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Implementing an MSP430 Accelerometer-Based Data Acquisition System

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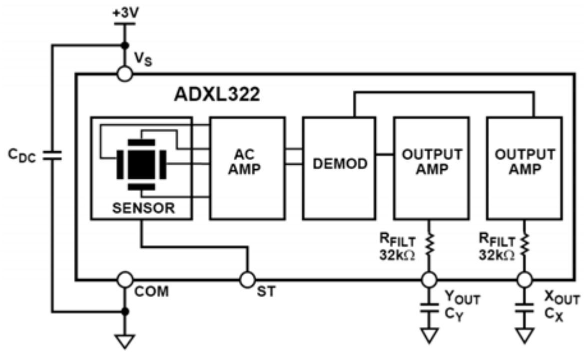
Agenda

- Accelerometer Basics
- Interfacing to the MSP430
- Lab: Accelerometer and MSP430 Setup
- Lab: Low-Power Anti-Theft Alarm
- Lab: Tilt Ball

MSP-EXP430F5438 Accelerometer Overview



- Two- or three-axis analog-output accelerometer are used
- Measures dynamic and static acceleration

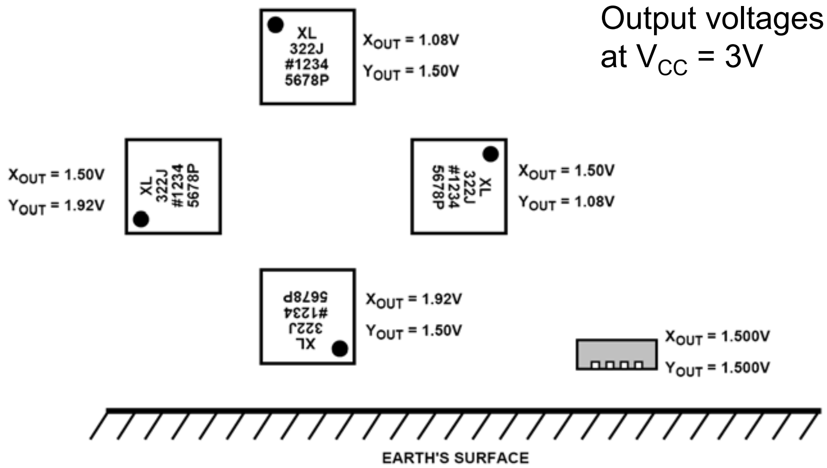
MSP-EXP430F5438 Accelerometer Specs

	ADXL322	ADXL330
Number of Axis	2 (X, Y)	3 (X, Y, Z)
Sensitivity	420mV/g	300mV/g
Measurement Range	±2g	±3.6g
Current Consumption	450µA	320µA
Wakeup Time	20ms	1ms

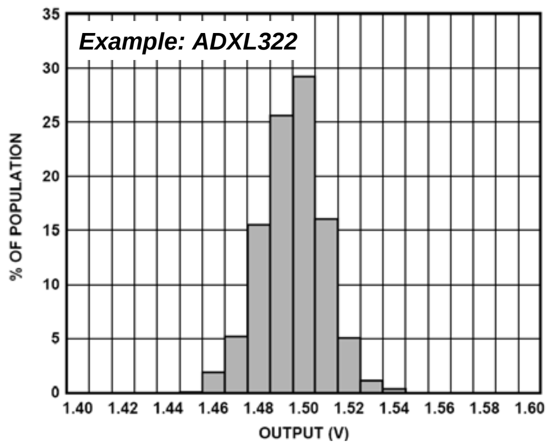
Which one is used on your board?

Output Response vs. Orientation

Output voltages at V_{CC} = 3V



Accelerometer Output Voltage Distribution



Zero-g Output Performance @ V_{CC} = 3V

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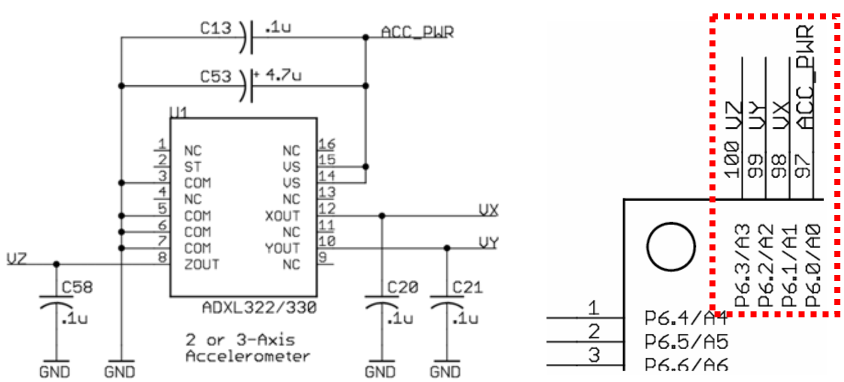
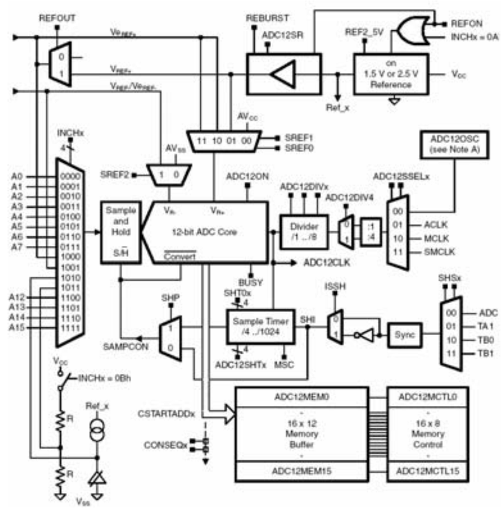
MSP430F5438 – Accelerometer Connections



- Accelerometer is powered by the MSP430 – allowing on-demand operation

MSP430F5438 ADC12 Enhanced Features

- Low power modes
  - Selectable speed vs. power mode
  - References automatically shut down to conserve power
- High clock dividers for fast system clocks
- Low I_{CC}
  - 130µA for ADC
  - 100µA for V_{REF}



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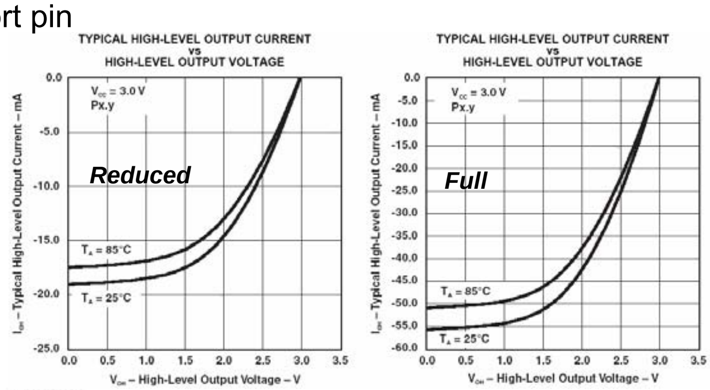
MSP430F5438 GPIO Features

- Programmable Reduced/Full drive strengths (PxDS)
- Internal programmable pull-up/down pin resistors on every port pin



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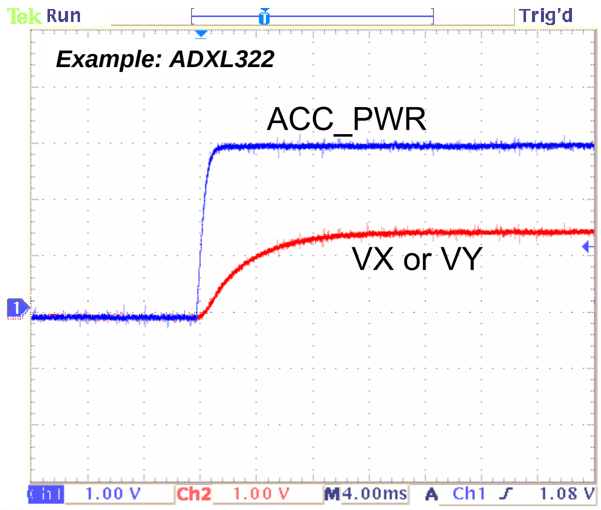
Accelerometer Turn-On Behavior (PxDS = 0)



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Lab 1: Goal

- Configure and use the MSP430 to periodically read out accelerometer sensor data using Timer_A and ADC12
- Calculate the physical g-force values from the ADC12 conversion results
- Display the X and Y g-force readings on the LCD in real-time every 100ms

Before we get started…let's setup CCE!

- Open the TI CCE IDE
- Select "Import…" from the "File" menu
- Select "General/Existing Projects into Workspace"
- Select "Browse…" and navigate to the folder containing the lab / demo project folders
- The dialog box should now list three lab projects
- Select "Copy projects into workspace"
- Click on "Finish"

Lab 1: Port-Pin Configuration

```
// Power the accelerometer through P6.x
P6OUT __________;
P6DIR __________;

// Configure P6.x, P6.x, and P6.x as analog pins
P6SEL __________;

// Configure P6.x, P6.x, and P6.x as inputs
P6DIR __________;
```

- Check the interconnections in the schematic
- Power the accelerometer through a port pin
- Configure analog pins for peripheral function
- Note: Configure pins for 3-channel accelerometer

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Lab 1: Timer_B Setup

```
// Use TBCLK = ACLK, clear TBR
TBCTL = ____________________;
// Set OUT1 on EQU1, reset on EQU0
TBCCTL1 = ____________________;
// Set period to 1/10Hz
TBCCR0 = ____________________;
// Set EQU1 event
TBCCR1 = ____________________;
```

- Use TBCLK = ACLK = LFXT1 = 32,768kHz
- Use capture/compare block TB1 in compare mode
- Generate a rising edge on Timer_B.OUT1 every 100ms (will be used to trigger A/D conversions)

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Lab 1: ADC12 Setup 1/2

```
// Configure S&H time, enable multiple conversions,
// enable ADC12
ADC12CTL0 = ____________________________________;
// Use Timer_B.OUT1 to trigger conversions,
// pulse mode, single sequence of channels
ADC12CTL1 = ____________________________________;
// 12-bit mode, use signed output format
ADC12CTL2 = ____________________________________;
```

- Configure the sample and hold time
- Use Timer_B.OUT1 to trigger the ADC12 start-of-conversion
- Use 12-bit mode
- Configure for signed output format

Lab 1: ADC12 Setup 2/2

```
// Setup a two-channel ADC12 conversion sequence
// Accelerometer X-channel
ADC12MCTL0 = ___________;
// Accelerometer Y-channel, end-of-sequence
ADC12MCTL1 = ______________________;
// Enable interrupts on ADC12MEM1
ADC12IE = _____;
// Enable conversions
ADC12CTL0 |= __________;
```

- Setup and convert a sequence of two channels (X and Y)
- Use A_{VCC} and A_{VSS} as reference
- Enable interrupts on ADC12MEM1
- Enable conversions

Lab 1: ADC12 Interrupt Service Function

```
#pragma vector = ADC12_VECTOR
__interrupt void ADC12_ISR(void)
{
  ADCResultX = _________;    // Read out results, clear IFGs
  ADCResultY = _________;

  ADC12CTL0 __________;      // Toggle ADC12ENC
  ADC12CTL0 __________;

  __bic_SR_register_on_exit(LPM0_bits);
}
```

- Move conversion results to global variables
- Toggle the enable conversion bit to allow new SOC

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Lab 1: Calculating the g-Force Values

```
// Calculate the g-force values assuming a VCC of 3V
// to use the accelerometer's datasheet sensitivity factor.
// Since the output is ratiometric the actual VCC level
// doesn't matter.

AccelX = ______________________ ADCResultX _____;
AccelY = ______________________ ADCResultY _____;
```

- Check the User's Guide for details on how to interpret the ADC12 conversion data, and calculate the g-force values
- Start the code, and move the board around watching the g-fore readings on the LCD.
- LED1 should toggle every 1s during operation

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Lab 1: Port-Pin Configuration – Solution

```
// Power the accelerometer through P6.0
P6OUT |= 0x01;
P6DIR |= 0x01;

// Configure P6.1, P6.2, and P6.3 as analog pins
P6SEL |= 0x0e;

// Configure P6.1, P6.2, and P6.3 as inputs
P6DIR &= ~0x0e;
```


Lab 1: Timer_B Setup – Solution

```
// Use TBCLK = ACLK, clear TBR
TBCTL = TBSSEL_1 + TBCLR;
// Set OUT1 on EQU1, reset on EQU0
TBCCTL1 = OUTMOD_3;
// Set period to 1/10Hz
TBCCR0 = 32768 / 10;
// Set EQU1 event
TBCCR1 = TBCCR0 >> 1;
```

- Note that the value used for TBCCR1 is somewhat arbitrary however one needs to make sure it is within the count range of TBR

Lab 1: ADC12 Setup 1/2 – Solution

```
// Configure S&H time, enable multiple conversions,
// enable ADC12
ADC12CTL0 = ADC12SHT0_6 + ADC12MSC + ADC12ON;
// Use Timer_B.OUT1 to trigger conversions,
// pulse mode, single sequence of channels
ADC12CTL1 = ADC12SHS_3 + ADC12SHP + ADC12CONSEQ_1;
// 12-bit mode, use signed output format
ADC12CTL2 = ADC12RES_2 + ADC12DF;
```


Lab 1: ADC12 Setup 2/2 – Solution

```
// Setup a two-channel ADC12 conversion sequence
// Accelerometer X-channel
ADC12MCTL0 = ADC12INCH_1;
// Accelerometer Y-channel, end-of-sequence
ADC12MCTL1 = ADC12INCH_2 + ADC12EOS;
// Enable interrupts on ADC12MEM1
ADC12IE = 0x0002;
// Enable conversions
ADC12CTL0 |= ADC12ENC;
```

Lab 1: ADC12 ISR – Solution

```
#pragma vector = ADC12_VECTOR
__interrupt void ADC12_ISR(void)
{
  ADCResultX = ADC12MEM0;   // Read out results, clear IFGs
  ADCResultY = ADC12MEM1;

  ADC12CTL0 &= ~ADC12ENC;   // Toggle ADC12ENC
  ADC12CTL0 |= ADC12ENC;

  __bic_SR_register_on_exit(LPM0_bits);
}
```

- Toggling of ADC12ENC is needed to ready the ADC12 for the next sequence of channels to be converted when the next trigger occurs

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Lab 1: Calculating the g-Force Values – Solution

```
// Solution for ADXL322 (2-axis Accelerometer)
AccelX = 3.0f / 4096 / 0.42f * (ADCResultX >> 4);
AccelY = 3.0f / 4096 / 0.42f * (ADCResultY >> 4);
```

```
// Solution for ADXL330 (3-axis Accelerometer)
AccelX = 3.0f / 4096 / 0.30f * (ADCResultX >> 4);
AccelY = 3.0f / 4096 / 0.30f * (ADCResultY >> 4);
```

- Note that both flavors of accelerometers have a slightly different gain

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- Accelerometer Basics
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- Lab: Low-Power Anti-Theft Alarm
- Lab: Tilt Ball

Lab 2: Goal

- Flash the LCD backlight and output a tone in case your MSP-EXP430F5438 gets moved
- Use low-power best practices to achieve lowest possible average current
  - Timer and interrupt-driven activity
  - On-demand accelerometer operation
  - Maximize time in low-power mode

Lab 2: Timer_B Setup

```
// Use TBCLK = ACLK, clear TBR, enable TBR
// overflow interrupt
TBCTL = _______________________;
// Set 1s interval for overflow
TBCCR0 = __________;
// Set OUT1 on EQU1, reset on EQU0
TBCCTL1 = _________;
// Set EQU1 event. Used as accelerometer power-on delay and
// ADC12 start of conversion trigger via OUT1.
TBCCR1 = _________;
```

- Use TBCLK = ACLK = LFXT1 = 32,768kHz
- Setup for 1s overflow interval, enable interrupt
- Use TBCCR1 to trigger start of conversion, and to wait for the accelerometer to settle. How long is good?

Lab 2: Accelerometer On-Demand Operation

```
void System_Init(void)
{
  // Init P6.x output latch to prepare powering
  // the accelerometer via ACC_PWR
  P6OUT ________;
```

```
#pragma vector = TIMERB1_VECTOR
__interrupt void TIMERB1_ISR(void)
{
  switch (__even_in_range(TBIV, 0x0e))
  {
    case 0x0e:                // TBIFG
      P6DIR _______;          // Set ACC_PWR to output to
                              // power-up accelerometer
```

- Idea: Switch accelerometer power signal between “output high” and “input” to achieve on-demand operation

Lab 2: Low-Power Mode Handling 1/2

```
void main(void)
{
  (…)
  while (1)
  {
    // Wait in low-power mode X, enable interrupts
    __bis_SR_register(______________);
```

- Which low-power mode is most suitable and will result in the lowest possible stand-by current?
- The interrupts section in the User's Guide has more info
- Enter selected low-power mode to wait until an ADC12 conversion has been completed

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Lab 2: Low-Power Mode Handling 2/2

```
#pragma vector = ADC12_VECTOR
__interrupt void ADC12_ISR(void)
{
  (…)
  // Exit low-power mode
  __bic_SR_register_on_exit(__________);
}
```

- Exit the low-power mode upon completion of the ADC12 ISR
- Clearing the low-power mode bits on the top of the stack will wake up the system's main() context – same as on all MSP430

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Lab 2: Finishing Up…

```
while (1)
{
  (…)
  while (__________________ || // Check limits to trigger
         __________________ || // alarm
         __________________ ||
         __________________)
  {
    (…)
```

- Determine and fill-in suitable X and Y channel boundaries to set off alarm by moving the board and using the debugger to inspect the ADC12 conversion results
- What is the board's total current consumption measured through jumper JP2?

Lab 2: Timer_B Setup – Solution

```
// Use TBCLK = ACLK, clear TBR, enable TBR
// overflow interrupt
TBCTL = TBSSEL_1 + TBCLR + TBIE;
// Set 1s interval for overflow
TBCCR0 = 32768 - 1;
// Set OUT1 on EQU1, reset on EQU0
TBCCTL1 = OUTMOD_3;
// Set EQU1 event. Used as accelerometer power-on delay and
// ADC12 start of conversion trigger.
TBCCR1 = 655;                 // For ADXL322
// or
TBCCR1 = 33;                  // For ADXL330
```

- Note that both flavors of accelerometers have a different settling time

Lab 2: On-Demand Operation – Solution

```
void System_Init(void)
{
  // Init P6.0 output latch to prepare powering
  // the accelerometer via ACC_PWR
  P6OUT |= 0x01;
```

```
#pragma vector = TIMERB1_VECTOR
__interrupt void TIMERB1_ISR(void)
{
  switch (__even_in_range(TBIV, 0x0e))
  {
    case 0x0e:                 // TBIFG
      P6DIR |= 0x01;           // Set ACC_PWR to output to
                               // power-up accelerometer
```


Lab 2: Low-Power Mode Handling 1/2 – Solution

```
void main(void)
{
  (…)
  while (1)
  {
    // Wait in low-power mode 3, enable interrupts
    __bis_SR_register(LPM3_bits + GIE);
```

- LPM3 is most suitable, since it leaves the 32,768kHz XTAL on while keeping the high-speed DCO and the CPU off

Lab 2: Low-Power Mode Handling 2/2 – Solution

```
#pragma vector = ADC12_VECTOR
__interrupt void ADC12_ISR(void)
{
  (…)
  // Exit low-power mode
  __bic_SR_register_on_exit(LPM3_bits);
}
```

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Lab 2: Finishing Up… – Solution

```
while (1)
{
  (…)
  while (ADCResultX >  200 ||  // Check limits to trigger
         ADCResultX < -200 ||  // alarm
         ADCResultY >  200 ||
         ADCResultY < -200)
  {
    (…)
```

- A value of 200 was used since it allows for enough headroom to accommodate non-calibrated systems
- The total current consumption measured through jumper JP2 should be in the 3µA range while the system is in LPM3

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Lab 3: Goal

- Load and run the provided code on the MSP-EXP430F5438
- Tilting the board to X and Y will move around the ball on the LCD
- Set the board flat on the desk. What happens to the ball?
- Incorporate a calibration mechanism to establish a zero-g position

Lab 3: Implementing Push-Button Control

```
// Configure P2.x for 'S1' push-button operation

// Configure P2.x as input
P2DIR __________;

// Prepare P2.x pull-up resistor
P2OUT __________;

// Enable P2.x pull-up resistor
P2REN __________;
```

- Check where ‘S1’ is connected to
- Note that an internal pull-up must be used
- Configure GPIO accordingly
- The button will be checked inside the main while() loop

Lab 3: Adding Accelerometer Calibration

```
while (1)
{
  // Wait in low-power mode 0, enable interrupts
  __bis_SR_register(LPM0_bits + GIE);

  P1OUT ^= 0x01;                // Toggle LED1

  /* INSERT S1 BUTTON HANDLING HERE */
  /* APPLY CALIBRATION VALUES TO ADCResultX&Y HERE */

  dx = ADCResultX >> 8;         // Scale accelerometer
  dy = ADCResultY >> 8;         // readings
```

- Add two variables to the code to hold calibration data
- Use button S1 to capture the ADC12 results at the time of button press and use as zero-g calibration data

Lab 3: Push-Button Control – Solution

```
// Configure P2.6 for 'S1' push-button operation

// Configure P2.6 as input
P2DIR &= ~0x40;

// Prepare P2.6 pull-up resistor
P2OUT |= 0x40;

// Enable P2.6 pull-up resistor
P2REN |= 0x40;
```

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Lab 3: Accelerometer Calibration – Solution

```
int ADCResultXCal = 0;        // Initialize cal values
int ADCResultYCal = 0;

(…)

while (1)
{
  if (!(P2IN & 0x40))         // Cal button pressed?
  {
    // If yes, store current values
    ADCResultXCal = ADCResultX;
    ADCResultYCal = ADCResultY;
  }

  // Apply calibration values
  ADCResultX -= ADCResultXCal;
  ADCResultY -= ADCResultYCal;
```

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Thank you


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