THE 'HOW TO' OF ROTORCRAFT FUEL INJECTION

by Vann Hand

Since an article by Don Parham titled "Rotorcraft Power" (Homebuilt Rotorcraft, December 1993, Vol 6, No 12) covered fuel injection theory, this article is limited to the practical 'how to' of converting a non-turbo Subaru Legacy EJ- 22 engine to fuel injection. The engine is installed in an RAF 2000 GTX of 1995 vintage. The conversion falls into four major efforts: finding the correct items, making the cables, installation and test. A set of cables from a 1991-1993 Subaru Legacy is required. These cables are in three groups. The first group is located inside the passenger compartment on the firewall and includes the Electronic Control Unit [ECU, sometimes called the MPFI or MultiPort Fuel Injector unit, figure] with its three associated yellow connectors [figure 2, B48, B58, B56, a fourth, F47 from the firewall cable is also required]. Attached to this cable is the Automatic Transmission Control Unit [green connectors], the ABS unit and a huge firewall connector B27 which is not required. Be sure you do not mistake the Automatic Transmission Unit [ATU] unit for the ECU. This cable also contains the ignition relay [B29, brown six pin connector with relay, figure 1] and the fuel pump relay [B30, green four pin connector with top hat relay, figure 1].

The second of the three cables is the engine compartment firewall cable. This cable connects to the airflow sensor [B1], crank angle sensor [B18], knock sensor [B19] cam angle sensor [B17] and leads down the left [port] side of the engine compartment to the battery area. The cable also includes the alternator connector and the main relay and fuse box on the fender well. The main relay and fuse box is not needed, nor is the alternator connector [unless you plan to use the Subaru alternator]. This cable has a huge connector [F45] that mates to the above cable [B27]. This connector is not used. The cable also contains three large female connectors [gray] that mate to the engine cable [E]. The ignitor connector [B8] is the connector on the long cable extension to the passenger side. The conversion of this cable requires the splicing of the two large connector leads F45 to B27.

The third and final cable is the engine cable attached to the intake manifold. This cable must be retrieved intact! This cable includes connectors for the fuel injectors [E4, E5, E12, E13, figure 2], the air by-pass [E9], the CPC [E11], the ECU water temperature [E7], the panel meter water temperature sensor, and the three connectors that mate to the engine compartment firewall cable [E1, E2, E3, figure 2]. In converting to fuel injection, the intake manifold is rotated 180 degrees, the engine cable is not. This cable is routed over the top of the manifold to keep the area under the manifold clear for the prerotator cable and to keep the cable away from heat.

A fuel pump and regulator capable of 40 psi is required. One of the possible choices is the Mallory unit which includes a separate mechanical regulator. These are available from any good speed shop. Highly recommended is a panel mounted fuel pressure gage with sender to mate up to the mechanical regulator. The gage should measure from 0-80 psi. The gage or a test gage is required to set the fuel pressure to 36 psi for the pump.

The throttle sensor which is part of the intake manifold, faces the rear of the engine in the Subaru. The sensor and manifold are turned 180 degrees [relative to the engine] to face forward in the gyro [the engine cable is not rotated relative to the engine].

The intake manifold is a four port unit that includes the four lead dual ignition coil with its plug wires. The manifold contains the fuel injectors, air by-pass, CPC unit and throttle sensor. The manifold has an extensive network of steel fuel lines which interfere with the prerotator cable on the starboard side. These are removed. Leave about three inches of line on the outside of the injectors to connect pressurized fuel lines. Also leave the fuel lines between the injectors on each side [front-to-rear, not side to side]. The fuel pressure regulator on the unit is securely plugged [figure 3]. This regulator is replaced by the regulator from the Mallory fuel pump. The line that will be located by injector #3 [starboard-rear of manifold after 180 degree rotation] is also plugged. These lines are under 40 pounds of pressure and must be securely plugged and connected.

A three wire oxygen sensor is required. This unit is mounted at the junction of the port and starboard exhaust pipes. These units are fairly standard and some dollars might be saved by not buying from Subaru. The use of a used unit is not recommended.

An air intake to the manifold was fabricated from a four inch rubber elbow and connected to the manifold via hose clamps. The elbow was located at a local building supply. The air flow sensor was mounted to this elbow. An air cleaner with a four

inch neck was attached to the elbow which completed the air intake setup shown in figure 3.

Since the manifold makes it difficult to mount an alternator, the best approach is to purchase the NIPONDENSO unit from RFI with the fabricated brackets. This unit mounts on the port-forward [left front] part of the engine [figure 3].

An ignitor is required. The mating connector [B8, figure 2] comes from the engine firewall cable which mates to the manifold cable. This unit is about three by four inches, an inch thick with a six pin integral connector. Mount the ignitor off the engine away from the heat. In any case DO NOT MOUNT ON THE ENGINE. A good location is on the starboard side front engine mount. A good location for the fuel pump is on the starboard side keel aft of the mast, but clear of the control tube assembly.

In the new installation, the throttle pull is to the rear instead of forward. A bracket with a ball bearing pulley was fabricated to allow throttle control from the front. This bracket was mounted on the large bracket attached to the manifold behind the throttle sensor. Other than miscellaneous easily acquired material such as hoses, this completes the material acquisition.

The cable fabrication is the hardest part of the project. Subaru has made it easier since all connectors, except when obvious [the injectors], mate with only one other connector. The manifold harness is fairly straight forward. None of the leads should be cut on this cable! The injector numbering does not change. The throttle sensor, CPC and air by-pass connector sides are switched. The three large engine cable connectors [E1, E2, E3] are located on the starboard side of the engine. In the RAF gyro application the ECU is placed behind the passenger's head for a short lead to the engine cable connectors.

The engine compartment firewall cable is the messy cable. Over 90% of this cable is junked. While a bit scary, the recommendation is locate the air-flow sensor connector [B1], the crank angle connector [B18], the cam angle connector [B17], the knock sensor connector [B19] and B57/B59 and the fourth yellow connector for the ECU [F47]. Also locate the three connectors [F26, F25, F27] that mate to the engine harness. Cut their cables about three feet back from the connector. Ignore all the power hookups such as the relay box, alternator leads and battery leads. Most of these you will not use.

The final cable is the passenger compartment cable which contains the ECU. About 70% of this cable is junked. The cable should be unwrapped, but keep some tape on the leads in several areas to avoid tangles. Locate the ignition relay [B29 brown six p in], the fuel relay [B30 green four pin], the three yellow ECU connectors [B48, B58, B56],the diode [F48, figure 1], and the ignitor cable [B8]. Cut these cables about three feet back from the connectors. Some of the circuits should not be cut, just cut the leads to the unused items. Sort out the Automatic transmission unit, the ABS unit, extraneous relays, etc. The large firewall connector [B27] is not used. Remember the ECU has four yellow female connectors mounted along one side. Do not confuse this with the transmission controller which has four green connectors.

Commence installation by assembling the manifold. Do not connect any connectors at this time, as they will need to be free for checking cable continuity. Once this cable is installed. Associate the engine compartment firewall cable connectors with the manifold cable. This includes F25, F26, F27 and the crank, cam, airflow and knock sensor connections.

Begin splicing the engine compartment firewall cable to the ECU cable and the RAF cable to the dash. Use a good mechanical butt splice on the cables. When joining to the RAF dash make cable removable spade connections to ease testing. Use the diagrams in figures 1-4 to assist in this effort. If you are also referencing Chilton or the Subaru manuals, you will find conflicts as given in figure 4. Use the enclosed figures for guidance. In all conflicts the end-to-end references are the same. The conflict is on the intermediate connectors such as F25 or F26.

Pay close attention to the pins which are grounded or not connected [nc, figure 2]. The speed sensor input [b11] is not connected. The ECU must be fooled into thinking the engine is in the automatic transmission park mode. This ensures there is no error due to a lack of a speed sensor input. To place the ECU in the automatic transmission mode, b9 must be grounded. This means the ECU must not recognize that the AT is in the neutral position. This requires b10 to be high which means no connection [nc]. If b10 is grounded, a code 11 [figure 4] will occur which is a false crank angle error. A final check is to ensure the ECU case is grounded. If not, engine will fail to start.

The ECU requires a backup voltage when the ignition is turned off. Check to see that a15 is connected [figure 1] to a source of power at the master switch. The ECU remembers the last set of operating conditions prior to shutdown. This reduces the amount of hunting, hard start, and other related problems that could occur on starting.

Even though a starter signal is not required to the ECU to start, an error [code 12] will occur if c10 is not connected to the starter switch. Also a double start

is required as the fuel pump is not timed properly. Remember the ECU is connected to the fuel pump relay. For your safety do not connect the pump where the ECU cannot control its start and stop! The fuel pump relay is a must!

Some leads shown may be redundant to the reader such as the extra ground leads. Common grounds help minimize noise and improve reliability. In some cases this approach reduces radio noise. For example, the auxiliary setup avoids a common ground with the strobe lights. Please note the use of the radio interference filter in the auxiliary circuit of figure 1. Also the separate grounds reduce ground lead resistance, thus avoiding different ground potentials over time due to corrosion.

A setup problem can occur on idle. The throttle sensor contacts must close at idle [E8 1&2]. If you try to control hot idle with the idle screw, these contacts could fail to close. This will cause a fast running engine when cold [almost three times the normal idle speed]. This may result in the aircraft accelerating out of control.

Overvoltage protection is required on the alternator. The alternator's internal regulation depends on the battery voltage. If the battery load is dropped, the alternator could lose its regulation causing an overvoltage. The overvoltage could destroy sensitive electronic devices including the ECU. Also note the alternator field connection to the accessories position of the ignition switch [red wire of figure 1]. This eliminates the alternator load when starting as the accessories are not connected when starting.

The check engine light should be installed. If engine trouble occurs, this light will stay on while the engine is running indicating maintenance is required. Figure 4 shows the various error codes that can occur. The ECU is placed in the 'Test Mode' by grounding C13 [B52], then turning on the ignition without starting the engine. A steady blink indicates everything is OK. Long and short blinks indicate trouble code(s). A long blink is a tens and a short blink is a unit. Several codes can exist, but the pattern repeats. For example, long-short, long-long--short-short-short is a code 11 and code 23 respectfully. The eleven is a crank angle sensor problem [figure 4] and the 23 is an airflow sensor problem. Also, the ECU also has an internal LED that blinks.

Testing is easy if you followed the wiring diagrams and carefully checked and rechecked the wiring and components. All leads should be checked for continuity. All leads should be checked for at least one megohm to ground [unless ground]. While conflicts exist with the various manuals, the drawings should work. Most of the conflicts were with intermediate connectors. Reverify that all splices are solid by testing. Avoid poking holes in cable insulation if at all possible, as this may cause a long term failure problem. Remember, do not plug or unplug powered connectors, especially to the ECU. It is a good ideal to clean all connectors with an electronic contact cleaner such as found at Radio Shack.

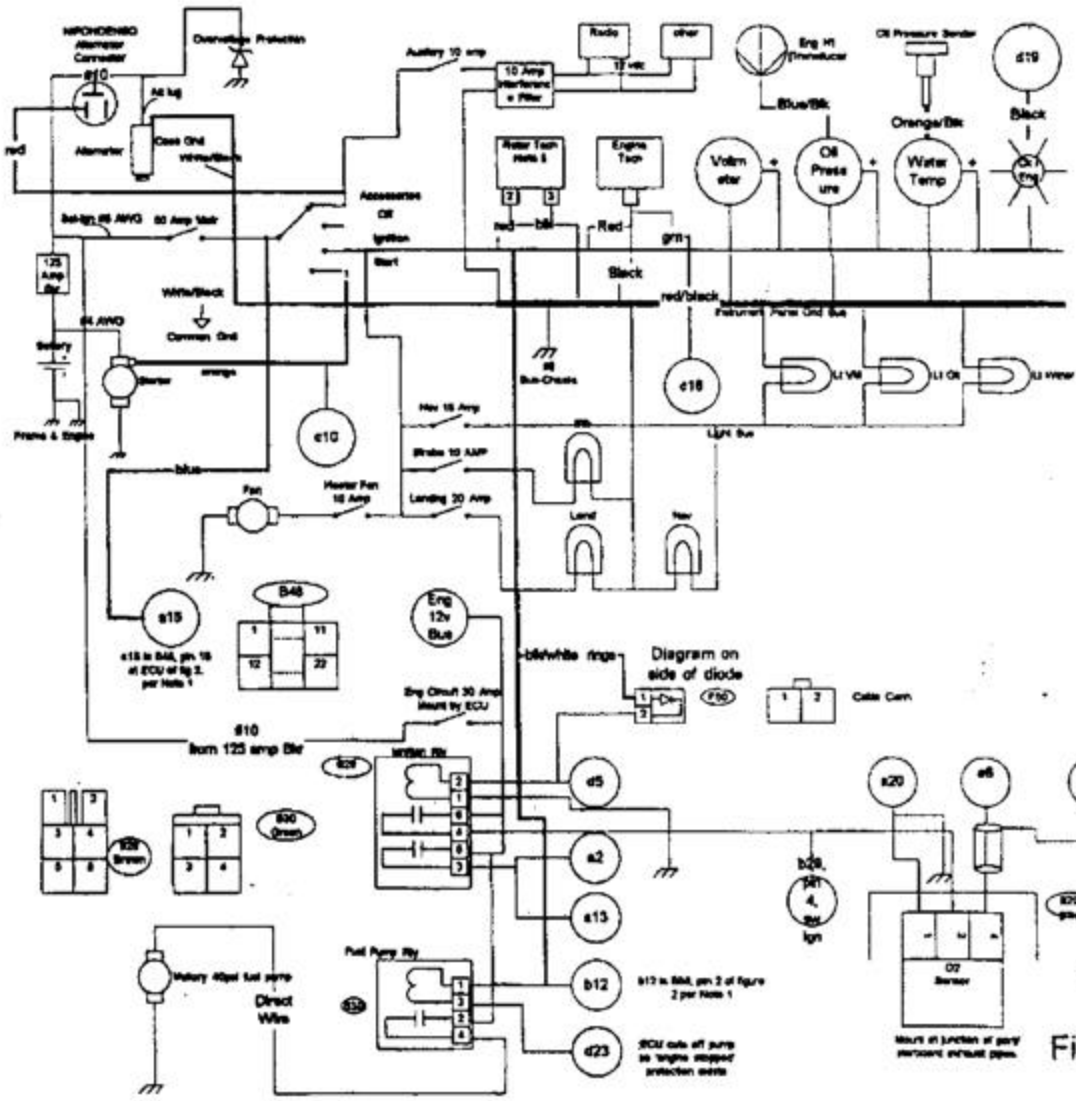
Operation of the key components should have been tested as they were installed. Check the throttle sensor for electrical resistance, closed contact at idle, and smooth operation. Operate the relays prior to connecting the fuel pump. If you are using the RAF digital tachometers, the engine tach will take a direct input from the ECU via c16. The RAF tachs were received with the displays installed upside down with reversed inputs as shown by 8888 on the tach. Test the injectors by grounding the appropriate pin [d11, d12, d13, d28] with power applied via the engine bus. Operation is verified by hearing a "clicking' noise.

The crank, cam and knock sensor usually do not require testing. Before installing the by-pass air, check coil continuity. Apply 12 vdc to see if the unit operates. Ensure you have the three pin version. Check the resistance of the temperature sensors, both the ECU and the panel unit. Validate the airflow sensor is the correct thin film unit for an automatic transmission Subaru. If these tests are successful, the power up test should go very fast. Any problems at this stage, the ECU can spot. Figure 4 is a good reference at this time.

After everything is connected and individually tested, adjust the fuel pump pressure to 36 psi. This is critical. Ensure all connections are tight, because at this pressure a fuel leak could be disastrous. Also check for air leaks. A small air leak can cause erroneous idling. For example, using outside air for the PVC system without flowing it past the airflow sensor.

When testing and taxi tests are complete, the connectors should be sealed and leads dressed to avoid vibration failures. This is an important reliability consideration.

Check the starter with the engine bus power off [figure 1]. If okay, start the engine. Trouble shoot any starting problems such as a missing ECU case ground. Remember your safety, all testing is done with the prop disconnected and the redrive mounted . The redrive provides an engine load as the flywheel is also attached. If the check light is on with the engine running, check per above and figure 4. When everything is okay, install the propeller. Congratulations you have arrived. Go to taxi tests until everything meets your satisfaction, then have fun in the sky with improved performance and reliability.



SUBARU DASH CONTROL

Note 1: a,b,c,d refers to ECU [MPFI] yellow connectors
a: B48
b: B58
c: B56
d: F47

Note 2: Mating connectors shown in Fig 2 diagram of ECU.

Note 3: No connection at crossing unless 'T'. Shown as wired. Chilton and Subaru drawings in conflict [see figure 4]

Note 4: RAF 11 conductor cable harness shown in heavy black with cable color , i.e. white/black is white with black

Note 5: Rotor tach wired per RAF Diagram

Note 6: While some lines such as the white/ black line to alternator case ground from the instrument bus are at ground potential, the lines must exist

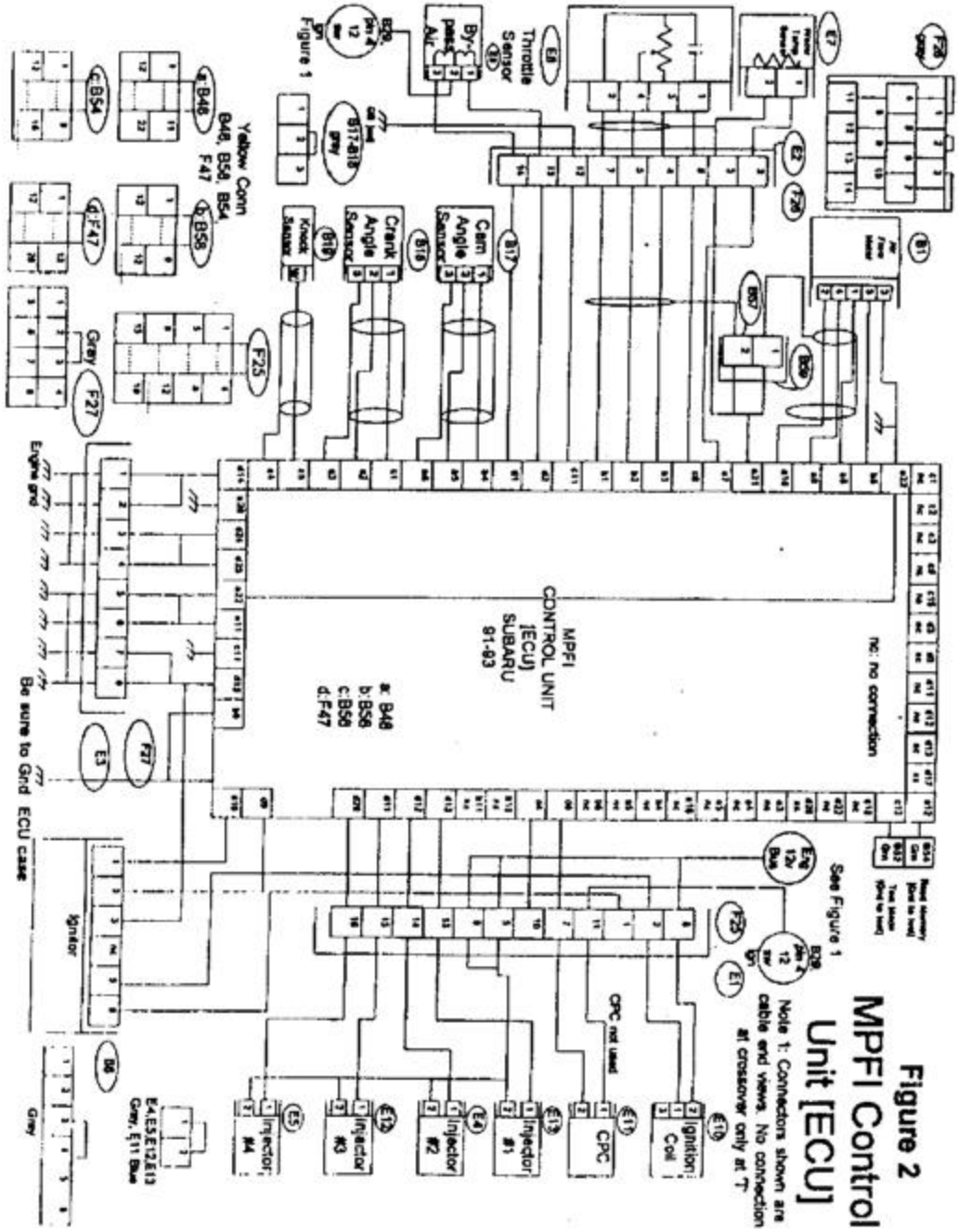

MPFI Control Unit [ECU]
MPFI CONTROL UNIT [ECU] SUBARU 91-93
nc: no connection
a: B48
b:B56
c:B56
d:F47
Note 1: Connections shown are cable end views. No connection at crossover only at 'T'
See Figure 1
Be sure to Grd ECU case
Engine grd
Yellow Conn B48, B56, B54 F47
Grey
Throttle Sensor
Knock Sensor
Crank Angle Sensor
Cam Angle Sensor
Ignitor
Ignition Coil
CPC
CPC not used
Injector #1
Injector #2
Injector #3
Injector #4
E4,E5,E12,E13 Grey, E11 Blue

Figure 2

ENGINE LAYOUT
[post conversion]

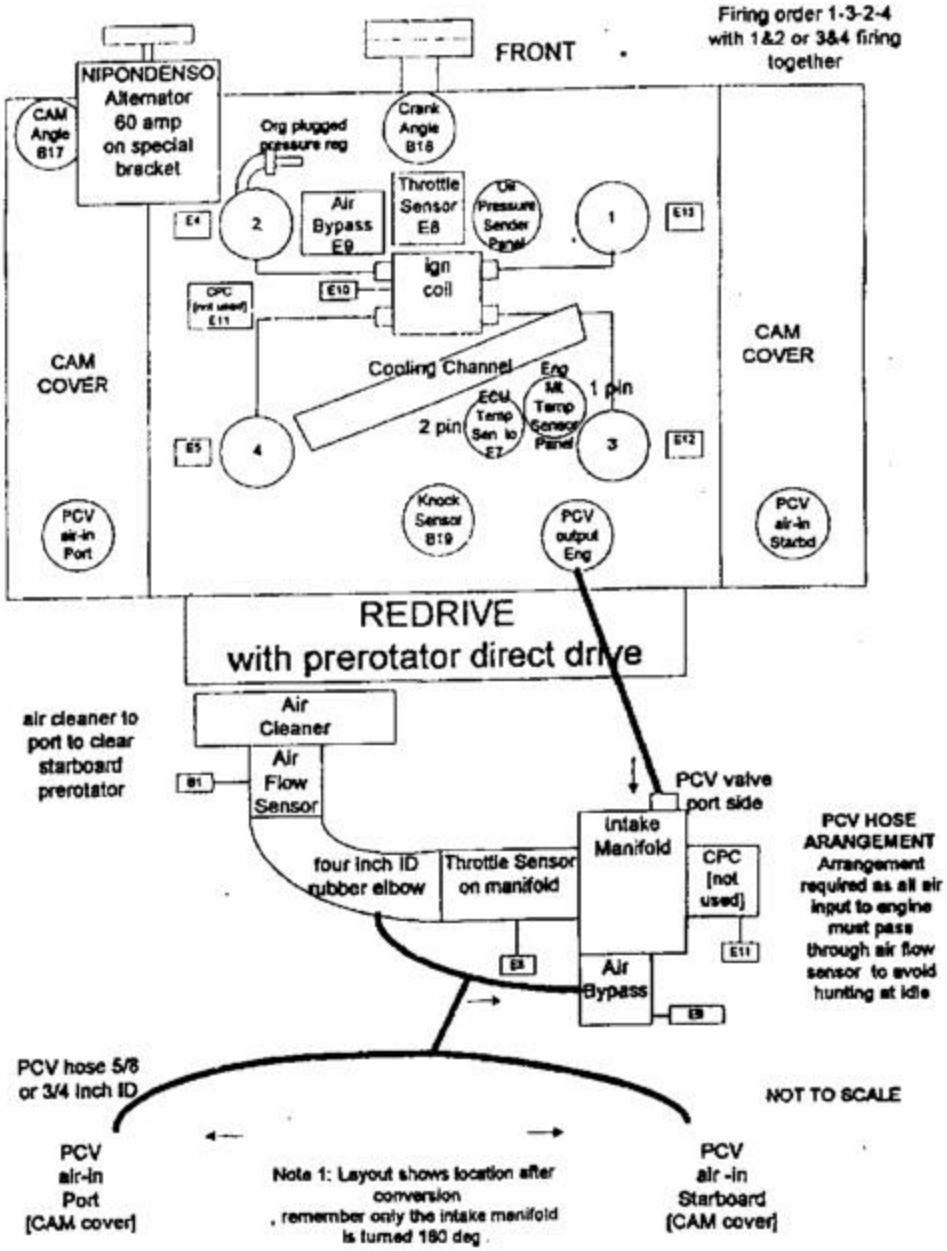


FIGURE 3

EJ-22 with MPFI

TROUBLE CODE SUBARU

	TROUBLE CODE	ITEM (non-turbo only, AT setup)	COMMENT
	11	CRANK ANGLE SENSOR	B18[1,2,3], c:B56[c1,c2,c3]. B18[1,2] 0.1 VAC on cranking of engine. c2 and c3 are at gnd potential.
	12	STARTER SWITCH	c:B56[c10]
	13	CAM ANGLE SENSOR	B17[1,2,3], b:B58[b4,b5,b6]. B17[1,2] 0.1 VAC on cranking of engine. b5, b6 at gnd potential.
	14	INJECTOR #1	Starboard Front E13[1,2] F25[5,9,13], d:F47[d13]. F25[5,9] +12v from 30 amp breaker, gnd d13 to hear click
	15	INJECTOR #2	Port Front E4[1,2], F25[5,9,14), d:F47[d12].F25[5,9]+12v from 30 amp breaker, gnd d12 to hear click
	16	INJECTOR #3	Starboard Rear E12[1,2], F25[5,9,15],d:F47[d11]. F25[5,9] +12v from 30 amp breaker, gnd d11 to hear click
	17	INJECTOR #4	Port Rear E5[1,2], F25[5,9,16], d:F47[d26].F25[5,9] +12v from 30 amp breaker, gnd d26 to hear click
	21	WATER TEMP SENSOR	a:B8[a7, a21], F26[2,3], E7[1,2], 2k-3k cold , 0.3-0.4k hot [panel sensor not applicable].
	22	KNOCK SENSOR	B19 [W], c:B56[c4 {gnd},c5], between knock sensor and body around 560K
	23	AIR FLOW SENSOR	B1[1,2,3,4,5], a:B48[a8, a9,a10, a21], b:B58[b8], B57[1,2], B3 gnd for non-turbo. Conflicting schematics in Chilton & Subaru manuals. a10, a21 to gnd , 10-14 volt ignition on and B1 cable connected, a:B48[a9] 0-.3v engine off/ign on or 0.8-1.2v eng idle.
			Air Flow Sensor uses thin film type for AT units. Looks like a small Printed Wiring board. Do not use hot wire air flow unit of turbo model. b:B48 10-14 vdc with ign on or engine running.

TROUBLE CODE SUBARU

	24	BY-PASS AIR CONTROL VALVE	E9[1,2,3], F26[13,14], d:F47[d1,d2], B29[4]. Chilton and Subaru confict on F26 Subaru shows F26[11,12]. Be sure to use unit with the three pin out, not the two pin out [three with one pin missing]. Fig 2 correct. B29[4] is 10-14 vdc ign on.
	31	THROTTLE SENSOR	E8[1,2,3,4], F26[3,4,5,6,7], b:B58[b1,b2,b3], a:B48[a21], c:B56[c6]. Subaru and Chilton conflict. Subaru shows F26[1,2,3,4,6]. However, E8 still matches to ECU. Figure 2 correct. E8[1,2] 0 ohm throttle closed, inf open. E8[2,3] 12K ohm,
	31	THROTTLE SENSOR	E8[2,4] 12K ohm throttle closed, 5K ohm throttle fully open with smooth transistion to 5K.
	32	OXYGEN SENSOR	B20[1,2,4], a:B48[6, 20, 17], B29[4]. B20[2] 10-14 volt with ignition on. a:B48[a6] 0.1-1.0vdc at idle with connection on. a:B48[a17] connects to d;F47[d14] internally then d14 connects to gnd.
	33	VEHICLE SPEED SENSOR	No connection to b11. Be sure b10 not connected to simulate AT not in neutral. b9 is grounded to simulate AT in park. a20 is grounded to simulate AT in non-turbo mode. c11 is grounded to simulate California mode.
	35	PURGE CONTROL SOLENOID VALVE [CPC]	Not used. E11[1,2], F25[7,11], d:F47[d6]. Chilton and Subaru in conflict. Subaru shows F25[2,3]. Figure 2 is correct. Leave mounted and connect electrically. No mechanical connections.
	41	AF (AIR/FUEL) LEARNING CONTROL	Check in order injectors, air flow sensor, temperature sensor, throttle sensor, oxygen sensor, fuel pressure, recheck injectors. Normal learning takes three cycles to full speed [2000 rpm or greater] and back.
	42	IDLE SWITCH	See code 31.

EJ-22 with MPFI

TROUBLE CODE SUBARU

	45	ATMOSPHERIC PRESSURE SENSOR	On non-turbo installed inside ECU. If verified defective replace ECU.
	49	AIR FLOW SENSOR	Using improper airflow sensor. No not use hot-wire type. Use thin film sensor. Looks like small PC board inside throat. Replace with correct type.
	51	INHIBITOR SWITCH (AT)	b:B58[b10]. Be sure b10 is not connected but floats. If grounded puts AT in neutral with other signals in park such as b9.
	52	PARKING SWITCH	b:B58[9], Be sure b9 is grounded to simulate parking mode. See code 33 on vehicle speed sensor.
	All	Control Unit Power Supply	Ensure that d:F47[d14,d15,d24,d25], a:B48[a11,a22] go to gnd.
	All	Control Unit Power Supply	Ensure that case is grounded or engine will not start
	All	Control Unit Power Supply	b:B58[b12], a;B48[a2,a13,a15] must have 10-14 volts with ignition [eng 12v bus on] on and engine not running. Remember a15 is not dependent on ignition switch per figure 1.
	All	Ignition coil	Primary E10 on coil 1-2 or 3-2 is 0.7 ohm, Secondary 1-2 or 3-4 [21K ohms Diamond] or [13,8K ohms Hitachi]. See figure 3. F25[8], E10[2] 10-14 vdc with ignition on.
	All	Standard checks all leads	terminal/terminal around 0-1 ohm. Lead to gnd around 1 megohm or greater. All above codes require this check
	To test for codes	Connect c13 [B52] to gnd.	Turn on ignition but do not start engine.
			If check light blinks. Everything is OK. If light blinks Long and short blinks. Read code Long blinks are tens and short blinks are units. For example. Long-Short, Long-Long-Short, then repeats. Code is 11 and 21.