Smarter, Greener, and More Connected

Wayne Huang (wayne@ti.com)
Technical support of Microcontrollers and Wireless Connectivity for Delta Group
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Agenda

• C2000 roadmap
• PWM/ADC enhancement on F2837x/F2807x
• MSP432 - low power and high performance
• Wireless connectivity
C2000 roadmap
Where is Real-time Control?

Renewable Energy
- Solar Power Inverters
- Wind Power Inverters

Motor Control
- DC/DC Converters
- White Goods
- Power Tools
- E-bike

Digital Power
- Uninterruptable Power Supplies
- AC/DC Rectifiers
- Telecom / Server
- Power Supplies
- Power Delivery

Industrial Drives
- Robotics
- Automation
- Servo Drive
- AC Drives

Transportation
- Pumps
- Auto Headlamps
- Motor Control
- Radar / Collision Avoidance

Smart Grid & PLC
- Smart Metering
- Power Line Communication
- Line Monitoring

Texas Instruments
C2000™ Real Time Control: Processing

DSP Math Efficiency
- Single cycle execution across pipeline
- Up to 300 MIPS per core
- Single cycle real-time operations such as 32 x 32-bit multiply-and-accumulate (MAC)

Application Acceleration
- Trigonometric math acceleration
- Complex math, FFT, and Viterbi algorithm acceleration
- Floating point support, IEEE Single Precision

Parallel Processing
- Independent processing of multiple control loops with CLA Real-Time Coprocessor
- Up to 2x C28x CPUs and 2x CLA Real-Time Coprocessors
C2000™ Real Time Control: Actuation

- High resolution PWM duty cycle
- High resolution PWM period
- High resolution PWM phase control
- High resolution PWM dead-band
- Advanced time synchronization between PWMS

- Advanced inter-PWM and ADC synchronization
- Variety of timer count modes
- Customizable triggering
- External DACs for reference bias waveform generation

- Directly trip PWMS without CPU intervention, nor clocking
- Supports PWM shutdown or cycle-by-cycle PWM modification
- Peak current mode control support
C2000™ Real Time Control: Sensing

Precise Sensing
- Up to 12.5 mega-samples-per-second (MSPS) conversion rates
- 12-bit to 16-bit sampling resolutions
- Sigma delta filter modules for isolated current sensing or resolver position decoding
- PGAs for easy signal conditioning

Responsive Protection
- Comparator tied directly to PWM for asynchronous PWM trip
- High speed, 30ns comparator outputs

Digital Interfacing
- High resolution digital signal capture with precise 150ps resolution
- High performance motor speed and position interfacing
C2000™ Offers a Range of Solutions

C2000™ Real-Time Control MCUs

Piccolo™ MCUs
- Broad real-time control MCUs

Delfino™ MCUs
- Top performance real-time control MCUs

Value
Top Performance
Real-Time Control Portfolio

Delfino™
- F2833x/23x
- 100 MIPS
- 12 PWM ch., Type 1
- 1x 12-bit, 2 S/H
- 12.5 MSPS ADC

F2834x
- 120 MIPS
- 24 PWM ch., Type 4
- 4x 12/16-bit, 4 S/H
- 4/1 MSPS ADCs

F2837xS
- 800 MIPS
- 24 PWM ch., Type 4
- 4x 12/16-bit, 4 S/H
- 4/1 MSPS ADCs

F2837xD

Piccolo™
- F2802x
- 40 MIPS
- 8 PWM ch., Type 1
- 1x 12-bit, 2 S/H
- 2 MSPS ADC

F2803x

F2804x
- 240 MIPS
- 24 PWM ch., Type 4
- 3x 12-bit, 3 S/H
- 4 MSPS ADCs

F2805x

F2806x

F2807x

Texas Instruments
Increasing Processing, Memory, and Peripheral Counts
Piccolo™ TMS320F2807x

**Differentiation**

- Floating point C28x core with real-time control accelerator (CLA) for multi-tasking critical control loops with general applications actions
- Trigonometric Math Unit (TMU) hardware accelerator for reduced cycle times on trig math instructions (common in torque loops)
- Faster flash access speed in new 65nm technology (2-wait states instead of 5) driving faster command execution
- Integration of three independent 12-bit ADCs driving simultaneous conversion of multiple domains
- 8x Windowed Comparators for voltage and current limit protection of power stage
- 8 Sigma Delta Decimation Filters for isolated current sensing

**Tools**

- TMS320F2807x Isolated controlCARD
  - Part Number: TMDXCNCD28075
- TMS320F2807x Experimenter’s Kit
  - Part Number: TMDXDOCK28075

**Software**

- controlSUITE™ Software
- Code Composer Studio (CCS) IDE
Delfino™

Increasing Processing, Memory, and Peripheral Counts

Development  Sampling  Production

Texas Instruments
Delfino™ TMS320F2837xD

**Differentiation**
- Real-time performance of dual C28x core with dual CLA co-processors to run parallel control loops
- 4 differential 16-bit ADC, 1MSPS each, 4x S/H
- 3x 12-bit DAC (external)
- Trigonometric Math Unit (TMU) - 1 to 3 cycle SIN, COS, ARCTAN instructions
- Direct memory access through dual EMIFs (16bit/32bit)
- 8x Windowed Comparators w/ 12b DAC which can be used as peak current mode comparators (PCMC)
- 8x Sigma Delta channels, 2x Filters per channel

**Tools**
- Industrial Drives Control Kit
  Part Number: TBD
- TMS320F2837xD Isolated controlCARD
  Part Number: TMDXCNCD28377D
- TMS320F2837xD Experimenter’s Kit
  Part Number: TMDXDOCK28377D

**Software**
- controlSUITE™ Software
- Code Composer Studio (CCS) IDE

**Packages**
- 176-pin HLQFP 24x24mm
- 337-pin NFBGA 16x16mm

**View Configurations**

**TMS320F2837xD**

<table>
<thead>
<tr>
<th>Sensing</th>
<th>Processing C28x™ DSP core</th>
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</tr>
</thead>
<tbody>
<tr>
<td>ADC1: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS</td>
<td>200 MHz</td>
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</tr>
<tr>
<td>ADC2: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS</td>
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<td>FPU</td>
</tr>
<tr>
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<td>TMU</td>
<td>TMU</td>
</tr>
<tr>
<td>ADC4: 16-bit, 1.1-MSPS 12-bit, 3.5 MSPS</td>
<td>VCUIII</td>
<td>VCUIII</td>
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<td>8x Windowed Comparators w/ Integrated 12-bit DAC</td>
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<td>200 MHz</td>
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<td>8x Sigma Delta Channels (2x filters per channel)</td>
<td>FPU</td>
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</tr>
<tr>
<td>Temperature Sensor</td>
<td>6ch DMA</td>
<td>6ch DMA</td>
</tr>
<tr>
<td>3x eQEP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6x eCAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Modules</td>
<td>Memory</td>
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</tr>
<tr>
<td>3x 32-bit CPU Timers</td>
<td>Up to 512 KB</td>
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</tr>
<tr>
<td>NMI Watchdog Timer</td>
<td>Flash</td>
<td>Flash</td>
</tr>
<tr>
<td>2x 192 Interrupt PIE</td>
<td>2x 128-bit Security Zones</td>
<td>Boot ROM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2x EMIF</td>
</tr>
</tbody>
</table>

**Temperatures**
- 105°C, 125°C, Q100

**Actuation**
- 12x ePWM Modules (Type 3)
- 24x Outputs (16x High-Res)
- 3x 12-bit DAC

**Connectivity**
- 4x UART
- 2x I2C (w/ true PMBus)
- 3x SPI
- 2x CAN 2.0B
- USB 2.0 OTG FS MAC & PHY

**Power & Clocking**
- 2x 10 MHz OSC
- Ext OSC Input

**Debug**
- Real-time JTAG

**Processing**
- C28x™ DSP core
- 200 MHz
- FPU
- TMU
- VCUII

**Memory**
- Up to 512 KB
- Flash
- SRAM

**Sampling**
- 2x 128-bit Security Zones
- Boot ROM
- 2x EMIF

**Tools**
- Industrial Drives Control Kit
  Part Number: TBD
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**View Configurations**

**Texas Instruments**
Delfino™ TMS320F2837xS

Differentiation

- Real-time performance of C28x core with CLA co-processor to run parallel control loops
- 4 differential 16-bit ADC, 1MSPS each, 4x S/H
- 3x 12-bit DAC (external)
- Trigonometric Math Unit (TMU) - 1 to 3 cycle SIN, COS, ARCTAN instructions
- Direct memory access through dual EMIFs (16bit/32bit)
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Tools

- Industrial Drives Control Kit
  Part Number: TBD

- TMS320F2837xD Isolated controlCARD
  Part Number: TMDXCNCD28377D

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  Part Number: TMDXDOCK28377D

TMS320F2837xS

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 Channels (2x filters per channel)
- Temperature Sensor
  3x eQEP
  6x eCAP

Processing
- C28x™ DSP core
  200 MHz
- FPU
- TMU
- VCUII

Actuation
- 12x ePWM Modules (Type 3)
- 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 2.0B
- USB 2.0 OTG FS MAC & PHY
- UPP

Power & Clocking
- 2x 10 MHz OSC
- 4-20 MHz Ext OSC Input
- 2x 10 MHz OSC
- 4-20 MHz Ext OSC Input

Debug
- Real-time JTAG

System Modules
- 3x 32-bit CPU Timers
- NMI Watchdog Timer
- 192 Interrupt PIE

Memory
- Up to 1 MB Flash +ECC
- Up to 164 kB SRAM +parity
- 2x 128-bit Security Zones
- Boot ROM
- 2x EMIF

Software
- controlSUITE™ Software
- Code Composer Studio (CCS) IDE

Packages

<table>
<thead>
<tr>
<th>Package</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-pin HTQFP</td>
<td>14x14mm</td>
</tr>
<tr>
<td>176-pin HLQFP</td>
<td>24x24mm</td>
</tr>
<tr>
<td>337-pin NFBGA</td>
<td>16x16mm</td>
</tr>
</tbody>
</table>

View Configurations
F2837x/F2807x Enhancements on PWM
ePWM Module Signals and Connections

- ePWM Module Signals: ePWMx, ePWMx+1
- Connections: EPWMxSYNCI, EPWMxSYNCO
- External Signals: PIE, CLA, GPIO, MUX, ADC
- Internal Signals: EPWMxA, EPWMxB, EPWMxSOCA, EPWMxSOCB
- Sources: INPUT X-Bar, eQEP, SYSCTRL, CPU
- Events: EQEPERR – TZ4, CLOCKFAIL – TZ5, EMUSTOP – TZ6
Topics

• Key Enhancements in F28M35x/F28M36x (ePWM Type 2)
• Key Enhancements in F2837x/F2807x (ePWM Type 4)
• CLA Enhancements
Key Enhancements (ePWM Type 2)

• **High-Resolution on xB Output**: High resolution on PWMxB with separate CMPBHR

• **High-Resolution Dead-Band**: High resolution dead-band capability

• **CMPC & CMPD**: Allows generation ADC SOC and INT anywhere in PWM period

• **Load on SYNC**: Support for shadow to active load on a SYNC event

• **Simultaneous Writes to Registers**: Simultaneous writes to registers in multiple PWM modules

• **Event Trigger Enhancements**: Support for up to 15 events

• **Action Qualifier Registers**: Shadowing of AQCTLA and AQCTLB registers

**Other**

• **CBC Trip Action**: Additional options to clear CBC trip

• **Increased Options for DC Trip**: OR all trip signals (TZ or CMPxOUT signals) together. Users can select which signals to be OR’d
Shadow to Active Load on SYNC
(Variable Frequency Application)

Note: Since this is variable frequency app, we use Shadowed Period Load.
Simultaneous Writes to Registers Between Modules 
(Variable Frequency Application)

Note: Since this is variable frequency app, we use Shadowed Period Load.
Event Trigger Sub-Module Changes
(Example: PFC + Motor Control Application)

Achieved by initializing ET_CTR every SYNC event
The control loop frequency desired for the PFC is half the switching speed ➔
Configure ET sub-module to generate ISR every 2nd event
Event Trigger Sub-Module Changes
(Continued…)

• Event-Trigger Interrupt Generator
• Similar changes made for Event-Trigger SOCx changes
Shadowing AQ Registers
(Example: Motor Control)

Requirement: To cleanly disable and re-enable one phase of the motor drive.
Key Enhancements (ePWM Type 4)

- **Delayed Trip Functionality:** Dead-band insertion capability on a trip event.

- **One Shot Reload:** One shot reload from shadow to active registers.

- **Global Reload:** Global reload of shadow to active registers with programmable pre-scale of load events.

- **Remapped Register Space:** Registers grouped by their functionality for better alignment and future expansion.

- **Support for Valley switching:** Ability to switch PWM output at the valley point for valley switching.

**Other**

- **Blanking Window:** Increased possible window size.

- **Independent TZ Flags:** Independent flags to reflect the trip status for each of TZ sources.

- **SYNCOOUT Generation:** SYNCOOUT generation capability based on CMPC/D events.
Delayed Trip Functionality
Peak Current Mode Control – Sync Buck

Peak current mode control of a synchronous DC-DC buck converter.
Peak Current Mode Control – PSFB

Peak current mode control of a Phase Shifted Full-Bridge (PSFB) DC-DC converter.
## ePWM Action Qualifier Actions for EPWMA and EPWMB

<table>
<thead>
<tr>
<th>S/W Force</th>
<th>Time-Base Counter equals:</th>
<th>Trigger Events:</th>
<th>EPWM Output Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zero</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CMPA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CMPB</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TBPRD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SW X</td>
<td>Z X</td>
<td>P X</td>
<td>Do Nothing</td>
</tr>
<tr>
<td></td>
<td>CA X</td>
<td>T1 X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CB X</td>
<td>T2 X</td>
<td></td>
</tr>
<tr>
<td>SW ↓</td>
<td>Z ↓</td>
<td>P ↓</td>
<td>Clear Low</td>
</tr>
<tr>
<td></td>
<td>CA ↓</td>
<td>T1 ↓</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>T2 ↓</td>
<td></td>
</tr>
<tr>
<td>SW ↑</td>
<td>Z ↑</td>
<td>P ↑</td>
<td>Set High</td>
</tr>
<tr>
<td></td>
<td>CA ↑</td>
<td>T1 ↑</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CB ↑</td>
<td>T2 ↑</td>
<td></td>
</tr>
<tr>
<td>SW T</td>
<td>Z T</td>
<td>P T</td>
<td>Toggle</td>
</tr>
<tr>
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<td></td>
<td>CB T</td>
<td>T2 T</td>
<td></td>
</tr>
</tbody>
</table>

**Tx Event Sources**: DCAEVT1, DCAEVT2, DCBEVT1, DCBEVT2, TZ1, TZ2, TZ3, EPWMxSYNCIN
One Shot & Global Reload Capability
Shadow to Active Load of Registers

- Many enhancements already in place in Type-2
  - EPWM link, enables user to update all PWMs simultaneously
  - Reload on Sync, ensures that registers are loaded with the correct values

- What is missing on type-2?
  - INT can happen anytime during the update of multiple linked registers
  - Issue when all registers are not updated and Sync happens.
**One Shot & Global Reload**

- For all registers that have this mode enabled, shadow to active loads occur at the same event defined by GLDCTL[GLDMODE]
- Global reload pulse pre-scalar provides capability to choose transfers to happen once in ‘N’ occurrences of selected event
One Shot & Global Reload

• For all registers that have this mode enabled, shadow to active loads occur at the same event defined by GLDCTL[GLDMODE]

• Global reload pulse pre-scalar provides capability to choose transfers to happen once in ‘N’ occurrences of selected event

One shot reload usage

Initialization
– Enable global reload
– Link GLDCTL2 registers

Run Time
– Update all registers
– Write ‘1’ to GLDCTL2[OSHTLD]
– Write ‘1’ to GLDCTL2[GFRCLD], if desired
Remapped Register Space
## Register Mapping

- PWM registers are spread over four data pages to allow future expansion

- Registers are grouped according to their functionality

- This reduces number of data page moves required, improving execution time

<table>
<thead>
<tr>
<th>Page 1</th>
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<tr>
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<tbody>
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<td>DCTRIPSEL, DCCAPCTL, DCFCTL, DCCAP, DCFWINDOW, etc.</td>
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</table>
## Register Mapping

### Problem

- Register addresses are not compatible with type-2 and earlier PWMs

### Solution!

- TI header files to the rescue

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</table>
Other
Blanking Window

- Blanking window register has been increased from 8 to 16 bits to match with 16 bit blanking offset register

TZ Flags

- Separate trip flags for different trip events provide information on exactly which trip source caused a trip. This is required if multiple TZs are used to trip the same PWM

SYNCO OUT Generation

- ePWM Type 4 allows PWM SYNCO OUT generation based on CMPC and CMPD events
ePWM X-Bar

CMPSS1

CMPSS8

EPWM/ECAP sync

ADCSOCAO

ADCSOCBO

ADCA

ADCB

ADCC

ADCD

ECAP1

ECAP2

ECAP3

ECAP4

ECAP5

ECAP6

TRIPIN4

TRIPIN5

TRIPIN7

TRIPIN8

TRIPIN9

TRIPIN10

TRIPIN11

TRIPIN12

INPUT1

INPUT2

INPUT3

INPUT4

INPUT5

INPUT6

FLT1.COMPH

FLT1.COMPL

FLT4.COMPH

FLT4.COMPL

FLT1.COMPH

FLT1.COMPL

FLT4.COMPH

FLT4.COMPL
CLA Enhancements
CLA Enhancements

Highlights

• Greater granularity and flexibility of RAM blocks:
  – There are 6 * 4Kbyte RAM blocks attached to CLA
  – Each RAM block can be mapped as Program storage or Data
  – For example: User can have 20Kbytes of program + 4Kbytes for Data

• Increased program address range from 2K to 32K instructions.

• More triggers can be attached to CLA interrupts
Analog Subsystem and Enhancements
Module Objectives

• Understand the operation of the:
  – Analog-to-Digital Converter (ADC)
  – Comparator Subsystem (CMPSS)
  – Digital-to-Analog Converter (DAC)
  – Sigma Delta Filter Module (SDFM)

• Use the ADC to perform data acquisition
Analog Subsystem

• Four dual-mode ADCs
  – 16-bit mode
    • 1 MSPS each (up to 4 MSPS system)
    • Differential inputs
    • External reference
  – 12-bit mode
    • 3.5 MSPS each (up to 14 MSPS system)
    • Single-ended
    • External reference

• Eight comparator subsystems
  – Each contains:
    • Two 12-bit reference DACs
    • Two comparators
    • Digital glitch filter

• Three 12-bit buffered DAC outputs
• Sigma-Delta Filter Module (SDFM)
ADC Subsystem

**Multiple ADC modules allow simultaneous sampling or independent operation**
ADC Module Block Diagram

ADC full-scale input range is $V_{\text{REFLO}}$ to $V_{\text{REFHI}}$
ADC SOCx Functional Diagram

This block diagram is replicated 16 times.
Purpose of the Post Processing Block

• Offset Correction
  – Remove an offset associated with an ADCIN channel possibly caused by external sensors and signal sources
    • Zero-overhead; saving cycles

• Error from Setpoint Calculation
  – Subtract out a reference value which can be used to automatically calculate an error from a set-point or expected value
    • Reduces the sample to output latency and software overhead

• Limit and Zero-Crossing Detection
  – Automatically perform a check against a high/low limit or zero-crossing and can generate a trip to the ePWM and/or an interrupt
    • Decreases the sample to ePWM latency and reduces software overhead; trip the ePWM based on an out of range ADC conversion without CPU intervention

• Trigger-to-Sample Delay Capture
  – Capable of recording the delay between when the SOC is triggered and when it begins to be sampled
    • Allows software techniques to reduce the delay error
Post Processing Block Interrupt Event

• Each ADC module contains four (4) Post Processing Blocks
• Each Post Processing Block and be associated with any of the 16 ADCRESULTx registers
Comparator Subsystem

- Eight Comparator Subsystems (CMPSS)
- Each CMPSS has:
  - Two analog comparators
  - Two programmable 12-bit DACs
  - Two digital filters
  - Ramp generator
- Digital filter used to remove spurious trip signals (majority vote)
- Ramp generator used peak current mode control
- Ability to synchronize with PWMSYNC event
Comparator Subsystem Block Diagram

Comparator Truth Table

<table>
<thead>
<tr>
<th>Voltages</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage A &lt; Voltage B</td>
<td>0</td>
</tr>
<tr>
<td>Voltage A &gt; Voltage B</td>
<td>1</td>
</tr>
</tbody>
</table>
Digital-to-Analog Converter

- Three buffered 12-bit DACs
- Provides a programmable reference output voltage
- Capable of driving an external load
- Ability to be synchronized with PWMSYNC events
- Selectable reference voltage
Buffered DAC Block Diagram

\[ V_{DACOUT} = \frac{\text{DACVALA} \times \text{DACREF}}{4096} \]

VREFHIA can supply reference for DAC A and DAC B; VREFHIB can supply reference for DAC C
Sigma Delta Filter Module (SDFM)

• SDFM is a four-channel digital filter designed specifically for current measurement and resolver position decoding in motor control applications

• Each channel can receive an independent modulator bit stream

• Bit streams are processed by four individually programmable digital decimation filters

• Filters include a fast comparator for immediate digital threshold comparisons for over-current monitoring

• Filter-bypass mode available to enable data logging, analysis, and customized filtering
SDFM Block Diagram
MSP432 – Best Optimization between Performance and Low Power
MORE PERFORMANCE FOR MSP430™ DEVELOPERS

Advance to higher levels of computing and analog performance, while maximizing your ultra-low-power MSP430 MCU investment and expertise

LOWER POWER FOR ARM® DEVELOPERS

Slash power consumption and boost performance with the world’s lowest power Cortex®-M4F microcontroller

NO COMPROMISES

Get low-power and performance with a scalable portfolio of 16-bit and 32-bit MSP microcontrollers in a variety of applications
MSP432™ MCUs: PERFORMANCE AT ITS CORE

Selecting the high-performance ARM® Cortex®-M4F core

Highest Coremark score: 3.41/MHz

Incorporating high-performance peripherals and features

- Simultaneously read and erase from flash
- Execute up to 200% faster with DriverLib in ROM vs. Flash
- 14-bit 1MSPS ADC with 13.2ENOB, differential mode & 2 window comparators
MSP432™ MCUs: LOW-POWER AT ITS BEST

Optimizing the architecture for ultra-low power

Industry’s lowest power ARM Cortex-M4F MCU

Industry-leading ultra-low-power
- Active power: 95 μA per MHz
- Sleep mode: 850 nA (with RTC)
- ULPBench score: 167.4

Optimizing peripherals for ultra-low power
- Save 40% more power with the integrated DC/DC vs. LDO
- Save 30nA per RAM bank with selectable RAM retention
- Consume minimal power (375uA) when sampling sensors at 1MSPS with 14-bit ADC
- DriverLib in ROM consumes up to 35% less power than Flash
MSP432™ MICROCONTROLLERS

**Differentiation**

- **Industry’s lowest power ARM® Cortex®-M4F MCU** — Best ULPBench score of 167.4. As low as 850nA Standby, 95µA/MHz Active; Deep sleep to Active: <10us typ
- **Wide supply range** — 1.62-3.7V, including flash operation, enabling multiple battery technologies and eliminating external regulation
- **Integrated high-performance and low-power analog** — Including 1MSPS 14-bit ADC, 375uA at 1MSPS
- **Secure MCU environment** — Flash IP protection & integrated AES-256 encryption
- **Simplified portability from MSP430** - Leverage software & know-how from existing MSP430 designs Using 430 Peripherals, Analog & Low Power Modes

**Tools**

- **LaunchPad**
  - MSP-EXP432P401R
  - $12.99
- **Target Board**
  - MSP-TS432PZ100
  - $89.00

**Status**

- LaunchPad and Target Board available
- Sampling 256KB (XMS432P401RIPZR)
- Pin-for-pin roadmap to 2MB

**Software**

- **MSPWare** — leverage
  - C-code portable MSP430 peripherals and analog
- **RTOS Support** - TI-RTOS, FreeRTOS, Micrium
- **ARM 3rd Party Ecosystem**
- **IDEs** - Code Composer Studio™, IAR, KEIL and gcc

**Packages**

- **Same as MSP430**
- **64QFN**
  - 5x5mm²
- **100LQFP**
  - 16x16mm²
MSP PLATFORM PORTABILITY

**Hardware**
- MSP 16-bit core
- MSP430 Modules

**Software**
- MSPWare
  - Register-Level
  - Driver Library
- Intrinsics & Interrupts
- RTOSs

**Development Tools**
- CCS IDE
- IAR IDE
- Energia
- GCC
- ULP Tools: ULP Advisor & EnergyTrace
- MSP Debugger
- BSL

**Development Kits**
- LaunchPad
- Booster Packs
- Target Board

**MSP430**
- ARM M4F 32-bit core
- New MSP432 Modules
- ARM Modules

**MSP432**
- Intrinsics & Interrupts
- Libraries

**CMSIS**

**Texas Instruments**

- Same as MSP430
- New for MSP432
- Slight modifications from MSP430
ENERGYTRACE+™ TECHNOLOGY

• Provides a complete ecosystem for real-time power debugging and quickens time to market. Spends less time debugging and more time developing.

• Graphical User Interface in TI’s Code Composer Studio integrated development environment (IDE) and IAR Systems’ Embedded provides energy profiles of your application
  – Current measurement and CPU states can be tracked over time to help identify power black holes
IT’S ALL IN MSPWARE

Your one-stop shop for all technical collateral
- User’s Guides
- Application Notes
- Deep-dive Training
- Code Examples

www.ti.com/tool/mspware
www.dev.ti.com
MSP432™ MCUs: OPTIMIZED FOR INDUSTRIAL

INDUSTRIAL SECURITY PANEL

Customers want to increase product capability with more sensors, and display data in real time, without sacrificing the portability enabled by ultra-low-power operation

WHY MSP432 MCUs?

Intelligent, fast sensing
- Motion sensing, proximity, fingerprint scan
- Signature analysis
- Fast processing from multiple serial interfaces

Ultra-low power
- Keeps system power low while collecting / processing sensor data

IP (code) Protection
- Preserves and secures customer’s unique code and algorithms

Touch capability
- High-performance, low-power analog enables touch capability

Large amount of flash
- Runs a large variety of wireless connectivity stacks
MSP432™ MCUs: OPTIMIZED FOR INDUSTRIAL

INDUSTRIAL SECURITY PANEL

Microphone
Speaker
Motion Sensor
Glass Breakage Sensor

Signal Conditioning
ADC14
PWM
SPI

QVGA Display
ADC14 for touch capability

MSP432 MCUs
ADC14

Wi-Fi (CC3100)

Temp Sensor (TMP006/7)
I2C

WHY MSP432 MCUs?

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INDUSTRIAL | PERSONAL ELECTRONICS | INTERNET OF THINGS
Wireless Connectivity Portfolio for Internet of Things
# Wireless Connectivity Portfolio

<table>
<thead>
<tr>
<th>Proximity</th>
<th>Personal area networks</th>
<th>Local area networks</th>
<th>Neighborhood area networks</th>
</tr>
</thead>
<tbody>
<tr>
<td>NFC RFID</td>
<td>Bluetooth®† Bluetooth LE</td>
<td>Proprietary 2.4GHz</td>
<td>ZigBee®</td>
</tr>
<tr>
<td>Identification</td>
<td>Personal Connection</td>
<td>Customizable</td>
<td>Mesh</td>
</tr>
<tr>
<td>Data Up to 848 Kbps</td>
<td>Data or Voice Up to 3 Mbps</td>
<td>Data Up to 1 Mbps</td>
<td>Data Up to 256 Kbps</td>
</tr>
<tr>
<td>No battery to coin cell</td>
<td>Coin cell to AAA</td>
<td>Coin cell</td>
<td>Energy harvesting to AAA</td>
</tr>
</tbody>
</table>

## Key Differences

- **Data**:
  - Up to 848 Kbps
  - No battery to coin cell

- **No battery to coin cell**

## Key Attributes

- **Passive operation & data storage**
- **Interoperable with other Bluetooth devices**
- **Customizable to application**
- **Standards based**
- **Self-healing mesh**
- **Low power**
- **Large area coverage**
- **Existing infrastructure**
- **IPv6 stack**
- **Longest range**
- **Customizable to application**
- **Robust RF**

## Range

<table>
<thead>
<tr>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
</tr>
</tbody>
</table>

![Texas Instruments Logo]
TI wireless connectivity portfolio: The broadest in the industry

**THE Largest selection**
Support for all key technologies and standards for industrial, automotive and consumer
A solution for any application. Future proof. Leverage your investment

**THE lowest power**
Use a coin cell for multi-year, always-on operation or go battery-less with energy harvesting
Ultra-low power by design

**Easiest to design with**
Quickest learning-curve and development time with full broad market ecosystem
Software, tools, E2E, certified TI modules, TI Designs, SensorTag

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Connect More with TI
## Portfolio positioning

<table>
<thead>
<tr>
<th>SimpleLink™ Solutions</th>
<th>WiLink™ Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing Products</strong></td>
<td><strong>– proven foundation of millions of devices shipped in the market</strong></td>
</tr>
<tr>
<td><strong>Smart RF Transceivers</strong></td>
<td><strong>Wireless Network Processors (WNPs)</strong></td>
</tr>
<tr>
<td><img src="image" alt="Smart RF transceivers" /></td>
<td><img src="image" alt="Wireless network processors" /></td>
</tr>
<tr>
<td>Application</td>
<td>Application</td>
</tr>
<tr>
<td>RF Radio</td>
<td>RF Radio</td>
</tr>
</tbody>
</table>

- **SimpleLink**: Broad offering of RF transceiver, wireless network processors and wireless microcontrollers
- **WiLink**: High performance Wi-Fi + Bluetooth/BLE combo devices

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Single Mode – Bluetooth Smart (BLE)
Low Power, Low Latency, Low Throughput

Value Propositions

- **Easiest to design with**: Complete SW stack, wiki guides, dynamic design kits, low-cost tools, & software starting points
- **Lowest Power**: Multi-year operation on smaller coin-cell
- **The most Integrated**: single chip wireless MCU, integrated flash, small package

Products

- SimpleLink™ Wireless MCU
  - Flash based wireless MCU
  - CC2640 (Ultra Low Power)
  - CC2540 (USB interface)
  - CC2541 (I2C interface)
  - CC2540T (125°C)
- Apps developer tools
- Many TIDesigns

Features

- Lowest Power down to 1/10th of BT Classic
- Run BT stack and application on one single chip down to 4x4mm QFN package
- Fully Featured BT4.1 LE Stack
- Industrial and extended temp range: -40 to 85 C and 125 C
- Automotive qualification option

Applications

- Home and building
- Health and medical
- Remote
- Industrial
**Dual-mode Bluetooth (Classic + BLE)**

Bluetooth connection across any end point (BLE or classic); enables bridge between BLE and classic

### Value Propositions

| Tools/Modules/TI Designs | • Best Performance: reliable connection over a long range (100m) with optimized power consumption  
| | • Flexible: connect to any host (MCU or processor)  
| | • Most proven solution: 300 millions devices shipped, robust royalty free SW, solution available for broad market  
| | • FCC, IC, CE & Bluetooth SIG Fully Certified module |

### Products

| • Smart RF transceivers  
| | • CC2560 (Classic only)  
| | • CC2564 (Classic + BLE)  
| | • Pin-to-pin compatible  
| | • TI modules  
| | • CC2564MODN  
| | • 3 Parties Modules  
| | • Audio TI Designs (sink and source) |

### Features

| • Performance over long range (100m) with throughput up to 3Mbps  
| | • Connect to any MCU or processor  
| | • BT stack runs on external host  
| | • Bluetooth 2.1 +EDR/ BT 4.0  
| | • Fully certified module (FCC, IC, CE, Bluetooth SIG) |

### Applications

| • Embedded audio  
| | • Health and medical care  
| | • Mobile device accessories  
| | • Toys |
SimpleLink™ Wi-Fi® platform
Lowest power, programmable wireless MCU, easiest to use

<table>
<thead>
<tr>
<th>Products</th>
<th>Features</th>
<th>Applications</th>
</tr>
</thead>
</table>
| **CC3200** (Wireless MCU) | • On-chip Internet & Wi-Fi security  
• Wireless MCU separate from TCP/IP Stack, free for customer applications 
• Flexible provisioning such as SmartConfig, WAC, & AP Mode  
• Cloud supported  
• FCC/CE/ETSI certified modules  
• SDK for development with Code Composer Studio and IAR support | • Internet of Things (IoT)  
• Home automation & appliance  
• Safety and security  
• Smart energy  
• Industrial M2M communication  
• Wireless audio streaming |
| **CC3100** (Internet-on-a-chip Wi-Fi network processor) | • Integrated ARM Cortex-M4 MCU + Wi-Fi network processor  
• First programmable single chip Wi-Fi solution  
• Embedded TCP/IP stack  
• Connect any MCU to the Internet of Things | |
**Wilink™ Combo solutions**
high-performance WiFi + Bluetooth/Bluetooth Low Energy

### Value Propositions

<table>
<thead>
<tr>
<th>Tools/modules for easy development</th>
<th>Products</th>
<th>Features</th>
<th>Applications</th>
</tr>
</thead>
</table>
| ▪ Performance and low power: 100Mbps with the lowest power (800uA IDLE) | ▪ WL18xx Combo  
  ▪ WiFi Only  
  ▪ WiFi + BT/BLE  
  ▪ WiFi + BT/BLE + GNSS  
  ▪ TI Modules  
  ▪ WL1801MOD  
  ▪ WL1805MOD  
  ▪ WL1831MOD  
  ▪ WL1835MOD  
  ▪ WL1807MOD  
  ▪ WL1837MOD  
  ▪ 3d Parties modules | ▪ Combo BT Dual Mode + WiFi on one single-chip  
  ▪ Rock solid performance: long distance, stability, robustness, throughput and co-existence with BT 4.0  
  ▪ Connect to processors(high level OS)  
  ▪ Industrial temp -40 to 85 C  
  ▪ 2.4GHz and 5GHz support  
  ▪ Fully certified module (FCC, IC, CE, Telec) | ▪ Security Camera  
  ▪ Portable Data Terminal  
  ▪ Gateways  
  ▪ Audio  
  ▪ Industrial Panel/ HMI  
  ▪ Professional Camera  
  ▪ Wearable |

- Certified and easy to use: Pre-integrated, certified, production ready solutions, software downloadable. Open documentation (Wiki), Forums (E2E), TI and 3rd party network
- Integrated and scalable: single chip multi-combo with pin to pin compatible variants, consumer, industrial (85 degree C) and automotive grade (Q100)
## Sub-1 GHz Value Line

**315/ 433/ 470/ 868/ 915/ 920 MHz solutions for consumer applications**

<table>
<thead>
<tr>
<th>Value Propositions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Robust RF range</strong> in your house: Longer range than 2.4 GHz. Stable wireless links that go through walls</td>
</tr>
<tr>
<td><strong>Most complete design support</strong>: 15 years of accumulated knowledge documented on the web: 100+ app notes, dedicated E2E forum, SmartRF tools</td>
</tr>
<tr>
<td><strong>Most optimized</strong> Sub-1 GHz solutions: Tx, Rx, Trx, wireless MCU + small SW stack</td>
</tr>
</tbody>
</table>

### Products
- Smart RF transceiver
  - **CC110L**
- Wireless MCU
  - **CC1110**
  - **CC430**
- Wireless MCU with USB
  - **CC1111**
- Free software examples
  - SimpliciTI software stack

### Features
- Complete solutions for 315, 433, 470, 868, 915 and 950 MHz
- SimpliciTI network protocol on CC11xx devices. Only 0.5kB RAM, 8kB Flash MCU needed. 5yr battery life on AA cells
- SmartRF Studio windows software enable fast RF development and testing
- Flexible RF packet sniffer helps debug RF solutions quicker

### Applications
- Home and building automation
- Safety and security
- Consumer applications
### Sub-1 GHz Performance Line
Industrial 169/ 315/ 433/ 470/ 868/ 915/ 920 MHz solutions

#### Value Propositions

- **Longest real-world range:** Beyond 25km range, full-building to city-wide RF coverage
- **Robust low-power communication:** Less retransmissions of RF packets means less power consumption in the application
- **Supports more standards:** 6LoWPAN, 802.15.4g, WiSun, wM-Bus, ETSI Cat 1, FCC Part 90 and more

#### Products

- Smart RF transceiver
  - CC1120
- Smart RF transceiver for 802.15.4g
  - CC1200
- Smart RF transceiver for ultra narrowband
  - CC1125
- Software stacks
  - Free SimpliciTI software stack
  - wM-Bus software

#### Features

- High sensitivity & narrowband support, the de facto standard for long range communication
- Advanced wavematch receiver gives best selectivity and blocking including low power sniff mode
- Low-power RX sniff mode enable automatic duty-cycling of the receiver
- SmartRF software tools enable fast RF development and testing

#### Applications

- Wireless meter reading
- Alarm and security
- Home, building and industrial automation
SimpleLink™ 6LoWPAN
IP cloud connection, lowest power, largest network

Value Propositions

- **Complete solution from silicon to Cloud**: Best-in-class performance, comprehensive and intuitive software with sample code and examples, large cloud partners to support both industrial and consumer markets
- **Lowest power**: Use a coin cell for multi-year, always-on operation or go battery-less with energy harvesting
- **Large and secure mesh network**: Connect up to 1000s of nodes

<table>
<thead>
<tr>
<th>Products</th>
<th>Features</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>SimpleLink 6LoWPAN/ZigBee</td>
<td>- An edge router connects the 6LoWPAN network to IP Applications. No gateway needed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Mesh routing that is robust and self-healing</td>
<td>• Internet of Things (IoT)</td>
</tr>
<tr>
<td></td>
<td>- Can achieve multi-year operation on a coin-cell battery</td>
<td>• Home and building automation</td>
</tr>
<tr>
<td>SimpleLink Range Extender</td>
<td></td>
<td>• Safety and security</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Low-power sensor networks</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contiki Software, Open source</td>
<td></td>
<td>Home Automation and Monitoring</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Contiki Software: Open source solution

% Image Source: Texas Instruments
**ZigBee®**

Lowest power, large secure mesh network, easiest to use

### Value Propositions

- **The lowest power**: Multi-year operation on small coin-cell
- **Robust and standardized mesh network**: Connect up to 100s of nodes in industrial settings
- **Easiest to design with**: Proven and robust ‘copy-paste’ kits, reference designs together with Golden Unit software stack

### Products

<table>
<thead>
<tr>
<th>Wireless MCUs</th>
<th>Features</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>o CC2630 (Ultra low-power Wireless MCU)</td>
<td>o Run Z-Stack and application on one single chip&lt;br&gt; o Secure Over-the-air software update capability&lt;br&gt; o Industrial temp range: -40 to 125 C&lt;br&gt; o Certified ZigBee Golden Unit&lt;br&gt; o USB support</td>
<td>o Home automation&lt;br&gt; o Comfort&lt;br&gt; o Security&lt;br&gt; o Energy efficiency</td>
</tr>
<tr>
<td>o CC2530 (Wireless MCU)</td>
<td>o Range extender&lt;br&gt; o CC2592 (Extends up to 7x range)</td>
<td>o Lighting networks&lt;br&gt; o Lights&lt;br&gt; o Switch/sensor&lt;br&gt; o Generic mesh&lt;br&gt; o IP-to-ZigBee gateways</td>
</tr>
<tr>
<td>o CC2531 (with USB)</td>
<td>o Z-Stack: Robust and Proven TI ZigBee stack</td>
<td></td>
</tr>
<tr>
<td>o CC2538 (High performance, large memory)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Support Resource

• C2000

• Wireless connectivity
  – www.ti.com/wireless

• TI Wiki
  – processors.wiki.ti.com

• TI E2E support forum
  – e2e.ti.com