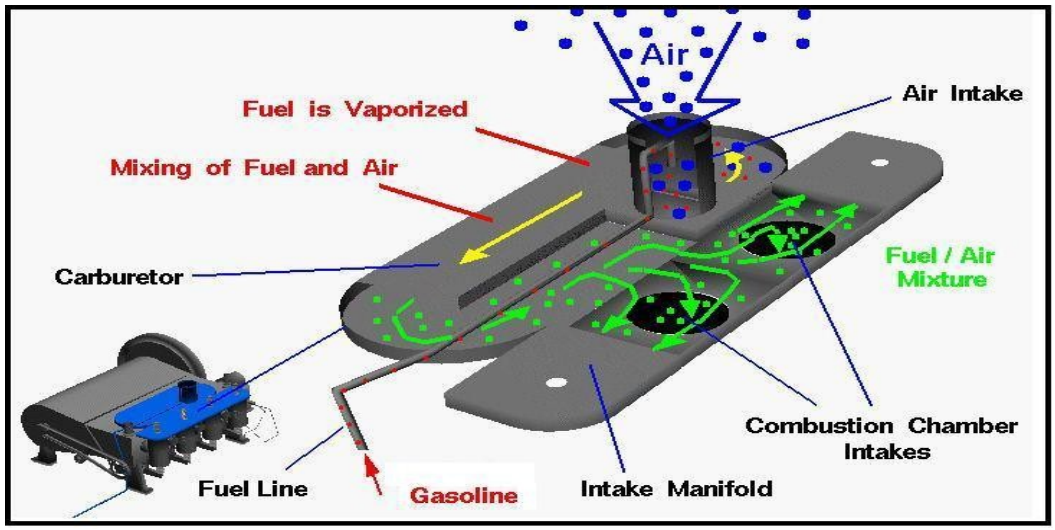
555 FUEL INJECTION SYSTEM

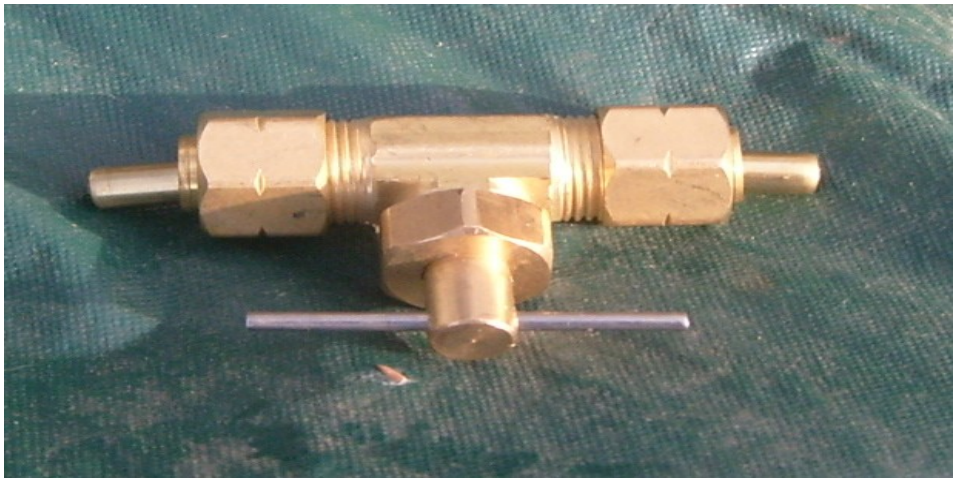
The Wright Brothers 1903 aircraft piston engine fuel flowed through a small metal fuel line from the high mounted tank to the engine. The fuel dripped into a flat, enclosed pan that sits on the top of the engine. The floor of the pan was hot because it sat over the hot engine cylinders. Air was drawn into the pan through the air intake, because of the action of the pistons. The combination of air being drawn over the fuel and the heat of the floor of the pan caused the gasoline to evaporate.



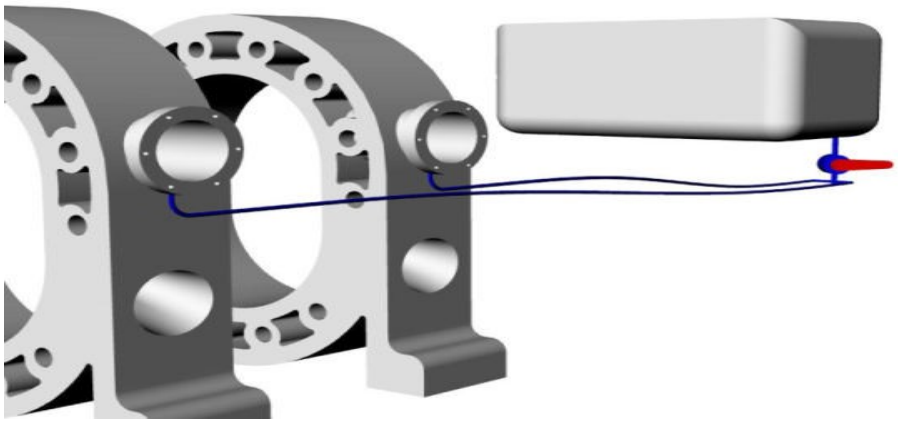
The fuel flow to the engine was adjusted while the aircraft was waiting on the launch rail. When the engine was running as fast and smooth as possible the aircraft was ready for launch. The pilot had a control lever which was connected to a cut-off valve to stop the engine at the end of the flight. The brothers had no throttle or engine control during the 1903 flights. The Wright "carburetor" and intake system had no moving parts. Without the moving parts, the brothers engine ran at just one speed throughout the flights of 1903.

My hangar neighbor Klaus Saviour's O-200 engine also runs with a constant speed dribble system consisting only of one small tube, poked into the throttle body, gravity feeding fuel from a header tank and using a fixed throttle opening and at a given RPM. He uses it as a back up system to his 555 integrated circuit based EFI.

Here is suitable $7 valve from Home depot.

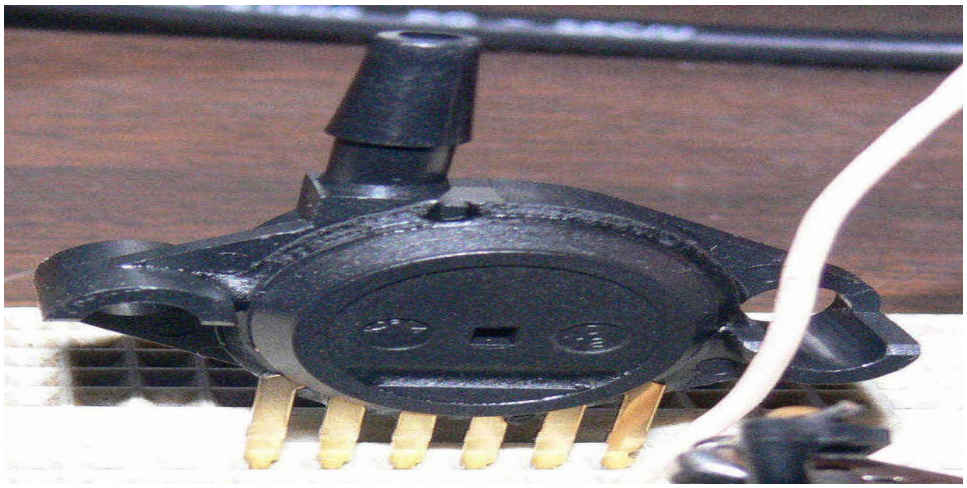


Here is what a similar emergency system would look like for a two rotor Mazda p-port engine.

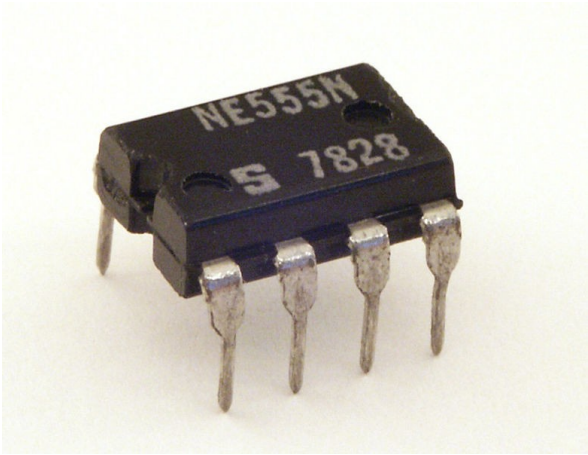


Airplane engines are different from car engines. Unlike car engines they have a known and repetitive load verses RPM curve using a fixed pitch prop. There are no requirements for rapid acceleration or rapid changes in load or RPM. Consequently the fuel system can be very rudimentary. In a car engine it is possible to have high RPM with low fuel flow if there is no load on the engine. You don't see that in aircraft engines with fixed pitch props. Load is probably proportional only to RPM squared when driving a prop when tip speeds are below the transonic range. At that point the load approaches very high values indeed.

The hot wire mass airflow sensor is probably the most ubiquitous way to control an automotive EFI system. It automatically compensates for humidity and intake air temperature unlike a manifold pressure sensor. You do need the e-shaft trigger but the mass air flow sensor can control the pulse width while the e-shaft triggers the injector once per revolution. Unfortunately it is not a linear device. It takes a computer to deal with it's voltage output as a function of the mass air flow through it. For that reason we are not going to use it with this system. Instead we will use manifold pressure to control a 555.

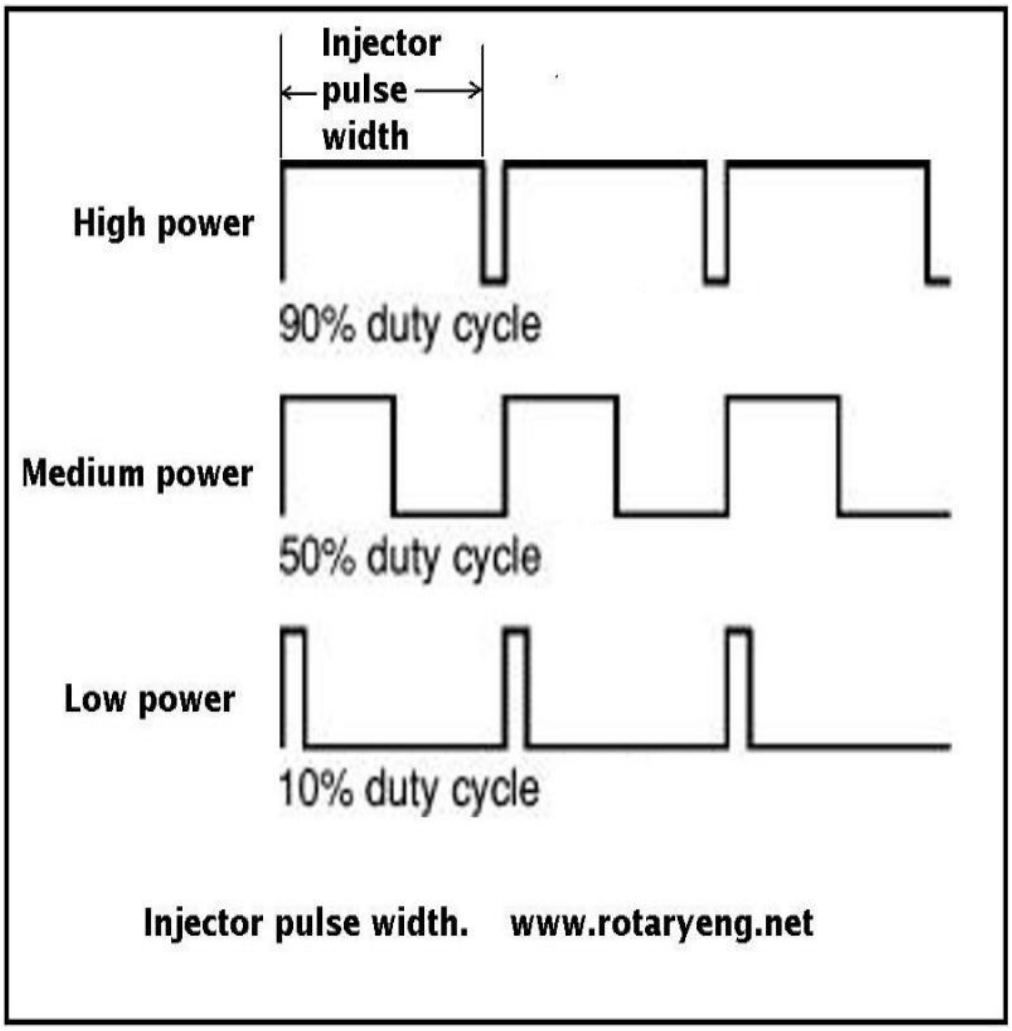


The 555 is a small and cheap integrated circuit implementing a variety of timer and multi-vibrator applications. The IC was designed and invented by Hans R. Camenzind in 1970. The original was called "The IC Time Machine". It is still in wide use, thanks to its ease of use, low price and good stability. As of 2003 one billion units are manufactured every year.

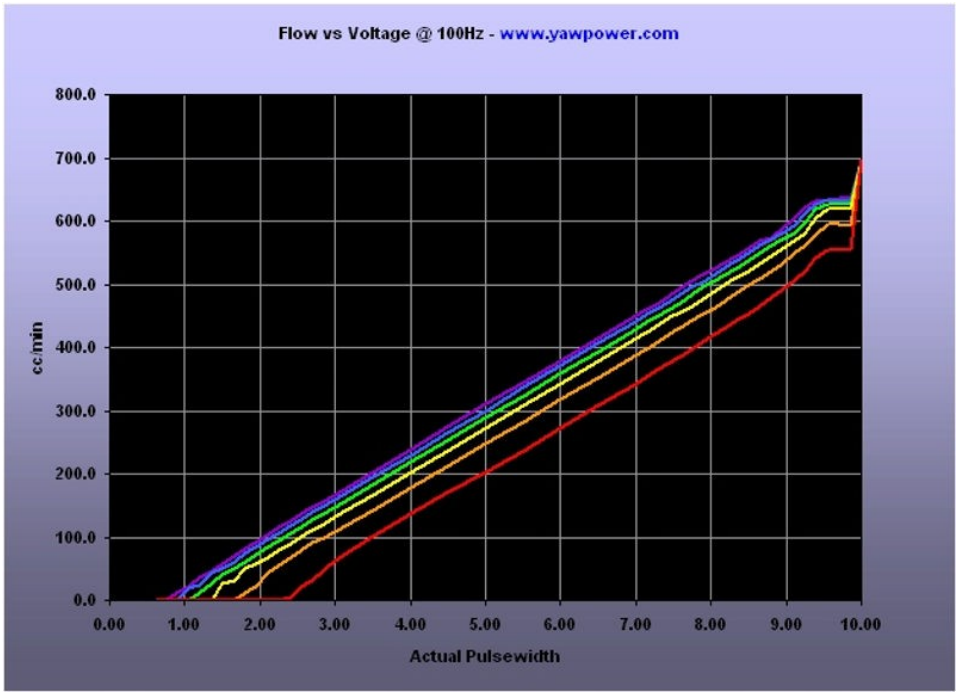


The 555 timer is one of the most popular and versatile integrated circuits ever produced. It includes 23 transistors, 2 diodes and 16 resistors on a silicon chip installed in an 8-pin mini dual-in-line package. Also available from TI are ultra-low power versions of the 555 such as the TLC555. This one works the best and it will be the one we are going to use. No other one, that I have found, works nearly as well. In essence, what the EFI computer does is gather data from its sensors and then use that data to to determine an injector pulse width. The TLC555 can do the same thing in a simple and cheap $1 chip.

The TLC555 has a pulse width modulation mode that works very well. In essence it is a complete EFI system for less than $1. One TLC555 per injector. If one fails no big deal.



This next chart from Paul Yaw shows the wider dynamic range of the more modern fuel injectors. The purple line. The delay on the lower end is the dead time.Earlier Mazda injectors had a longer dead time so it was necessary to use staged injectors. In other words one injector per rotor at low power and a two injectors per rotor at higher powers. I don't think that is now necessary for aircraft use. Also idle and low RPM with car use precise fuel control was very important to to emissions requirements.

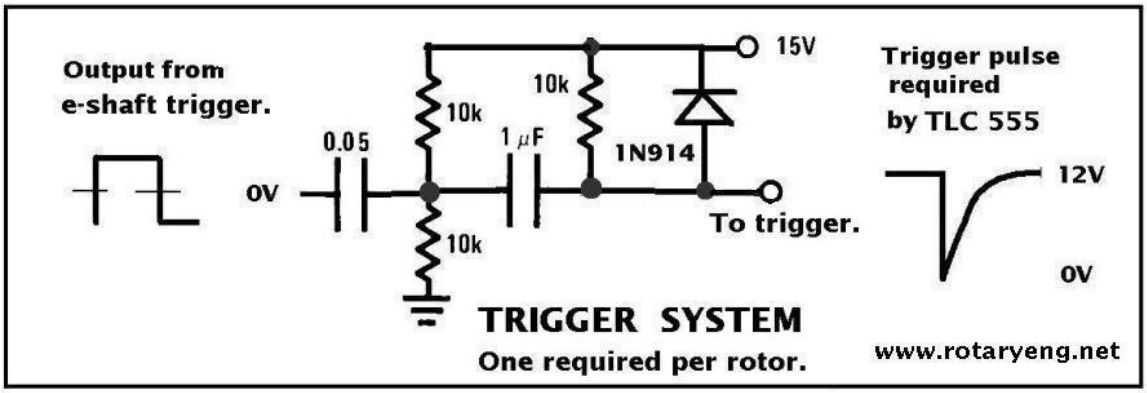


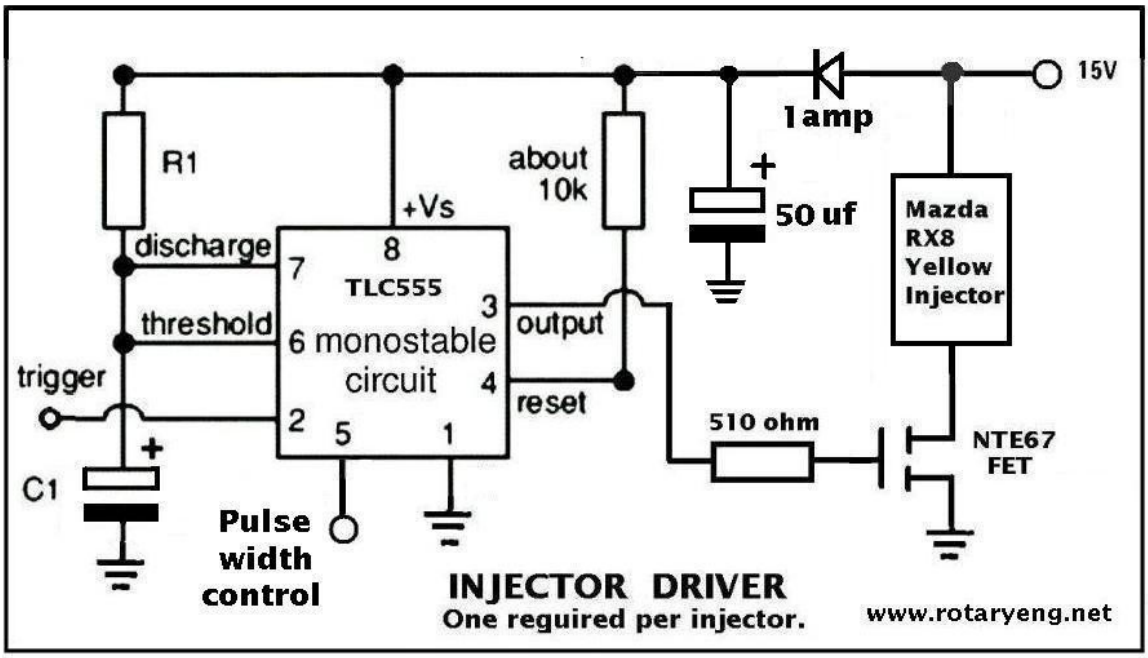
The main sensor required is the intake manifold pressure.

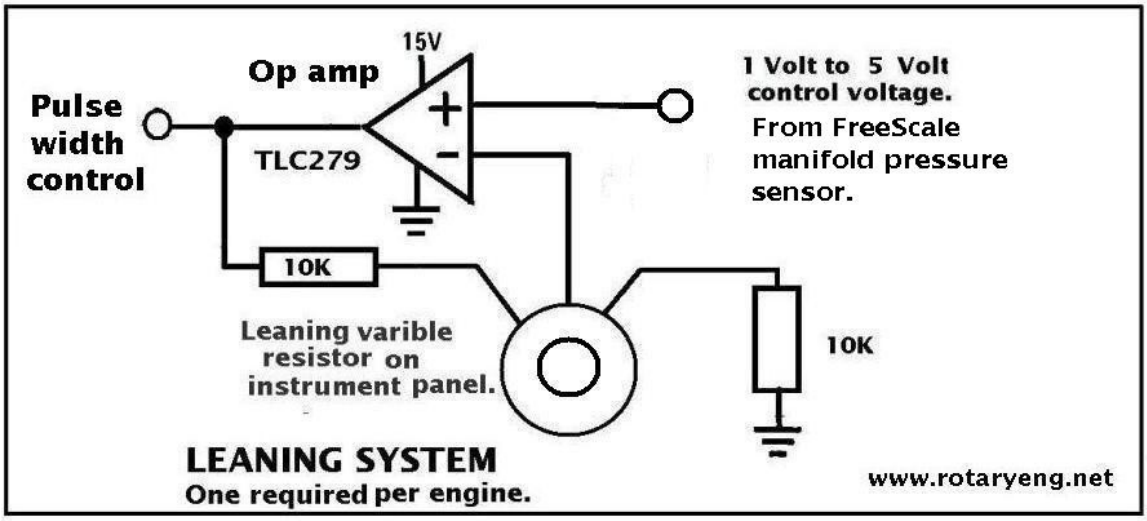
The TLC555 can change the amount of fuel over a nine to one range at 6000 RPM as the pulse width varies from 1 msec to 9.5 m sec as the signal from the mass airflow sensor changes its output voltage from zero to five volts. A bonus for the TLC 555 chip is it's high output drive current of 15 ma source and 150 ma sink on pin 3. It is not your grandfather's 555 or even your dad's for that matter. That should be enough to drive the injector FET directly and it was.

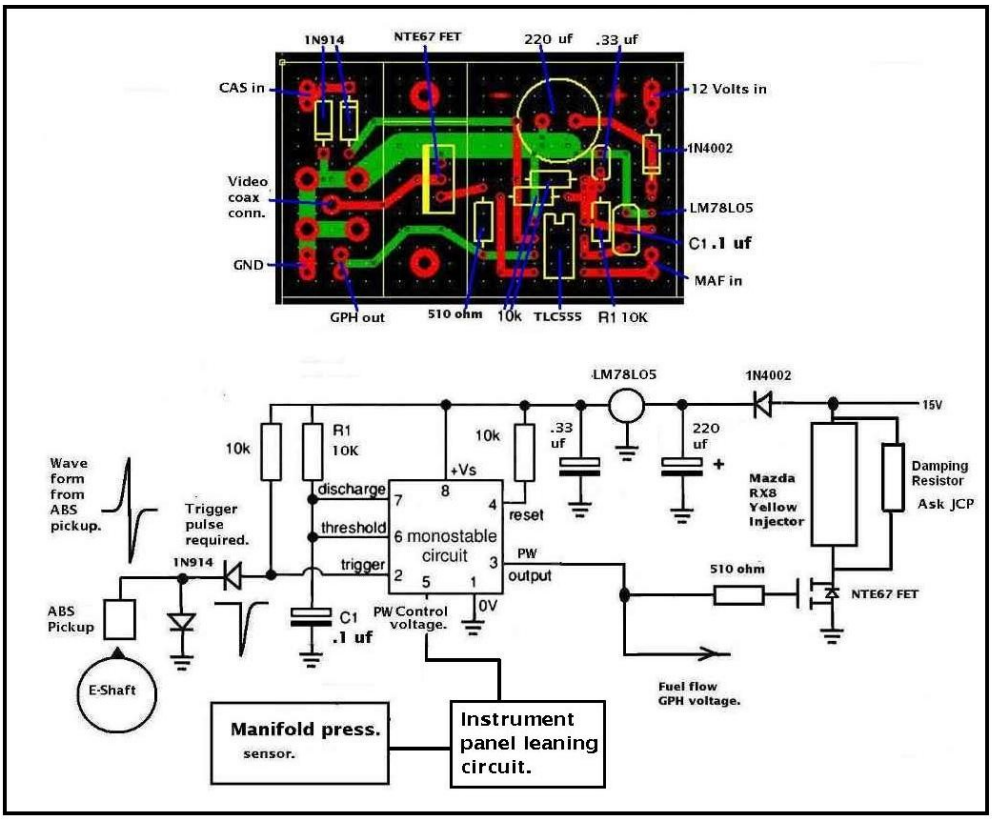
I am talking about a complete TLC555 based EFI system costing less than 100 dollars while the cheapest micro computer system, the Megasquirt, is over $300 (completely assembled). Tracy Crook's dual system is over $750 and many, like the Haltech, are over $1000. Plus the TLC555 EFI is a super simple system and anybody that anybody can fix or build from scratch. No need to learn programming or guess what a proprietary EFI software program is trying to do. There is no software. Suitable carburetor's are over $1000.

Here is the skematic.


Output from
e-shaft trigger.
0V
0.05
10k
10k
1 μF
10k
1N914
15V
To trigger.
Trigger pulse
required
by TLC 555
12V
0V
TRIGGER SYSTEM
One required per rotor.
www.rotaryeng.net


15V
1amp
R1
about
10k
+Vs
+
50 uf
Mazda
RX8
Yellow
Injector
discharge
8
7
TLC555
3
output
threshold
6 monostable
circuit
4
reset
trigger
2
5
1
510 ohm
NTE67
FET
C1
+
Pulse
width
control
INJECTOR DRIVER
One reguired per injector.
www.rotaryeng.net


15V
Op amp
Pulse
width
control
TLC279
+
-
1 Volt to 5 Volt
control voltage.
From FreeScale
manifold pressure
sensor.
10K
Leaning varible
resistor on
instrument panel.
10K
LEANING SYSTEM
One required per engine.
www.rotaryeng.net



You don't need a degree in computer science or electronics to understand it or fix it. Any mechanic or electronics technician should be able to build and fix it. It is organized as three simple and reliable systems. Simple manual controls in the form of switches help diagnose the system and give flexibility of use.

The Trigger system conditions the pulse from the e-shaft position sensors and feeds it to the Injector driver. Only one trigger system is require per rotor. More than one trigger system can be implemented for redundancy as this is a true modular system with stand alone capabilities.

The Injector Driver system contains the TLC 555 and a transistor to turn the injector on and off. One or two can be used per rotor. If two are used per rotor and the engine is two rich at idle one per rotor can be turned off with the addition of two switches. Smooth running at low RPM is seldom required of an aircraft engine. Newer injectors have a wider dynamic range so smooth running is still possible with four injectors. In other words the minimum amount of fuel injected has been extended downward. We will find out when we test various injectors.

The Leaning System is used to lean the engine at cruise. One per rotor can be used to adjust the mixture on each rotor separately. You don't have to use one per rotor if you don't want to. One unit can lean all injectors. Its output is connected to pin 5 of the TLC555 to control the pulse width. It get's its input information voltage from the mass airflow sensor. We would set up the TLC 555 pulse width in an aircraft engine to be rich all the time for engine acceleration purposes. No need for an accelerator pump. Many aircraft engine carbs don't have them. Once you reach cruise you lean the mixture to as little as 18:1 for best BSFC.

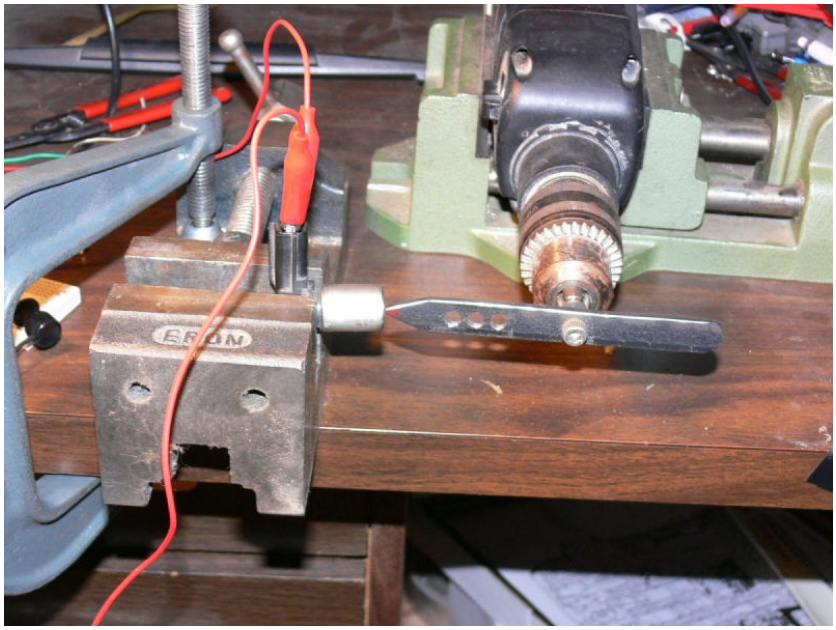
There are two sensors on the e-shaft steel trigger plate 180 degrees out... one for each rotor. The angular position of the sensors control when the fuel is injected. Here are a couple of stock Mazda triggers.



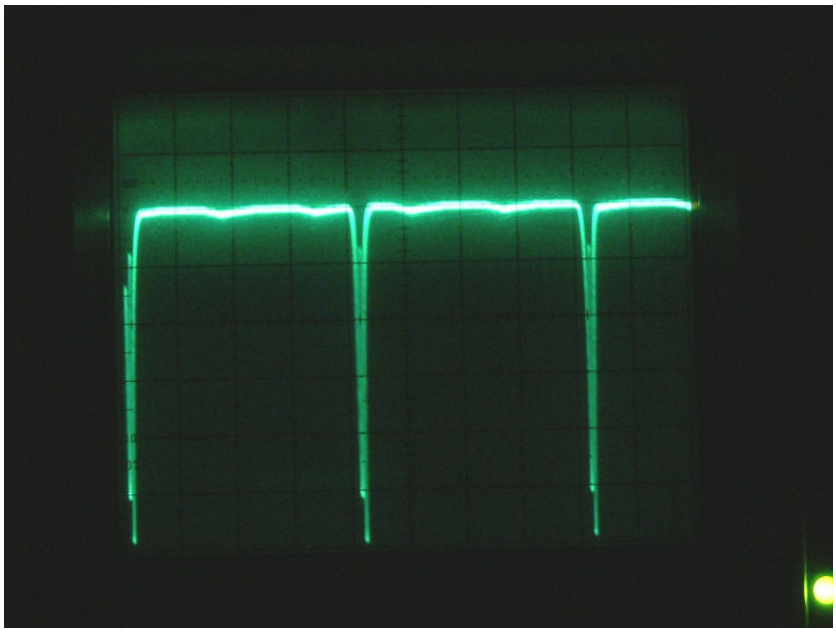
Also note it is simple to adapt this system to a three or four rotor engine. Just replicate the systems as needed. This is an e-shaft trigger mounted on Mark Steitle's three rotor powered Lancair ES. The trigger wheel shown is not the right one for this system.



Test set up for magnetic trigger.



As you can see all I used is a simple bar of steel about 6 inches long 3/4 inch wide and 1/8th inch thick. This is to trigger the 555 fuel injectors. It can be rotated on the e-shaft pulley to set the injector timing anywhere. The scope is set at 5 volts per vertical division and 10 ms per horizontal division.



At 1500 RPM it is still - 30 volts which is more than enough to trigger the 555. A simple full wave bridge is used that only requires four low cost diodes.

The ideal trigger tooth is about 1/4 to 3/8 thick (wide) and comes to a sharp point. The spacing must be .050 or less. The amplitude of the trigger pulse is a very VERY strong function of the spacing. 0.010 will make a HUGE difference.

I would use a feeler gage to set it.

There will be only one trigger tooth and four mag pickups. Two for ignition (about 22 degrees BTDC) and two for fuel injection (about 90 degrees BTDC). The angular position of the pickup relative to top dead

center will adjust the timing of both 555 fuel injection and ignition.

A fuel injector is nothing more than an electronically controlled valve. It is supplied with pressurized fuel by the fuel pump and it is capable of opening and closing many times per second. The amount of fuel supplied to the engine is determined by the amount of time the fuel injector stays open. This is called the pulse width. Injectors are classified into two categories.

High coil resistance (saturated) 12-16 Ohms.

Low coil resistance (peak & hold) 0.5-6 Ohms.

Saturated injectors require roughly 1-1.5 amps to open the injector. Peak & hold injectors initially needs about 4-6 amps, and once open drops to roughly 2-3 amps to keep it open. This system uses the high coil resistance injectors to keep it simple. With four injectors and a P-port engine you will need injectors capable of feeding about 75 Horses each.

Fuel Injector flow rates compiled by steve@aems.com.au

Injectors listed by max flow rate, from lowest to highest

Manufacturer	Part Number	cc per minute	Colour	Ohms	lbs per hour	Est HP	Press Kpa	Vehicle	Engine
Nippon Denso		250	yellow/orange	1.7	24.5	50.0	255	Toyota	22RTE
Nippon Denso		250	green	13.8	24.5	50.0	290	Toyota	4AGE
Nippon Denso		250	violet	13.8	24.5	50.0	290	Toyota	4AGE
Nippon Denso		250	brown	13.8	24.5	50.0	255	Toyota	3SGE
Nippon Denso		251	violet	13.8	24.5	50.2	290	Toyota	1UZFE
Nippon Denso		282	light green	13.8	27.6	56.4	290	Toyota	2RZE
Nippon Denso		282	violet	13.8	27.6	56.4	290	Toyota	2TZFE
Bosch	0 280 150 802	284			27.8	56.8	300	Volvo	B200 Turbo
Nippon Denso		295	yellow	2.7	28.9	59.0	255	Toyota	7MGE
Nippon Denso		295	pink	1.6	28.9	59.0	255	Toyota	22RTE
Nippon Denso		295	green	13.8	28.9	59.0	255	Toyota	3SGE
Bosch	0 280 150 811	298			29.2	59.6	350	Porsche	944 Turbo
Bosch	0 280 150 200	300			29.4	60.0	300	BMW	
Bosch	0 280 150 335	300			29.4	60.0	300	Volvo	B230 Turbo
Bosch	0 280 150 945	300	red/brown		29.4	60.0		Ford	MotorSport
Nippon Denso		315	pink	13.8	30.9	63.0	290	Toyota	3SGE
Nippon Denso		315	Light green	13.8	30.9	63.0	290	Toyota	7MGE
Bosch	0 280 150 402	338			33.1	67.6	300	Ford	
Bosch	0 280 155 009	346			33.9	69.2	300	Saab	Turbo
Bosch	0 280 150 951	346			33.9	69.2	300	Porsche	
Nippon Denso		365	red/orange	2.9	33.9	73.0	255	Toyota	4AGZE
Bosch	0 280 150 024	380			37.3	76.0	300	Volvo	B30E
Bosch	0 280 150 036	380			37.3	76.0	300	MB	4.5L
Bosch	0 280 150 043	380			37.3	76.0	300	BMW	
Bosch	0 280 150 835	397			38.9	79.4	300	Chrysler	
Nippon Denso		430	black	2.9	42.2	86.0	255	Toyota	7MGTE,3SGTE
Bosch	R 280 410 144	434			42.5	86.8	300	Bosch R	Sport
Bosch	0 280 150 400	437			42.8	87.4	300	Ford	4.5L
Bosch	0 280 150 401	437			42.8	87.4	300	Ford	
Bosch	0 280 150 041	480			47.1	96.0	300	MB	6.9L
Bosch	0 280 150 403	503	blue	0.5	49.3	100.6	300	Ford	

Conversion From cc per min to lbs per hour to HP. 500cc per minute is approximately equal to 49lbs per hour which is equal to approximately 100 HP.

Common conversions

lbs/hour = cc per minute / 10.2

lbs per hour = HP / 2.04

cc per minute = lbs per hour x 10.2

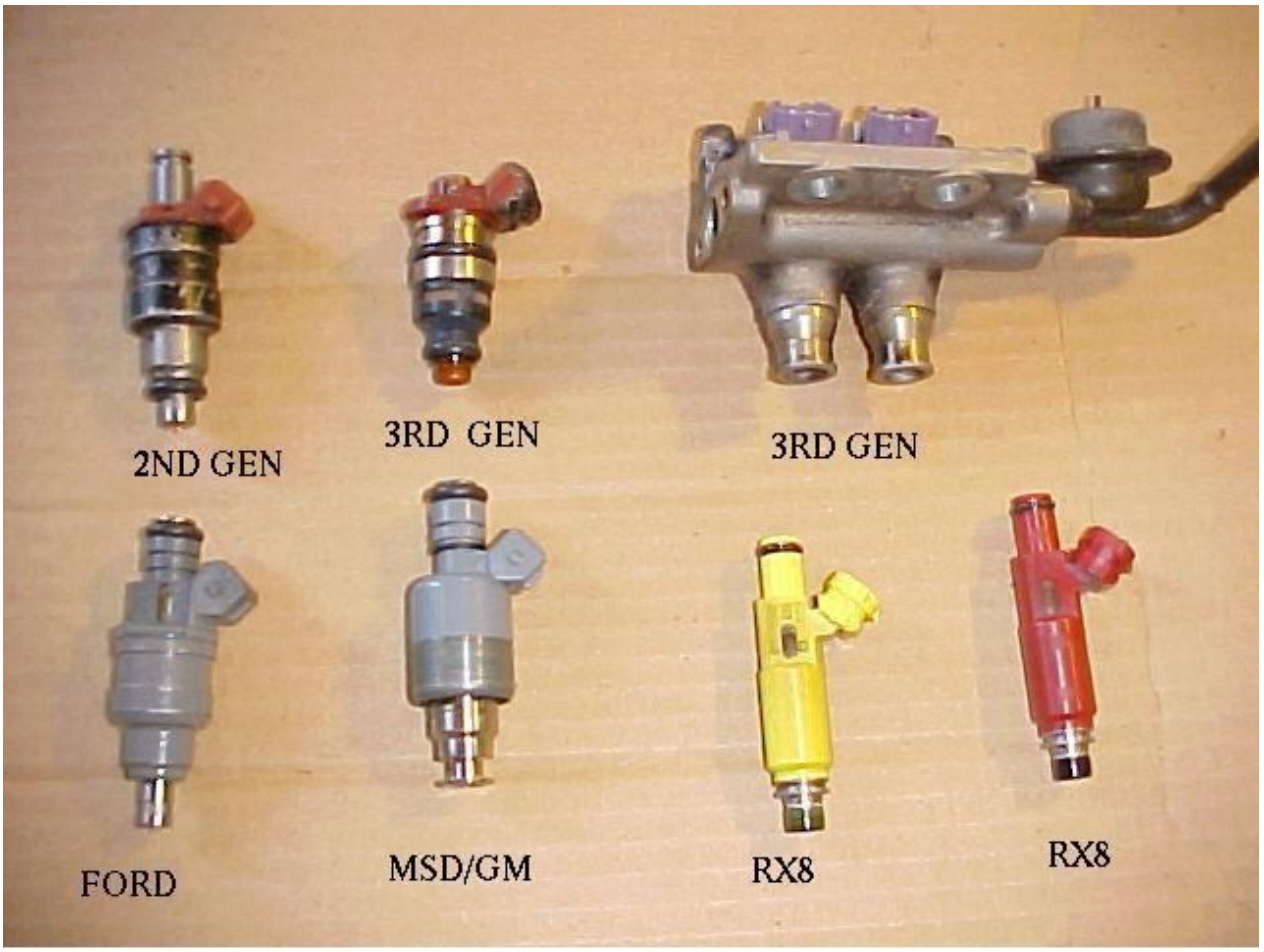
cc per minute = HP x 5

HP = cc per minute / 5

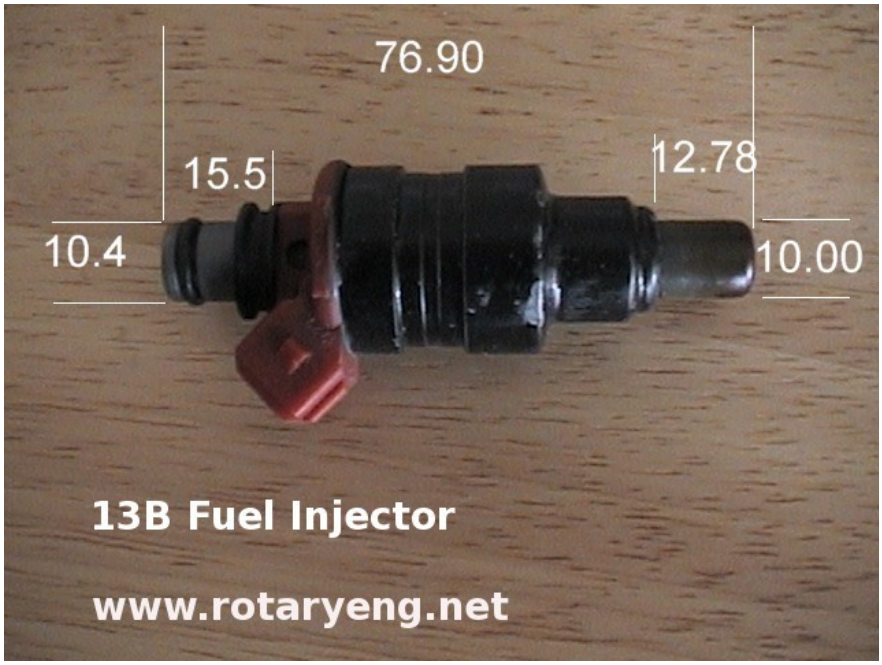
HP = lbs per hour x 2.04

Note: This is a rough guide for conversions and flow rates. If you have any information that would help in increasing the quality of this data base, please send email to steve@aems.com.au.

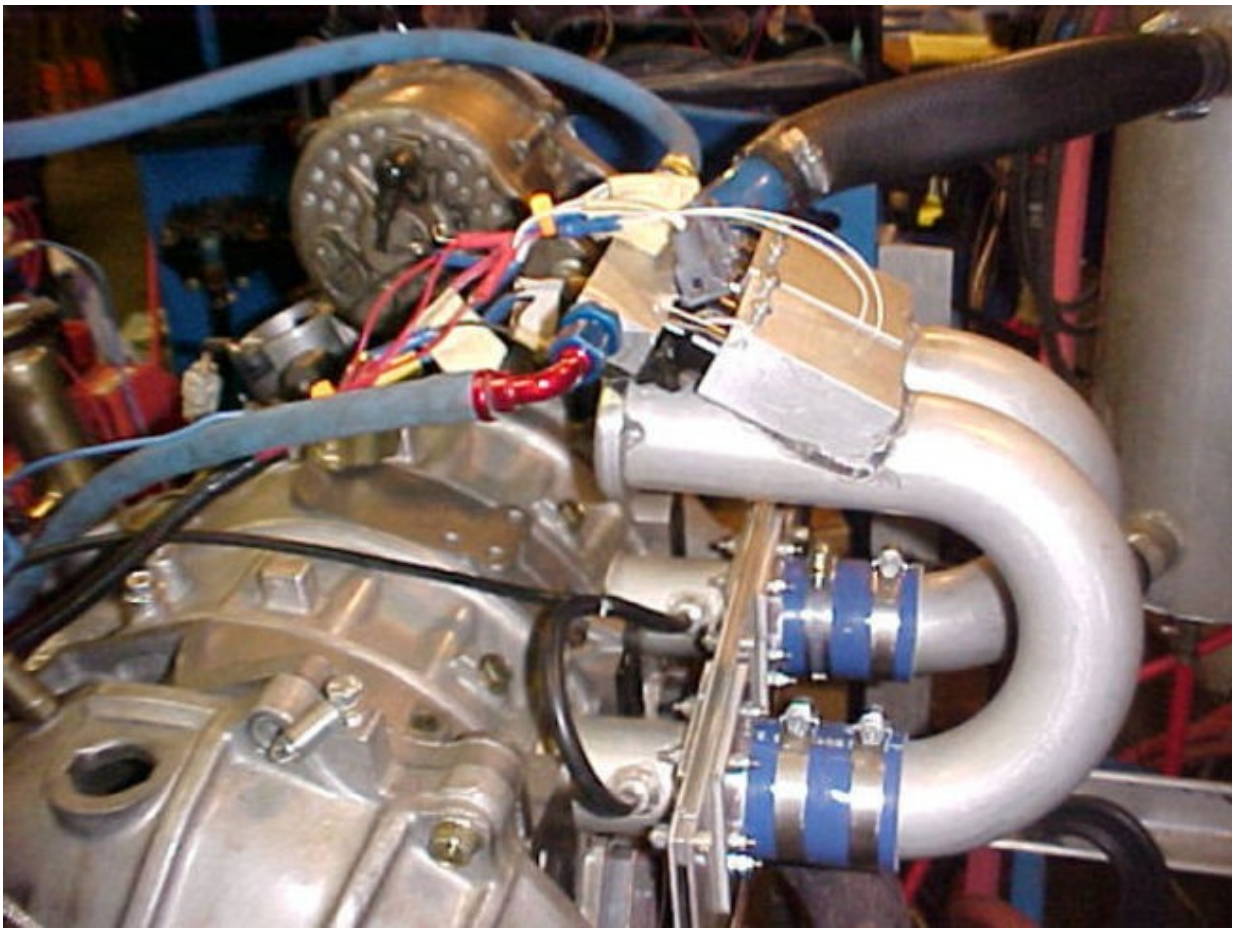
I really like the small diameter of the RX8 injectors. They may not flow enough for a p-port engine however. Two can be mounted side by side on a 2 inch P-port intake tube.



Mazda and Ford injectors
www.rotaryeng.net



Here is what the 250 HP p-port installation looks like.



Here is what the p-port installation looks like with the mandatory air box plenum. If you don't do this tuned intake system spit back fuel vapor and it can be a fire hazard. See UTUBPLEASE for a Youtube video of a p-

port RX8 engine running on a dyno showing the spit back.



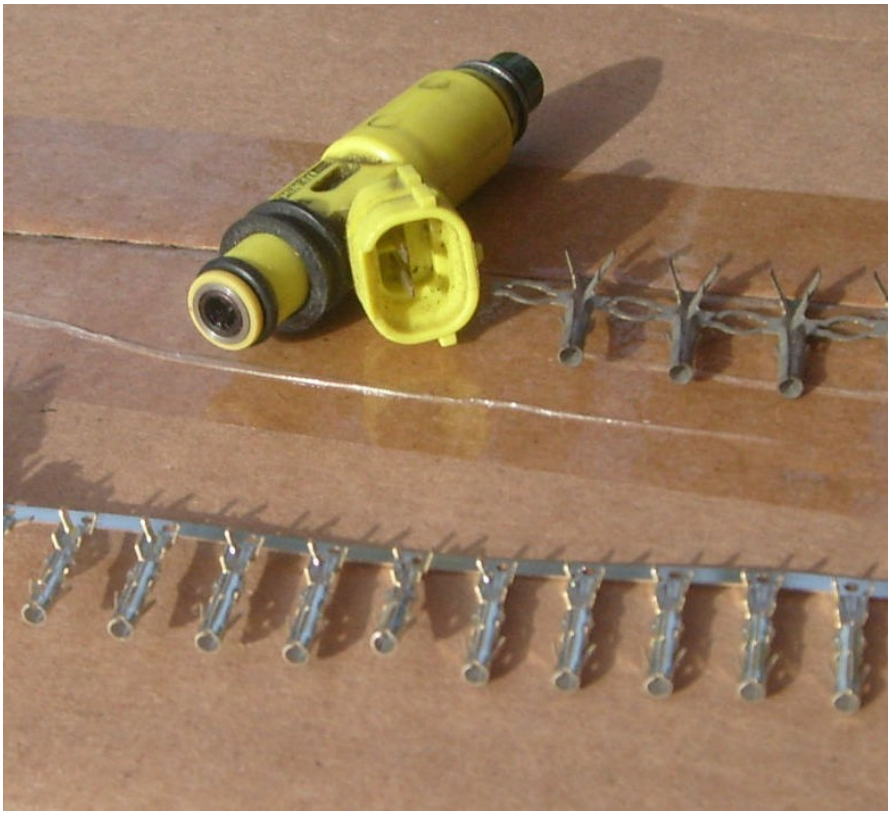
One of the problems most people are confronted with is obtaining connectors. There appears to be no standardized fuel injector connectors. Here are a couple of examples.

Mazda 2nd gen injector





Here is a way around it. These are Molex female sockets used in just about every PC in the world to connect the power supply to the mother board. Electronic stores like Fry's sells them for about $1 a dozen. solder them to the wires and use a bit of heat shrink tubing. When you are ready to fly you can put a dab of red RTV in the socket to hold them in. If you grease the walls of the socket you might get lucky and have your own custom injector plugs after the red RTV hardens.



BTW Klaus is telling me the Continental O-200 engine in his Varieze is getting 100 mpg at 110 kts at altitude using a 555 based EFI system. Klaus's O-200 555 based system is a bit more complicated but it does indeed run and run well. 100 MPG at altitude and 110 Kts proves it. I see him start his engine and take off almost every day. I can not guarantee this system will work as well as Klaus's as the devil is always in the details.

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http://www.lightspeedengineering.com/News/News.htm

2008 Copperstate FuelVenture:

Klaus Savier flies top scores in the Delamintor:

Best MPG (60.3 mpg @ 164 mph) and best overall score.

This event is similar to the CAFE 400 of the 80's where fuel efficiency, speed and the ability to carry a payload is measured over a 400 mile course.

At the first annual Fuelventure, the competitors flew a 401 mile course with carefully weighed airplanes and a payload of up to 200 lbs / seat. The aircraft were weighed again after landing to determine the total fuel used and were scored with the following formula.

score= mph x 1.3 x mpg x (payload)^.6

This is not only a fun and very educational race, it also demonstrates the real world usefulness of airplanes and the effectiveness of modern technology.

The Delaminator uses two LSE Plasma III CDI ignitions and a proprietary, timed sequential, high pressure Fuel Injection system on a modified Continental 0-200 engine.

This airplane is well known for winning all kinds of races since 1984. From the CAFE efficiency races in the late 80's to the AirVenture Cup race in 2007, where it won the 400 mile race from Dayton to Oshkosh at an average speed of 254 mph. In 1990, two closed course world records were set in the C1-A weight class for the 1,000km and 2,000km distances at over 200 mph. They are still standing.

The Delaminator's configuration for this endurance flight was identical to that used in the AirVenture Cup:

- Same LSE Composite 64x86 Propeller,

- Dual Plasma III CDI,

- Our own Timed Sequential High Pressure Electronic FI,

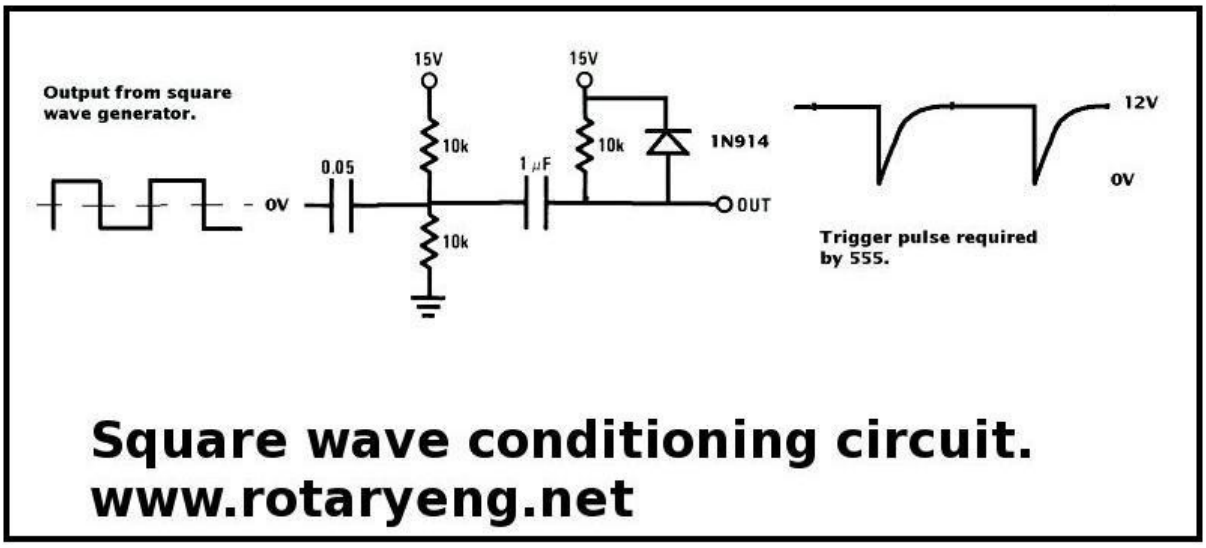
- No extra tank- standard 29-gal Vari Eze fuel system,

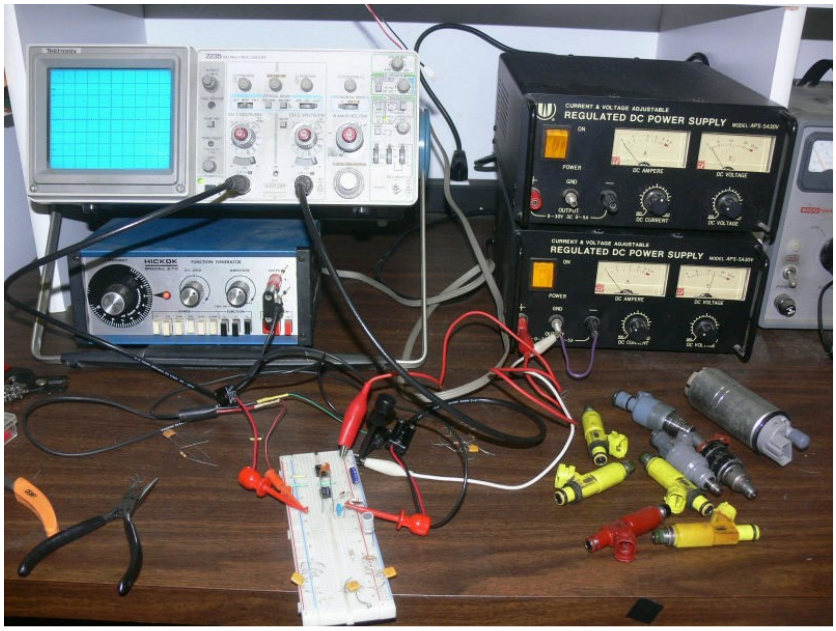
- About 25 pounds of luggage: minimal tools, no spare parts.

==========

The pulse rate of the TLC555 is directly proportional to RPM in the system. The pulse after all is triggered by the crank angle sensor. The pulse width is constant so the fuel supplied will also be a linear function of RPM. The air required with no load is also a linear function of RPM in this case. You can verify this in your car. With the TX in neutral it does not take much throttle opening for the engine RPM to hit redline.

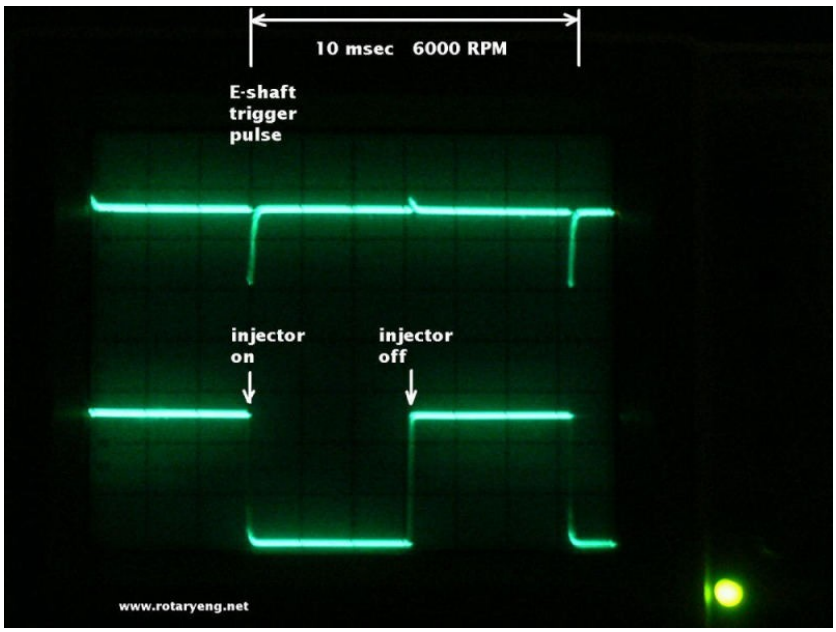
One of the first things to do is simulate the signal from a crank angle sensor on the test bench. The TLC555 requires a negative narrow pulse to trigger it. Most low cost signal generators put out square waves or sine waves. One needs to convert the square wave to a negative going narrow 12 Volt pulse. This trigger circuit will do the trick. It works from 1000 RPM to 11,000 RPM.



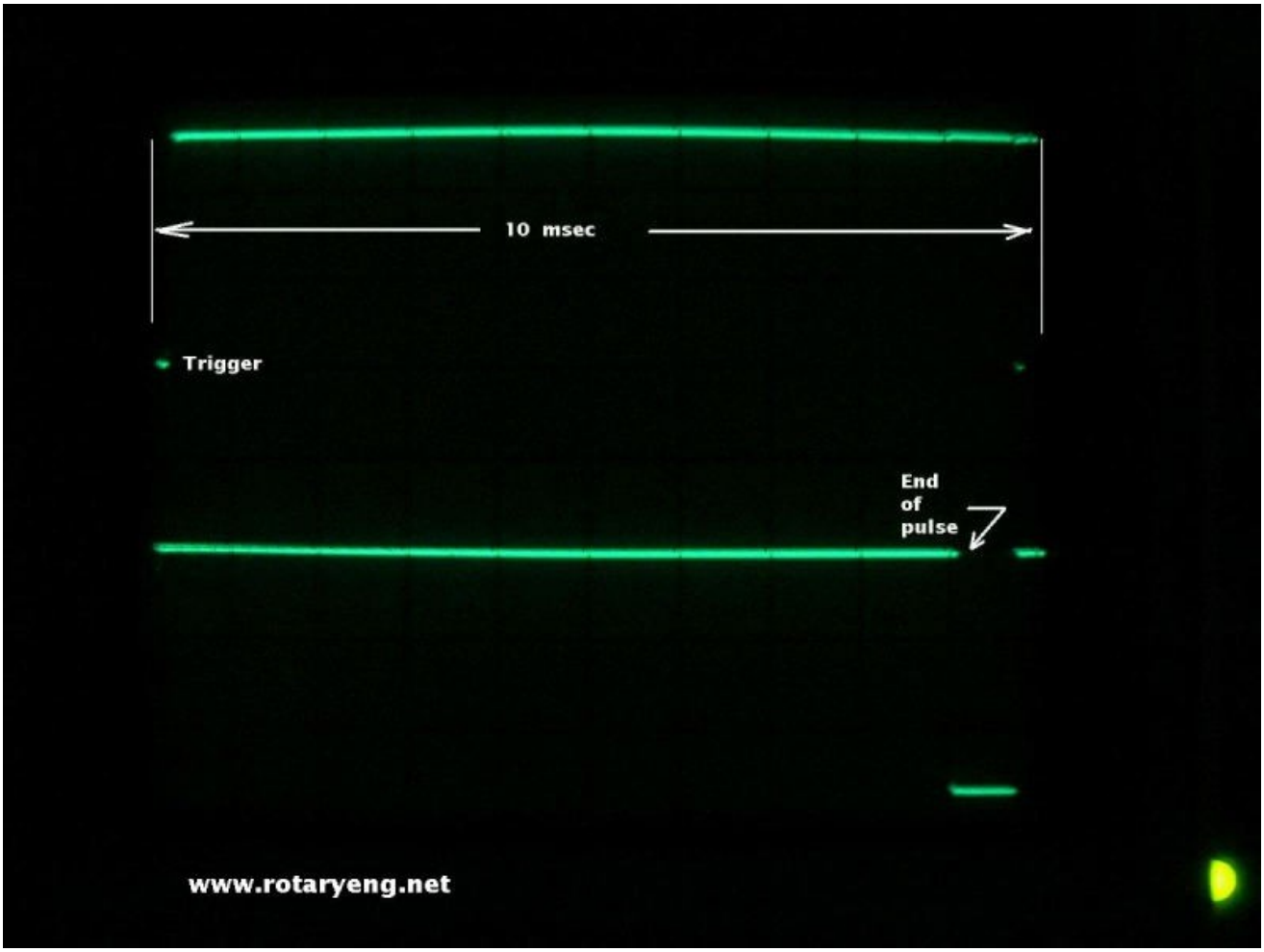


Bench test set up
www.rotaryeng.net

Scope view of trigger and medium pulse width. C1 is about .1 uf at the moment. The scope is set to 10 msec per division so the positive output pulse is about 9 msec long. Goes high. The bottom of the screen is 0 volts. Lower trace. Upper trace shows the negative going trigger pulse.



Scope view of trigger and wide pulse width.



Parts required for injector driver. Page numbers are from a DigiKey catalog.

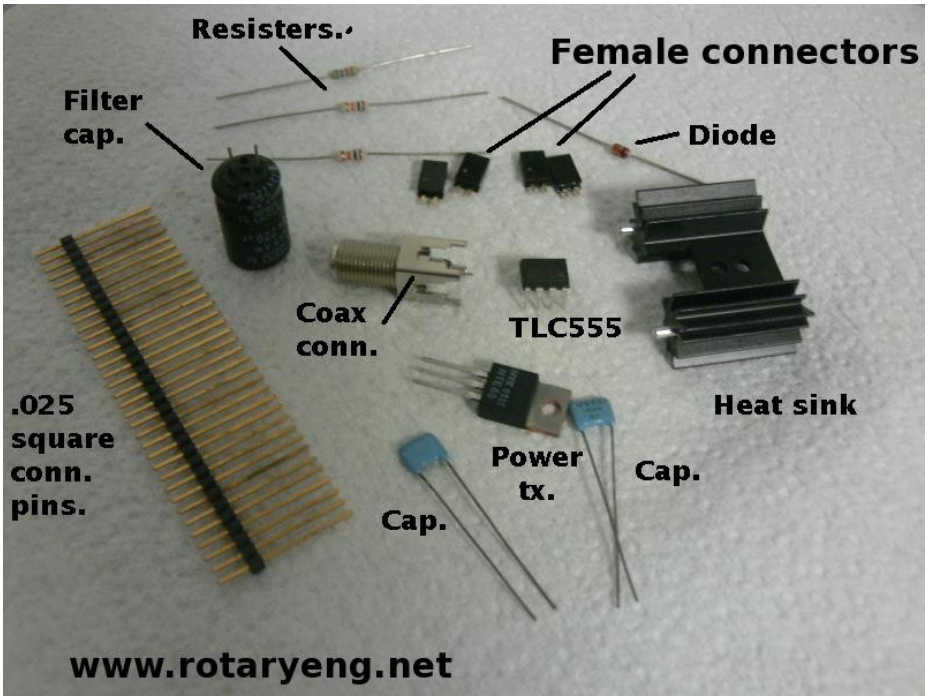
Page1 164 .025 square connectors male and female .1 inch centers Sullins 2 pos $13 per 100

P age 1103 Part # S7035-ND heat sink fig 25 one inch high 1.4 inches wide $1.15 each

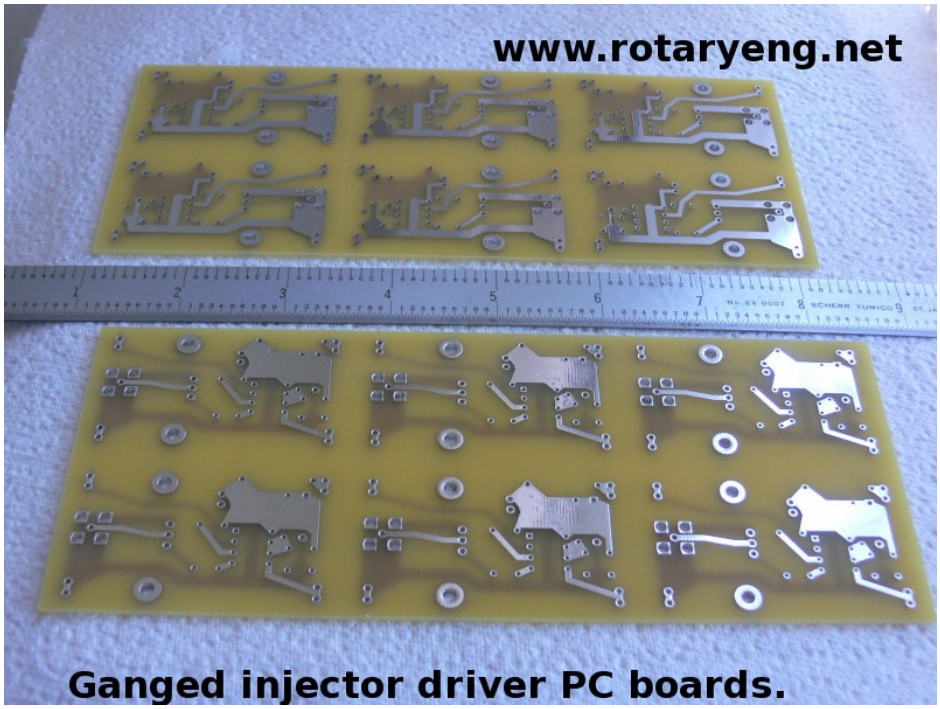
Page 1183 MOSFET TO22 ST injector driver 100 V 40 amps $1.54 each

Page 792 TI Op amp TLC272 ACP 8 pin dip dual op amp for leaning circuit $.92 each

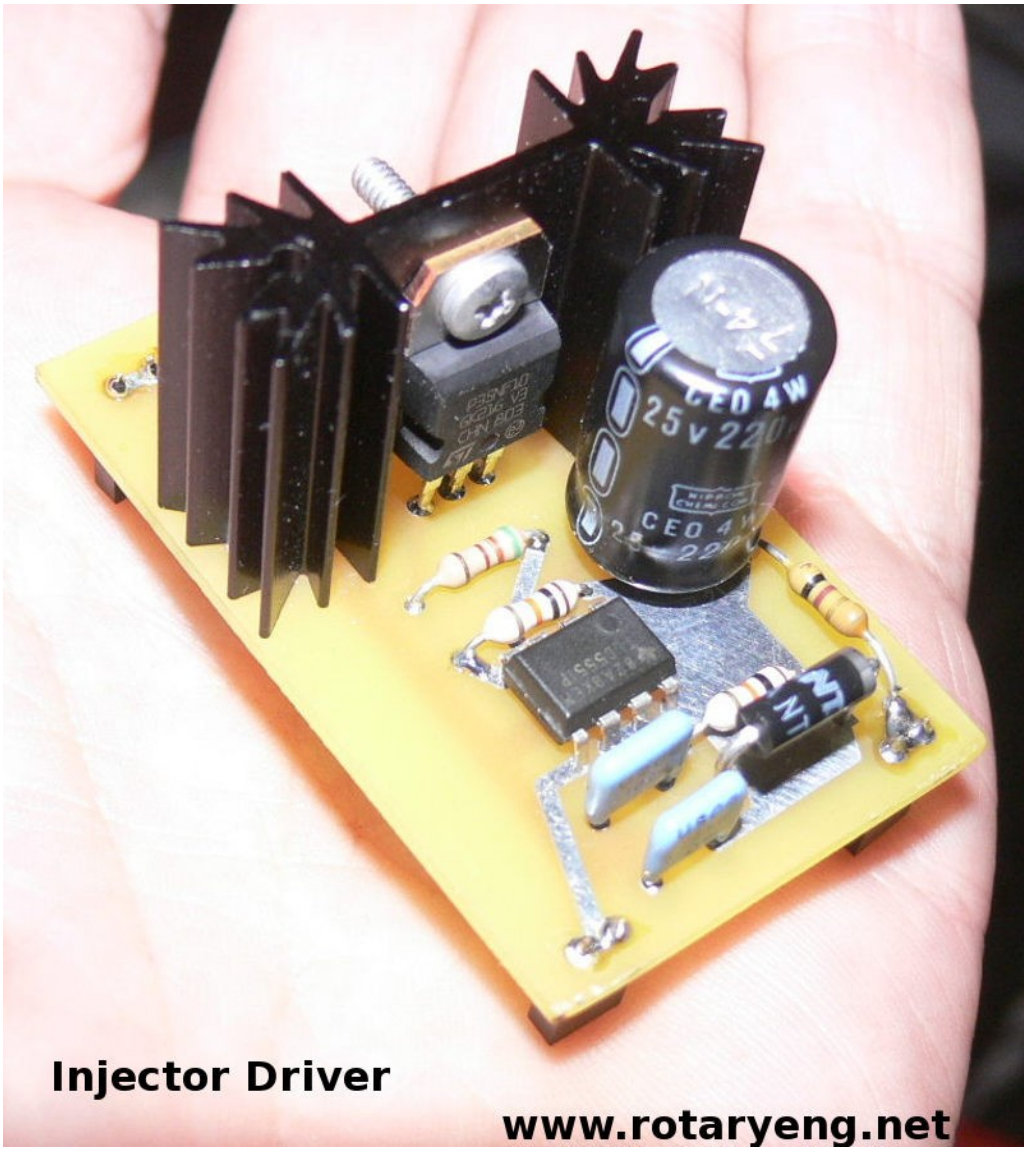
The heat sink and power transistors are over kill but what the heck, they are cheap.



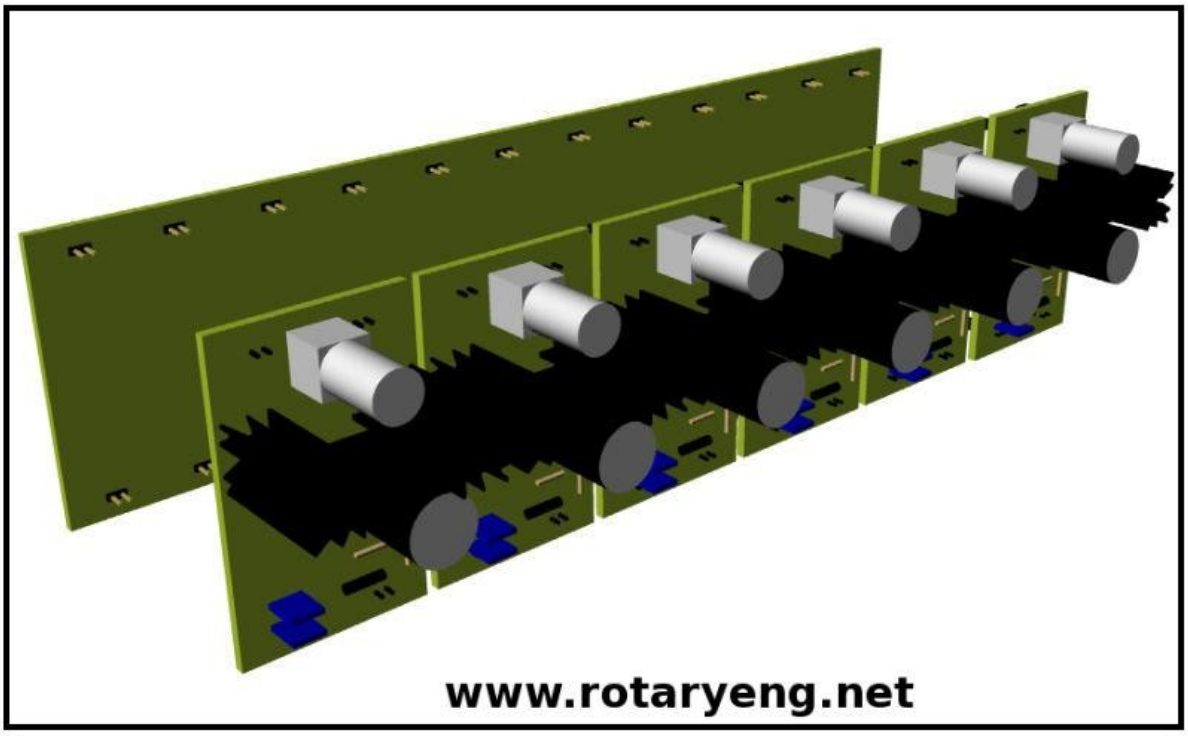
Ganged together injector driver PC boards. Cheaper to cut them out yourself.

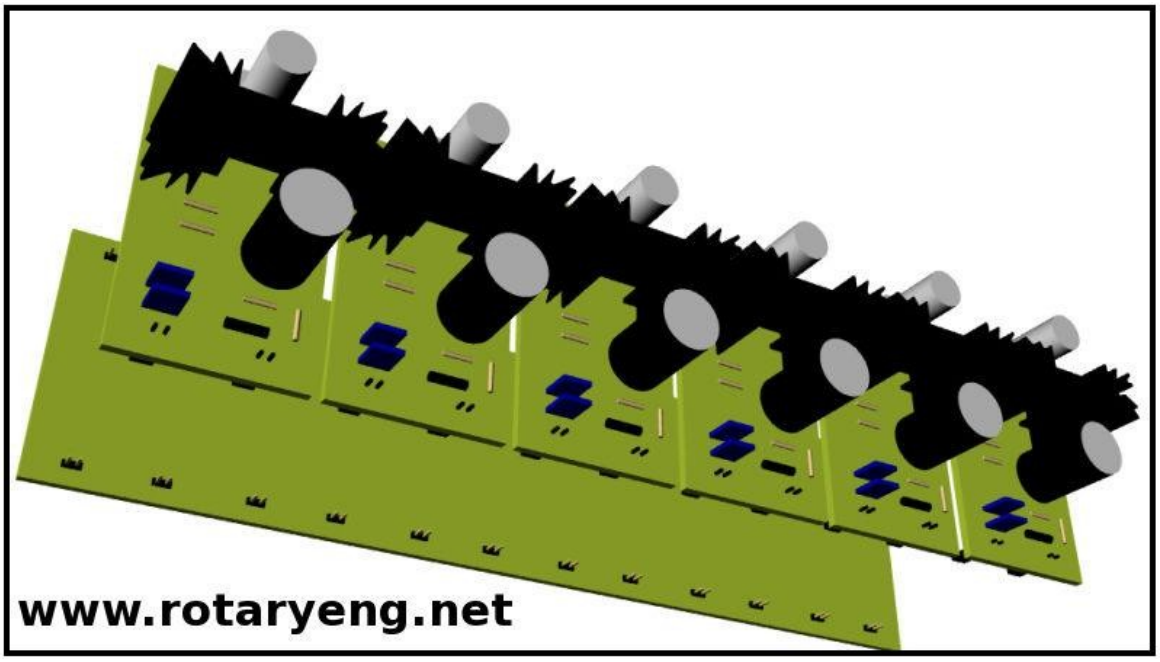


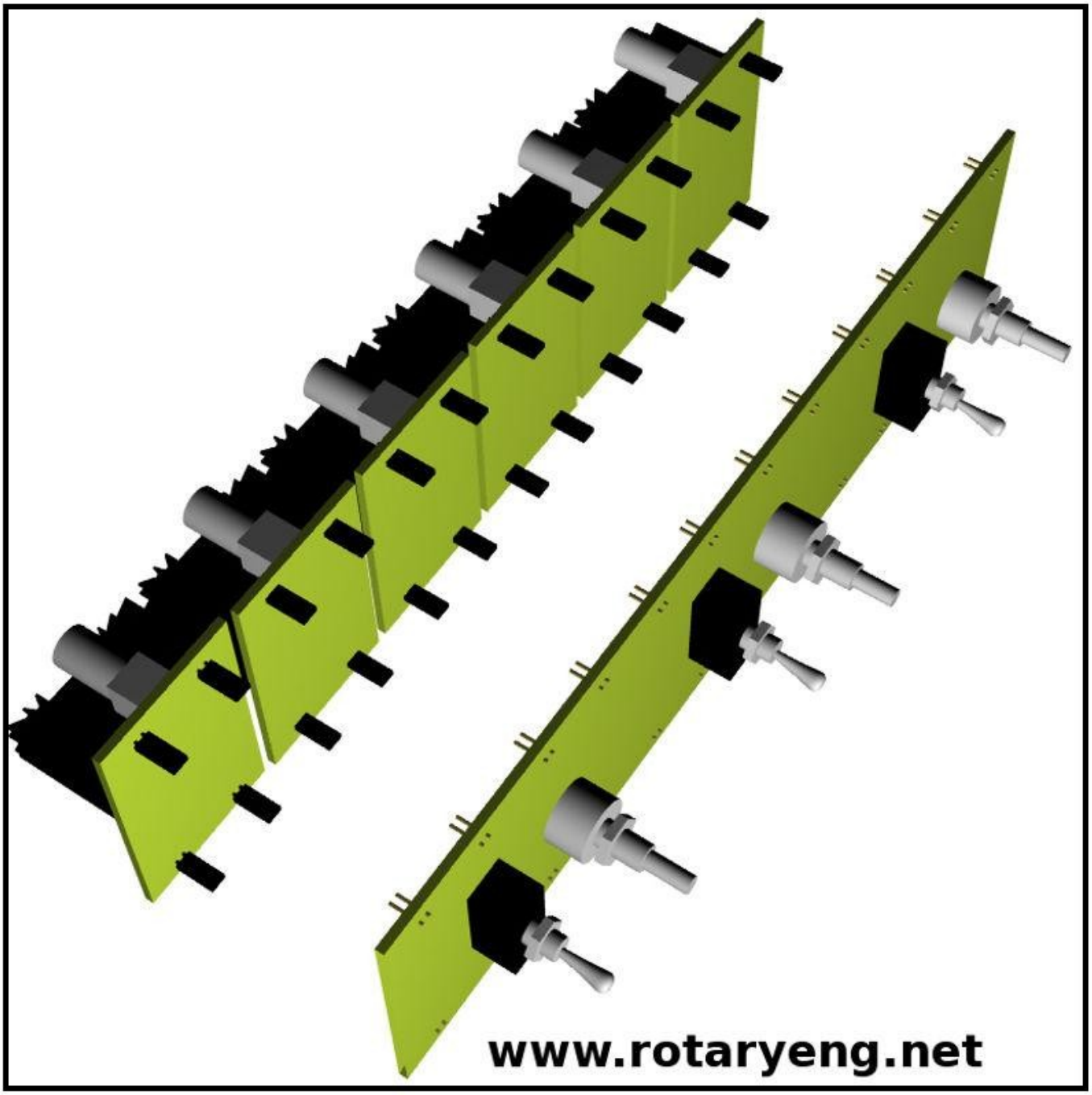
Assembled Injector Driver. One required per injector.



This is how I suggest building it. This 3D is a 3 rotor with two injectors per rotor. It is a modular system so any injector driver can be swapped out all most in the air. The connector to the injectors uses screw on video coax. The coax size can be tiny as the impedance has nothing to do with it. I suggest using coax as it is automatically well shielded. There are three leaning knobs with on and off switches one each to kill a rotor system for purposes of trouble shooting. Each rotor can be leaned individually based on it's EGT. This leads to the lowest fuel burn much like matching the injectors does in a aircraft engine.


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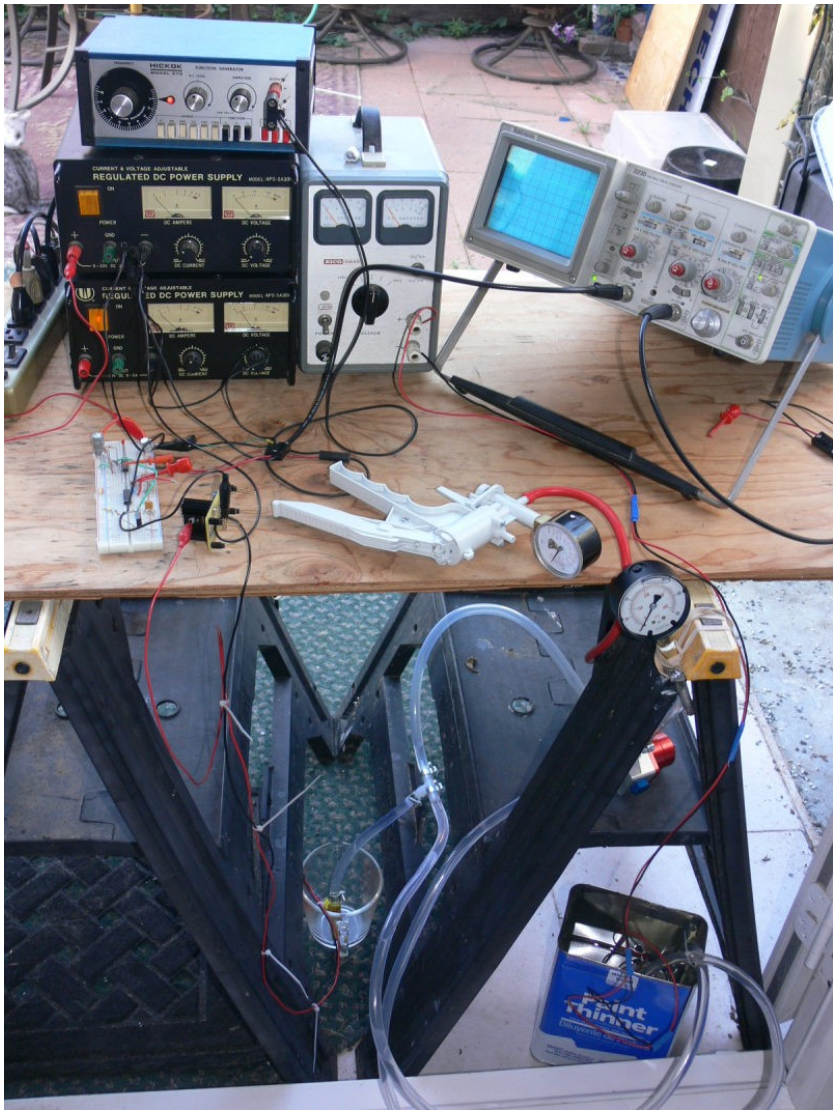

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Fuel pumps. There are lots of automotive high pressure fuel pumps out there. There appears to be a trend in saving a buck on a high pressure fuel pump by making them two speed. One speed for full power and the other for 50 HP max freeway cruise speed. The RX8 does this. That makes some car fuel pumps not suitable for continuous high power aircraft use. Beware. I like the MSD pump as it works differently than the popular Walbro type pumps. It uses roller vanes so it draws fuel better than the Walbro centrifugal type pumps giving you more flexibility as to mounting. Some pumps are required to be mounted inside the tank. It is a bit heavier than the typical pump. A pound and a half compared to one pound but I suspect it is a lot more reliable.



Bench test setup. I am using paint thinner here instead of gasoline. Less volatile so it is less of a fire hazard. Also do it out doors as the fumes can get to you.



We have not yet tested the pure 555 system yet and it is in the category of highly experimental.