ABSTRACT
TI’s LDC1000 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 LDC1000 or even LDC1101 can provide. With proper configuration of the LDC, an external time measurement device can be used for improved inductance measurement resolution.

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1 Performing L Measurements from LDC DRDY Timing
The LDC1000 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

\(^{(1)}\)

For example, with a RESPONSE\_TIME = 6144 and \( f_{\text{SENSOR}} = 1 \text{ MHz} \), the conversion interval will be 2.048ms. An LDC1000 with a reference frequency of 8 MHz will have 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 1. Timing Resolution

<table>
<thead>
<tr>
<th></th>
<th>LDC1000</th>
<th>LDC1101</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Reference Frequency</td>
<td>8 MHz</td>
<td>16 MHz</td>
</tr>
<tr>
<td>Best timing resolution</td>
<td>125ns</td>
<td>62.5ns</td>
</tr>
</tbody>
</table>

When the LDC is configured to report DRDY (for the LDC1000, register 0x0A:bits[2:0] = b’100, for the LDC1101, register 0x0A = 0x84), the LDC will assert the INTB signal on the completion of each conversion.

The time between successive DRDY assertions will 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 1. LDC1101 DRDY Signal Output on SDO Pin

Figure 2. LDC1000 DRDY Signal Output on INTB Pin

Figure 3. MCU Connections
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:

\[ f_{\text{SENSOR}} = \frac{\# \text{pulses} \times \text{RESPONSE}_{\text{TIME}}}{3 \times \text{MCU}\_\text{Measured}\_\text{time}} \]

where

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

For example, if 4 DRDY assertions were measured over a duration of 3.75ms when the LDC is configured with a \( \text{RESPONSE}_{\text{TIME}} \) of 6144, then the sensor frequency would be 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 output\_code would be the \( \text{MCU}\_\text{Measured}\_\text{time} \).

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 50ps 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 LDC1000 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 LDC1000 would have its INTB pin connected to the TDC7200 STOP pin, while the LDC1101 would have its SDO pin connected to the TDC7200 STOP pin.

![Figure 4. LDC1000 and TDC7200 Connections](image-url)
When a high resolution L measurement is desired, the LDC1000 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 250ns, so it monitors the INTB pin and only sends the START pulse at a permitted time. After 5 conversion cycles of the LDC, the TDC7200 timestamps are read back.

The sensor frequency is then: 
\[
  f_{\text{SENSOR}} = \frac{\text{RESPONSE_TIME}}{12 \times (t_5 - t_1)}
\]

Where \( t_X \) are the timestamps indicated in Figure 5. Alternatively, you could calculate the frequency for each \( t_X - t_{X-1} \) and average the 4 measurements. Using a lower value for the LDC RESPONSE_TIME setting is acceptable.

The TDC7200 has a maximum measurement time of 8ms with an 8MHz 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 2. Minimum LDC Sensor Frequency for Various LDC and TDC Configurations

<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>32kHz</td>
<td>64kHz</td>
<td>128kHz</td>
<td>256kHz</td>
<td>512kHz</td>
<td>1.024MHz</td>
</tr>
<tr>
<td>4 TDC Stop Events</td>
<td>24kHz</td>
<td>48kHz</td>
<td>96kHz</td>
<td>192kHz</td>
<td>384kHz</td>
<td>768kHz</td>
</tr>
<tr>
<td>3 TDC Stop Events</td>
<td>16kHz</td>
<td>32kHz</td>
<td>64kHz</td>
<td>128kHz</td>
<td>256kHz</td>
<td>512kHz</td>
</tr>
<tr>
<td>2 TDC Stop Events</td>
<td>8kHz</td>
<td>16kHz</td>
<td>32kHz</td>
<td>64kHz</td>
<td>128kHz</td>
<td>256kHz</td>
</tr>
</tbody>
</table>

3  **Use with the LDC1101**

For the LDC1101, this technique is often not necessary, as the LDC1101 supports a 16MHz reference clock versus the 8MHz reference on the LDC1000. In addition, the LDC1101’s LHR (High-resolution inductance mode) measurements have an effective reference frequency of 32MHz (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 should be grounded.

For the LDC1101, it is recommended to use the L-only measurement mode, which is detailed in section 8.4.5 of the LDC1101 datasheet.

Because the INTB signal is being used to directly measure the sensor frequency, the schematic and layout of this trace should be designed to maintain its signal integrity. The trace should 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.
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