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

Texas Instruments
April, Y18
**WW Solar Trends**

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

TI Design map for Solar Inverters and Renewable Energy Storage
TI Designs – Power Conversion Stages

DC/AC

- TIDM-Solar-ONEPHINV
  - Single Phase, Current Source Inverter, full bridge, grid-tied, 96% peak eff. & <5% THD
  - Input: 400 VDC
  - Output: 120/220 VAC

- TIDM-HV-1PH-DCAC
  - Single Phase, Voltage Source Inverter, full bridge, grid-tied mode, 98% peak eff. & <1% THD (LL)
  - Input: 380 VDC
  - Output: 110/220 VAC

- TIDM-SOLARINV
  - Active clamp fly-back DC/DC Grid-tied AC/DC with MPPT, 93% peak eff. & <4% THD
  - Input: 28 VDC – 45 VDC
  - Output: 110/220 VAC

- TIDM-SOLAR-DCDC
  - DC/DC with two-ph interleaved boost con. for MPPT (String Level), resonant LLC con. & Iso
  - Input: 200 VDC – 300 VDC
  - Output: 400 VDC

DC/DC

- TIDA-00120
  - MPPT Charge Controller for Low Voltage Systems, 96% eff.
  - Max o/p I of 20A (small form factor)
  - Input: 15 VDC – 44 VDC
  - Output: 12/24 VDC

- SM72445EVM
  - SM72445 Module Level Micro-Converter, 99.5% Eff, Max 11A & 300W
  - Input: 15 VDC – 50 VDC
  - Output: 5 VDC – 43 VDC

- TIDM-BUCKBOOST-BIDIR
  - Bi-Directional Non-Isolated Buck Boost Converter, Fast PWM switch 250kHz, >95% eff
  - Input: 10 VDC - 100 VDC
  - Output: 5 VDC - 100 VDC

- TIDM-BIDIR-400-12
  - Bi-Directional Isolated Buck Boost Converter, 300W, <80% eff, Seamless transition buck/boost
  - Input: 200 to 400 VDC
  - Output: 12 VDC
**Gate Drivers**

- **PMP9455**
  - 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

- **TIDA-00638**
  - Isolated Gate Driver for 100V to 400VAC inverters (SN6505 & ISO5451)

- **TIDA-00195**
  - 2.5 A, Single Ch, Isolated, Prop Delay 76 ns, IGBT Driver

- **PMP9461**
  - Complete Micro-inverter design using SM72295 full bridge driver with int. I sense

**HMI**

- **TIDEP0044**
  - Solar Inverter Gateway Development Platform (AM3358)

- **TIDEP0015**
  - Capacitive Touchscreen Display (Sitara AM4376)

- **TIDM-CAPTIVATE-64-BUTTON**
  - 64-Button Capacitive Touch Panel With TI Microcontroller With CapTIvate Technology

**In-Design**

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

- 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

**Full system design**

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

- Supports Ethernet, RS-485, CAN, and Display

- Single and multitouch detection, 100bps and 10ms typical delay
TI Designs – V & I Sensing

**Shunts**
- **Non-Isolated**
  - TIDA-00528 (OPA333/NA226)
    - 40 to 400 V Uni-Directional Current/Voltage/Power Monitoring
    - Max Voltage: 400 V
    - Max Current: 8 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-00639 (OPA333/NA226)
    - 600 V Uni-Directional Current/Voltage/Power Monitoring for Smart Combiner Box
    - Max Voltage: 600 V
    - Max Current: 15 A

  - TIDA-00601 (AMC1304)
    - I&V Sense using fully diff. Isolated DS Mod, and MSP430F6761
    - 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

**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

**Wide Input Current Using Shunts and Voltage Measurement**
TI Designs – Communication & Power Supply

**Comm**

- **TI Designs SOMPLC-FCC**
  - System on Module for PLC (FCC Frequency Band)
  - Input: 35-450 kHz & 34-234 kbps Data

- **TI Designs SOMPLC-F28PLC84**
  - System on Module for PLC (CENELEC Frequency Band)
  - Input: 35-80 kHz & 34-234 kbps Data

- **TI Designs Industrial-PLC**
  - PLC Lite for Industrial Applications
  - Input: 35-150 kHz & 2.4 - 21 kbps Data

**AC/DC**

- **PMP8966**
  - Primary-Side Regulated Flyback with 85-265 VAC Input and 9V/2.5A Output
  - Input: 85 VDC – 265 VAC
  - Output: 9 VDC @ 2.5 A

- **PMP7991**
  - High and Wide AC Vin Quasi-Resonant Isolated Flyback
  - Input: 85 VDC – 265 VAC
  - Output: 12 or 5 VDC @ 2 A

**DC/DC**

- **PMP8878**
  - High Voltage Input (185 Vdc to 700 Vdc) to 12 V @ 1 A, 3.3 V @ 100 mA Non-Isolated
  - Input: 185 VDC – 700 VDC
  - Output: 12 V @ 1 A, 3.3 V @ 100 mA

- **TIDA-00173**
  - 400 to 690 VAC Input or 400 to 1200VDC Input, 50 W Isolated Power Supply
  - Input: 400-690VAC or 400-1200 VDC
  - Output: 24V, 16V & 6 V
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

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.

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
# Specifications

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

**Target End Equipment's**

String Inverters – Residential/Commercial
10kW Three Level Inverter Hardware

Total Size: 350mm x 200mm x 100mm
10kW Three Level Inverter Measurements

Measured Efficiency (vs) Load

99.07% Peak Efficiency

Efficiency (%) vs Load (% of 10kW)

- Input - 600V
- Input - 800V
- Input - 1000V
10kW Three Level Inverter Summary

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

<table>
<thead>
<tr>
<th>SYSTEM PARAMETER</th>
<th>VALUE</th>
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<tbody>
<tr>
<td>Input Voltage</td>
<td>600-1000Vdc</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>400VAC 50/60Hz</td>
</tr>
<tr>
<td>Maximum Power</td>
<td>10kW</td>
</tr>
<tr>
<td>PWM Frequency</td>
<td>50kHz</td>
</tr>
<tr>
<td>Efficiency (Peak)</td>
<td>99.07% @ 8kW</td>
</tr>
<tr>
<td>Efficiency (Full Load)</td>
<td>99.02% @ 10kW</td>
</tr>
<tr>
<td>Size</td>
<td>350mm x 200mm x 100mm</td>
</tr>
</tbody>
</table>
C2000 - Essentials of Real-time Control

Factors affecting real-time control performance:
- Greater the application
- Faster the update rate…
- Limited Time Window to Update Power Electronics Stimulus

Microcontroller → Ref \[ \sum \] Processing → Actuation → Power Electronics

Sensing

Limited Time Window to Update Power Electronics Stimulus

Analog To Digital
Update Control Loop
Digital To Analog
Background Tasks

Faster the update rate…

Greater the application performance
C2000 - The Real-Time Control Portfolio

Delfino™
- F2833x/23x
- C2834x
- F2837xS
- F2837xD

100 MIPS
12 PWM ch., Type 1
1x 12-bit, 2 S/H
12.5 MSPS ADC

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

Piccolo™
- F2802x
- F2803x
- F2805x
- F2806x
- F28004x
- F2807x

40 MIPS
8 PWM ch., Type 1
1x 12-bit, 2 S/H
2 MSPS ADC

240 MIPS
24 PWM ch., Type 4
3x 12-bit, 3 S/H
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
- Code Composer Studio (CCS) IDE
- controlSUITE™ Software
- SafeTI

### Packages
- **176-pin HLQFP**: 24x24mm²
- **337-pin NFBGA**: 18x18mm²

### TMS320F2837xD

<table>
<thead>
<tr>
<th>Sensing</th>
<th>Processing</th>
<th>Processing</th>
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</thead>
<tbody>
<tr>
<td>ADC1: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS</td>
<td><strong>C28x™ DSP</strong> core 200 MHz</td>
<td>FPU</td>
</tr>
<tr>
<td>ADC2: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS</td>
<td>TMU</td>
<td>TMU</td>
</tr>
<tr>
<td>ADC3: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS</td>
<td>VCPU-III</td>
<td>VCPU-III</td>
</tr>
<tr>
<td>ADC4: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS</td>
<td><strong>CLA DSP</strong> core 200 MHz Floating-Point Math</td>
<td><strong>CLA DSP</strong> core 200 MHz Floating-Point Math</td>
</tr>
<tr>
<td>8x Windowed Comparators w/ Integrated 12-bit DAC</td>
<td>6ch DMA</td>
<td>6ch DMA</td>
</tr>
<tr>
<td>8x Sigma Delta Interface</td>
<td>Temperature Sensor</td>
<td>Temperature Sensor</td>
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<tr>
<td>3x eQEP</td>
<td>3x eCAP</td>
<td>6x eCAP</td>
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<tr>
<th>System Modules</th>
<th>Memory</th>
<th>Memory</th>
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<tbody>
<tr>
<td>3x 32-bit CPU Timers</td>
<td>Up to 512 KB Flash</td>
<td>Up to 512 KB Flash</td>
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<tr>
<td>NMI Watchdog Timer</td>
<td>Up to 102 KB SRAM</td>
<td>Up to 102 KB SRAM</td>
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<tr>
<td>2x 192 Interrupt PIE</td>
<td>2x 128-bit Security Zones</td>
<td>Boot ROM</td>
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<tr>
<th>Actuation</th>
<th>4x UART</th>
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<tbody>
<tr>
<td>12x ePWM Modules (Type 4)</td>
<td>2x UART (w/ true PMBus)</td>
</tr>
<tr>
<td>24x Outputs (16x High-Res)</td>
<td>3x SPI</td>
</tr>
<tr>
<td>Fault Trip Zones</td>
<td>2x SPI</td>
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<tr>
<td>2x CAN 2.0</td>
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<tr>
<th>Connectivity</th>
<th>4x UART</th>
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<td>4x UART</td>
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<tr>
<td>2x 12C (w/ true PMBus)</td>
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<tr>
<td>3x SPI</td>
<td></td>
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<tr>
<td>2x SPI</td>
<td></td>
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<tr>
<td>2x CAN 2.0</td>
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<tr>
<td>USB 2.0 OTG FS MAC &amp; PHY</td>
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<tr>
<td>uPP</td>
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<tr>
<th>Power &amp; Clocking</th>
<th>2x 10 MHz OSC</th>
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<td>2x 10 MHz OSC</td>
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<tr>
<td>Ext OSC Input</td>
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<tr>
<th>Debug</th>
<th>Real-time JTAG</th>
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**Temperatures**
- 105°C
- 125°C
- Q100
UCC53xx Family

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

**Features**

- **Integrated SiO$_2$ 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/µs 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

![Diagram of UCC53xx Family](image)
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/µs CMTI (typ) / 100 kV/µs (min)
  • 30ns Integrated Glitch Filter
  • 110 ns (max) Prop Delay
  • 4kV ESD on all pins

• Immunity and Certifications
  • 12.8 kVpk Surge (8 kV VIOSM) per VDE Reinforced Isolation
  • 5.7 kVrms isolation rating per UL1577
  • 8000 Vpk VİOTM (transient) and 2121 Vpk VİORM (working voltage) per VDE0884-10
  • Enables IEC61800-5-1, IEC60664-1 & IEC62109-1

• Power and Package
  • Wide VCC2 Range: 15V-30V
  • 16-pin Wide SOIC Package (>8mm Creepage)
  • Extended Temp: -40 to 125 °C

Benefits

• 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

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<tr>
<th>PART #</th>
<th>Split outputs</th>
<th>Soft Turnoff</th>
<th>UVLO+/ UVLO- (typ)</th>
<th>PKG</th>
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<tbody>
<tr>
<td>ISO5852S</td>
<td>Yes</td>
<td>Yes</td>
<td>11.6/10.3</td>
<td>16DW</td>
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</tbody>
</table>

DW Package
16-Pin SOIC Top View

Texas Instruments
AMC1306
Small Reinforced Isolated Modulator, ±50mV | ±250mV Input, CMOS Interface/Manchester Encoding

**Features**

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

**Benefits**

- **Unique ±50-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**

**Applications**

- **Shunt-based Current Measurement:**
  - Compact Motor Drives
  - Frequency Inverter Applications
  - Solar Inverters
**AMC1306– Advantages**

Small Reinforced Isolated Modulator, ±50mV | ±250mV Input, CMOS Interface/Manchester Encoding

- 80% lower power dissipation vs. ±250mV
- ±50 mV drop
- Small package size: DWV-8
- Manchester encoding option provides for encoded clock and DC-free operation
- Isolated 21 MHz ΔΣ modulator with integrated gain stage - supporting fast overload response
- External clock input simplifies system level synchronization
- 80% lower power dissipation vs. ±250mV
- ±50 mV drop
- Small package size: DWV-8
- Manchester encoding option provides for encoded clock and DC-free operation
- Isolated 21 MHz ΔΣ modulator with integrated gain stage - supporting fast overload response
- External clock input simplifies system level synchronization
Thanks!
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