Iontophoresis Implementation Using a Low-Cost Microcontroller

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ABSTRACT

Iontophoresis is a process used to deliver drugs through the skin into the body. A transdermal drug is a charged compound driven through the skin by the flow of electrical current. To deliver the correct dosage the current flow through the skin must be actively controlled. This can be performed by means of an automated system.

INTRODUCTION

Iontophoresis is the method of using an electrical current to assist the infusion of a drug through the skin. The advantages to this approach are many. First, the medicine can be dosed at very high levels locally, rather than a lower dose distributed throughout the body. Second, there are far fewer side-effects associated with localized application of the medicine. At very high levels, the efficacy of the medication can be greatly improved. In order to accomplish this, a specially formulated medicine is prepared, which bonds to the electrons and is moved by current through the skin. Historically, this has required significant electronics and a trained operator to monitor the current and the necessary safety features to protect the patient. However, with recent advances in technology, switched mode power supply design, and cost-effective, high-performance microcontrollers, the production of low-cost or single-use dispensers for these drugs has become possible. This proof of concept design uses a low-cost, 8-bit PIC12F683 microcontroller with mixed signal features and some off-the-shelf components.

IMPLEMENTATION

To infuse the drug through the skin, the device must produce sufficient voltages to drive the current level needed for the specific infusion dose rate for the required duration period. The goal is to control the current flow through the skin, but, for safety reasons, the device should ensure that it does not generate excessive voltage. Otherwise, should the device become detached from the patient, breaking the current path, the control electronics would attempt to increase the voltage to maintain the current flow, which could cause discomfort on reattachment.

A boost regulator is used to step up the voltage from a low-voltage battery to sufficient levels to pass the required current through the skin. A discontinuous boost regulator topology was selected as it does not require the processor to provide a pulse at a specific time, allowing the current through the inductor to fall to zero. This simplifies the software development.

The microcontroller is configured with an external asynchronous Reset pin (Master Clear/$\overline{\text{MCLR}}$). Bringing this pin low will reset and wake the microcontroller from a low-power shutdown state (Sleep mode). The software currently goes to Sleep once it completes administering an infusion, and the button connected to the $\overline{\text{MCLR}}$ pin pulls the line low, triggering a wake-up from Sleep mode. When the device is woken from Sleep, it begins executing code from the Reset vector (`0x0000` in program memory), which is the same for any other Reset including power-up. The number of infusions that have been administered is stored in the internal EEPROM, which may be important depending on the implementation and the medication being administered. The circuit uses two AA alkaline cell batteries to provide power to the microcontroller and to the switching regulator.

The software monitors the voltage supplied to the skin using the microcontroller's built-in A/D converter, and compares it against a set threshold. If the voltage exceeds the predefined limit, the microcontroller will stop switching the MOSFET, preventing the voltage from being boosted higher. This feature limits the output voltage to a safe level, should the device become detached from the skin. The predefined limit is set in the software, however there is some scaling of this value as the voltage applied to the skin is greater than what can be applied to an input pin of the microcontroller or can be converted by its A/D converter. The applied voltage is scaled by resistors R1 and R2 as shown in Figure 2 (The Circuit Schematic) to within the supply rails of the microcontroller, 0 and 3V.

The current used in Iontophoresis varies with the medication and, in general, needs to be validated with the particular formulary. The current is controlled by an external resistor, R3, and the internal comparator of the PIC12F683. The comparator threshold is set in the code by defining the desired current level, 0.5 mA-4 mA.

The software tests the comparator output to determine the current level. If the current level exceeds the required level, then the microcontroller does not switch the MOSFET, otherwise the MOSFET is switched to boost the voltage, driving more current through the skin.

The output current is limited to the power available at the input, times the efficiency of the converter, divided by the voltage needed at the output (as shown in Equation 1).

EQUATION 1: THE OUTPUT CURRENT

$$I_{OUT} = P_{in} * \eta / V_{OUT}$$

$$\eta \approx 0.85 \text{ (measured on the demo board)}$$

The duration of the infusion is controlled using the built-in 16-bit hardware timer plus a 16-bit software timer. When the desired dose is reached, the microcontroller stops switching the MOSFET and goes to Sleep to await a button press.

For added patient comfort, the ramp rate of the voltage output during the power-up sequence can be adjusted.

The software for the microcontroller is available from the Microchip web site (www.microchip.com).

FIGURE 1: SOFTWARE FLOWCHART

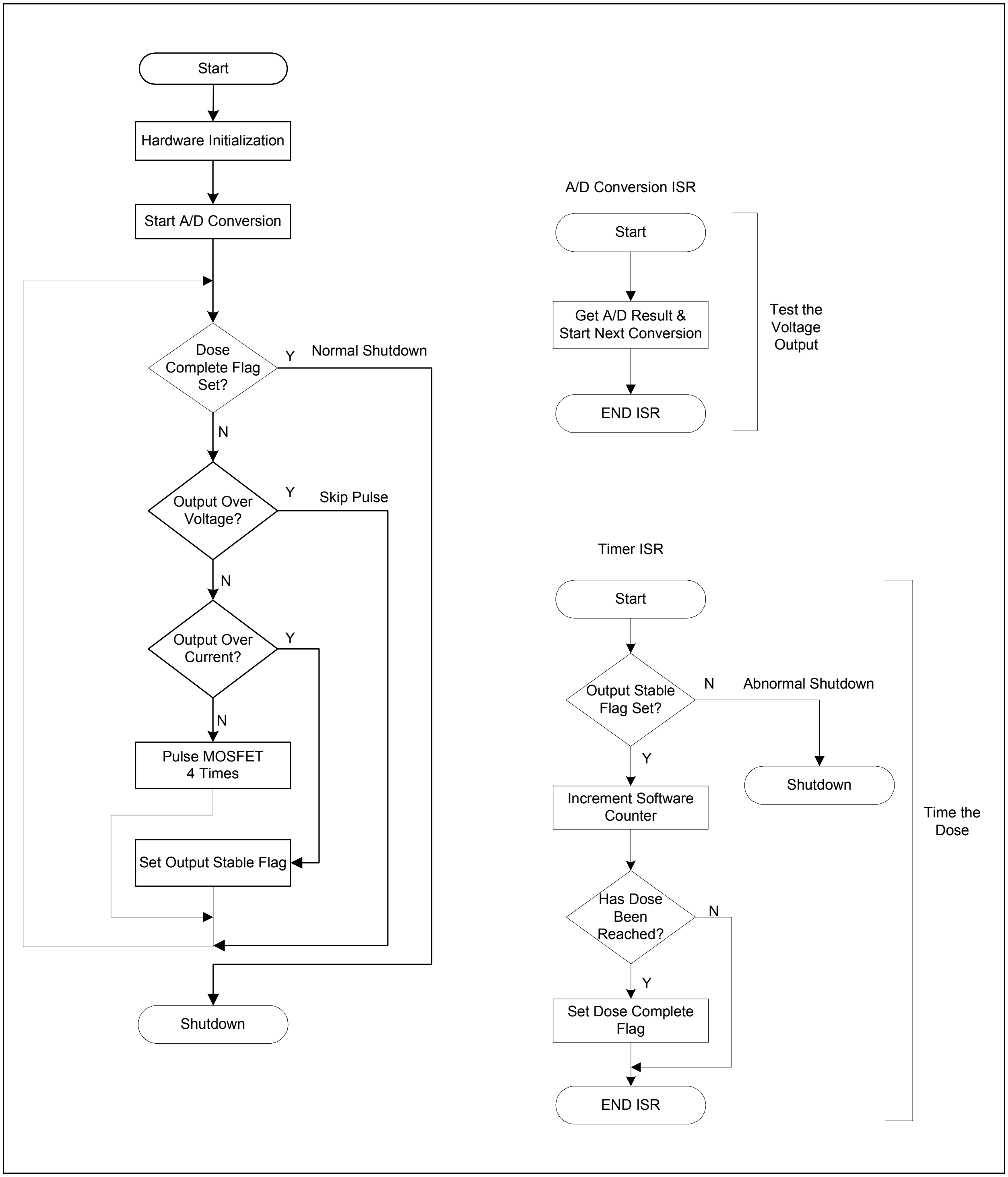
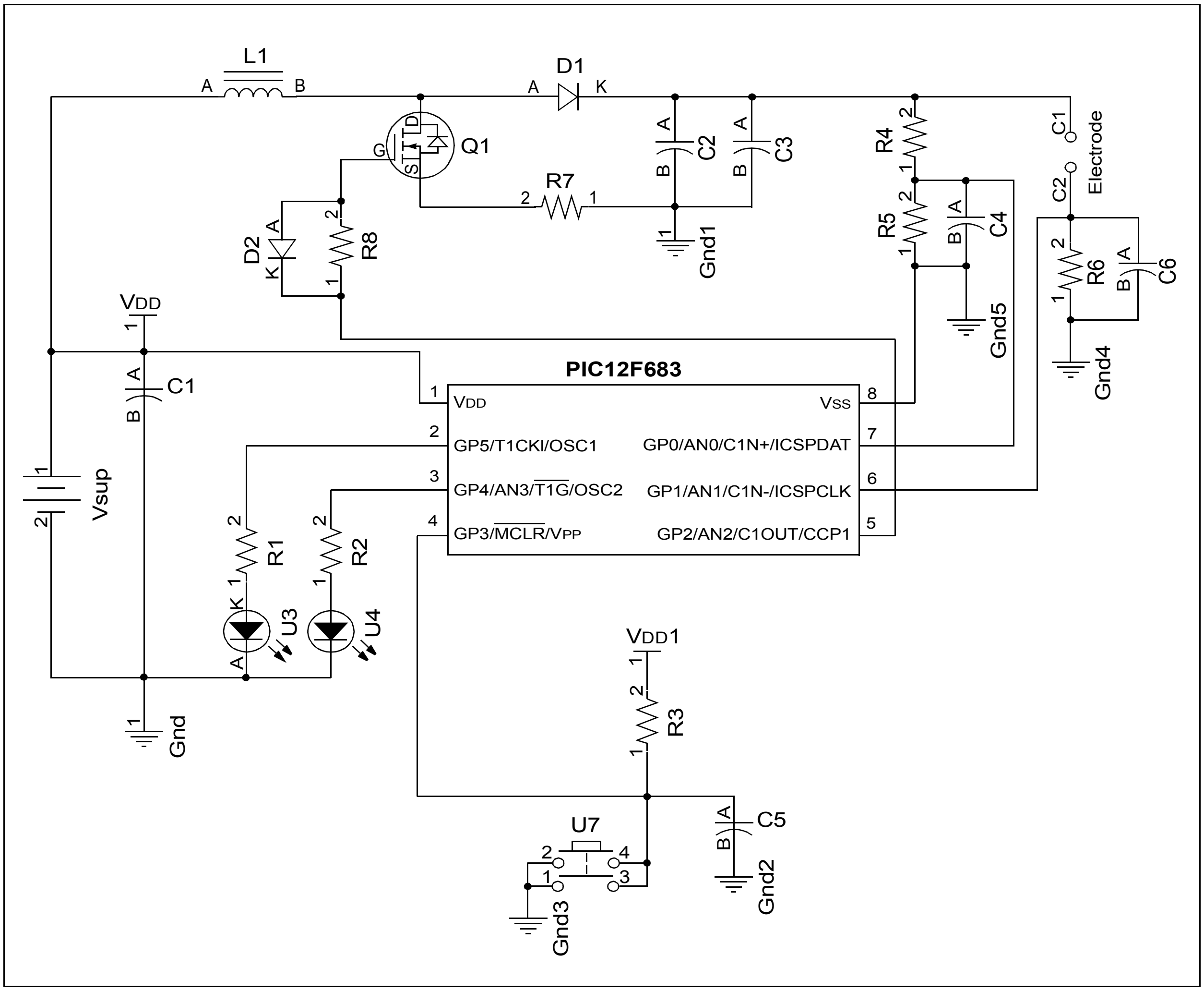


FIGURE 2: THE CIRCUIT SCHEMATIC



In the circuit schematic (Figure 2), Q1 is the main switching transistor. The MOSFET V_{DS} breakdown and the breakdown voltage of D1 should be greater than the maximum desired voltage output of the circuit. When the microcontroller detects that the output current has dropped below the required level, it pulses the MOSFET four times in rapid succession to boost the voltage output. Four pulses are used to generate more current flow and to speed up the rise time under load. Alternately, the PWM can be used to drive the MOSFET which allows higher output from the boost circuit. R6/C6 is the current sense network.

The PIC12F683 was selected as the microcontroller for the device because of its small size, low-cost, internal analog-to-digital converter, fixed voltage reference, integrated comparator, PWM, hardware timer, and internal EEPROM. The fixed voltage reference eliminates the need for a regulator or an external reference, and keeps the design to an 8-pin device to lower cost.

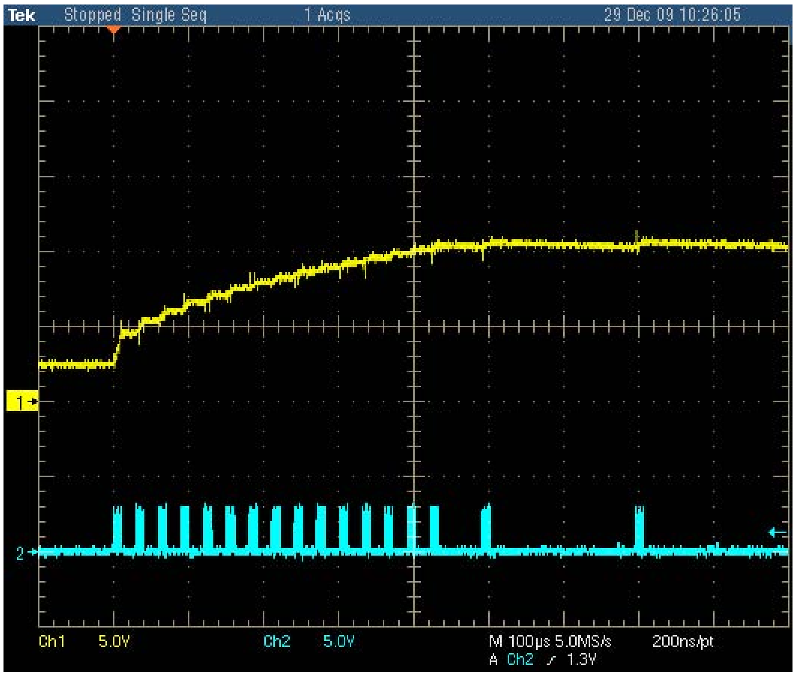
The design also includes two LEDs for the user interface. There is a start button, which is connected to the Reset of the part.

TESTING

Test Results

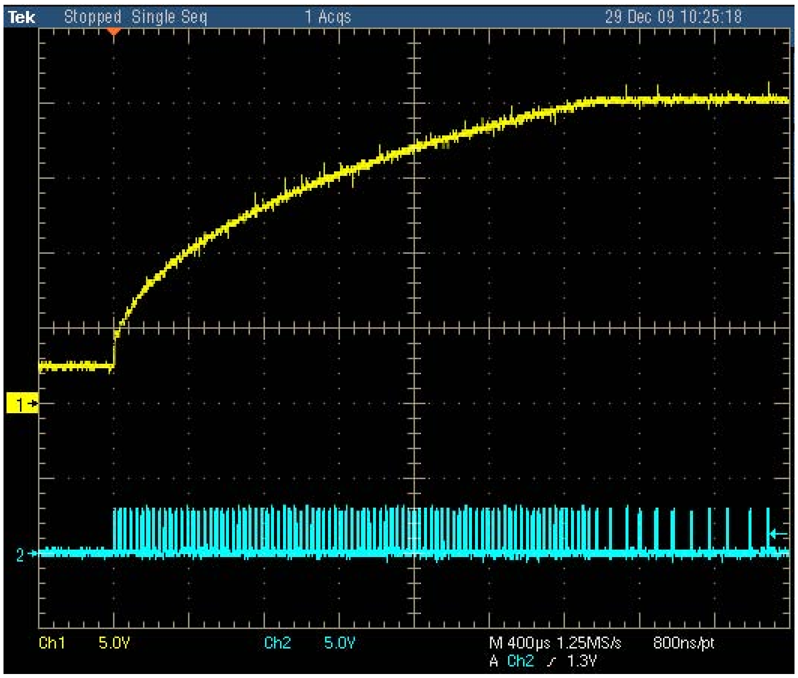
During testing, the following traces were taken:

FIGURE 3: TURN-ON WITH 10K LOAD



Typical start-up condition.
The voltage rises over approximately 0.45 mS until the current set point, then remains at a steady level.
The current loop is set to approximately 1 mA.

FIGURE 4: TURN-ON WITH 20K LOAD



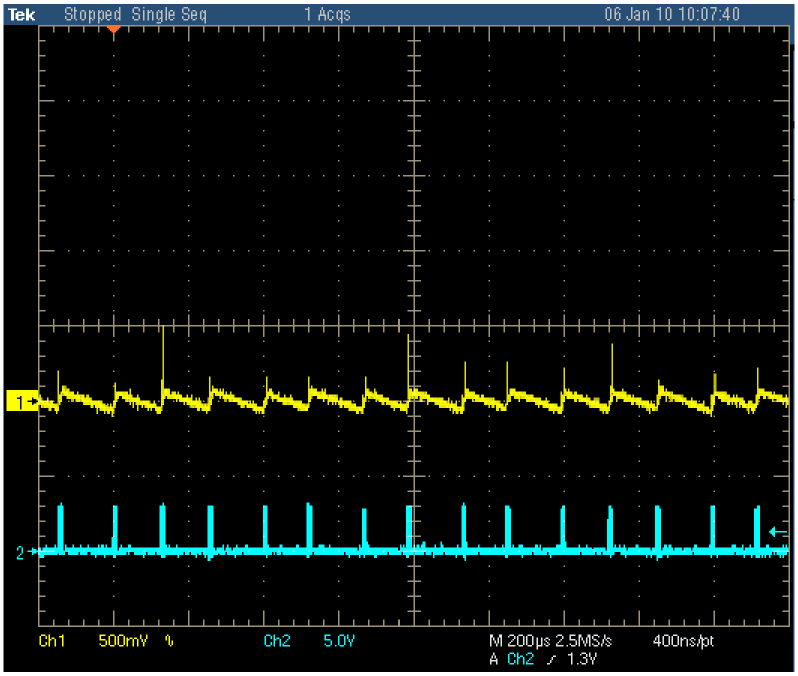
Typical start-up condition.

The output voltage is dependant on the current set point.

For the current set-point of 1 mA, the output voltage should be approximately 20V and has stabilized in 2.6 mS.

Using a 1µF ceramic capacitor as the output capacitor, the voltage ripple is shown in Figure 5.

FIGURE 5: REGULATED OUTPUT AT 20K LOAD (AC COUPLED TO SEE THE RIPPLE)



Conclusions

The electronics required for Iontophoresis can be implemented using a small, low-cost microcontroller to control a DC/DC boost converter to drive a controlled current through the skin. The software-based control can be easily modified for additional features and for changes in the dose and duration without requiring hardware changes.

REFERENCES

AN1114, *Switch Mode Power Supply (SMPS) Topologies.*

APPENDIX A: COMPONENTS LIST

TABLE 1: CIRCUIT COMPONENTS LIST

Component	Value
R1	1 kΩ
R2	1 kΩ
R3	1 kΩ
R4	1 MΩ
R5	36 kΩ
R6	500Ω
R7	0.5Ω
R8	10Ω
C1	10 nF
C2	1 µF
C3	10 nF
C4	10 nF
C5	10 nF
C6	10 nF
L1	10 µH
D1	1N914
D2	1N914
U3	LED
U4	LED
Vsup	3V

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