TI Designs
Ultralow-Power Blood Pressure and Heart Rate Monitor

TI Designs

TI Designs provide the foundation that you need including methodology, testing, and design files to quickly evaluate and customize the system. TI Designs help *you* accelerate your time to market.

Design Resources

TIDM-BPM	TI Design Files
MSP430F6638	Product Folder
LMV324	Product Folder
TPS76333	Product Folder

TI E2E™ Community

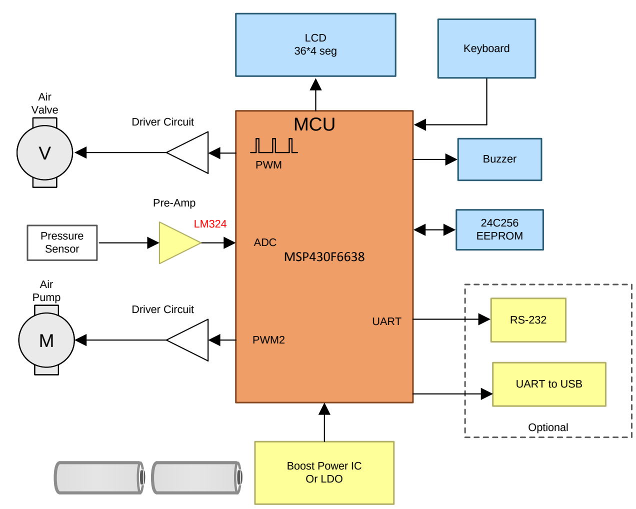
ASK Our E2E Experts
WEBENCH® Calculator Tools

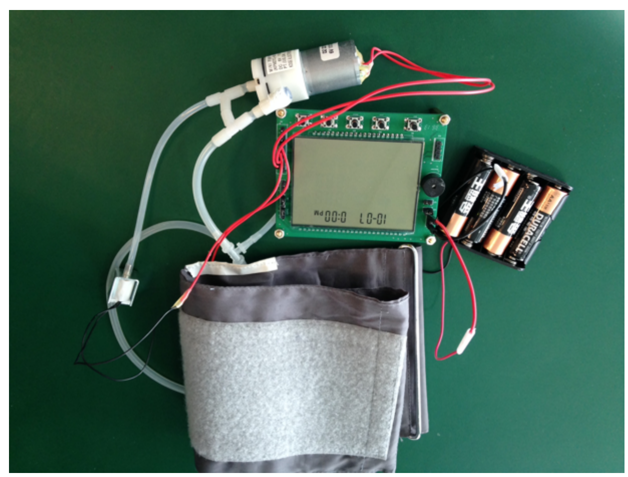
Design Features

- Offers Ultralow-Power in Standby Mode
- Offers Battery Power, Portable Electronic
- Offers MCU with LCD Driver, One-Chip Solution
- Offers Easy-to-Use, Two Buttons, Four Operation Modes
- Supports Raw Data Readout
- Features a Real Product (Not Only Reference Design)

Featured Applications

- Portable BPM in Hospitals
- Portable BPM in Homes
- Healthcare





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TouchPro is a trademark of Elo Touch Solutions,Inc.
MATLAB is a registered trademark of The MathWorks Inc.
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1 Key System Specifications

PARAMETER	SPECIFICATION	DETAILS
System Battery	6-V DC power	Four 1.5-V AA batteries
Pressure Sensor	Supply voltage: 2.7-V to 3.3-V pressure range: 0 kPa to 50 kPa	LP3V5050
DC Air Bump	Rated voltage: 6-V rated current: <430-mA diameter of air tap: 4.3 mm	Referenced KPM27L
DC Air Valve	Rated voltage: 6-V normal open type diameter of air tap: 3 mm	
LCD	Customized LCD to display special icons	

2 System Description

This design is a reference design for an electronic sphygmomanometer that can get systolic, diastolic, and heart-rate data through one measurement. This design collects data from a cuff tied to the upper arm and then processes these data. The algorithm is designed to calculate systolic, diastolic, and heart rate data from raw pressure data. The measured result will be stored in the E2PROM each time, which can store up to 80 records. The latest record will overwrite the earliest record when the store range is full.

2.1 MCU-MSP430F6638

This device is selected as the system MCU and is the brain of the system. The device can perform the following actions:

- Display the date and time in standby mode
- Support date and time settings in set mode
- Display history records in memory mode
- Measure systolic, diastolic, and heart rate in measure mode

2.2 OPA-LMV324

This device uses the signal from the pressure sensor and converts it to a level that the analog-to-digital converter (ADC) module of the MCU can handle.

2.3 LDO-TPS76333

This device converts the input voltage from the battery (approximately 6 V) to 3.3 V and supplies it to the MCU. The device can provide stable input voltage to the MCU. The 6-V battery output is supplied to the pump and valve to drive them normally.

3 Block Diagram

Figure 1 shows the block diagram.

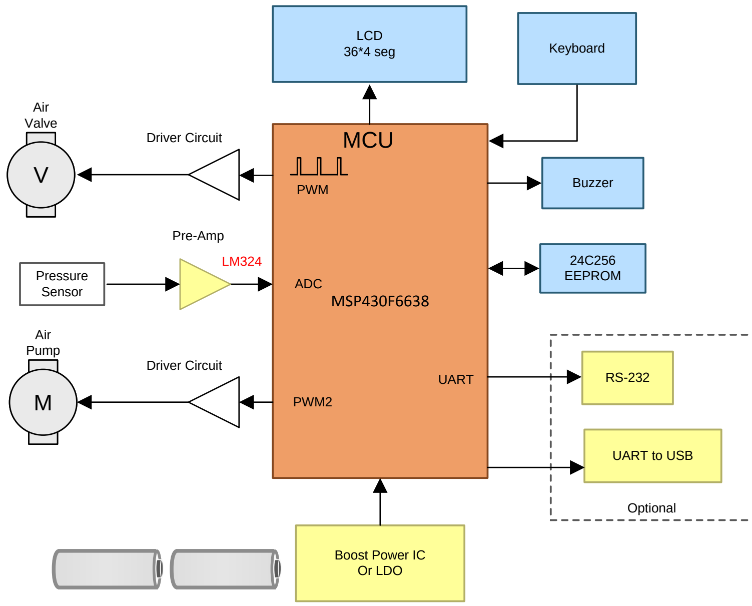


Figure 1. System Block Diagram

3.1 *Highlighted Products*

3.1.1 MCU-MSP430F6638

This MCU has 256k flash, 16k RAM, and 2k USB RAM. The MCU has rich peripherals, such as a universal serial communication interface (USCI) module, a timer module, an ADC module, a USB module, and so forth. The USCI module supports multiple serial-communication modes with one hardware module that has different configurations. The USCI module can be configured as inter-integrated circuit (I^2C) mode, universal asynchronous receiver and transmitter (UART) mode, or serial peripheral interface (SPI) mode.

The TI MSP430™ family of ultralow-power microcontrollers consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally-controlled oscillator (DCO) lets the device wake up from low-power modes to active mode in 3 µs (typical). The MSP430F663xx series are microcontroller configurations with a high-performance 12-bit ADC, comparator, two USCIs, USB 2.0, a hardware multiplier, DMA, four 16-bit timers, a real-time clock module with alarm capabilities, an LCD driver, and up to 74 I/O pins.

Typical applications for this device include analog and digital sensor systems, digital motor control, remote controls, thermostats, digital timers, and hand-held meters. Figure 2 shows the functional block diagram for the MSP430F6638.

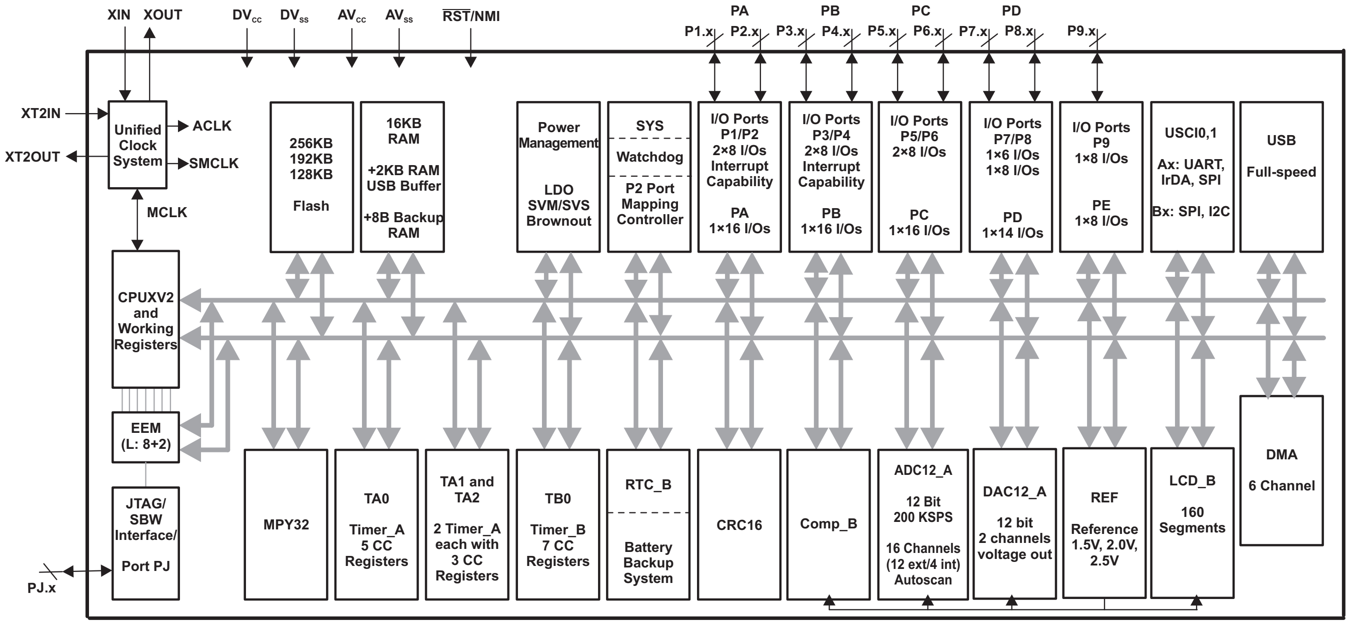


Figure 2. Functional Block Diagram for MSP430F6638

3.1.2 OPA-LMV324

The LMV324 is a quad low-voltage (2.7 V to 5.5 V) operational amplifier with rail-to-rail output swing. The LMV324 is the most cost-effective solution for applications where low-voltage operation, space saving, and low cost are required. These amplifiers are designed for low-voltage (2.7 V to 5 V) operations with performance specifications that meet or exceed the LMV324 device that operates from 5 V to 30 V. Additional features of the LMV3xx devices are a common-mode input voltage range that includes ground, 1-MHz unity-gain bandwidth, and 1-V/μs slew rate.

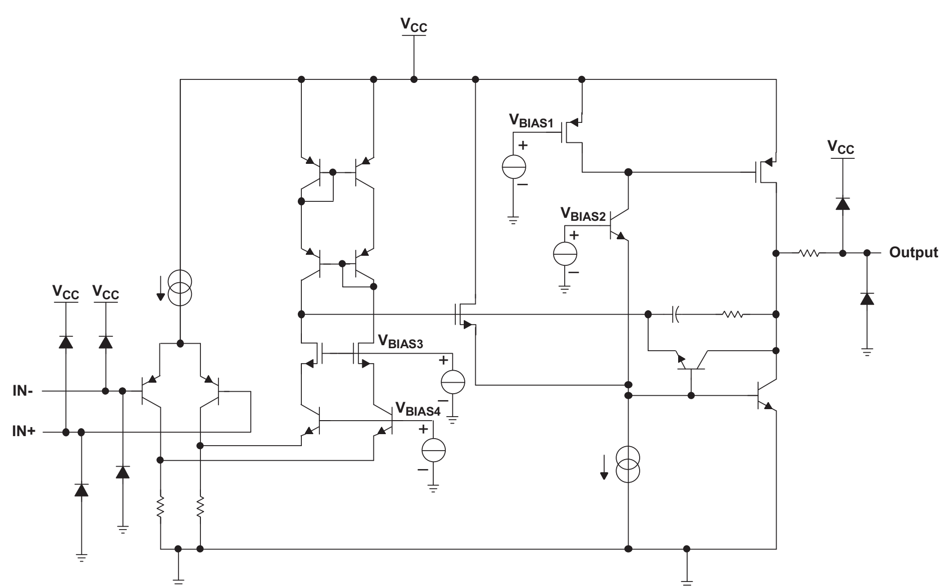


Figure 3. LMV324 Detailed Schematic

3.1.3 LDO-TPS76333

The TPS763xx family of low-dropout (LDO) voltage regulators offers the benefits of low-dropout voltage, low-power operation, and miniaturized packaging. These regulators feature low-dropout voltages and quiescent currents compared to those of conventional LDO regulators. Offered in a 5-terminal, small-outline integrated-circuit SOT-23 package, the TPS763xx series is ideal for cost-sensitive designs and for applications where board space is limited.

The TPS763xx also features a logic-enabled sleep mode to shut down the regulator, reducing the quiescent current to 1-µA maximum at T_J = 25°C. The TPS763xx is offered in 1.6-V, 1.8-V, 2.5-V, 2.7-V, 2.8-V, 3.0-V, 3.3-V, 3.8-V, and 5-V fixed-voltage versions and in a variable version (programmable over the range of 1.5 V to 6.5 V).

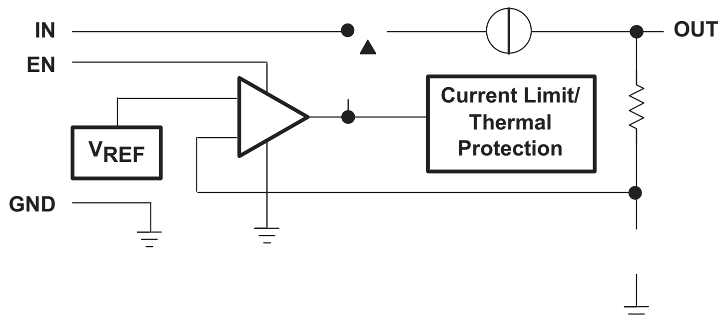


Figure 4. TPS76333 Detailed Schematic

4 System Design Theory

Blood pressure is an important physiological parameter of the human body that carries a lot of physiological and pathological information. The two basic methods to get blood pressure are the Korotkoff-Sounds method and the oscillography method.

To use the blood pressure monitor, do as follows:

1. Tie the cuff to the upper arm of the subject.
2. Aerate the cuff slowly to constrict the arm.

Blood flows into the arm and creates pressure in the blood vessel; the blood flow changes with the heart rate and creates a periodic waveform. The blood flow is blocked when the pressure of the cuff is greater than systolic; after the blood flow is blocked, the waveform disappears. During the measuring period, the pressure data from the sensor is the superposition of static pressure from the cuff and the oscillation wave from the vessel. The oscillation wave becomes larger with the further increase of pressure in the cuff. After reaching the maximum value, the oscillation wave lessens; after the blood vessel is blocked, the oscillation wave disappears. The pressure of the cuff is called average pressure where the oscillation wave has the maximum value. See Figure 5.

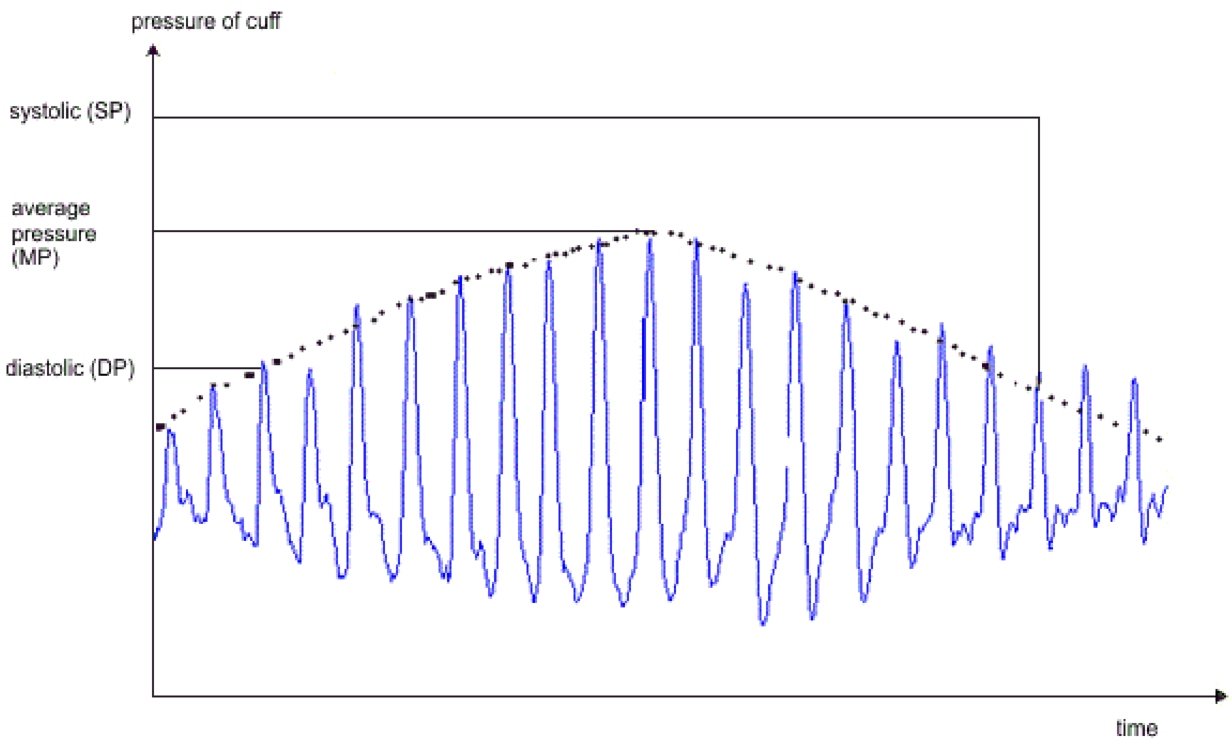


Figure 5. Oscillation Method to Get Blood Pressure

Obtaining the oscillation wave and its envelop is easy (see Figure 5), but systolic and diastolic parameters are required. There are two methods get these parameters from the oscillation curve. One method is called the proportionality coefficient method, where a proportional relationship exists between average pressure and systolic and diastolic (the coefficients are called Ks and Kd, respectively).

SP/MP = Ks (value range: 0.3 to 0.75), DP/MP = Kd (value range: 0.45 to 0.90).

These two coefficients are obtained from a large number of statistical data. The proportionality coefficient method is simple and suitable for MCU applications, but difference between individuals is large and inconsistent. Sometimes large errors occur with this method.

The other method is called the eigenvalue method. This method determines whether the oscillation wave has saltation in systolic and diastolic pressure points. The eigenvalue method must distinguish the inflection point of a curve and build math models to analyze data; this method requires more resources and time to calculate results than the proportionality coefficient method. The eigenvalue method is complex and less suitable for MCU applications.

The algorithm in this system is based on the proportionality coefficient method. The proportionality coefficients (Ks, Kd) are listed in Table 1.

Table 1. Ks, Kd Value According to Average Pressure Range (J Moraes)

AVERAGE PRESSURE RANGE (mmHg)	Ks	AVERAGE PRESSURE RANGE (mmHg)	Kd
MAP > 200	0.5	MAP > 180	0.75
200 ≥ MAP > 150	0.29	180 ≥ MAP > 140	0.82
150 ≥ MAP > 135	0.45	140 ≥ MAP > 120	0.85
135 ≥ MAP > 120	0.52	120 ≥ MAP > 60	0.78
120 ≥ MAP > 110	0.57	60 ≥ MAP > 50	0.6
110 ≥ MAP > 70	0.58	50 ≥ MAP	0.5
70 ≥ MAP	0.64	50 ≥ MAP	0.5

5 Getting Started Hardware

To set up the hardware, connect all the parts of the system. Before connecting, assemble the components to the board. See Section 5.1.

5.1 System Connection

1. Connect the gas path as shown in Figure 6 (pressure sensor, pump, valve, and cuff must be connected).

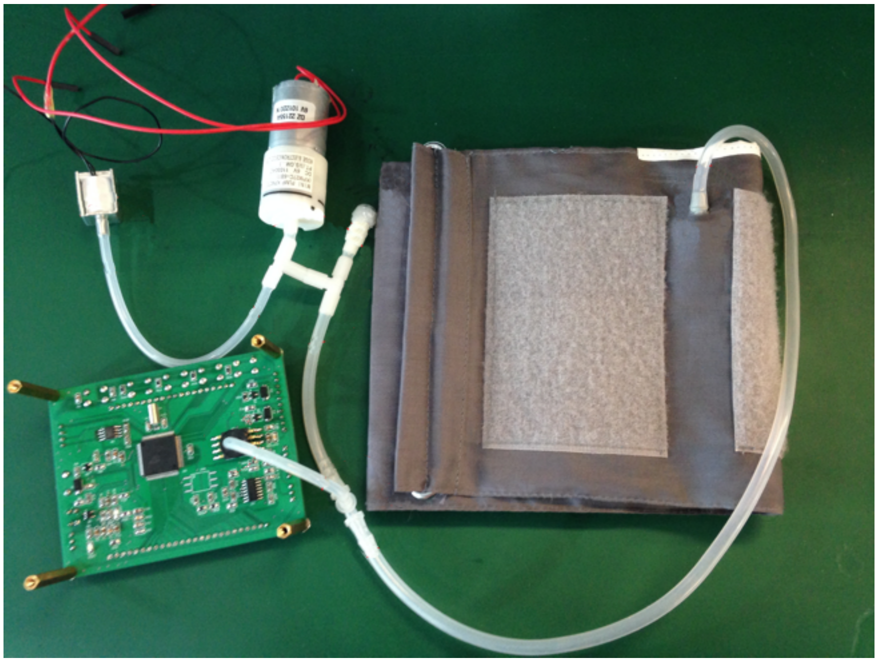


Figure 6. Connection of Cuff, Pump, Valve, and Sensor for Gas Path

2. Connect one wire of the pump to BAT and the other wire to CN5.
3. Connect one wire of the valve to BAT and the other wire to CN6 (see Figure 7).

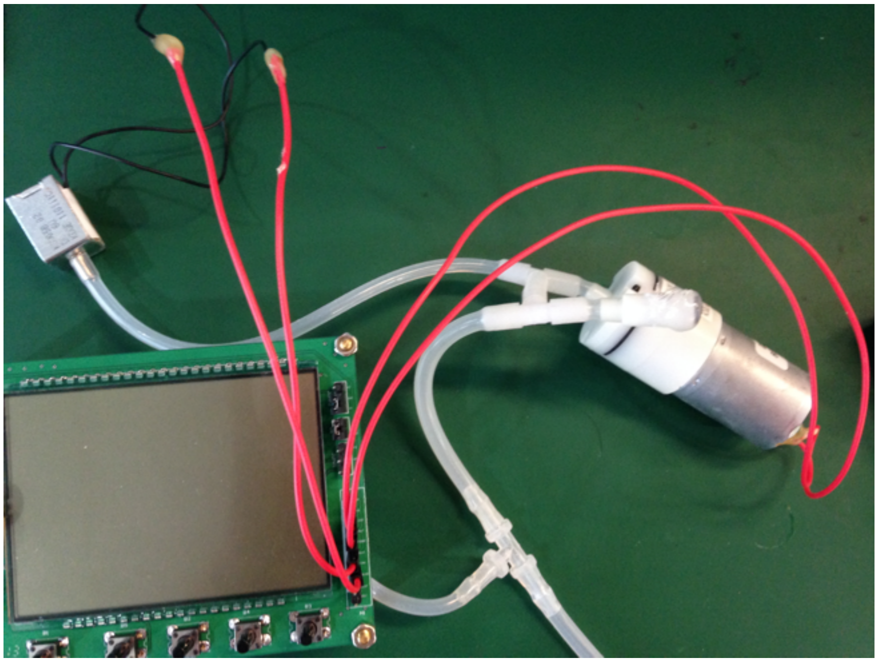


Figure 7. Pump and Valve Electronic Connection to the Board

4. Connect the battery to the board.
5. Connect the positive end of the battery to the VBAT pin of P1.
6. Connect the negative end of the battery to the GND pin of P1 (the date and time should appear on the LCD after it powers up, see Figure 8).

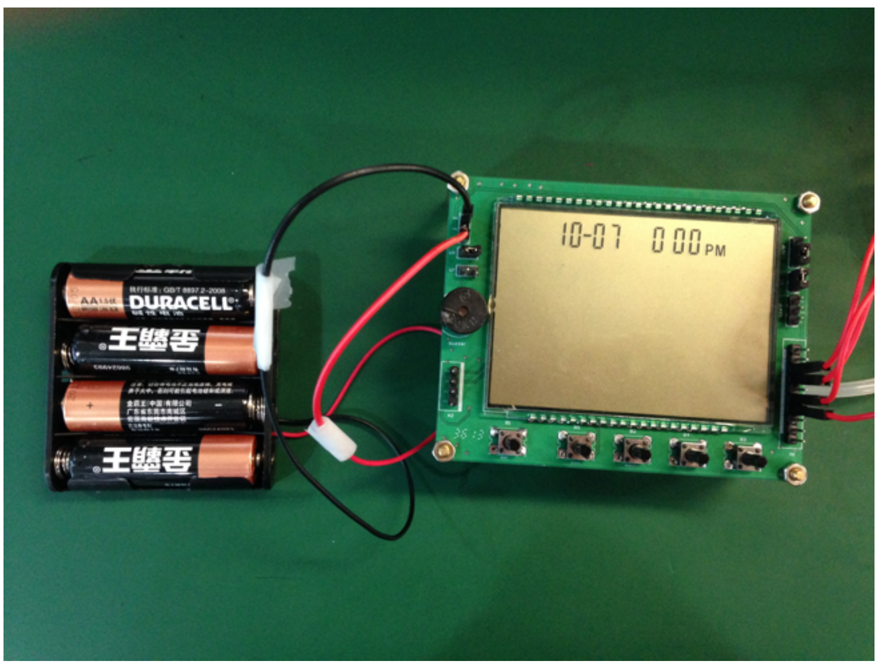


Figure 8. Connect to the Board

To see or collect raw data, connect UART to the PC (see Figure 9).

7. Connect the TXD of H2 to the TXD of the MSP430 emulator (or another emulator).
8. Connect the GND (TouchPro™ GUI must be installed on the PC to support this function, see http://www.ti.com/tool/msptouchprogui?keyMatch=touch_pro&tisearch=Search-EN).

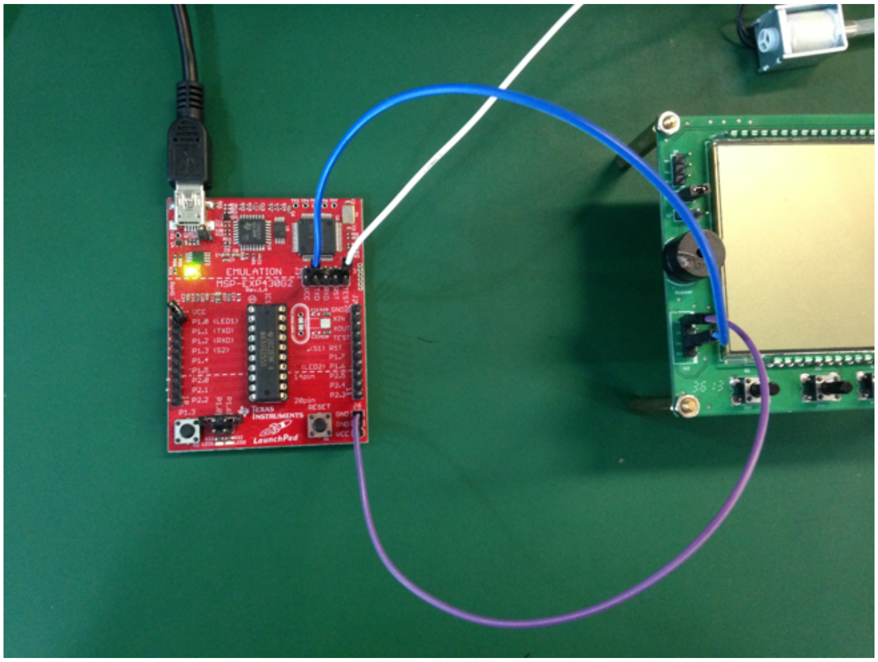


Figure 9. Raw Data Readout Through UART

5.2 Running the Demo

After powering up, the system enters standby mode and shows the date and time.

1. Press the start and memory buttons simultaneously for three seconds (the system should enter time-set mode).

NOTE: In this mode, the month position blinks.

2. Use the memory button to adjust the number in the current position.
3. Use the start button to select the next position.
4. When the minute position is blinking, press the start button to end time-set mode and enter standby mode.

NOTE: The selection logic for the start button is month → date → hour → minute → standby mode.

5. Press the memory button in standby mode will enter the system into memory mode.

NOTE: The memory icon and total-records number appear for three seconds and the display shows the latest record. Every record includes systolic, diastolic, heart rate, date, and time.

6. Press the memory button in this mode switch to the next record or press the start button to end this mode and enter standby mode.

NOTE: Pressing the start button in standby mode causes the system to enter measure mode. Before entering this mode, ensure that the cuff is correctly tied to the upper arm, otherwise the system will report an error. In measure mode, the system takes a measurement and shows the result on the LCD. After entering this mode, all LCD segments appear and the buzzer works. This stage lasts three seconds, during which the system does not respond to any action. After this stage, the system aerates the cuff and the LCD shows the pressure of the cuff. After the pressure of the cuff reaches the goal pressure (145 mmHg set by the system), the system stops aerating and begins deflating. The system calculates and shows the results.

6 Getting Started Firmware

To start using the firmware, do as follows:

1. Download the firmware.
2. Compile it in CCS.
3. Download it to MCU

NOTE: The system runs as described in Section 5.2.

To collect the raw data for further analysis, use the TouchPro tool and connect the hardware as described in Section 5.1. The raw data is pressure data collected by the sensor-ADC module.

7 Test Setup

1. Connect the system as shown in Figure 6.
2. Check the connection point and ensure there is no air leakage.
3. Connect the system as described in Section 5.1 and power it up.

NOTE: The date and time appear on the LCD. The default value is the 7th of October, 0:00. If nothing appears on the LCD, check the battery and the LDO output

4. Run the system as described in Section 5.2.

NOTE: To get raw data in measure mode, connect the system as shown in Figure 10.

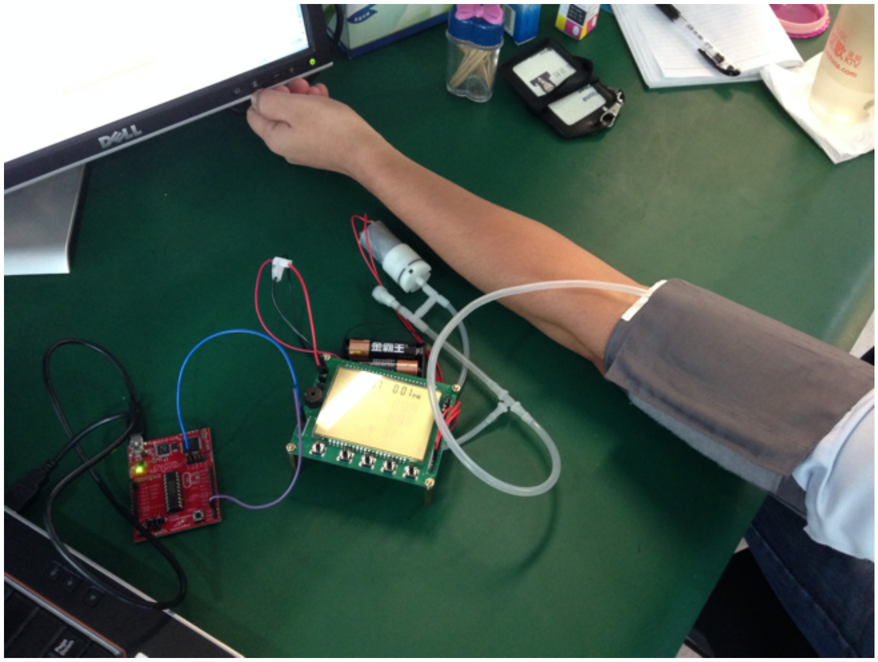


Figure 10. Measure Demo

5. Connect UART to TouchPro in PC.
6. Select the correct COM and 9600 as the baud rate (see Figure 11).
7. Click the open button to open the COM.

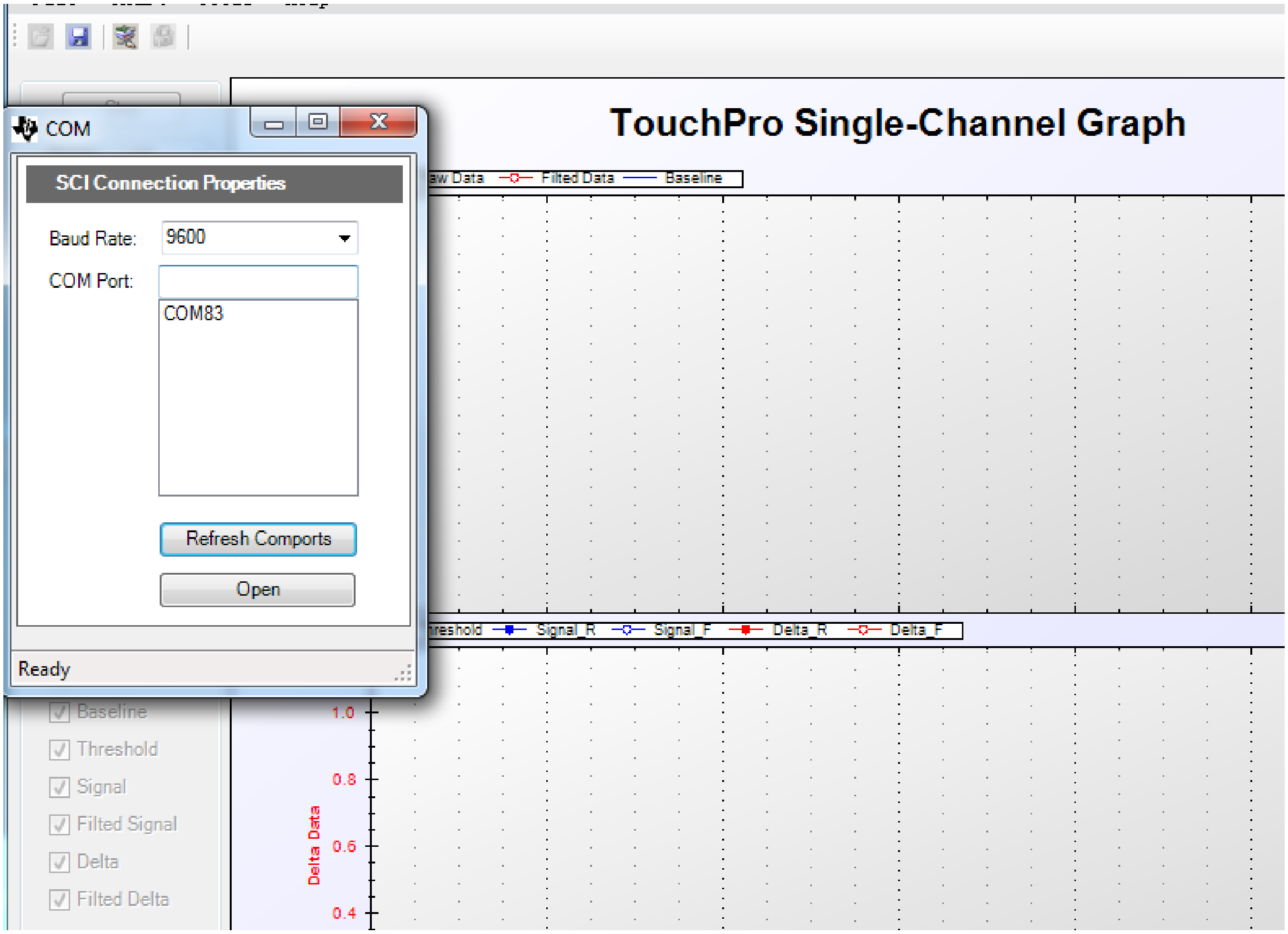


Figure 11. TouchPro Tool

NOTE: When the system receives the data, a curve appears on the panel of this tool.

To save the raw data in the PC for further analysis, do as follows:

1. Click File Directory.
2. Name the file.
3. Click the Record button (see Figure 12).

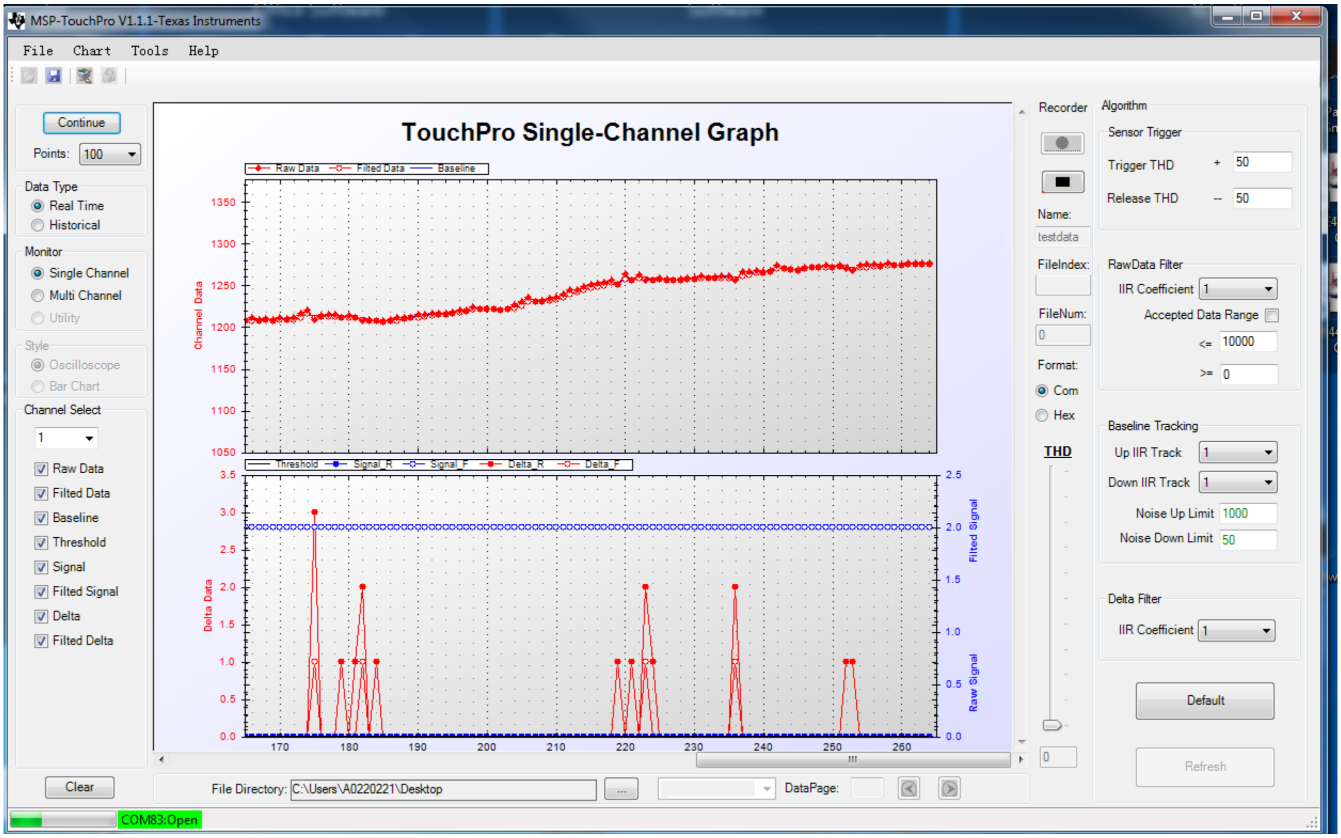


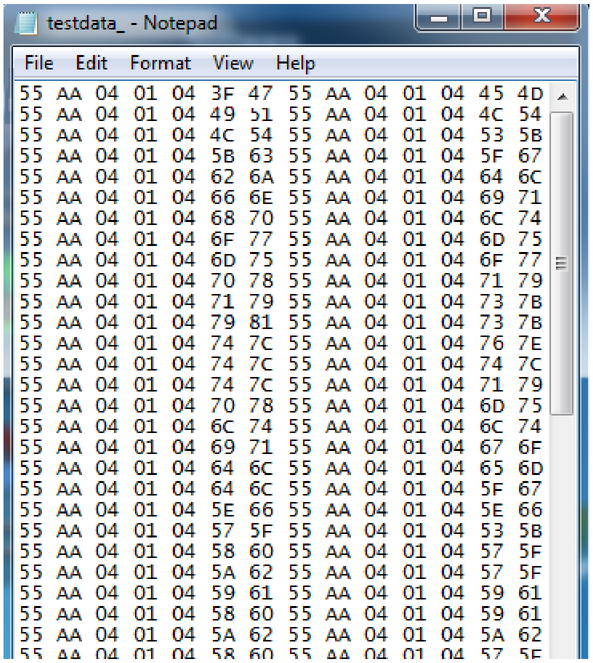
Figure 12. Collecting and Saving Raw Data

8 Test Data

The saved data is a .txt file and its format is as shown in Figure 13. The frame headers are 0x55 and 0xaa; the following is the data length 0x04 and then channel number 0x01. The fifth and the sixth data are the real data from the 12-bit ADC. To get the real value, use the following equation:

fifth data × 256 + sixth data

Every frame has 7 bytes and the last data is the checksum.

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55 AA 04 01 04 3F 47 55 AA 04 01 04 45 4D
55 AA 04 01 04 49 51 55 AA 04 01 04 4C 54
55 AA 04 01 04 4C 54 55 AA 04 01 04 53 5B
55 AA 04 01 04 5B 63 55 AA 04 01 04 5F 67
55 AA 04 01 04 62 6A 55 AA 04 01 04 64 6C
55 AA 04 01 04 66 6E 55 AA 04 01 04 69 71
55 AA 04 01 04 68 70 55 AA 04 01 04 6C 74
55 AA 04 01 04 6F 77 55 AA 04 01 04 6D 75
55 AA 04 01 04 6D 75 55 AA 04 01 04 6F 77
55 AA 04 01 04 70 78 55 AA 04 01 04 71 79
55 AA 04 01 04 71 79 55 AA 04 01 04 73 7B
55 AA 04 01 04 79 81 55 AA 04 01 04 73 7B
55 AA 04 01 04 74 7C 55 AA 04 01 04 76 7E
55 AA 04 01 04 74 7C 55 AA 04 01 04 74 7C
55 AA 04 01 04 74 7C 55 AA 04 01 04 71 79
55 AA 04 01 04 70 78 55 AA 04 01 04 6D 75
55 AA 04 01 04 6C 74 55 AA 04 01 04 6C 74
55 AA 04 01 04 69 71 55 AA 04 01 04 67 6F
55 AA 04 01 04 64 6C 55 AA 04 01 04 65 6D
55 AA 04 01 04 64 6C 55 AA 04 01 04 5F 67
55 AA 04 01 04 5E 66 55 AA 04 01 04 5E 66
55 AA 04 01 04 57 5F 55 AA 04 01 04 53 5B
55 AA 04 01 04 58 60 55 AA 04 01 04 57 5F
55 AA 04 01 04 5A 62 55 AA 04 01 04 57 5F
55 AA 04 01 04 59 61 55 AA 04 01 04 59 61
55 AA 04 01 04 58 60 55 AA 04 01 04 59 61
55 AA 04 01 04 5A 62 55 AA 04 01 04 5A 62
55 AA 04 01 04 58 60 55 AA 04 01 04 57 5F
```

Figure 13. Raw Data

Use MATLAB® to process the .txt file in Figure 13 and get the related curves described in Figure 14. These curves show the data flow process, which is saved in the MCU. This process runs automatically after the Start button is pressed.

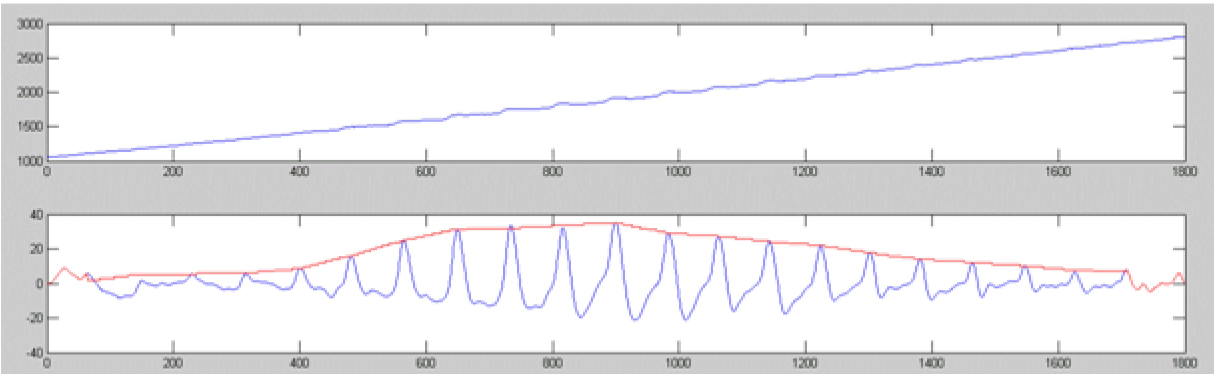

Figure 14. Signal Processed by Matlab

In Figure 14, the x-axis is the amount of raw data that can be converted to time (the sample rate is 100 Hz), and the y-axis is the amplitude. The upper half of this signal is the plot of raw data from Figure 13. The blue curve in the lower half of the signal is the plot of filtered raw data. The filter is a band-pass type with a set bandwidth of 0.3 Hz to 3.5 Hz; the order of this band-pass filter is 2. The red curve in the lower half of the signal is the envelop of the filtered data.

9 Design Files

9.1 Schematics

To download the schematics for each board, see the design files at http://www.ti.com/tool/TIDM-BPM

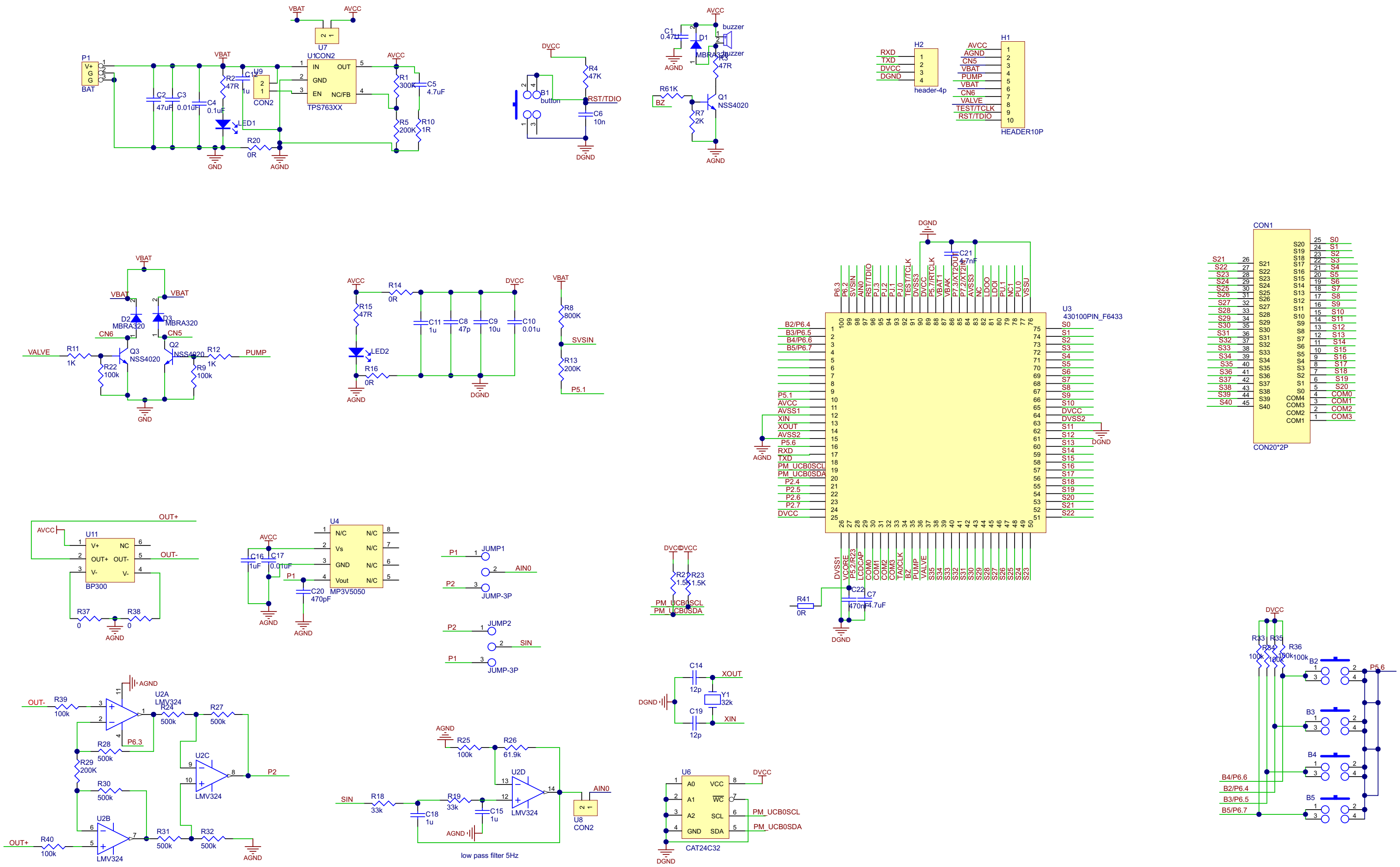

Figure 15. Schematic of System

9.2 Bill of Materials

To download the bill of materials (BOM) for each board, see the design files at http://www.ti.com/tool/TIDM-BPM

Table 2. BOM List

ITEM	QTY	REFERENCE	VALUE	PART DESCRIPTION	PCB FOOTPRINT
1	1	B1	button	BUTTON-4P	SW-4P
2	4	B2, B3, B4, B5	button	BUTTON-4P	SW-4P
3	1	buzzer	buzzer	buzzer	buzzer
4	1	C1	0.47 uF	CAP	C/0805/SMT1
5	1	C2	47 uF	CAP	C/0805/SMT1
6	2	C3, C17	0.01 uF	CAP	C/0805/SMT1
7	1	C4	0.1 uF	CAP	C/0805/SMT1
8	2	C5, C7	4.7 uF	CAP, CAP/0805	C/0805/SMT1
9	1	C6	10 nF	CAP	C/0805/SMT1
10	1	C8	47 pF	CAP	C/0805/SMT1
11	1	C9	10 uF	CAP	C/0805/SMT1
12	1	C10	0.01 uF	CAP	C/0805/SMT1
13	4	C11, C12, C15, C18	1 uF	CAP	C/0805/SMT1
14	2	C14, C19	12 pF	CAP	C/0805/SMT1
15	1	C16	1 uF	CAP	C/0805/SMT1
16	1	C20	470 pF	CAP	C/0805/SMT1
17	1	C21	4.7 nF	CAP/0805	C/0805/SMT1
18	1	C22	470 nF	CAP/0805	C/0805/SMT1
19	1	CON1	CON20*2P	CON20*2P	LCD1
20	3	D1, D2, D3	MBRA320	DIODE	DIODE
21	1	H1	HEADER10P	HEADER10P	CN10P/2.54
22	1	H2	header-4p	header-4p	CON4P-2.54H
23	2	JUMP1, JUMP2	JUMP-3P	JUMP-3P	CON3P-2.54H
24	2	LED1, LED2	LED	LED_1	LED0805
25	1	P1	BAT	BAT	CON3P-2.54H
26	3	Q1, Q2, Q3	NSS4020	NPN_BJT	SOT23-3P
27	1	R1	300 k	RES	R/0805/SMT1
28	3	R2, R3, R15	47 R	RES	R/0805/SMT1
29	1	R4	47 k	RES	R/0805/SMT1
30	3	R5, R13, R29	200 k	RES	R/0805/SMT1
31	3	R6, R11, R12	1 k	RES	R/0805/SMT1
32	1	R7	2 k	RES	R/0805/SMT1
33	1	R8	800 k	RES	R/0805/SMT1
34	9	R9, R22, R25, R33, R34, R35, R36, R39, R40	100 k	RES	R/0805/SMT1
35	1	R10	1 R	RES	C/0805/SMT1
36	3	R14, R16, R20	0 R	RES	R/0805/SMT1
37	2	R18, R19	33 k	RES	R/0805/SMT1
38	2	R21, R23	1.5 k	RES	R/0805/SMT1
39	6	R24, R27, R28, R30, R31, R32	500 k	RES	R/0805/SMT1
40	1	R26	61.9 k	RES	R/0805/SMT1
41	2	R37, R38	0	RES	R/0805/SMT1
42	1	R41	0 R	RES/0805	C/0805/SMT1

Table 2. BOM List (continued)

ITEM	QTY	REFERENCE	VALUE	PART DESCRIPTION	PCB FOOTPRINT
43	1	U1	TPS763XX	TPS763XX	SOT23-5P
44	1	U2	LMV324	LMV324	SO-G14/G3.3
45	1	U3	430100PIN_F6638	430100PIN	IC-LQFP100-PZ - duplicate
46	1	U4	MP3V5050	MP3V5050	MP3V5050
47	1	U6	CAT24C32	CAT24C32	SO-G8/D7.7
48	3	U7, U8, U9	CON2	CON2	CON2P-2.54H
49	1	U11	BP300	BP300	BP300UF
50	1	Y1	32 k	CRYSTAL	XIAL-2*5 V

9.3 PCB Layout Recommendations

This is a low-frequency system with no special PCB layout requirements. See recommendations from the device datasheet.

9.3.1 Layout Prints

To download the layout prints for each board, see the design files at http://www.ti.com/tool/TIDM-BPM

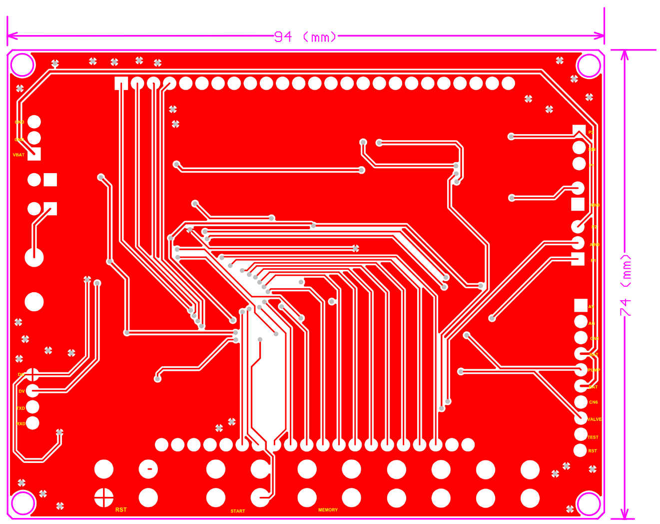

Figure 16. Top Silkscreen layer of PCB

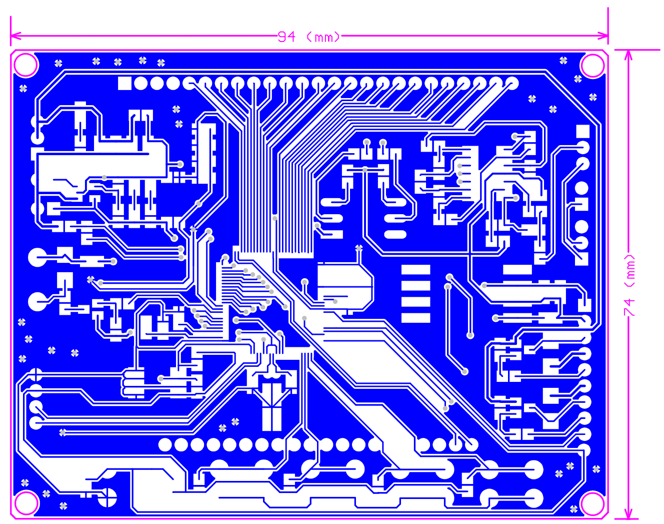

Figure 17. Bottom Solder Layer of PCB

9.4 Altium Project

To download the Altium project files for each board, see the design files at http://www.ti.com/tool/TIDM-BPM.

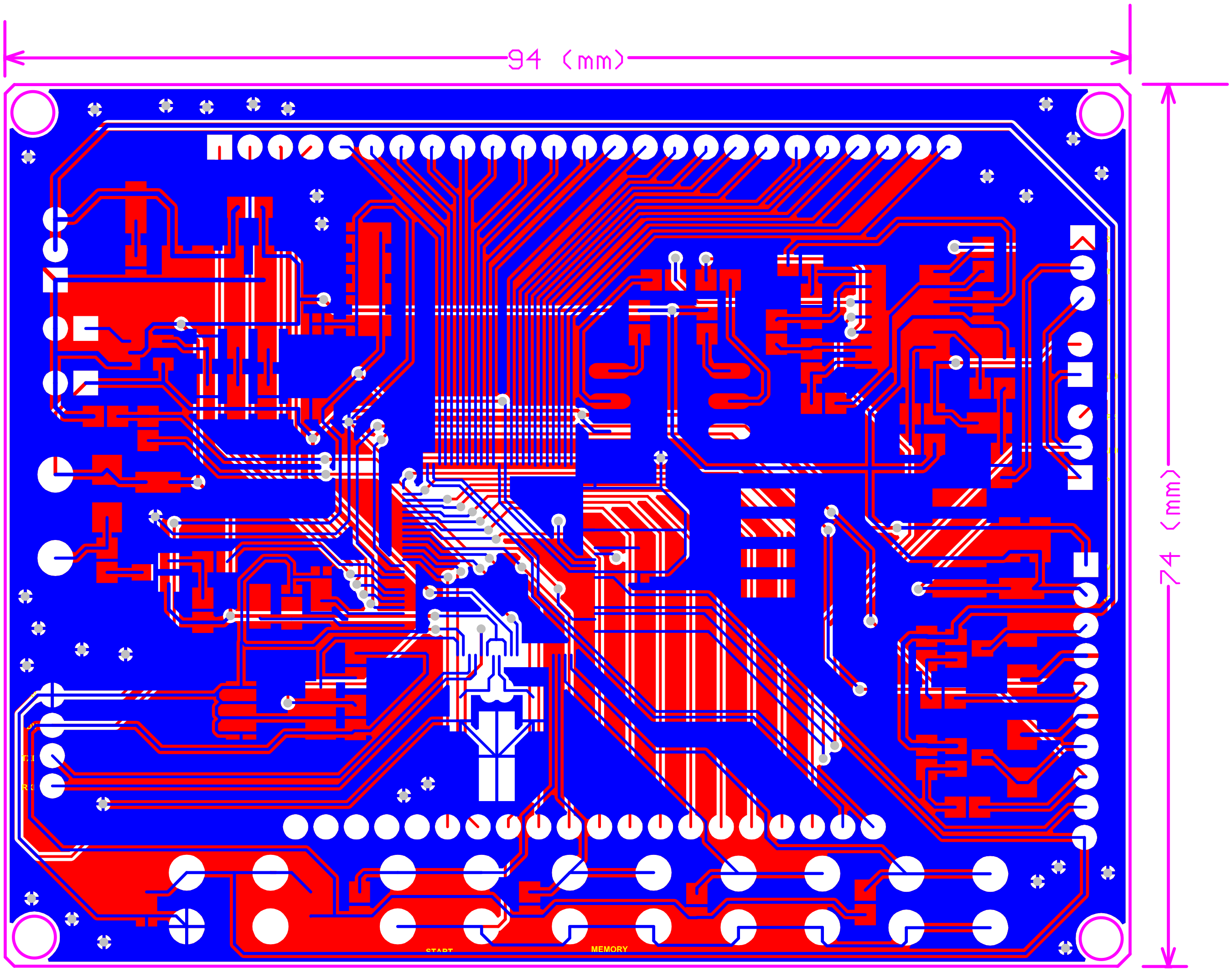

Figure 18. Multi-Layer Composite Print

9.5 Gerber files

To download the Gerber files for each board, see the design files at http://www.ti.com/tool/TIDM-BPM.

10 Software Files

To download the software files for this reference design, see the design files at http://www.ti.com/tool/TIDM-BPM.

11 References

1. Gallardo JE, Cotta C, Ferandez AJ. *On the hybridization of memetic algorithms with branch-and-bound techniques.* IEEE Transactions on Systems, Man, and Cybernetics, Part B:Cybernetics, 2007, 37(1): 77-83.
2. Texas Instruments: *MSP430x5xx and MSP430x6xx Family User's Guide* (SLAU208M).

12 Terminology

PPG, SYSTOLIC, DIASTOLIC

13 About the Author

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