Setting LDC1312/4, LDC1612/4, and LDC1101 Sensor Drive Configuration

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ABSTRACT

TI's multichannel inductance-to-digital converters (LDCs) LDC1612, LDC1614, LDC1312 and LDC1314 feature an adjustable sensor current-drive to set the sensor amplitude. The LDC1101, a high-speed device, also has an equivalent set of controls. The optimal current-drive of these devices is sensor-dependent and is based on the sensor parallel resistance at the sensor resonant frequency, R_P. A sensor with a lower R_P needs a higher current-drive than one with a higher R_P. This application note explains how an appropriate IDRIVE setting can be selected by analyzing the sensor signal with an oscilloscope, which is usually the most straight-forward method.

Contents

1 Why Do Different Sensors Need Different IDRIVE Settings?

The sensor can be modeled by a series electrical model, or as its equivalent parallel model, as shown in Figure 1.
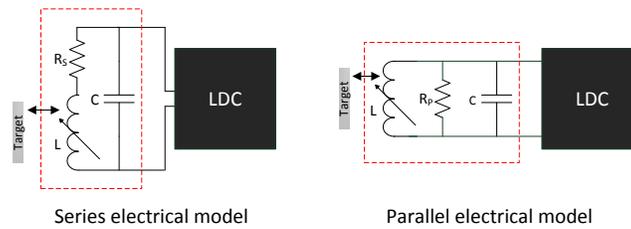
Figure 1. Electrical Models of the LC Sensor

R_P can be calculated by Equation 1.

$$R_P = \frac{L}{C \times R_S}$$

where

- R_P is the equivalent parallel resistance at the sensor resonant frequency
- L is the sensor coil inductance
- C is the sensor capacitor (including parasitic capacitance)
- R_S is the series resistance of the inductor at the sensor resonant frequency   (1)

Small coils and coils with wide traces tend to have a lower R_S than larger coils and coils with narrow trace width. Equation 1 shows that a low R_S results in a high R_P, and vice versa.

To maintain a given sensor oscillation amplitude, a sensor with a lower R_P needs a higher current-drive than one with a higher R_P. The peak sensor oscillation voltage is approximated by Equation 2.

$$V_{OSC} = \frac{4R_P \times I_{DRIVE}}{\pi}$$

(2)

The multi-channel LDCs have a dedicated current-drive control called the IDRIVE. This value is fixed, so Equation 2 says that as R_P varies, V_{SENSOR} will also vary. Each channel has an independent current drive setting which can range from 16 µA (IDRIVE = 0) to 1.56 mA (IDRIVE = 31), as shown in Table 1. A higher current increases a sensor's oscillation amplitude.

Table 1. CHx_IDRIVE Values for Maximum Measured R_P

Sensor R_P (kΩ)	CHx_IDRIVE Register Field Value (bits [15:11])	Nominal Current (µA)
90.0	0 (b00000)	16
77.6	1 (b00001)	18
66.9	2 (b00010)	20
57.6	3 (b00011)	23
49.7	4 (b00100)	28
42.8	5 (b00101)	32
36.9	6 (b00110)	40
31.8	7 (b00111)	46
27.4	8 (b01000)	52
23.6	9 (b01001)	59
20.4	10 (b01010)	72
17.6	11 (b01011)	82
15.1	12 (b01100)	95
13.0	13 (b01101)	110
11.2	14 (b01110))	127
9.69	15 (b01111)	146

Table 1. CHx_IDRIVE Values for Maximum Measured R$_P$ (continued)

Sensor R$_P$ (kΩ)	CHx_IDRIVE Register Field Value (bits [15:11])	Nominal Current (µA)
8.36	16 (b10000)	169
7.20	17 (b10001)	195
6.21	18 (b10010)	212
5.35	19 (b10011)	244
4.61	20 (b10100)	297
3.98	21 (b10101)	342
3.43	22 (b10110)	424
2.95	23 (b10111)	489
2.55	24 (b11000)	551
2.20	25 (b11001)	635
1.89	26 (b11010)	763
1.63	27 (b11011)	880
1.40	28 (b11100)	1017
1.21	29 (b11101)	1173
1.05	30 (b11110)	1355
0.90	31 (b11111)	1563

NOTE: For LDC1312, LDC1314, LDC1612, and LDC1614, the preferred IDRIVE setting is the highest value for which $V_{OSC} < 1.8$ V$_P$.

2 Why is the Correct Sensor Amplitude Important?

A sensor oscillation amplitude (V_{OSC}) between 1.2 V$_P$ to 1.8 V$_P$ results in the best measurement accuracy for the multichannel LDC devices. If the amplitude is not within that range:

- If $V_{OSC} > 1.8$ V$_P$, due to the internal architecture of the LDC, the measurement accuracy is reduced over temperature.
- If $V_{OSC} < 1.2$ V$_P$, then the Signal-to-noise ratio (SNR) degrades.
- If $V_{OSC} <$ about 0.5 V$_P$, then the sensor may not have a stable oscillation and the LDC cannot measure the inductance.

It is more important that the sensor amplitude is below 1.8 V$_P$ than it is to stay above 1.2 V$_P$. In general, the sensor amplitude decreases as the target moves close to the sensor because R$_P$ decreases. To avoid exceeding the upper limit, the measurement should be taken at the maximum target distance of the system. This can be free air if a target is not necessarily present in the system.

3 Which Methods Are There for Determining an Appropriate IDRIVE Setting?

There are several ways to determine a suitable current drive level:

1. The R$_P$ value of the sensor only can be measured with a network analyzer or impedance analyzer (see SNOA936).
2. IDRIVE can be adjusted until no warning flags are indicated (ERR_AHE and ERR_ALE).
3. The automatic amplitude control feature can be used during system prototyping to let the LDC select CHx_IDRIVE (see SNAA221).
4. Use an oscilloscope to measure oscillation amplitude.

4 Why Not Use the Automatic Amplitude Setting?

Automatic amplitude features are only recommended for one-time system configuration purposes. If Auto amplitude control is enabled for normal operation, the LDC may adjust the current during a measurement and introduce an offset that appears as a step in the target position. For normal operation, enable R_P override (RP_OVERRIDE_EN=1) and disable auto amplitude correction (AUTO_AMP_DIS=1), which forces the LDC uses the current-drive setting in the IDRIVE register. Manual control ensures that the same IDRIVE setting is used on each channel every time the system powers up, and that the same current-drive is used regardless of target distance.

5 How to Set IDRIVE

The IDRIVE setting can either be directly written to the DRIVE_CURRENT_CHx registers, or programmed using the GUI if using the LDC EVM, as shown in Figure 2.

Figure 2. Programming Sensor IDRIVE in the Sensing Solution's Evaluation Module GUI

6 Procedure for Determining an Appropriate Current-Drive

The following steps can be taken to determine an appropriate IDRIVE setting with an oscilloscope:

1. Move the target to the expected maximum distance from the sensor as it will be during normal system operation.
2. Configure IDRIVE to 31 (maximum). If the sensor R_P is known, the closest R_P value in the table can be used to estimate the starting value for IDRIVE.
3. Measure the oscillation amplitude with respect to ground at the INAx pin
4. Reduce IDRIVE until $V_{OSC} < 1.8$ V_P.

Figure 3 shows an example oscilloscope plot in which the peak amplitude is 3.3 V_P at an IDRIVE setting of 25. The peak amplitude is higher than the 1.8 V_P recommended limit.
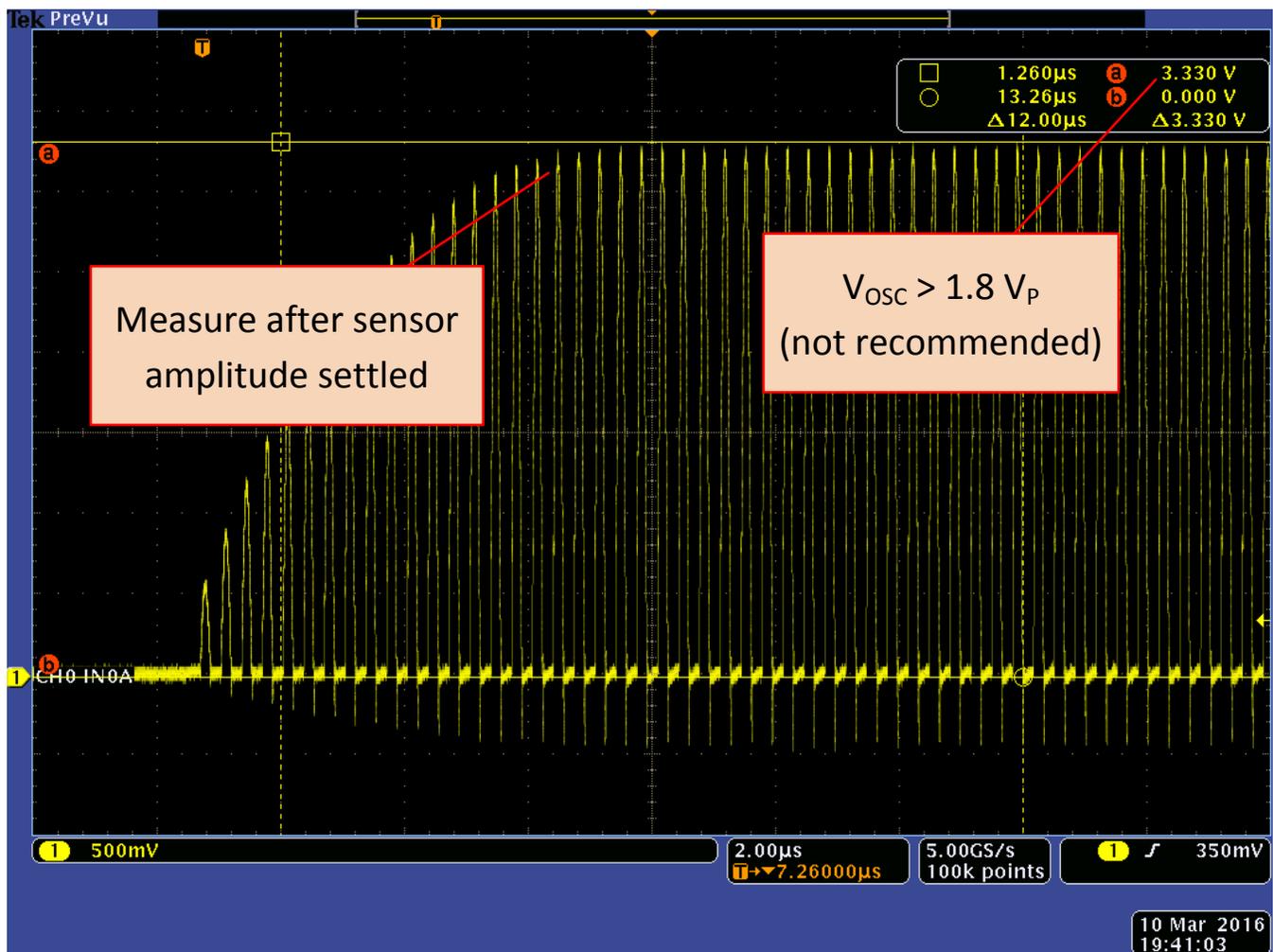

Figure 3. IDRIVE = 25 Causes $V_{OSC} > 1.8$ V (Not Recommended)

IDRIVE is then decreased until $V_{OSC} < 1.8$ V. With the chosen sensor and target distance, this happens at an IDRIVE setting = 19 (see Figure 4). Note that reducing the target distance caused the amplitude to decrease, but that is not a concern as long as system-accuracy specifications are still met.
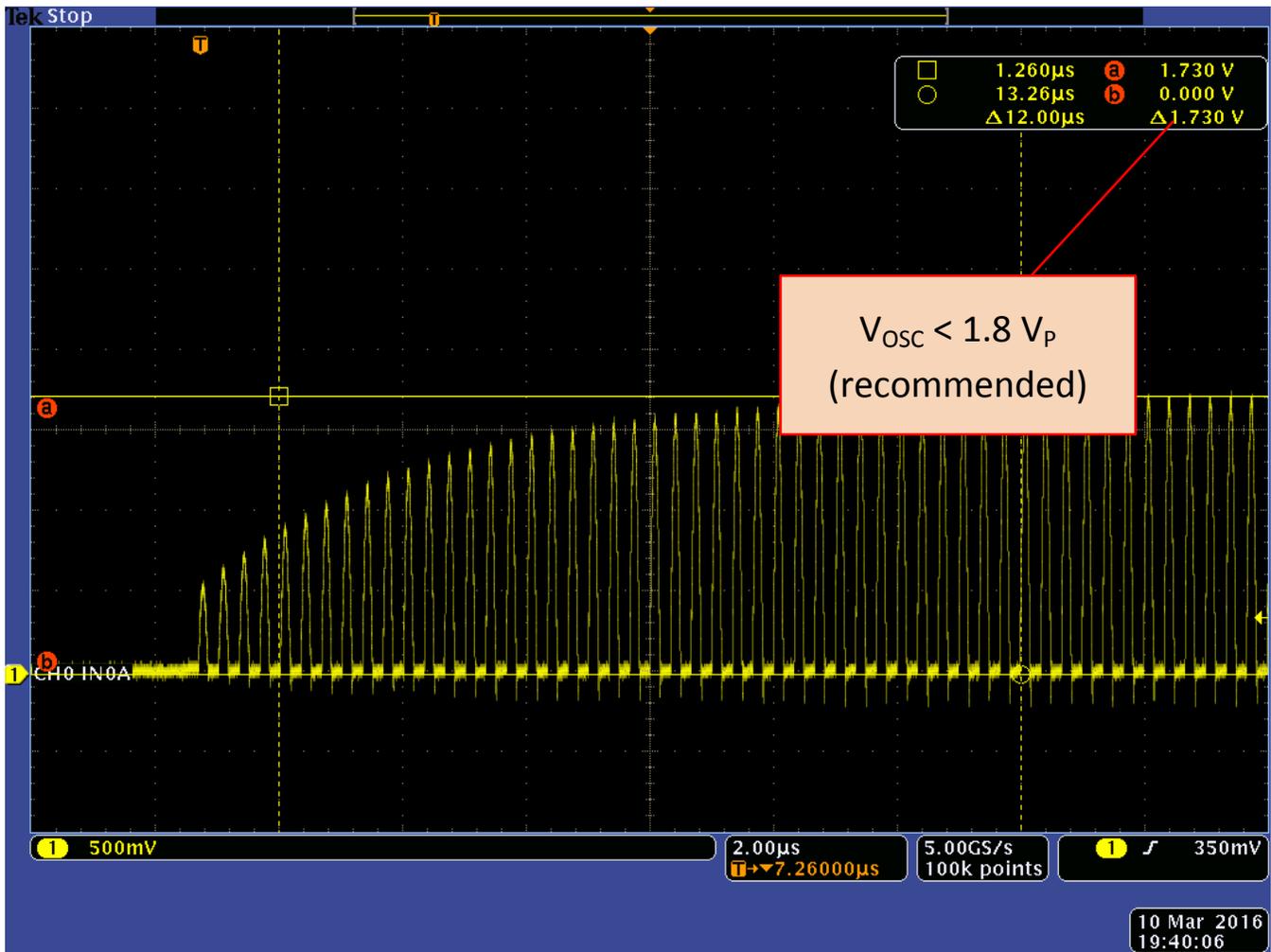
Figure 4. IDRIVE = 19, Which Is The Highest Setting That Meets the V$_{osc}$

7   High Current Sensor Drive Mode

The LDC has a high current sensor drive mode (HIGH_CURRENT_DRV) for channel 0 only, which ignores the IDRIVE setting. If R$_P$ is so low that an IDRIVE setting of 31 shows an amplitude of less than 1.2 V$_P$, then the current can be boosted by setting HIGH_CURRENT_DRV=1. In this mode, the current drive increases to twice its normal maximum of 1.5 mA in normal mode to 3 mA.

This mode is useful for applications in which very small sensors with a low R$_P$ is connected. Note that AUTOSCAN_EN must be set to 0 (single channel mode).

8   How to Use Multiple Sensors

It is not necessary to use the same IDRIVE setting across all channels. If different channels use different sensor components, then each channel must be evaluated individually.

However, many systems use multiple sensors with the same sensor characteristics in order to perform measurements of multiple targets, to perform differential measurements, or to use one sensor as a reference sensor. In this case, it is recommended to use the same IDRIVE setting for all channels to ensure consistent measurement results.

In case the procedure above results in different IDRIVE settings for different sensors, then the lower IDRIVE setting should be used. For example, if the procedure above shows that the optimal IDRIVE settings for the four LDC1614 channels are 14 (channel 0), 13 (channel 1), 13 (channel 2), and 14 (channel 3) and the same sensor components are used, then all four IDRIVE settings should be set to the lowest setting of 13.

9   LDC1101 Sensor Amplitude Control

The LDC1101 includes a LHR function (L Measurement, High-Resolution) that can be considered a single-channel, 24 bit equivalent of the LDC1612. The default configuration of the LDC1101 automatically controls the sensor amplitude; however, this automatic amplitude control increases the noise of the inductance measurement. To disable the automatic amplitude control, set the LOPTIMAL and DOK_REPORT device fields to 1. More information on this setting is available in section 9.1.10 of the LDC1101 device data sheet (SNOSD01).

The multichannel LDC devices use the IDRIVE setting; the equivalent control on the LDC1101 is RPMIN.

Table 2. LDC1101 RPMIN Sensor Drive Settings

RPMIN Field Value	Sensor Drive (µA)	Minimum Sensor R_P (kΩ)	Maximum Sensor R_P (kΩ)
b111	600	0.53	1.65
b110	300	1.1	3.3
b101	150	2.1	6.5
b100	75	4.2	13.1
b011	37.5	8.4	26.2
b010	18.7	16.9	52.4
b001	9.4	33.9	105
b000	4.7	67.9	209

While the LDC1101 has a different field name and different available settings for the IDRIVE control, the appropriate value can be determined using the Oscilloscope technique described in this application note.

NOTE: For the LDC1101, the preferred RPMIN setting is the highest value for which $V_{OSC} < 1.25\ V_P$.

10   Summary

Knowing the R_P value is not necessary for determining the preferred drive current. The optimal setting can also be determined by measuring the sensor amplitude with an oscilloscope with the target at the maximum operating distance from the sensor.

To achieve the highest performance, set the current drive setting as follows:
* For LDC1312, LDC1314, LDC1612, and LDC1614, set the IDRIVE current to the highest setting that gives $V_{OSC} \leq 1.8\ V_P$.
* For LDC1101 in LHR mode, set the RPMIN setting to the highest setting that gives $V_{OSC} \leq 1.25\ V_P$.

11   Additional Resources

* Download the data sheet for LDC1612 and LDC1614 (SNOSCY9).
* Download the data sheet for LDC1312 and LDC1314 (SNOSCZ0).
* Download the data sheet for LDC1101 (SNOSD01).
* Learn more about TI's inductive-sensing portfolio.
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