PIC Chip Boosts Four Rockets Skyward

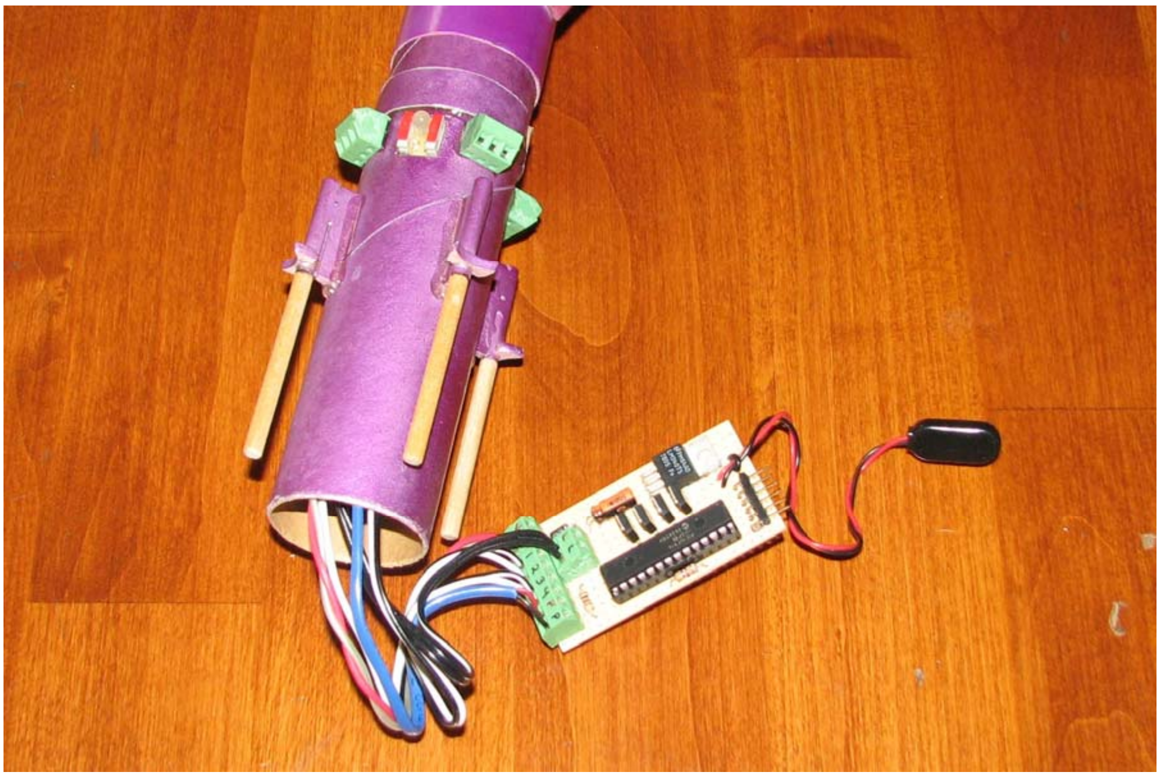
Joe Peck

Almost anyone can build a two-stage model rocket, but Joe Peck took a giant step for rocketeers and added four second stages. Think of them as MIRVs, microcontroller-ignited rocket vehicles. Shortly after the rocket starts its flight, a Microchip Technology MCU detects the absence of a pin attached to the launch platform and sequences through a firing order for the second stages as the booster rocket continues its climb. Mission Control, we have liftoff.

Overview

People of all ages and with a variety of skills can enjoy model rocketry as a fun and exciting hobby. But after launching a few rockets and better understanding what they can do, why not get creative and launch several rockets from one primary rocket, or booster stage? Joe Peck's unusual rocket is really five rockets in one. With the exception of the nose cone, the primary rocket looks much like one hobbyists often launch. In Joe's design, though, the nose-cone section includes four smaller rockets and self-contained launch electronics. The booster rocket launches the whole system and then each of the smaller rockets fly off on their own. Each rocket then returns safely to the ground and the builder can load new rocket engines and launch the rocket "system" again.

The basic circuit comprises a Microchip PIC16F916 microcontroller and four high-current field-effect transistors (FETs). As the rocket leaves its launch pad, it leaves a small metal pin at the launch site. This action opens a pair of electrical contacts and triggers the MCU to ignite each of the four second-stage rockets after a pre-programmed time delay.



WARNING: These build instructions assume familiarity with model-rocket construction, so they do not provide information about how to build the booster stage or the four second-stage rockets. Likewise, this project assumes familiarity with the electrical circuit and components used to safely ignite rocket engines. If you lack this knowledge, DO NOT proceed with this project until you understand basic principles of model rocketry. Rockets and rocket engines can be dangerous if improperly designed and used.

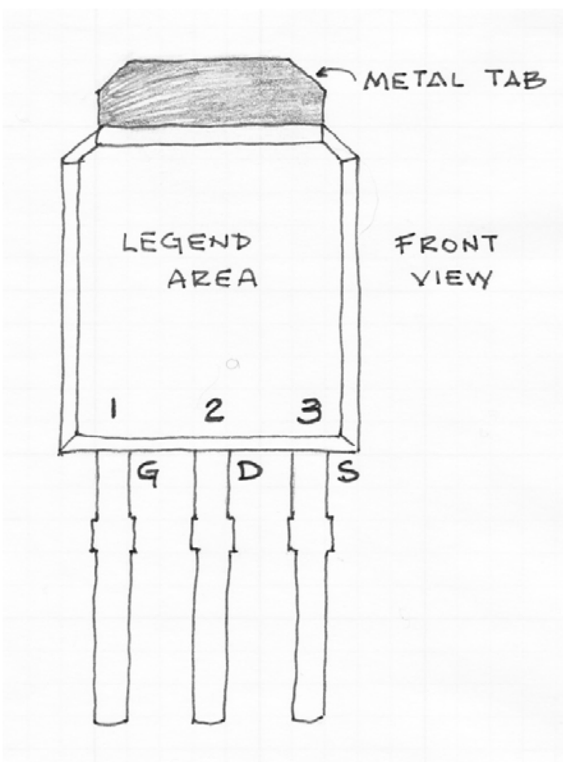
If you are unfamiliar with rocket-construction methods, visit the National Association of Rocketry at: <A HREF = "http://www.nar.org/">www.nar.org</A>. The NAR has a <A HREF = "http://www.nar.org/NARmrsc.html">safety code</A>, and NASA provides <A HREF = "http://exploration.grc.nasa.gov/education/rocket/rktsafe.html">Model Rocket Safety information</A>. The NAR Web site provides information about local rocketry clubs.

Build Instructions

Joe placed four 3-contact terminal strips 90 degrees apart on the booster-rocket tube as connection points for the second-stage rockets' ignition wires. Each thin ignition wire has a small amount of pyrotechnic material that you carefully insert into a rocket-engine nozzle. When enough current flows through the wire, the pyrotechnic material ignites, which in turn ignites the rocket propellant. (The bill of materials for this project indicated 2-contact terminal strips. Joe just had 3-terminal strips on hand when he built his rocket.)

For the connections between the terminal strips and the circuit board and power source, use at least 20-gauge wire. Connect a common POWER wire (use a colored wire) to one of the two terminals on each terminal strip and connect a separate control wire (use a different color or carefully identify each of these wires) to the unconnected terminal on each terminal strip. Thus, each terminal has a power wire and an igniter wire. Identify each ignition wire as IGN1, IGN2, IGN3, and IGN4, or note their color to identify them later. Glue the terminal strips in place on the booster-rocket body as shown in the nearby photo.

Identify the leads on the FETs. With the FET facing you so you can read the legend on the front and with the lead wires pointing down, manufacturers number the terminals 1, 2, and 3, from left to right. (See the drawing below.)



FET Pin-Designations.

Terminal 1 (left most) is the FET's GATE, terminal 2 (middle) is the FET's DRAIN, and terminal 3 (right most) is the FET's SOURCE. Note that the metal "tab" on the back of each FET connects to the DRAIN, so do not let this piece of metal touch any other metal.

Connect each of the four IGN*x* wires from the terminal strips to the DRAIN terminal on an FET. Wire the SOURCE terminal on each FET to a ground connection point. The GATE of each FET connects to a pin on the PIC MCU, as shown later in the schematic diagram.

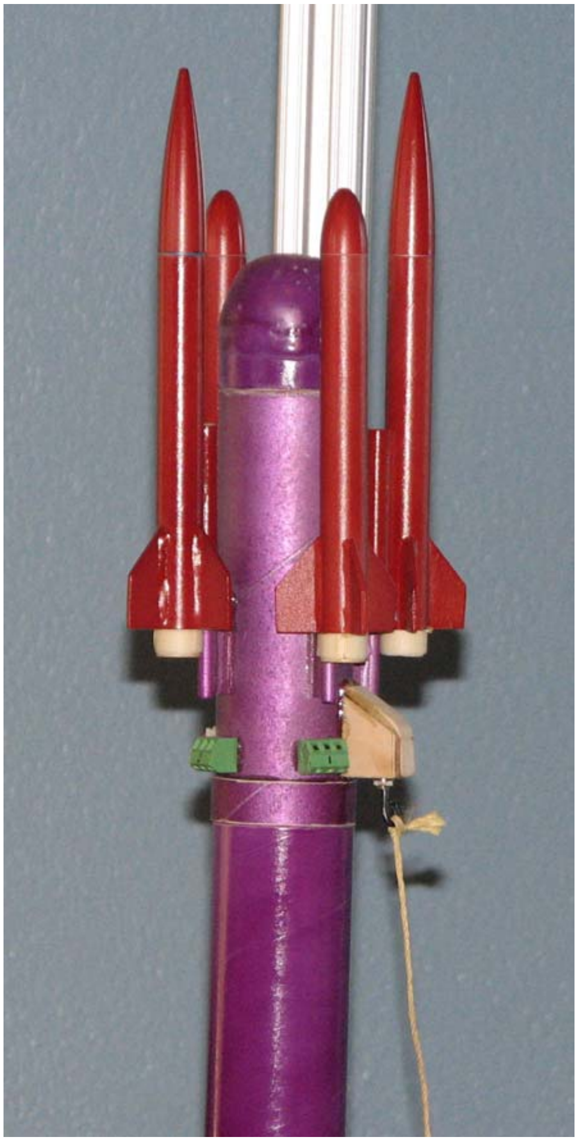
Connect the POWER wire that goes to all four terminal strips to one side of switch SW2.

You can build the MCU and FET circuit on a small piece of "perf board" or a small breadboard available from Radio Shack, SchmartBoard, or another source. Place SW1 and SW2 so the switch actuator extends through the rocket body. (Make the switches turn on in the DOWN position. The high G force the rocket experiences might otherwise turn the switches off. Note the ON position on the rocket body.)

Label SW1 as "Controller Power" and label SW2 as "Igniter Power." Also, make a small hole in the rocket body and place LED D2 part way through it so you can see the state of the Status LED. You can use small dabs of glue to hold it and the switches in place.

The rocket includes an external set of contacts (Pull Plug) that indicate to the PIC MCU that the booster rocket has started to move up its launch rail--a successful launch. Joe fabricated two contacts to create a normally open circuit. One contact connects to ground and the other connects to pin 24 on the PIC MCU.

<A HREF = "http://www.ksmetals.com">K&S Engineering</A> sells a wide variety of shim brass, brass tubing, aluminum tubing, and plastic forms through hobby and hardware stores. You can use these materials--or others--to create the external pull plug. Visit the K&S Web site for retail-outlet information.



Booster stage with nosecone rockets in place.
Note the position of the pin and string.

A small *conductive* pin--nail, brad, coat-hanger wire--fits between the contacts and completes the circuit. When you remove the pin, the circuit should open and the fixed contacts should not touch. The Pull-Pin socket, which sticks out the side of the tube, forms part of the nose cone assembly. Tie the pin to the launch pad with a piece of string--Joe used Kevlar string-- and leave about six inches of slack. Once the booster rocket launches and gets six inches up the launch rail, the pin will get pulled out.

Thus when the pin is IN, the circuit is closed and the microcontroller detects a logic-low on input pin 24. When the pin pulls OUT, the circuit opens and the microcontroller detects a logic-high on the pin 24 due to the pull-up resistor, R1, that connects to power.

When you build the circuit, the Status LED (D2) requires careful attention because it will illuminate green when current passes through in one direction and red when current flows in the opposite direction. In the schematic diagram, note the Pin1 and Pin 2 legends near LED D2. Now, look carefully at the bicolor LED, Allied part number 405-0065. The ring at the base of the plastic has a flat side. The pin nearest this flat side is Pin 1. The Pin-1 wire on the bicolor LED also is the shorter of the two.

Joe used the Microchip MPLAB integrated development environment (IDE) to create his assembly-language program. After assembling the program, he used the Microchip PICkit 2 to program the PIC16F916 chip. See the flow-chart and code listing at the end of this text. The 6-position connector, J7, connects the circuit to the PICkit 2 programmer.

After you assemble the circuit, turn off Igniter Power (SW2) and turn off Controller Power (SW1). Connect the 9-V battery to the battery clip and place it and the hardwired breadboard or perf-board in the nose-cone portion of the booster stage. DO NOT install rocket engines at this time. You must first test the circuit.

Test the Sequencer Circuit

Test 1: After you have the battery and electronics in place, connect an LED and a 1000-ohm 1/4W or 1/8W resistor in series across each pair of contacts on each igniter terminal strip. The LED/resistor circuits will simulate an igniter for initial testing. Insert the pull pin in its mating connector. Turn on Controller Power (SW1). If the controller initializes successfully and detects that you have the pull pin installed, the Status LED will light green. Green indicates the controller is operating properly. If the Status LED appear off or red, turn off Controller Power (SW1), check your wiring, and review the assembly-language code for any errors you might have made when you cut and pasted it into the MPLAB IDE.

When the Status LED turns green, turn on the Igniter Power (SW2). Next, remove the pull pin to start the sequence that would power each igniter wire. You should see each LED attached to a igniter terminal strip turn on in sequence. The sequence will start approximately one seconds after you remove the pull pin. There's a period of about about 1/4 second between each LED's illumination. If one of the igniter-test LEDs does not light, first reverse its leads in the igniter terminal strip and run the test again. (An LED turns on for current flow in only one direction. Reversing the connections reverses the direction of current flow through the LED.) If the LED still does not light, check the wiring between the terminal block and the FET and between the FET and the MCU.

After you successfully test the ignition circuit, turn off Igniter Power (SW2) and turn off Controller Power (SW1).

Test 2: It is equally important to check that the system doesn't immediately start the second stage launch sequence if the pull pin is left out when you power the ignition circuit. In this test, leave the pull pin out, switch on the Controller Power (SW1) and then switch on the Igniter Power (SW2). Make sure the status LED turns red and that the LEDS used to test the igniters remain off.

Remove the LED/resistor circuit from each igniter terminal strip.

Rocket Materials

The booster rocket measures approximately 1.6 inches in diameter and 23 inches long, and materials came from various sources. The main cardboard tube was left over from a roll of wrapping paper. Joe used hard foam to fabricate the nose cone, which he covered with an epoxy. The second stage rockets, however, parachutes, and the engine mount for the booster rocket came from from Estes Rockets (<A HREF = "http://www.estesrockets.com/">www.estesrockets.com</A>). In addition to complete kits, Estes sells many individual parts, such as nose cones, body tubes, and launchers.

Joe used small rocket engines that hobbyists can purchase without any special certification. The E15-4W engine for the booster rocket came from Aerotech Consumer Aerospace <A HREF =

"http://www.aerotech-rocketry.com/"> www.aerotech-rocketry.com</A>. This engine is larger than ones most hobby stores carry, but are readily available via mail order. The second-stage 1/2A3-4T engines came from Estes Rockets. Hobby stores that carry model rockets might have these engines in stock.

Ready for Launch

Ensure you have turned off Controller Power (SW1) and Igniter Power (SW2). The Status LED should be off. The booster stage and each of the four second-stage rockets should have their rocket engine in place and their igniter wire placed into the rocket-engine nozzles. Place each small rocket on its short launch rod. Connect the igniter wires to the screw terminal, one wire per contact.

Place the rocket system (booster rocket and four second stage rockets) on its launch rail. Insert the pull pin into its connector on the rocket. Ensure you have the other end of this pin securely attached to the launch pad with an length of string that provides about six inches of slack.

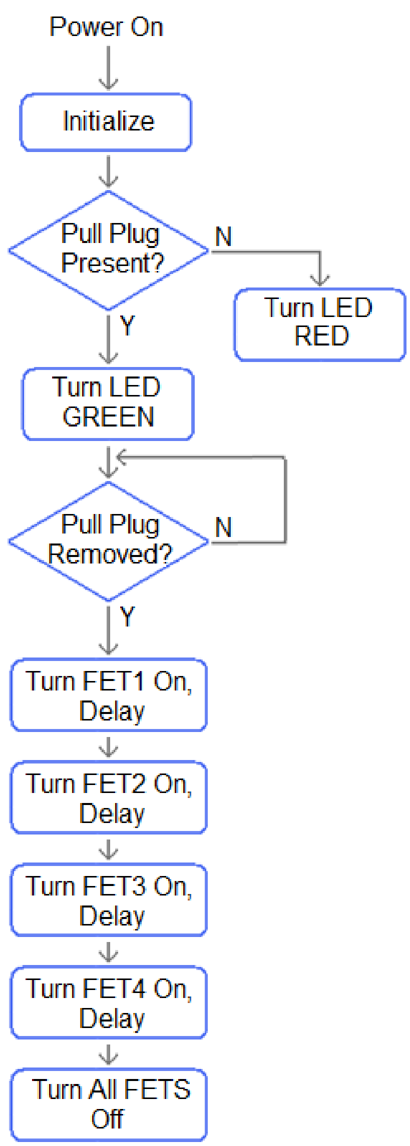
Turn on the Controller Power (SW1). When the controller detects the presence of the pull pin and proper operation of the MCU code, the Status LED will turn green. If the Status LED does not turn green or if it turns red, turn off the Controller Power (SW1), remove the second stage rockets, remove the rocket engines from all rockets and recheck your wiring. If necessary, repeat the test procedures described above.

After the Status LED turns green, you can turn on Igniter Power (SW2). Your rocket is now ready for launch. Everyone should move away an appropriate distance (see the NAR information for a safe-distance table), and you can use a standard model-rocket launcher to ignite the booster-rocket motor. As the rocket takes off, the pull-pin will be yanked free from the rocket, and the microcontroller will then sequence the ignition of the smaller rocket motors while in flight. If all goes well, you can now track the rockets' flights and recover the five independent rockets.

Additional Details

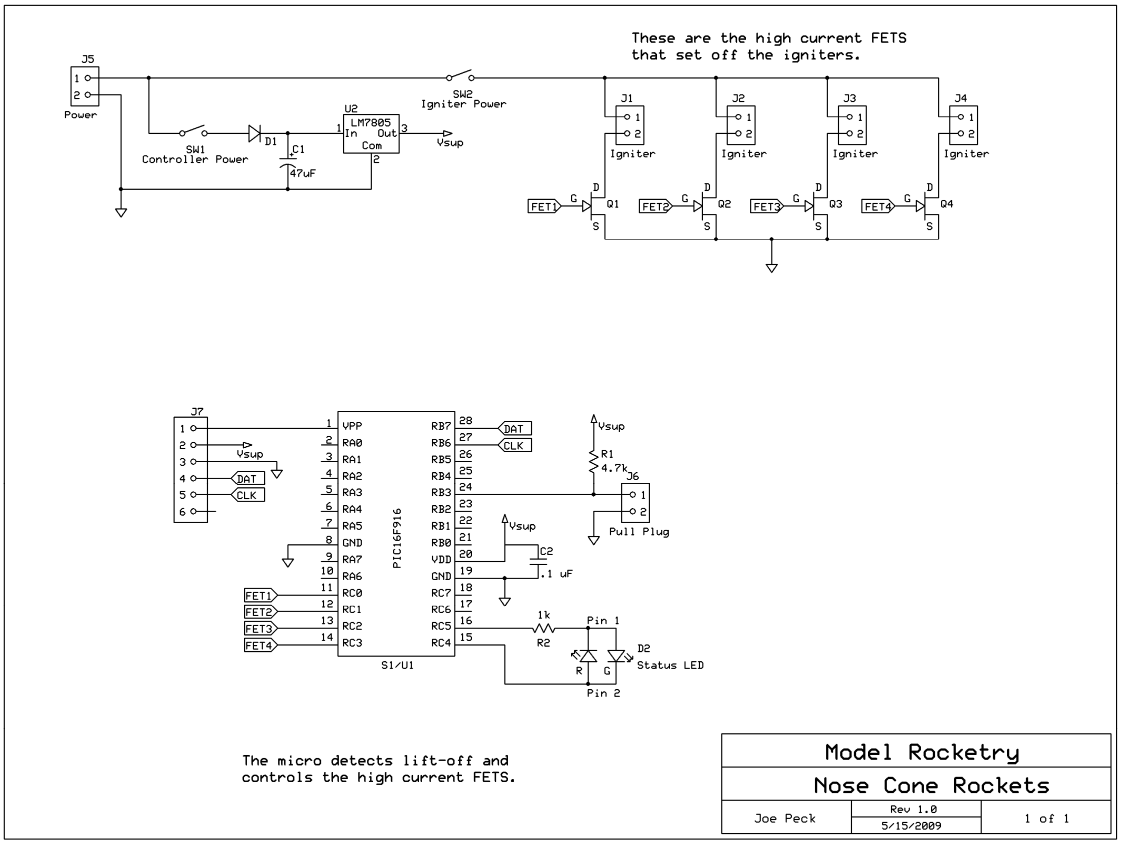
For standard rocket-engine igniters, turning on the FET for two seconds should provide enough power to ignite the engine. The resistance of common igniters ranges from about 0.5 to 2 ohms, so an FET with a low on-resistance (R_{dson}) will ensure the igniter dissipates most of the power. Depending upon the power supply used (a 9-V NiCad battery in this circuit), the FET must pass from several amps to tens of amps for a brief time.

Microcontroller Program Sequence



Schematic Diagram

For a larger version of this schematic diagram, go to the Gadget Freak download site at: <A HREF = "http://www.gfreak.com/GF158/GF158_NoseConeSchematic.bmp"> www.gfreak.com/GF158/GF158_NoseConeSchematic.bmp</A>.



Bill of Materials

"NOSE-CONE ROCKETS"		
Amt	**Part Description**	**Allied Part #**
4	Terminal Strip, 2-Position	409-0032
1	47µF, 25V Capacitor	507-0866
1	0.1µF, 50V Capacitor	881-0514
4	Field-Effect Transistor, IRFU3704ZPBF	273-1665
1	Voltage Regulator, LM7805CT	288-0001
1	DIP Socket, 28-Pin	374-5540
2	Miniature Slide Switch	758-0248
1	Diode, 1N5818TR (D1)	503-0127
1	PIC16F916 Microcontroller	383-0503
1	9-V Cabled Battery Connector	839-0474
1	4.7kΩ, 1/4W Resistor	296-4769
5	1.0kΩ, 1/4W Resistor	840-0399
1	LED, Bicolor-Red/Green	405-0065
1	Terminal Strip, 6-Position	618-5001
4	LED, Red	405-0053

PIC Firmware

```
#include <p16F916.inc>
        __CONFIG  _FCMEN_OFF &_IESO_OFF & _BOD_OFF & _CPD_OFF & _CP_OFF &
_MCLRE_ON & _PWRTE_OFF & _WDT_OFF & _INTOSC

        cblock 0x20
        InnerDelay
        MiddleDelay
        OuterDelay
        endc

        org 0
Start
; Initialize outputs (FETs off, PWR LED red{bicolor})
        bcf             STATUS,RP0      ; Select Register Page 0
        bcf             STATUS,RP1
        movlw   0x10
        movwf   PORTC           ; Initialize output data
        bsf             STATUS,RP0      ; Select Register Page 1
        bcf             STATUS,RP1
        movlw   0xC0
        movwf   TRISC           ; Enable output lines
        bcf             STATUS,RP0      ; Select Register Page 2
        bsf             STATUS,RP1
        movlw   0x00
        movwf   LCDCON                  ; Disable analog input lines

; Make sure pull plug is in on power-up
        bcf             STATUS,RP0      ; Select Register Page 0
        bcf             STATUS,RP1
        btfsc   PORTB,3                 ; Skip when pull plug is in
        goto    Done

; Turn PWR LED green{bicolor}
        bsf             PORTC,5
        bcf             PORTC,4

; Wait for pull plug to be removed
        btfss   PORTB,3                 ; Skip once pull plug is removed
        goto    $-1

; Delay before turning on 1st FET
        movlw   .255
        movwf   InnerDelay
        movlw   .255
        movwf   MiddleDelay
        movlw   .4
        movwf   OuterDelay
Delay1
        decfsz  InnerDelay,f
        goto    Delay1
        decfsz  MiddleDelay,f
        goto    Delay1
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```
        decfsz  OuterDelay,f
        goto    Delay1

; Turn on 1st FET
        bsf             PORTC,0

; Delay to 2nd FET
        movlw   .255
        movwf   InnerDelay
        movlw   .200
        movwf   MiddleDelay
        movlw   .2
        movwf   OuterDelay
Delay2
        decfsz  InnerDelay,f
        goto    Delay2
        decfsz  MiddleDelay,f
        goto    Delay2
        decfsz  OuterDelay,f
        goto    Delay2

; Turn on 2nd FET
        bsf             PORTC,1

; Delay to 3rd FET
        movlw   .255
        movwf   InnerDelay
        movlw   .200
        movwf   MiddleDelay
        movlw   .2
        movwf   OuterDelay
Delay3
        decfsz  InnerDelay,f
        goto    Delay3
        decfsz  MiddleDelay,f
        goto    Delay3
        decfsz  OuterDelay,f
        goto    Delay3

; Turn on 3rd FET
        bsf             PORTC,2

; Delay to 4th FET
        movlw   .255
        movwf   InnerDelay
        movlw   .200
        movwf   MiddleDelay
        movlw   .2
        movwf   OuterDelay
Delay4
        decfsz  InnerDelay,f
        goto    Delay4
        decfsz  MiddleDelay,f
        goto    Delay4
        decfsz  OuterDelay,f
        goto    Delay4
```

```
; Turn on 4th FET
        bsf             PORTC,3

; Wait to turn FETs off
        movlw   .255
        movwf   InnerDelay
        movlw   .255
        movwf   MiddleDelay
        movlw   .6
        movwf   OuterDelay
Delay5
        decfsz  InnerDelay,f
        goto    Delay5
        decfsz  MiddleDelay,f
        goto    Delay5
        decfsz  OuterDelay,f
        goto    Delay5

; Turn FETs off
        bcf             PORTC,0
        bcf             PORTC,1
        bcf             PORTC,2
        bcf             PORTC,3

Done
        goto    Done

        end
```