Piezoelectric Micropump Driver Reference Design

Author: *Zhang Feng*
Fu-Ho Lee
Microchip Technology Incorporated

Overview

In medical devices for precision controlled drug delivery, such as infusion pumps, insulin pumps or nebulizers, piezoelectric micropumps offer an attractive alternative to standard pumps. Piezoelectric micropumps are small, lightweight, low power, low cost, and accurate.

This application note describes the implementation of a basic driver circuit for driving a piezoelectric micropump with flow control in an example of fluid delivery. The described system includes a control board, a high voltage driver board, and an mp6 Piezoelectric Diaphragm Micropump.

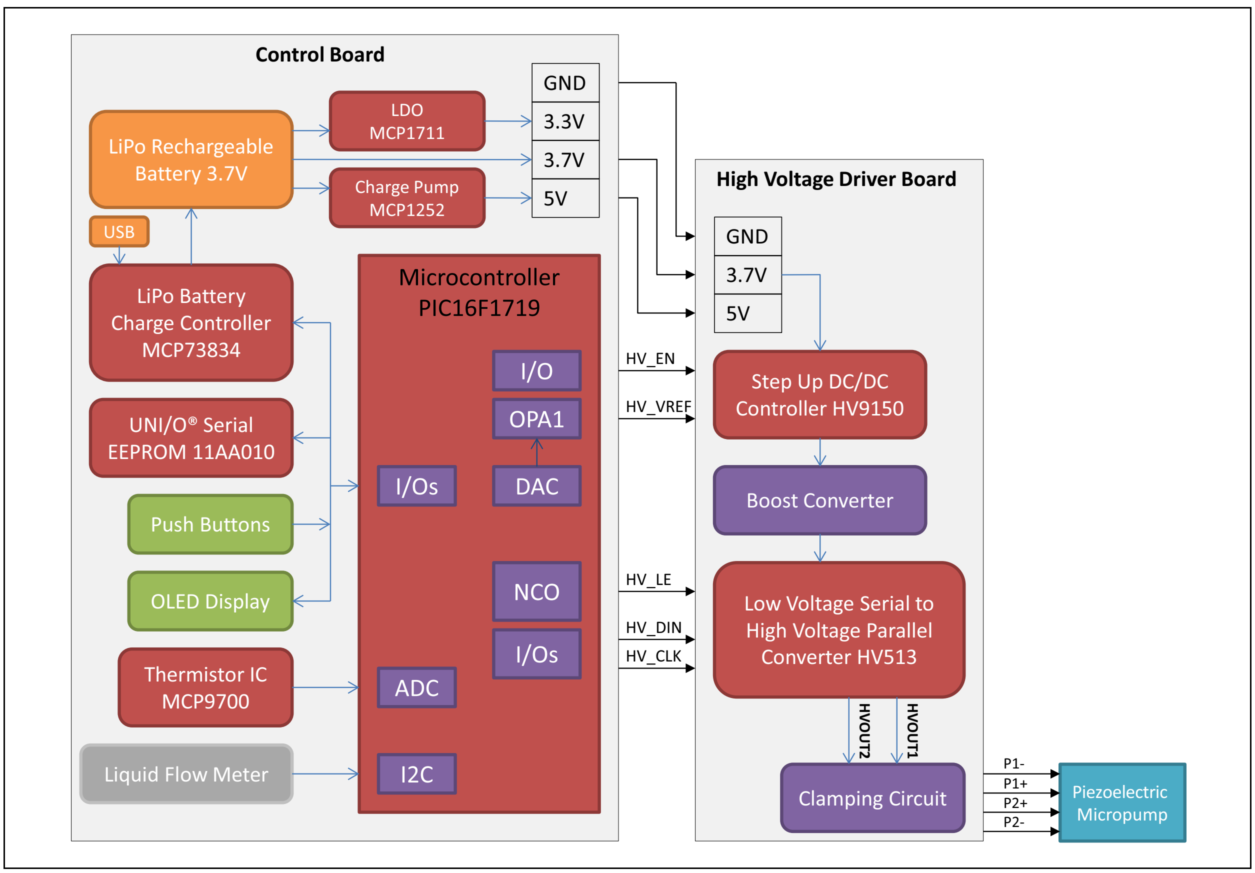
Microfluidics Technology Introduction

Microfluidics deals with miniature devices which can pump, process and control small volumes of fluids. It is an essential part of precision control systems for biomedical analysis and drug delivery. In the drug delivery system, a flow-controlled piezoelectric micropump can provide the actuation source to transfer the drug (liquid or gas) from the drug reservoir to the body with accuracy and reliability.

Basics of Piezoelectric Micropumps

A Piezoelectric micropump is a miniaturized mechanical pumping device employing a piezoelectric actuator in combination with passive check valves. When voltage is applied, a piezoelectric actuator expands or contracts, which causes the liquid or gas to be sucked into or expelled from the pump chamber. The check valves on both sides of the pump chamber govern the flow in one direction.

FIGURE 1: BLOCK DIAGRAM FOR THE PIEZOELECTRIC MICROPUMP DRIVER DEMO



One of the challenges in designing a piezoelectric micropump driver is the requirement for high supply voltage to be applied to the piezoelectric actuator. The following sections demonstrate how to use the Core Independent Peripherals (CIPs) and the intelligent analog peripherals featured in Microchip's 8-bit microcontrollers, along with Microchip's high voltage device family to generate reliable high voltage signals at a specific frequency for driving a piezoelectric diaphragm micropump.

PIEZOELECTRIC MICROPUMP DRIVER DEMO SYSTEM

Microchip's piezoelectric micropump demo (see Figure 12) is comprised of the following components:

- Piezoelectric Micropump
- Control Board
- High Voltage Driver Board

The control board provides the power, the adjustable voltage and frequency control signals to the high voltage driver board. The high voltage driver board delivers the boosted signals in specific waveform on multiple output channels with adjustable peak-to-peak voltage (VPP) and frequency to the piezoelectric micropump. The demo can supply a maximum of 250 V of VPP and a maximum frequency of 300 Hz. This adjustability allows the basic driver to drive different types of piezoelectric micropumps on the market. The Bartels mp6 Piezoelectric Diaphragm Micropump was selected for use in this particular demo.

mp6 Piezoelectric Micropump

The mp6 Piezoelectric Diaphragm Micropump is designed and manufactured by Bartels Mikrotechnik GmbH (www.bartels-mikrotechnik.de), and is supplied by Servoflo Corporation (www.servoflo.com) in North America.

The Bartels mp6 micropump operates on the basic principle of piezoelectric micropump as introduced in the previous section. According to its data sheet, the mp6 combines two piezoelectric actuators, each with two passive check valves, inside a single housing. Hence, the mp6 has an increased priming capability and higher bubble tolerance, and can handle greater back pressure. In the entire pump, the polyphenylsulfone (PPSU) is the only material which contacts the medium.

Control Board

The control board provides the power, the adjustable voltage, and frequency control signals to the high voltage driver board. The demo system is powered by a 3.7V 700mAh Li-Polymer rechargeable battery. The MCP73834 Li-Polymer charge controller manages the battery charging via USB. Through the MCP1711 LDO and the MCP1252 charge pump, the battery supplies 3.3V, 3.7V and 5V voltage sources to different portions of circuitry in the demo. An MCP9700 Linear Active Thermistor IC is used for general purpose temperature measurement. A 11AA010 1K UNI/O® serial EEPROM is used for data storage. An OLED displays the demo's information, such as voltage and frequency settings for the pump. Onboard push buttons are used to change the pump's settings.

In the heart of the control board is a PIC16F1719 8-bit microcontroller. The PIC16F1719 monitors the push buttons' status, as well as the MCP73834's status, utilizing the Interrupt-On-Change (IOC) interfaces. The PIC16F1719 reads the temperature data sent from the MCP9700 utilizing the Analog-to-Digital Converter (ADC) module. The PIC16F1719 can store data, like the pump's settings, to the 11AA010 using a single General Purpose I/O (GPIO) pin. The PIC16F1719 can communicate with a flow meter via an I2C interface for closed-loop flow control. Figure 5 shows the flowchart of the firmware.

CONTROL SIGNALS SENT TO THE HIGH VOLTAGE BOARD

The PIC16F1719 sends five critical control signals to the high voltage driver board:

- HV_EN
- HV_VREF
- HV_DIN
- HV_CLK
- HV_LE

These signals control the VPP and the frequency of the final high voltage driving signals to the mp6 micropump.

HV_EN

The HV_EN signal (generated from a GPIO port) is used to enable or disable the HV9150 Step-Up Controller. This HV9150 is a high output voltage hysteretic mode step-up DC/DC controller that is located on the high voltage driver board.

HV_VREF

The HV_VREF is an adjustable voltage reference signal generated by the PIC16F1719's internal Digital-to-Analog Converter (DAC) module. Due to the limited current drive capability of the DAC, one of the PIC16F1719's internal Operational Amplifier (OPA) modules is used as a buffer on the DAC's voltage reference output. The HV_VREF signal is connected to the HV9150's external reference voltage input (EXT_REF) port to control its boost converter output level. This converter output level controls the VPP level of the final mp6 driving signal.

When the user selects the voltage adjustment menu from the OLED, the VPP of the mp6 driving signals can be linearly increased or decreased by pressing the push buttons to change the DAC voltage reference output value. This allows the user to change the pump's speed while it is running.

HV_DIN

The HV_DIN signal, which is generated from a GPIO port carrying up to 8 bits of data, is connected to the serial data input (DIN) port of the HV513 Parallel Converter. The HV513 is an 8-channel serial-to-parallel converter with high voltage push-pull outputs and is located on the high voltage driver board. The HV513 converts the serial data received on the HV_DIN to parallel data and then outputs them to corresponding high voltage push-pull output channels. Therefore, the HV_DIN defines the final output data used to turn on, or off, up to 8 piezoelectric actuators simultaneously. In this demo only two high voltage output channels (HVOUT1 & HVOUT2) are needed and enabled, because there are two piezoelectric actuators in the mp6 micropump.

HV_CLK

The HV_CLK signal is generated from a GPIO port that is connected to the HV513's clock (CLK) pin. The HV_CLK provides the input clock signal to the HV513 for its 8-bit data shift register. The corresponding 8 bits of data received on the HV_DIN will be shifted through the shift register on the rising edge of the input clock.

HV_LE

The HV_LE signal is connected to the HV513's latch enable (LE) pin. When the HV_LE signal goes high, the data will transfer from the shift register to the latch and appear on the HV513's 8 high voltage output channels. The data in the latch is stored when the HV_LE is low. Therefore, the HV_LE is used to define the frequency of the final high voltage driving signals. The HV_LE signal is generated by the PIC16F1719's Numerically Controlled Oscillator (NCO) module. The NCO outputs a pulse as the latch enable signal at a user-defined frequency. With a 20-bit increment function, the NCO can generate pulses with a frequency that is linearly adjustable with fine resolution. When the user selects the frequency adjustment menu from the OLED, the frequency of the mp6 driving signals can be linearly increased or decreased by pressing the push buttons to change the NCO output frequency. This allows the user to change the pump's speed while it is running.

In Operation

To turn on the micropump, the PIC16F1719 microcontroller first initializes the DAC & OPA to set LE_VREF, and then enables the HV9150 to generate the high output voltage. Next, the PIC16F1719 enables the NCO's interrupt function. After the first NCO interrupt occurs, the first NCO pulse appearing on the HV_LE will clear the HV513 outputs with all 0s (zeros). Then the PIC16F1719 sends out a data 0x01 on the HV_DIN, along with the 4 bits of clock signal on the HV_CLK. The data 0x01 will be clocked into the HV513's shift register serially. When the next NCO interrupt takes place, the second NCO pulse on the HV_LE will latch the data 0x01, received by the HV513's shift register, onto the HV513's parallel output channels. Output channel-1 (HVOUT1) will then go high to the preset high voltage level and the rest of the output channels will remain 0 (zero). The HVOUT1 is fed to a positive biased clamp circuit formed by the components C17, D2, D4, and an RC filter formed by the R15 and the mp6 micropump. The output of the RC filter is connected to the positive terminal (P1+) of the piezoelectric actuator P1 in the mp6. The negative terminal (P1-) of P1 is grounded. During this cycle, P1 is engaged and P1+ will stay high for the period of the NCO interrupt.

In the next cycle, the PIC16F1719 sends out a data 0x02 on the HV_DIN and repeats the rest of the operation for the HV_CLK and the HV_LE (see Figure 2). The output channel-2 (HVOUT2) will then go high to the preset high voltage level and the rest of the output channels will remain 0. The HVOUT2 is fed to a positive biased clamp circuit formed by the components C18, D3, D5 and an RC filter formed by R16 and the mp6. The output of the RC filter is connected to the positive terminal (P2+) of the piezoelectric actuator P2 in the mp6 micropump. The negative terminal (P2-) of P2 is grounded.

During this cycle, P2 is engaged and P2+ will stay high for the period of the NCO interrupt. By repeating the above operations, the P1 and P2 piezoelectric actuators are alternatively engaged at the NCO's frequency and the mp6 micropump is turned on.

The high voltage driving signals presented on the HVOUT1 & HVOUT2 are square waves from 0V to preset VPP. The positive biased clamp circuit placed on each HVOUT channel is designed to pull down the high voltage driving signal to -50V (see Figure 3) as required by the mp6's specification. The RC filters placed at the output of the clamp circuits round the edges of the square waves (see Figure 4). With the edges rounded off, the high voltage driving signals will drive the piezoelectric actuators more gently than square waves would and thus create less audible noise.

FIGURE 2: SIGNAL TIMING WAVEFORM FOR HV_DIN, HV_CLK, HV_LE

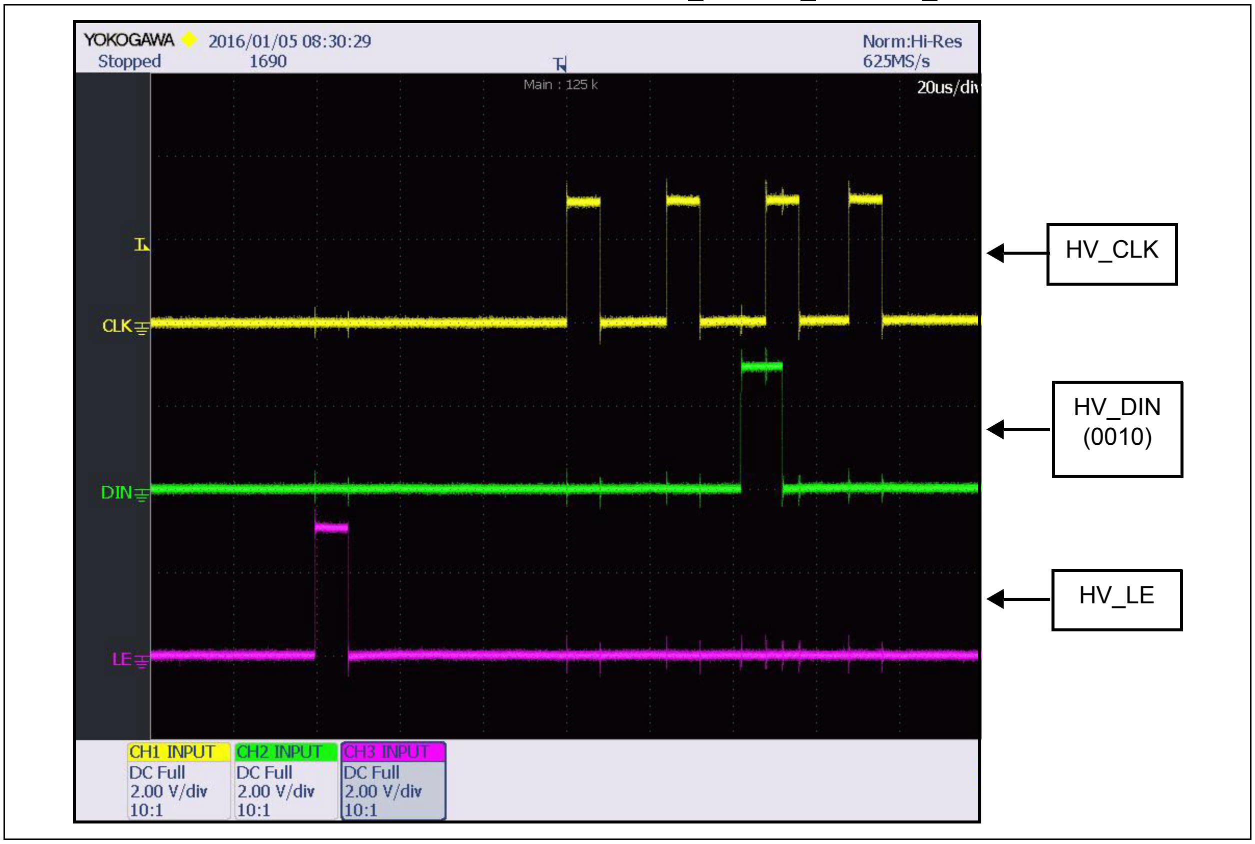


FIGURE 3: SQUARE WAVE OF THE DRIVING SIGNALS

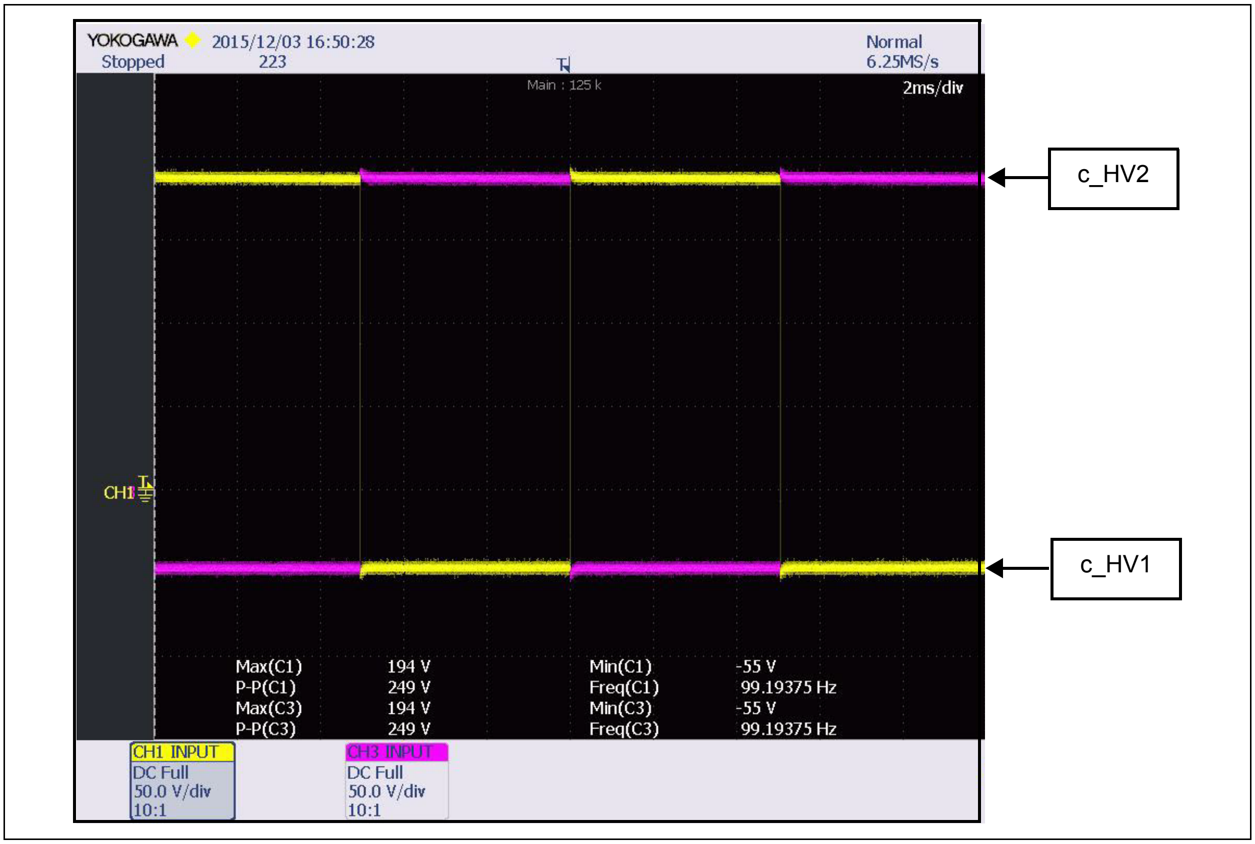


FIGURE 4: ROUNDED SQUARE WAVE OF THE DRIVING SIGNALS

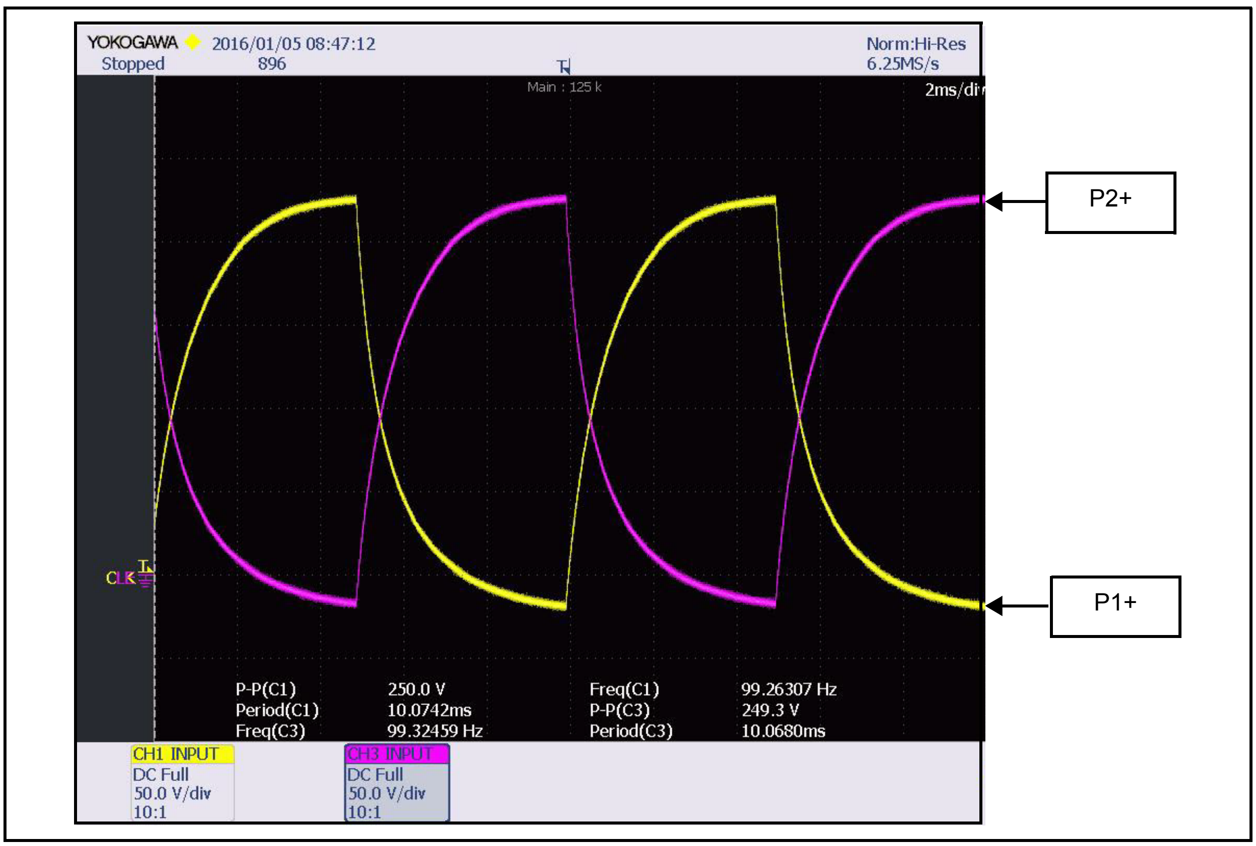
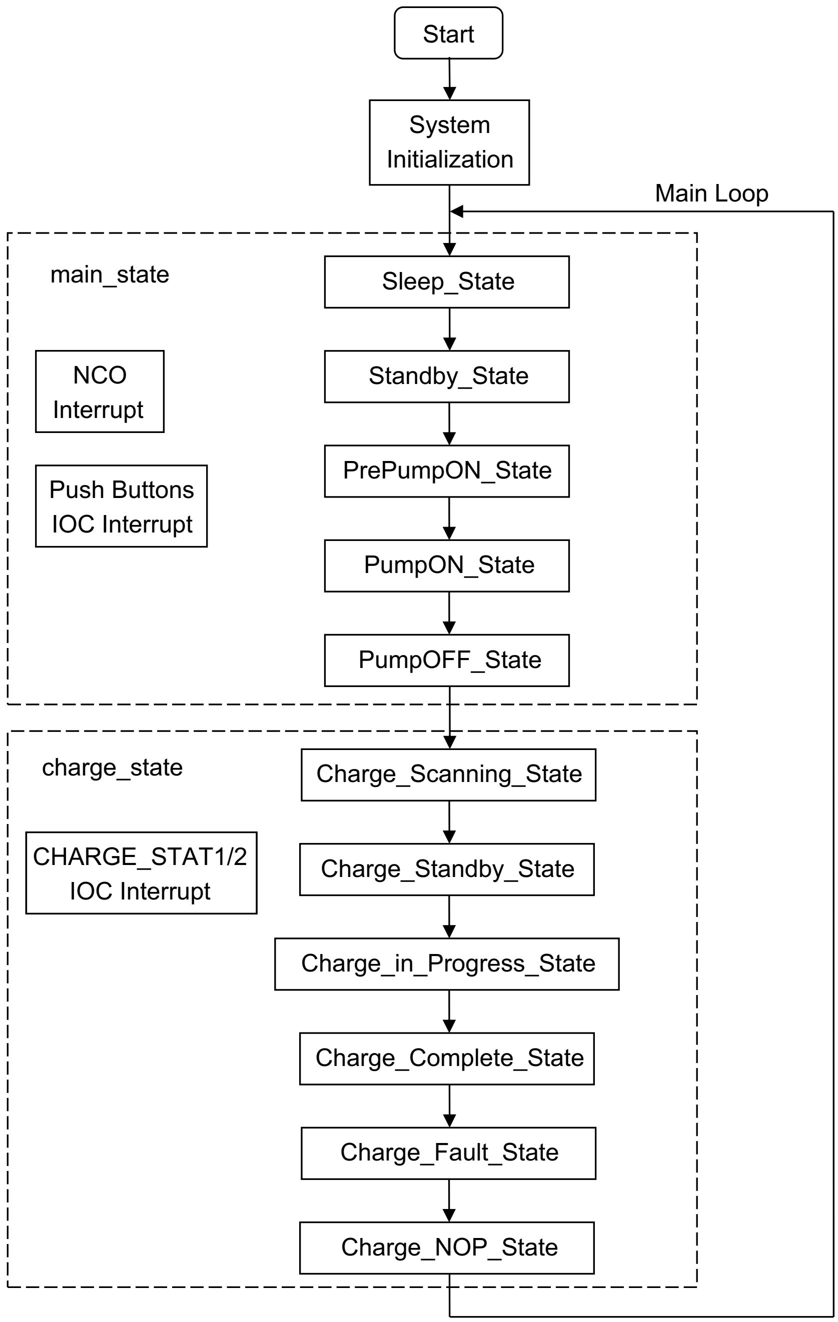


FIGURE 5: FIRMWARE PROCESS FLOWCHART



High Voltage Driver Board

The high voltage driver board delivers the boosted signals in specific waveforms on dual output channels, with adjustable peak-to-peak voltage and frequency, to the piezoelectric micropump. Both pulse frequency and the peak-to-peak voltage can be controlled by the software.

The high voltage driver board (see Figure 6) consists of two functional blocks:

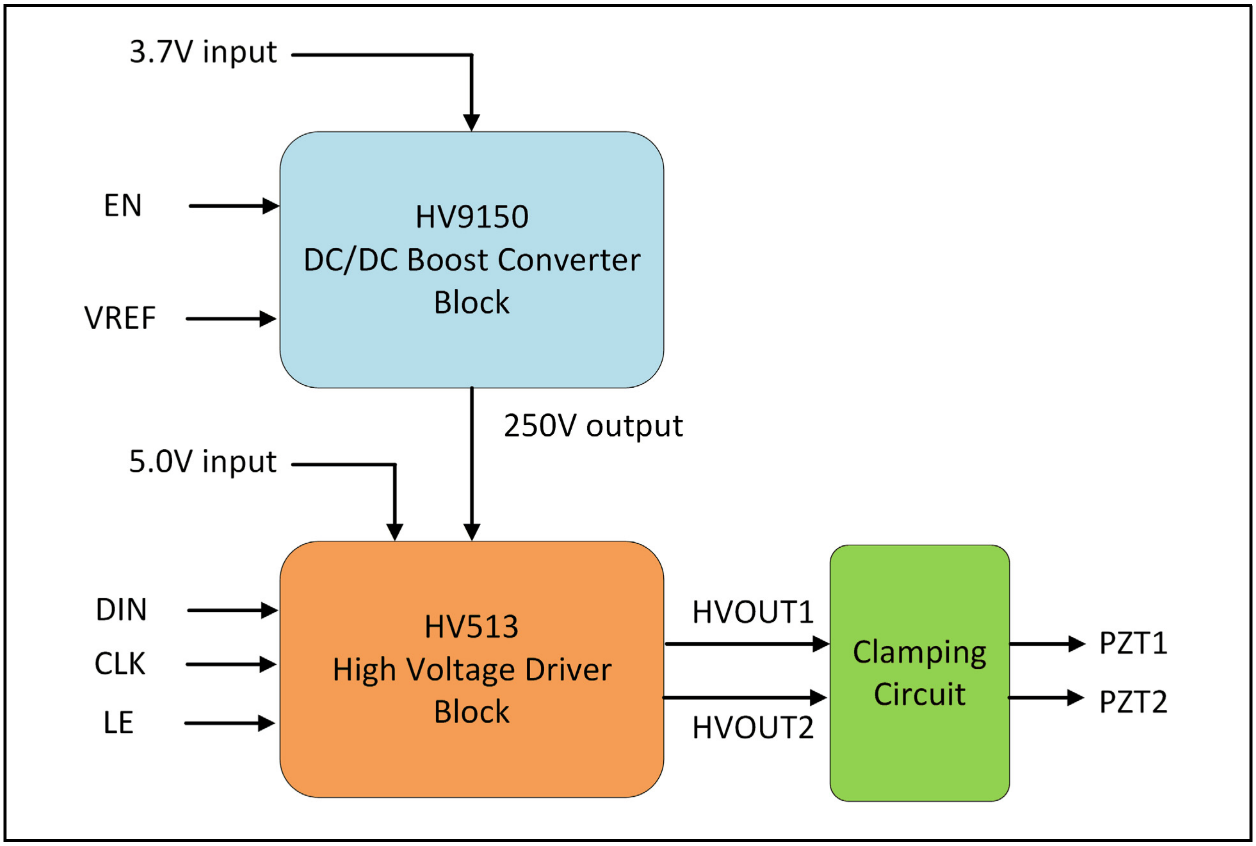
- DC/DC Boost Converter
- High Voltage Push-Pull Driver

The DC/DC boost converter converts the low supply voltage from the battery to 250V high supply voltage. This high supply voltage is used to power the driver IC to actuate the piezoelectric micropump. The driver IC provides a high voltage unipolar push-pull output and a series of pulses are generated from the controller IC to drive the piezoelectric element.

DC/DC BOOST CONVERTER

Microchip's HV9150 boost controller IC is used to convert the 3.7 volt battery supply to a 250V output to power the driver IC (see Figure 7). The HV9150 boost controller is a simple hysteretic converter which operates in conjunction with an external power MOSFET. It has a built-in 3X charge pump converter and its output powers the internal gate driver to drive the external power MOSFET. The charge pump converter multiplies the low input supply voltage by roughly three times with a two stage charge pump circuit. The charge pump output voltage is high enough to drive the gate of the external MOSFET. This converter has a fixed duty cycle and a fixed switching frequency, which improve the system stability. The trade-off is larger ripple at the output voltage. Since the required power to drive the piezoelectric micropump is relatively small, a few microfarads of decoupling capacitor at the high voltage output can reduce the output ripple to an acceptable level.

FIGURE 6: BLOCK DIAGRAM OF HIGH VOLTAGE DRIVER BOARD

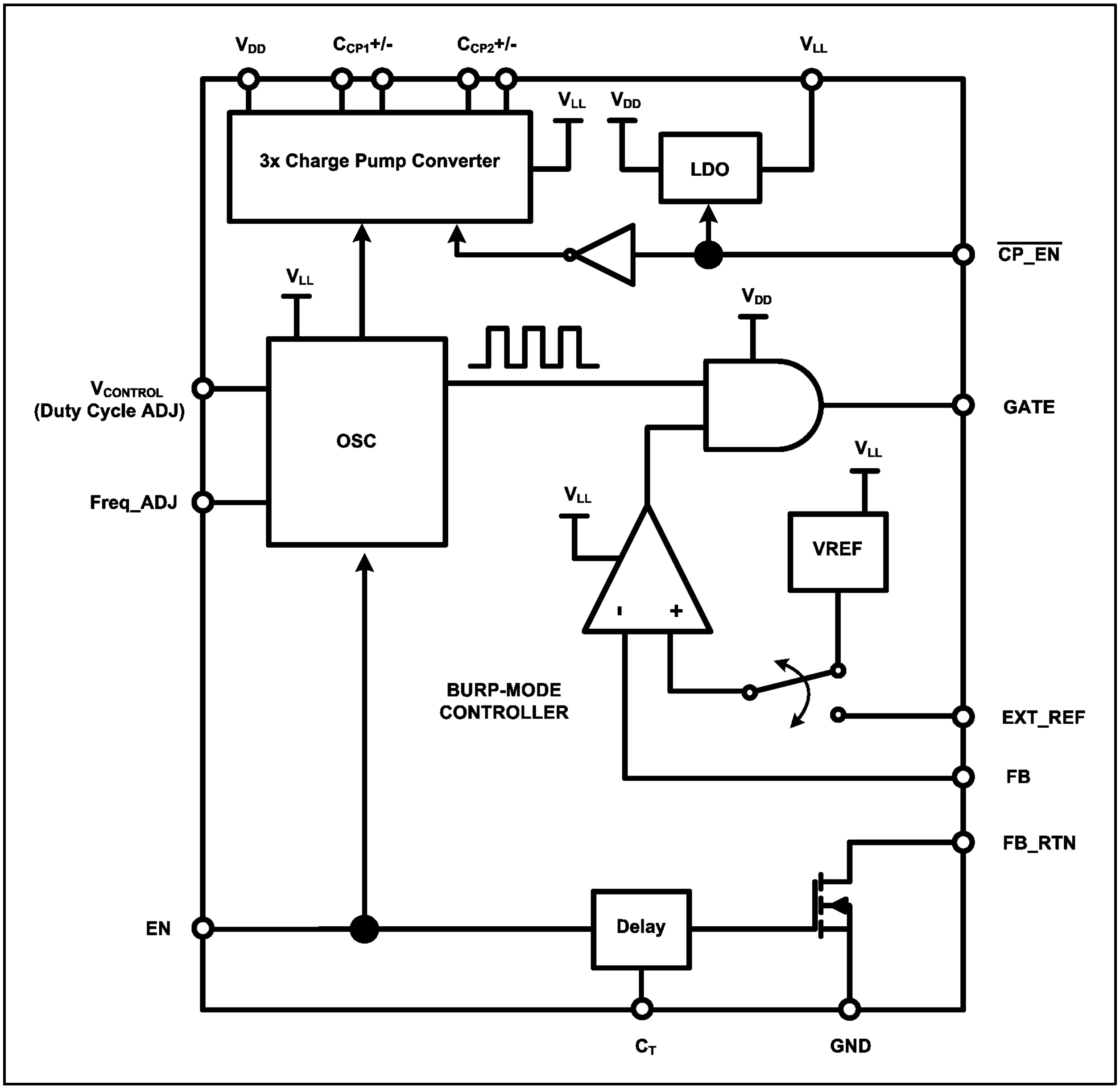


The gate driver sends the controlled pulses to the external power FET in a classic boost converter topology with an inductor, a high voltage rectifier diode, and a storage capacitor. An intermediate voltage is created at about half of the target 250V. There is a good selection of high voltage MOSFETs at this voltage level and many off-the-shelf alternatives can be easily found. Subsequently, this intermediate voltage is further enhanced to reach 250V with an external charge pump doubler circuit. This charge pump circuit is formed with two additional rectifier diodes and two storage capacitors (see Figure 8). The 250V high voltage output is monitored by the controller via the 7.5M feedback resistor network. The high feedback resistor value minimizes the idle power consumption for low power application.

The HV9150 Step-Up Controller has an option to use an external reference voltage for a high-precision output voltage. The user can program the output voltage of the DAC in the PIC® microcontroller, and connect the DAC output to the external reference pin of the HV9150 so that the high voltage output can be adjusted in the software. This will allow the same circuit to accommodate a piezoelectric micropump actuator that might have different characteristics and requirements.

An enable function is also available to enable/disable the boost controller IC for power sensitive applications. The boost controller can be turned off by setting the EN pin to 0 (zero).

FIGURE 7: BLOCK DIAGRAM OF THE HV9150 BOOST CONTROLLER



HIGH VOLTAGE PUSH-PULL DRIVER

The HV513 is a low voltage serial to high voltage parallel converter with a push-pull high voltage output structure. This device has been designed to drive small capacitive loads such as piezoelectric actuators. The HV513 consists of an 8-bit shift register, 8 latches, and control logic to perform the polar select and blanking of the outputs (see Figure 9). Data is shifted through the shift register on the low to high transition of the clock. In this piezoelectric micropump application the blank, polarity, high impedance, and short circuit pins are not used. Only one data signal and two control signals, Data In (DIN), Latch Enable (LE) and Clock (CLK), are needed to send the data from the microcontroller to the driver IC.

FIGURE 8: TOPOLOGY OF TWO STAGE BOOST CONVERTER (EXTERNAL CIRCUIT)

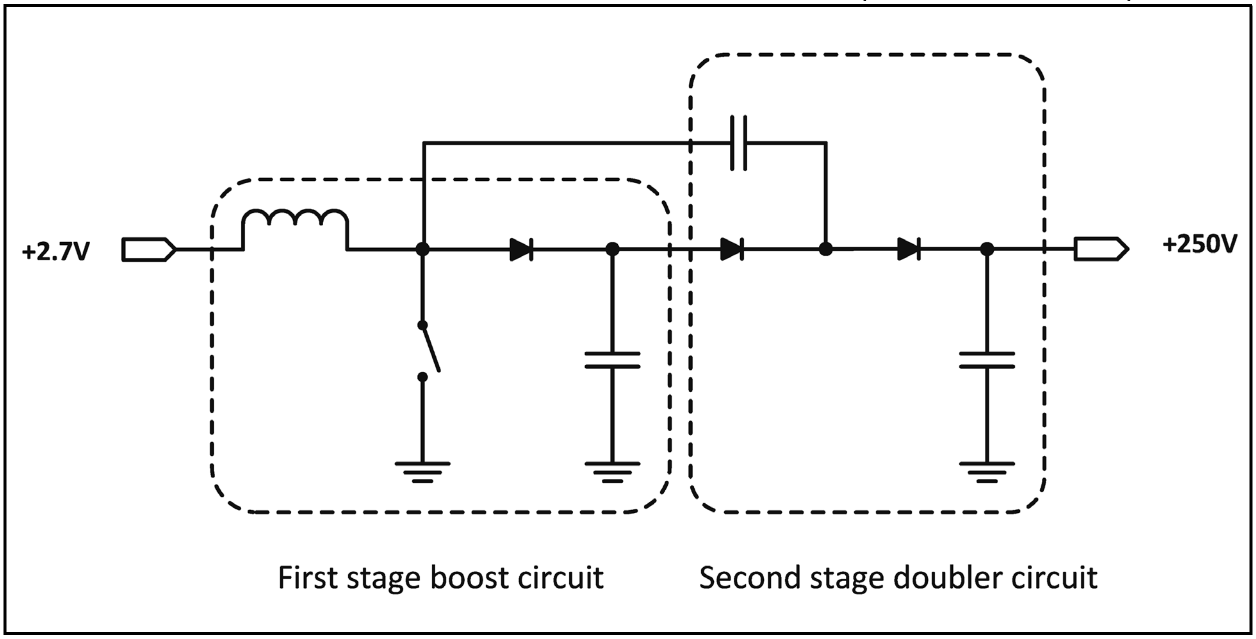
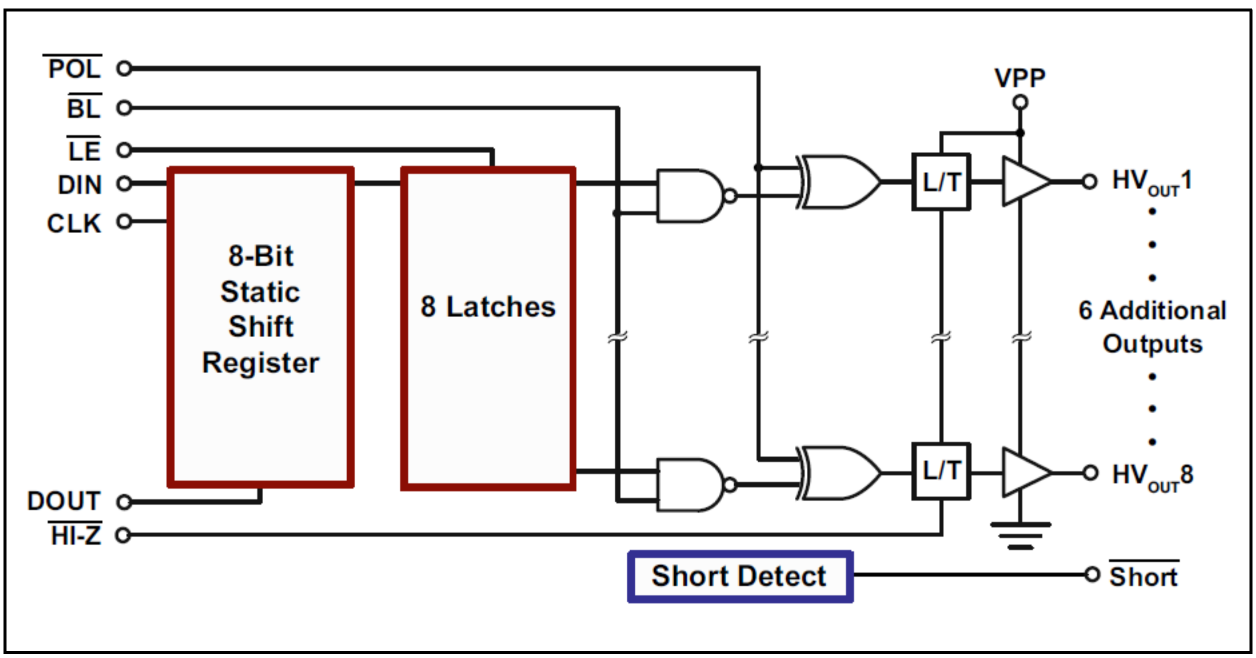


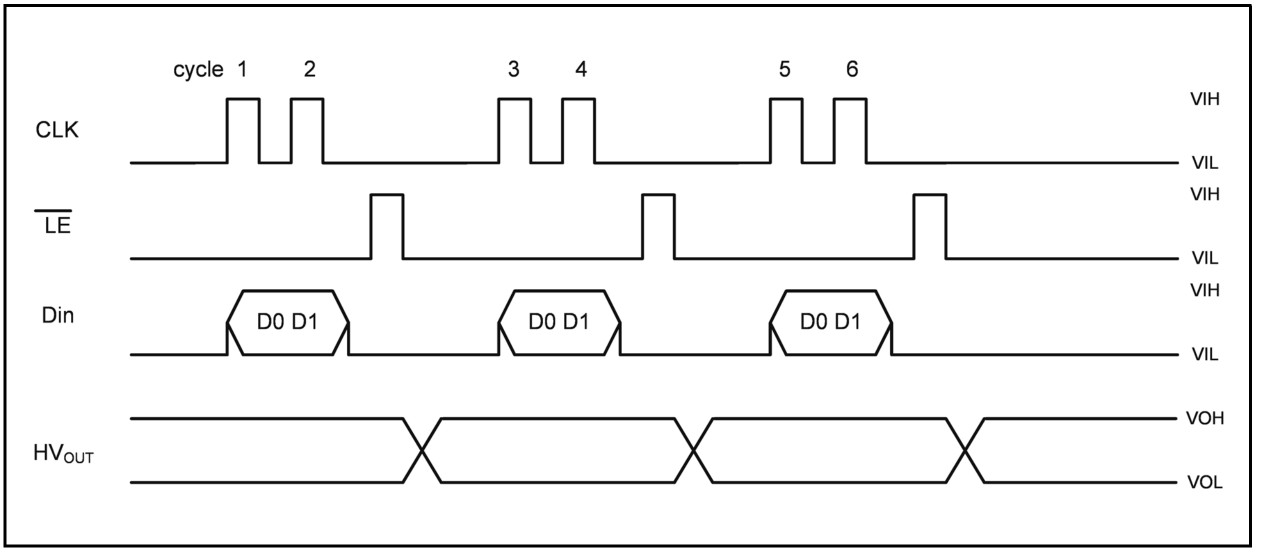
FIGURE 9: FUNCTIONAL BLOCK DIAGRAM OF HV513 HIGH VOLTAGE DRIVER



This driver IC requires a 5V supply for its 5V logic input signal, and a high voltage supply ranging from 50V to 250V for its high voltage output driver. The input serial-to-parallel shift register receives the data through the Data In and Clock pins. After the last data bit has been successfully transmitted to the shift register, the user must insert a single pulse at the Latch Enable pin to load the new data to take affect at the high voltage output (see Figure 10). Since only two channels among the available eight channels are used in this application, the HV513 driver can be treated and operated as a 2-channel driver. The HV513 shift register accepts serial data up to 8MHz and has plenty of room for this piezoelectric micropump application (that requires only a hundred Hertz of output switching). This driver can be seen as a simple high voltage level translator and all output transitions are controlled by the microcontroller. Hence, all output pulse timing and transitions must be maintained and tracked by the microcontroller.

With no load, the HV513's high voltage output can swing between 0V and 250V at tens of kHz. When the output is loaded with the piezoelectric actuator, the output switching frequency will be limited by the rise/fall time of the output pulses and the output power of the DC/DC boost converter. The current design is optimized to work with an 8.2nF load in 100Hz of switching frequency.

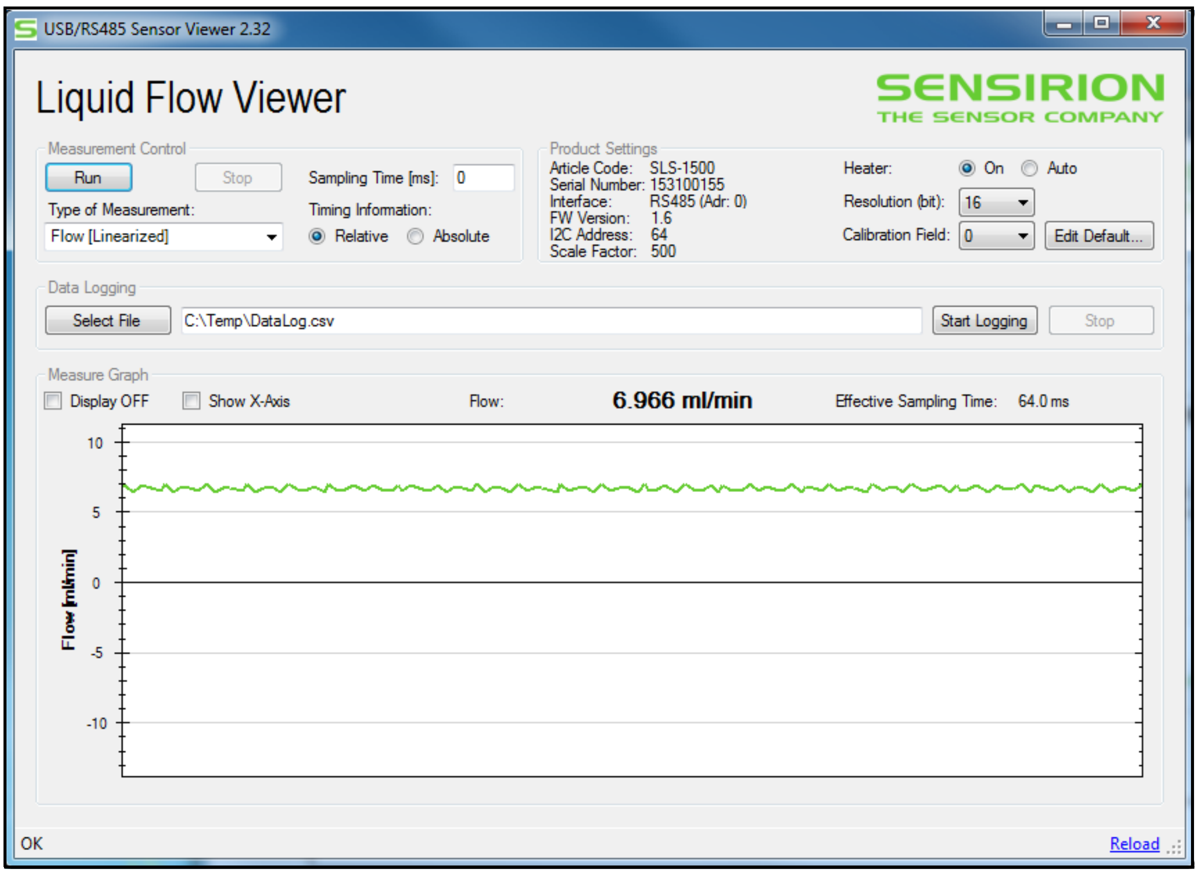
FIGURE 10: ROUNDED SQUARE WAVE OF THE DRIVING SIGNALS



Demo Application Example

Figure 13 shows an application example for testing and evaluation of the piezoelectric micropump driver demo board. An infusion bag and a medication syringe are connected to the mp6 micropump via a 3-way stopcock. The mp6 micropump is able to pump the liquid out of either container in a controlled manner. The flow rate can be manually adjusted by using the push buttons on the control board to change the voltage or frequency setting of the driving signal. A Sensirion SLS-1500 liquid flow meter and associated software GUI are used to measure the flow rate. While pumping the test liquid (water) out of the infusion bag the flow rate is measured at around 7 ml/min (see Figure 11) with the driving signal set to 250VPP and 100Hz.

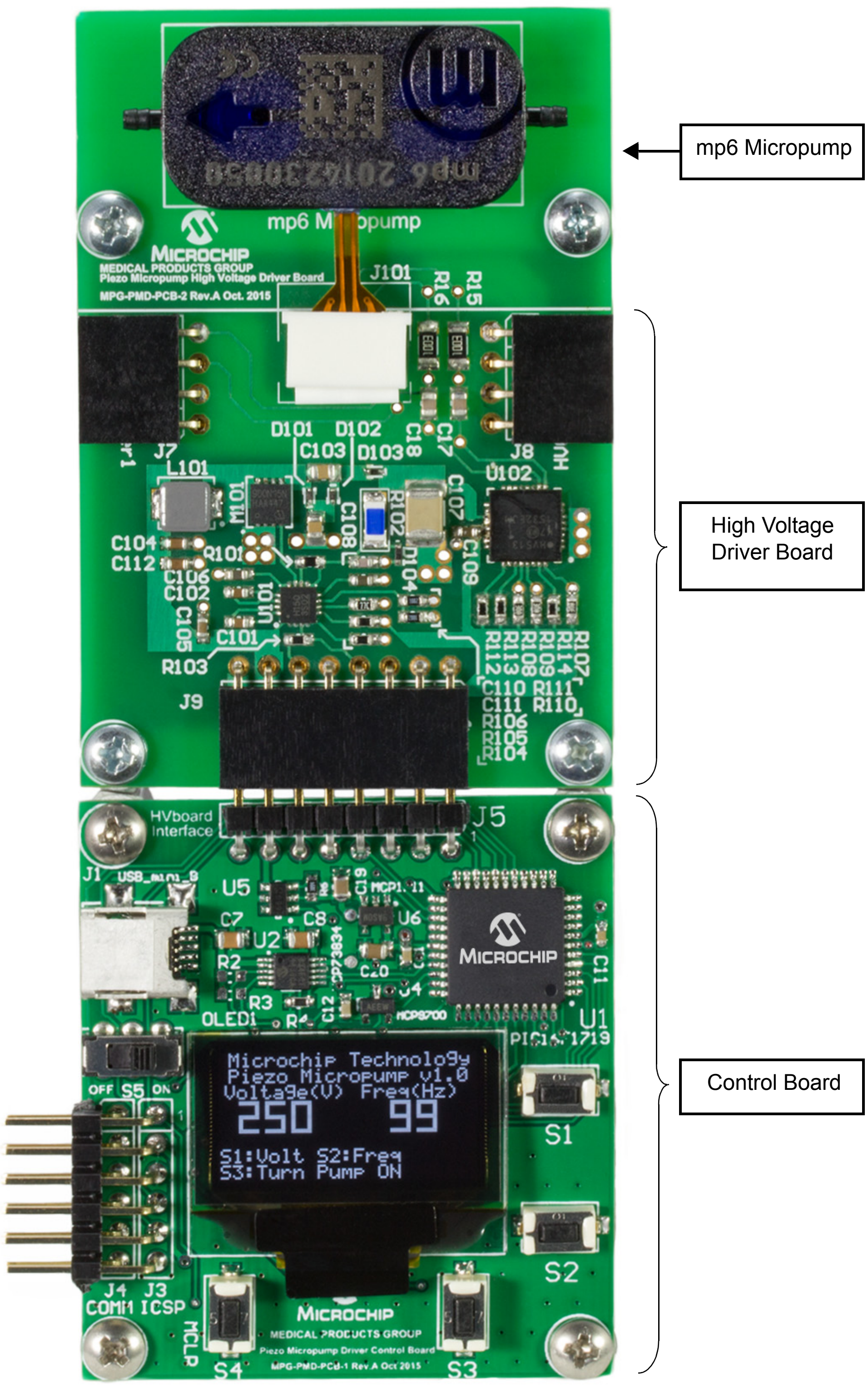
FIGURE 11: FLOW RATE MEASURED BY THE SENSIRION SLS-1500 LIQUID FLOW METER



APPENDIX A: PIEZOELECTRIC MICROPUMP DEMO IMAGE

Figure 12 shows the piezoelectric micropump demo control board and the high voltage driver board with the micropump.

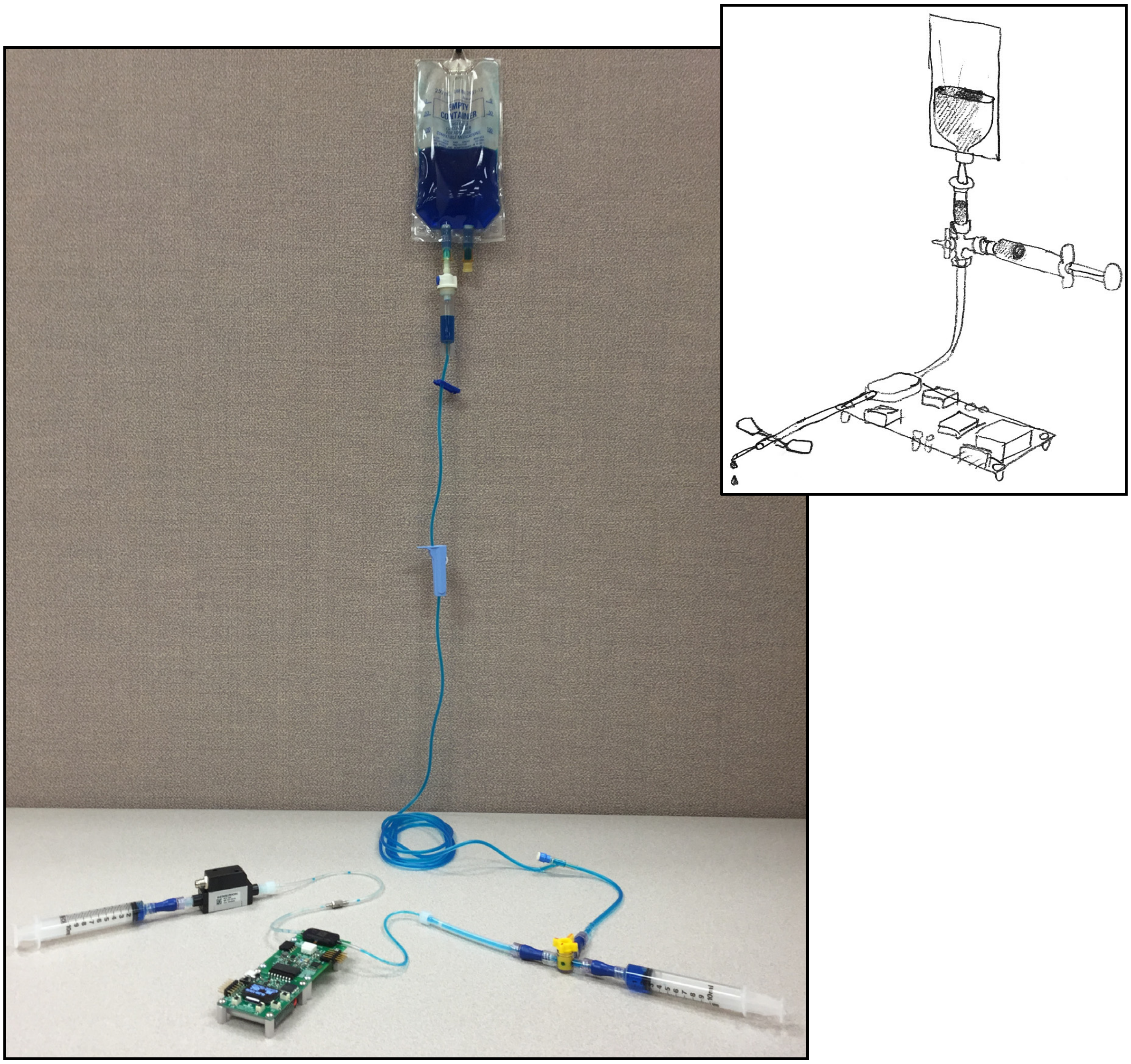
FIGURE 12: PIEZOELECTRIC MICROPUMP DEMO BOARD PICTURE



APPENDIX B: PIEZOELECTRIC MICROPUMP DEMO APPLICATION EXAMPLE

Figure 13 shows the piezoelectric micropump demo application example with infusion bag, medication syringe, and flow sensor connected to the demo board.

FIGURE 13: PIEZOELECTRIC MICROPUMP DEMO APPLICATION EXAMPLE



APPENDIX C: PIEZOELECTRIC MICROPUMP DEMO APPLICATION EXAMPLE

Figure 14 shows the schematic of the piezoelectric micropump demo high voltage driver board.

FIGURE 14: PIEZOELECTRIC MICROPUMP DEMO HIGH VOLTAGE DRIVER BOARD SCHEMATIC

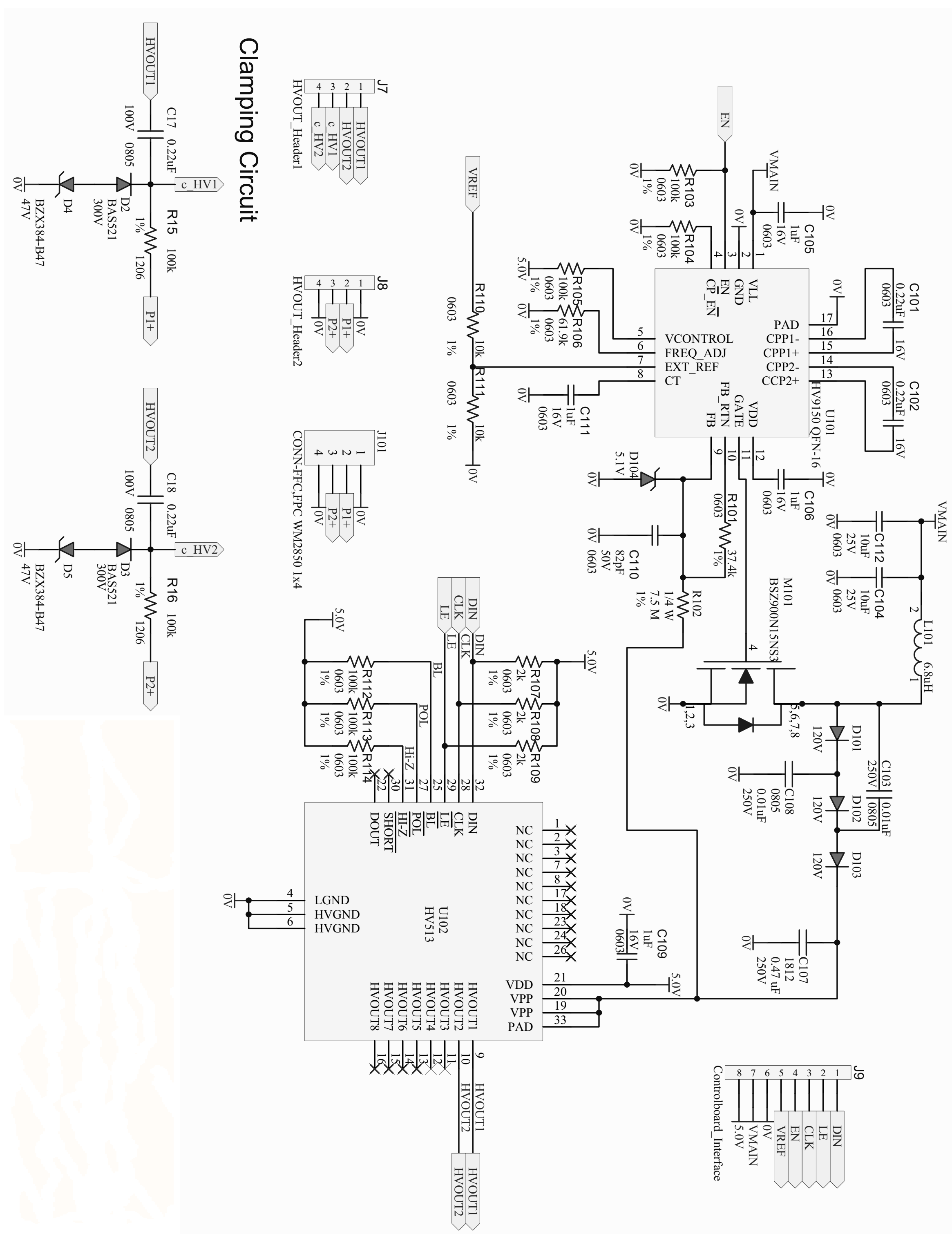
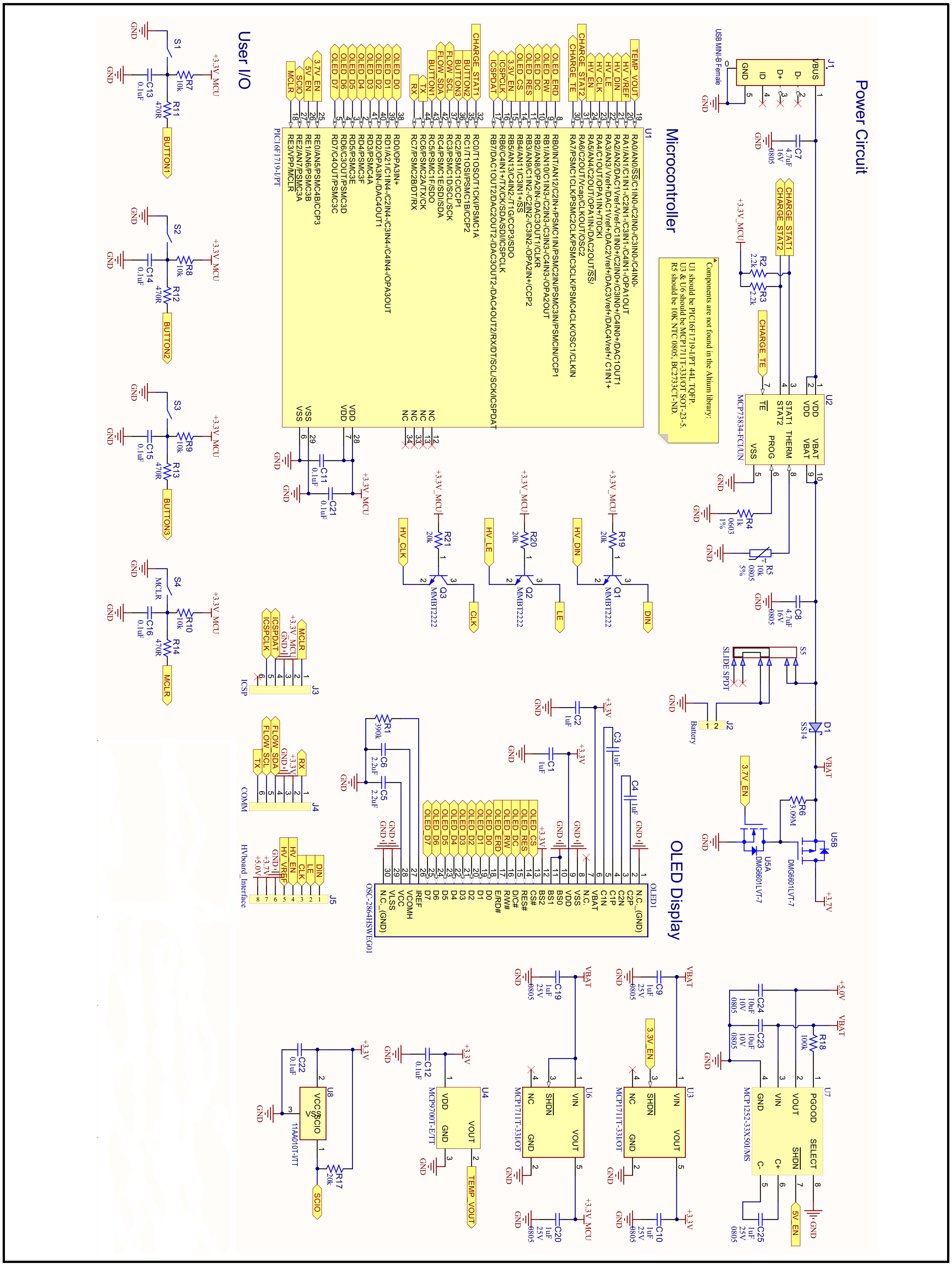


Figure 15 shows the schematic of the piezoelectric micropump demo control board.

FIGURE 15: PIEZOELECTRIC MICROPUMP DEMO CONTROL BOARD SCHEMATIC



APPENDIX D: LAYOUTS

Figure 16 shows the top side and the bottom side layouts of the piezoelectric micropump demo's control board.

FIGURE 16: PIEZOELECTRIC MICROPUMP CONTROL BOARD TOP AND BOTTOM LAYOUTS

Top Sides **Bottom Sides**

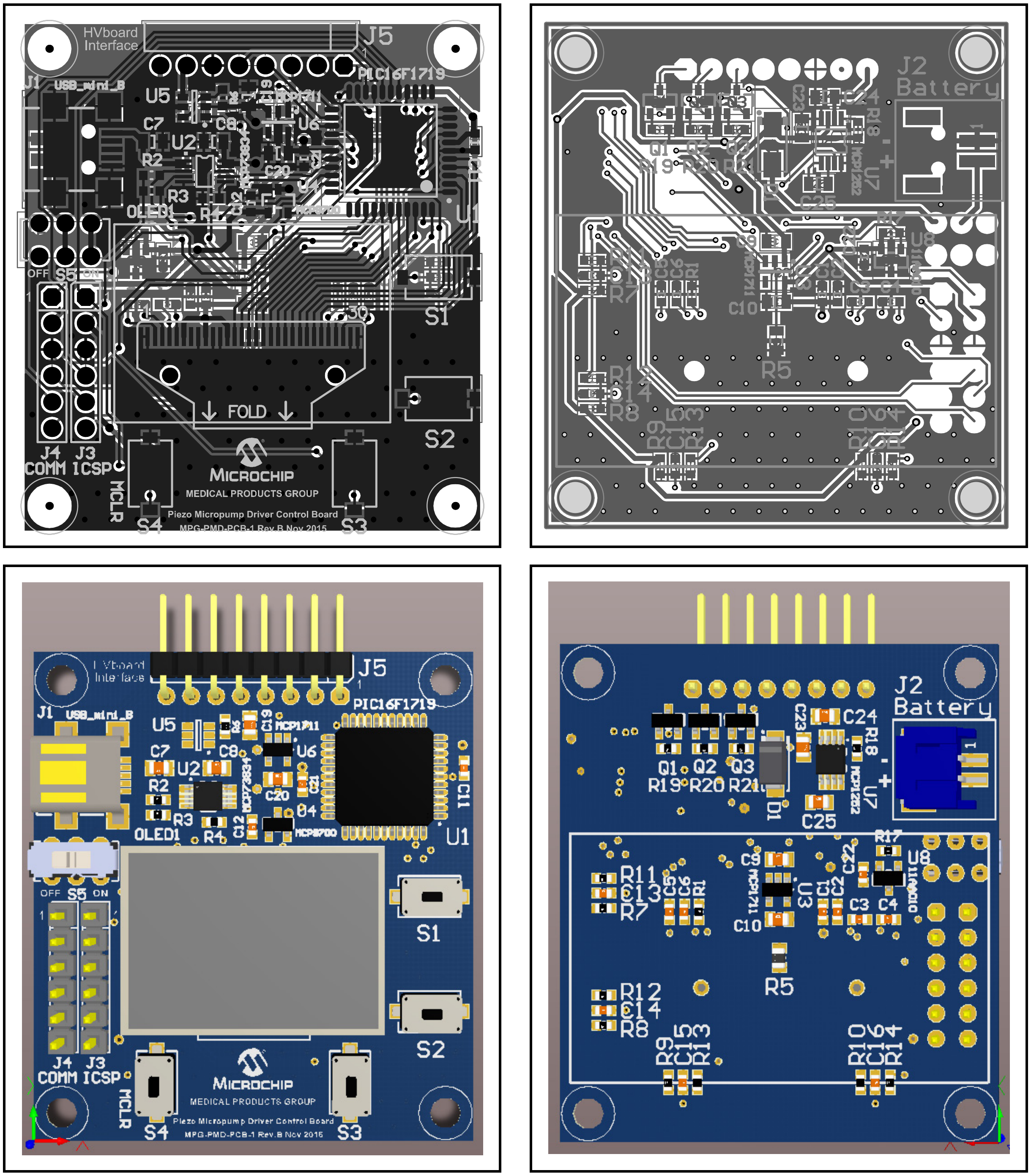
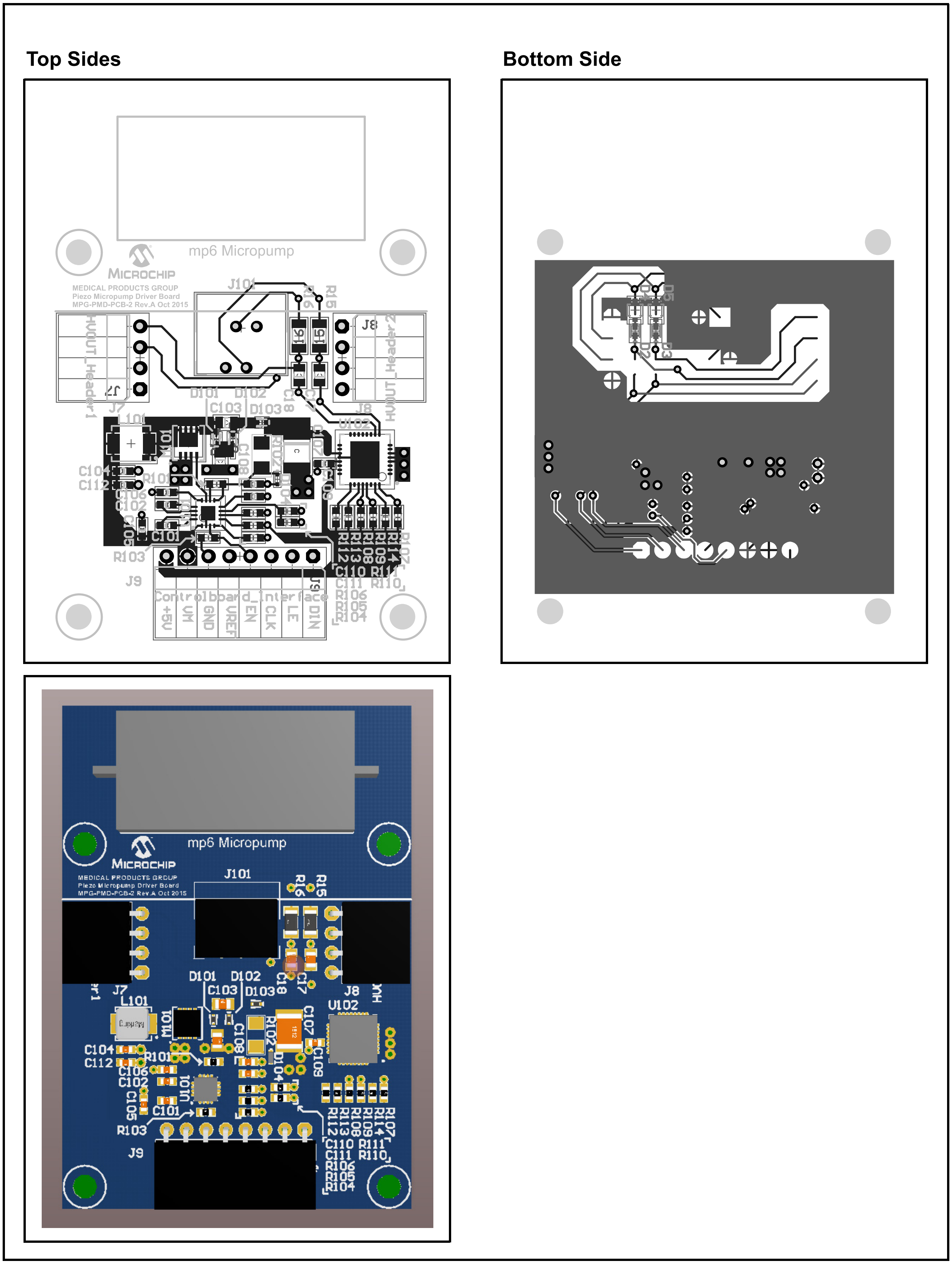


Figure 17 shows the top & bottom side layouts of the piezoelectric micropump demo high voltage driver board.

FIGURE 17: PIEZOELECTRIC MICROPUMP HIGH VOLTAGE DRIVER BOARD BOTTOM LAYOUTS



APPENDIX E: BILL OF MATERIALS

Table 1 shows the bill of materials (BOM) of the piezoelectric micropump demo's control board.

TABLE 1: PIEZOELECTRIC MICROPUMP CONTROL BOARD BOM

Designator	Value	Description	Supplier	Supplier Part Number	Quan.
C1, C2, C3, C4	1 µF	CAP CER 1UF 16V X7R 0603	Digi-Key®	587-1241-1-ND	4
C5, C6	2.2 µF	CAP CER 2.2UF 16V X5R 0603	Digi-Key	445-5157-1-ND	2
C7, C8	4.7 µF	CAP CER 4.7UF 16V Y5V 0805	Digi-Key	PCC2232TR-ND	2
C9, C10	1 µF	CAP CER 1UF 25V X7R 0805	Digi-Key	478-6357-2-ND	2
C11, C12, C13, C14, C15, C16, C21, C22	0.1 µF	CAP CER 0.1UF 16V X7R 0603	Digi-Key	478-1239-1-ND	8
C19, C20, C25	1 µF	CAP CER 1UF 25V X7R 0805	Digi-Key	478-6357-2-ND	3
C23, C24	10 µF	CAP CER 10UF 10V X7R 0805	Digi-Key	445-6857-1-ND	2
D1	SS14	DIODE SCHOTTKY 40V 1A SMA	Digi-Key	SS14CT-ND	1
J1	UX60-MB-5ST	Connector Receptacle USB - mini B 2.0 5 Position SMD RA	Digi-Key	H2959CT-ND	1
J2	S2B-PH-SM4-TB(LF)(SN)	CONN HEADER PH SIDE 2POS 2MM SMD	Digi-Key	455-1749-1-ND	1
J3, J4	HDR-2.54 Male 1x6	CONN HEADER 6POS .100 STR 30AU	Digi-Key	609-3272-ND	2
J5	HDR-2.54 Male 1x8	CONN HEADER .100 SINGL R/A 8POS	Digi-Key	S1111E-08-ND	1
OLED1	OSC-2864HSWEG01	OLED Display 128x64 3V	OSD Displays	OSC-2864HS-WEG01	1
Q1, Q2, Q3	MMBT2222A	TRANS NPN 40V 0.6A SOT23	Digi-Key	MMBT2222ATPM-SCT-ND	3
R1	390k	RES SMD 390K OHM 1% 1/10W 0603	Digi-Key	P390KHCT-ND	1
R2, R3	2.2k	RES SMD 2.2K OHM 1% 1/10W 0603	Digi-Key	P2.20KHCT-ND	2
R4	1k	RES SMD 1K OHM 1% 1/10W 0603	Digi-Key	P1.00KHCT-ND	1
R5	10k	Thermistor NTC 10K OHM SMD 0805	Digi-Key	BC2733CT-ND	1
R6	3.09M	RES SMD 3.09M OHM 1% 1/10W 0603	Digi-Key	541-3.09MHCT-ND	1
R7, R8, R9, R10	10k	RES SMD 10K OHM 1% 1/10W 0603	Digi-Key	P10.0KHCT-ND	4
R11, R12, R13, R14	470R	RES SMD 470 OHM 1% 1/10W 0603	Digi-Key	311-470HRCT-ND	4
R17, R19, R20, R21	20k	RES SMD 20K OHM 1% 1/10W 0603	Digi-Key	P20.0KHCT-ND	4
R18	100k	RES SMD 100K OHM 1% 1/8W 0603	Digi-Key	MCT0603-100K-CFTR-ND	1
S1, S2, S3, S4	147873-1	Pushbutton Switches SW TACT SMT J-LEAD 5.0MM	Mouser	506-147873-1	4
S5	EG1271	SWITCH SLIDE SPDT 300MA 30V	Digi-Key	EG1918-ND	1
U1	PIC16F1719	Cost Effective 8-Bit Intelligent Analog Flash MCU 44L TQFP	Microchip	PIC16F1719-I/PT	1
U2	MCP73834	Stand-Alone Linear Li-Ion / Li-Polymer Charge Management Controller 10L MSOP	Microchip	MCP73834-FCI/UN	1
U3, U6	MCP1711	LDO Regulator 3.3V SOT23-5	Microchip	MCP1711T-33I/OTCT	2
U4	MCP9700	Linear Active Thermistor IC SOT23-3	Microchip	MCP9700T-E/TT	1
U5	DMG6601LVT-7	MOSFET N/P-CH 30V 26TSOT	Digi-Key	DMG6601LVT-7DICT-ND	1
U7	MCP1252	Inductorless, Positive-Regulated, Low-Noise Charge Pump 5.0V 8L MSOP	Microchip	MCP1252-33X50I/MS	1
U8	11AA010	1K UNI/O® Serial EEPROM SOT23-3	Microchip	11AA010T-I/TTCT	1

Table 2 shows the BOM of the piezoelectric micropump demo's high voltage driver board.

TABLE 2: PIEZOELECTRIC MICROPUMP HIGH VOLTAGE DRIVER BOARD BOM

Designator	Value	Description	Supplier	Supplier Part Number	Quan.
C17, C18	0.22 µF	CAP CER 0.22UF 100V X7R 0805	Digi-Key	399-6946-1-ND	2
C101, C102	0.22 µF	CAP CER 0.22UF 16V X7R 0603	Digi-Key	445-1318-1-ND	2
C103, C108	0.01 µF	CAP CER 10000PF 250V X7R 0805	Digi-Key	445-2280-1-ND	2
C104, C112	10 µF	CAP CER 10UF 25V X5R 0603	Digi-Key	490-7202-1-ND	2
C105, C106, C109, C111	1 µF	CAP CER 1UF 16V X7R 0603	Digi-Key	587-1241-1-ND	4
C107	0.47 µF	CAP CER 0.47UF 250V X7R 1812	Digi-Key	490-3549-6-ND	1
C110	82 pF	CAP CER 82PF 50V NP0 0603	Digi-Key	490-1425-1-ND	1
D2, D3	BAS521	DIODE GEN PURP 300V 250MA SOD523	Digi-Key	568-6009-1-ND	2
D4, D5	BZX384-B47	DIODE ZENER 47V 300MW SOD323	Digi-Key	568-3830-1-ND	2
D101, D102, D103	CMAD4448 TR	DIODE GEN PURP 120V 250MA SOD923	Digi-Key	CMAD4448 CT-ND	3
D104	DZ2705100L	DIODE ZENER 5.1V 120MW SSSMINI2	Digi-Key	DZ2705100LTR-ND	1
J7, J8	HDR-2.54 Female 1x4	Connector Receptacle 4 Position 0.100" (2.54mm) Gold TH RA	Digi-Key	SAM1225-04-ND	2
J9	HDR-2.54 Female 1x8	Connector Header 8 Position 0.100" (2.54mm) Gold TH RA	Digi-Key	S5483-ND	1
J101	0039532044	CONN FFC FPC TOP 4POS 1.25MM R/A	Digi-Key	WM2850-ND	1
L101	6.8 µH	Inductor-6.8uH Wurth WE LHMI SMD Low Profile High Current Molded Inductor	Digi-Key	732-3335-1-ND	1
M101	BSZ900N15NS3 G	MOSFET N-CH 150V 13A TDSON-8	Digi-Key	BSZ900N15NS3 GTR-ND	1
R15, R16	100k	RES SMD 100K OHM 1% 1/4W 1206	Digi-Key	P100KFCT-ND	2
R101	37.4k	RES SMD 37.4K OHM 1% 1/10W 0603	Digi-Key	P37.4KHTR-ND	1
R102	7.5 M	RES SMD 7.5M OHM 1% 1/4W 1206	Digi-Key	RHM 7.5M AICT-ND	1
R103, R104, R105	100k	RES SMD 100K OHM 1% 1/8W 0603	Digi-Key	MCT0603-100K-CFTR-ND	3
R106	61.9k	RES SMD 61.9K OHM 1% 1/10W 0603	Digi-Key	P61.9KHCT-ND	1
R107, R108, R109	2k	RES SMD 2K OHM 1% 1/10W 0603	Digi-Key	P2.00KHTR-ND	3
R110, R111	10k	RES SMD 10K OHM 1% 1/16W 0603	Digi-Key	A102203CT-ND	2
R112, R113, R114	100k	RES SMD 100K OHM 1% 1/8W 0603	Digi-Key	MCT0603-100K-CFTR-ND	3
U101	HV9150	High Voltage Output Hysteretic Mode Step-up DC/DC Controller 16L VQFN	Microchip	HV9150K6-G	1
U102	HV513	Low Voltage Serial to High Voltage Parallel Converter 32L WQFN	Microchip	HV513K7-G	1

APPENDIX F: WARNINGS, RESTRICTIONS AND DISCLAIMER

This demo is intended solely for evaluation and development purposes. It is NOT intended for medical, diagnostic, or treatment use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer's risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use.

APPENDIX G: REFERENCES

Microchip, *PIC16(L)F1717/8/9 Cost Effective 8-Bit Intelligent Analog Flash Microcontrollers* data sheet (DS40001740)

Microchip, *HV9150 HV Output Hysteretic Mode Step-Up DC/DC Controller* data sheet

Microchip, *HV513 Low Voltage Serial to High Voltage Parallel Converter with 8 High Voltage Push-pull Outputs* data sheet

Servoflo, *mp6 Micropump Datasheet*

Sensirion, *SLS-1500 Liquid Flow Meter Datasheet*

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

QUALITY MANAGEMENT SYSTEM CERTIFIED BY DNV

═ ISO/TS 16949 ═

Trademarks

The Microchip name and logo, the Microchip logo, AnyRate, dsPIC, FlashFlex, flexPWR, Heldo, JukeBlox, KEELOQ, KEELOQ logo, Kleer, LANCheck, LINK MD, MediaLB, MOST, MOST logo, MPLAB, OptoLyzer, PIC, PICSTART, PIC32 logo, RightTouch, SpyNIC, SST, SST Logo, SuperFlash and UNI/O are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

ClockWorks, The Embedded Control Solutions Company, ETHERSYNCH, Hyper Speed Control, HyperLight Load, IntelliMOS, mTouch, Precision Edge, and QUIET-WIRE are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Analog-for-the-Digital Age, Any Capacitor, AnyIn, AnyOut, BodyCom, chipKIT, chipKIT logo, CodeGuard, dsPICDEM, dsPICDEM.net, Dynamic Average Matching, DAM, ECAN, EtherGREEN, In-Circuit Serial Programming, ICSP, Inter-Chip Connectivity, JitterBlocker, KleerNet, KleerNet logo, MiWi, motorBench, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICkit, PICtail, PureSilicon, RightTouch logo, REAL ICE, Ripple Blocker, Serial Quad I/O, SQI, SuperSwitcher, SuperSwitcher II, Total Endurance, TSHARC, USBCheck, VariSense, ViewSpan, WiperLock, Wireless DNA, and ZENA are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

Silicon Storage Technology is a registered trademark of Microchip Technology Inc. in other countries.

GestIC is a registered trademarks of Microchip Technology Germany II GmbH & Co. KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.

ISBN: 978-1-5224-0308-1

Worldwide Sales and Service

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
http://www.microchip.com/support
Web Address:
www.microchip.com

Atlanta
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455

Austin, TX
Tel: 512-257-3370

Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

Cleveland
Independence, OH
Tel: 216-447-0464
Fax: 216-447-0643

Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Novi, MI
Tel: 248-848-4000

Houston, TX
Tel: 281-894-5983

Indianapolis
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608

New York, NY
Tel: 631-435-6000

San Jose, CA
Tel: 408-735-9110

Canada - Toronto
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC

Asia Pacific Office
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon

Hong Kong
Tel: 852-2943-5100
Fax: 852-2401-3431

Australia - Sydney
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

China - Beijing
Tel: 86-10-8569-7000
Fax: 86-10-8528-2104

China - Chengdu
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

China - Chongqing
Tel: 86-23-8980-9588
Fax: 86-23-8980-9500

China - Dongguan
Tel: 86-769-8702-9880

China - Hangzhou
Tel: 86-571-8792-8115
Fax: 86-571-8792-8116

China - Hong Kong SAR
Tel: 852-2943-5100
Fax: 852-2401-3431

China - Nanjing
Tel: 86-25-8473-2460
Fax: 86-25-8473-2470

China - Qingdao
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

China - Shanghai
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

China - Shenyang
Tel: 86-24-2334-2829
Fax: 86-24-2334-2393

China - Shenzhen
Tel: 86-755-8864-2200
Fax: 86-755-8203-1760

China - Wuhan
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

China - Xian
Tel: 86-29-8833-7252
Fax: 86-29-8833-7256

ASIA/PACIFIC

China - Xiamen
Tel: 86-592-2388138
Fax: 86-592-2388130

China - Zhuhai
Tel: 86-756-3210040
Fax: 86-756-3210049

India - Bangalore
Tel: 91-80-3090-4444
Fax: 91-80-3090-4123

India - New Delhi
Tel: 91-11-4160-8631
Fax: 91-11-4160-8632

India - Pune
Tel: 91-20-3019-1500

Japan - Osaka
Tel: 81-6-6152-7160
Fax: 81-6-6152-9310

Japan - Tokyo
Tel: 81-3-6880- 3770
Fax: 81-3-6880-3771

Korea - Daegu
Tel: 82-53-744-4301
Fax: 82-53-744-4302

Korea - Seoul
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or
82-2-558-5934

Malaysia - Kuala Lumpur
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

Malaysia - Penang
Tel: 60-4-227-8870
Fax: 60-4-227-4068

Philippines - Manila
Tel: 63-2-634-9065
Fax: 63-2-634-9069

Singapore
Tel: 65-6334-8870
Fax: 65-6334-8850

Taiwan - Hsin Chu
Tel: 886-3-5778-366
Fax: 886-3-5770-955

Taiwan - Kaohsiung
Tel: 886-7-213-7828

Taiwan - Taipei
Tel: 886-2-2508-8600
Fax: 886-2-2508-0102

Thailand - Bangkok
Tel: 66-2-694-1351
Fax: 66-2-694-1350

EUROPE

Austria - Wels
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

Denmark - Copenhagen
Tel: 45-4450-2828
Fax: 45-4485-2829

France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany - Dusseldorf
Tel: 49-2129-3766400

Germany - Karlsruhe
Tel: 49-721-625370

Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781

Italy - Venice
Tel: 39-049-7625286

Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340

Poland - Warsaw
Tel: 48-22-3325737

Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

Sweden - Stockholm
Tel: 46-8-5090-4654

UK - Wokingham
Tel: 44-118-921-5800
Fax: 44-118-921-5820

07/14/15