Application Report
SNOA958 – Ocotober 2016

How to Calibrate FDC1004 for Liquid Level Sensing Applications

Nate Enos

ABSTRACT

Calibration is required to maximize accuracy for liquid level sensing applications. This is a step by step guide to performing this calibration with the FDC1004 for two sensor systems (see Figure 1). Refer to *Capacitive Sensing: Out-of-Phase Liquid Level Technique* (SNOA925) for an introduction to liquid level sensing with the FDC1004.

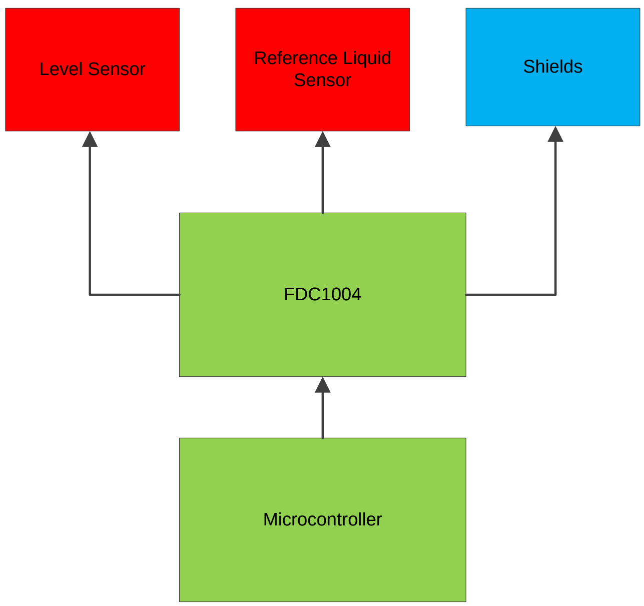

Figure 1. Block Diagram

There are two main phases of calibration with the FDC1004:

1. Baseline measurement: $C_{level}(0)$ and $C_{RL}(0)$
2. Absolute error correction

Contents

1 Performing the baseline measurement 2
2 Performing the Absolute error correction 2
3 Appendix 4

List of Figures

1 Block Diagram 1
2 Calculated and Actual Liquid Level Height 2
3 Corrected and Actual Liquid Level Height 3

1 Performing the baseline measurement

1. Empty the reservoir completely
2. Measure the C_{level} (capacitance of the LEVEL sensor) and C_{RL} (capacitance of the REFERENCE sensor) while empty. These will correspond to $C_{level}(0)$ and $C_{RL}(0)$
3. Equation 1 can be used to calculate the liquid level.

$$\text{Level} = h_{RL} \frac{C_{level} - C_{level}(0)}{C_{RL} - C_{RL}(0)} \tag{1}$$

Where:

h_{RL} = the unit height of the reference liquid sensor (often 1). Note: the unit here will determine the unit of Equation 1

C_{level} = capacitance of the LEVEL sensor

$C_{level}(0)$ = capacitance of the LEVEL sensor when reservoir is empty

C_{RL} = capacitance of the REFERENCE sensor

$C_{RL}(0)$ = capacitance of the REFERENCE sensor when reservoir is empty

2 Performing the Absolute error correction

The absolute error correction accounts for gain and offset errors in the sensor and device. To perform the absolute error correction, a "wet calibration" must be done, where liquid is added to the reservoir and capacitance levels are measured. The steps are as follows:

1. Add liquid to a known level height
2. Read the capacitance levels from the FDC device (C_{level}, C_{RL})
3. Use equation 1 to determine calculated liquid level height (remember the units for equation 1 will be the same as the units used to measure the reference liquid sensor, h_{RL})
4. Repeat steps 1-3 at least once with different known level height(s) to gain enough sample points
5. Compare the calculated liquid level heights to the actual level height. Example:

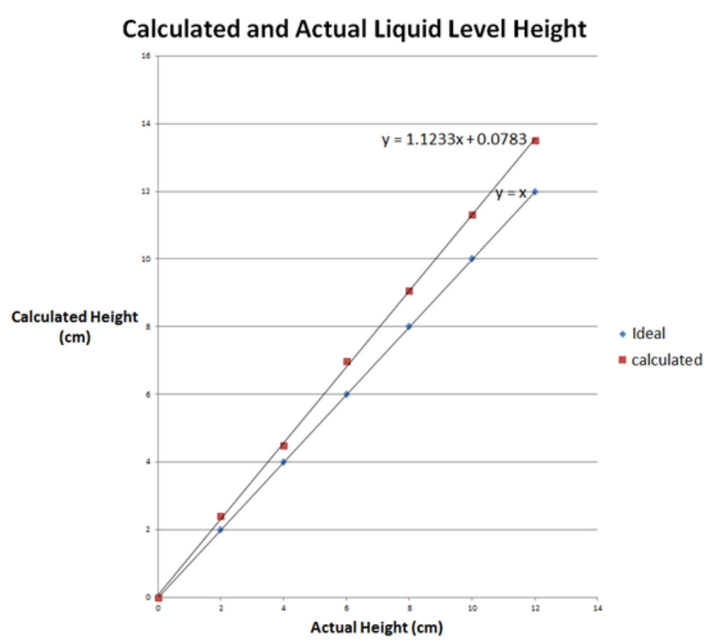

Figure 2. Calculated and Actual Liquid Level Height

6. Draw a best fit line through the calculated data.

7. To determine the gain and offset registers values (registers 0x0D-0x14, see datasheet for more details) use Equation 2 and Equation 3.

Best fit line: y = m × x + b, where m is the slope and b is the y-intercept

$$\text{Gain} = 1 / m \tag{2}$$

$$\text{Offset} = -b / m \tag{3}$$

For more details on these equations, see Section 3.

Once the gain and offset registers are updated in the FDC1004 equation 1 will yield the corrected level.

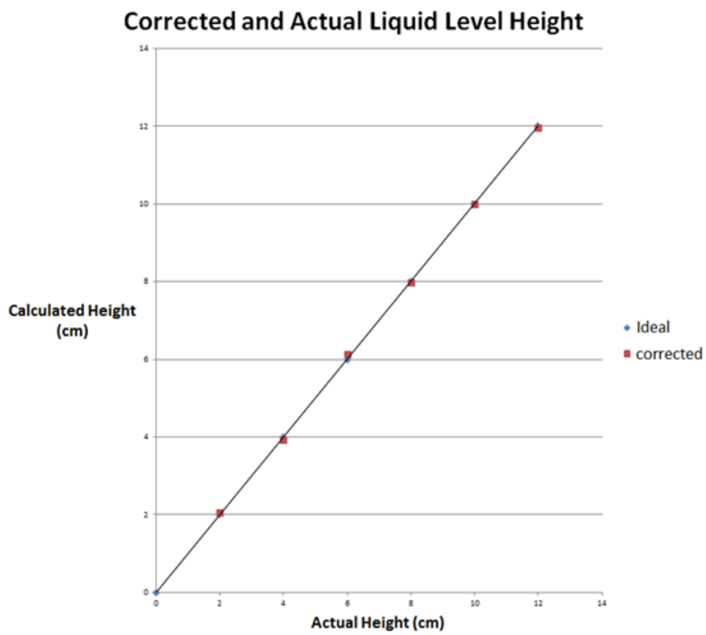

Figure 3. Corrected and Actual Liquid Level Height

Now the corrected data overlaps the ideal response and your system is calibrated.

3 Appendix

Proof of Equation 2 and Equation 3:

- Height measured: $y1 = x1 \times m + b$
- Ideal result: $y' = x1$ (where y' is corrected y)
- $y' = (y1) \times gain + offset$
- Let $gain = 1 / m$, and $offset = –b / m$
- $y' = (x1 \times m + b)m – b / m$
- $y' = x1 \times m/m + b/m – b / m$
- $y'= x1$

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		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265