SJSU SAN JOSÉ STATE UNIVERSITY

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Department of Computer Engineering

Real-Time Embedded System
Co-Design
CMPE 146 Section 1
Fall 2024

Basic Peripherals

Basic Peripherals

Low-level and basic peripherals commonly used in embedded systems

- General-Purpose Input/Output module
- ADC/DAC
- Voltage regulators
- Timing components
  - Crystals, Real-Time Clock (RTC), Timers, clock generators, phase-locked loop (PLL) circuits
- Voltage reference module
- Reset controller
- Electrostatic discharge module
- Temperature sensor
- Analog filters
- Power management module

GPIO Controller

- Programmer's view on an I/O line:
  - Input: Read as 1 or 0
  - Output: Binary control of a signal line, either high or low
  - Usually mapped as part of an 8-bit byte in the memory space
    - One controller can support tens or hundreds of lines
- Individual I/O bits are independently programmable
  - Input or output
  - Interruptible or not, edge- or level-triggering
- Line can be attached with pullup, pulldown or no resistor
- Wake-up capability
  - In low-power mode, generates an interrupt on state change
- Capacitive-touch functionality
  - Used for detecting user finger touches by measuring capacitance changes
- High current drive capability
- Equipped with filter to remove noisy signal spikes

ADC/DAC

Analog-to-Digital Converter (ADC)

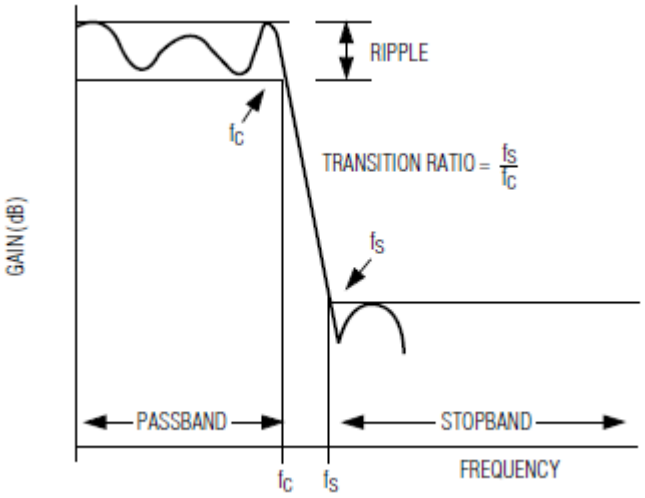
- Converts a continuously-valued signal (analog) to discretely-valued signal (digital) that can be processed by a digital computer
  - Real-world signals mostly all analog: temperature, speed, volume, weight, etc.
- Input modes:
  - Single-ended: measure input signal in reference to ground
  - Differential : measure difference of two input signals
- Usually has a front-end anti-aliasing filter
  - Sampling rate > maximum frequency component of the signal of interest X 2
- Need a precise voltage reference
- Common resolutions: 12, 14, 16 bits

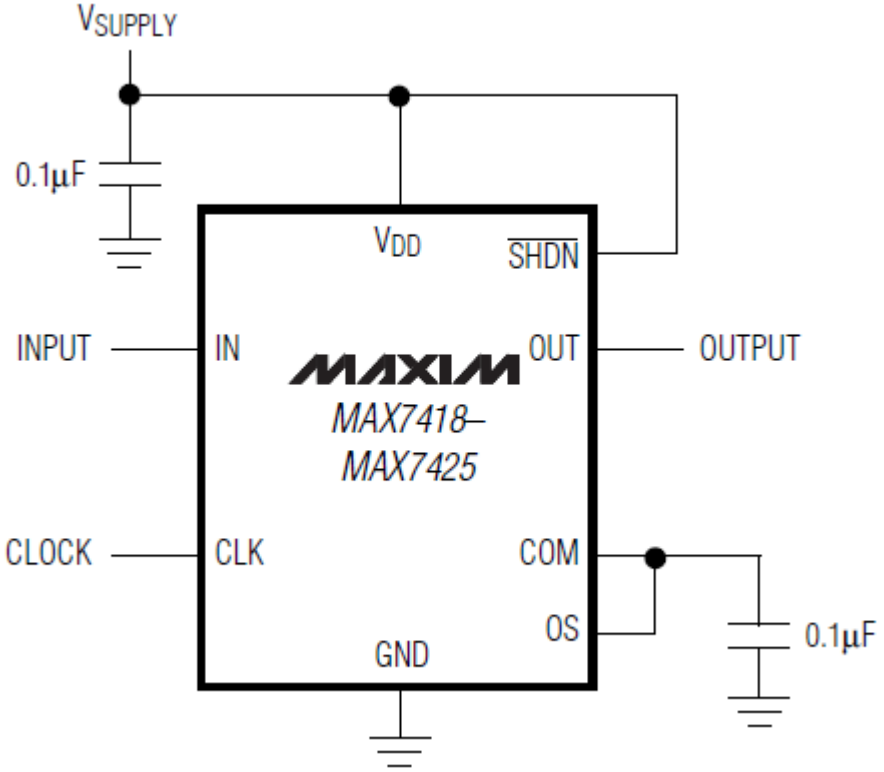
Digital-to-Analog Converter (DAC)

- Reverse of ADC
- A low-pass filter is typically placed after DAC

Analog Filters

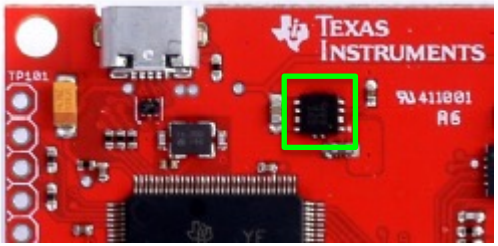
- Some signal processing must be done in analog domain. Examples:
  - ADC: anti-aliasing filter
  - DAC: reconstruction filter
- One example of analog filter module: Maxim MAX74xx
  - 5th-Order low-pass filters
  - Clock-tunable corner frequency: 1 Hz to 45 kHz
  - Low Power
    - Operating Mode: 3mA
    - Shutdown Mode: 0.2µA



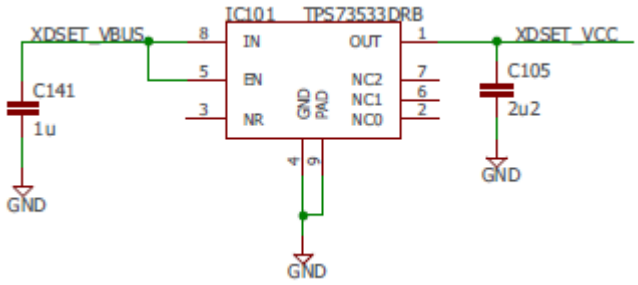


Voltage Regulators

- Maintain stable operating voltages despite unstable input power source
- Typically stand-alone devices on circuit board
  - Many modern MCUs have built-in regulator for processor core and digital modules
- May use separate devices for analog and digital components
  - Separate supply voltages and grounds for low-noise applications
- LaunchPad uses TI TPS73533DRB voltage regulator
  - 3.3-mm X 3.3-mm surface-mount package
  - Input voltage: 2.7 V to 6.5 V
  - Output voltage: 3.3 V
  - 2% overall accuracy
  - Maximum output current: 500 mA
  - Very low dropout: 280 mV at 500 mA
  - Thermal and overcurrent protection
  - Low Noise: 13.2 μV_{RMS}
  - Fast start-up time: 45 µs



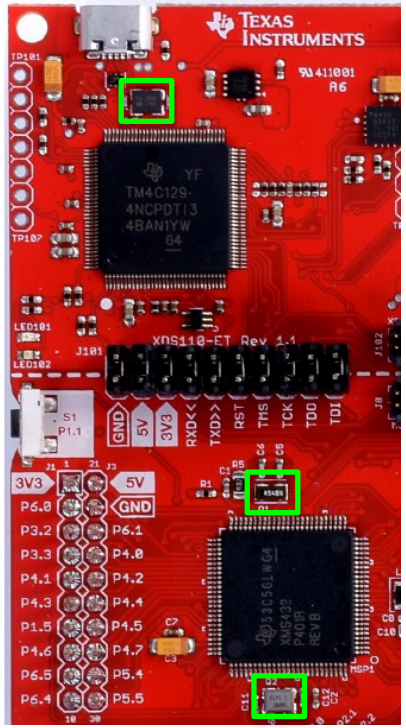
LaunchPad MSP-EXP432P401R



Timing Components

Various types for diverse applications

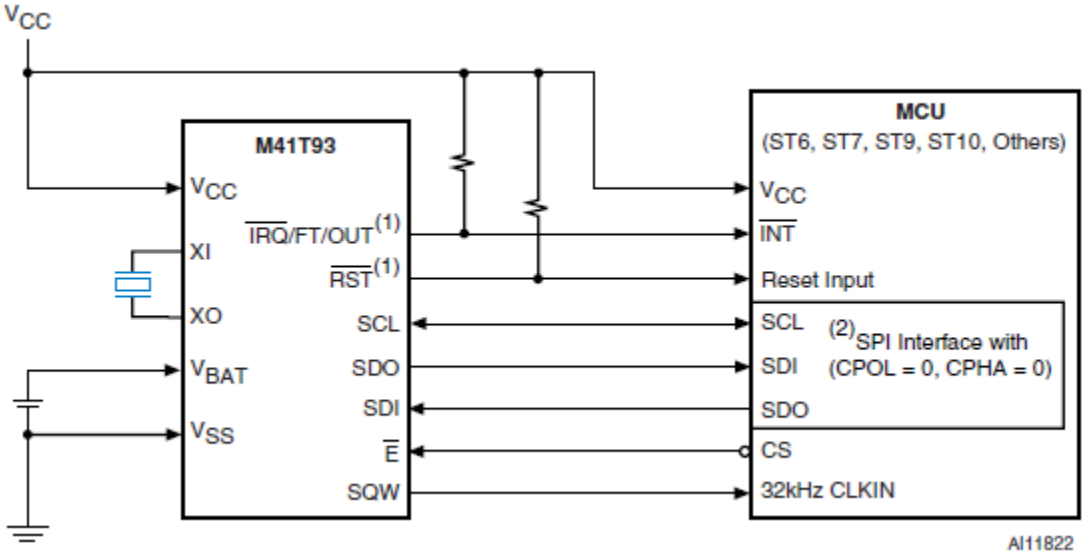
- Crystal units
  - External analog devices providing oscillation for generating digital clocks
  - LaunchPad has three on board
    - 16 MHz for debug probe, 32 kHz and 48 MHz for MCU
- Phase-Locked Loop (PLL)
  - Tunable feedback-loop circuitry to produce desired frequency
  - Many modern MCUs have unit built-in
- Timers
  - High-resolution for general-purpose operations
    - Can run at system clock frequency
  - Can work independently or combined with other peripherals
    - Provides timing for ADC, DAC, DMA, PWM (Pulse Width Modulation), capacitive touch, etc.



LaunchPad MSP-EXP432P401R

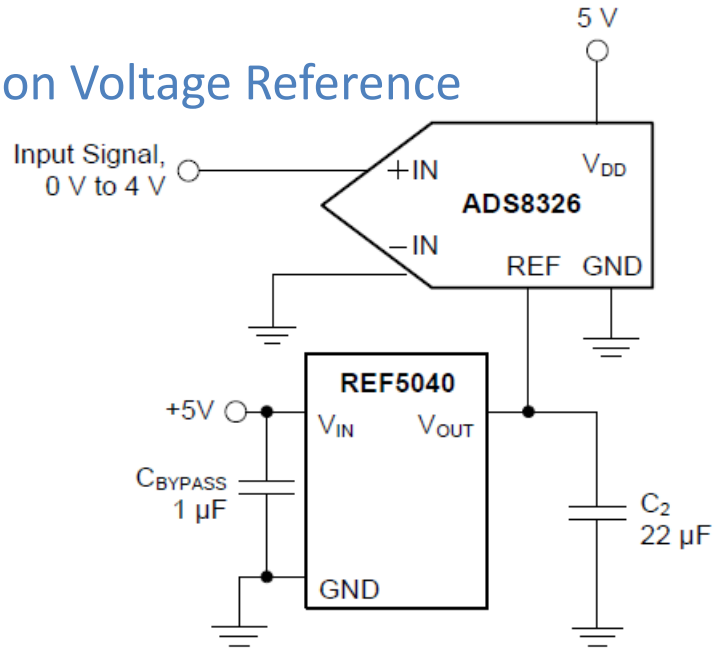
Timing Components (cont'd)

- Real-Time Clock (RTC)
  - Provides real-world time information: seconds, minutes, hours, day of week, day of month, month, and year (including leap year correction)
  - Operates in very low-power mode
    - Low frequency (in kilohertz)
    - Typically backed up by external battery that can last for years
  - One standalone example: STMicroelectronics M41T93 RTC module
    - Small package: 4 mm X 4 mm
    - Ultra-low battery supply current: 365 nA
    - Low operating current: 80 µA
    - Connect to MCU with SPI (Serial Peripheral Interface, a serial bus)



Voltage Reference Module

- Generates reference voltages for various analog modules
- Regular power supply voltage is not stable and accurate enough
  - An accuracy of 2-5% is common
- Reference module can output fixed voltage at 0.1% or better accuracy
  - Temperature compensated
- On LaunchPad, MCU has a built-in voltage reference while the debug probe uses an off-chip version
- A standalone example: TI REF5040 Precision Voltage Reference
  - 0.05% accuracy
  - Low noise: 3 $\mu V_{PP}/V$
  - High output current: 10 mA
  - Small package: 3 mm x 3 mm

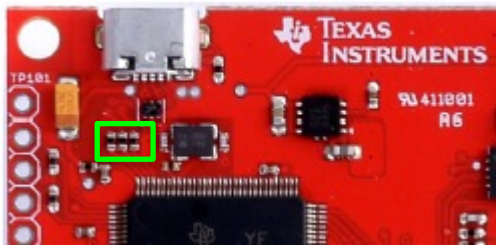


Reset controller

- Controls how the system is reset
  - Registers maintain the source of reset
- On ARM Cortex-M MCU, typically there are three types of reset
  - Power-On Reset (POR)
    - Includes initiation by reset pin, power supply system, clock system
    - Reset everything in MCU: processor, debug support component, peripherals
  - System Reset
    - Same as POR but without the debug support component
      - Connection with debug host maintains
      - Can be initiated by debug host
  - Processor Reset
    - Reset processor only
    - Program is restarted

Electrostatic Discharge (ESD) Module

- Protect devices from (ESD)
  - Many embedded systems are portable; chances of accumulating electrostatic charges are high
- LaunchPad uses TI TPD4E004
  - Protects against ESD pulses up to ±15 kV
  - Provides a safe path to discharge through Vcc or ground



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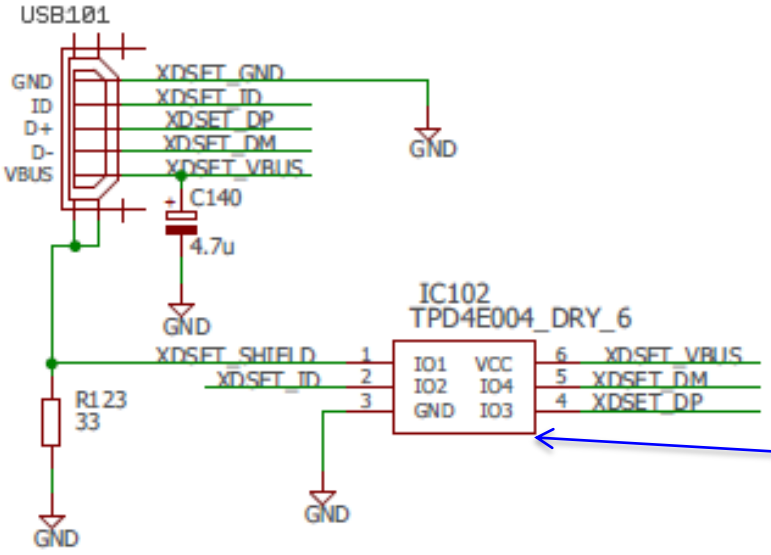

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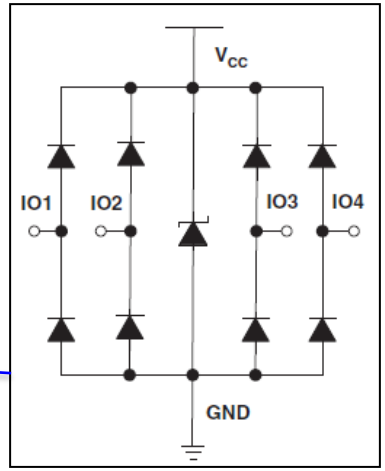
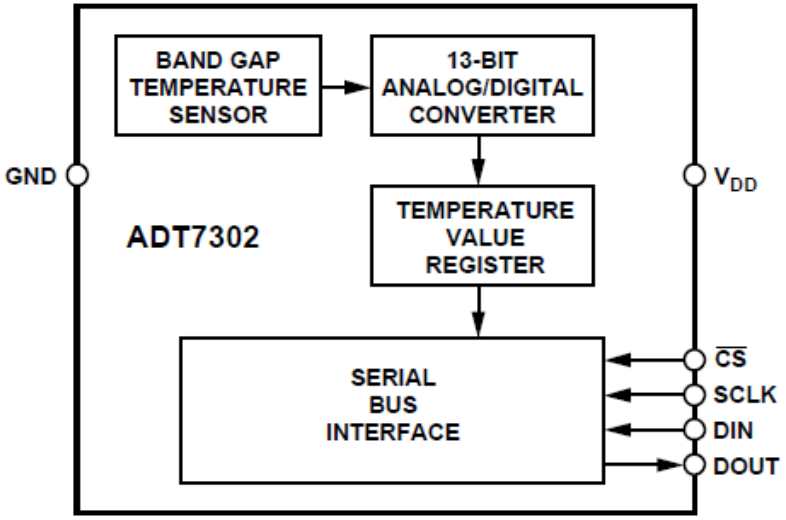


TPD4E004

Temperature Sensor

Temperature sensors are commonly used on embedded applications

- Many applications are directly temperature related
  - Thermostats, refrigerators, ovens, air conditioners, ...
- Protection of circuitry from overheating
- Compensation for component characteristics drift due to temperature changes
- One temperature sensor module example: ADI ADT7302
  - -40°C to +125°C operating temperature range
  - ±2°C accuracy
  - Operating power of 0.631 mW
  - Shutdown mode power of 4.88 µW
  - SPI connection to MCU



Power Management Module

- Various power modes available for optimization of power in different execution conditions
- Two factors to tune: frequency and supply voltage
- On the MSP432 MCU, two main power operating modes
  - Active Mode (AM): CPU instruction execution is possible
  - Low Power Mode (LPM): CPU instruction execution is suspended
- AM is further divided to six sub-modes
  - Based on a combination of voltage regulator used, voltage and frequency settings
- LPM is further divided to 12 sub-modes in 3 general categories
  - Sleep
    - Processor is not active but peripherals are
  - Deep Sleep
    - Peripheral functionality is reduced or totally disabled
  - Stop or Shut Down
    - Processor and almost all peripherals are powered down