DSP C2000 Applications

谭徽
tanhui@ti.com
Advance Embedded Control
Texas Instruments, Shanghai
Introduction to C2000 DSP

Agenda:

• Digital Motor Control (DMC)
• Digital Power Supplier (DPS)
• Power Meter/Analyzer & Embedded-PLC
• Expanding from DMC & DPS
  • Power Supplier for HDTV & Others
  • Smart Sensing and Measurement
  • Other EE Applications
• Summary & Call to Action
Digital Motor Control
C2000 Advantages in VF Home Appliance
Solution Package for VF Home Appliances

1. 120-Degree BLDC Compressor Control Solution #1 for Variable-Frequency (VF) Air Conditioners (A/Cs)
2. 120-Degree BLDC Compressor Control Solution #2 for VF Air Conditioner
3. 180-Degree BLDC Compressor Control Solution for VF Air Conditioner
4. 180-Degree BLDC Compressor Control Solution for VF Refrigerator
5. ACI Compressor Control Solution for VF Air Conditioner
6. Digital Power Factor Correct Solution for VF Air Conditioner
7. Analog Power Factor Correct Solution for VF Air Conditioner
Motor-Control Features of the Solution Package

- Industrial proven solutions in terms of reliability
- Input voltage range: 145 ~ 270 VAC (in this voltage range, BLDC compressor can stable startup and running)
- Operating Environment Temperature range: -15 ~ 50°C
- Output power capacity: 1~3 KW, Depend on IPM capacity
- Motor frequency range from 20 ~ 300Hz (Electrical)
- Flexible to adapt to different motor through external EEPROM by updating the control parameters in it.
- Multiple protect functions
  - Voltage & Current protection
  - Motor over temperature & overload protection
  - IPM FO protection
  - Temperature sensor error protection
  - Communication error protection
C2000 Advantage in VF Home Appliance

• **Reduced system cost**
  - Cost of C2000 DSP has become competitive (~$2)
  - Same DSP to implement both compressor control and PFC
  - Advanced algorithms to reduce cost of circuit modules – simplified zero crossing detection, true SVPWM and PFC resulting in higher bus voltage and lower IPM current rating
  - Optimized control algorithms reducing size of heat sink - random PWM, dead time compensation, accurate real-time signal generation
  - Universal platform, reducing R&D investment

• **Increased performance**
  - Capable of implementing algorithms that are impossible for MCU, directly impacting noise reduction, starting/cooling speed (comfort factor), efficiency, etc.
  - Authentic PFC solution better guarantees CCC certification, reducing sensitivity to change in component, circuit and load
  - Room for more sophisticated system functions and future expansion

• **Increased reliability**
  - Capable of advanced algorithms that are impossible for MCU, increasing circuit and system reliability – simplified zero crossing detection, controlled current startup, accurate over load protection, wider supply voltage range
  - Optimized system solution and algorithms reduce heat dissipation and increase system reliability (random PWM, dead time compensation, accurate real-time signal generation, discrete IGBT solution, reduced IPM module current)
TI total solution benefits

• Complete solution, including H/W and S/W, accelerating customer’s time to market

• Open technology - full disclosure of core control algorithms, system functions, source code, PCB schematic and layout, allowing customers to focus on introducing differentiated products

• Full support to strategic customers and third parties, further accelerating customer’s time to market and empowering the third parties
## Software Modules in DMC Library

- Available in assembly and CCA

<table>
<thead>
<tr>
<th>#</th>
<th>Module</th>
<th>Description</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FC_PWM_DRV</td>
<td>Full Compare PWM driver (configurable for - active Hi/Lo, Dead-band, asm/sym)</td>
<td>Driver</td>
</tr>
<tr>
<td>2</td>
<td>CAP_EVT_DRV</td>
<td>Capture input event driver with 16 time stamps &amp; pre-scaler selection</td>
<td>Driver</td>
</tr>
<tr>
<td>3</td>
<td>QEP_THETA_DRV</td>
<td>Quadrature Encoder Pulse interface driver with position (theta) as output</td>
<td>Driver</td>
</tr>
<tr>
<td>4</td>
<td>ILEM2_DRV</td>
<td>LEM based 3 phase current measurement driver (2 meas method)</td>
<td>Driver</td>
</tr>
<tr>
<td>5</td>
<td>ILEG2_DRV</td>
<td>Leg shunt resistor based 3 phase current measurement driver (2 meas method)</td>
<td>Driver</td>
</tr>
<tr>
<td>6</td>
<td>ADC04_DRV</td>
<td>General purpose 4 conversion ADC driver with Gain / offset &amp; channel selection</td>
<td>Driver</td>
</tr>
<tr>
<td>7</td>
<td>BLDC_PWM_DRV</td>
<td>BLDC PWM driver – uses High side chopping and fixed on/off for low side</td>
<td>Driver</td>
</tr>
<tr>
<td>8</td>
<td>HALL3_DRV</td>
<td>Hall effect interface driver for sensored 3 phase BLDC trapezoidal control</td>
<td>Driver</td>
</tr>
<tr>
<td>9</td>
<td>LEG_VBUS_DRV</td>
<td>Leg shunt resistor &amp; DC bus voltage meas driver used for MRAS ACI</td>
<td>Driver</td>
</tr>
<tr>
<td>10</td>
<td>DAC_VIEW_DRV</td>
<td>4 channel DAC driver (for EVM) useful for displaying “real-time” variables on scope</td>
<td>Util</td>
</tr>
<tr>
<td>11</td>
<td>VHz_PROF</td>
<td>Volts / Hertz profile for ACI (Voltage vs Frequency)</td>
<td>TI / AC</td>
</tr>
<tr>
<td>12</td>
<td>PID_REG</td>
<td>Proportional / Integral / Derivative controller with 32 bit Integration</td>
<td>TI / AC</td>
</tr>
<tr>
<td>13</td>
<td>SPEED_PRD</td>
<td>Speed calculator based on period measurement between events (speed = 1/period)</td>
<td>TI / AC</td>
</tr>
<tr>
<td>14</td>
<td>SPEED_FRQ</td>
<td>Speed calculator based on frequency measurement – tacho style method</td>
<td>TI / AC</td>
</tr>
<tr>
<td>15</td>
<td>FLUX_ANGLE</td>
<td>Flux angle model for 3 phase ACI vector control</td>
<td>TI / AC</td>
</tr>
<tr>
<td>16</td>
<td>COMPEN</td>
<td>DC ripple compensator for single phase ACI variable speed drives</td>
<td>TI / AC</td>
</tr>
<tr>
<td>17</td>
<td>COMTN_TRIG</td>
<td>Commutation trigger generator for BLDC sensorless trapezoidal / BEMF / ZC tech.</td>
<td>TI / AC</td>
</tr>
<tr>
<td>18</td>
<td>PMSM_SMO</td>
<td>PMSM Sliding mode observer for position estimation in sensorless 3 phase Vector drives</td>
<td>TI / AC</td>
</tr>
<tr>
<td>19</td>
<td>ACI_MRAS</td>
<td>Model Reference Adaptive System speed estimator. used for 3phase ACI drives.</td>
<td>TI / AC</td>
</tr>
<tr>
<td>20</td>
<td>PHASE_V3</td>
<td>3 Phase Voltage reconstruction function based on PWM duty cycle inputs.</td>
<td>TI / AC</td>
</tr>
<tr>
<td>21</td>
<td>PFC_2V</td>
<td>Power factor correction based on 2 voltage meas method</td>
<td>TI / AC</td>
</tr>
<tr>
<td>22</td>
<td>SVGEN_MF</td>
<td>Space vector generator function with Magnitude &amp; Frequency control (scalar drives)</td>
<td>TI / AI</td>
</tr>
<tr>
<td>23</td>
<td>CLARK</td>
<td>Clark transform – 3 phase to 2 phase (quadrature) conversion</td>
<td>TI / AI</td>
</tr>
<tr>
<td>24</td>
<td>CLARK_I</td>
<td>Inverse Clark transform – 2 phase (quadrature) to 3 phase conversion</td>
<td>TI / AI</td>
</tr>
<tr>
<td>25</td>
<td>PARK</td>
<td>Park Transform – Stationary to Rotating reference frame conversion</td>
<td>TI / AI</td>
</tr>
<tr>
<td>26</td>
<td>PARK_I</td>
<td>Inverse Park Transform – Rotating to Stationary reference frame conversion</td>
<td>TI / AI</td>
</tr>
<tr>
<td>27</td>
<td>SVGEN_DQ</td>
<td>Space vector generator function with Quadrature control (Vector drives)</td>
<td>TI / AI</td>
</tr>
<tr>
<td>28</td>
<td>SINCOS_PH</td>
<td>2 phase Sine generator function with variable phase control</td>
<td>TI / AI</td>
</tr>
<tr>
<td>29</td>
<td>RAND_GEN</td>
<td>Random generator function – useful in randomizing PWM modulation</td>
<td>TI / AI</td>
</tr>
<tr>
<td>30</td>
<td>DLOG_VIEW</td>
<td>Data logging utility – useful for variable graphing in Code composer</td>
<td>Util</td>
</tr>
</tbody>
</table>
## Modular Systems in DMC Library

- Available in assembly and CCA

<table>
<thead>
<tr>
<th>System</th>
<th>Motor Type</th>
<th>Description</th>
</tr>
</thead>
</table>
| ACI1-1 | 1 ph AC induction | Sensored – Tacho i/p  
VHz / SinePWM / Closed loop (CL) speed PID |
| ACI3-1 | 3 ph AC induction | Sensored – Tacho i/p  
VHz / SVPWM / Closed loop speed PID |
| ACI3-2 | 3 ph AC induction | Sensorless – MRAS (speed estimator)  
VHz / SVPWM / Closed loop speed PID |
| ACI3-3 | 3 ph AC induction | Sensored – Tacho i/p  
FOC / SVPWM / Closed loop current PID for D,Q / CL speed PID |
| ACI3-4 | 3 ph AC induction | Sensorless – Direct Flux estimator + speed estimator  
FOC / SVPWM / Closed loop current PID for D,Q / CL speed PID |
| ACI3-5 | 3 ph AC induction | Sensorless – Direct Torque Control (DTC)  
Modified SVPWM / Closed loop current / CL speed |
| PMSM3-1 | 3 Ph Permanent Magnet Synch | Sensored - QEP  
FOC / SVPWM / Closed loop current PID for D,Q / CL speed PID |
| PMSM3-2 | 3 Ph Permanent Magnet Synch | Sensorless – SMO (Sliding mode observer) position estimator  
FOC / SVPWM / Closed loop current PID for D,Q / CL speed PID |
| BLDC3-1 | 3 ph Trapezoidal Brushles DC | Sensored – 3 Hall effect i/p  
Trapezoidal / Closed loop current PID / CL Speed PID |
| BLDC3-2 | 3 ph Trapezoidal Brushles DC | Sensorless – BEMF / Zero crossing detection  
Trapezoidal / Closed loop current PID / CL Speed PID |
## DSP for DMC

### What is it?
- End Equipments that control and monitor all types of electric motors, including BLDC, ACI, Switched Reluctance, etc.
- End Equipments include White Goods, Factory Automation, Automotive applications, and Consumer products.

### Why TI DSP?
- Offers most highly integrated solution, enabling system cost reduction, and board space reduction.
- DSP Control offers most precise control with bandwidth remaining to enable future growth & innovation.
- Provides control, sensing, high precision PFC, and housekeeping functions all on one chip.
- Programmability enables faster time to market and last minute changes in these emerging applications (Software upgradeable in field).

### TI Solution
- Breadth of C2000 TI DSP solutions with to meet each customers requirements.
- C2000 DSPs provided high performance and a high level of integration to enable reduced system cost, and innovative motor control designs.
- DMC Software Library
- Third Party Motor control development boards
Motor Control System Components

AC Input → Bridge Rectifier → Power converter → Motor

Bridge Rectifier → DC link

Power converter → Motor

Motor → Load

Power Supply
- LDO
- PFC
- SVS
- PWM

MOSFET driver

Current and voltage sense

Current sense

Resolver

Optical encoder

Hall effect

Simult. Sampling

ADCs

Network interface
- Ethernet

4-20mA interface
- 4-20mA loop

Data line
- CAN
- RS232
- RS485

DAC interface
- +/- 10V

ADC interface
- +/- 10V
Motor Control system Components From TI

- AC Input
- Bridge Rectifier
- Power converter
- Motor
- Load

- Current and voltage sense
- Power supply
  - LDO
  - PFC
  - SVS
  - PWM

- DSP Controller
- Simult. Sampling
- ADCs and interface
- Resolver
- Optical encoder
- Hall effect

- Network interface
- 4-20mA interface
- Data line
- ADC interface
- DAC interface

- Ethernet
- 4-20mA loop
- CAN
- RS232
- RS485
- +/- 10V
- +/- 10V
Measurements for Servo Application

Motor Current:
- Two Phase Measurement
- Three Phase Measurement
- Motor current value for control algorithm
- Sign of the phase current for "dead time" compensation
- Over-Load and Over Current protection

Motor Encoder or Resolver:
- Rotor Speed
- Rotor Position

Load Encoder:
- Load Position
- DC-Link voltage
- Temperature
- Etc...
Cost Effective High Accuracy Position Measurement by Resolver

\[ \sin(\alpha) \]
\[ \cos(\alpha) \]
\[ \alpha(t) = \omega t \]

Sim. Samp

SAR 500kSPS

12Bit OPA4340 ADS7861

16Bit OPA4350 ADS8361
**Incremental Encoder Measurement with ADS7869**

- Two Synchronous inputs
- Two Asynchronous inputs
- Differential inputs
- Two 12 bits 1MSPS ADCs
- 20% Gain correction
- 20% Offset correction

Two Sign Comparators
16-bit UP/DOWN Counter
State Machine
Digital Filter
4 Registers
26-bit total resolution
DC-Link Voltage and Phase Currents Measurement for Servo Application
Motor Current Measurement with ADS7869

Three:
- Sample & Hold
- 12BIT ADC 1MSPS
- PGA

iu(t) = IU \sin(\omega t)
iv(t) = IV \sin(\omega t + 120^\circ)
iw(t) = IW \sin(\omega t - 120^\circ)

Simultaneous Sampling
Motor Current Measurement with ADS7869

Three:
- Sample & Hold
- 12BIT ADC 1MSPS
- PGA
- Sign Comparators
- Window Comp.

Three simultaneous sampling inputs
No time difference error in sampling of signals

Three differential inputs
High CMRR for noisy environment

Three PGA are simultaneously scaling inputs
Same HW for different power range

Three 12 bits 1MSPS ADCs
Low delay in control algorithm

Three sign comparators
SW Lockout time compensation

One 8 bit DAC for set up of current limit
Dynamic control of motor acceleration

Three programmable window comparators
Separate control of motor phases over-current
ADS7869 Complete Motor Control Analog Front-End

- 12 FULLY DIFFERENTIAL INPUTS
- 5 SIMULTANEOUS SAMPLED CHANNELS AND 2 ASYNCHRONOUS SAMPLED CHANNELS
- 3 SYNCHRONIZED 12-BIT ADCs
- 1us THROUGHPUT RATE
- DIGITALLY SELECTABLE INPUT RANGES (PGA)
- DIGITALLY ADJUSTABLE GAIN AND OFFSET FOR EVERY INPUT
- 7 SIGN AND 3 DIGITALLY PROGRAMMABLE WINDOW COMPARATOR
- TWO 16 BIT UP/DOWN SYNCHRONIZED COUNTERS WITH DIGITAL FILTER
- DAC FOR ADJUSTABLE OVERCURRENT PROTECTION
DMC - Low end single axis

Solution characteristic

- One main s/w control thread
- Multiple sub-loops (current, speed, position cntl)
- Sensored control: 8 ~ 15 MIPs (core code)
- Sensorless control: 15 ~ 30 MIPs (core code)
- Usage: White goods, HVAC, low-end Industrial
DMC - High end Multi axis

Solution characteristic

• Multiple system ("algorithm") instantiation
• High level network protocols
  o CAN (deviceNet, CANopen,…)
  o Ethernet (TCPIP)
• Sensored control: 30 ~ 60 MIPs (3 axis)
• Sensorless Hi-end control: 60 ~ 90 MIPs (3 axis)
Motor Type & Common applications

AC Induction
- Today's most commonly used motor
- Pumps
- Fans
- White Goods
- General industrial and heavy traction machinery

Brushless DC (BLDC)
- Small high efficiency drives
- Servo drives, very small fans
- increasing into other applications

Permanent Magnet Synchronous Motor
- servo drives
- Electronic power steering
- Also increasing into other applications

Brushed DC (Small) motors
- hand-tools
- various machinery and appliances including washers dryers.
- Automotive:
- Starters
- Wipers
- power windows

Switched Reluctance SR Motor
- Fans
- Appliances
- Emerging automotive applications

Stepper
- Printers
- Machinery
- Medical
- Low cost automotive applications
Digital Power Supplier
Agenda

- Introductions
- The Digital Power Evolution & Comparison to Analog
- Overview of TI’s Digital Power Strategy
  - UCD7xxx Product Brief
  - UCD8xxx Product Brief
  - UCD9xxx/C24xx/C28xx Product Brief
- UCD8x ¼ brick reference design
- UCD9501 rectifier reference design
Various Digital Power Perspectives

- Communication
- Monitoring & Supervision
- Digital Control
- Fusion Digital Power
- Power Peripherals
Convergence of Digital + Analog for Power Management

Fusion Digital Power™

C2000 DSP
MSP430 MCU

Unitrode
TI Power Management

• Microcontroller and DSP experience
  – More than 20 years of DSP development
  – Successfully changed motor control from analog to digital
  – Continuous effort to lower cost and improve performance

• Power Management
  – More than 20 years of power supply IC and design experience
  – Integration of Unitrode Business
  – Solid trend to add more digital control to power management:
    • PoE, Battery Management, DC/DC, Predictive Gate Drive
What is Digital Power?

- Digitally controlled power products that provide **supervisory** and **monitoring** functions, which extends to **full loop control**.
  - Initial customer targets:
    - From AC-line to point-of-load, covering uninterruptible power supplies, server, telecom, data-centric and VRM applications.
    - Expanding digital control capabilities into new markets
Digital Power Advantages

• Flexibility
  – Customization through software (platform development)
  – Enhanced control & monitoring
    • Load-share, Thermal management, Hot-swap
  – Faster time to market
  – Adjustability (voltages, currents, frequencies, limits, fault containment strategies)
  – Centrally managed start-up / shut-down / Sequencing

• IP Protection through software code security
  – Product differentiation

• Remote Diagnostics
  – Intelligent Fault Management & down-time avoidance
    • Efficiency, ripple, temp,… may be leading indicators of pending failures
  – Data logging (Vout, Pout, Vin, Pin, temp, etc)
Digital Power Advantages (cont)

• Communication
  – Increasingly more power supplies are required to report parameters, perform sequencing, and handshake with downstream systems

• Programming
  – Operating parameters
    • Switching frequency / input voltage level / Output voltage
  – Protection function parameters
    • Output current limit threshold
    • Input under / over-voltage protection thresholds
    • Output over-voltage protection
    • Temperature shutdown threshold
  – Control parameters
    • Start up profile
    • Over current protection profile
Digital Power Advantages (cont)

• Performance and Reliability
  – System awareness and responsiveness
  – Industry-leading 150 ps digital PWM resolution
  – Integrated safety, bias supply management
  – Real-time over-current protection and management

• Reduced component count for Higher Complexity
  – Lower manufacturing costs
  – Higher Reliability
# Analog vs. Digital Control

<table>
<thead>
<tr>
<th>Analog Controller</th>
<th>Digital Controller</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>• High bandwidth</td>
<td>• Insensitive to environment (temp, drift,…)</td>
</tr>
<tr>
<td>• High resolution</td>
<td>• High reliability</td>
</tr>
<tr>
<td>• Easy to understand / use</td>
<td>• S/W programmable / flexible solution</td>
</tr>
<tr>
<td>• Relatively low cost</td>
<td>• Precise / predictable behavior</td>
</tr>
<tr>
<td>• Component drift and aging / unstable</td>
<td>• Advanced control possible (non-linear, multi-variable)</td>
</tr>
<tr>
<td>• Component tolerances</td>
<td>• Can perform multiple loops and “other” functions</td>
</tr>
<tr>
<td>• Hardwired / not flexible</td>
<td></td>
</tr>
<tr>
<td>• Limited to classical control theory only</td>
<td></td>
</tr>
<tr>
<td>• Large parts count for complex systems</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>• Numerical problems (quantization, rounding,…)</td>
<td>• AD / DA boundary (resolution, speed, cost)</td>
</tr>
<tr>
<td>• AD / DA boundary (resolution, speed, cost)</td>
<td>• CPU performance limitations</td>
</tr>
<tr>
<td>• CPU performance limitations</td>
<td>• Bandwidth limitations (sampling loop)</td>
</tr>
<tr>
<td>• Tradeoffs between Cost, Switching Frequency, Resolution, and Number of Functions</td>
<td>• High end processors require large amounts of power</td>
</tr>
</tbody>
</table>

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Digital Controller

- Precise / predictable behavior
- Advanced control possible (non-linear, multi-variable)
- Can perform multiple loops and “other” functions
System Overview

Operating Frequencies

Single Phase PFC
2 Interleaved PFC

Flyback
Forward
2-switch Forward
Half-Bridge
Phase-Shifted Full-Bridge

Flyback
Forward
2-switch Forward
Push-Pull
Half-Bridge
Phase-Shifted Full-Bridge

Synchronous Buck
Boost
Multiphase Sync Bucks
Push-Pull

Output Voltages

AC Line: 85-265 VAC

Rectified AC

385V - 400V
Boosted DC
Output

Distribution BUS Voltage
(48, 24, 12V)

Main Card
Power 3.3V

PFC
Down-Stream
DC/DC

MOSFET
Drivers

Isolated
Feedback

Isolated
DC/DC

Local
DC/DC

Synch.
Buck
Driver

Local
DC/DC

3.3V

2.5V

1.xV

Synchronous Buck
Boost
Multiphase Sync Bucks
Push-Pull

Output
Voltages

it's customers • it's market share • it's execution

TExAS INSTRUMENTS
Partitioning Issues

• Partitioning Choices
  – Speed
    • 1MHz design will be a different implementation than a 100kHz converter
  – Bandwidth
    • Transient Response Requirements
    • Trade-offs in number of outputs or converters being controlled

• Strictly Analog
  – Gate Drive
  – Backup Over-Current Protection (in case of system lockup)
  – Bias Supply
Fusion Digital Power™ Solutions for the Broad Market

- **UCD9K/C24xx/C28xx Digital Power Controllers**
  - Close multiple loops digitally
  - Provide industry standard communication and supervision

- **UCD8K Digital Power PWM Controllers**
  - Integrated, digitally controlled, analog PWM and driver to close the loop

- **UCD7K Digital Power Drivers**
  - Interface digital controller to power stage
  - Provide protection and bias
UCD7K Digital Power Drivers

- Interface digital power controller to the power stage
- Allow the digital controller to have direct control of the power stage while providing protection

<table>
<thead>
<tr>
<th>Key Features</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Current Gate Drivers</td>
<td>Interfaces to the power stage</td>
</tr>
<tr>
<td>Programmable Analog Over-Current Limit with Flag</td>
<td>Fail-proof and Flexible Overload Protection</td>
</tr>
<tr>
<td>On-board 3.3-V, 10-mA Linear Regulator</td>
<td>Provides Power to the Digital Controller</td>
</tr>
</tbody>
</table>
UCD8K Digital Power Controllers

- Integrate a digital compatible PWM controller and a driver to close the loop in the analog domain under digital supervision

### Key Features

<table>
<thead>
<tr>
<th>Key Features</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Mode or Peak Current Mode Control</td>
<td>Provides flexibility of Control Methods</td>
</tr>
<tr>
<td>Programmable Over Current Limit with Flag</td>
<td>Fail-proof and Flexible Overload Protection</td>
</tr>
<tr>
<td>Accepts Clock Input from the Digital Controller</td>
<td>Digitally Control Switching Frequency and Maximum Duty Cycle</td>
</tr>
<tr>
<td>On-board 3.3V, 10mA Linear Regulator</td>
<td>Provides Power to the Digital Controller</td>
</tr>
</tbody>
</table>
UCD9K High-Resolution Digital Power Controllers

- Close multiple feedback loops digitally
- Provide communication and supervision
- Scalable, power-specific peripherals

<table>
<thead>
<tr>
<th>Key Features</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital PWM, up to 150-ps Resolution at 100MHz</td>
<td>No Limit Cycle at MHz switching frequencies</td>
</tr>
<tr>
<td>ADC, up to 12-Bits resolution</td>
<td>Accurate regulation and monitoring</td>
</tr>
<tr>
<td>ADC, as fast as to 50-ns conversion time</td>
<td>Wide Voltage Loop Bandwidth and Fast Transient Response</td>
</tr>
<tr>
<td>Flash Memory, up to 64-KW for Program and Data</td>
<td>Allows for high complexity UCD9K</td>
</tr>
<tr>
<td>Multifunction IO ports, up to 48</td>
<td>Allows for high flexibility</td>
</tr>
<tr>
<td>PM Bus™ Compliant</td>
<td>Hardware Peripheral for Standardized Communication</td>
</tr>
</tbody>
</table>
High Resolution PWM vs. Conventional PWM

TMS320F2808 @ 100 MHz
PWM freq = 10 MHz
Period = 10 clocks
(i.e. 10 step resolution using conventional PWM)
Application Example: DC-DC Converter

- DC-DC converter controlled by TMS320F2808 @100MHz
- $V_{in} = 8V$, $V_{out} = 1.3V$, $I_{o} = 5A$
- PWM Frequency = 1MHz using conventional PWM capability
  - Output oscillation of 10mV at 66KHz (the limit cycle) is caused by a lack of PWM resolution

- PWM Frequency = 1MHz, using High-resolution PWM capability
  - Output oscillation (the limit cycle) has been eliminated by using High-resolution PWM
Application Example: DC-DC Converter
(Larger time scale)

- DC-DC converter controlled by TMS320F2808 @100MHz
- Vin= 8V, Vout= 1.3V, Io = 5A

- PWM Frequency = 1MHz using conventional PWM capability
- Output oscillation of 10mV at 66KHz (the limit cycle) is caused by a lack of PWM resolution

- PWM Frequency = 1MHz, using High-resolution PWM capability
- Output oscillation (the limit cycle) has been eliminated by using High-resolution PWM
**UCD9K: System Simplification, Programmability in a Telecom Rectifier**

**Traditional Analog Power Supply**
- Multiple chips for control
- Micro-controller for supervisory
- Dedicated design

**Digital Power Supply**
- Eliminate Components
- Reduce Manufacturing Cost
- Better Performance Across Corners
- One Design, Multiple Supplies
- Failure Prediction

*Image of diagram with components labeled: Filter Bridge, PFC, DC/DC, Inrush/Hot-plug Control, Interface Circuit, PFC Control, DC/DC Converter Control, Current/Load Sharing Control, Multi-mode Power control, MCU, Supervisory Housekeeping Circuits, Aux P/S, To Host, Power Management UCD9501.*
UCD8K Concept Design Specifications

SWITCHING FREQUENCY = 500 kHz / Phase

• INPUT:
  • Vin = 48 V Telecom (36V – 75V)

• OUTPUT:
  • Vout = 12 V
  • Pout = 100 W

• SIZE:
  • Component Footprint = ¼ Brick
  • Component Placement = Double-sided
  • Component Height = ½ Inch Each Side

• Microcontroller:
  • MSP430F1232

• PWM Controller:
  • UCD8509 Digital Compatible PWM Controller
UCD8K Concept Design Graphical User Interface

UCD8509 Demonstration Software

<table>
<thead>
<tr>
<th>Current limit count link</th>
<th>32000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low VIN stop link</td>
<td>32.2V</td>
</tr>
<tr>
<td>Low VIN start link</td>
<td>35.1V</td>
</tr>
<tr>
<td>High VIN start link</td>
<td>76.1V</td>
</tr>
<tr>
<td>High VIN stop limit</td>
<td>81.9V</td>
</tr>
<tr>
<td>VDS limit</td>
<td>200.0V</td>
</tr>
<tr>
<td>Temperature stop link</td>
<td>100 °C</td>
</tr>
<tr>
<td>Temperature start link</td>
<td>85 °C</td>
</tr>
<tr>
<td>V+5 Margin</td>
<td>15 %</td>
</tr>
<tr>
<td>DMax limit</td>
<td>75 %</td>
</tr>
<tr>
<td>Min DAC</td>
<td>0</td>
</tr>
<tr>
<td>Stall start delay</td>
<td>7 ms</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vin</th>
<th>Vds</th>
<th>Temp</th>
<th>I_in_avg</th>
<th>Vctrl</th>
<th>CLFcnt</th>
<th>stat</th>
<th>PWM</th>
</tr>
</thead>
<tbody>
<tr>
<td>46.82V</td>
<td>152.1V</td>
<td>21.2°C</td>
<td>0.89 A</td>
<td>1.02 V</td>
<td>0</td>
<td>13</td>
<td>40.6 %</td>
</tr>
</tbody>
</table>

Real World Signal Processing™

it's customers - it's market share - it's execution

Texas Instruments
UCD8509 Development Platform

Top View

Bottom View
DSP Concept Design Specifications/Requirements

- Industrial Applications

- Off-Line Input
  - Wide input voltage range 85-265Vrms VAC
  - Power Factor Correction
  - 2-Channel Interleaved Boost

- Output
  - 48V distributed bus
  - Phase-Shifted Full-Bridge Topology
  - 1000W output power

All with 1 DSP!
Rectifier Concept Design – full digital control

- 1000W
- F2810 DSP based
- 2 Phase PFC-IL
- Phase shifted ZVS-FB
- 250 KHz PWM (DC/DC)
- 125 KHz PWM (PFC)
DSP based AC/DC Rectifier Concept design (continued)
Interleaved Boost PFC

- 2 Interleaved boost converters
- MOSFET Rds,on current sense
- Excellent current sharing between modules
Phase Shifted Full Bridge

- DC-DC Phased-Shifted Full-Bridge operates off PFC boost
- Vds of Q6/Q7
Zero Voltage Switching

- ZVS of the PSFB
- Bottom trace is Vgs top trace is Vds.
- Vds falls to 0V before Vgs turns on MOSFET
Interleaved PFC

• Line current, \( V_{\text{line}} = 120\text{Vrms} \), \( P_{\text{out}} = 850\text{W} \); 2A/Div
Interleaved PFC

- Line current, $V_{\text{line}} = 240\text{Vrms}$, $P_{\text{out}} = 850\text{W}$; 2A/Div
Power Meter/Analyzer & Embedded-PLC

Power Line Communication and Inverter functions
Measurement Application Utility Meter

DSP performance required for class .5 utility meter
Requires high speed and 64Kw memory and board space reduction
DSP is measuring phase voltages

Voltage phase 1
Current phase 1
V & I phase 3
ADC 9 Inputs
F2812
SPI
GPIO

From Utility

To Host computer (upgrades)

Powerline communications

Texas Instruments
Motivation

Implementing power line communication and other system related functions using a single DSP resulting in a flexible system for various communication protocols and also a cost reduction for the complete system.
Power Line Communication Methods

- TurtleTech, TWACS
  - <10 Hz modulation, freq division multiplexing, ~3bits/hour data rate.
  - Utility automatic meter reading. Very long reach.
- X-10
  - Modulate at 120 kHz for 1 msec at 60 Hz zero-cross
  - Aimed at home automation, 120 b/sec.
- UPB
  - Pulse position modulation on each half sine wave
  - Aimed at home automation, 240 b/sec
- FSK (ST7537)
  - 131.85/133.05 kHz modulation
  - Aimed at utility communication, 2.4 kb/s
- CEA-709 (Echelon Lonworks)
  - BPSK on 132 kHz or a secondary frequency.
  - Full 7 layer protocol stack
  - Aimed at control applications, 5.5 kb/s
- Home-plug
  - Broadband over power lines, 1.8 Mb/s
  - OFDM modulation. Subcarrier frequencies from 4.5 to 20.7 MHz
Modulation Alternatives

- Frequency Bands:
  - Europe:
    - A-band: 9kHz to 94.5 kHz allocated for utility communication
    - C-band: 95 kHz to 148.5 kHz allocated for consumer communication
  - North America
    - modulate < 450 kHz

- Two approaches:
  - Narrow-band: X10, FSK, CEA-709, etc
  - Wide-band: HomePlug, other proprietary systems

- Narrow-band
  - Modulate phase or frequency around 132 kHz.
  - Use FIR filter techniques to detect transmitted symbols.
  - Simple method, minimal MIPS used, but no error correction applied to data.

- Wide-band (TI E-meter design)
  - Use the FFT algorithm to modulate and demodulate the transmitted signal.
  - Spread data across multiple carriers and add redundancy. Then use redundancy to do error correction at the receiver.
  - More robust to interference tones, but ECC takes more MIPS to implement.
PLC Transmit Function

- Each transmitted bit consists of 24 cycles of 131.579 kHz
- The transmit DAC is constructed using 2 PWM outputs.
- Update rate = bit rate due to PWM automation
- Signal filtered and amplified by OPA561 line driver.
PLC Receive Function

- The received command is amplified and bandpass filtered with an **OPA353** based circuit.
- The ADC samples the filtered signal at $25/24 \times F_{\text{carrier}}$ or 137.06 kHz.
- This "downsamples" the signal to a 5.5 kHz waveform.
- Each sample filtered with 25-tap digital FIR.
- Differential phase of each bit detected using a digital correlation filter. (Each bit is correlated to the previous bit to detect phase.)
PLC Receive Function cont.

- Example receiver waveforms

- System frequency response

![System Frequency Response Graph](image)

- Frequency: 5.5 kHz
The packet and bit boundaries are identified with a 24-bit pattern of alternating phase.

Word Sync signifies the start of data.

Each 8-bit command byte is encoded as an 11-bit word by the transmitter. The receiver decodes this word and shifts the detected data into a memory buffer.

For PLC, we have added a 16-bit CRC to the command data.

The end of the packet is identified by the 11-bit EOP word (repeated twice).
TMS320F280x Resource Allocation

- TMS320F280x DSP provides:
  - 16 PWM channels
  - 12 Time Bases
  - 16 Analog-to-Digital Channels
  - 100 MHz performance

- TMS320F2806 (F2808)
  Available Memory Allocation:
  - 100 MIPS
  - 32 (64) kW FLASH
  - 10 (18) kW SARAM
  - 4 kW Boot ROM
  - 1 kW OTP
  - Code Security

Application requirements

<table>
<thead>
<tr>
<th>Function</th>
<th>Time Base</th>
<th>PWM</th>
<th>ADC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter_1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Inverter_2</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Inverter_3</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Inverter_4</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>PFC</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>PLC</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
</table>

Application memory usage

<table>
<thead>
<tr>
<th>Function</th>
<th>Memory (Program)</th>
<th>Memory (Data)</th>
<th>MIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLC</td>
<td>~ 6 kW</td>
<td>&lt; 4 kW</td>
<td>&lt;50</td>
</tr>
<tr>
<td>PFC</td>
<td>&lt; 1kW</td>
<td>&lt; 1kW</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>Inverter</td>
<td>&lt; 5kW*</td>
<td>&lt; 1kW*</td>
<td>&lt;30*</td>
</tr>
</tbody>
</table>

* Estimated, based on three phase sensorless PMSM Field Oriented Control
# Measured on F2812; should be faster on F280x.
DSP Hardware Resource usage

### USED IN REAL APPLICATION

<table>
<thead>
<tr>
<th>Function</th>
<th>Registers</th>
<th>Pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLC Tx Waveform</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tx+ output</td>
<td>CMP1</td>
<td>PWM1</td>
</tr>
<tr>
<td>Tx- output</td>
<td>CMP2</td>
<td>PWM3</td>
</tr>
<tr>
<td>Polarity control</td>
<td>ACTRA</td>
<td></td>
</tr>
<tr>
<td>Period register</td>
<td>T1PR</td>
<td></td>
</tr>
<tr>
<td>Tx Bias Enable</td>
<td></td>
<td>GPIOA11</td>
</tr>
<tr>
<td>ADC Rx Input</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADC Input</td>
<td>ADCIN6</td>
<td>ADCINA6</td>
</tr>
<tr>
<td>Period register</td>
<td>T2PR</td>
<td></td>
</tr>
</tbody>
</table>

### USED ONLY FOR DEMO BOARD

<table>
<thead>
<tr>
<th>Function</th>
<th>Registers</th>
<th>Pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED Intensity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWM output</td>
<td>CMP5</td>
<td>PWM9</td>
</tr>
<tr>
<td>Period register</td>
<td>T3PR</td>
<td></td>
</tr>
<tr>
<td>RS-232 Interface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serial Data Tx</td>
<td>SCITXDA</td>
<td></td>
</tr>
<tr>
<td>Serial Data Rx</td>
<td>SCIRXDA</td>
<td></td>
</tr>
<tr>
<td>RTS</td>
<td>GPIOF0</td>
<td></td>
</tr>
<tr>
<td>CTS</td>
<td>GPIOF1</td>
<td></td>
</tr>
<tr>
<td>Status LEDs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rx Good</td>
<td>GPIOA8</td>
<td></td>
</tr>
<tr>
<td>Rx Busy</td>
<td>GPIOA9</td>
<td></td>
</tr>
<tr>
<td>Tx</td>
<td>GPIOA10</td>
<td></td>
</tr>
<tr>
<td>Option Jumpers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opt1</td>
<td>GPIOB9</td>
<td></td>
</tr>
<tr>
<td>Opt0</td>
<td>GPIOB10</td>
<td></td>
</tr>
<tr>
<td>Opt2</td>
<td>GPIOB11</td>
<td></td>
</tr>
<tr>
<td>Opt3</td>
<td>GPIOB12</td>
<td></td>
</tr>
</tbody>
</table>
Ballast Demonstration

• Propose narrow-band approach
  – All signal processing for communication, PFC and inverter done by single DSP.
  – Based on existing power line communication (PLC) standard.
  – Modified to support DALI-like command protocol.

• PLC method
  – Compatible with CEA-709 protocol (LonWorks)
  – Single carrier: 131.579 kHz
  – Differential binary phase shift keyed modulation (DBPSK)
  – 5.5 kb/s transfer rate (4 kb/s after encoding)
  – Command Packet time: 14.1 msec
Entire PLC/Ballast system uses just 3 ICs: DSP, line driver and low noise amp
Expanding from DMC & DPS
Power Supplier for HDTV & Others

- LCD Backlight & System Power Supplier
- PDP Power Supplier
- DLP Led Power Supplier
- Ballast Control
PDP SPMS Block Diagram

Character: AC input Under-Voltage Protection; OVP; UVP; OCP; Short-Circuit Protection
Royer oscillator backlight driver

Advantages:
- Proven drive method.
- DSP provides precise start-up control.
- Can implements both linear or low-freq PWM dimming control.
- Moderate MIPs demand.
VCO is a table lookup sine generator. One table is used for all 16 outputs.
Table values are adjusted to account for of driver.
Each loop contains proportional-integral (PI) controller.

Advantages:
- Very tight frequency control. Wide range of drive frequencies possible. (for instance: slew freq at startup.)
- More efficient than linear oscillator.
- Fewer parts, simpler transformer.
Ballast Control

LC2404/6A DSP Controller

PWM1
PWM2

ADC In 7
PWM5
ADC In 1 & 2

ADC In 3 & 4
ADC In 8
ADC In 9
ADC In 10
ADC In 11
ADC In 12
ADC In 5 & 6

Vin
Vout

PFC

9600 baud modem

Powerline Signal Conditioning

50% duty cycle fixed
Freq = 60 to 200 kHz

Deadband

T2PWM
T4PWM

Bulb 1
Bulb 2
Bulb 3
Bulb 4

Vin
Vout

Iout

Zero-Cross

Case Temperature

PWM3
PWM7
PWM8

Ballast V & I
Ballast V & I
Ballast V & I
Ballast V & I
Sensors & Measurement
Sensor Application: **RFID Tag System**

DSP to stimulate system, than measure response, than take action

- **Interference with E-mag ring**
- **Electromagnetic Ring**
- **Tag**
- **High Power Pulse to de-activate TAG**
  - Checkout counters (can also be hand-held)
- **E-mag Field Measurement (Detection)**
  - Door monitoring – retail stores
- **Charged Ring**
- **H-Bridge Configuration**
  - Power Amp or discretes
  - **Vsupply**
  - **OUT_L**
  - **OUT_R**
  - **IN_L**
  - **IN_R**
- **serial comms link**
- **F2810 DSP**
  - **PWM EVT1**
  - **SCI**
  - **ADC**
  - **Alarm activation**

**2002**

*it's customers - it's market share - it's execution*
Sensor Application: Medical Oxygen Measurement

DSP to stimulate system, than measure response, than take action

Interest in USB at several customers
Brake Line Pressure Control
Tractor Trailer

DSP to stimulate system, than measure response, than take action

DC Power Signal

Vin = 12Volts

Powerline Signal Conditioning

9600 baud modem

F2812 DSP Controller

EVT1

Cap1

ADC

PWM signal – 10 to 20ms

Multiple Brake Lines and valves per trailer

Brake Line Valve

Wheel Speed

Brake Line Pressure

Various Vehicle Voltages

Wheel Temp

Temp Sense Input

Vin = 12Volts

Wheel Vibration

ADC
Measurement Application
Point of Sales Liquid Measurement (Precision)

DSP accurately determines speed of turbines (flow rate).
Offers up to .2% accuracy vs 2% seen today
Result is much more accurate billing

DSP to measure system parameter, than take action
Other Emerging Applications

- **Audio amplifier**
  - Leverage C2000 CPU bandwidth, on-chip PWM, and ADC

- **Power meter**
  - Leverage C2000’s on-chip ADC, processing power and comms peripherals

- **Auto**
  - Leverage C2000 advantage as motor and GP controller
  - May take long time as C2000 only goes into critical systems such as EPAS

- **Inter-comm**
  - Leverage fast on-chip ADC, PWM (DAC), comms peripherals, security and CPU power

- **Finance and security**
  - Leverage C2000’s security and other features, as well as RFID technology

- **Sensor and measurement**
  - Leverage C2000 small size and fast on-chip ADC
  - Need to id opportunities, partners and customers
Summary

✓ C2000 platform is uniquely addressing the embedded control space

✓ Large control market ranging from established motor control segments to multiple new control end-equipments

✓ 19 products available today delivering 3000 Design Ins to Date

✓ 28xx “Killer” products:
  32-bit core, 150MIPs, Flash, 12-bit ADC, and more..

✓ F28xx u-*BGA recognized as absolute best Onet device today

✓ Moving to mainstream tools platform with CCS3.1 – 24xx and 28xx
C2000 Application Base Expanding From The Initial DMC Cluster to The Broad Control Market

Digital Power Supply
Provides control, sensing, PFC, and other functions

TV screen
Deflection of electron beam for small angle and sharp corner TV screen

Optical Networking
Control of laser diode

Printer
Print head control
Paper path motor control

Automotive - EPS
Battery operated precision for steering

Tire Pressure
Low cost pressure sensing based on tire rotation speed measurement

“Segway”
Many new cool Application to come