ABSTRACT

TI’s LDC100x and LDC1101 devices measure the resonant frequency of an LC tank to determine the inductance of a sensor. Some applications require higher measurement resolution than the LDC100x or even LDC1101 can provide. With proper configuration of the LDC, an external time measurement device can be used for improved inductance measurement resolution.

1 Performing L Measurements from LDC DRDY Timing

The LDC100x and LDC1101 can be configured to issue a DRDY pulse when a conversion completes. The conversion time off these LDCs is a function of the sensor frequency:

\[
\text{Conversion Time(s)} = \frac{\text{RESPONSE\_TIME}}{3 \times f_{\text{SENSOR}}}
\]

where
- \( f_{\text{SENSOR}} \) is the sensor resonant frequency
- \( \text{RESPONSE\_TIME} \) is the programmed response time in register 0x04

For example, with a \( \text{RESPONSE\_TIME} = 6144 \) and \( f_{\text{SENSOR}} = 1 \text{ MHz} \), the conversion interval is 2.048 ms. An LDC100x with a reference frequency of 8 MHz has an L conversion output code of 16384.

The timing resolution is \( 1/f_{\text{REFERENCE}} \). A higher reference frequency corresponds to a higher timing resolution.
Performing $L$ Measurements from LDC DRDY Timing

<table>
<thead>
<tr>
<th>Table 1. Timing Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDC100x</td>
</tr>
<tr>
<td>Maximum Reference Frequency</td>
</tr>
<tr>
<td>Best timing resolution</td>
</tr>
</tbody>
</table>

When the LDC is configured to report DRDY (for the LDC100x, register 0x0A:bits[2:0] = b’100, for the LDC1101, register 0x0A = 0x84), the LDC asserts the INTB signal on the completion of each conversion.

![Figure 1. LDC1101 DRDY Signal Output on SDO Pin](image1)

![Figure 2. LDC100x DRDY Signal Output on INTB Pin](image2)

The time between successive DRDY assertions correspond to the conversion interval, which is a function of the sensor frequency. Directly measuring the time between DRDY assertions can actually be used to accurately measure the sensor frequency.

![Figure 3. MCU Connections](image3)

Many MCUs have a timing peripheral which can measure events to a higher resolution than provided by the LDC. In addition, some MCU timer peripherals can be configured to measure the interval between several pulses; this can be used to measure the sensor frequency over a longer interval than the LDC can be configured to. When measuring frequency, longer measurement intervals can provide a higher resolution measurement.
Measuring the time between DRDY assertions can therefore be used to determine the sensor frequency by:

\[
f_{\text{SENSOR}} = \frac{\text{#pulses} \times \text{RESPONSE\_TIME}}{3 \times \text{MCU\_Measured\_time}}
\]

where
- \( f_{\text{SENSOR}} \) is the sensor resonant frequency
- \( \text{RESPONSE\_TIME} \) is the programmed response time in register 0x04
- \( \text{#pulses} \) is the number of DRDY assertions that have occurred

For example, if four DRDY assertions were measured over a duration of 3.75 ms when the LDC is configured with a \( \text{RESPONSE\_TIME} \) of 6144, then the sensor frequency is 2.185 MHz.

For many applications, computing the actual sensor frequency is usually not necessary to determining the target position; usually the equation of interest is the application specific equation:

\[
\text{position}\_\text{target} = f(\text{output\_code})
\]

In this case, the \text{output\_code} is the \text{MCU\_Measured\_time}.

Also, it may be necessary for some MCUs to manage the timer peripheral interrupt servicing to ensure that another ISR does not affect the sensor frequency measurement.

2 Other Timing Measurement Approaches

An LDC can be connected to a TDC7200 for even higher resolution inductance measurements – up to 50 ps timestamp resolution. In this arrangement, the TDC7200 is set to MODE2, and the START input is connected to an MCU GPIO, which is used to initiate a measurement.

The LDC100x is configured to output DRDYB pulses on the INTB pin by setting register 0x0A to 0x04. The TDC7200 is configured to timestamp when it gets a falling edge on the STOP pin.

The LDC100x has its INTB pin connected to the TDC7200 STOP pin, while the LDC1101 has its SDO pin connected to the TDC7200 STOP pin.

![Figure 4. LDC100x and TDC7200 Connections](image)

When a high-resolution L measurement is desired, the LDC100x is enabled, and the MCU sends a START pulse to the TDC7200. Note that the MCU needs to ensure that \( t_1 \) is at least 250 ns, so it monitors the INTB pin and only sends the START pulse at a permitted time. After five conversion cycles of the LDC, the TDC7200 timestamps are read back.

The sensor frequency is then:

\[
f_{\text{SENSOR}} = \text{RESPONSE\_TIME}/12 \times (t_5-t_1)
\]
Where tX are the timestamps indicated in Figure 5. Alternatively, users can calculate the frequency for each tX-tX-1 and average the four measurements. Using a lower value for the LDC RESPONSE_TIME setting is acceptable.

![Figure 5. Timing Diagram](image)

The TDC7200 has a maximum measurement time of 8 ms with an 8-MHz reference when using Mode 2. This introduces a limitation for the minimum sensor frequency based on the device configuration, as listed in Table 1.

<table>
<thead>
<tr>
<th>LDC RESPONSE_TIME</th>
<th>192</th>
<th>384</th>
<th>768</th>
<th>1536</th>
<th>3072</th>
<th>6144</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 TDC Stop Events</td>
<td>32 kHz</td>
<td>64 kHz</td>
<td>128 kHz</td>
<td>256 kHz</td>
<td>512 kHz</td>
<td>1.024 MHz</td>
</tr>
<tr>
<td>4 TDC Stop Events</td>
<td>24 kHz</td>
<td>48 kHz</td>
<td>96 kHz</td>
<td>192 kHz</td>
<td>384 kHz</td>
<td>768 kHz</td>
</tr>
<tr>
<td>3 TDC Stop Events</td>
<td>16 kHz</td>
<td>32 kHz</td>
<td>64 kHz</td>
<td>128 kHz</td>
<td>256 kHz</td>
<td>512 kHz</td>
</tr>
<tr>
<td>2 TDC Stop Events</td>
<td>8 kHz</td>
<td>16 kHz</td>
<td>32 kHz</td>
<td>64 kHz</td>
<td>128 kHz</td>
<td>256 kHz</td>
</tr>
</tbody>
</table>

### 3 Use with the LDC1101

For the LDC1101, this technique is often not necessary, as the LDC1101 supports a 16-MHz reference clock versus the 8-MHz reference on the LDC100x. In addition, the LDC1101’s LHR (High-resolution inductance mode) measurements have an effective reference frequency of 32 MHz (when the external reference frequency is set to the maximum supported 16MHz).

### 4 Circuit Implementation Recommendations

If the TBCLK pin (the CLKIN pin for the LDC1101) is not used, it must be grounded.

For the LDC1101, it is recommended to use the L-only measurement mode, which is detailed in the LDC1101 data sheet.

Because the INTB signal is being used to directly measure the sensor frequency, the schematic and layout of this trace must be designed to maintain signal integrity. The trace must have a continuous ground plane underneath to maintain constant impedance. Minimize the number of vias and minimize the parasitic capacitance on the INTB (or SDO pin for the LDC1101) for the highest slew rate.

If the DRDYB signal is routed to both the TDC7200 and an MCU, route the trace as a continuous path rather than splitting the trace as a Y connection.

### 5 Summary

Some LDC applications require higher resolution than the reference frequency of the LDC can provide. Using an external time measurement device is one method to consider.
## Revision History

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

<table>
<thead>
<tr>
<th>Changes from Original (November 2015) to A Revision</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Changed LDC1000 to LDC100x throughout</td>
<td>1</td>
</tr>
<tr>
<td>• Updated app report for clarity throughout</td>
<td>1</td>
</tr>
</tbody>
</table>
IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale (www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2020, Texas Instruments Incorporated