Application Note AN2xxx

Fuel Injection Controller

Author: Pamela Howell
Associated Project: Yes
Associated Part Family: CY8C27xxx
PSoC Designer Version: 4.00

Summary
A design for a complete fuel injection control system is presented. This particular application supplements a gasoline carbureted single-cylinder generator engine with a PSoC controlled gaseous fuel injection system. This design presents an add-on fuel injection system that allows a gasoline powered engine to be run on CNG or LPG fuel.

Introduction
With residential backup generators becoming more common after the 2003 North American blackout, a diverse fuel source for these systems is desired. This design presents an add-on fuel injection system that allows a gasoline powered engine to be run by Compressed Natural Gas (CNG) or Liquid Propane Gas (LPG).

A modern fuel injection system measures engine parameters that are needed for proper fuel control. This may include Engine Speed, Cam Position, Engine Coolant Temperature, Ambient Air Temperature, Throttle Position, Intake Manifold Pressure, Inlet Mass Airflow, Fuel Pressure, Fuel Temperature, and an Exhaust Gas Oxygen Sensor. Since this design is for a simple low-cost air-cooled generator engine, the Cam Position, Engine Coolant Temperature, Ambient Air Temperature, and Exhaust Gas Oxygen sensor will not be included in the design.

Engine Load is ideally measured using an off-the-shelf automotive mass airflow sensor so that precise air mass, and thus desired fuel mass, is known. Such a system may be capable of controlling various engines with the same calibration. Unfortunately, a single cylinder engine with a small intake manifold volume presents a challenge for a hotwire airflow measurement device. The intake airflow is not constant, but pulsed as the intake valve opens. For this case, we'll be forced to use a Throttle Position Sensor as a load input, as a Manifold Pressure Sensor suffers from the same pressure pulses during intake events.

Ignition Coil Input
A 16-bit Timer with the conditioned coil input routed to the capture pin allows timing between coil rising edges and allows fuel output scheduling.

Even though a gaseous fuel system places higher demands on the ignition system (higher firing voltages are required), the carry-over gasoline ignition system is considered adequate. The stock coil drive circuit (connection between ignition coil and points or electronic ignition) is tapped and used to trigger the EP16_Interrupt() software interrupt handler through the Timer16 capture pin.

During the Engine Position interrupt routine, the fuel injection output pin is energized, the fuel injector output timer is loaded and started, and the time between coil events is saved for background calculations of Engine Speed.

Due to the inductive nature of the coil primary and coupling with the secondary high-voltage coil, the hardware conditioning of this coil input is not a simple task. Since we don't have strict engine position timing requirements like an ignition system, we can make use of filtering to ensure that we don't get multiple rising-edge triggers for one coil event. Multiple triggers, although possible to filter within the software, could cause an enormous chronometrics hit.

Fuel Injector Output

An off-the-shelf automotive gasoline fuel injector is used to meter the gaseous fuel. This high-impedance injector is energized with battery voltage through a low-side driver controlled by the PSoC. The mass of fuel delivered to the engine is controlled by modifying the amount of time that the injector is open. The calculations for the injector on-time will be discussed in the Control System section.

The fuel injection one-shot timing is controlled using a Timer16 module and manual software control of one pin on Port_2_0 that connects to the hardware low-side driver input.

During the EP_Interrupt() handler (ie coil event), the fuel injector is turned on and the Fuel Injection Timer (FI16) is set with an initial period equal to the time of desired fuel injection on-time. The FI16 interrupt is setup to trigger once the FI16 count reaches 0x0001 (Injector has completed it's desired on-time). During the FI_Interrupt() handler, the injector is turned off and the interrupt is disabled. This sequence repeats for each coil event.

Analog Inputs

Four analog inputs are routed to a 4 input MUX and Programmable Gain Amplifier which feeds a single 8-bit Delta Sigma ADC. Due to the ratiometric requirements of the Throttle Position, Fuel Rail Pressure, and Fuel Rail Temperature inputs, the PSoC ADC is setup for a reference voltage of Vdd/2. The high-speed aspects of the fuel injection system are performed via the two interrupt routines. The ADCs samples are polled in the background and the MUX is incremented once the previous sample is complete.

Fuel Rail Pressure

A standard automotive rail pressure sensor is used to measure the Gauge Pressure in the fuel rail. This pressure sensor requires 5V (supplied Vdd and Vss) and outputs a ratiometric voltage with the following characteristics (assumes Vdd=5V) 0.5v – 4.5v is 0psig – 150psig. The use of this sensor will be discussed in the Control System section.

Fuel Rail Temperature

This automotive thermistor is used to measure fuel temperature in the fuel rail. The thermistor, also referred to as an NTC (Negative Thermal Coefficient) has a resistance that changes with temperature (resistance increases with decreasing temperature). This sensor is connected between Vss and a pullup resistor to Vdd. The voltage directly across the sensor is sampled using the PSoC ADC. Assuming Vdd=5V and the pullup resistor is a known value, the voltage to temperature lookup table can be modeled in the PSoC software. The use of this sensor will be discussed in the Control System section.

Throttle Position

As discussed in the introduction, a throttle position sensor is used as an engine load measurement. This sensor is a potentiometer that's connected between Vdd and Vss and outputs a signal that's proportional to throttle position. The use of this sensor will be discussed in the Control System section.

Battery Voltage

A resistor voltage divider for the 12V battery prepares the input so that 0-20V can be resolved. This will be used to compensate for the injector opening characteristics and will be discussed in the Control System section.

Serial Data I/O

The PSoC UART is used to monitor the operation of the Control System. A simple terminal interface allows access to Sensor Inputs and Fuel Injection pulsewidth. The PSoC UART clock is setup using one Counter8 and SysClk*2 to generate a clock that results in ~38400 baud. A MAX232 is connected to both the UART Rx and Tx lines and the 9-pin RS232 interface. An enhancement that is currently being developed is a custom WIN32 program that allows both enhanced monitoring and calibration of internal mapping parameters.

Control System

The control system is an open loop fuel controller based on a Coil input (sometimes referred to as Tachometer input), Fuel Rail Pressure, Fuel Rail Temperature, and Battery Voltage. The output is a low side drive to a fuel injector.

Engine Speed

As previously discussed, there are two interrupt handlers, one that executes at each coil event capture (rising edge on coil input) and the other that executes once the fuel injection time has elapsed (count compare <= 0x0001). The coil event causes a timer capture, and this captured value is saved for use in the background loop to calculate Engine Speed (rev/min). Since the EP16 clock is running at 46875Hz, there are 60 seconds per minute, and the EP16 Period is reset to 0xFFFF at the beginning of each interrupt:

```
Eng_Spd=60.0*46875/(0xFFFF-EP_Capture);
```

Density Multiplier

The fuel rail pressure (FRP) and fuel rail temperature (FRT) are used to compensate for density changes in the fuel rail. The assumption is that the fuel injector will be operating under choked flow conditions during normal operation and thus changes in pressure do not change the volume of gas that flows through the injector. Changes in pressure and temperature in the rail will change the density of the gas and thus the mass of fuel delivered. Since the control system attempts to deliver a known mass of fuel, not volume, the rail conditions need to be compensated. Using the ideal gas law (PV=nRT), we can easily compensate for Pressure and Temperature values (FRP,FRT) that are different than the values used during engine mapping (Po,To).

Density Multiplier = (Po/FRP)*(FRT/To)

The above pressure and temperature values must be absolute, with pressure in PSIA and temperature in Rankine. If either of the sensors are out of range, then the Density Multiplier is set to 1.0. The out of range values are based on the circuit and the sensor. For the temperature sensor, below 0.25V or above 4.5V is considered out of range. For the Pressure sensor, below 0.25V or above 4.75V is out of range.

Injector Opening Delay

The fuel injector takes some time to open and close which is dependant on the battery voltage and delta pressure. The pressure portion will be ignored since it's influence is minor. As the battery voltage decreases, there is less magnetic force to open the injector, and the injector takes longer to open. This opening time is modeled as a separate function of battery voltage and added to the base pulsewidth.

PW_Open_ms = fnopenpw(vbat_volts);

Base Pulsewidth

The base pulsewidth is just that, the desired injector pulsewidth based on Engine Speed and Throttle Position. At a sufficiently large injector pulsewidth, the injector behaves as a linear device. For this reason, we will not separate the base table into a desired mass that is later converted to a pulsewidth. To keep things manageable, and easier to debug, the base pulsewidth is an injector opening time in milliseconds, but we can consider it a mass request. The injector opening pulsewidth is modeled separately so that we can directly compensate the base pulsewidth with the density multiplier without incorrectly including the opening characteristics.

PW_Base_ms = fnbasepw(Eng_Spd, tp_volts);

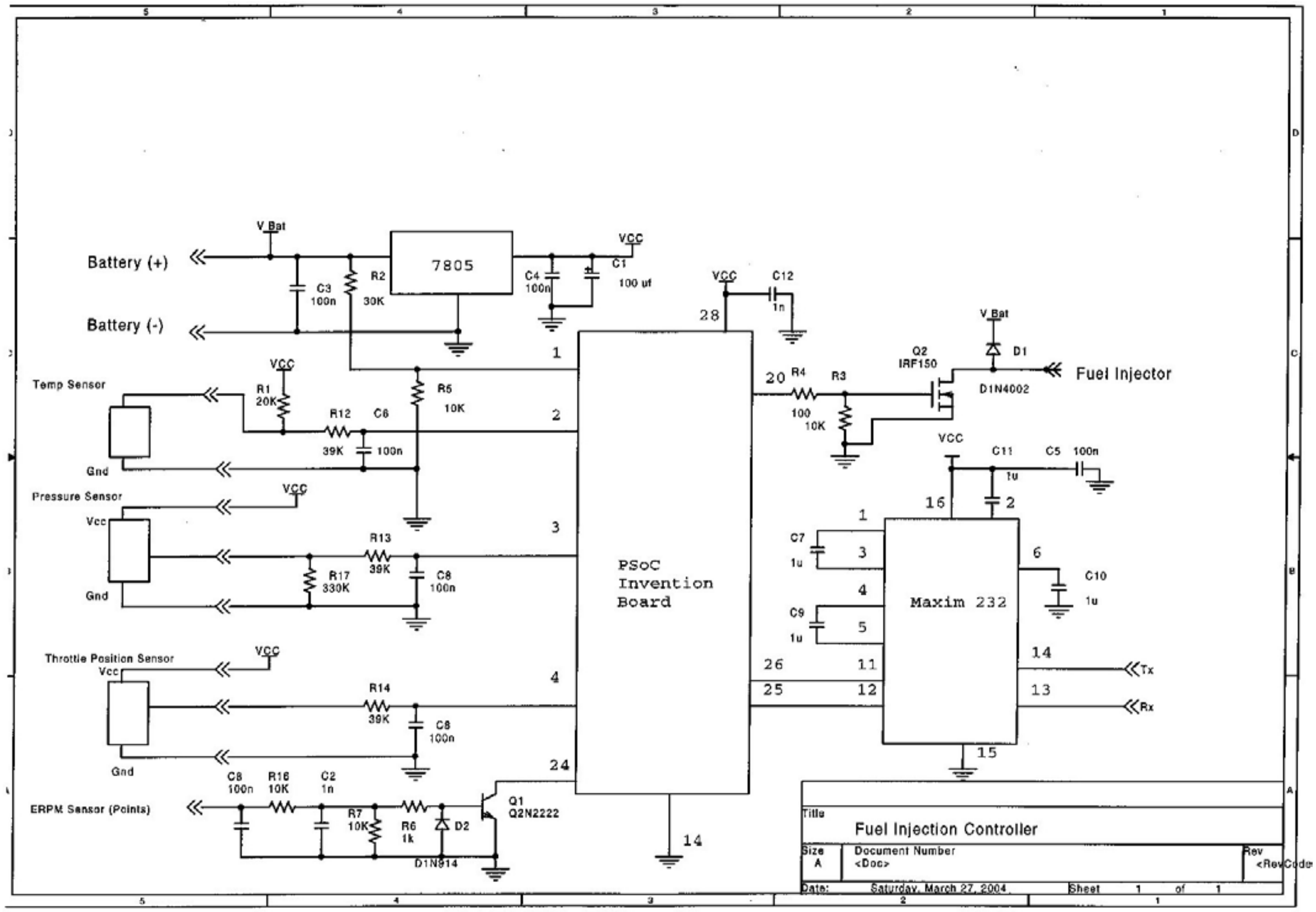
Injector Ticks

The final value that is used by the interrupt routine to schedule injector on-time is injector ticks (PW_Inj_Ticks). Before converting to injector ticks, we first need the final injector pulsewidth in milliseconds. You may have already concluded that from the discussions above:

PW_Inj_ms = PW_Base_ms * Density_Mult + PW_Open_ms;

Since the injector Open Timer (FI16) runs at 46.875kHz and there are 0.001sec/ms we have the following:

PW_Inj_Ticks = PW_Inj_ms * 46.875;



V_Bat
Battery (+)
Battery (-)
C3
100n
R2
30K
7805
C4
100n
C1
100 uf
VCC
C12
1n
28
1
2
3
4
24
14
20
R4
100
R3
10K
Q2
IRF150
D1
D1N4002
Fuel Injector
Temp Sensor
R1
20K
R12
39K
C6
100n
R5
10K
Gnd
Pressure Sensor
Vcc
R13
39K
R17
330K
C8
100n
PSoC
Invention
Board
Throttle Position Sensor
R14
39K
ERPM Sensor (Points)
R16
10K
C2
1n
R7
10K
R6
1k
D2
D1N914
Q1
Q2N2222
C11
1u
C5
100n
16
C7
1u
C9
1u
5
6
C10
1u
11
12
13
15
26
25
Maxim 232
Tx
Rx
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Fuel Injection Controller
Size
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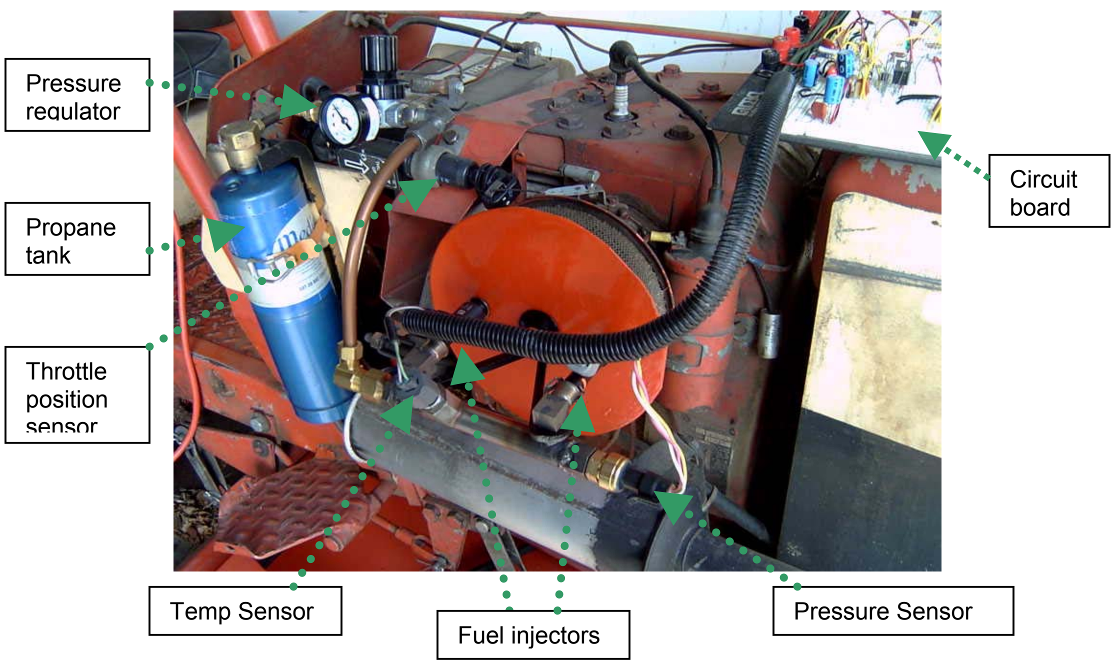
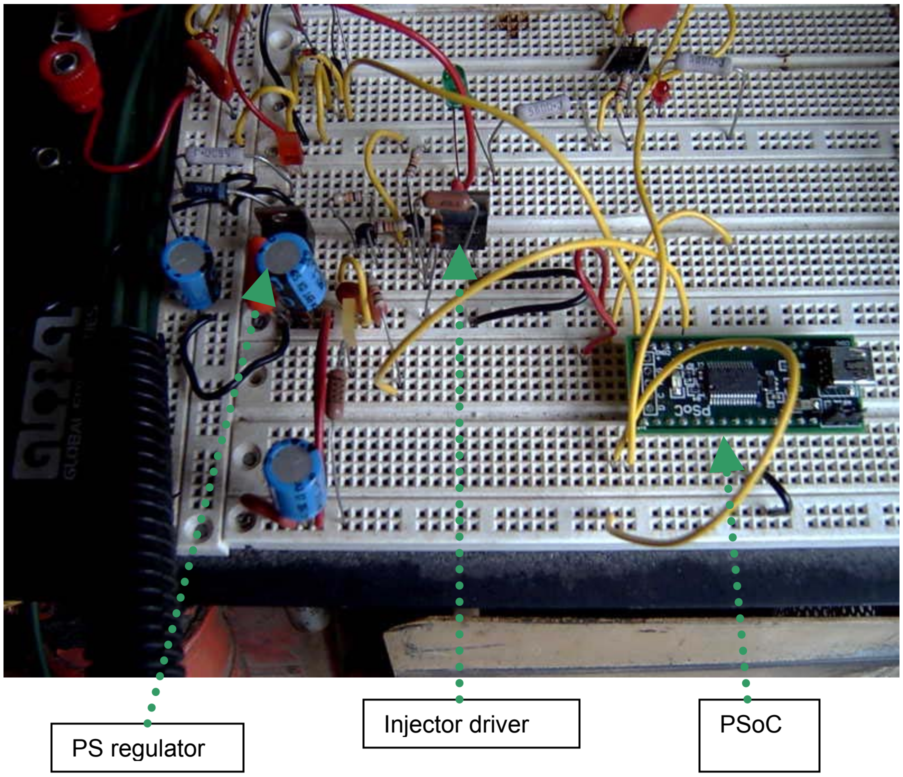
Document Number
<Doc>
Rev
<RevCode>
Date:
Saturday, March 27, 2004
Sheet 1 of 1

Figure 1

Input/Output	Type	CY8C27xxx Port	PSoC Pin, IC Pin
Coil Input	Digital	P0[0]	J2-5, 24
Injector Output	Digital	P2[0]	J2-9, 20
Throttle Position Sensor	Analog 0-5V	P0[1]	J1-4, 4
Fuel Rail Pressure Sensor	Analog 0-5V	P0[3]	J1-3, 3
Fuel Rail Temperature Sensor	Analog 0-5V	P0[5]	J1-2, 2
Battery Voltage Monitor Input	Analog 0-5V	P0[7]	J1-1, 1
UART Transmit	Digital	P0[4]	J2-3, 26
UART Receive	Digital	P0[2]	J2-4, 25
Vdd	5V Power	Vx	J2-1, 28
Vss	Ground	GND	J1-14, 14





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