Walther Free Pistol Replacement Electronics Board Project

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I recently purchased a Walther Model FP free pistol. The pistol had a malfunctioning electronics board. This article reports on my experiments to design a replacement board. The new board includes a dry fire function. See a picture of the board on page 5.

This information is made freely available to anyone who wishes to use it. However, I cannot be responsible for use of the ideas contained here. I am not willing to "sell" circuit boards or components for this project. I am making available circuit board files and the software file so others can replicate and improve on it.

These decisions are made due to the state of liability in the USA. I am not incorporated and I am not prepared to risk my family assets by selling a product that might shoot or shock others. I also have no control over others and how they might use this information.

For these reasons the following warnings must be presented:

Warning: The reader must assume full responsibility for any experimentation, construction or use of the ideas contained in this article:

This document reports ongoing personal study and experimentation. No warranty can be provided as to the suitability of this design for use by others.

The author is an electronics hobby builder, not a professional engineer.

This design is experimental and has not been proven by intensive testing. The user should be prepared for the possibility of unintended discharge of a firearm, the results of which could be potentially fatal.

The design is for a single shot firearm intended for use within the structured protocol of a shooting range. This design does not include safety mechanisms found in commercial firearms.

This design cannot be used for semi-automatic or fully automatic firearms. The loading lever switch performs as a disconnector. The minimum charge time between shots is six seconds.

Both this and the original factory circuit board make use of high voltage. Under ideal circumstances this voltage can be lethal.

A Brief Summary

During the 1980's Walther produced a free pistol of unusual design. The Walther model FP employed an electronic trigger with an electromagnet to propel a firing pin. The pistol went through a series of electronic problems. After several years Walther stopped support for the gun. As electronic boards failed, these pistols became nonfunctional.

I've sought to design a board that is easy to build and functionally equivalent to the original board. I've designed six different circuit boards over the past year.

My electronic board differs from the factory design:

It selects live versus dry fire mode based on the position of the loading lever when the power switch is turned on. Dry fire propels the firing pin with a "light tap" that can be felt, and heard, in a quiet environment. If the loading lever is open when the power switch is turned on, live fire is selected. If the lever is closed, dry fire is selected.

My board is limited to a single indicator light. The light is on when the trigger is pulled. The light flashes when the gun is fully charged and ready to shoot. Fully charging the gun takes about six to twelve seconds depending on battery condition.

The power turns on by moving the power switch towards the grip. This is reverse of the factory board, but consistent with customary switch protocol. This switch direction can be reversed by moving two wires.

While the factory board used various digital logic and analog components, the new board uses a microcontroller, a small computer. This allows for a smaller number of electronic parts. It also allows gun functions to be altered and optimized.

Electronics are noted for having a short technological life span. Therefore, details are provided so future designs can be developed when current generation electronics become outdated.

While this board is intended for use in a Walther Free Pistol there is sufficient detail to design a firing mechanism for a new single shot firearm. The electronic firing pin requires only three parts; electric coil, firing pin and return spring. This design also permits extremely precise trigger design as there are no loaded sear points that wear and require adjustment and tuning.

How It Functions on Firing Line

This is the intended operation when using the replacement board:

The shooter comes onto the range and prepares equipment. The sighting scope is set up, ammunition is laid out and the gun, with breech open, is set on the shooting table.

The "Begin Preparation Time" command is given. The shooter begins dry fire practice. An empty cartridge case is inserted into the chamber, the loading lever is closed and the power switch is switched on. After each dry fire shot the loading lever must be opened a few millimeters (1/8th inch) and closed, to recharge the gun.

The command to "Start" is given. The shooter begins live fire. The gun is switched off. The breech is opened and the gun is switched on. The gun is now in live fire mode. It can be loaded and fired like any other firearm.

Once shooting is completed the power switch is turned off. This causes the gun to immediately eliminate its electrical charge, rendering it safe.

Dry fire mode uses an empty case in the chamber. This is to protect the firing pin and chamber edge from the light firing pin taps. It would be unwise to use a live round for dry fire practice. Repeated taps might fire the cartridge.

Design Strategy

I wanted an electronics design that was easy to build. The design makes use of through hole components, not surface mount devices. There are two surface mount components. But these are large and can be soldered without special equipment.

The pistol interior required a board no wider than 0.95 inches. I decided to limit the board to 3.8 inches long. This is the distance from the front of the board chamber to the screw plate that mounts the battery cover. This makes my board an inch shorter than the original factory board. This board length permits use of a low cost, commercially available circuit board.

Parts cost is low. The electronic components cost less than $20. The cost of the blank circuit board depends on its source.

Factory Board Variations

My project was made more complex because Walther made at least two different circuit boards.

The early 1987 board used through hole components and included a relay. See a picture of this board on page 6. Three wires connected the loading lever switch. The power switch was mounted through a hole in the board and then through a hole in the cover plate. Thus the power switch mounted the board in place. The power switch and loading lever switch wires were soldered directly to the board. The battery leads, trigger sensor wires and firing coil connections terminated in an eight pin header based on 0.100 inch pin distances. My pistol, serial number 1202, is of this vintage.

Note that I have not personally examined a later version pistol so these details are taken from Walther factory documents. Therefore, conclusions stated in this article may contain errors: The 1989 board used surface mount components. Board connections used individual plug in connectors. The board appears to be mounted separately from the power switch. The trigger was connected to the board with a three pin connector, each pin separated by 0.100 inches. The loading lever switch connector used a two pin connector with the same spacing. To avoid accidental connector hookup mistakes, the other two connectors used 0.156 inch pin spacing. The firing coil used a two pin connector while the power switch connector used three pins.

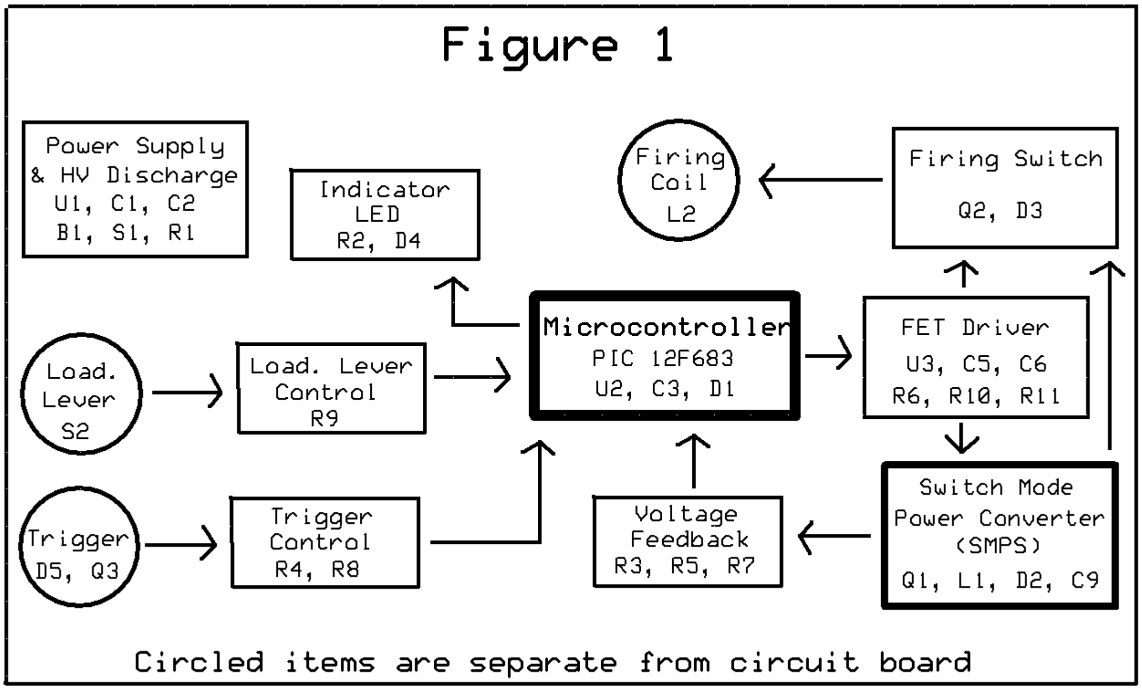
I sought to develop a replacement board that served both pistol generations. My board mounts on the power switch, like the earlier pistols. It uses connectors like the later pistols. The owner of an older pistol will need to rewire the loading lever switch and lengthen the wires from the trigger to reach the new connector. Hopefully, the owner of a newer pistol might be able to simply plug in to the new board.

Function Summary

Figure 1, next page, is a block diagram of the board. Items in rectangles are contained on the circuit board. Items in circles are contained elsewhere in the pistol.

The <u>Microcontroller</u> is a Microchip PIC 12F683. It is a computer that controls all the functions in the gun. It performs at the speed of one million instructions per second.

The <u>Indicator LED</u> is controlled by the PIC. It lights up or flashes to report conditions to the shooter. It is located in the window behind the power switch.



The Loading Lever tells the PIC whether the gun breech is open or closed. The loading lever switch is mounted beside the circuit board inside the pistol.

The Trigger is an optical device. Pulling the trigger blocks a light beam that tells the PIC to fire the pistol. The optical mechanism is mounted in the bottom back of the trigger guard.

The FET Driver is a special electronic chip that controls the FETs and protects the PIC from the high voltage in the gun. It drives the high voltage supply and gun firing functions.

The Switch Mode Power Converter, often called SMPS, for Switch Mode Power Supply, increases the battery voltage to high voltage. Approximately 150 volts are required to live fire the gun. The voltage drops to about 70 volts for dry fire. It is controlled by the PIC.

The Voltage Feedback monitors the voltage level in the SMPS, making certain it stays at the desired high voltage level. The PIC turns on and off the SMPS to maintain proper voltage.

The Firing Switch discharges the SMPS when the PIC reads that the trigger is pulled. The time between pulling the trigger and starting the firing pin pulse is about 40 millionths of a second.

The Firing Coil is the coil that propels the firing pin onto the primer. It is powered by the discharge of the SMPS. The coil fits in the gun breech, behind the chamber.

The Power Supply employs a 78L05 voltage regulator powered by a 9 volt alkaline battery. It provides about 5 volts for the PIC microcontroller. This voltage also powers the functions on the left of the PIC. Higher battery voltage powers functions to the right of the PIC. The power switch also discharges all high voltage when the power supply is turned off.

The schematic diagram for the board is found on page 22.

The Circuit Board

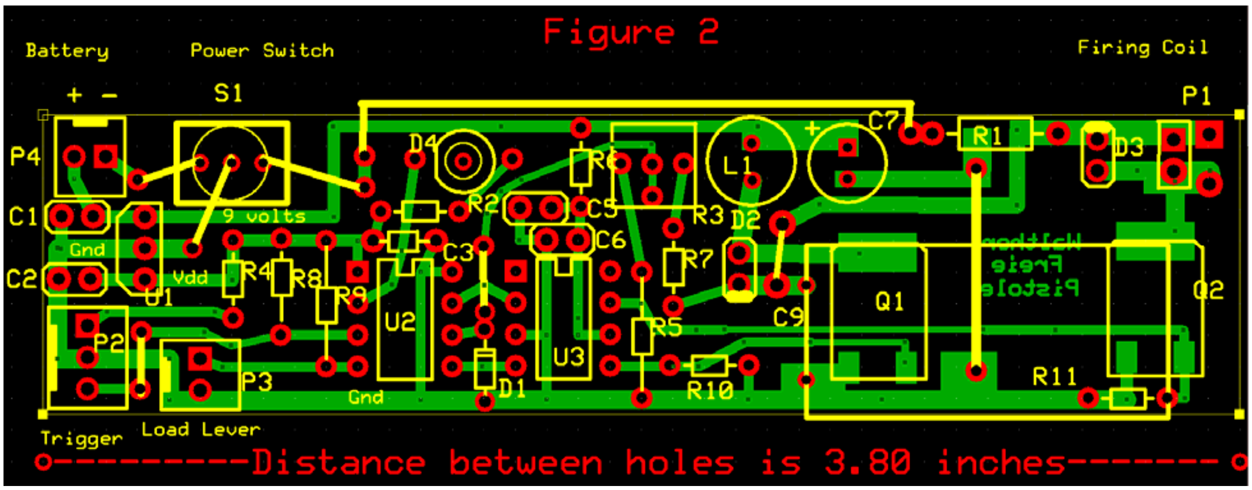
To build this board one must make or buy the blank circuit board. To better understand this, take a look at Figure 2 and the photo on the next page. The photo shows my single sided, home made board with components installed. Remember this image is of a board that is less than 1 inch by 4 inches in size. Details are easily seen when zoomed to 200%.

The board may seem to have closely spaced components. But it was not difficult to populate with a small soldering iron and 0.032 diameter rosin core solder—and—perhaps magnifying glasses for older eyes.

The green color represents the copper traces that appear on the back of the board. You are actually looking through the board as though it were transparent. The green trace is the main layer of the board. Most components have leads that are inserted through holes from the front of the board and soldered to the traces on the back. In the photo you can actually see the traces through the board.

Yellow figures display outlines of electronic components. Red circles and squares represent drilled holes in which component wires are placed and soldered.

Yellow lines represent wires called "jumpers." These are wires that make contact to traces on the board. Seven jumpers can be seen in the photograph. The eighth jumper runs under the big capacitor, C9. I mounted this jumper on the back of my board.



In the photo see simple "snap apart" headers for P1, P2, and P3, while Figure 2 displays "KK" type headers. In the photo the battery connector, P4, is a KK connector. The PIC is installed in a socket while U2, the TC4427A, is soldered to the board. Q1 and Q2 are mounted on the back of the board, as is the jumper below R1. Note how few parts there are.

I made my on own single sided board that contained only the green traces. The actual image to make the board is on page 23. I used the "toner transfer method." Google "toner transfer PCB." The board uses wide traces so fairly crude board techniques should still prove successful.

Free software from ExpressPCB.com was used to make my board. The software file is available so others can alter the board for their own designs.

A file for a two sided factory board is available. The advantage of the two sided board is that jumpers are etched into the front surface. The front board surface also shows parts identification.

ExpressPCB provides several options for making boards. Their “Miniboard” service provides three 2.5 inch by 3.8 inch boards, delivered in the USA for about $60. The board size is fixed so two of the Walther boards can be placed on each of their boards for a total of six, or a cost of $10 each. The customer is responsible for cutting the boards apart.

Using their “Standard” service the board is constructed to the actual finish size. An average cost of $10 per board could be realized by ordering nine boards. A single board would cost about $66. These costs include shipping. The company provides “second day” delivery in the USA from the time you send them the file.

Disclosure: I have no financial interest in ExpressPCB.

This photo shows the board from my early Walther pistol. Notice the black relay in the center. The three loose wires went to the loading lever switch. The red device is the 8-pin connector. The factory board was dipped in a rubber compound to secure components and to keep prying fingers away from high voltage. The capacitor is only rated for 160 volts, but my pistol was operating at 154 volts. This suggests voltage was raised above the designed level to ensure reliable primer detonation. Me thinks this was a recipe for disaster.

Fitting the Board

In the following descriptions I often go into detail. Certain tasks like fitting the switch, mounting the LED and FET’s, and choosing connectors could be challenges for my audience. You experts will have to put up with the detail.

The circuit board is mounted within the pistol forearm. The power switch is mounted in a metal plate under the barrel, that covers the pistol forearm. This plate is part #69, in the factory drawing. It is called Elektronikhalter, which translates into electronics holder. I will call it the “forearm cover plate.”

This is how I fit the board into my early model Walther FP. These comments, with further clarification, were taken from my notes as I constructed my latest board:

“First task is to fit the board and power switch inside the forearm cover plate:

The board width had to be such as to fit in the forearm cover plate. Filed board edges until it fit, being careful not to scratch the circuit traces.

Fitting the switch was a challenge. It sits on the edge of the board and it mounts against the inside edge of the forearm cover plate.   The factory switch had a custom threaded nut and spacer that provided clearance between the switch and forearm cover plate edge.

Drilled out the yellow circle in switch S1 in Figure 2. The drill center point was marked by slipping the board into the gun and marking it through the switch hole in the forearm cover plate.

Drilled an undersize hole and reamed the hole for a close fit on the switch. Made certain to leave a strip of board between the hole and the edge of the board. Otherwise the nut to attach the switch wouldn't fit. The 9-volt trace that passes around the switch had clearance so there was no danger of cutting it. Removed the nuts from the switch, slipped the switch into the board, and inserted the board/switch pair into the gun. It fit. But when I put a nut on the switch it was a tight fit. Realized I'd have to file the edge of the nut to make final fitting.

Removed the switch. It is easier to solder components without the switch in place.

Using the old switch might be a good idea. The custom threaded spacer instead of a nut would make fitting simpler."

Soldering the Components in Place

Referring to Figure 2, the trace, green side of the board is the "back" of the board. The side with most of the components is called the "front" of the board. The power switch inserts at the "top, left" of the board. Resistor, R11, is visible on the "bottom, right" of the board.

My log entry continues: "I began by <u>installing the two FETs</u> on the back of the board.

Q1 and Q2 are FETS. FETS can be damaged by static electricity so touch a metal surface before handling these parts.

Looking at the bottom of the FET's see a large solder area for the wide pad and two extended legs. The large pad is intended to be soldered to a large trace on the board. This allows the board to dissipate heat generated in the FET. I don't have to worry about heat because the circuit has a very low duty. This means pulses going through the FET's are quick and spaced a long period apart. So the solder pad on the board was made smaller than the pad on the FET.

For a two sided factory two side board I could simply solder the FETs in place. With my single sided board I had to bend the two legs so the FET stands up. The reason for this is two traces run under Q1 and one trace runs under Q2. These traces must not contact the large pad on the bottom of each FET.

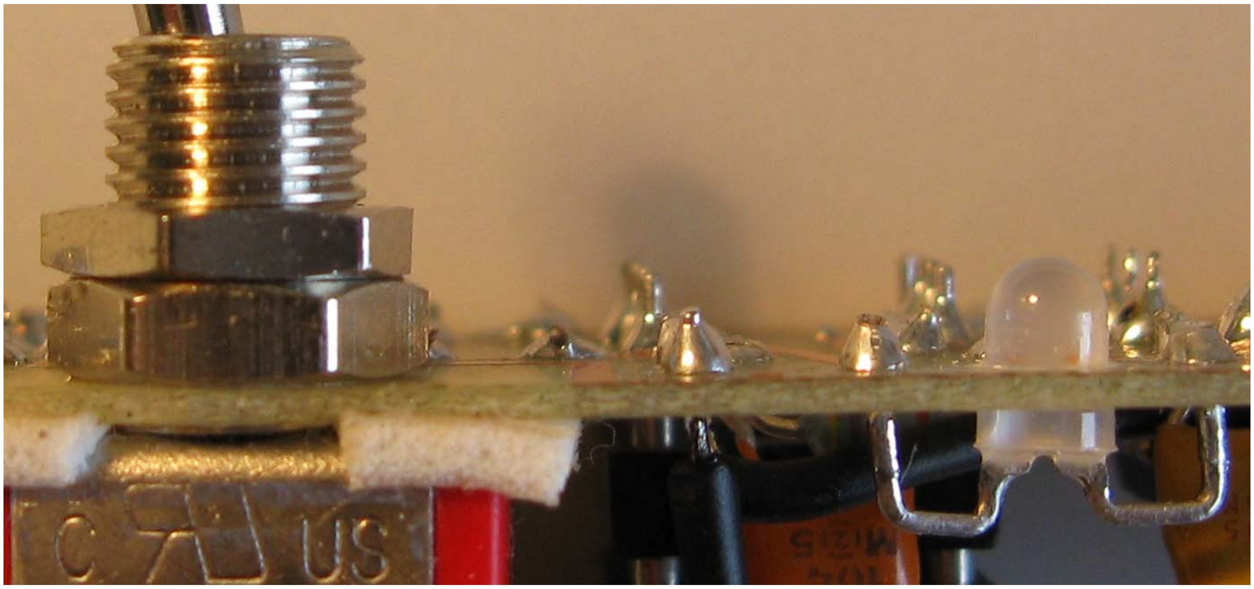
Soldered on FETs. It was simple. Heated a small amount of solder on one of the small leg traces on the board. Placed the FET over the solder and heated the leg and trace so both were soldered together. If the FET was off a bit the leg was reheated and placement was adjusted. Made certain the wide copper pad was visible beyond the FET pad. Made certain solder traces under FET was clear. Soldered the other leg in place. Finished FET by soldering wide end of FET to trace. Repeated with second FET.

The term used below, "polarized" means the component leads are not reversible. So the component must be mounted in the correct direction.

The <u>indication diode, D4</u> is polarized so it must be installed correctly. The light must be visible from the bottom of the board. It appears in the window in the pistol forearm cover plate.

D4 was installed upside down so the bottom of the diode faced the component side of the board. See the photo below of finished result.

Referring to Figure 2, drilled out the small yellow circle, shown in D4 with a #32 drill. The center round solder pad acted as a drill center. A 7/64 inch drill could be used. But it might be necessary to slightly ream the hole so the body of the LED just fits the hole. I don't want the LED bottom flange to go through the hole. Refer to the photo below.



This photo shows details of the diode, D4, installation and power switch. Note the compressed double stick tape that secures the power switch to the board. Note how close the switch mounting nuts are to the edge of the board. Filing the edge of the nuts may be necessary.

The leads of the LED were bent so they look like the picture above. I inserted the leads into the board from the front side and pressed the LED until it fit in the hole. The LED has polarized leads so the correct lead placement was critical. The cathode lead was marked by a flat on the side my diode base. That lead must go through the hole that faces the switch.

The resistors, except for R1, are designated as 1/8th watt components. This was to allow these components to fit flat against the board. While ¼ watt resistors could be used the leads would have to be formed to stand up the component, like D2.

I soldered on resistors R1 through R11. The center connector for the trimmer R3 has two holes so trimmers with different mounting lead configurations could be used.

The zener, D1, was soldered in place. It is polarized. The zener was placed so the band around one end was towards the center of the board.

U1, the 78L05 voltage regulator is polarized. I made certain the leads were inserted so the curved edge faced toward the edge of the board, as shown in Figure 2.

Next came the bypass capacitors C1, C2, C3, C5 and C6. These are not polarized. My components came with leads bent for 0.2 inch spacing. I removed the bend on all but C3 by crimping the leads with needle nose pliers, right next to the component body.

For my single sided board I had to make and insert the jumper, shown in yellow, between headers P2 and P3. I also installed a jumper that runs from the end of D1 between U2 and U3. A wire snipped off of the resistors worked fine.

Next came the socket for U2, the 12F683. The socket has a notch on one end. The notch matches the notch in the board layout.

Diodes D2 and D3, UF4004's, were installed vertically. These diodes are polarized, so they must face in the proper direction. Each diode has a band around one end. The wire from this end must go into the hole marked with a yellow bar on the circuit board in Figure 2.

For my single sided board I installed the jumper that runs to the right of D2. A wire trimmed from D2 or D3 was used for this connection.

For my single sided board there is a jumper than runs between in the space between Q1 and Q2. While I drilled holes to make the jumper on the front surface I decided to run a stranded wire between the pads on the back side. This was an insulated wire as the wire must not contact either of the traces under the wire.

I chose not to install L1 or U3 until I performed preliminary tests.

C7 was installed. It is polarized so the negative lead must go into the hole closest to the center of the board.

C9 is polarized so the negative lead went toward the bottom edge of the board. I bent the leads so the bottom end of the capacitor didn't extend beyond the end of the board. I've tried both the capacitor in the parts list and one taken from a disposable camera. The latter capacitor had a gray line to designate the negative terminal."

A Discussion of Headers and Connectors: Headers are the male pins soldered onto the board. Connectors are the wire terminations that plug into the headers.

The newer guns have four individual connectors. These owners should only have to find headers to mate with existing connectors.

My older pistol had one 8-pin connector. My replacement board used individual connectors. This meant I had to install headers on the board and attach connectors to wires. I've used Tyco MTA and Molex KK headers in the past. These come in spacing that will fit the newer Walther board connectors. Each brand has its own connector assembly tool. The MTA uses a punch and the KK uses a crimper. Many electronics hobbyists have the tools to install these connectors.

An option is to buy wire assemblies with connectors in place. These come with a wire length and the header. For example, Allelectronics.com sells their CON-242 assembly for $0.70. It comes with #22 wire. They have assemblies for 0.10 and 0.156 inch space connectors.

Another option is to solder the wires directly to the board without connectors. All the wires, except for battery and firing coil are very low current. So #28 wire is adequate for the connections. The existing firing coil wire is long enough to solder directly to the board. The 9-volt battery connector can be soldered directly to the board.

In the following discussion headers and connectors are assumed.

"I soldered in the firing coil header P1: The board has mounting holes for both a 0.100 and 0.156 inch pin spacing headers. The newer Walther board used the wider spaced connector to make it impossible to accidently plug this connector into the loading lever switch connector. The smaller spacing is adequate for the high voltage. My early board had two gold colored transparent insulated wires for this connection. Either wire could go to either pin—there is no polarity.

Next came the loading lever switch header P3: This is a 0.10 inch spaced two pin header. The wires coming from the switch can go to either pin—there is no polarity.

On my early gun the loading lever switch had three wires soldered directly to the board. My new board only required two wires. I unsoldered the three wires from the switch. Two wires were soldered to the two switch terminals towards the muzzle end. I made the wires long enough to reach header P3 when the board was installed. If necessary, the switch can be unscrewed from the gun to remove and replace the wires. The switch is mounted with two screws. After reinstalling the switch check its action by listening for the "click" as the loading lever is raised slightly from the closed position.

The battery connection is marked header P4. The battery leads can be wired directly to the board or a connector may be used. This connection is polarized. The left lead must be the red, positive wire and the right lead must be the negative, black terminal. I chose to use a "KK" connector.

The three pin P2, trigger header was saved for last because the three wires must go on in correct order.

My connector was wired in the same order as the shown in original Walther documentation. This should permit simple plug in for owners with the newer boards.

With my older board I had to order the wires to the connector. The gun wires needed to be lengthened to reach the new connector. I soldered extra wire to each of the existing wires and covered the junction with heat shrink tubing. On my gun the light bluish or grayish wire is from the LED. It went to the top connection of P2, as seen in the Figure 2. The brown ground wire went to the middle connection. The sensor yellow wire went to the bottom connection.

It was time to install the power switch.

I removed all the nuts from the switch. This left a flat surface on the top of the switch. Small bits of double side tape were placed on the flat surfaces so the tape would stick the switch to the board. Inserting the switch into the board, the nut was tightened up to compress the tape. Refer to the picture on page 8 for details. A second nut was fitted over the first to create a spacer. On my board the face of the nut hexes had to be parallel to the board edge. Otherwise the board would not fit in the forearm cover plate. I had one case where the nut hex edge had to be filed to make it fit. The two nuts generate a space between the forearm cover plate and bottom of the circuit board. The LED and FETs sit in this space.

My pistol came with a plastic liner that kept electrically active points on the board from touching the forearm cover plate. This is important, as metal contact could short out the board. On my board the edge of the first switch nut made make contact with the 9 volt battery line trace. So no part of the nut should contact the forearm cover plate. The switch in the parts list has no contact between the switch bushing and any of the switch terminals. These fitting issues probably caused Walther to remove the switch from the board on their newer, 1989 factory board.

I used about #24 wire to install the power switch jumpers shown in figure 2."

Note: As wired, the switch works backward from the factory board. Moving the switch towards the grip turns the gun on. This seems consistent with most switch wiring practice—right to turn on, left to turn off. If this is not acceptable, the two outside wires on the switch can be reversed.

We can now check board function.

Preliminary tests on the board.

The board does not need to be mounted in the gun for these tests but the wires from the gun to board must be connected as directed.

A digital multimeter is needed to read volts and ohms.

Leave the PIC socket is open. Inductor L1 and chip U3 are not yet installed. These are the instructions as I wrote them in my construction log:

“Flip the power switch so it faces toward the muzzle. This is the off position. Connect an ohm meter between the battery terminals on the board. The meter should read high resistance. Flip the power switch to on. You should get a lower reading. On my board it was 802 ohms. If it reads 0 ohms there is a short in the board. Look for a solder point that bridges to an adjacent pad. This can be corrected by resoldering the offending solder joint.

Flip the power switch so it faces toward the muzzle. This is the off position. Plug in a fresh battery. Read the voltage between the battery terminals. It should be close to 9 volts.

Turn on the switch by moving it towards the breech and check the voltage between the left switch terminal and the top wire end of resistor R6, next to the trimmer R3. This voltage should be the same as the battery voltage measured above. Turn off the power switch.

The PIC pins on U2 will be checked. The pins are numbered in counterclockwise direction with the top left pin being number 1 and the top right pin being number 8. Pin 1 is the positive voltage and pin 8 is ground.

Turn on the power and check the voltage between PIC pins 8 and 4. Voltage should be 4.75 to 5.15 volts. We will call this voltage **Vdd**. If voltage is incorrect check that U1 was installed in the proper direction. Turn power off.

Plug in the wire connector to the loading lever switch. Turn power on. With the loading lever closed check for voltage between PIC pins 4 and 8. The voltage should read 0 volts with the lever closed and Vdd volts with the lever open. If this test fails check the wiring and switch using the ohmmeter. Confirm the loading lever switch can be heard “clicking” as the lever is opened and closed.

Plug in the trigger connector. With power on check the voltage between pins 8 and 3 on the PIC socket. With trigger open the readings should be below 1.0 volts. With trigger pulled it should be above 1.3 volts. Voltage must swing from below to above 1.25 volts for the trigger to work. A slightly smaller resistor for R8 will raise the voltage range. A slightly larger value resistor will lower the voltage range. On my pistol the voltage was 0.78 volts with trigger open and 1.47 volts with trigger pulled.

Using a wire connect pin 8 to pin 2. The LED should turn on. If not, the LED may be soldered in backwards.

Turn off the power.

Disconnect the wires and remove the battery.

Now, it was time to finish the board construction:

I Soldered in U3, the TC4427A Driver making certain the notch in the end of the chip faced toward the center of the board.

L1was soldered into place.

A jumper runs from the right switch terminal to a pad at the end of R1. This wire was placed so it didn’t block the LED. This jumper is required for a two sided board.

The programmed PIC was installed with the dimple facing toward the center of the board.”

Setting the High Voltage Level

Before performing final tests consider the high voltage setting. The factory high voltage setting was about 150 volts. The voltage set resistor, R3, can adjust between 125 and 170 volts. Set the lowest voltage that gives consistent primer ignition for your ammunition.

Final Tests

Now it was time to finish testing. These were my written instructions in my log:

"Connect the voltmeter across the leads of C9. Set it to 200 volt DC range.

THIS IS A HIGH VOLTAGE TEST SO KEEP YOUR FINGERS CLEAR OF THE BOARD!!!

Make certain all the connectors are in place

Pull and hold the trigger. Turn on the power switch. The LED should light until the trigger is released. Turn off the power

Open the loading lever. Turn on the power. Insert a **FIRED** cartridge case in the chamber and close the loading lever. After a few seconds the LED should flash. Voltage should be about 150 volts across C9. It can be adjusted using R3. Pull the trigger. You should hear the firing pin striking the cartridge with primer detonation force. Turn off the power. The high voltage should quickly fall to zero. If no firing pin strike occurs but voltage is correct check that D3 is installed in the correct direction. Guess how I know this?

Leave the loading lever closed. Turn on the power. After no more than a few seconds the voltmeter should show close to 70 volts. The LED should flash. Pull the trigger, you should hear and feel a light "tap" of the firing pin against the cartridge. This is the dry fire test.

Pull the trigger again. The LED should light up until it is released.

One final test: With power off, crack open the loading lever and turn power on. Close the loading lever. When the LED flashes you have live fire power. Turn off the power switch. The firing pin may strike with less than dry fire force. Don't let this catch you by surprise. It is discussed further in the "Remaining Questions" section at the end of this article.

The circuit board could now be installed in the pistol. The board was set in place and secured with a lock washer and nut on the power switch. Wires were dressed so the forearm could be placed on the gun, taking care not to pinch any wires. The battery connector was clear and in the battery area. The forearm was screwed in place. A battery was installed as was the battery cover."

Board Components

I have prepared a list of components and parts number for Mouser, an electronics supply house. Some of the listed component values are not critical. When choosing components be aware of height limitations within the circuit board cavity.

The following is a review of the components and latitude in selection. Prices are for one each:

Capacitors

C2, C3, and C6 are standard 0.1uf radial ceramic capacitors used for bypassing. One Mouser part number is 594-K104M15X7RF53H5. They cost 12 cents each.

C1 and C5 are 1uf bypass capacitors. C1 could be anything from 0.33 to 1uf. A Mouser part is 594-K105Z20Y5VF5TL2. They cost 13 cents each.

C7 is a radial electrolytic capacitor. I chose a 100 uf 25 volt capacitor. Any reasonable capacitor that will fit the space is fine. I wouldn't go less than 16 volts or more than 220uf. Mouser part is 871-B41828A5107M000. Cost is 7 cents.

C9 is the storage capacitor for the firing coil. One is listed in the parts list as a 100uf, 200 volt capacitor. A Mouser part is 647-UVR2D101MHD. The cost is 99 cents. I also took one from a one-use camera. My Fuji cameras had a smaller diameter, unmarked unit that measured 101uf, 330 volts. The Kodak camera had a fatter, 120uf unit, made by Rubycon. I'm told these units are fairly good quality even though they aren't intended to last for a long period of time. This board operates them at 45% of their rated voltage.

Resistors

R1 is a quarter watt. All other fixed resistors are eighth watt to fit flat on the small board. Quarter watt resistors could be used by standing them up similar to diodes D2 and D3. Each resistor, except R3, costs 10 to 12 cents in single units.

R1 is a quarter watt 330 to 470 ohm resistor. It discharges the high voltage capacitor, C9, when the power switch is turned off. Mouser part is 271-470-RC.

R2 is a 220 to 680 ohm resistor to limit current through the visual indicator LED. Change the value as needed for proper brightness. The smaller the resistance, the brighter the LED, and the higher the battery current draw. The Mouser part is 470 ohms, 71-RN55D4700FTR.

R3 is a 5k ohm trimmer used to set the high voltage charge level. It provides about a 35 volt adjustment range. The board is designed to use a ¼ inch square trimmer unit with three wire terminals across. I used a Bourns model 3362U unit in my board. A 3362P should also work. It has diagonally placed wires. The Mouser part is 652-3362U-1-502LF. The cost is 83 cents.

R4 is an 820 ohms load resistor for the trigger LED. In my gun this resistor pulls 4.5 milliamps and provides reliable trigger action. Stay with this value unless you want to experiment with a larger value resistor. Too small a value and you may burn out the LED. Replacing a dead LED could be difficult. Mouser part is 71-RN55C-F-825.

R5 is discussed below. Mouser part is 71-RN55D1202F.

R6 is a 10 to 15 ohm resistor as recommended in Microchip Application Note AN797: "A 10 to 15 ohm resistor in series with the power supply filters voltage spikes present at the TC4427 supply terminal. Should latch up occur, this will also limit current." The Mouser part is 71-RN55C-F-10.

R7 is discussed below. The Mouser part is 71-RN55D-F-470K.

R8 is a 20K load resistor used on the trigger phototransistor. I chose this value because, on my gun, it achieved voltage shifts that read the trigger analog to digital converter values. Read more about this in the operational discussion later on. The Mouser part is 71-RN55D-F-20K.

R9, R10 and R11 are 4.7K to 12K resistors for pull-up and pull down functions. R9 pulls up the pin reading the loading lever switch. R10 pulls down the gate pin on the charger FET. It ensures the gate is pulled to ground unless it is specifically pulled up by the PIC. R11 is like R10, but provides extra measure of security against unwanted discharge. The Mouser part is the same number as R5, 71-RN55D1202F.

Resistors R7, R5, and R3 form a voltage divider that reports the high voltage charge level back to the PIC. R3 can be set to provide about 135 to 170 volts. With R7 set as 470K and R5 set as 12K ohms, the 5K trimmer, R3 achieves this range.

Diodes

D1 is a 5.1 volt zener to protect the PIC from feedback voltages that exceed the PIC limits. It has minimal current requirements. The Mouser part is 512-1N5231CTR. The cost is 4 cents.

D2 and D3 are high speed diodes. I chose UF4004's. Any replacement diode should have a 150 nanosecond rating and appropriate current rating. The Mouser part is 512-UF4004. The cost is 15 cents each.

D4 is the LED used as the visual indicator. This LED must be visible on the trace side of the circuit board so it can be seen through the gun indicator window, next to the power switch. More details about LED selection are given in the board assembly instructions. This can be about any T1 size diode. The value of R2 may need to be adjusted to provide appropriate brightness. A Mouser part is 638-264-7HD. It costs 15 cents.

Major components

U1 is a standard 78L05, 5 volt voltage regulator in a TO-92 package. I chose this package because it is robust and not prone to oscillation. Bypass capacitor values are not critical. It has worked well. The Mouser part is 512-MC78L05ACPXA. It costs 35 cents.

U2 is a Microchip TC4427A FET driver in DIP package. I chose this unit to protect both the PIC and the FET's. It can be soldered into the board. However, placing it in a socket is an option. The Mouser part is 579-TC427CPA. Cost is $1.36.

U3 is a Microchip PIC 12F683 microcontroller, installed in a socket to allow possible reprogramming. The PIC must be programmed before it is installed. Mouser part is 579-PIC12F683-I/P. It costs $1.41.

L1 is a 330uh coil rated for 0.38 amps. Mouser part is 580-22R334. It costs 60 cents.

Q1 and Q2 are FQD12N20L N-MOSFETS in a D-PAK package. It is overkill for Q1 and proper size for Q2. A similar unit could be used. It should be rated for at least 200 volts. Consider the gate characteristics on any replacement unit. I didn't have the space for a large TO-220 or D2PAK FET. I chose this package because it was large enough to be soldered by my intended audience. The mouser part is 512-FQD12N20LTM. The cost is 81 cents each.

S1, the power switch is a 0.25 by 0.50 inch, single pole, double throw toggle switch without a center position. The threaded bushing needs to be long enough to pass through the circuit board and the forearm cover plate, including the spacer. When switched to 'power on' it connects the battery minus terminal to the circuit board ground. When switched off it connects the high voltage capacitor (C9), bleeder resistor (R1), to ground. The Mouser part is 108-1MS1T1B1M1QE-EVX. It costs $2.09. Also consider reusing the switch from the factory board.

An 8-pin socket should be used for the PIC. It is optional on U2. If the PIC needs to be reprogrammed it needs to be removed from the board. Mouser part is 575-193308. The cost is 61 cents.

For a battery connector considers 121-0626/OM-GR. It costs 44 cents.

Programming the PIC Microcontroller

I hope that as a result of this article a number of interested parties will come together to help each other in the completion of new boards.

The PIC is programmed by loading a “hex” file into it. The source of the program can be the hex file, or the same file compiled from the assembler file. This process normally requires the free Microchip Integrated software environment and a programmer. A basic programmer, like the PicKit 2 serves this function well. The software is loaded into a computer. The programmer is plugged into a USB port. The assembled file is opened and compiled. Then the program is told to download the program into the PIC. The PIC is then installed on the pistol board.

PIC’s are commonly used within the electronics hobby environment. So expect little difficulty in finding a local individual to program a chip for modest or no cost.

Board Development History

The idea for this project first developed in 2006. At that time I raised the issue on Pilkguns “Target Talk,” (topic=12450) and on the Yahoo “Free Pistol” forum (message 692). Over the years the project kept coming back to haunt me but I wasn’t prepared to spend $700 on a pistol I probably wouldn’t use.   I didn’t need a third free pistol. In February, 2011, I was made aware of a Walther with kaput electronics board for sale in Germany. The price was $185. Getting it to the USA is a story in itself. Delivery took six months

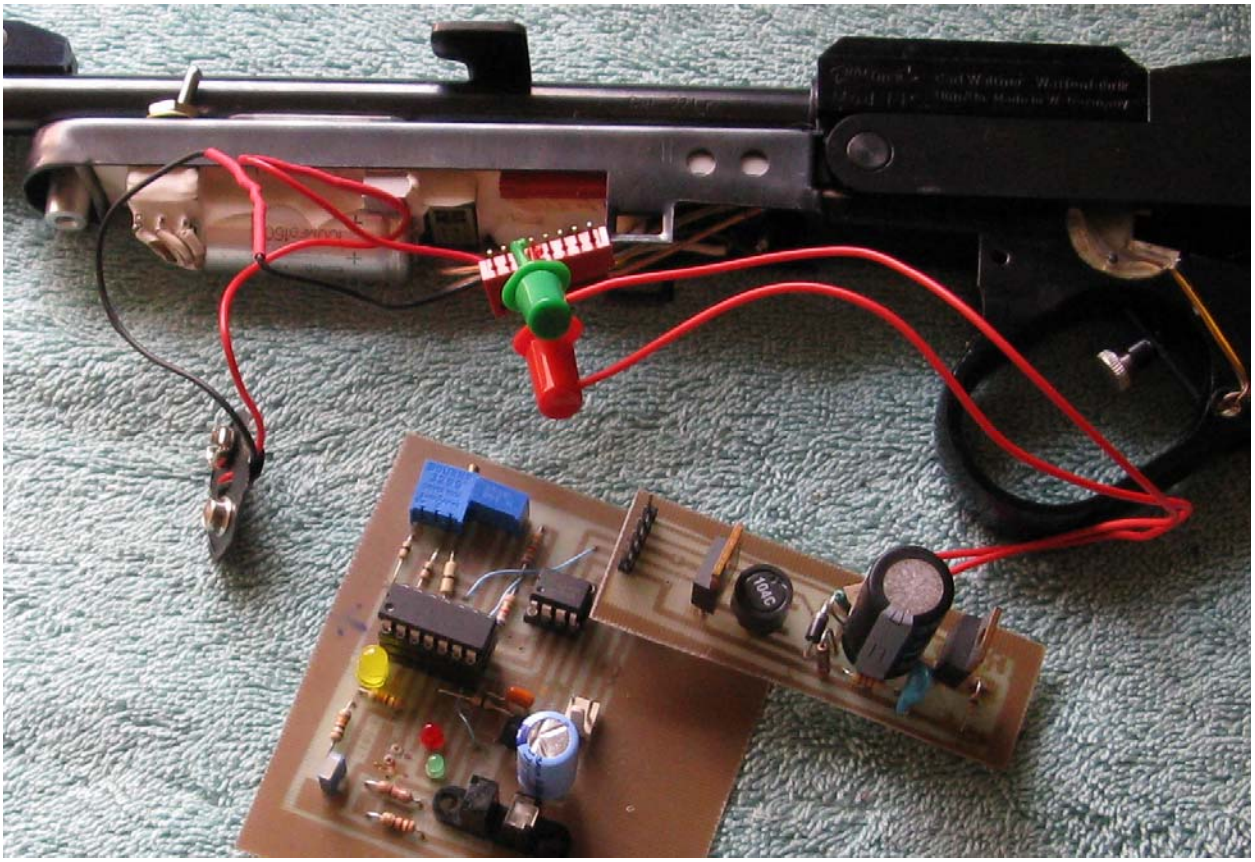
Since then, I’ve spent almost year working, on and off, on this project. Though I have been a “ham” since the 1960’s, I have no formal electronics training and I had a considerable learning curve, especially regarding switch mode power supplies.

For some years I’ve engaged in “what is possible?” thinking. Taking a cue from trainers, like the *Scatt*, I thought these functions could be embedded within a pistol. It would use gyros and accelerometers, rather than lasers, to read pistol movement. Imagine a pistol that stores individual shot data and reports it out as tables and graphs. Plug in a USB cable and download your shot history. It might even know the shooter’s proper shot routine and signal the shooter when it was time to abort the shot and start again.

I soon realized this Walther project wasn’t the appropriate venue for such grandiose ideas. While waiting for the pistol to arrive I began program and board designs. I started with a 14 pin microcontroller using several adjustment “trimmer” pots, similar to R3. It included red, green and yellow LED’s, each of which, could be off, on, or flashing. The result was 81 different light combinations to report battery voltage, charge level, trigger state, and loading lever position. I couldn’t read the LED’s without a program. It was too much. I actually built this board as a proof of concept; see the photo below. It was too big to fit in the pistol, but all functions worked.

In the photo below I’ve wired this board up to the firing coil using the 8-pin connector in the pistol. I was experimenting with high voltage levels and firing pin pulse times. I have bypassed the original circuit board still mounted in the pistol. You can also see the brown and yellow wires coming from the trigger sensor. Also note how close the switch is to the edge of the forearm cover plate. After building the board shown above I built two boards that used surface mount devices (SMD). They retained the 14 pin microcontroller and used three SMD LED’s. SMD construction was required to get all the components on the board.   About then I started thinking about a board built by shooters not electronics hobbyists. I also realized I couldn’t make and sell these boards. The market was too small and the liability too great. Those considerations would require eliminating surface mount components and moving to a smaller PIC.

These considerations were reinforced when my gun arrived from Germany. I decided to replicate its minimalist circuitry approach. This meant using a single LED to report the trigger is pulled and the gun is charged. These decisions allowed use of an eight pin microcontroller, and through hole construction; methods from the 1970's—decisions that made construction by electronics novices possible.



In this first test board the 14 pin PIC and other logic components are on the big board. The small board is the SMPS high voltage converter.   Large, TO-220 FETS are seen on the small board. The slot device on the big board is an optointerruptor to simulate the trigger.

I've built three different boards using the 8-pin PIC. The first was to optimize the inductor size and SMPS protocol. The other two were to achieve a board that was most easily built. The board contained in this article is the last board I've designed.

Other Experimentation

<u>Trigger Experimentation.</u> The Walther trigger is simple, yet elegant. A small hole is drilled across the bottom of the trigger guard. A short, larger hole is drill in from each side. The LED is stuffed into the right hole and the phototransistor is stuffed into the left. The brown ground wire and sensor yellow wire are connected on the left side of the gun. The LED blue/grey wire is connected on the right side. Pulling the trigger causes a steel wire, attached to the trigger, to block the light beam, which the circuit reports as "trigger pulled."

The trigger components are robust unless overloaded. I would not want to repair damaged trigger components so I was careful driving them. I am comfortable using the 820 ohm resistor, R4, for the LED. It pulls 4.5 milliamps and the trigger functions well.

The sensor voltage, going to pin 3 of the PIC12F683, climbs when the trigger is pulled. After several different resistances for R8, I decided on 20K. Voltage range is 0.78 volts with trigger open and 1.47 volts with trigger closed. This range is significant as the trigger position is read using the top two bits of the PIC analog to digital converter output. There is more about that in the software discussion.

If I wanted to design a pistol, it would be easy to replace the optical trigger with a micro or other break contact switch. A pull down resistor on the PIC pin would allow an opening switch contact to perform the trigger function. Such a switch would work without changing existing software.

<u>The switch mode power converter (SMPS)</u> is a basic boost converter. Referring to the diagram on page 22, the inductor, L1, is powered by the nine volt battery. When the gate of Q1 is powered up by the PIC, the battery is in a short circuit to ground, except for the inductor. The inductor charges. But before it reaches saturation, and becomes a short circuit, Q1 turns the power off. The charge in L1 has no place to go except through diode, D2 into capacitor C9. Once it discharges the process is repeated. The PIC provides the pulse signal to keep this process going, 25,000 times per second. As long as pulses continue the voltage in C9 rises until a natural limit is reached—about 180 volts.

R3 provides a voltage back to PIC pin 6 that is proportional to the voltage in C9. The PIC comparator is used to turn on and off the pulses to Q1 thus maintaining the desired level in C9.

<u>The Firing Coil</u> provided some interesting analysis. Below is a photo of the firing pin mechanism. My interest was in the coil design that permitted a 150 volt charge to fire a cartridge.

My coil had originally been wrapped with a thin adhesive tape. The adhesive had long since failed so the outer wire layer was floating free. The coils on the top layer were wobbling like a spring so I was concerned that continued firing could result in a short. There are very thin adhesive tapes called “transformer tapes” to cover coil windings. High temperature resistance Kapton is commonly used. But a 36 yard roll can cost $45. I decided to use “scotch” tape. It’s not temperature resistant, but the coil should not get very warm given the low duty cycle.

Based on measurements the coil appears wound with #29 varnish insulated copper magnet wire. The coil is 4 layers deep and 66 turns wide. The coil wire length is about 43 feet. The measured DC resistance was 4.7 ohms. Calculated open air inductance is 215 micro henries. The wound area of the coil is 0.700 inches long with a diameter of 0.748 inches. The cap is bored to fit the firing pin. It has an exterior flange that fits into the coil. The cap has a turned exterior diameter of 0.509 inches. The turned down portion of the cap is 0.375 inches long.

The firing pin has an OD of 0.392 inches. Two slots run the length of the firing pin to permit the passage of air. The cap also has a hole to allow the release of air as the firing pin acts as a piston. The primer contact end of the firing pin is 0.062 in diameter. The overall firing pin length is 1.00 inches. The firing pin stroke is about 0.10 inches.

The return spring has an OD of 0.150 inches. It is 0.625 inches in length.

I have the impression that English, rather than metric measurements were used for designing many parts on this pistol.

Note the simplicity of the firing pin mechanism. The coil is four layers deep.

<u>SMPS experimentation.</u> The SMPS can pull a lot of power. I wanted to get as many shots as possible from a battery. To maximize the number of shots I had to experiment with the size of L1 and the dimensions of the charging pulse.

I started with data from Microchip document 91053b, TB053. This bulletin discusses using a PIC for a high voltage power supply. Based on its material I developed a prototype board that used a 100 microhenry coil. The SMPS square wave was 7 microseconds long and the overall period was 11 seconds. These parameters were successful in developing a 100 volt capacitor charge in about a second.

But it had two downfalls: The startup current was simulated to be in the amps, not tens of milliamps, which overloaded the battery. Peak current draw after startup was about 200 ma. The battery failed to operate once battery voltage dropped to about 8.5 volts.

The Walther FP has a slow duty cycle. It’s reasonable that the gun is fired once every 45 seconds. There is no need to charge up in one second.

So I experimented with a larger inductor and longer charge times. A 330uh coil provided a smaller current draw. This allowed the circuit to function to a lower battery level, below 8 volts. But to achieve this operation I had to increase the pulse width to 9 microseconds. I then extended the overall period to lengthen the charge times. The pulse width sets the current draw. With 9 microseconds I come up with an instantaneous current of 210ma and average current draw of 25ma.

New battery voltage is about 9.1 volts. Charge times, from power on, average about 7 seconds. As the voltage drops to 8.1 volts the charge time increases to 10 seconds.

The PIC waits 60 milliseconds after power up before it starts up. The SMPS power up current peak takes less than two milliseconds so I haven’t had a problem with the power up affecting PIC operation.

I have not intensively tested board function at lower battery voltages. Testing suggests as battery voltage drops, a point will be reached where it can no longer bring the C9 to full power. But the electronics may still function.

Original Pistol Connector

My early version pistol used an eight pin connector to connect the board to pistol components; the red device seen in previous photos. This is the sequence of wires to that connector moving from muzzle end, back:

Red wire—Positive lead from 9 volt battery
Black wire—Negative lead from 9 volt battery
Gold wire—High voltage lead to firing coil
Gold wire—High voltage lead to firing coil
Brown wire—Ground connection to trigger
Grey wire—LED wire to trigger
Yellow wire—Sensor wire to trigger
Steel wire—Index wire to prevent installing connector backward

Brief Software Overview

When powered up a routine named LiveDry checks the position of the loading lever. If the loading lever is closed the gun begins dry fire mode. If the lever is open live fire is indicated. The two modes are identical expect for the voltage delivered to the firing pin coil. The power must be turned off to switch between live and dry fire.

The next routine is called TriggerTest. If the trigger is pulled the indicator LED lights up. The program stops further activity until the trigger is released. With the electronic trigger it is possible to adjust the trigger so it is always in the pulled state. This test is for safety purposes.

The software then begins a loop called NextShot that is repeated with every shot:

The routine ShootLoop checks the loading lever. If the loading lever is open the gun goes into wait mode. A closed loading lever signifies the gun is loaded and ready to fire. This causes the software to charge up the power supply. ShootLoop also checks to see the trigger is open. The trigger state is tested every 30 millionths of a second. When the power supply is charged up it turns on the flashing LED. If the trigger is pulled ShootLoop is exited.

The TriggerFire routine is entered when the trigger is pulled. The SMPS turns off, and the firing pin coil is turned on. The software waits for a specified period, 8 milliseconds, before turning the trigger coil off. This period can be adjusted in software.

The routine TriggerRelease waits for the trigger to open. The length the trigger is pulled has no bearing on the length of the firing coil pulse.

The software then performs LeverTest waiting for the loading lever to open, signifying the end of the shot.

The software returns to NextShot, above and, waits for the next close of the load lever. This signifies the beginning of the next shot process.

Anytime the shooter wishes to wait, the gun can be put into standby by cracking open the loading lever. This causes the SMPS to stop. The charge level will slowly drain off . It will recharge in less than ten seconds when the loading lever is closed. Whenever the dry fire mode is first selected the gun will go immediately into charge mode as the loading lever is closed. If the shot is delayed the loading lever can be opened.

Further Software Details

The software is written in Microchip Assembler. It was written for novice users so it has no include files and it is written in absolute code. The codes require about 120 instructions.

The PIC CCP module provides the pulse for the SMPS. The pulse remains high for 9 microseconds with a total period of 35 microseconds. A routine named ChargeLoop operates the SMPS. The charge voltage is set by clearing and setting the CCPR1L byte which turns on and off the PWM pulse. The TMR2 timer is used by the CCP module.

The Comparator module controls the fully charged voltage level. The voltage divider provides feedback voltage to the comparator that is proportional to the capacitor, C9, voltage. When this feedback reports that C9 is charged, the charging pulse is turned off. As the C9 voltage drops, the charging pulse is turned back on.

The comparator uses the internal, high voltage reference range. Changing the value of byte VRCON changes the voltage level range. The voltage difference between live and dry fire is set by changing VRCON. R3 sets the live fire voltage level and the dry fire level follows it.

The analog to digital converter, ADC module, reads the trigger state using a routine named TriggerRead. The value of resistor, R8, was selected so that the voltage to PIC pin 3 is below 25% of Vdd (about 1.25 volts) when the trigger is open and above 25% of Vdd when the trigger is pulled. On my gun, a 20K resistor provides a voltage of 0.78 volts with trigger open and 1.47 volts with trigger closed.

The ADC has 10 bit resolution. It is set with right justification. This means the upper byte, ADRESH, holds the two upper bits. This byte will equal zero if the voltage is below 25% of Vdd. It will not equal zero if the voltage is above 25% of Vdd. So the STATUS byte, ZERO flag, is used to read the trigger state.

It takes about 30 microseconds for the software to request and receive the current trigger status.

Four, one bit flags, are defined in software. Flag 1 is the PWMFlag. This flag is set when the SMPS is charging and clear when the charger is off.

Flag 0 is the ChargedFlag. Once C9 reaches charged voltage this flag is set. This flag is used to set the LED indicator flashing. The PWMFlag is not used because it turns on and off as the C9 voltage varies so using it would cause the LED to flutter and dim as the charger turned on and off.

Flag 3 is the FlashLEDFlag. It reads the current state of flash. By reversing the current state of this flag the LED is made to turn on and off.

Flag 4 is the TriggerFl. This flag is set when the ADC reports the trigger is pulled. It allows the state to be remembered as program steps are made.

There is no debounce procedure on the trigger or loading lever switch. There is no evidence of false switch state change problems. The process loops are slow enough that multiple reports from a switch state change is not a problem.

Remaining Questions

Q2 FET Headroom

The firing FET, Q2, may be the weakest link in the circuit. My tests suggest it is adequate to the task. It has a continuous maximum rating of 9 amps and a pulse rating of 36 amps. My estimate is at the end of one capacitor discharge time constant of 1.7milliseconds the current draw is about 8.8 amps. The trigger pulse is 8 milliseconds, the end of which leaves the capacitor at about 14 volts. User experience will tell us if the component is properly sized. Feedback on this point is welcomed.

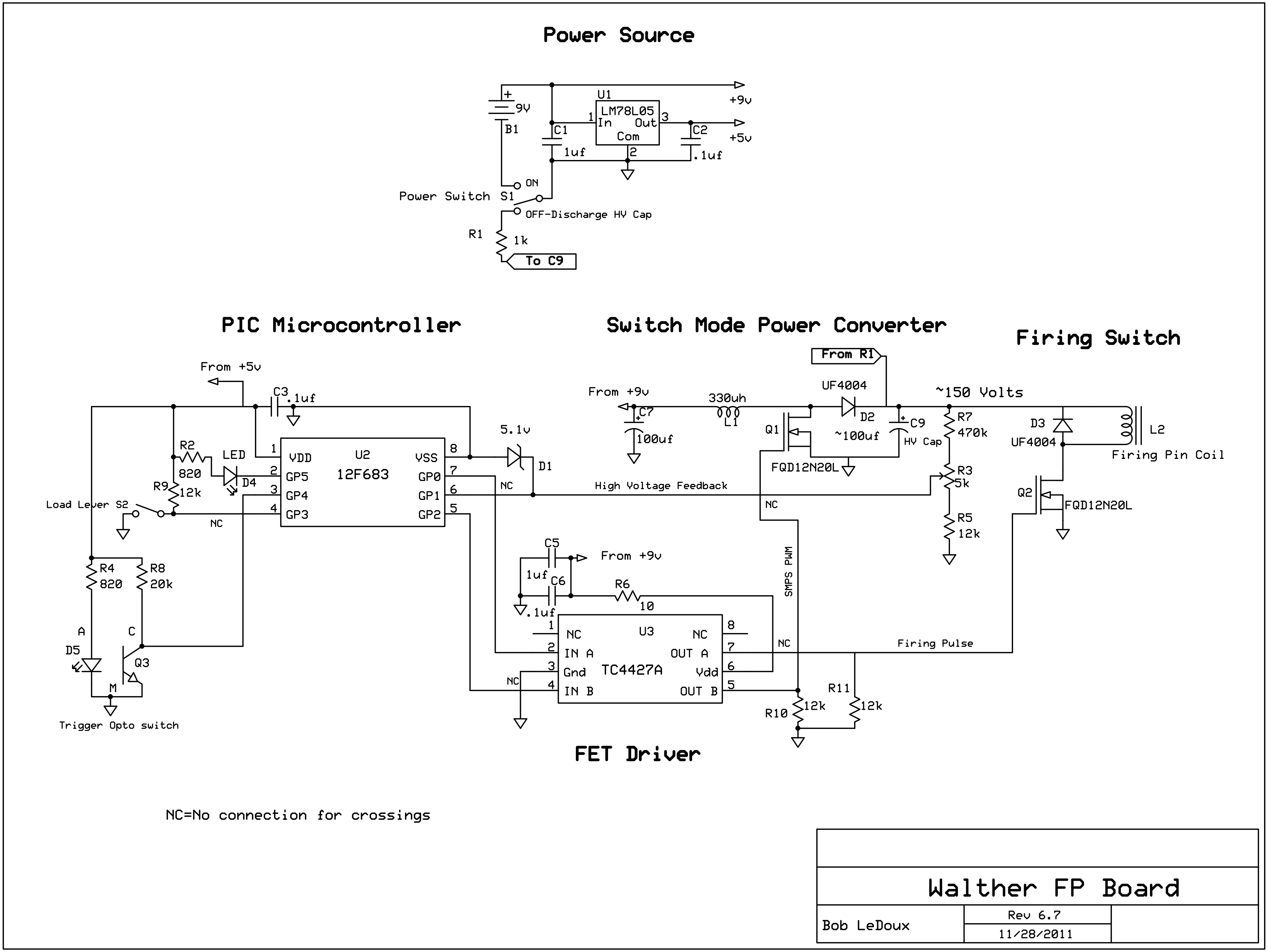
Power Down Idiosyncrasy

Assume the shooter is performing live fire. The gun is loaded, the loading lever is closed and the gun is charged up. If the shooter switches the power switch to “off,” the firing pin may hit the cartridge with less than dry fire force.

If the shooter performs this same routine while dry firing, a barely discernable click may be sensed.

When power is switched off the high voltage capacitor, C9 immediately starts discharging through bleeder resistor, R1. At the same time, power to the microcontroller is cut off so it loses control of board operations. The remaining charge in C9 may power the firing pin coil. A smaller value R1 may reduce the firing pin power. But I haven’t developed a way to eliminate this idiosyncrasy.

This issue does not occur if the shooter follows normal protocol of opening the breech if further shooting is not intended.



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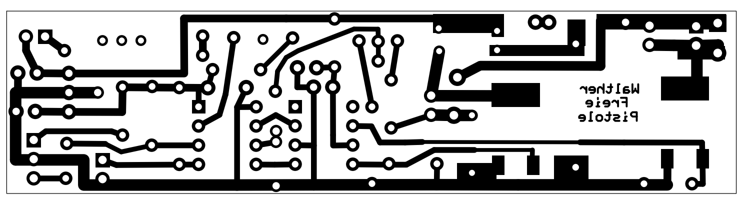

o--------Distance between holes is 3.80 inches---------o