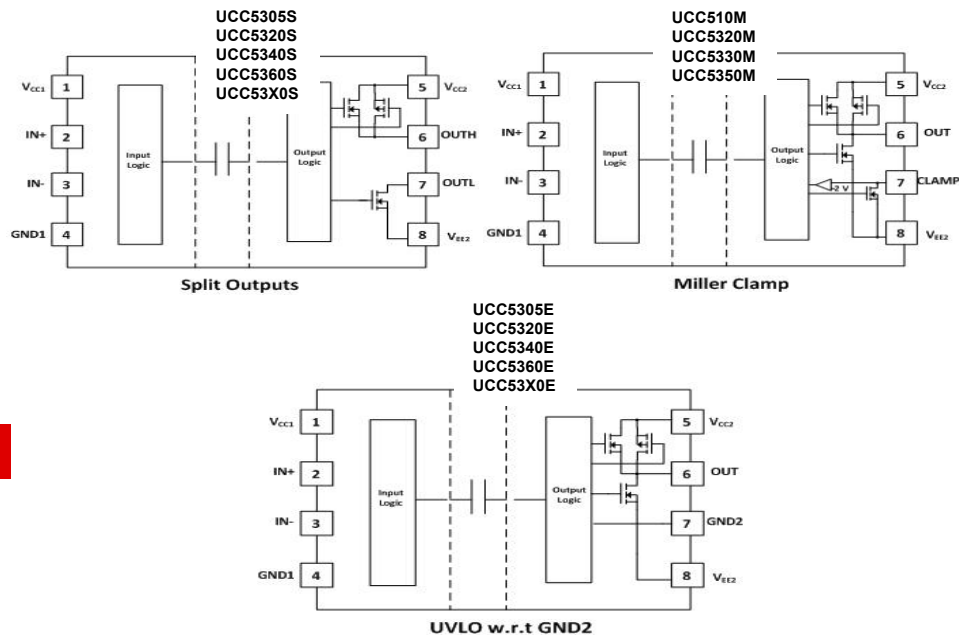
- **Integrated SiO₂ Dielectric Capacitor**
 - 0.5A, 2A, 4A, 6A, 10A Peak Source/Sink Drive
 - Flexibility and Options
 - Split Outputs (ISO53xxS)
 - UVLO with respect to IGBT emitter (ISO53xxE)
 - Miller Clamp option (ISO53xxM)
 - 100 kV/us CMTI min
 - 70 ns (max) Prop Delay.
 - 4kV ESD on all pins
- **Immunity and Certifications**
 - Basic and Reinforced Isolation Options
 - Upto 5.0 kVrms Isolation rating (UL 1577)
 - Upto 8kVpk Transient (VDE0884-10)
 - Upto 1414 Vpk Working Voltage (VDE0884-10)
 - Enables IEC61800-5-1, IEC60664-1 & IEC62109-1
- **Power and Package**
 - Wide V_{CC2} Range: 15V-35V
 - 8-pin Narrow Body SOIC (4 mm Creepage)
 - 8-pin Wide SOIC Package (>8.3mm Creepage)
 - 3V to 15V input supply range.
 - Extended Temp: -55 to 125 °C

Applications

- Industrial Motor Control Drives
- Industrial Power Supplies
- Solar Inverters
- HEV & EV power modules

Benefits

- Reinforced isolation rating
- Different configuration options available
- Improved system performance
- Enabling low power & efficient solutions



ISO5852S: +2.5A/-5A, Isolated, High CMTI, Miller Clamp

Features

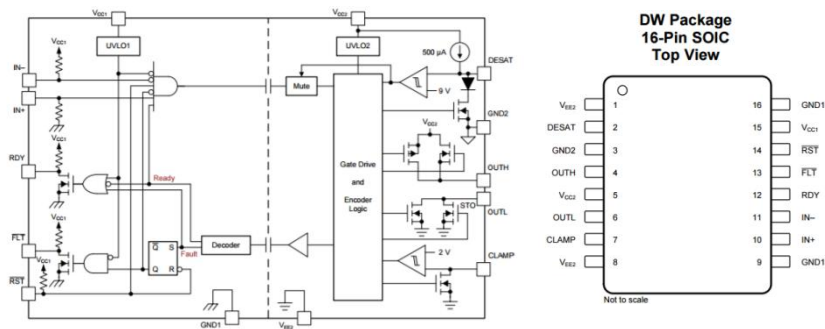
- **Integrated SiO₂ Dielectric Capacitor**
 - CMOS compatible logic input threshold
 - Safety Features: Miller Clamp, Desat Detect, UVLO, Fault feedback, Ready status feedback, auto soft-shutdown on short
 - +2.5/-5A Peak Source/Sink Split Outputs
 - 120 kV/ μ s CMTI (typ) / 100 kV/ μ s (min)
 - 30ns Integrated Glitch Filter
 - 110 ns (max) Prop Delay
 - 4kV ESD on all pins
- **Immunity and Certifications**
 - 12.8 kVpk Surge (8 kV V_{IOSM}) per VDE Reinforced Isolation
 - 5.7 kVrms Isolation rating per UL1577
 - 8000 Vpk V_{IOTM} (transient) and 2121 Vpk V_{IORM} (working voltage) per VDE0884-10
 - Enables IEC61800-5-1, IEC60664-1 & IEC62109-1
- **Power and Package**
 - Wide V_{CC2} Range: 15V-30V
 - 16-pin Wide SOIC Package (>8mm Creepage)
 - Extended Temp: -40 to 125 °C

Benefits

 : AEC-Q100

- Component-level Reinforced rating
- Improved system performance
- Enabling low power & efficient solutions
- High Immunity for Noisy Environments
- High Reliability in Harsh Environments
- Certified by all 3 World Wide agencies

PART #	Split outputs	Soft Turnoff	UVLO+/ UVLO- (typ)	PKG
ISO5852S	Yes	Yes	11.6/10.3	16DW



AMC1306

Small Reinforced Isolated Modulator, $\pm 50\text{mV}$ | $\pm 250\text{mV}$ Input, CMOS Interface/Manchester Encoding

Features

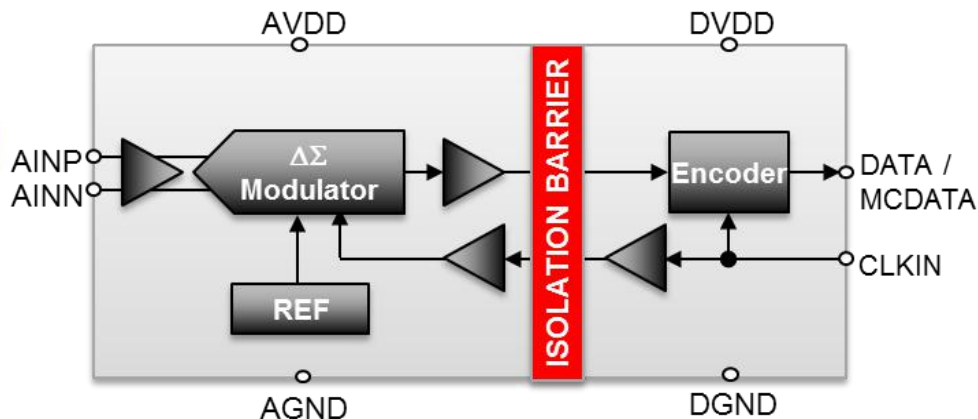
- **Reinforced Isolation (UL1577 & VDE 0884-10)**
 - Working Voltage: $1.5\text{ kV}_{\text{RMS}}$, $2.1\text{ kV}_{\text{DC}}$
 - Isolation Voltage: $7\text{ kV}_{\text{PEAK}}$ / $12.8\text{ kV}_{\text{SURGE}}$
 - Isolation Lifetime: $>> 135\text{ years}$
- CMTI: $100\text{ kV}/\mu\text{s}$ (typ) / $50\text{ kV}/\mu\text{s}$ (min)
- Clock: **5-21 MHz (external)**
- Various Input Voltage Ranges:
 - $\pm 50\text{ mV}$ & $\pm 250\text{ mV}$
- Superior DC Performance:
 - Offset / Offset Drift: $\pm 4.5\text{ }\mu\text{V}$ ($\pm 100\text{ }\mu\text{V max}$) / $\pm 1\text{ }\mu\text{V}/^\circ\text{C}$
 - Gain / Gain Drift: $\pm 0.2\%$ (max) / $40\text{ ppm}/^\circ\text{C}$ (max)
- Manchester-coded Modulator Bitstream Options
- Temperature Range: -40°C to 125°C
- Small Package: **SO-8 (DWV)**

Applications

- Shunt-based Current Measurement:
 - Compact Motor Drives
 - Frequency Inverter Applications
 - Solar Inverters

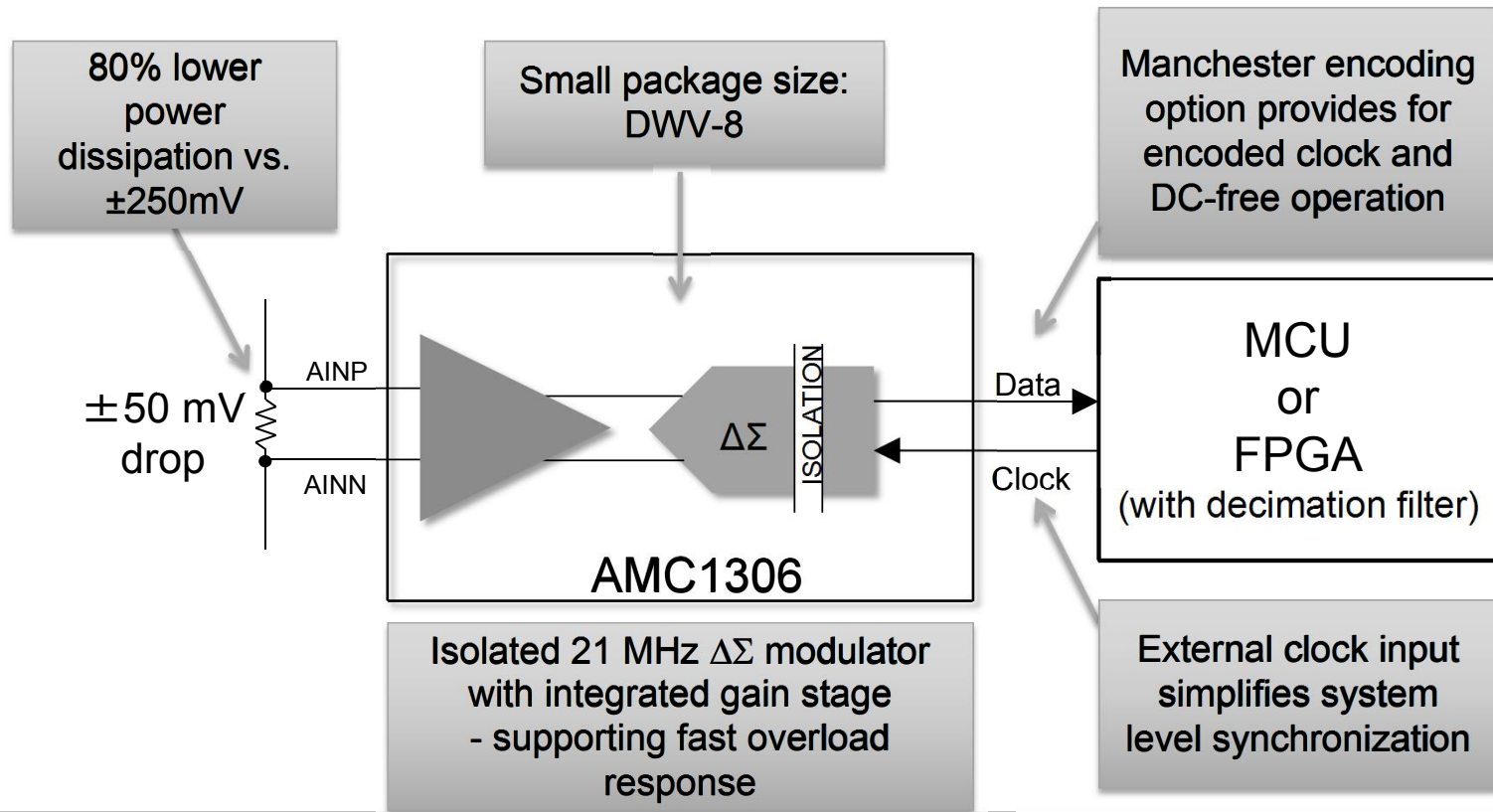
Benefits

- Unique $\pm 50\text{-mV}$ input & Manchester coded (DC-free) output options
- Reduced input voltage range for lowest P_D on shunt
- Smallest package size
- Simplified clock routing & duty cycle correction with Manchester Encoding
- Missing high-side supply & input common-mode over-range indication



AMC1306– Advantages

Small Reinforced Isolated Modulator, $\pm 50\text{mV}$ | $\pm 250\text{mV}$ Input, CMOS Interface/Manchester Encoding



Thanks!

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