Increasing efficiency through digital power control

Jim Carver – Avnet Electronics Marketing
Brett Novak – Texas Instruments
Introduction

• Energy efficiency is EVERYTHING
  – Energy Costs are rising
  – Resources are finite
  – Regulatory compliance is not optional

• Achieving energy efficiency is demanding
  – High bandwidth control loops
  – Demanding real time performance is needed
    • Real time means REAL TIME!

• C2000 family from Texas Instruments is the ideal solution
  – Very high performance real time microcontrollers
  – A Broad portfolio of solutions for a wide variety of applications
  – Proven reference designs and development systems
    • Faster time to market
Agenda

• Introduction to TI C2000 MCU’s
  – Fixed point, floating point and multi-core processors
  – Focus on the peripherals allowing us to achieve greater efficiency in digital power solutions

• Introduction to “digital” power solutions
  – Increasing energy harvesting capabilities in solar applications
  – Getting more out of LED systems with an MCU
  – Driving higher efficiency levels in motor control applications
TI has a broad and growing embedded processing portfolio

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<th>ARM®-Based Processors</th>
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<td><strong>32-bit ARM® MCUs</strong></td>
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<td><strong>32-bit real-time MCUs</strong></td>
<td><strong>32-bit ARM® MPUs</strong></td>
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<td><strong>C2000™ Concerto™ Delfino™ Piccolo™</strong></td>
<td><strong>Stellaris® ARM® Cortex™-M3</strong></td>
<td><strong>C6000™ C6-Integra™ DaVinci™</strong></td>
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<tr>
<td>Up to 25 MHz</td>
<td>Up to 80 MHz</td>
<td>Video processors 300 MHz to &gt;1.5GHz Floating point + Video Accelerators</td>
</tr>
<tr>
<td><strong>MSP430™</strong></td>
<td><strong>Sitara™ ARM® Cortex™-A8 &amp; ARM9</strong></td>
<td><strong>C6000™</strong></td>
</tr>
<tr>
<td><strong>Up to 40 MHz to 300 MHz</strong></td>
<td>Value line to 600 MHz Perf. Line to 1.5 GHz</td>
<td>Up to 10GHz Multi-core, fixed/floating + Accelerators</td>
</tr>
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<td><strong>MPUs – Microprocessors</strong></td>
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<td><strong>C5000™</strong></td>
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<td></td>
</tr>
</tbody>
</table>
What is C2000™?
The 32-bit real-time microcontroller family

- **DSP performance within a Microcontroller architecture**
  - 40-300MHz C28x™ CPU
    - Built-in DSP functions
    - Single-cycle 32×32-bit MAC
  - Control Law Accelerator
  - Floating-point unit
  - Viterbi and Complex Math Unit
  - Embedded flash
- **Fine-tuned for real-time control**
  - Optimized core
  - Fast interrupts
  - Flexible interrupt system
  - Real-time debugging

- **Comprehensive Peripheral Set**
  - Best-in-class ADC performance
  - Flexible high-resolution PWMs
  - Advanced capture, Quadrature encoder interfaces
  - CAN, LIN, SPI, I²C, SCI/UART, McBSP, USB

- **Broad portfolio of configurations**
  - 40-300 MHz
  - Fixed- and floating-point devices
  - Multi-core with ARM® Cortex™-M3
  - 16-1024KB of Flash
  - From sub $2 to $20
  - Software compatibility across C2000 platform
C2000™ 32-bit MCU roadmap (public)

**Concerto™**
(144 Pins)
$\leq 7 - $20

- **Fixed Pt**
- **Low Cost**

**Delfino™**
(176-256 Pins)
$9 - $16

- **Floating Pt Performance**
- **CAN**

**Piccolo™**
(38-100 Pins)
$\leq 2 - $8

- **Floating Pt w/ Co-Processor Options**
- **Future**

**Fixed Pt w/ Co-Processor Options**

**Fixed Pt Low Cost**

**Production**

**Development**

**Sampling**

**Future**

- **ENET**
- **USB**
- **CAN**

All pricing is to be considered budgetary and subject to change. Pricing is 1KU SRP -40 to 105°C.
## C28x Compared to ARM Cortex-M3

<table>
<thead>
<tr>
<th>C28x</th>
<th>Cortex-M3</th>
</tr>
</thead>
<tbody>
<tr>
<td>32-bit Proprietary C28x Core</td>
<td>32-bit Industry Standard ARM Cortex-M3</td>
</tr>
<tr>
<td>Up to 300 MHz</td>
<td>Up to 100 MHz</td>
</tr>
<tr>
<td>8-stage pipeline</td>
<td>3-stage pipeline</td>
</tr>
<tr>
<td>32/16-bit Instructions</td>
<td>32/16-bit Instructions (Thumb2)</td>
</tr>
<tr>
<td>32x32 MAC = Upper 32 in Single Cycle</td>
<td>32x32 MAC = Lower 32 in Single Cycle (16-bit!)</td>
</tr>
<tr>
<td>Control Lite (PID) 50% Better</td>
<td>General Purpose (Dhrystone) 25% Better</td>
</tr>
<tr>
<td>Control Heavy (Buck) 400% Better</td>
<td>Best Code Density &amp; Deterministic Interrupts</td>
</tr>
</tbody>
</table>

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### C28x

**The Right Solution for Real-Time Control**

- Best CPU for Precision Math/Control
- Fixed & Floating Point
- Control Law Accelerator
- Broadest Offering
  - 40 to 300 MHz
  - 38 to 256 Pins
  - $1.85 to $16 1Ku

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### Plant

- Highest Speed
- Best Resolution
- Lowest Latency
- Most Flexible Triggering & Synchronization

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### AVNET

Texas Instruments
**Piccolo: Real-time control in an MCU package and price**

**Leading 32-bit performance for real-time control**
- High-performance C28x CPU
- Intelligent peripherals optimized for control applications
- Control Law Accelerator
- Viterbi, CRC and Complex arithmetic co-processor
- Native Floating Point

**Lower System Cost & Ease of Use**
- Best mix of control peripherals
- Robust software libraries
- Code compatibility across C2000 platform ranging from 40MHz to 300MHz
- Increased on-chip analog integration

**MCU Package & Price**
- Starting at $1.85 1ku
- Package options from 38 to 100-pins
- Bringing real-time control to cost sensitive applications

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**Piccolo**

**C28x 32-bit CPU**
- Up to 80 MHz
- 32x32-bit Multiplier
- RMW Atomic ALU

**Floating Point**
- Control Law Accelerator (CLA)
- VCU

**Memory**
- 16-256 KB Flash
- 6-100 KB RAM

**Power & Clocking**
- Dual Osc 10 MHz
- On-Chip Osc
- Dynamic PLL Ratio
- Changes

**Debug**
- Power-on Reset
- Brown Out Reset

**Direct Memory Access**

**Peripherals**
- 3x Comparator
- Missing Clock Detection Circuitry
- 128-Bit Security Key/Lock

**Converter**
- 16 ch, 12-bit A/D Converter

**Serial Interfaces**
- 2x SPI
- 2x SCI, 1x McBSP
- 1x I^2C
- 1x LIN
- 1x CAN
- 1x USB Host/Device

**Timer Modules**
- 8x ePWM Modules: (8x 150ps high-res)
- 3 x 32-bit eCAP
- 4 x HRCAP
- 2 x 32-bit eQEP
- Watchdog Timer
- 3x 32-bit CPU Timers

**Connectivity**
- 60 I/Os

---

**48-pin LQFP**
0.5mm pitch

**64-pin LQFP**
0.5mm pitch

**80-pin LQFP**
0.5mm pitch

**100-pin LQFP**
0.5mm pitch

-40 to 105C/125C and Q100
Concerto: Control + Connectivity. No compromise.

**Control Subsystem**
- Precision Control
  - Industry leading computational performance
  - Expanded instruction set
  - Industry’s highest-resolution PWMs

**Shared**
- Low-latency control loops
- Real-world, modular control software
- High-speed precision analog
- Fine-tuned control architecture

**Host Subsystem**
- Ecosystem for Developers
  - Operating System
  - Middleware
  - SW Infrastructure

**System & Clocking**
- 32Ch DMA
- 4 Timers
- 2 Watchdogs

**Memory**
- 256-512 KB ECC Flash
- 20 KB ECC RAM
- 128-bit Security
- 16 KB Parity RAM
- 64 KB ROM

**Control Modules**
- 9x ePWM Modules:
  - 18 Outputs / 16x HR
- Fault Trip Zones
- 6 x 32-bit eCAP
- 3 x 32-bit eQEP

**Comms**
- McBSP/SPI/I2S
- UART

**System**
- 6Ch DMA

**Analog**
- Temp Sense
- 12b, 10ch, 2SH, 3 MSPS
- 3ch Analog Comparator

**Parity RAM**
- 2 KB Message
- 2 KB Message
- Up to 64 KB

**Pwr & Clocking**
- 10 MHz / 30 KHz INT OSC
- 4x20 MHz EXT
- Clock Fail Detect
- 3.3V VREG
- POR/BOR

**VCU**
- Viterbi
- CRC
- Complex MPY
- FFT

**ARM® Cortex™-M3**
- 32-bit CPU
- Up to 100 MHz

**Memory**
- 256-512 KB ECC Flash
- 16 KB ECC RAM
- 16 KB Parity RAM
- 64 KB ROM
- External Interface

**Communications**
- 10/100 Ethernet MAC
- 1588 w/ MII
- USB OTG FS PHY
- 4x SSI
- 5x UART
- 2x I²C
- 2x CAN

**Operating System**
- Operating System

**Middleware**
- Operating System

**SW Infrastructure**
- Operating System

**Low-latency control loops**
- Real-world, modular control software
- High-speed precision analog
- Fine-tuned control architecture

**Natural user interface**
- Motion profile
- Safety
Delfino: Floating point real-time control MCU

**Highest 32-bit performance for real-time control**
- High-performance C28x CPU up to 300 MHz
- 32-bit Single Precision Floating Point Unit
- 50% code reduction for floating point math
- 100%+ throughput improvement
- Zero-wait RAM for full performance

**Control Optimized Peripherals**
- Support for up to three 3Ph Motor Control
- Most advanced PWM modules with up to 55ps resolution, rising and falling edge dead-band, and hardware fault detection
- 12-bit 12.5 MSPS ADC or External ADC interface with event synchronized triggering

**Scalable Platform**
- 100 to 300 MHz and Flash or RAM only options
- Pin-pin with fixed point versions
- IQMath and Floating Point for single source code
- Code compatibility across C2000 platform ranging from 40MHz to 300MHz
What is “Efficiency”

ef·fi·cien·cy
noun, plural -cies.

1. the state or quality of being efficient; competency in performance.

2. the ratio of the work done or energy developed by a machine, engine, etc., to the energy supplied to it, usually expressed as a percentage.

3. accomplishment of or ability to accomplish a job with a minimum expenditure of time and effort: The assembly line increased industry's efficiency.

*reference 1
Increasing “efficiency” in applications: Advanced Motor Control
Why do we care about efficiency with motors?

- 45% of global electricity used on motors
- 50%+ in USA
- 60%+ in Europe
- 80%+ in China

Example Application

Induction Motors used for Air & Humidity Control

Savings moving from Triacs to Smart Control
- 70% of energy using Simple Variable Frequency
- 85% of energy using latest adaptive FOC

- 1% motor efficiency gain in Japan = 1 Nuclear Power Plant that doesn’t have to be built!
Increasing “efficiency” in motor control applications – power consumption

• For motor control, the biggest advances in energy savings come from adding variable-drive, and high performance power factor correction.

• Variable Drive – System now becomes adaptive to load. This can translate into a potential energy savings of up to 87% at light loads vs. constant speed motors!

• Active Power Factor Correction – Reducing the reactive power consumption to near zero increases grid delivery efficiency, and can lessen end user power bills!
C2000 in Digital Motor Control

- **C2000 MCU In Motor Control** – It’s our legacy! C2000 has proprietary on-chip systems and software for intelligent motor control.

- **Power Factor Correction & Inverters** – C2000 has a long history in power conversion and is very well respected in high efficiency, intelligent motor control applications.

- **Communications** –
  - C2000 is used as the main processor in TI’s PLC applications.
  - Concerto Class devices marry the connectivity of an ARM Processor with the legacy of control with the C28x core.

Integration of all these features into one controller can potentially reduce chip count, size of the board, cost, and allow the full system to be “smarter”. (this allows for potentially significant customer IP to be written to increase efficiency)
Digital Motor Drive

C2000 Controller

- Safe operating area manager
- Speed profile generator
- Command interpreter
- Command queue
- SCI protocol stack
- CAN protocol stack
- TCP/IP protocol
- MAC/PHY Hardware
- Input power stage
- PWM Gen
- ADC
- Power Inverter

- MIPS enables high performance
  - FOC gives full torque from zero to full speed
  - Enables four quadrant operation
- Sensor-less control techniques possible in software
- Software integrates a variety of “auxiliary” functions
- Software flexibility enables one controller for many drives.

- Flux and speed estimators
- Speed controller
- FOC Core
- Software filtering
- Command queue
- SCI protocol stack
- CAN protocol stack
- TCP/IP protocol
- RS-232/485
- CAN PHY
- MAC/PHY Hardware

- Speed profile generator
- \( \omega_r \)

- Sensor-less control techniques possible in software
Digital Motor Control - Dual Inverter + PFC Boost

Piccolo-B

CPU
32 bit DSP core
60 MHz

ADC
12 bit
5 MSPS

MCLA
32 bit
FPU
60 MHz

Comms
I2C
SPI
UART
CAN

V-batt
DC link
V-dcBus

I-boost
I-boost1
I-boost2

I-boost

V-dcBus

Motor 1

Motor 2

V-dcBus

V-batt

I-boost
I-boost1
I-boost2

I-boost

PWM 1
(PHR)

ADC

PWM 2
(PHR)

PWM 3
(PHR)

PWM 4
(PHR)

PWM 5
(PHR)

PWM 6

PWM 7

3V3

CPU

ADC

Vref

V-dcBus

I L-1/IL-2

I PH-1/I PH-2

I L-1/I L-2

I L-1/I L-2
Increasing “efficiency” in motor control applications – System Level

Design Re-Use…! Design Re-Use…! Design Re-Use…!

• Single hardware designs can be “re-purposed” for multiple applications

• Faster time to market, less time spent in hardware development to support multiple products

• Higher controller integration means less on-board components = less potential points of failure

• Increased flexibility through software control – IE: self tuning systems, variable load management, etc.

• Increased system flexibility through modular software updates

DRV8312-C2-Kit
• Drives 3-Phase brushless AC or Brushless DC Motors

• Single MCU in application can control PFC and 2x 3 Phase Motors
### A Few of the C2000 Motor Control Development Kits! (We have 12!)

<table>
<thead>
<tr>
<th>Kit Code</th>
<th>Description</th>
<th>Price</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMDS1MTRPFCKIT</td>
<td>Motor Control and PFC Developer's Kit</td>
<td>$369.00</td>
<td><a href="http://focus.ti.com/docs/toolsw/folders/print/tmds1mtrpfckit.html">http://focus.ti.com/docs/toolsw/folders/print/tmds1mtrpfckit.html</a></td>
</tr>
<tr>
<td>TMDS2MTRPFCKIT</td>
<td>Dual Motor Control and PFC Developer's Kit</td>
<td>$399.00</td>
<td><a href="http://focus.ti.com/docs/toolsw/folders/print/tmds2mtrpfckit.html">http://focus.ti.com/docs/toolsw/folders/print/tmds2mtrpfckit.html</a></td>
</tr>
<tr>
<td>TMDSHVMTRPFCKIT</td>
<td>High Voltage Motor Control and PFC Developer's Kit</td>
<td>$599.00</td>
<td><a href="http://focus.ti.com/docs/toolsw/folders/print/tmdshvmtrpfckit.html">http://focus.ti.com/docs/toolsw/folders/print/tmdshvmtrpfckit.html</a></td>
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</table>
DMC Library

Blocks are Modular C functions
- Variables as Inputs, Variables as Outputs
- Library of Source Code
- Most are IQ based, tune to your stability needs!

Multi-page Documentation & Theory of Operation for each module

Other Libraries Available
- FFT (32-bit Complex & Real)
- Filters (FIR, IIR)
- QMath (Trig, SQRT, INV, LOG, DIV)
- IQMath Virtual Floating Point
  (Conversion, Arithmetic, Trig, Math)
- Signal Generation (Sine, Ramp, Trapezoidal)
- Digital Power
Increasing “efficiency” in applications: Digital LED Control
Why do we care about efficiency with LED lighting?

- 19% of global electricity used on lighting!
- 48%+ For Services
- 28%+ Residential
- 8% Street lighting
- 70% of global lighting sales still consist of inefficient incandescent lamps!!

Example Application

LED Lighting versus traditional incandescent bulbs

30K Hour Comparison

1x 60W LED – 300KW Consumed - $30
1x 60W Inc. – 1500KW Consumed - $150
* Based on $0.10/kW/Hr
Increasing “efficiency” in LED applications – Power System

Remember – LED’s are DC! They don’t exactly work well off AC mains!

- Most high LED count applications are migrating to SMPS systems to increase power supply performance, both in controllability and increased energy conversion efficiency.

- By integrating INTELLIGENCE into these controllers, we can start seeing a change in overall system efficiency

- Power Line Communications, Intelligent Dimming or turn on / turn off.
C2000 in Lighting

• **LED lighting** – C2000 has all the features necessary to control LEDs efficiently and safely.

• **DC/DC Power Conversion and PFC** – C2000 has a long history in power conversion and is very well respected in high efficiency applications.

• **Communications** –
  - C2000 is used as the main processor in TI’s PLC applications.
  - DALI, DMX512, and KNX are standard lighting protocols
  - RF is also possible

Integration of all these features into one controller can potentially reduce chip count, size of the board, cost, and allow the full system to be “smarter”. (this allows for potentially significant customer IP to be written to increase efficiency)
Digital LED Control – Active PFC, isolation and multiple string drive
Increasing “efficiency” in LED applications – Power System

• Secondary benefits for digitally controlling LED’s
  – Intelligent Dimming based on environmental variables
  – Color Balancing or Color Mixing
  – Active communications – Power Line Comm’s.
Increasing “efficiency” in LED lighting applications – System Level

• Design Re-Use…! Design Re-Use…! Design Re-Use…!

• Single hardware designs can be “re-purposed” for multiple applications

• Faster time to market, less time spent in hardware development to support multiple products

• Higher controller integration means less on-board components = less potential points of failure

• Increased flexibility through software control – IE: self tuning systems, variable load management, etc.

• Increased system flexibility through modular software updates

TMDSA Clash KIT
• PFC Corrected AC Input
• Res LLC Isolation Stage
• 6x Individually Dimmable strings @1.0A each
• Enhanced Communications
• 90% Total system efficiency!
## TI Tools for Intelligent LED Lighting

<table>
<thead>
<tr>
<th>Part Number</th>
<th>AC/DC</th>
<th>DC/DC</th>
<th>Lighting</th>
<th>Communications</th>
<th>Microcontroller</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMDSDCDCLEDKIT</td>
<td>None</td>
<td>Sepic, Buck/Boost</td>
<td>8-channel common rail PWM dimming</td>
<td>None</td>
<td>TMS320F2803x</td>
</tr>
<tr>
<td>TMDSRGBLEDKIT</td>
<td>None</td>
<td>Boost and Sepic Buck/Boost</td>
<td>8-channel multi-rail PWM dimming</td>
<td>None</td>
<td>TMS320F2802x</td>
</tr>
<tr>
<td>TMDSIACLEDCOMKIT</td>
<td>UCC28810D based AC/DC w/ PFC</td>
<td>Resonant LLC</td>
<td>6-channel common rail PWM dimming</td>
<td>PLC, DALI, DMX, KNX, RF</td>
<td>TMS320F2802x or TMS320F2803x</td>
</tr>
</tbody>
</table>
Increasing “efficiency” in applications: Solar Power Systems
Why do we care about efficiency in solar applications?

The sun provides us with a huge amount of potential “free energy”

- Clean Source of Energy
  - Negligible CO2 footprint, No noise, No water consumption.
  - No emissions
  - Less geographical restrictions.
  - No moving parts
- Brings electricity to remote rural areas
- Requires low maintenance, easy installation
- Integrated in buildings

Estimated that 1/100000000 of the available solar radiation can power the planet!
(That’s a hundredth of 100 million!)
Switching gears from power conversion to energy harvesting

• Primary goal in energy harvesting applications is to convert as much available input power to a “useable” output power – either to drive a load, or augment power on the grid

• This means utilizing the most efficient energy conversion stages to maximize output!

• Most single solar panels. Only output ~20V, with power ranging from 50W to 260W

• Most solar panels only convert ~18% of light energy to electrical energy!
C2000 in Solar Applications

- **Solar Power Stages**—C2000 has all the features necessary to control all of the power stages in solar applications.

- **DC/DC Power Conversion**—C2000 has a long history in power conversion and is very well respected in high efficiency applications.

- **Communications**—
  - C2000 is used as the main processor in TI’s PLC applications.
  - Concerto MCU’s incorporate USB and Ethernet communications with the control processor.
  - RF is also possible.

Integration of all these features into one controller can potentially reduce chip count, size of the board, cost, and allow the full system to be “smarter”. (this allows for potentially significant customer IP to be written to increase efficiency)
Increasing “efficiency” in Solar applications – Power System

• Solar panels typically output ~20VDC ranging from 50W to ~250W

• Power optimization can either be at the “string” level, or in newer systems, right at the panel.

• For driving the grid – we need 3 power stages.
  1 – Boost & MPPT
  2 – Isolation (optional)
  3 – Inverter

• By utilizing digital control, we are able to increase the system efficiency through advanced control techniques as well as add additional safety and control features!
Digital control in solar applications: MPPT

- Panel volt/current characteristics change with lighting condition and temp of PV cell.
- Available panel power changes as a function of panel output volt/current.
- Power curve has a distinct maxima for a given IV curve. This max available power changes as the day progresses.
- It is necessary to maintain PV panel output voltage and current corresponding to MPP to fully utilize the panel capacity.
- MPPT should be fast to increase energy extraction but not too fast to cause instability.
- MPPT should sweep entire curve, find the global maxima and should not lock to a local maxima.
Digital control in solar applications: Isolated power stage (Resonant LLC)

- 120kHz Resonant Operation, Isolated DC/DC
- ZVS Switching, Optimum TFMR Design => High Efficiency
- Output Diode Bridge Rectifier, High Voltage
- Open-Loop Operation with Unity Conversion Ratio (Vboost ≈ Vbus)
Digital control in solar applications: Isolated power stage (Resonant LLC)

- 120kHz Resonant Operation, Isolated DC/DC
- ZVS Switching, Optimum TFMR Design => High Efficiency
- Output Diode Bridge Rectifier, High Voltage
- Open-Loop Operation with Unity Conversion Ratio (Vboost ≈ Vbus)
Digital control in solar applications: The inverter stage

A grid-connected solar inverter must work in harmony with the grid. Inverter internal oscillator is phase and frequency locked to fundamental grid voltage frequency.

• Phase Detector (PD)
  Output signal (Ve) proportional to the phase difference between its two input signals.

• Loop Filter (LF)
  Filters out the high frequency ac components from the PD output. Typically this is a 1-st order LPF or PI controller.

• Voltage Controlled Oscillator (VCO)
  Generates ac signal whose frequency varies with respect to a central frequency
  Freq of VCO is a function of Loop Filter output.
# TI Tools for solar development

<table>
<thead>
<tr>
<th></th>
<th>TMDSSLREXPLRKIT</th>
<th>TMDSHVMPPKTKIT</th>
<th>TMDSHV1PHINVKIT</th>
<th>Micro-Converter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topology</strong></td>
<td>Multi-Topology Single Controller Solar Explorer Kit</td>
<td>High Voltage String Inverter Front End Development Kit</td>
<td>High Voltage Single Phase DC/AC Inverter Development Kit</td>
<td>Piccolo Controlled DC/DC Buck – Boost Micro Converter</td>
</tr>
</tbody>
</table>
| **Features**           | • Integrated Panel Emulation  
• Single Phase MPPT Boost Stage  
• SEPIC Battery Charger  
• 24VAC DC/AC Inverter Stage | • 200-360VDC Panel Input  
• 2 Phase Interleaved MPPT Boost Stage  
• Open Loop Resonant LLC Isolation Stage | • 400VDC Input IGBT Based Inverter  
• selectable 120 or 220 VAC output  
• Grid-matching  
• Anti-Islanding  
• Network & USB Connectivity with Concerto | • Voltage controlled MPPT Buck / Boost for Micro-Converter Applications  
• C2000 Based Controller + UCD27242 6 Channel Integrated Driver |
| **Device**             | F28035 & Concerto | F28035 | F28035 & Concerto | F28027 |
| **Input / Output Voltage** | • up to 20VDC Panel or Power Supply Input w/ 36VDC or 24VAC Output | • 200-360VDC Panel String Input  
• 400VDC Isolated or Non-Isolated Output | • 400VDC Input  
• 120 / 220 VAC Output | • up to 100V input  
• Up to 100V Output |
| **Available**          | Available Now | Available 1Q12 | Available 1Q12 | Available 2H12 |
How do I get started?

Special offer for all attendees

– 50% discount on the **F28069x controlSTICK**
  (Listed web price $39)

– **Piccolo™ F28069x controlSTICK:**

The innovative C2000™ Piccolo controlSTICK allows quick and easy evaluation all of the advanced capabilities of TI's new Piccolo microcontroller. Slightly larger than a memory stick, the Piccolo controlSTICK features on board JTAG emulation and access to all control peripherals. Example projects walk the user through the advanced functionality of Piccolo, from simply blinking an LED to configuring the high resolution ePWM peripherals.

Purchase from: [www.AvnetExpress.com](http://www.AvnetExpress.com)

Part Number: TMDX28069USB

Coupon code: TMDX28069USB50

- Offer valid through April 15, 2012 or while supplies last. For purchase of TI part #TMDX28069USB purchased through the AvnetExpress.com Americas site only.
- Enter the discount code TMDX28069USB50 on the order summary page to receive your discount of 50% off the listed AvnetExpress Resale.
- Not valid for offline orders. Shipping charges, taxes, and fees may apply. Offer is subject to change without notice. Other restrictions apply.

* Offer limited to first 300 requests*
Special bonus!

Code Composer Studio for $1

- Only with purchase of controlSTICK
- Full version, a $445 value

**Code Composer Studio v5**
The new Eclipse-based Code Composer Studio™ (CCStudio) is the integrated development environment for TI's DSPs, microcontrollers and application processors. CCStudio includes a suite of tools used to develop and debug embedded applications.

Any customer who attends the webinar and orders a TMDX28069USB will be provided with a special code. Simply order a Piccolo™ F28069x controlSTICK on-line through AvnetExpress and you will be sent a discount code via e-mail.

Your discount code will be provided within one week of your on-line purchase and can be used to order a Code Composer Studio™ v5 (part #TMDSCCS-ALLN01D) for downloading through the TI eStore for $1.
Additional offers
C2000™ MCU Multi-DC/DC Color LED Kit

For qualified attendees*

– 10% Discount on C2000™ MCU Multi-DC/DC Color LED Kit
  (Listed web price $499)

C2000™ MCU Multi-DC/DC Color LED Kit
The Multi-DC/DC Color LED Kit includes all of the hardware and software to start experimenting and developing a digitally controlled multi-DC/DC LED lighting system. This kit is based on the Piccolo™ microcontroller and the controlCARD development platform. One Piccolo MCU is able to directly control eight separate DC/DC power stages as well as up to eight LED strings of various LED types and string lengths.

* To qualify please respond to our post event e-mail update. First five qualified respondents will receive a 10% off discount code to order a TMDSRGBLEDKIT through the TI eStore.
Additional offers
Concerto™ MCU Experimenters Kit

For qualified attendees*

- 15% Discount on Concerto™ MCU Experimenters Kit
  (Listed web price is $185)

**Concerto™ MCU Experimenters Kit:**
The C2000™ Experimenter Kits from Texas Instruments are ideal Products for initial device exploration and testing. The Concerto H52C1 Experimenter Kit has a docking station that features access to all controlCARD signals, breadboard areas and RS-232 and JTAG connectors. Each kit contains a H52C1 controlCARD. The controlCARD is a complete board level module that utilizes and industry-standard DIMM form factor to provide a low-profiles single-board controller solution. Kit is complete with Code Composer Studio™ IDE v4 and USB cable.

* To qualify please respond to our post event e-mail update. First five qualified respondents will receive a 5% off discount code to order a TMDXDOCKH52C1 through the TI eStore.
Thank You

For additional information please contact you local Avnet sales representative

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References

1. Modern Language Association (MLA):