ABSTRACT

Some members of the Stellaris microcontroller family have an analog-to-digital converter (ADC) module. The hardware resolution of the ADC is 10 bits; however, due to noise and other accuracy diminishing factors, the true accuracy is less than 10 bits. This application report provides a software-based oversampling technique, resulting in an improved effective number of bits (ENOB) in the conversion result. This document describes methods of oversampling an input signal, and the impact on precision and overall system performance.

Contents

1 Oversampling ................................................................. 1
2 Averaging ........................................................................ 2
3 Implementation ............................................................... 4
4 Oversampling More Than 8 Times Using Multiple Sequencers or a Timer .............................................. 6
5 Oversampling Using a Rolling Average ................................ 10
6 Issues to Consider .......................................................... 11
7 Conclusion ....................................................................... 12
8 References ..................................................................... 12

List of Figures

1 Averaged Conversion Results .................................................. 2
2 Normal Averaging ................................................................. 3
3 Rolling Average ................................................................ 4
4 Oversampling by 16 ............................................................ 6

1 Oversampling

As the name implies, oversampling gathers additional conversion data from an input signal. Standard convention for sampling an analog signal indicates that the sampling frequency $f_s$ should be at least twice that of the highest frequency component $f_H$ of the input signal. This is referred to as the Nyquist Theorem (see Equation 1).

\[ f_s = 2f_H \]  

Nyquist Theorem

Any sampling frequency selected above $f_s$ is considered to be oversampling, and when combined with averaging techniques, improves the ENOB. This is possible because averaging the oversampled results also averages the quantization noise, therefore, improving the signal-to-noise ratio (SNR), which has a direct effect on the ENOB.

For each bit of accuracy improvement, the signal must be oversampled by a factor of four, meaning that the relationship between the oversampling frequency $f_{os}$ and sampling frequency $f_s$ is as shown in Equation 2.

\[ f_{os} = 4^x \times f_s \]  

Oversampling Frequency

where $x$ is the desired improvement on the ENOB (for example, for two bits of improvement, $x = 2$).
Figure 1 shows how oversampling improves the accuracy of the conversion result. In this diagram, the input signal is oversampled by four (sample groups are shown in green and purple) and averaged. The sample points shown illustrate the difference between the raw, noisy signal and the average; the noise in this example affecting ±3 bits of accuracy on an individual sample. Note that the averaged values (orange dots) are much closer to the ideal value than most of the single samples.

2 Averaging

Averaging acts as a low-pass filter on the input signal, with the pass band of the filter narrowing as the sample size increases. When averaging conversion results, there are two approaches that can be taken: normal average or rolling average.

2.1 Normal Average

Taking $n$ samples, adding them, and dividing the result by $n$ is referred to as a normal average, and is shown in Figure 1. When using normal averaging in an oversampling scenario, after the technique is applied, the sample data used in the calculation is discarded. This process is repeated every time the application needs a new conversion result.

In an application, the normal averaging approach is ideally used in cases where the sampling frequency is low compared to the sampling rate of the ADC.

NOTE: Important: When oversampling by $n$ in a normal averaging scenario, the effective ADC sample rate is reduced by that same factor. For example, oversampling an input signal by 4 cuts the maximum effective ADC sample rate by 4, meaning that a 250K-samples/s ADC effectively becomes a 62.5K-samples/s ADC.
Figure 2 shows a situation where normal averaging is used to oversample an input source by 4. For this example, the application requires that a new conversion value be ready (averaging complete) at each step of \( t \) (\( t_0 \), \( t_1 \), \( t_2 \), and so on).

When using averaging techniques, there is a slight delay associated with the calculated conversion result since it corresponds to the average of the last \( n \) samples. The delay can be calculated using the formula shown in Equation 3.

\[
\text{Averaged Sample Delay } \ t_{\text{delay}} = (t_{sn} - t_{s0})/2 + t_{\text{process}}
\]  

(3)

where \( t_{s0} \) is the time at which the first sample of the average occurs, and \( t_{sn} \) is where the last sample occurs. The time required by the interrupt handler to process the sample data and calculate the average \( t_{\text{process}} \) to supply to the application is also factored into the equation. In Figure 2, the delayed conversion result is highlighted in orange.

2.2 Rolling Average

A rolling average uses a sample buffer of the \( n \) most recent samples in the averaging calculation, allowing the ADC to sample at its maximum rate (the ADC sample rate is not reduced by \( n \) as in normal averaging), making it ideally suited for applications requiring oversampling and higher sample rates. The sample buffer can be prefilled with valid sample data (by taking \( n-1 \) samples prior to the first “real” data point), or can be left in an unknown state, depending on the application. The disadvantage of not prefilling the buffer is that the first \( n-1 \) samples contain invalid data and adversely affect the rolling average calculation. If acceptable by the application, buffer padding can be eliminated if the software can account for the possibility of the first \( n-1 \) samples being skewed.

Figure 3 shows an example of oversampling with a rolling average. The diagram shows a case where the input signal is oversampled by 4, meaning that the sample buffer uses the four most recent samples to calculate the average. In this example, the application requires a new sample at each step of \( t \). Before the first oversampled result is calculated at \( t_0 \), the sample buffer collects three samples so that the first data supplied to the application is valid.

When using a rolling average, the same sample delay calculated by Equation 3 applies. In Figure 3, the delayed values for \( t_0 \), \( t_1 \) and \( t_2 \) (shown as \( d_0 \), \( d_1 \) and \( d_2 \), respectively) are highlighted in orange.

Important: Using a rolling average adds additional processing overhead due to the sample buffer manipulation that must be performed during each interrupt.
3 Implementation

The sample sequencer architecture in the ADC makes oversampling simple by allowing for up to 17 unique samples (from any of the analog channels) to be collected using a single trigger. This allows for flexibility in software by providing the means for an application to oversample a number of channels at any given time.

This section shows various implementations of oversampling using the Stellaris microcontrollers. There are numerous methods that work using combinations of sample sequencer configurations, ADC triggers and interrupts, however, the examples shown here focus on techniques that are most likely to be used.

All the example code uses the Stellaris Peripheral Driver Library ADC functions. The source code for the Driver Library and the software examples shown in this application note can be found on the website at http://www.ti.com.

3.1 Oversampling Up to 8 Times Using the Driver Library Functions

The Stellaris Peripheral Driver Library has built-in functions that allow oversampling up to 8 times. For most applications, this level of oversampling is sufficient since the improvement on the ENOB is approximately 1.4 bits.

Using the Driver Library oversampling functions is the easiest way to oversample the input signal. The main difference between configuring a “typical” ADC conversion and an oversampled conversion is the function calls. The oversampling functions have an ADCSoftwareOversample prefix, and are easily distinguished from the standard ADC functions.

Once the parameters for the ADC conversion process are determined (sample frequency, trigger source, channel, and so on), writing the code is straight-forward. For example, the code to set up a 10-ms periodic conversion (triggered by a timer) that is oversampled by 8 consists of the code segments shown in Example 1.
3.2 8x Oversampling With the Driver Library Functions

Example 1. Code Segment 1.a. ADC Configuration — Driver Library Functions

```c
// Initialize the ADC to oversample channel 1 by 8x using sequencer 0.
// Sequencer will be triggered by one of the general-purpose timers.
//
ADCSequenceConfigure(ADC_BASE, 0, ADC_TRIGGER_TIMER, 0);
ADCSoftwareOversampleConfigure(ADC_BASE, 0, 8);
ADCSoftwareOversampleStepConfigure(ADC_BASE, 0, 0, (ADC_CTL_CH1
    | ADC_CTL_IE | ADC_CTL_END));
//
// Initialize Timer 0 to trigger an ADC conversion once every 10 milliseconds
//
TimerConfigure(TIMER0_BASE, TIMER_CFG_32_BIT_PER);
TimerLoadSet(TIMER0_BASE, TIMER_A, SysCtlClockGet() / 100);
TimerControlTrigger(TIMER0_BASE, TIMER_A, true);
```

The ADC configuration shown in Code Segment 1.a dictates that an interrupt occurs when sampling completes, meaning that an interrupt handler must be implemented (see Code Segment 1.b). Since the Driver Library oversampling functions automatically average the sampled data, the interrupt handler function is relatively basic. Keep in mind that having the average calculated during each interrupt adds computational overhead to the interrupt handler.

Example 2. Code Segment 1.b. ADC Interrupt Handler

```c
void ADCIntHandler(void)
{
    long lStatus;
    //
    // Clear the ADC interrupt
    //
    ADCIntClear(ADC_BASE, 0);
    //
    // Get averaged data from the ADC
    //
    lStatus = ADCSoftwareOversampleDataGet(ADC_BASE, 0,&g_ulAverage);
    //
    // Placeholder for ADC processing code
    //
}
```
With the configuration steps and interrupt handler in place, the conversion process is initiated. Before the timer is turned on (begins counting), the ADC sequencer and interrupt must be enabled (see Code Segment 1.c).

**Example 3. Code Segment 1.c. Enabling the ADC and Interrupts**

```c
// Enable ADC sequencer 0 and its interrupt (in both the ADC and NVIC)
ADCSequenceEnable(ADC_BASE, 0);
ADCIIntEnable(ADC_BASE, 0);
IntEnable(INT_ADC0);

// Enable the timer and start conversion process
//
TimerEnable(TIMER0_BASE, TIMER_A);
```

4 Oversampling More Than 8 Times Using Multiple Sequencers or a Timer

The Driver Library oversampling functions are limited to oversampling by 8 times (based on hardware limitations of the sample sequencers), meaning that applications requiring larger oversampling factors must use an alternative implementation. This section shows how to approach such a situation using two methods: multiple sample sequencers and a timer running at the oversampling frequency.

4.1 16x Oversampling Using Multiple Sample Sequencers

The flexibility of the sample sequencer allows a wide range of configurations. To oversample by 16, sample sequencers 0-2 can be used since their accumulated capacity is 16 samples (8 + 4 + 4). For this level of oversampling to work, all steps in the sequencers must be set to sample the same analog input, meaning the ability to sample multiple inputs using a single sequencer is lost.

**Code Segment 2.a** configures a 10-ms periodic conversion using sequencers 0-2. A single timer trigger is used to initiate sampling on all 3 sequencers, eliminating the need for complex trigger configurations. To obtain the desired result, the sample sequencer priorities are configured such that sample sequencer 2 has the lowest priority (meaning it samples last), and the “end of conversion” interrupt is configured to assert after the last step of sample sequence 2 (as shown in Figure 4).

**Figure 4. Oversampling by 16**
Example 4. Code Segment 2.a. ADC Configuration – Multiple Sample Sequencers

```c
//@
//@ Initialize the ADC for 16x oversampling on channel 1 using sequencers
//@ 0-2. The conversion is triggered by a GPTM.
//@
ADCSequenceConfigure(ADC_BASE, 0, ADC_TRIGGER_TIMER, 0);
ADCSequenceConfigure(ADC_BASE, 1, ADC_TRIGGER_TIMER, 1);
ADCSequenceConfigure(ADC_BASE, 2, ADC_TRIGGER_TIMER, 2);
//@
//@ Configure sequence steps for sequencer 0
//@
ADCSequenceStepConfigure(ADC_BASE, 0, 0, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 0, 1, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 0, 2, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 0, 3, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 0, 4, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 0, 5, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 0, 6, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 0, 7, (ADC_CTL_CH1 | ADC_CTL_END));
//@
//@ Configure sequence steps for sequencer 1
//@
ADCSequenceStepConfigure(ADC_BASE, 1, 0, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 1, 1, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 1, 2, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 1, 3, (ADC_CTL_CH1 | ADC_CTL_END));
//@
//@ Configure sequence steps for sequencer 2
//@
ADCSequenceStepConfigure(ADC_BASE, 2, 0, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 2, 1, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 2, 2, ADC_CTL_CH1);
ADCSequenceStepConfigure(ADC_BASE, 2, 3, (ADC_CTL_CH1 | ADC_CTL_IE \ADC_CTL_END));
//@
//@ Initialize Timer 0 to trigger an ADC conversion once every 10 milliseconds
//@
TimerConfigure(TIMER0_BASE, TIMER_CFG_32_BIT_PER);
TimerLoadSet(TIMER0_BASE, TIMER_A, SysCtlClockGet() / 100);
TimerControlTrigger(TIMER0_BASE, TIMER_A, true);
```

In Code Segment 2.b, the interrupt handler must gather the data from the FIFOs and perform the averaging calculation. The ADCSequenceDataGet function is not used here since the desired results are obtained without having to deal with the function overhead, so direct register reads are used to empty the sequencer FIFOs. Using ADCSequenceDataGet requires the function to define an extra 8-entry sample buffer. Even with direct register reads, there is still computational overhead from the sum and average calculations performed in the interrupt handler.

Example 5. Code Segment 2.b. ADC Interrupt Handler

```c
void
ADCIntHandler(void)
{
unsigned long ulIdx;
unsigned long ulSum = 0;
//@
//@ Clear the interrupt
//@
ADCIntClear(ADC_BASE, 2);
//@
//@ Get the data from sequencer 0
```
Example 5. Code Segment 2.b. ADC Interrupt Handler (continued)

```c
//
for(ulIdx = 8; ulIdx; ulIdx--)
{
ulSum += HWREG(ADC_BASE + ADC_O_SSFIFO0);
}
//
// Get the data from sequencers 1 and 2
//
for(ulIdx = 4; ulIdx; ulIdx--)
{
ulSum += HWREG(ADC_BASE + ADC_O_SSFIFO1);
ulSum += HWREG(ADC_BASE + ADC_O_SSFIFO2);
}
//
// Average the oversampled data
//
g_ulAverage = ulSum >> 4;
//
// Placeholder for ADC processing code
//
}
```

Before initiating the conversion process, the sample sequencers and interrupts are enabled (see Code Segment 2.c).

Example 6. Code Segment 2.c. Enabling the ADC and Interrupts

```c
//
// Enable the sequencers and interrupt
//
ADCSequenceEnable(ADC_BASE, 0);
ADCSequenceEnable(ADC_BASE, 1);
ADCSequenceEnable(ADC_BASE, 2);
ADCIIntEnable(ADC_BASE, 2);
IntEnable(INT_ADC2);
//
// Enable the timer and start conversion process
//
TimerEnable(TIMER0_BASE, TIMER_A);
```
4.2 16x Oversampling Using a Timer Running at f_{OS}

Another way to oversample (without consuming a large portion of the ADC sequencer resources) is by using a periodic timer that runs at the oversampling frequency. For example, if a conversion must be returned to the main application every 10 ms and is to be oversampled by 16, a timer can be configured to take a single sample every 625 µs. Having the timer trigger a conversion at the oversampling frequency obviously generates additional ADC interrupt traffic, which must be accounted for in the application.

The code that configures the ADC and timer to operate like this is shown in Code Segment 3.a.

Example 7. Code Segment 3.a. ADC Configuration – Timer Running at f_{OS}

```c
// Initialize the ADC to take a single sample on channel 1, sequencer 3
// when a trigger is detected.
ADCSequenceConfigure(ADC_BASE, 3, ADC_TRIGGER_TIMER, 0);
ADCSequenceStepConfigure(ADC_BASE, 3, 0, (ADC_CTL_CH1 | ADC_CTL_IE |
| ADC_CTL_END));
// Initialize Timer 0 to trigger an ADC conversion once every 625 microseconds
// TimerConfigure(TIMER0_BASE, TIMER_CFG_32_BIT_PER);
TimerLoadSet(TIMER0_BASE, TIMER_A, SysCtlClockGet() / 1600);
TimerControlTrigger(TIMER0_BASE, TIMER_A, true);
```

Now that the ADC is sampling at the oversampling frequency, the interrupt handler must keep track of the number of samples taken and the overall sum (see Code Segment 3.b). When 16 conversions have been accumulated, the averaging is performed and the global sample count and sum variables are cleared.

Example 8. Code Segment 3.b. ADC Interrupt Handler

```c
{ // Clear the interrupt
  ADCIntClear(ADC_BASE, 3);
  // Add the new sample to the global sum
  g_ulSum += HWREG(ADC_BASE + ADC_O_SSFIFO3);
  // Increment g_ucOversampleCnt
  g_ucOversampleCnt++;
  // If 16 samples have accumulated, average them and reset globals
  if(g_ucOversampleCnt == 16)
  {
    g_ulAverage = g_ulSum >> 4;
    g_ucOversampleCnt = 0;
    g_ulSum = 0;
  }
  // Placeholder for ADC processing code
  }
```

Finally, before enabling the timer, sequencer 3 and its interrupt are enabled, and the global counter and sum variables are cleared (see Code Segment 3.c).
Example 9. Code Segment 3.c. Enabling the ADC, Interrupts and Global Variables

```c
//
// Enable the sequencer and interrupt
//
ADCSequenceEnable(ADC_BASE, 3);
ADCIntEnable(ADC_BASE, 3);
IntEnable(INT_ADC3);
//
// Zero the oversample counter and the sum
//
g_ucOversampleCnt = 0;
g_ulSum = 0;
//
// Enable the timer and start conversion process
//
TimerEnable(TIMER0_BASE, TIMER_A);
```

5 Oversampling Using a Rolling Average

The rolling average approach is useful in situations where the sampling frequency is closer to the maximum sample rate of the ADC. The main component of a rolling average application is the sample buffer, which drops and adds data each time a conversion completes.

In Section 5.1, the ADC is configured to sample once every 100 μs, and the sample buffer contains 16 entries. Note that the application does not prefill the sample buffer with valid data, so the first 16 samples must be handled accordingly by software. The ADC is configured to sample on a timer trigger, and interrupts the processor after every conversion.

5.1 Oversampling Using a Rolling Average Every 100 Microseconds

Example 10. Code Segment 4.a. ADC Configuration – Rolling Average

```c
//
// Initialize the ADC to take a single sample on channel 1, sequencer 3
// when a trigger is detected.
//
ADCSequenceConfigure(ADC_BASE, 3, ADC_TRIGGER_TIMER, 0);
ADCSequenceStepConfigure(ADC_BASE, 3, 0, (ADC_CTL_CH1 | ADC_CTL_IE |
| ADC_CTL_END));
//
// Initialize Timer 0 to trigger an ADC conversion once every 100 microseconds
//
TimerConfigure(TIMER0_BASE, TIMER_CFG_32_BIT_PER);
TimerLoadSet(TIMER0_BASE, TIMER_A, SysCtlClockGet() / 10000);
TimerControlTrigger(TIMER0_BASE, TIMER_A, true);
```

The interrupt handler is responsible for updating the sample buffer and performing the averaging calculation (see Code Segment 4.b). For each ADC interrupt, the last element in the sample buffer is dropped, and the remaining data is shifted over one place in the buffer. The new conversion result is then placed at the beginning of the sample buffer before the average is computed. Again, the additional computations performed in the interrupt handler add overhead that must be taken into account.

Example 11. Code Segment 4.b. ADC Interrupt Handler

```c
void
ADCIntHandler(void)
{ }
```
Example 11. Code Segment 4.b. ADC Interrupt Handler (continued)

```c
// Clear the interrupt
ADCIntClear(ADC_BASE, 3);
// Check g_ucOversampleIdx to make sure that it is within range
if(g_ucOversampleIdx == 16)
{
    g_ucOversampleIdx = 0;
}
// Subtract the oldest value from the global sum
g_ulSum -= g_ulSampleBuffer[g_ucOversampleIdx];
// Replace the oldest value with the new sample value
g_ulSampleBuffer[g_ucOversampleIdx] = HWREG(ADC_BASE + ADC_O_SSFIFO3);
// Add the new sample to the overall sum
g_ulSum += g_ulSampleBuffer[g_ucOversampleIdx];
// Increment g_ucOversampleIdx
++g_ucOversampleIdx;
// Get the averaged value from the sample buffer data
g_ulAverage = g_ulSum >> 4;
// Placeholder for ADC processing code
}
```

Again, before the timer is started, the sequencer and its interrupt are enabled (see Code Segment 4.c).

Example 12. Code Segment 4.c. Enabling the ADC and Interrupts

```c
// Enable the sequencer and the interrupt
ADCSequenceEnable(ADC_BASE, 3);
ADCIntEnable(ADC_BASE, 3);
IntEnable(INT_ADC3);

// Enable the timer and start conversion process
TimerEnable(TIMER0_BASE, TIMER_A);
```

6 Issues to Consider

The oversampling techniques described in this document have an obvious impact on overall system performance since they require additional code to perform the averaging calculations, additional interrupts, and most of the sample sequencer resources. Choosing the technique that best suits the application requires analyzing the trade-offs between increased interrupt traffic and bulkier interrupt handlers.
7 Conclusion

The sample sequencer architecture offers a wide range of options for implementing oversampling techniques. When combined with software averaging, the architecture enables system designers to effectively make the engineering trade-offs between sampling frequency, system performance and sampling resolution.

8 References

The following related documents and software are available on the Stellaris web site at:

www.ti.com/stellaris:

- Stellaris LM3S Microcontroller Data Sheet (individual device documents available through product selection tool).
- StellarisWare Driver Library User's Manual, publication SW-DRL-UG (SPMU019)
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
Audio www.ti.com/audio
Amplifiers amplifier.ti.com
Data Converters dataconverter.ti.com
DLP® Products www.dlp.com
DSP dsp.ti.com
Clocks and Timers www.ti.com/clocks
Interface interface.ti.com
Logic logic.ti.com
Power Mgmt power.ti.com
Microcontrollers microcontroller.ti.com
RFID www.ti-rfid.com
OMAP Applications Processors www.ti.com/omap
Wireless Connectivity www.ti.com/wirelessconnectivity

Applications
Automotive and Transportation www.ti.com/automotive
Communications and Telecom www.ti.com/communications
Computers and Peripherals www.ti.com/computers
Consumer Electronics www.ti.com/consumer-apps
Energy and Lighting www.ti.com/energy
Industrial www.ti.com/industrial
Medical www.ti.com/medical
Security www.ti.com/security
Space, Avionics and Defense www.ti.com/space-avionics-defense
Video and Imaging www.ti.com/video

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2013, Texas Instruments Incorporated