ABSTRACT

Designing an application with the analog-to-digital converter (ADC) requires several considerations to optimize for power and performance. This application report discusses the basics of how you would analyze a data sheet and user’s guide to design your application. It goes into the fundamentals of how to optimize your design based on the external requirements and available ADC configurations. The goal is to consider various ADC parameters before writing a single line of code. This helps to avoid any unnecessary design changes down the path.

Contents

1 ADC Overview – ADC12_B ................................................................. 1
2 Tailoring the ADC and Reference Voltages to Your Application ........................................................................... 2
3 Window Comparator to Monitor Signal Without CPU Intervention .............................................................................. 7
4 Calibration to Improve Performance .......................................................................................................................... 8
5 ADC12_B Example Code and Resources ..................................................................................................................... 9
6 References ................................................................................................................................................................. 9

List of Figures

1 Input Signal Voltage vs ADC Code ............................................................................................................................... 2
2 Example of an Analog Sensor Powered From a Dedicated LDO .................................................................................. 3
3 Signal Resolution .......................................................................................................................................................... 4
4 Input Signal to ADC Code ................................................................................................................................................ 4
5 ADC12_B Grounding and Noise Considerations ........................................................................................................... 5
6 Analog Input Equivalent Circuit ......................................................................................................................................... 6

1 ADC Overview – ADC12_B

MSP430FR58xx/FR59xx/68xx/69xx devices use a new class of 12-bit ADC12_B. The lists of features for the ADC12_B are the following:

• 200-ksps maximum conversion rate at maximum resolution of 12 bits
• Operates across the entire voltage range of the device (1.8 V to 3.6 V)
• Lowest-power 12-bit ADC in the MSP430™ MCU product portfolio
• Supports up to 32 single-ended external input channels. These can be combined to form external differential input channels or any combination in between.
• Window Comparator that allows you to set threshold levels and compare conversion results to the thresholds without any CPU intervention
• Option to enable 8-bit, 10-bit, or 12-bit conversion
• Requires 10, 12, or 14 ADC12CLK clock cycles for sample conversion at 8-bit, 10-bit, or 12-bit resolutions, respectively
Tailoring the ADC and Reference Voltages to Your Application

- An option to save power at reduced clock rates, 1/4 the maximum using the ADC12PWRMD bit in the ADC12_B Control 2 Register (ADC12CTL2)

ADC12_B is highly configurable into various modes for best performance in your application. By default, ADC12_B is configured as a single-ended input mode converter in which all analog input signals are referenced to AVSS. ADC12_B also supports a differential input mode, which should be selected for differential signals and can also be used for single-ended signals by tying the negative input to AVSS. The advantage of using differential mode for a single-ended input is noise rejection with the cost of a small increase in current consumption. Set the ADC12DIF bit in the ADC12_B Conversion Memory Control x Register (ADC12MCTLx) to enable differential mode. Overall the same principles for designing with the ADC apply to differential and single-ended input modes.


2 Tailoring the ADC and Reference Voltages to Your Application

Each application is unique and has different reference voltage considerations. As an example, when connecting a sensor to the ADC front-end, you would need to consider the voltage dynamic range, the sensor settling time, powering and disabling the sensor when needed for an energy optimized application. Once the considerations are understood, the ADC12_B reference can be tailored for various applications through the configuration registers. Consideration areas for the reference voltage are described in this section.

2.1 Reference Voltages

A reference voltage is a fixed voltage that ideally should not have any temperature and supply dependent variations. ADCs require a reference voltage that has a negative and positive side as a reference point for the ADC input signal. It then translates the input signal to a digital value (ADC code) based on the signal relative to the reference voltage. The application code then deciphers the ADC code in reference to the input signal voltage. Figure 1 showcases a linear translation graph of a reference voltage to an ADC code.

![Figure 1. Input Signal Voltage vs ADC Code](image)

The maximum ADC code value is calculated by \(2^n - 1\) where \(n\) is the number of ADC resolution bits. The positive side of the reference voltage translates to the highest ADC code. If an input signal is higher than the reference voltage, the measurement is then saturated to the maximum ADC code value. For example, if the ADC is 12 bits, the maximum ADC code is \((2^{12} - 1) = 4095\) injecting a voltage above the device specification into the ADC pins can cause permanent damage to the pin or the device itself. For more information, see the data sheet parameter on analog input voltage range. For measuring voltages that exceed the input range of the ADC an external resistive voltage divider can be used.
2.1.1 Internal vs External Reference Voltage

All MSP430 ADCs have integrated internal reference voltages. The ADC also allows external references to be attached if the internal reference performance is not sufficient or if an alternate reference voltage is required. Deciding between internal and external reference needs to be determined early in the design cycle by considering the various conditions of the application. If the reference voltage is used to source multiple devices or external sensors, consider the current load. The MSP430 reference voltage output can only handle a maximum load as stated in the data sheet. The MSP430FR58xx/FR59xx/68xx/69xx reference module can generate three selectable internal reference voltages, 1.2 V, 2.0 V, 2.5 V. AVCC is also a selectable reference voltage. Using AVCC as a reference is lower power, however, it measures analog voltages ratiometric to a potential imprecise and changing AVCC voltage. For some applications, this may be exactly what is desired (for example, measuring full-bridge sensors that are also powered by AVCC).

2.1.1.1 Load Dependency

Sourcing an external device or sensor through the reference voltage is not recommended if care is not taken for proper design specification. The internal reference output buffer has limited drive strength capability. If the current drive is exceeded, the ADC and reference performance could be severely affected resulting in false measurements. Consider using an external reference voltage to source your external sensor and as an external reference voltage to the MSP430FR58xx/FR59xx/68xx/69xx device.

Figure 2. Example of an Analog Sensor Powered From a Dedicated LDO

Figure 2 shows an example on how a sensor could be powered and connected to the ADC for best analog performance. Deciding how the external sensor is powered based on its power requirements is critical for optimal analog performance.

2.1.1.2 Temperature Drift

Another factor that could affect the reference voltage is the dependence on temperature. The reference voltage temperature drift is located in the device-specific data sheet. If an application is in an environment with large temperature swings and accuracy is required over the entire temperature range, evaluate if the internal reference temperature coefficient is good enough. If not, consider using one of Texas Instrument’s external reference solutions with a low temperature coefficient and connect use the VeREF+ pin on the MSP430.

2.1.1.3 Analog Reference Voltage Offset

Another consideration between internal vs external reference is the analog reference voltage offset. All internal references have a voltage offset that needs to be taken into consideration and TLV calibration data can be used to reduce this. For more information, see Section 4. However, using an external reference voltage for the ADC would have a smaller voltage offset relative to the internal reference. The external reference may also be calibrated to obtain the closest reference voltage target. Provide some headroom when selecting the right reference voltage for the application so that the signal is not saturated during conversion or the signal attenuated.
2.1.2 Signal Resolution

Signal resolution determines how accurate a signal can be measured when translated into a digital value since the digital value is finite. The smaller the signal resolution, the better the signal accuracy one can capture. Signal resolution is calculated based on the ADC reference voltage and the number of ADC bits. First, determine your input signal voltage peak-to-peak. Then, select the smallest reference voltage larger than the peak voltage to be captured. This provides the finest signal resolution when calculating it in code. Signal resolution can be calculated using Equation 1.

\[
\text{Signal Resolution} = \frac{V_{R+} - V_{R-}}{2^n}, n = \text{ADC conversion resolution}
\]  

(1)

Assuming \( V_{REF+} = 2.5 \text{ V} \) and \( V_{REF-} = 0 \text{ V} \) and \( n \) is 12 bits, the signal resolution can be calculated using Equation 2.

\[
\text{Signal Resolution} = \frac{2.5 \text{ V}}{2^{12}} = \frac{2.5 \text{ V}}{4096} = 610 \mu\text{V} / \text{bit}
\]

(2)

![Figure 3. Signal Resolution](image)

As an example, if your sensor output swings between 0 V to 1.8 V and you want to use the internal reference, you would select the reference voltage of 2 V. This allows the input signal to not saturate the ADC while providing the finest resolution.

Based on the signal resolution, you can calculate the ideal ADC code from the input voltage. To calculate the ADC code, assuming \( V_{REF+} \) is 2.5 V, 1 V input voltage and 12 bits of resolution, the following formula where Equation 1 has been solved for the signal applies.

\[
\text{ADC Code} = \frac{\text{Input Voltage}}{\text{Signal Resolution}} = \frac{1 \text{ V}}{610 \mu\text{V} / \text{bit}} = 1638
\]

(3)

![Figure 4. Input Signal to ADC Code](image)
2.1.3 Noise Consideration

Hardware layout is critical for achieving the best ADC performance. The power supply and VREF capacitors should be designed per the user's guide [1] recommendation and properly routed.

![Diagram showing decoupling capacitors for digital and analog power supplies, as well as for using an external positive and negative reference.]

---

2.1.3.1 Reference Noise

For the best ADC performance consideration, minimizing noise on the reference should be a priority. Some noise on the reference voltage is white noise and averaging the ADC results in software helps reduce its effects.

Other noise on the internal reference voltage is low frequency and random in time. It can be hard to quantify on-bench measurements but it can affect ADC performance of the MSP430FR58xx/FR59xx/68xx/69xx devices. Averaging and filtering do not help with this type of noise. In certain performance critical application the use of a specialized external precision voltage reference will help achieve better analog system performance. For more information, see the Texas Instrument's external reference page.

When an external reference is used, or the internal reference is used and REFOUT=1, the decoupling caps should be placed as close to the pin as possible to minimize noise. Suggested decoupling cap values are provided in the data sheet [2] and PCB layout advice is provided in the ADC12_B chapter of the user's guide [1] and also Figure 5.

---

2.1.4 More Resources on Voltage Reference Affecting ADC Performance

- Journal - How the voltage reference affects ADC performance, Part 3 (SLYT355)
2.2 Selecting the Right Sample-and-Hold Time (SHT)

Sample-and-hold time determines how long to sample a signal prior to digital conversion. During sample time, an internal switch allows the input capacitor to be charged. The required time to fully charge the capacitor is dependent on the external analog front-end (AFE) connected to the ADC input pin. Figure 6 demonstrates a typical ADC model of an MSP430. The $R_s$ and $C_I$ value can be obtained from the device-specific data sheet.

$$t_{\text{sample}} \geq (R_s + R_I) \cdot \ln \left( \frac{2^n + 2}{2^n} \right) \cdot (C_I + C_{\text{pext}}) R_s < 10 \, k\Omega$$

Once the minimum sample-and-hold time is calculated, the appropriate settings for the ADC can be determined including selecting the right ADC clock. The key goal is to optimize the sample-and-hold time to your application. If the sample-and-hold time is excessively longer than required, it is a waste of energy for the ADC to be operational during that period of time. The sample-and-hold time will also limit the maximum sample rate. If your application requires a larger sample and hold time than the minimum, there will be a tradeoff between performance and maximum sample rate.

The following is an example of an external sensor with the assumption that it can be modeled with $R_s = 1k\Omega$ and $C_{\text{pext}} = 1$ nF.

- $R_I = 1k\Omega$ (see [2])
- $C_I = 10$ pF (see [2])
- $R_s = 1k\Omega$
- $C_{\text{pext}} = 100$ pF

$$t_{\text{sample}} \geq (1k \Omega + 1k \Omega) \cdot \ln \left( \frac{2^{12} + 2}{2^{12}} \right) \cdot (10 \, \text{pF} + 100 \, \text{pF})$$

$$t_{\text{sample}} \geq 2.1 \, \mu\text{s}$$

If the ADC12CLK is at 4.8 MHz, the minimum required sample-and-hold time would be as shown below:

$$\text{SHT} = 2.1 \, \mu\text{s} \cdot 4.8 \, \text{MHz} = 11 \, \text{cycles}$$

The next closest sample-and-hold time (ADC12SHTx) would be 16 ADC12CLK cycles according to the MSP430FR59xx, MSP430FR58xx, MSP430FR68xx, and MSP430FR69xx User’s Guide [1]. This value would be the most efficient to enable full ADC performance for this application example.
A C-code example implementation would look something like the following.

```c
ADC12CTL0 = ADC12SHT0_2 | ADC12ON; // Sampling time, S&H=16, ADC12 on
ADC12CTL1 = ADC12SHP; // Use sampling timer
ADC12CTL2 = ADC12RES_2; // 12-bit conversion results
ADC12MCTL0 |= ADC12INCH_1; // A1 ADC input select; Vref=AVCC
ADC12IER0 |= ADC12IE0; // Enable ADC conv complete interrupt
```

If none of the pre-fixed sample-and-hold time works, the timer could be used to trigger the sample-and-hold time for the extended period of sampling (ADC12CTL1.ADC12SHT0_2). The following C-code example demonstrates the use of a Timer triggering the ADC12_B.

```c
// Configure ADC12
ADC12CTL0 &= ~ADC12ENC; // Disable ADC12
ADC12CTL0 = ADC12SHT0_2; // Configure sample and hold time for 16 ADCCCLK cycles
// ADCCCLK = MODOSC; sampling timer, trigger from TA0.1, repeated single channel
ADC12CTL1 = ADC12SHS_1 | ADC12SHP | ADC12CONSEQ_2;
ADC12CTL2 = ADC12RES_2 | ADC12PWRMD; // 12-bit conversion results + low power mode since we're sampling at 1 sample/sec
ADC12IER0 |= ADC12IE0; // Enable ADC conv complete interrupt
ADC12MCTL0 |= ADC12INCH_2; // A2 ADC input select
ADC12CTL0 |= ADC12ON;

// Use TimerA0.1 to trigger the ADC periodically at 100Hz
TA0CCRO = 32767; // 32768
TA0CCR1 = 3276; // 10% duty cycle
TA0CC1L = OUTMOD_7; // set/reset mode
TA0CTL = TASSEL_1 | MC_1; // ACLK, Up mode
```

As a note, if the internal reference is used, ensure it is ready before any sampling is performed. The ready state of the voltage reference can be checked via the REFCCTL0.REFGENRdy bit.

### 2.3 Clock Selection

ADC12_B requires a clock source to convert the sampled analog input pin to an ADC code. This step occurs after the sample-and-hold period as discussed in Section 2.2. If ADC12SHP=1, clock source is also needed to generate the sample-and-hold time from the internal ADC sample timer. Four clock sources can be selected for ADC12_B: MODOSC, ACLK, MCLK, and SMCLK. MODOSC is an internal clock source that is automatically enabled once requested by the ADC12_B module. There is also a clock divider that can be configured to lower the frequency. The clock source selection directly correlates to the system sampling rate. The slower the ADC12 clock, which reduces power consumption, the slower the sampling rate. Keep in mind that the ADC12_B maximum sampling rate is 200 ksps.

Another power saving feature is to use the ADC12PWRMD bit if the clock is <= 1/4 the specified maximum.

### 3 Window Comparator to Monitor Signal Without CPU Intervention

The window comparator has the capability to set threshold levels and compare conversion results to the thresholds without any CPU intervention during low-power modes (LPM). The thresholds are set in LSB units and if a conversion result falls within the range of pre-set low and high threshold levels, an interrupt is triggered. Note that the same window comparator thresholds are shared among all channels, and conversion results from different channels are compared against the same threshold levels when the feature is enabled.

This feature is extremely useful for saving power, because it allows the device to stay in a LPM until the ADC input reaches a specific threshold. All other conversion results are discarded automatically, and the device only wakes up on threshold triggers.
The following is a C-code example snippet on enabling the window comparator in ADC12_B.

```c
#define High_Threshold 0xCCC // ~2V
#define Low_Threshold 0x666 // ~1V
...

// Configure ADC12
// tsample = 16ADC12CLK cycles, tconvert = 14 ADC12CLK cycles
// software trigger for SOC, MODOSC, single ch-single conversion,
// tsample controlled by SHT0x settings
// Channel 1, reference = internal, enable window comparator
// Set thresholds for ADC12 interrupts
// Enable Interrupts
ADC12CTL0 = ADC12SHT0_2 | ADC12ON;
ADC12CTL1 = ADC12SHS_0 | ADC12SSEL_0 | ADC12CONSEQ_0 | ADC12SHP;
ADC12MCTL0 = ADC12INCH_1 | ADC12VRSEL_1 | ADC12WINC;
ADC12HI = High_Threshold;
ADC12LO = Low_Threshold;
ADC12IER2 = ADC12HIIE | ADC12LOIE | ADC12INIE;

// Configure internal reference
while((REFCTL0 & REFGENBUSY)); // If ref generator busy, WAIT
REFCTL0 |= REFVSEL_2|REFON; // Select internal ref = 2.5V
while(!(REFCTL0 & REFGENRDY)); // Wait for reference generator
    // to settle
```

### 4 Calibration to Improve Performance

Calibration can be done to improve ADC performance. Real-time calibration provides the best performance as it accounts for temperature drift and voltage dependencies, but it can require additional hardware on the board. During production, measurements can be done specific to the application and those calibration values stored, and later used by the code to calibrate. The device also contains some calibration values pre-programmed by Texas Instruments that can be used to improve performance. These values are stored in the Device Descriptor Table (TLV). The device-specific data sheet shows the TLV calibration values available on the device and the correction equations are provided in the Device Descriptor Table section in [1]. To calibrate using TLV values, the code needs to implement the correction equations.

If the internal reference is used, the reference factor can be used to know the exact reference voltage at room temperature. More details on this procedure are provided in the Device Descriptor Table section of the user's guide [1].

The ADC has a gain factor and offset stored in TLV that is pre-programmed on the device based on measurements using an external reference at room temperature. When the calibration equations are applied, gain and offset error are improved as well as total unadjusted error. At room temperature, gain and offset error will be improved to ±0.5 LSB. Note the gain factor TLV value is measured with an external reference without internal buffer ADC12VRSEL = ADC12VRSEL_2, ADC12VRSEL_4, or ADC12VRSEL_14. Other settings (for example, using internal reference) can result in different correction factors. For obtaining the offset, TLV value is measured with ADC12VRSEL = ADC12VRSEL_2 or ADC12VRSEL_4 and VR+=2.5V and VR=AVSS. Other settings can result in a different correction factor. As voltage drop increases on AVSS, the offset would increase and not be accounted for in the TLV value.
5 ADC12_B Example Code and Resources

- For more comprehensive code examples on using the ADC, see MSP430FR59xx, MSP430FR58xx Code Examples (SLAC536).
- EnergyTrace++ technology offers an advanced approach in debugging and optimizing your application power consumption by observing various aspects of the code and its power consumption. To use EnergyTrace++ Technology, see MSP430 Advanced Power Optimizations.
- MSP430 Advanced Power Optimizations: ULP Advisor and EnergyTrace Technology (SLAA603)
- For a complete online training workshop, see the MSP430FR59xx Training Workshop wiki.

6 References

2. MSP430FR59xx, MSP430FR58xx Mixed Signal Microcontroller Data Sheet (SLAS704)
3. MSP430FR59xx, MSP430FR58xx Code Examples (SLAC536)
4. MSP430 Advanced Power Optimizations
5. MSP430 Advanced Power Optimizations: ULP Advisor and EnergyTrace Technology (SLAA603)
6. For a complete online training workshop, see the MSP430FR59xx Training Workshop wiki.
### Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

<table>
<thead>
<tr>
<th>Changes from Original (May 2014) to A Revision</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Update was made in Section 2.2.</td>
<td>6</td>
</tr>
</tbody>
</table>
## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have not been so designated is solely at the Buyer’s risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

### Products

<table>
<thead>
<tr>
<th>Audio</th>
<th><a href="http://www.ti.com/audio">www.ti.com/audio</a></th>
<th>Automotive and Transportation</th>
<th><a href="http://www.ti.com/automotive">www.ti.com/automotive</a></th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplifiers</td>
<td>amplifier.ti.com</td>
<td>Communications and Telecom</td>
<td><a href="http://www.ti.com/communications">www.ti.com/communications</a></td>
</tr>
<tr>
<td>DSP</td>
<td>dsp.ti.com</td>
<td>Energy and Lighting</td>
<td><a href="http://www.ti.com/energy">www.ti.com/energy</a></td>
</tr>
<tr>
<td>Interface</td>
<td>interface.ti.com</td>
<td>Medical</td>
<td><a href="http://www.ti.com/medical">www.ti.com/medical</a></td>
</tr>
<tr>
<td>Logic</td>
<td>logic.ti.com</td>
<td>Security</td>
<td><a href="http://www.ti.com/security">www.ti.com/security</a></td>
</tr>
<tr>
<td>Power Mgmt</td>
<td>power.ti.com</td>
<td>Space, Avionics and Defense</td>
<td><a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a></td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>microcontroller.ti.com</td>
<td>Video and Imaging</td>
<td><a href="http://www.ti.com/video">www.ti.com/video</a></td>
</tr>
<tr>
<td>RFID</td>
<td><a href="http://www.ti-rfid.com">www.ti-rfid.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OMAP Applications Processors</td>
<td><a href="http://www.ti.com/omap">www.ti.com/omap</a></td>
<td>TI E2E Community</td>
<td>e2e.ti.com</td>
</tr>
<tr>
<td>Wireless Connectivity</td>
<td><a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2016, Texas Instruments Incorporated