Electronic - pneumatic Injector Controller PWA Circuit Description.

1. Scope.

This document describes the Electronic-pneumatic Injector Controller (EIC) PWA circuit.

2. Applicability.

This circuit description applies to the following drawings:
03-925016-00 - Schematic Rev 3 or later.
03-925013-00 - Assembly Rev 3 or later.

3. Terminology.

GC - Gas Chromatograph.
EFC - Electronic Flow Control.
EIC - Electronic-pnuematic Injector Controller.
EDC - Electronic-pnuematic Detector Controller.

4. Description of the circuit.

Refer to the Schematic.
The following functions exist on the board, with major components as indicated:

Function:	Major Components:
Digital Interface	U1,U2,U3,U4
Analog Interface	U5,AR3
Diagnostics	CR1,CR2,R38,R39,R44,R45
Power Control	Q1,Q5,Q6,Q7,VR1
Flow Controller	AR7,AR4,AR5,AR6,AR3,Q3
Pressure Controller	AR7,AR2,AR5,AR6,AR3,Q2
Temperature Controller	AR1,AR5,Q4
Reference Voltage	AR7,R50,C29,R3

4.1 Description of the Mercury EFC interface.

The Injector EFC bus is distributed via a 34 pin ribbon cable, which connects J8 on the main board to up to three Injector EFC boards located inside the pneumatics compartment of the GC. J9 on the main board is an identical interface that is intended to support up to three Detector EFC boards.
The signals on the Injector EFC bus are:

Digital Signals.

EFCA1	-	Address bit
EFCA2	-	Address bit
EFCA3	-	Address bit
EFC1SEL	-	Module Select #1
EFC2SEL	-	Module Select #2
EFC3SEL	-	Module Select #3
S2CLK	-	Serial bus clock
S2IN	-	Serial data to main board
S2OUT	-	Serial data from main board
SYSENAB	-	System enable signal.

Analog Signals.

IEFCANLG	-	Multiplexed Analog Return signal.
+5VREF	-	+5.00 Volt Reference.

Ribbon cable pin assignments are as follows:

Pin#	Signal
1,2,17	+15Volts Supply
3,4	-15 Volts Supply

10,11	+5.25Volts Supply
5,6,9	Analog Ground 2
7	IEFCANLG
12,13	-5Volts Supply
18,19,20,21	+24Volts Supply
15	Proportional Valve Return Ground
14,16,23,24	Digital/Power Ground
22	+5 Volts Digital Supply
8	+5VREF
25	EFCA1
26	EFCA2
27	EFCA3
28	EFC1SEL
29	EFC2SEL
30	EFC3SEL
31	S2CLK
32	S2IN
33	S2OUT
34	SYSENAB

4.2 EIC PWA Digital Interface.

The three module Select bits are connected to J2 pins 2,4 & 6. For selection of Module #1, a jumper connects J2 pin 2 to J2 pin 1 on the EFC PWA. When EFC1SEL goes low it selects U1 and permits the address bits EFCA1 through EFCA3 to be decoded.
Modules #2 and #3 are selected in a similar manner by moving the jumper to positions that connect pins 4 to 3 and 6 to 5 respectively.
U2 is a serial EEPROM which is addressed by all address bits high. Serial communication to U2 is via a serial interface comprised of S2CLK, S2IN and S2OUT.
U3 is a serial shift register with latched outputs, that is used for configuring the EIC.
With SYSENAB low the input shift register of U3 is reset to zero, but the output remains unaffected.
After SYSENAB is released and goes high U3 can be addressed and loaded via the serial interface. In order to strobe the data to the output of U3, U1 should be addressed with (000).
Outputs of U3 are assigned as follows:

Bit#:	**High**	**Low**
QA LSB -	Connect Temp. to IEFCANLG	Disconnect Temp.
QB -	Connect Valve Diag. to IEFCANLG	Disconnect Valve Diag.
QC -	Connect Flow to IEFCANLG	Disconnect Flow.
QD -	Connect Pressure to IEFCANLG	Disconnect Pressure.
QE -	Turn on Split/Splitless Valve	Turn off Valve.
QF -	Turn on Septum Valve	Turn off Valve.
QG -	Turn on 14 Volt supply	Turn off Supply.
QH -	Turn off Block Heater	Turn on Heater.

U4 is a dual 12 bit serial input DAC. It is loaded by writing 24 bits over the serial bus while address (011) is active, and then writing address (010) to load the data.

4.3 EIC PWA Analog Interface.

A single analog signal is returned to the main board over the EFC ribbon cable.
This signal is IEFCANLG, and is multiplexed on the EFC PWA. U5 is a quad analog switch that is connected up as a 4 channel multiplexer. Analog signals called Temp,Valve Diag,Pressure & Flow are selected by turning on the appropriate bits from the serial shift register U3.

R22,C6,R21,C5,AR3 and R60 form a filter and output buffer circuit for the Flow signal. R60 is a pull up used to improve the capacitive load tolerance of AR3.
Similarly R40,R41,C23,C24 and R61 form a filter and output buffer for the Pressure signal.

4.4 Diagnostics.

R44 and R45 form a divider for the temperature controller diagnostic output. When the temperature controller is controlling at it's setpoint the output of AR1,7 is at zero volts +/- the opamp offset. The voltage presented at U5,11 is nominally 2.500 volts. A deviation of about 80 millivolts is equivalent to one degree Celsius at the output of AR1,7. This translates to a 40 millivolt change at U5,11.
Cr1,Cr2,R38,R39 form a simple OR function for the two valve drivers formed from Q5 & Q6. When both drivers are in the ON state the output voltage is less than 0.5 Volts, when either of the drivers is off with valves connected, the output voltage is approximately 1.0 Volt.

4.5 Power Control.

Q5 & Q6 are used as valve drivers to support up to two switching valves connected to J2,7/8 and J2,9/10. CR3 and CR4 are snubber diodes.
VR1 is a voltage regulator supplying 14 Volt power to the two proportional valve drivers formed by Q2 and Q3.
When Q7 is turned on the reference input to VR1 is shorted to ground, effectively turning off the +14 Volt supply.
Heater power can be turned off by turning on Q1, which removes base drive to Q4.

4.6 Flow Controller.

The Flow Controller is a closed loop Proportional Integral type (PI) controller.
A flow sensor is formed from a differential pressure transducer sensing the pressure drop across a flow restrictor. The Pressure transducer appears as a wheatstone bridge and is connected to the PWA via J3. The differential outputs of the bridge are connected to J3,4&2, which are then amplified by AR4. AR4 is a low drift instrumentation amplifier. [Gain = 49.4K/(R30) +1 = 80.8]
The top of transducer bridge is connected to J3,5 and is driven from the output of opamp AR7,7. The bottom of the bridge is connected to J3,3 and J3,25. This connection also connects a laser trimmed current sense resistor located on the transducer assembly to the bottom of the transducer bridge.
The remaining side of the current sense resistor connects to analog ground at J3,24.
The excitation current flowing through the bridge is sensed by the input to opamp AR7,6 and compared to the 2.5 Volt reference at AR7,5. In this way the bridge excitation current is kept constant with reference to the 2.5 Volt reference.
U4 is a digital to analog converter with a voltage output that varies between 0.0 Volts and - VREF. VREF is the +5.00 Volt reference voltage that connects to U4,2&7.
The Flow DAC output connects from U4,3 to R3,3. R3 is a precision low drift resistor network. Part of this network is used to form a summing node at R3,13 and R3,14. This node sums the output of the AR4 and U4,3 together. Under normal conditions the output of AR4 is positive and the output of U4,3 is negative. When the controller is at a controlled setpoint the junction of the summing node approaches zero.
The summing node junction connects to an integrator formed by AR6,C33 and R10, and an inverting amplifier formed by AR5,R4 and R37. The outputs of the integrator and the inverting amplifier are summed together at the node where R31 and R51 join together. In this way the integral and proportional terms of the controller are added together. The summed Integral and Proportional terms provide a driving voltage to AR3,3.
The coil of an analog proportional valve is connected to J2,13&14. Q3,R12,R56 and 1/4 of AR3 form a current sink driver for the proportional valve.
A voltage at AR3,3 translates into a current scaled by sense resistor R12.
In this way a control loop error occurring at the summing node of R3,13 and R3,14 causes a change to the valve coil current in a direction that corrects the error.
R55,C38,R56 and R57 keep the current sink stable.

R27 and R48 provide a nominal current drive to the proportional valve when the Integrator output is zero volts. Changing the impedance of R27 and R48 provides a means of adjusting the forward gain of the controller.
An offset voltage of 1.25 Volts is connected to AR4,5 ensures a positive offset voltage above zero. For a DAC voltage of zero the controller is guaranteed to turn the proportional valve hard OFF.
Partial immunity to ground noise is achieved by referencing the bottom of R48 and AR5,10 to the +14VGND.
Notes:
AR6 is a high gain extremely low input bias current precision opamp. It was selected for it's high gain, and the low input bias current permits easy use of high resistor values and low capacitor values in both the flow controller and pressure controller integrators.
R3 is a thin film resistor pack with a 5ppm/C ratiometric drift spec. It is used for it's thermal stability.

4.7 Pressure Controller.

The Pressure Controller is a closed loop Proportional, Integral, Derivative type (PID) controller. (Refer to Figure 1)
A Pressure transducer is connected to J3 appears as a wheatstone bridge. The differential outputs of the bridge are connected to J3,12&10, which are then amplified by AR2.
AR2 is a low drift instrumentation amplifier. [Gain = 49.4K/(R59) +1 = 10.9]
The top of transducer bridge is connected to J3,12 and is driven from the output of opamp AR7,14. The bottom of the bridge is connected to J3,11 and J3,17. This connection also connects a laser trimmed current sense resistor located on the transducer assembly to the bottom of the transducer bridge.
The remaining side of the current sense resistor connects to analog ground at J3,16.
The excitation current flowing through the bridge is sensed by the input to opamp AR7,13 and compared to the 2.5 Volt reference at AR7,12. In this way the bridge excitation current is kept constant with reference to the 2.5 Volt reference.
U4 is a digital to analog converter with a voltage output that varies between 0.0 Volts and - VREF. VREF is the +5.00 Volt reference voltage that connects to U4,2&7.
The Pressure DAC output connects from U4,6 to R3,5. R3 is a precision low drift resistor network. Part of this network is used to form a summing node at R3,11 and R3,12.
This node sums the output of the AR2 and U4,6 together. Under normal conditions the output of AR2 is positive and the output of U4,6 is negative. When the controller is at a controlled setpoint the junction of the summing node approaches zero.
The summing node junction connects to an integrator formed by AR6,C31 and R9, and an inverting amplifier formed by AR5,R5 and R36.
A derivative term is formed by AR5,R7,R8,C25,C26,R34 and R35. The input to the derivative term is connected to output of AR2.
The outputs of the integrator and the inverting amplifier as well as the derivative circuit are summed together by a summing amplifier formed by AR6,R32,R33,R42,and R6. In this way the Integral Proportional and Derivative terms of the controller are added together.
The summed terms at the output of AR6,14 provide a driving voltage to AR3,5.
The coil of an analog proportional valve is connected to J2,11&12. Q2,R13,R53 and 1/4 of AR3 form a current sink driver for the proportional valve.
A voltage at AR3,5 translates into a current scaled by sense resistor R13.
In this way a control loop error occurring at the summing node of R3,11 and R3,12 causes a change to the valve coil current in a direction that corrects the error.
R53,C35,R54 and R49 keep the current sink stable.
An offset voltage of 1.25 Volts is connected to AR2,5 ensures a positive offset voltage above zero. For a DAC voltage of zero the controller is guaranteed to turn the proportional valve hard OFF.
Immunity to ground noise on the +14VGND is improved by the 3.16K and 1K resistor network connected to AR6,12.
Notes:

AR6 is a high gain extremely low input bias current precision opamp. It was selected for it's high gain, and the low input bias current permits easy use of high resistor values and low capacitor values in both the flow controller and pressure controller integrators.
R3 is a thin film resistor pack with a 5ppm/C ratiometric drift spec. It is used for it's thermal stability.
The derivative term input is connected to the output of AR2 instead of the loop error to prevent a change in set point from causing a derivative "kick".

4.8 Temperature Controller.

The function of the temperature controller is to provide improved stability and calibration accuracy, by keeping the flow and pressure transducers at a near constant temperature.
The controller has a machined aluminum block which surrounds the two pressure transducers that are plugged into J3. The flow sensor flow restrictor is pressed into this same block.
Q4 functions as a heater and is bolted to the block. RT1 is a thermistor that is located inside the transducer cavity of the block. R30 and R59 are in close proximity to the thermistor.
Under normal use a jumper is installed between J2,15&16 connecting one side of R18 to RT1 to AR1,1. The output of AR1 provides a negative voltage to the bottom of resistor divider R20 and R18. Under conditions where the controller is at setpoint and controlling the resistance of RT1 will equal the resistance of R18 and the bridge formed by R18,R19,R20 and RT1 will be in balance with the voltage at AR1,5 approaching zero.
A deviation in temperature from the setpoint value will cause the output of AR1,1 to change and result in a correcting voltage at AR1,5. The output of AR1,7 drives the Integrator formed by AR1,C22,R47 and R2. As the Integrator output changes it causes a change to the heater drive circuit formed by AR5,R43,R14 and Q4. A voltage at AR5,12 causes a current to flow in Q4, the current sense resistor R14 returns a voltage to AR5,13 forming a current sink circuit. R70 and C42 roll off the amplifier for stability.
A 499 ohm resistor between the base and emitter of Q4 serves to reduce the loop gain of the circuit and help make it stable.
(The minimum current gain of Q4 is approximately 1000.)

As current in Q4 changes it's heat dissipation is also changed. As the control loop needs more heat the drive is increased and for less heat reduced. In this way a closed loop temperature controller with a fixed setpoint is formed. R18 is the setpoint value, and can be changed to be any resistance within the range of the thermistor temperature curve.
Zero compensation is included for stability. A capacitance multiplier is formed by AR1,R1,R26 and C21. This circuit behaves as if it were a capacitor across R23.
The value of capacitance is given by C21*(R26/R1) = 30uF.
The combination of this capacitance and R23 provides a compensating zero which stabilizes the circuit.
R28 and R46 form a resistor divider that sets the maximum current drive as well as changing the forward gain of the controller.
Bake out mode.
If the jumper connecting J2,15&16 is removed the temperature controller will run away and provide full power to the heater Q4, limited only by R28 and R46. Under normal ambient conditions this will cause the Aluminum block temperature to rise to approximately 80C which is a useful bake out temperature that can be used for cleaning of the block and associated components. Under these conditions the current in Q4 will be 567ma, with a power dissipation of approximately 13.5 Watts.
The junction temperature of Q4 under these conditions will be about 94C. (Tjmax = 150C)
Notes:

AR1 is an extremely low input bias current opamp that was chosen because it makes high resistor values and low capacitor values easy to use. It is also a low drift amplifier.
RT1 is a low cost surface mount thermistor with a 10% tolerance of resistance at 25C.
At 45C it's nominal value is close to 2.37K.

4.9 Reference Voltage.

The reference voltage is supplied by the main board, and connects to J1,8. R50 and C29 form a simple filter intended to reduce noise relative to Ground 2 on the EIC PWA. The buffered 5.00V reference is connected to U4,2&7, and then it is divided down to 2.5Volts for the transducer excitation reference. It is divided down once more to 1.25 Volts for the two transducer instrumentation amplifier offsets voltages AR2 and AR4.
Any change in reference relative to Ground 2 is ratio-metrically canceled because it causes equal percentage changes to the DAC output and the transducer excitation current as well as the instrumentation amplifier offset voltage.
Precision resistor pack R3 is used to divide down the reference voltage, this ensures that the temperature drift is kept low.

5.0 Revision Log and File Identification.

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Revision:	Date:	Summary of Changes:
3.0	7/28/95	Previouse version before error log.
3.1	9/26/95	Add error log and change file name.
4.0	1/27/97	Update Applicability section. Add information to 4.1 Revise description in section 4.8 to agree with eco's.