TI Designs
Mechanical-to-Electronic Converter with Three LC Sensors for Gas or Water Meter

TI Designs

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Design Resources

TIDM-3LC-METER-CONV	Design Page
MSP430FR6989	Product Folder
CC1120	Product Folder
TPS62237	Product Folder

TI E2E™ Community

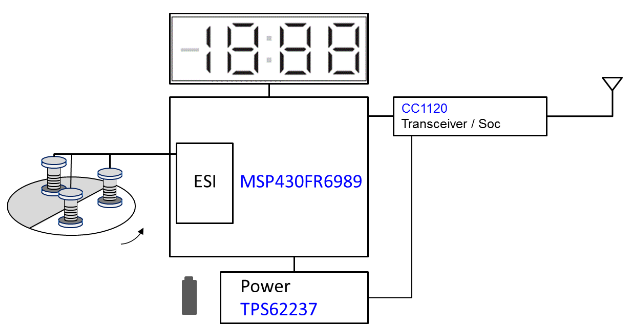
ASK Our E2E Experts
WEBENCH® Calculator Tools

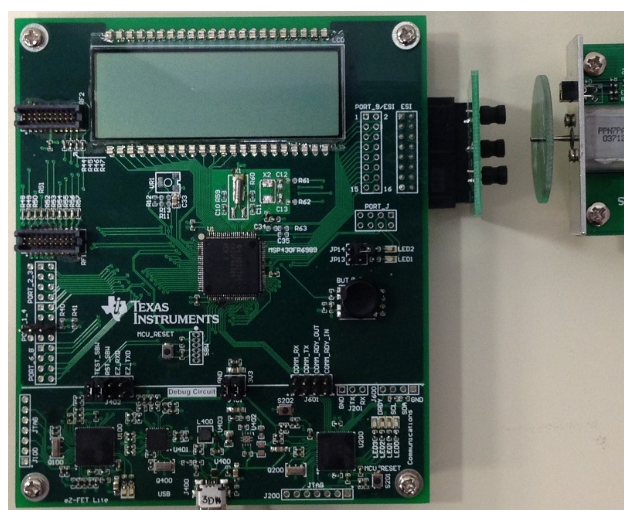
Design Features

- Ultra-Low Power Design
- Contactless Rotation Detection
- Enable Runtime Calibration with Very Slow Rotation
- Self-Calibration for Long-Term Operation
- Full Platform Design with Socket for Add-On Module and Flow Emulation by a Motor Board
- Onboard Debugging Circuit

Featured Applications

- Mechanical-to-Electronic Converter for Flow Meter
- Gas Meter
- Water Meter
- Heat Meter
- Rotation Detection
- Motor Position Detection





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1 System Description

A mechanic-to-electronic convert is designed for rotational flow meters. This reference design is built using the Extended Scan IF (ESI) of the MSP430FR6989 and three LC sensors. The reading of the meter is displayed on LCD. If an RF module, like CC1120, is added in, an AMR function is then enabled.

The system is built on the EVM430-FR6989. This board can be divided into three boards: the main board, the sensor board, and the motor board. The main board of EVM consists of an MSP430FR6989, a sensor board connector, an RF module socket, and a debugger circuit. The sensor board is constructed with three LC sensors. The motor board is also provided to drive a rotor disc to emulate water or gas flow, which moves the rotating disc in a flow meter.

This system is an ultra-low power design using the latest TI MCU MSP430FR6989 with FRAM to store the programming code. The MSP430FR6989 has a built-in module of ESI. The system block diagram shows all the elements to implement a converter (Figure 1).

The main board of EVM consists of an MSP430FR6989, a socket for add-on modules, a USB connection, and a sensor board connector. The bottom side of the main board has an onboard eZ-FET lite connected to the MCU. Program and debug the MCU firmware by directly connecting the board with a USB cable to PC. The IDE is TI's Code Composer Studio™. The debugging circuit also has an HID connection, which can receive the command of a dedicated PC GUI for this EVM.

2 Design Features

2.1 Ultra-Low Power Design

The MSP430FR6989 is an ultra-low power MCU that has a FRAM of up to 128 KB for code and data. Peripherals include ESI, RTC, ADC12, CRC, AES256, MPY32, eUSCI for communication, Comp_E for touch key module, an LCD, and six timers.

During the operation of the reference design, only the ESI, a timer, and the LCD continuously work with an oscillation crystal of 32,768 Hz. The CPU and other peripherals are off, in low power mode 3 (LPM3). The whole system takes around 11 µA for a sample rate of 500 Hz with three LC sensors without an LCD.

2.2 Contactless Rotation Detection

A mechanical flow meter needs to have a small rotating disc driven by the gears of the meter. The converter detects the number of times the disc rotates without contact. One half of the disc is covered with metal in a semi-circle and the other half with non-metal in another semi-circle.

2.3 Sensor Board with Three LC Sensors

An LC sensor consists of an inductor and a capacitor to form a tank oscillator. This sensor is the proven solution of low power consumption and reliable for long-term continuous operation of flow meters. When the sensor is excited by a very short pulse within 1 µs, it starts oscillating in its resonant frequency. The inductor then generates a magnetic field. Once the metal part of the rotating disc is cutting the magnetic field, an eddy current is formed in the metal, which absorbs the magnetic energy from the inductor and reduces the amplitude of the oscillating signal. The comparator and the DAC of the ESI can detect this signal change to detect the position of the rotating disc and count the number of rotations.

A long-term operation needs a system to adjust the signal due to environmental change or components aging issues (see Section 2.4).

When the rotating disc is moving quickly, a complete rotation can be detected by each LC sensor. During the self-calibrating process, each sensor can find the signal level of metal and non-metal; one is high, another is low. Using this information, the calibration process can find out the mid-level voltage as a reference to determine the position of the disc.

However, in a mechanical-to-electronic converter, the rotating disc usually moves slowly, which does not allow the mentioned calibration algorithm to work. To cope with this issue, three sensors are used and placed 120 degrees apart to each other (see Figure 1). This way, the converter will always know the location of a sensor over the plate. An algorithm to calibrate the sensor of a known position can be formed and activated at any time, a core advantage of using three sensors.

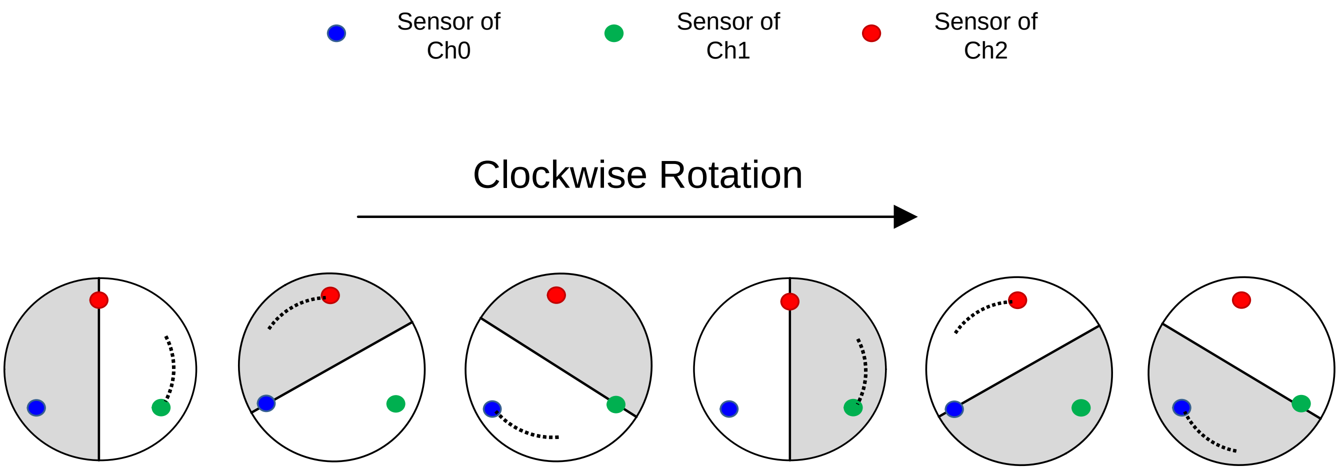

Figure 1. Detection Sequence with Three LC Sensors

2.4 Self-Calibration for Long-Term Operation

Due to the temperature, humidity, aging components, and signal drifts, a continuous adjustment circuit is necessary to ensure the system is within the range of reliable operation. The ESI has a duplicated circuit inside that can be used to detect the overall drift of the system. This circuit will only be activated periodically to save power consumption. Once the drift is found, the design adjusts the DAC values of the continuous operating part of the ESI to align it to the signal position of maximum reliability.

2.5 Full Platform Design with Add-On Module Socket and Flow Emulation by a Motor Board

The motor board provides a tool to emulate the rotating plate driven by the flow of water or gas. The rotating speed can be adjusted either manually or by the main board through the I2C link. The socket is connecting with various communication ports, SPI, UART, and I/O of the MCU. Some existing TI RF modules can directly plug into this socket to add on more features into the EVM. Engineers can also design their own modules, like NFC/RFID, valve control, and so on, and test it with the system without reconfiguring the whole board.

The sensor board is standalone. Engineers can design their own customized sensor board and plug into the main board for testing.

2.6 Built-In Debugging Circuit

The built-in debugging circuit facilitates the system setup without too many external connections of debugging tools. The bottom side of the main board has an onboard eZ-FET lite connected to the MCU. Engineers can program and debug the MCU firmware by directly connecting the board with a USB cable to the PC. The IDE is TI's Code Composer Studio™. The debugging circuit also has an HID connection, which can receive the command of a dedicated PC GUI for this EVM.

3 Block Diagram

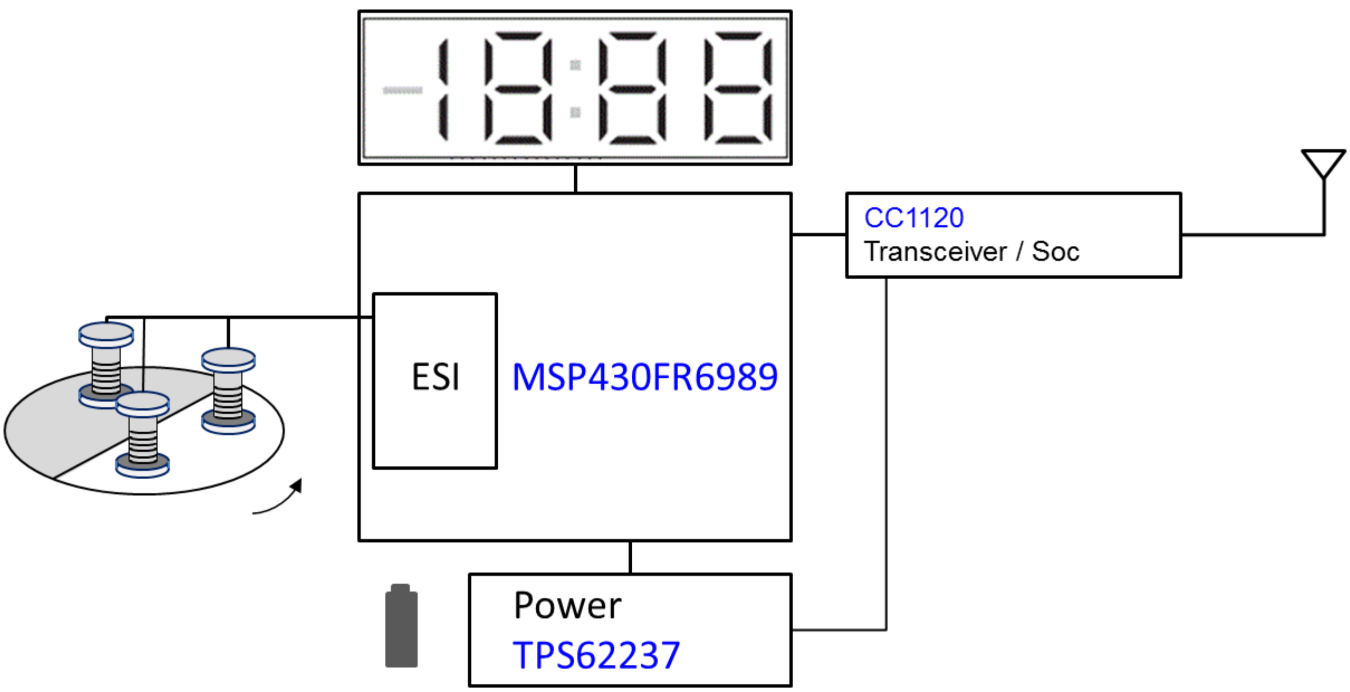

Figure 2. System Block Diagram

4 Circuit Design

4.1 Main Board

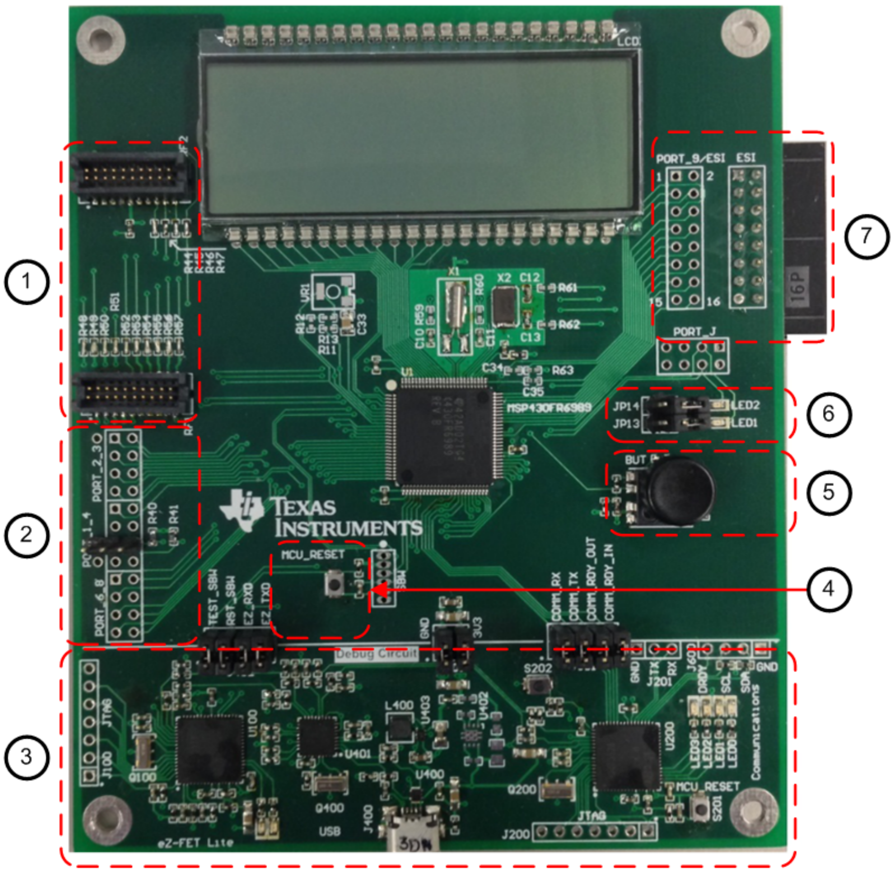

Figure 3. Main Board

This main board is built on MCU MSP430FR6989 with an LCD display. This board is powered by USB to provide 3.3 V through a buck converter. This board can be divided into seven parts and is a platform for developing flow meters with RF and USB connections. The application software has code for the ESI module for flow measurement, but the software does not connect to Part 1 and Part 6 in Table 1.

Table 1. Description of Main Board Layout

PART NUMBER	DESCRIPTION
Part 1	A socket for RF modules of sub-1 GHz or 2.4 GHz, connecting to the MCU with SPI and I/O. For details of RF modules, read the CC1120 development kit.
Part 2	Through holes connecting to I/O of no connection. The headers are the I2C connection.
Part 3	The JTAG debugger and a USB HID interface. The HID interface can connect the board to PC with a dedicated GUI.
Part 4	A reset button. This board does not have an on/off switch. To restart the firmware, push the reset button.
Part 5	This device has five push-button switches. The firmware does not have code for this part. Designers can use it to implement a key control.
Part 6	LED indicator, connecting to PJ.2 and PJ.3. For saving current consumption, remove the jumpers.
Part 7	The socket for the sensor board and connecting to the ESI of MCU.

The core part of the hardware for flow measurement is the connection of the MCU's ESI to the sensor board. A 470-nF capacitor connecting to ESICOM is used to stabilize the voltage of Vcc / 2. The ESI is a self-contained module inside the MCU.

For a low-power design, a 32,768-Hz crystal is used to continuously operate. To lower the power consumption further, turn on the LCD only when taking a reading is necessary. The rest of the MCU peripherals and its CPU are kept idle to save power. The CPU should only be active during a reading update and self-calibrating, which is done in a periodical manner lasting a few seconds to hours depending on the timer setting.

4.2 Sensor Board

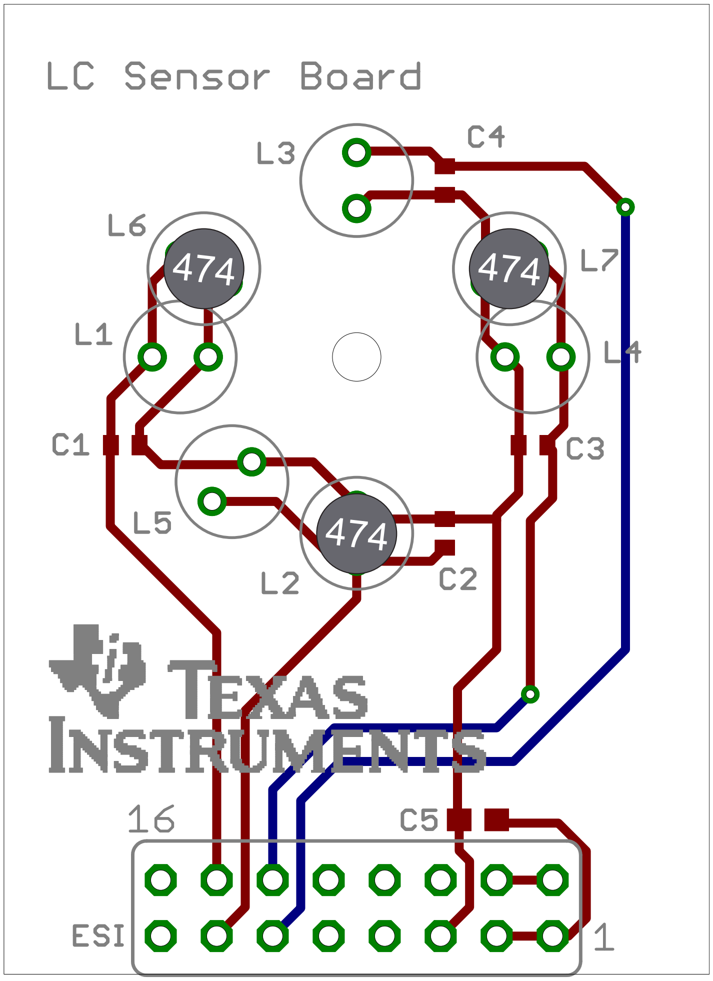

Figure 4. Sensor Board

The sensor board is designed for LC sensors only. The sensors can be placed in different orientations. For the half-covered metal rotor disc, the three sensors are placed 120 degrees apart.

The selection of the inductor (L) and the capacitor (C) is an important factor to affect the power consumption. Find a detailed selection guide as an application note for other types of sensors.

4.3 Motor Board

The motor board is to drive the rotor disc to emulate a gas or water flow. The battery socket is on the back of the board. The board consists of the following parts:

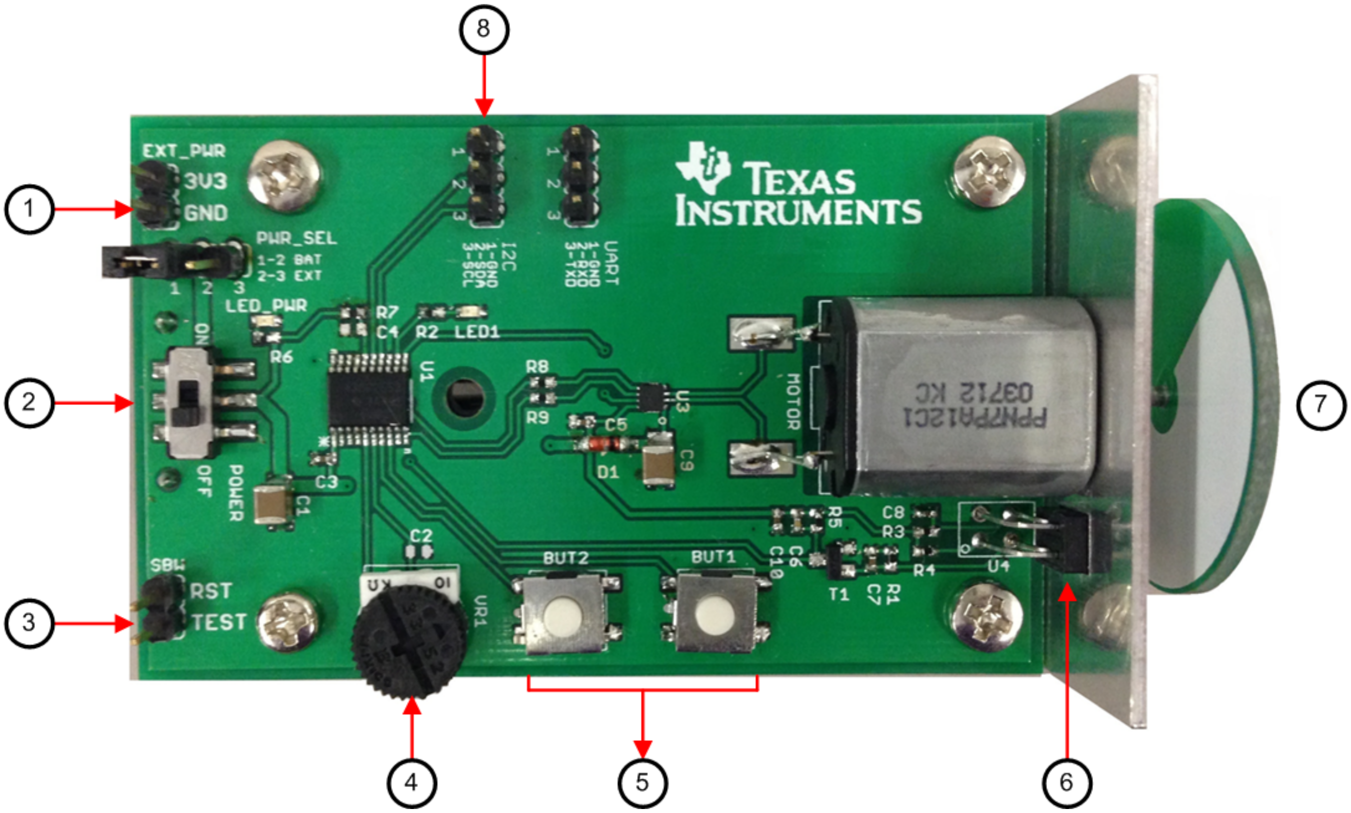

Figure 5. Motor Board

Table 2. Description of Motor Board Layout

PART NUMBER	DESCRIPTION
Part 1	Two pins connecting to external power
Part 2	Switch to power on and off the motor board
Part 3	2-wire Spy-Bi wire mode of JTAG. This mode can be used to program and debug the firmware
Part 4	Variable resistor to vary the rotation speed
Part 5	Buttons to select the rotation's direction. Also acts as a stop button
Part 6	An infrared sensor that provides feedback on the rotation speed of the rotor disc
Part 7	A rotor disc half covered by copper
Part 8	A connection header for I2C and UART

An I2C link can be connect to the main board. The motor board will receive the command from main board to rotate in a proper speed and send back the record of the number of rotations.

5 Software Description

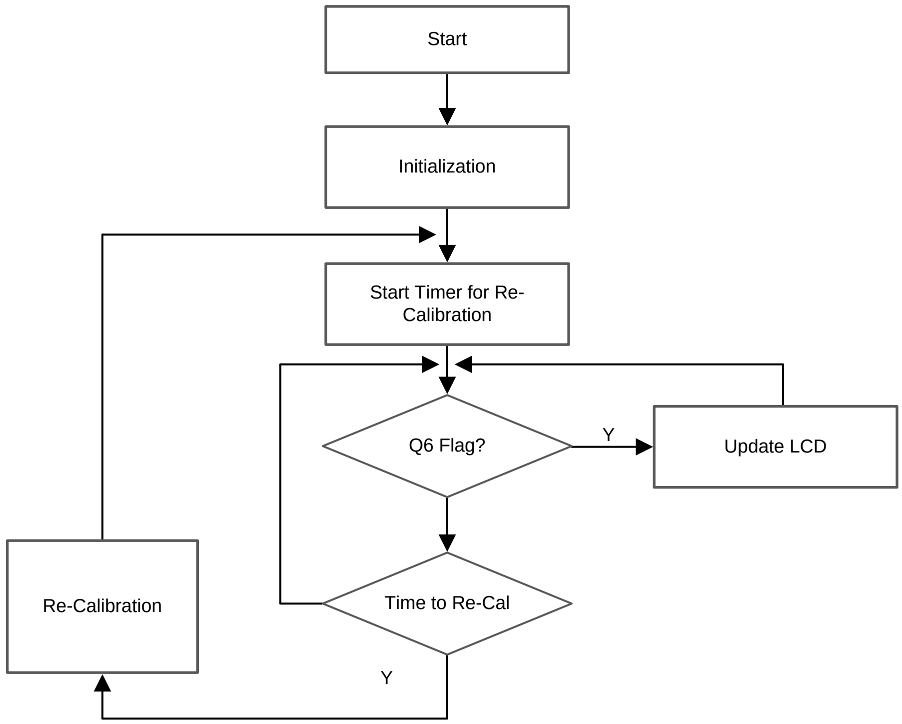

Figure 6. Software Flowchart

The software optimizes the system's power consumption. As shown in Figure 6, the system starts with initialization, which includes ports setting for low current leakage, LCD, ESI internal oscillator calibration, ESI registers, sampling rate, timing state machine (TSM) with auto-TSM calibration, optimal DAC level, and processing state machine (PSM) table setting. After initialization, the EVM can work well in low power mode with ESI and LCD as the only modules actively running. To avoid too many interrupts to wake up the CPU, the system uses the Q6 flag in the PSM table. This flag is set only when the rotor disc is rotating.

The system is in LPM3 mode when the rotor disc does not rotate. To lower the power consumption further, disable the LCD. Construct a key button to wake up the LCD when reading is necessary. For a stable, long-running lifetime for the system, the design includes a runtime re-calibration to track the drift of the sensors and system. A timer with the variable constant *Time_to_Recal* is used to count the period for re-calibration.

Once the timer triggers a re-calibration call, the firmware calibrates without the need of waiting **for** the Q6 flag. The three-LC system does not need the rotor disc to rotate during the re-calibration process.

6 Test Setup

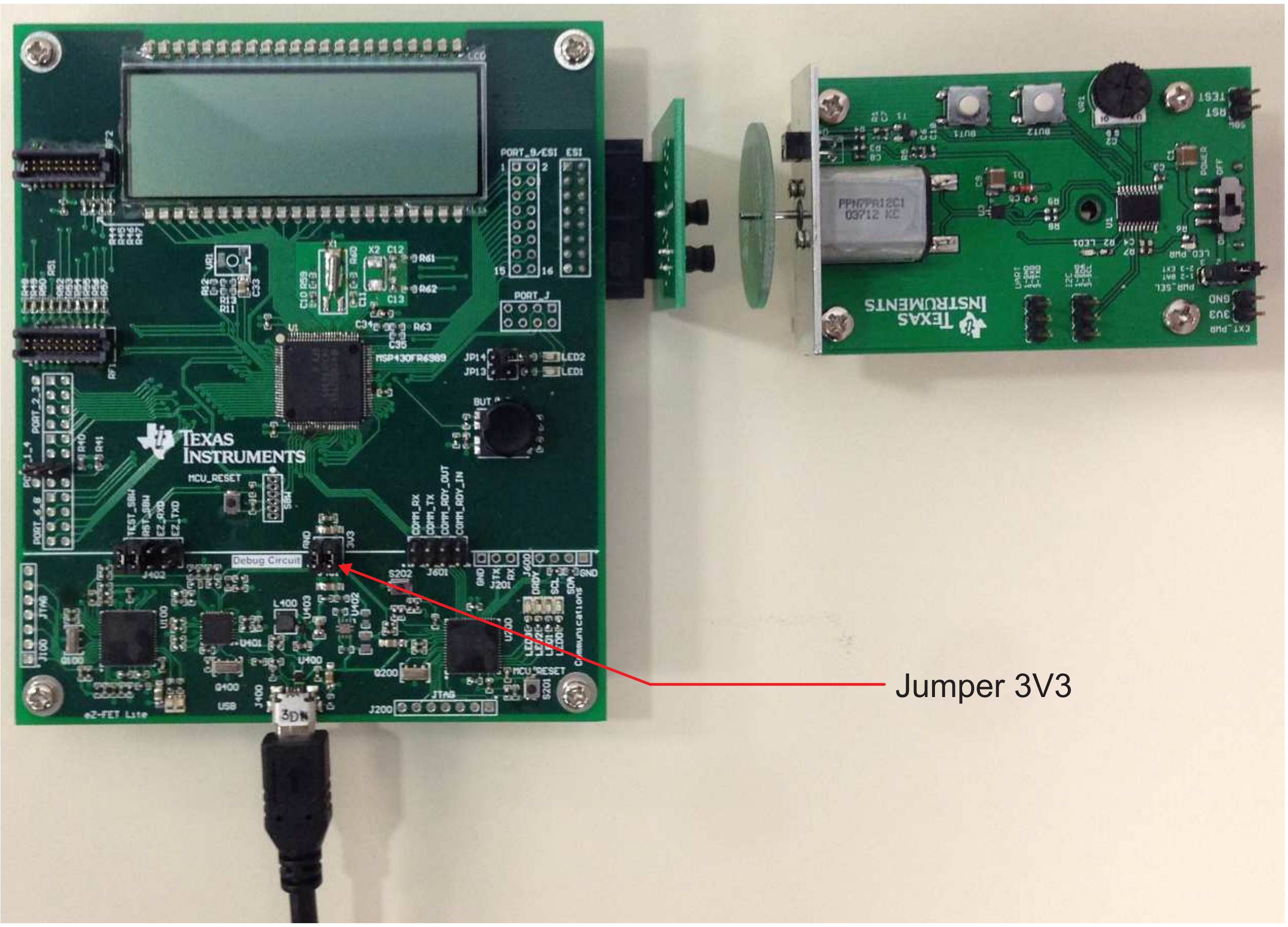

Figure 7. System Setup for Measurement of Current Consumption

Before testing, the main board and motor board have to be programmed with firmware. Follow this procedure to test the current consumption of the reference design:

1. Remove all jumpers of the main board except the jumper 3V3 and the ground jumper next to it.
2. Disconnect the jumper 3V3 and connect it with a current meter.
3. Set the rotor disc at 5 mm from the sensor board and switch off the motor.
4. Power up the main board with a USB cable.
5. Calibrate the TSM after powering up the main board. The LCD will show *0*. wait until it turns to *8888*, then go to the next step.
6. Switch on the motor and do not adjust the distance between the rotor and sensors. At this step, a calibration for searching proper reference voltages of DAC is working. This calibration will last for one second.
7. Finish initial calibration. The LCD will keep counting the number of rotations.
8. Turn off the LCD by pushing the black button.
9. Read the current meter indicating the current consumption of the reference design without the LCD.

7 Test Results

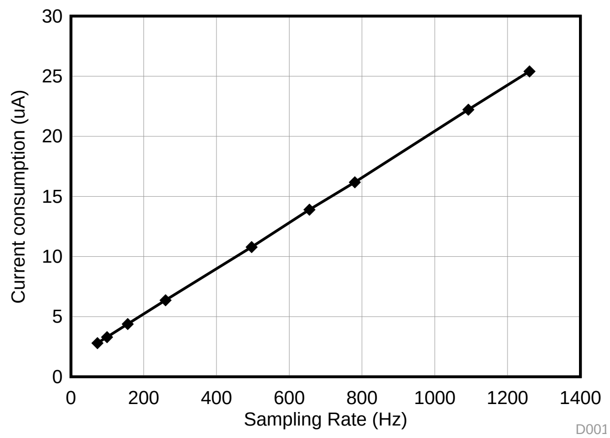

Figure 8. System Current Consumption (µA) for Three LC Sensors

Figure 8 shows the current consumption of the MCU with three LC sensors, not including all current flowing into the LCD, power, and other modules on the board. The data is taken by measuring the current flowing into the MCU connected to three LC sensors with the LCD switched off, varying with different sampling rate of the ESI of MSP430FR6989.

From the experimental data, the current consumption in MSP430FR6989 takes 19 nA per sample with three LC sensors.

In the application of mechanical to electronic converter, the rotation speed of the rotor disc is very slow, less than 10 rotations per second. Using a sample rate of 99 Hz, the total current taken is only 3.3 µA . A small battery can be used.

Using three LC sensors, the runtime self-calibration can be done during a very slow rotation of the rotor disc.

8 Design Files

8.1 Schematics

To download the schematics, see the design files at TIDM-3LC-METER-CONV.

8.1.1 Main Board without the Debugging Circuit

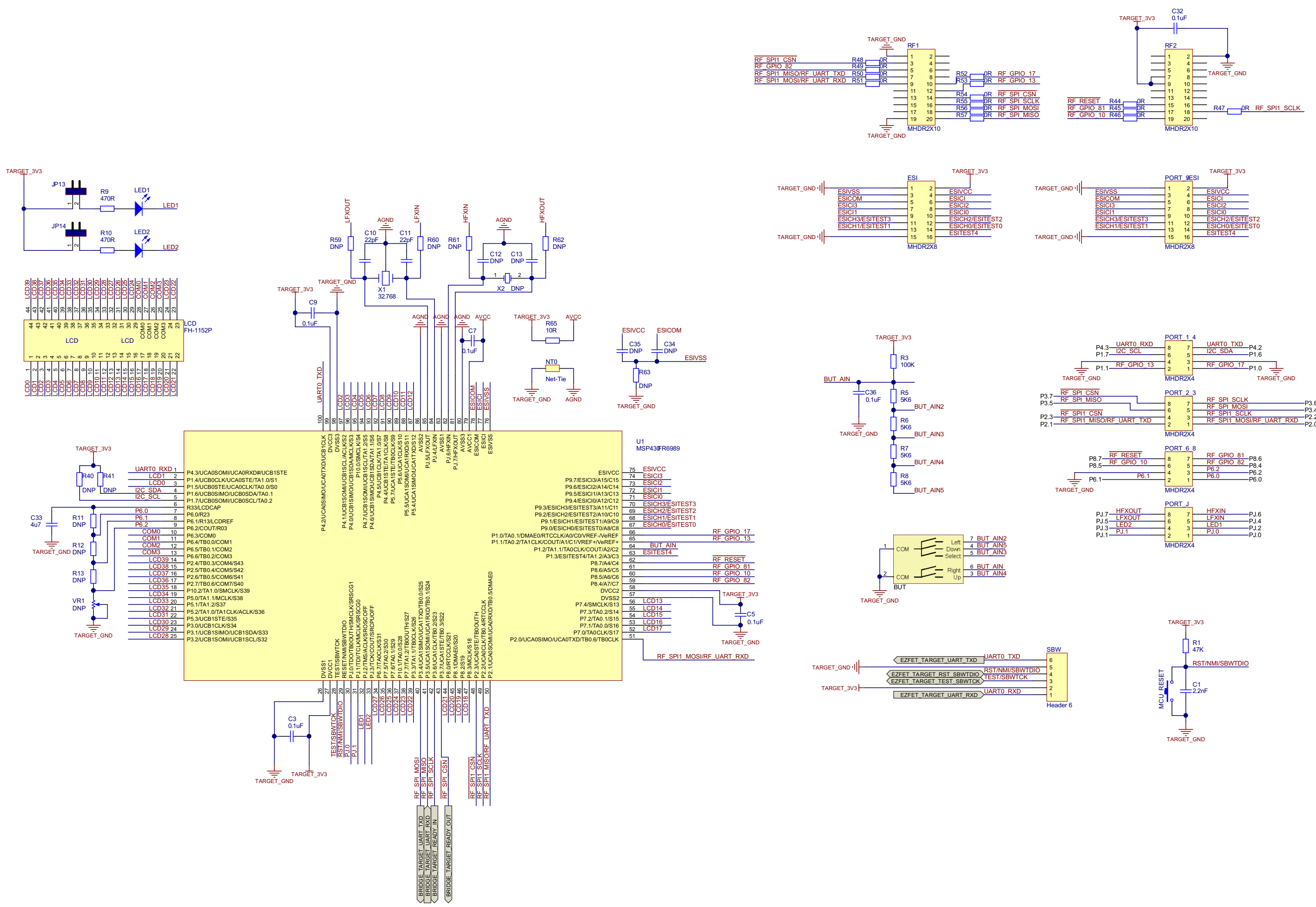

Figure 9. MSP430FR6989 Schematic

8.1.2 Sensor Board

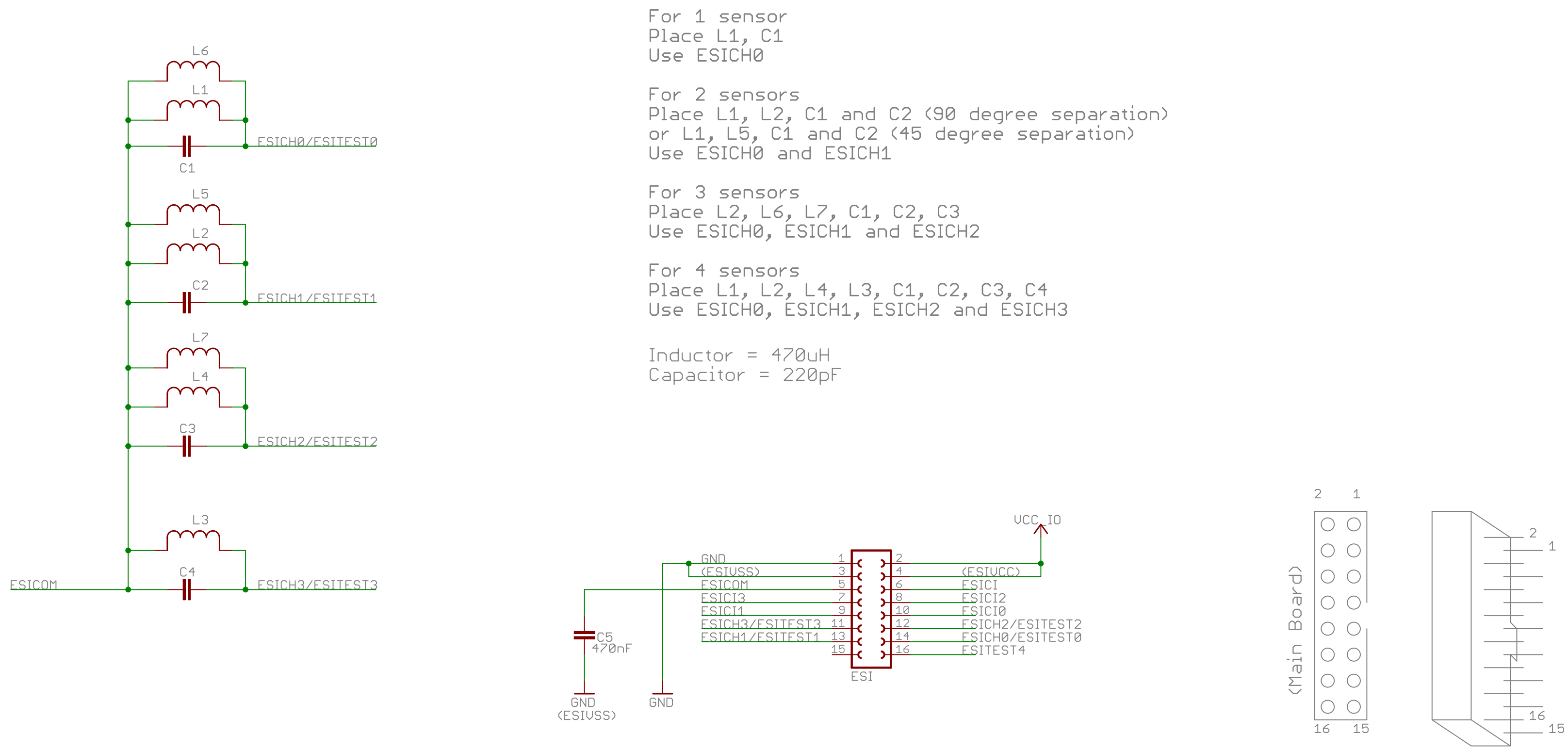

Figure 10. Sensor Board Schematic

8.1.3 Motor Board

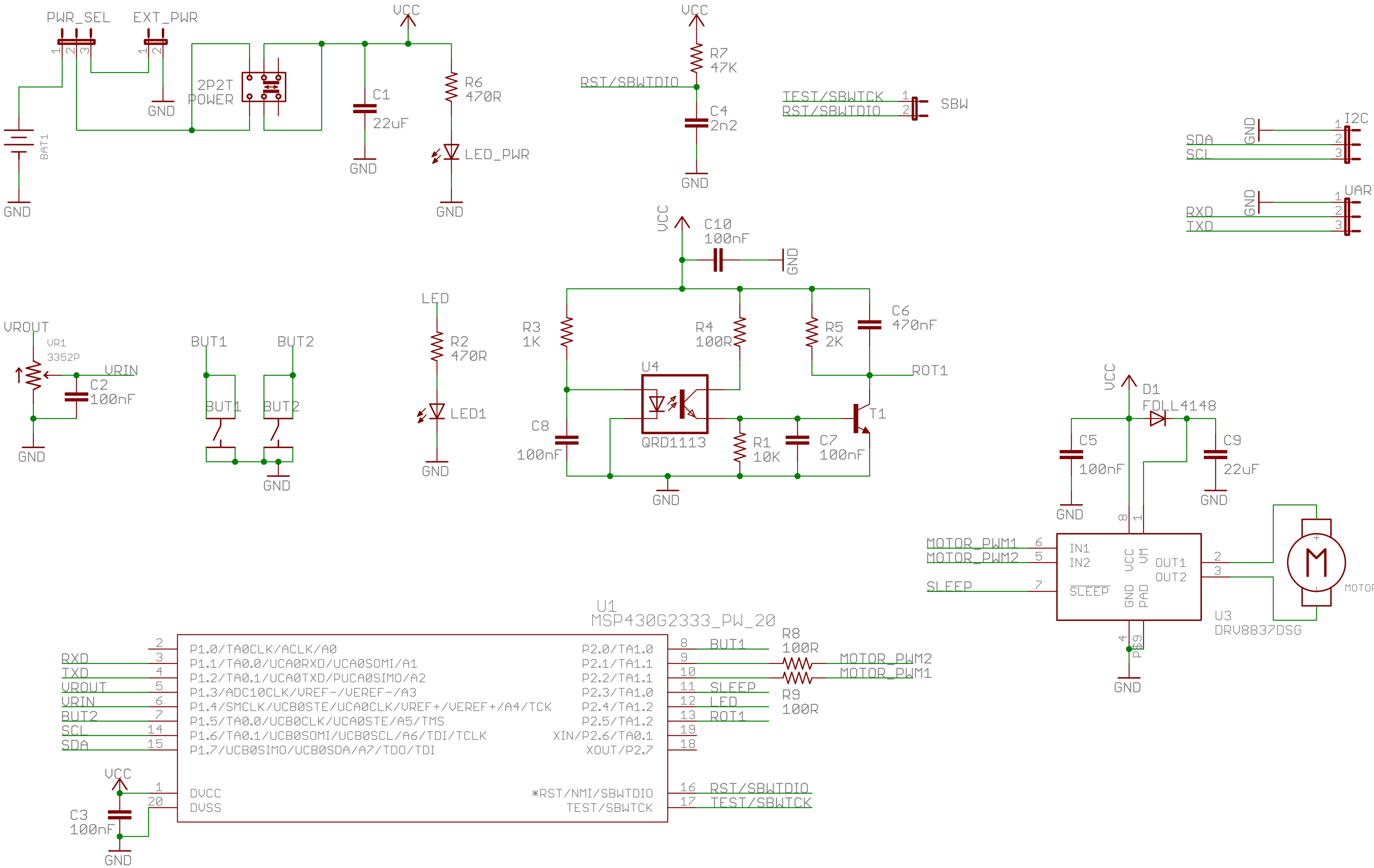

Figure 11. Motor Board Schematic

8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDM-3LC-METER-CONV.

Table 3. BOM: Main Board

DESIGNATOR	VALUE	QTY	DESCRIPTION	PACKAGE	MANUFACTURER PN	DIGIKEY PN	REMARK	MANUFACTURER
CAPACITORS								
C100, C101, C200, C201, C405, C406, C410, C412	10 pF (NP0/C0G)	8	Chip Capacitor, C0G, 50 V, ±5%	C0402	GRM1555C1H100 JA01D	490-5921-1-ND	Alternatives: NP0/C0G, 10 V, ±5% or better	Murata
C10, C11, C403, C404	22 pF (NP0/C0G)	4	Chip Capacitor, C0G, 50 V, ±5%	C0402	GRM1555C1H220 JA01D	490-5868-1-ND	Alternatives: NP0/C0G, 10 V, ±5% or better	Murata
C109, C110	33 pF (NP0/C0G)	2	Chip Capacitor, C0G, 50 V, ±5%	C0402	GRM1555C1H330 JA01D	490-5936-1-ND	Alternatives: NP0/C0G, 10 V, ±5% or better	Murata
C111, C210	1000 pF	2	Chip Capacitor, X7R, 50 V, ±10%	C0402	GRM155R71H102 KA01D	490-1303-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
C1	2200 pF	1	Chip Capacitor, X7R, 100 V, ±10%	C0402	GRM155R72A222 KA01D	490-6367-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
C3, C5, C7, C9, C32, C36, C102, C104, C108, C202, C204, C205, C400, C402, C407, C408	100 nF	16	Chip Capacitor, X7R, 16 V, ±10%	C0402	GRM155R71C104 KA88D	490-3261-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
C105, C106, C206, C207	220 nF	4	Chip Capacitor, X7R, 16 V, ±10%	C0402	GRM155R71C224 KA12D	490-5418-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
C107, C208	470 nF	2	Chip Capacitor, X5R, 10 V, ±10%	C0402	GRM155R61A474 KE15D	490-3264-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
C411, C415, C417	1 µF	2	Chip Capacitor, X7R, 25 V, ±10%	C0603	GRM188R71E105 KA12D	490-5307-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
C33, C401	4.7 µF	1	Chip Capacitor, X7R, 16V, -+10%	C0805	GRM21BR71C475 KA73L	490-4522-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
C103, C203, C209, C409	10 µF	4	Chip Capacitor, X7R, 25 V, ±10%	C1206	GRM31CR71E106 KA12L	490-6518-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
RESISTORS								

Table 3. BOM: Main Board (continued)

DESIGNATOR	VALUE	QTY	DESCRIPTION	PACKAGE	MANUFACTURER PN	DIGIKEY PN	REMARK	MANUFACTURER
R44, R45, R46, R47, R48, R49, R50, R51, R52, R53, R54, R55, R56, R57, R420	0 R	15	Chip Resistor	R0402	RC0402JR-070RL	311-0.0JRCT-ND	Alternatives: ±5% or better	Yageo
R65	10 R	1	Chip Resistor	R0402	RC0402JR-0710RL	311-10JRCT-ND	Alternatives: ±5% or better	Yageo
R407, R409, R412, R413, R416, R417	22 R	6	Chip Resistor	R0402	RC0402JR-0722RL	311-22JRCT-ND	Alternatives: ±5% or better	Yageo
R100, R101, R201, R203, R406	27 R	5	Chip Resistor	R0402	RC0402JR-0727RL	311-27JRCT-ND	Alternatives: ±5% or better	Yageo
R405	33 R	1	Chip Resistor	R0402	RC0402JR-0733RL	311-33JRCT-ND	Alternatives: ±5% or better	Yageo
R211	100 R	1	Chip Resistor	R0402	RC0402JR-07100RL	311-100JRCT-ND	Alternatives: ±5% or better	Yageo
R105, R202, R204, R205	390 R	4	Chip Resistor	R0402	RC0402JR-07390RL	311-390JRCT-ND	Alternatives: ±5% or better	Yageo
R9, R10, R104, R200	470 R	2	Chip Resistor	R0402	RC0402JR-07470RL	311-470JRCT-ND	Alternatives: ±5% or better	Yageo
R103, R206, R408	1.5 k	3	Chip Resistor	R0402	RC0402JR-071K5L	311-1.5KJRCT-ND	Alternatives: ±5% or better	Yageo
R600, R601	2.2 k	2	Chip Resistor	R0402	RC0402JR-072K2L	311-2.2KJRCT-ND	Alternatives: ±5% or better	Yageo
R40, R41	10 k	2	Chip Resistor	R0402	RC0402JR-0710KL	311-10KJRCT-ND	Alternatives: ±5% or better	Yageo
R400, R401, R402, R403, R410, R411, R414, R415	15.0 k	8	Chip Resistor	R0402	RC0402JR-0715KL	311-15KJRCT-ND	Alternatives: ±5% or better	Yageo
							Alternatives: ±5% or better	Yageo
R1, R106, R209, R404	47 k	4	Chip Resistor	R0402	RC0402JR-0747KL	311-47KJRCT-ND	Alternatives: ±5% or better	Yageo
R102, R210	1 M	2	Chip Resistor	R0402	RC0402JR-071ML	311-1.0MJRCT-ND	Alternatives: ±5% or better	Yageo
R5, R6, R7, R8	5.6 k	4	Chip Resistor 1%	R0402	RC0402FR-075K6L	311-5.6KLRCT-ND	Alternatives: ±1% or better	Yageo
R3	100 k	1	Chip Resistor 1%	R0402	RC0402FR-07100KL	311-100KLRCT-ND	Alternatives: ±1% or better	Yageo
R109	150 k	1	Chip Resistor 1%	R0402	RC0402FR-07150KL	311-150KLRCT-ND	Alternatives: ±1% or better	Yageo

Table 3. BOM: Main Board (continued)

DESIGNATOR	VALUE	QTY	DESCRIPTION	PACKAGE	MANUFACTURER PN	DIGIKEY PN	REMARK	MANUFACTURER
R107, R108	220 k	2	Chip Resistor 1%	R0402	RC0402FR-07220KL	311-220KLRCT-ND	Alternatives: ±1% or better	Yageo
R110	240 k	1	Chip Resistor 1%	R0402	RC0402FR-07240KL	311-240KLRCT-ND	Alternatives: ±1% or better	Yageo
INDUCTORS, DIODES, CRYSTALS								
L400	2.2 µH	1	SMD Inductor	3×3 mm	NR3010T2R2M	587-1638-1-ND		Taiyo Yuden
D100, D200	Red	2	LED, Red, SMD	603	LTST-C190CKT	160-1181-1-ND		Lite-On Inc
D101, D201, D202, D203	Green	4	LED, Green, SMD	603	LTST-C190GKT	160-1183-1-ND		Lite-On Inc
LED1, LED2	Amber	2	LED, Amber, SMD	603	LTST-C190AKT	160-1180-1-ND		Lite-On Inc
Q100, Q200	4Mhz	2	Ceramic Resonator	CSTCR	CSTCR4M00G15L99-R0	490-7861-1-ND		Murata
Q400	6 Mhz	1	Ceramic Resonator	CSTCR	CSTCR6M00G55-R0	490-5997-1-ND		Murata
X1	32.768 kHz	1	Crystal Oscillator	Cylindrical Can, Radial	CMR200T-32.768KDZF-UT	300-8340-1-ND		Citizen
ICs								
U1	MSP430FR6989PZ	1	Mixed Signal Microcontroller	MSP430FR6989	MSP430FR6989	N/A	Provided by TI	Texas Instruments
U100, U200	MSP430F5528IRGC	2	Mixed Signal Microcontroller	TI_RGC0064B_N	MSP430F5528IRGCR	296-27930-1-ND		Texas Instruments
U400	TPD2E001DRL	1	15-kV ESD-Protection Array	DRL0005A	TPD2E001DRLR	296-21883-1-ND		Texas Instruments
U401	TUSB2046BIRHB	1	4-Port Full-Speed USB Hub	RHB0032E	TUSB2046BIRHBR	296-21926-1-ND		Texas Instruments
U403	TPS62237DRY	1	3.3-V Buck Step Down Regulator	DRY0006A	TPS62237DRYT	296-25630-1-ND		Texas Instruments
CONNECTORS								
J400	micro B	1	micro-USB Type B, Reverse, Receptacle, SMD, RA	CONN_USB_micro_ZX62R-B-5PA	ZX62R-B-5P	H11574CT-ND		Hirose
RF1, RF2	2×10 SMD	2	Header, SMD, 1.27 mm, 2×10	HDR2X10	TFM-110-02-SM-D-A-K	N/A	Contact Samtec directly	Samtec
(JP13+JP14), J401	2×2	2	Header, TH, 2.54 mm, 2×2	HDR2X2	67997-104HLF	609-3225-ND	Alternative: Any similar JP13 and JP14 share same component	FCI

Table 3. BOM: Main Board (continued)

DESIGNATOR	VALUE	QTY	DESCRIPTION	PACKAGE	MANUFACTURER PN	DIGIKEY PN	REMARK	MANUFACTURER
J402, J601 PORT_1_4, PORT_2_3, PORT_6_8, PORT_J	2×4	6	Header, TH, 2.54 mm, 2×4	HDR2X4	67997-108HLF	609-3226-ND	Alternative: Any similar	FCI
ESI	2×8 RA	1	Shrouded Header, TH, 2.54 mm, 2×8, Right Angled	HDR2X8	SBH11-PBPC-D08-RA-BK	S9179-ND		Sullins Connector Solutions
(Jumpers)	1×2	12	2-pin Jumper, 2.54 mm	N/A	QPC02SXGN-RC	S9337-ND	Alternative: Any similar	Sullins Connector Solutions
MISCELLANEOUS								
BUT	TPA511GLFS	1	4-Way Navigation Switch w/select	TPA511GLFS	TPA511GLFS	401-1130-1-ND		C&K
BUT (Accessory)	Y43109100OP	1	Cap for TPA511GLFS	N/A	Y43109100OP	401-1997-ND		C&K
MCU_RESET, S201, S202	B3U-1000P	3	Push Button	B3U-1000P	B3U-1000P	SW1020CT-ND		Omron
LCD	FH-1152P	1	Custom 160 segment LCD	FH-1152P	FH-1152P	N/A		ADKOM Elektronik GmbH
M3 Hex Standoff	M3/13 mm	4	M3 13 mm Female, female	N/A	Harwin Inc	952-1488-ND		R30-1011302
M3 Screw	M3/6 mm	4	M3 Screw Philips Pan Head Head Diameter 5 to 6 mm Thread Length 6 mm		RM3X8MM 2701	335-1149-ND		APM Hexseal

Table 4. BOM: Sensor Board (2-LC Configuration)

DESIGNATOR	VALUE	QTY	DESCRIPTION	PACKAGE	P/N	DIGIKEY PN	REMARK	MANUFACTURER
CAPACITORS								
C1 C2 C3	220 pF (NP0/C0G)	2	Chip Capacitor, C0G, 50 V, ±5%	C0402	GRM1555C1H221JA01D	490-1293-1-ND	Alternatives: NP0/C0G, 10 V, ±5% or better	Murata
C5	470 nF	1	Chip Capacitor, X5R, 10 V, ±10%	C0402	GRM155R61A474KE15D	490-3264-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
INDUCTORS								
L2 L6 L7	470 µH	2		Radial	11R474C	811-2034-ND		Murata
CONNECTORS								
ESI	8×2	1	8×2 2.54-mm Female Socket		SFH11-PBPC-D08-ST-BK	S9196-ND		Sullins Connector Solution

Table 5. BOM: Motor Board

DESIGNATOR	VALUE	QTY	DESCRIPTION	PACKAGE	P/N	DIGIKEY PN	REMARK	MANUFACTURER
RESISTORS								
R4, R8, R9	100 R	3	Chip Resistor	R0402	RC0402JR-07100RL	311-100JRCT-ND	Alternatives: ±5% or better	Yageo
R2, R6	470 R	2	Chip Resistor	R0402	RC0402JR-07470RL	311-470JRCT-ND	Alternatives: ±5% or better	Yageo
R3	1 K	1	Chip Resistor	R0402	RC0402JR-071KL	311-1.0KJRCT-ND	Alternatives: ±5% or better	Yageo
R5	2 K	1	Chip Resistor	R0402	RC0402JR-072KL	311-2.0KJRCT-ND	Alternatives: ±5% or better	Yageo
R1	10 K	1	Chip Resistor	R0402	RC0402JR-0710KL	311-10KJRCT-ND	Alternatives: ±5% or better	Yageo
R7	47 K	1	Chip Resistor	R0402	RC0402JR-0747KL	311-47KJRCT-ND	Alternatives: ±5% or better	Yageo
VR1	10 K	1	10-K POT		3352P-1-103LF	3352P-103LF-ND	Alternatives: Same type, value between 10 to 100 K	Bourns Inc.
CAPACITORS								
C4	2200 pF	1	Chip Capacitor, X7R, 100 V, ±10%	C0402	GRM155R72A222KA01D	490-6367-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
C3, C5, C7, C8, C10	100 nF	5	Chip Capacitor, X7R, 16 V, ±10%	C0402	GRM155R71C104KA88D	490-3261-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
C6	470 nF	1	Chip Capacitor, X5R, 10 V, ±10%	C0402	GRM155R61A474KE15D	490-3264-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
C1, C9	22 µF	2	Chip Capicitor, X5R, 16 V, ±20%	C1206	GRM31CR61C226ME15L	490-4739-1-ND	Alternatives: X5R, 10 V, ±10% or better	Murata
DIODES, LEDs								
LED1	Red	1	LED, Red, SMD	603	LTST-C190CKT	160-1181-1-ND		Lite-On Inc
LED_PWR	Green	1	LED, Green, SMD	603	LTST-C190GKT	160-1183-1-ND		Lite-On Inc
D1	MBR0520L	1	0.5-A Schottky Diode, SMD	SOD123	MBR0520L	MBR0520LCT-ND		Fairchild
ICs, TRANSISTORS								
U1	MSP430G2553	1	MCU: MSP430G2553	20 TSSOP PW(R-PDSO-G20)	MSP430G2553IPW20	296-28430-1-ND		Texas Instruments
U3	DRV8837DSG	1	Low Voltage H-Bridge Driver	DSG(S-PWSON-N8)	DRV8837DSGR	296-34786-1-ND		Texas Instruments
U4	QRD1113	1	Reflective Optical Sensor	Custom 4L	QRD1113	QRD1113-ND		Fairchild

Table 5. BOM: Motor Board (continued)

DESIGNATOR	VALUE	QTY	DESCRIPTION	PACKAGE	P/N	DIGIKEY PN	REMARK	MANUFACTURER
T1	BC817-40L	1	NPN Transistor	SOT23	BC817-40L	BC817-40LT3GOSCT-ND		On Semi
JUMPERS, CONNECTORS, SWITCHES								
BUT1, BUT2		2	SMD push button	6×6 mm	B3SL-1002P	SW1064CT-ND		Omron
POWER	2P2T	1	SMD 2P2T Switch		JS202011SCQN	401-2002-1-ND		C&K Components
PWR_SEL, I2C, UART	3×1	3	3×1 2.54-mm Pin header		68001-103HLF	609-3468-ND	Alternative: Any similar	FCI
EXT_PWR, SBW	2×1	2	2×1 2.54-mm Pin header		68001-102HLF	609-3506-ND	Alternative: Any similar	FCI
(Jumpers)	1×2	1	2-pin Jumper, 2.54 mm	N/A	QPC02SXGN-RC	S9337-ND	Alternative: Any similar	Sullins Connector Solutions
MISCELLANEOUS								
Motor		1	Motor		PPN7PA12C1	P14355-ND		NMB Technologies Corporation
BAT	2xAAA	1	2xAAA Battery holder		2468	2468K-ND		Keystone Electronics
Motor Mount		1	Custom-made motor mount		N/A	N/A	Custom made by outsourcing	N/A
M2 Screws	M2/3 mm	2	M2 Screw Philips Pan Head Head Diameter 3 mm Head Height 1 mm Thread Length 3 mm Total length 4 mm			N/A	Alternative: M2 Screws with same dimension	
M2 Spring	M2/4-mm dia	2	M2 Spring Diameter around 4 mm Thickness <1 mm		MLWZ 002	H771-ND	Alternative: Similar M2 Springs	B&F Fastener Supply
M3 Screw	M3/6 mm	5	M3 Screw Philips Pan Head Head Diameter 5 to 6 mm Thread Length 6 mm		RM3X8MM 2701	335-1149-ND	Alternative: Similar M3 Springs	APM Hexseal
M3 Hex Standoff	M3/2.54 cm	4	M3 1-inch Standoff Female, female		R6397-02	952-2177-ND	Alternative: Similar M3 Standoff	Harwin Inc
M3 Nuts	M3	1	M3 Nut Width around 5 mm Thickness around 2 mm (for Mounting Battery Holder)			N/A	Farnell Alternative: 53M8681 (Duratool M3- HFST-Z100-) Or Similar M3 Nuts	

8.3 PCB Layout

To download the layer plots, see the design files at TIDM-3LC-METER-CONV.

8.3.1 Main Board

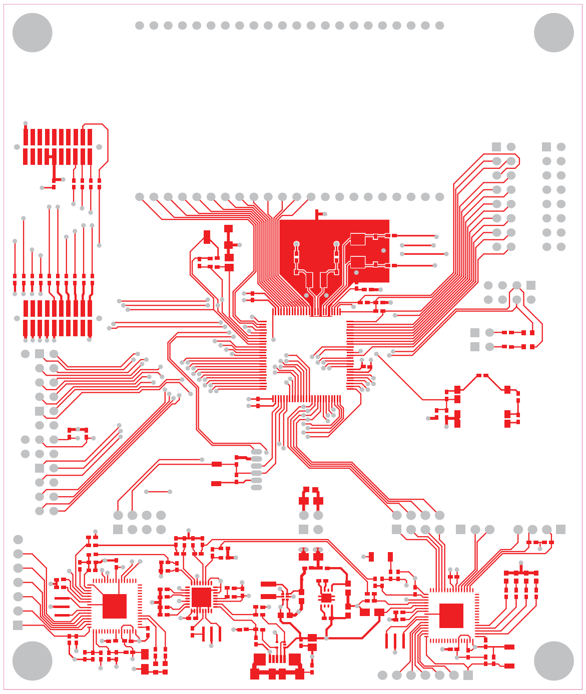
Figure 12. Main Board 1

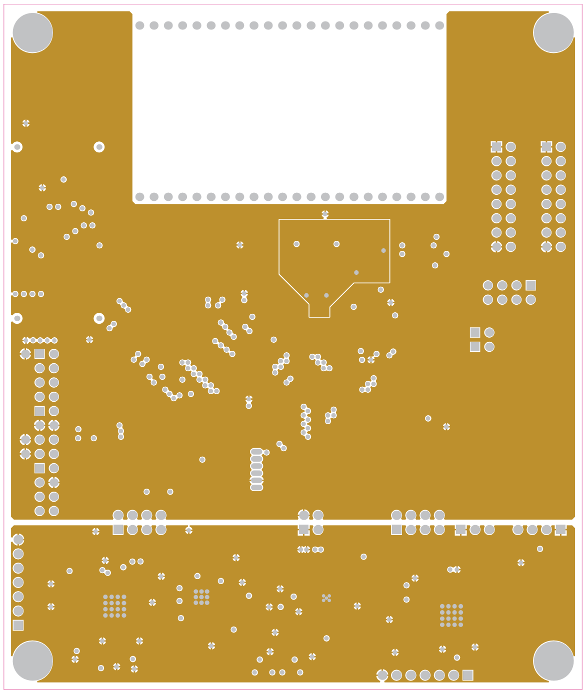
Figure 13. Main Board 2

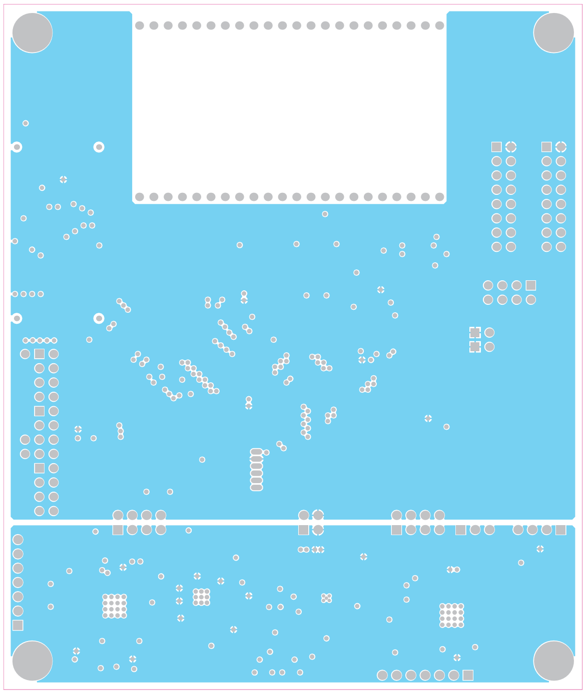
Figure 14. Main Board 3

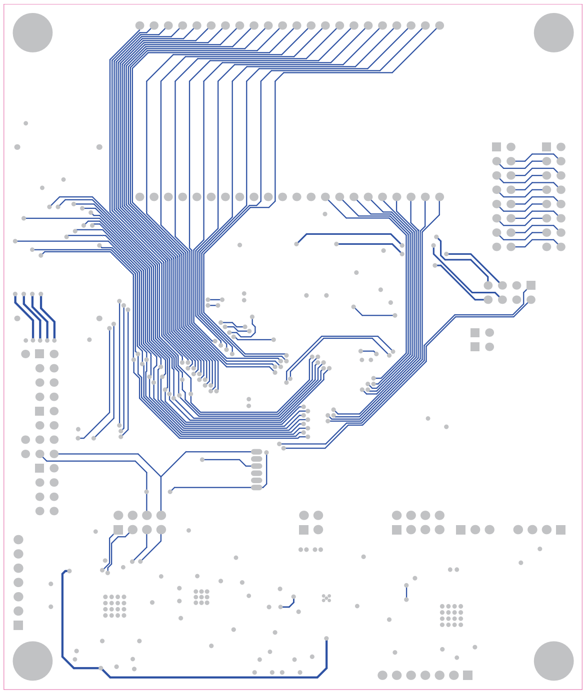
Figure 15. Main Board 4

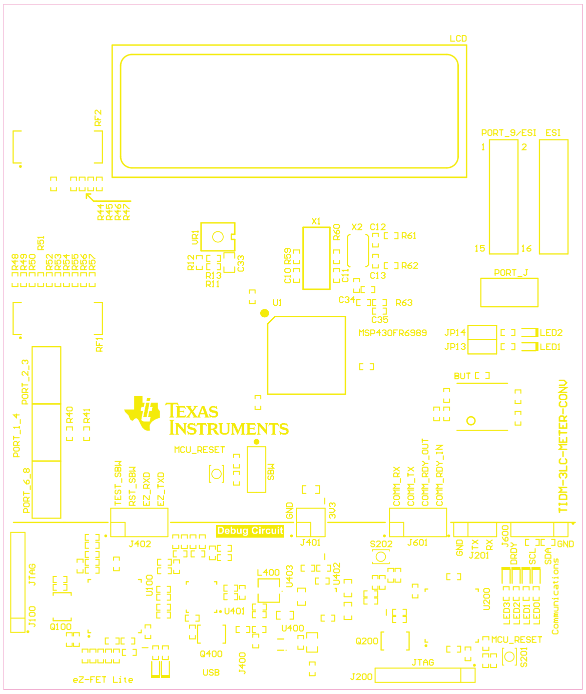

Figure 16. Main Board 5

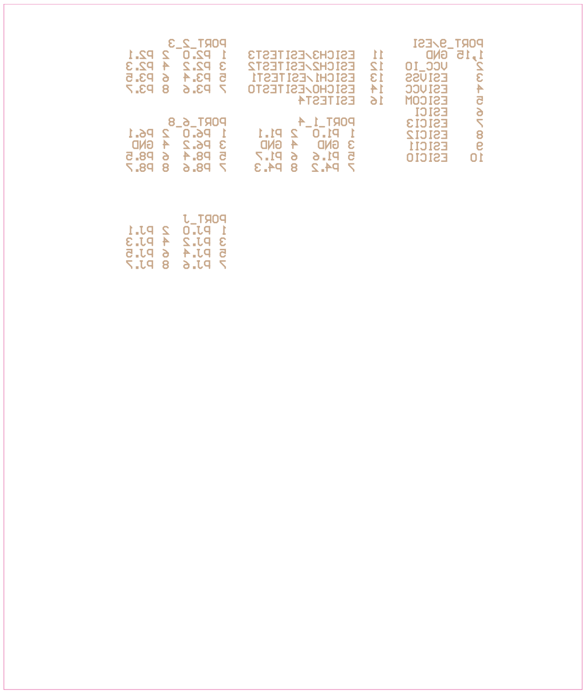

Figure 17. Main Board 6

8.3.2 Sensor Board

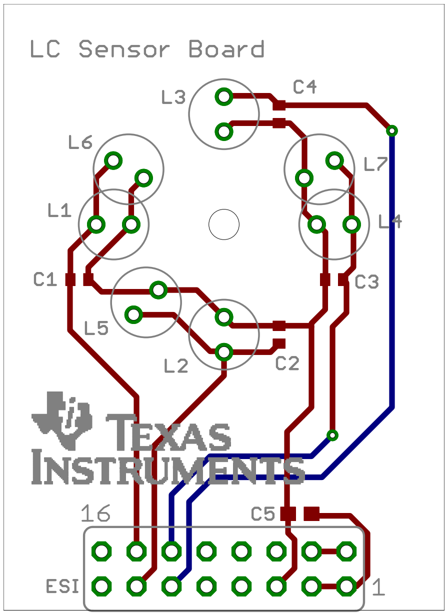

Figure 18. All Layers

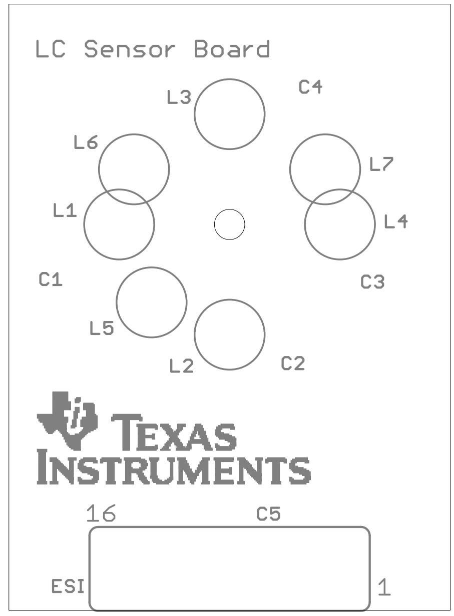

Figure 19. Top Silkscreen

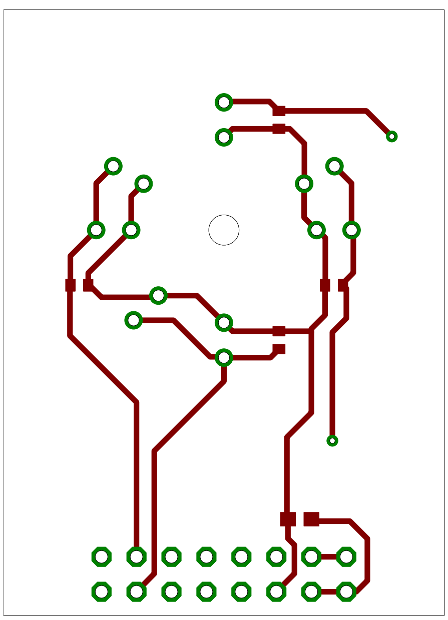

Figure 20. Component Side

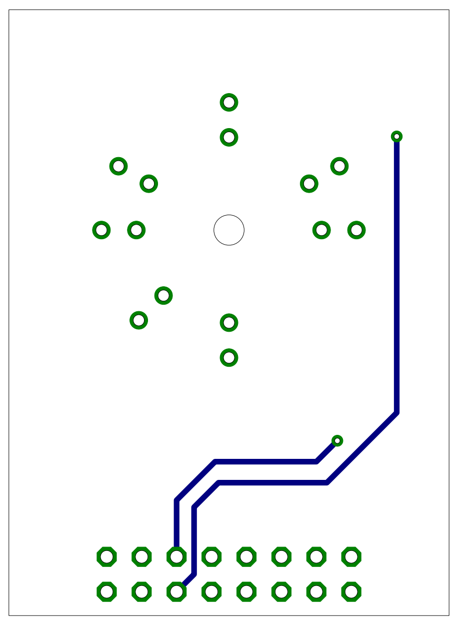

Figure 21. Solder Side

8.3.3 Motor Board

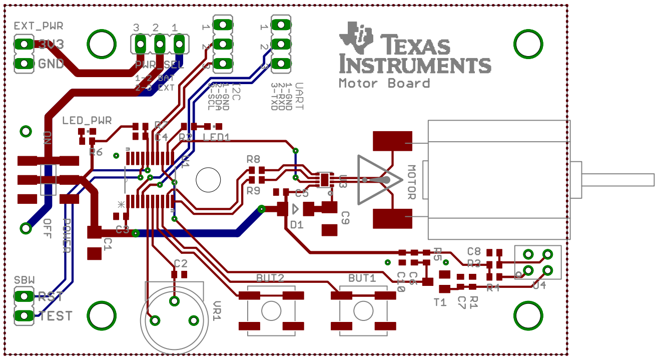

Figure 22. Motor Board 1

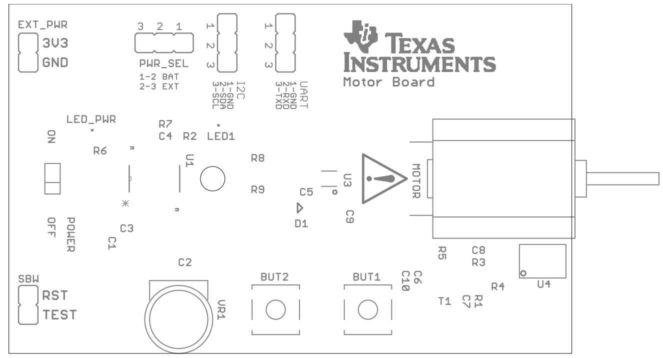

Figure 23. Motor Board 2

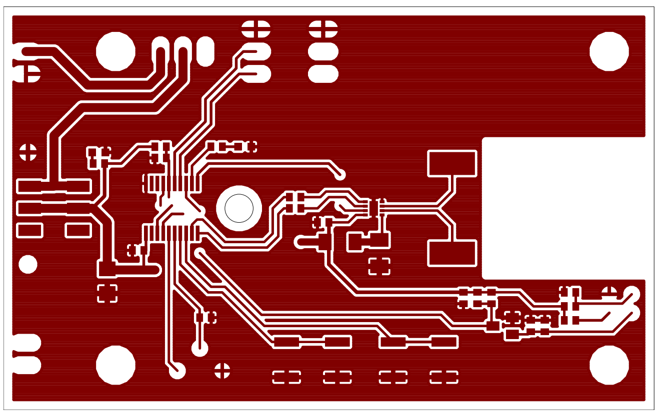

Figure 24. Motor Board 3

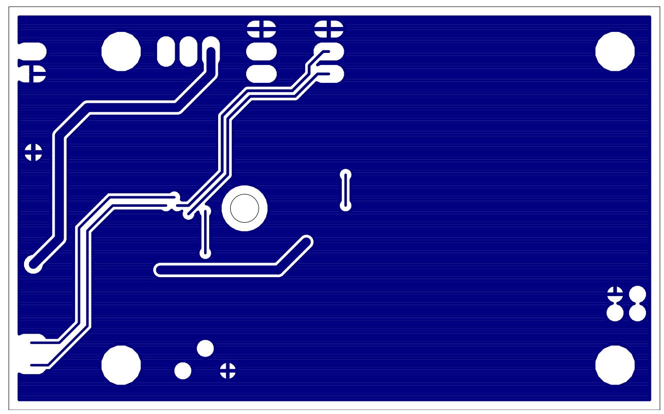

Figure 25. Motor Board 4

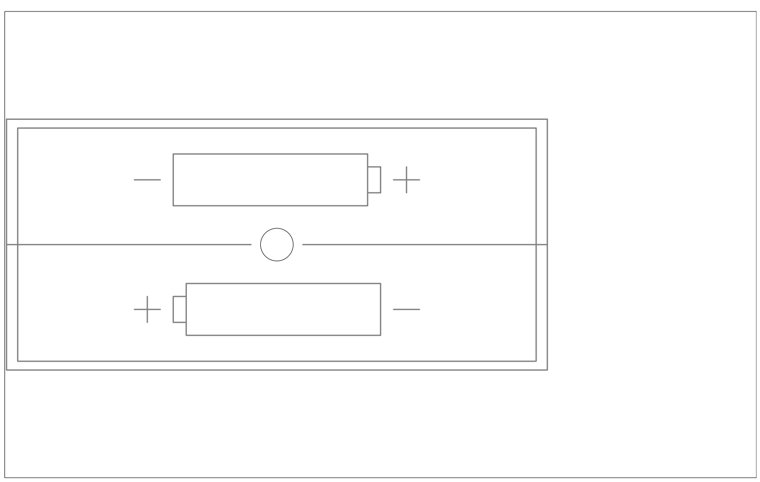

Figure 26. Motor Board 5

8.4 Altium Project

To download the Altium project files, see the design files at TIDM-3LC-METER-CONV.

8.5 Gerber Files

To download the Gerber files, see the design files at TIDM-3LC-METER-CONV.

9 Software Files

To download the software files, see the design files at TIDM-3LC-METER-CONV.

10 About the Author

THOMAS KOT is a system and solutions architect in the Smart Grid and Energy group at Texas Instruments, where he primarily works on the flow meter reference design development and customer support. Thomas received his bachelor of engineering in electronic engineering and his master of science in electronic and information engineering from Hong Kong Polytechnic University in 1995 and 2005, respectively. He received the master of business administration from City University of Hong Kong in 2007.