AN2736
Application note

L9707 gasoline direct injection (GDI) evaluation board

Introduction

This application note presents the STMicroelectronics L9707 evaluation board solution for GDI (Gasoline Direct Injection) applications.

The evaluation kit comprises the L9707 (GDI injector driver) and the L9777B (voltage regulator) mounted on a power board (see *Figure 1*) and the kit includes an ST10 Microcontroller Board.

The optional Graphical User Interface is also described in this document.

Figure 1. GDI power board based on L9707 and L9777B

Contents

List of tables

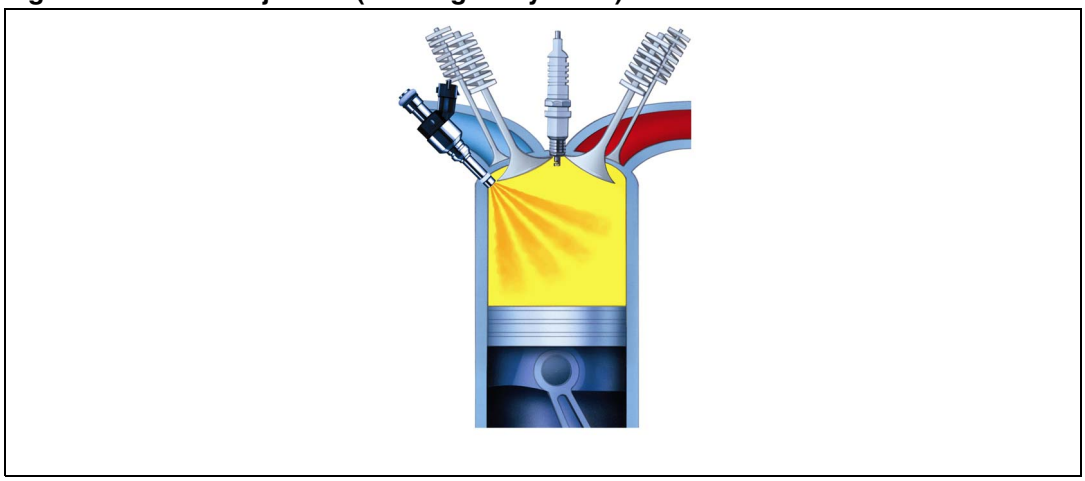
List of figures

1 Gasoline direct injection (GDI) systems

1.1 Overview

In Gasoline Direct Injection (GDI) systems, gasoline is injected directly into the combustion chamber of each cylinder of the engine (see *Figure 2*) as opposed to conventional multi-point Port Fuel Injection (PFI) systems, where the fuel is injected into the intake manifold (close to the inlet valves).

Figure 2. Direct injection (GDI engine cylinder)



GDI engines allow significant improvements in fuel economy maintaining higher power output over traditional PFI engines. This result is achieved by precisely controlling and adapting the fuel amount and the injection timing to load conditions.

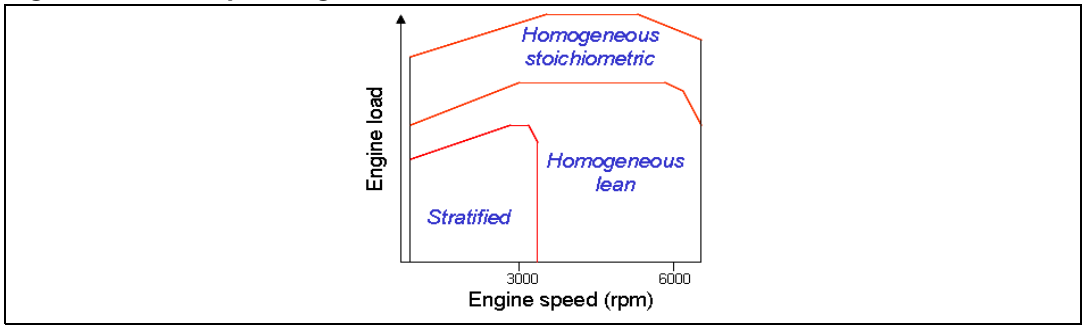
Based on the engine speed and load GDI, operation can be classified in three basic modes:

- Homogeneous stoichiometric mode
- Homogeneous lean mode
- Stratified mode

Homogeneous stoichiometric mode is used for full power. It is realized with an early injection (as for PFI systems) during the intake stroke and the Air/Fuel ratio is maintained stoichiometric or slightly richer than stoichiometric.

Homogeneous lean mode is used for medium loads and it is also realized with an early injection during the intake stroke. In this mode the air-fuel mixture is maintained globally lean.

Figure 3. GDI operating modes



In Stratified mode, used for idle and low load operation, the fuel is injected at the latter stages of the compression stroke, so that fuel stratification near the spark plug is realized. In this way, mixture near the spark gap is very rich and compatible with stable ignition whereas the overall mixture is very lean.

Charge stratification allows to operate the engine unthrottled at partial load with a very lean air-fuel mixture. This greatly reduces pumping losses due to the throttle and in turn significantly reduces fuel consumption. Moreover, charge stratification allows a more stable combustion with reduction of knock tendency and a more rapid start of combustion.

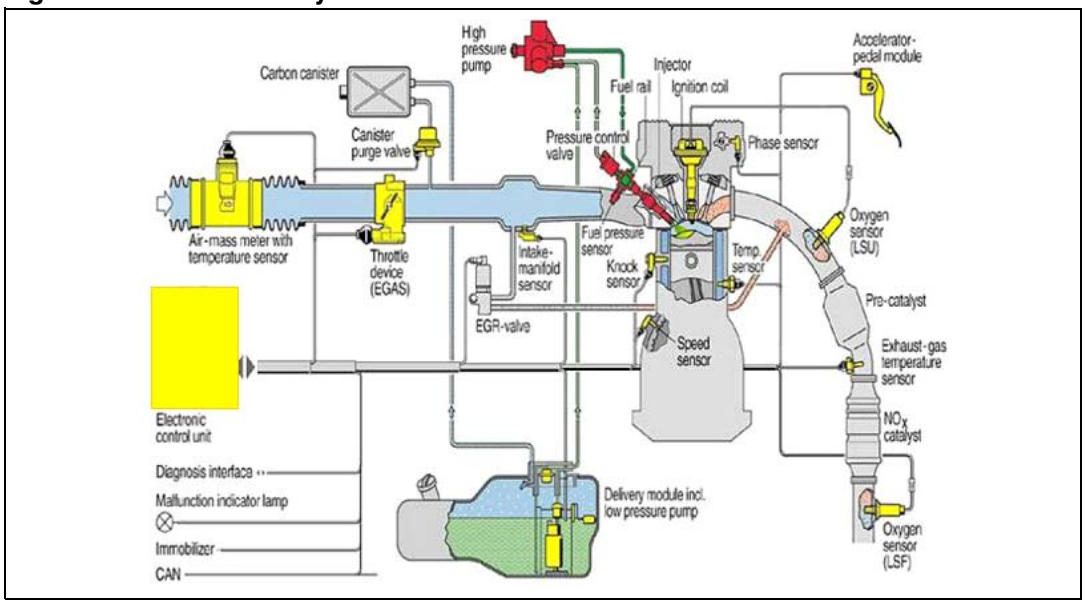
It is only by the use of the stratified-charge mode that the fuel-saving benefits of direct injection can be fully exploited. However there are also direct-injection systems which use a homogeneous, stoichiometric composition mixture across the entire engine operating range.

1.2 GDI systems architecture

Figure 4 shows an example of a GDI system architecture (Bosch system). Gasoline direct injection systems have some peculiarities compared to conventional PFI systems. An EGR valve is always present in a GDI system: this is generally driven by a stepper motor.

A GDI fuel injection system is equipped with a fuel rail (fuel pressure is maintained at 50-200 bar) and a high pressure pump. In order to reduce NO_x emissions a de-NO_x catalyst is generally present at the exhaust of a GDI engine. Moreover, the exhaust system is generally equipped with linear oxygen sensors instead of traditional two-state lambda sensors.

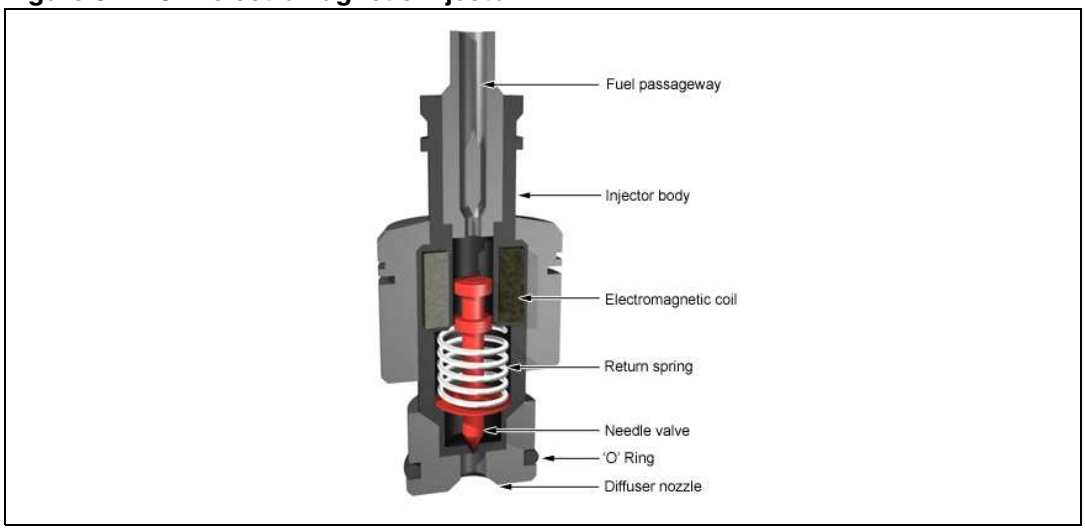
Figure 4. Bosch GDI system architecture



1.3 Injectors for GDI applications: electromagnetic injectors

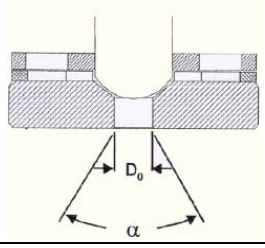
These injectors (see *Figure 5*) open when the injector's solenoid winding is energized by a trigger current: the coil responds by generating a magnetic field that lifts the armature. Consequently, the valve needle rises from the seat and fuel flows through the injector. System pressure and the exit aperture defined by the orifices in the injector nozzle are the primary factors in determining the injected fuel quantity per unit of time. The valve needle closes again as soon as the trigger current ceases to flow.

Figure 5. GDI electromagnetic injector



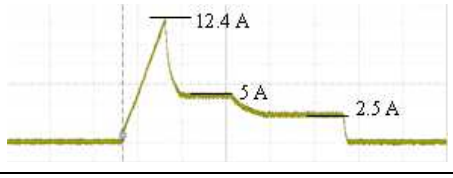
The so called swirl injectors for GDI applications are provided with a device able to induce a rotational motion of the fuel in the direction perpendicular to the injector axis. This rotational motion allows to obtain good fuel atomization also for low injection pressure. The fuel that leaves the injector orifice has the shape of a hollow cone (see *Figure 6*).

Figure 6. Orifice of a GDI swirl injector



In order to have a fast injector opening, the injector first receives a sudden burst of energy (a voltage of about 80 V). Then it is kept open by means of a lower hold current (2-5 A) until the fuel has been completely metered. The command current for a GDI injector has the typical shape as shown in *Figure 7*.

Figure 7. Typical command current for a GDI injector



2 Evaluation board operating requirements

2.1 Required hardware

1. L9707 evaluation board
2. ST10 eva board (ST10F252 or ST10F276)
3. 12 V 20 A power supply or battery
4. 1-6 GDI injectors or resistive-inductive load (1.2 Ω 150 µH)
5. Multitrace oscilloscope
6. 1-6 current probe
7. Multimeter (optional)
8. Windows-based PC
9. A set of mixed screwdrivers

2.2 Required software

1. L9707 GUI software package
2. ST10 flasher (optional)

3 Connections and settings

3.1 ST10 Power board connections

Table 1 shows the correct connections between the ST10 board and the L9707 board. These connections can be made by using unipolar cable or making a flat cable (not included).

Table 1. Connections between ST10 board and L9707 board

Function	L9707 Pin	Pin ST10F276	GPIO	F276_SH*	F276_FS*	Pin ST10F252	L9707 board P5 connector pin
Command / Status signals	Standby	Pin 60	P2.11	D22	D21	Pin 16	1
	Enable	Pin 61	P2.12	C23	C22	Pin 17	2
	/Fault	Pin 62	P2.13	D23	D22	Pin 18	12
Injection current signals	INJI_A1	Pin 49-CC2IO	P2.2	C18	C17	Pin 4-CC2IO	4
	INJI_A2	Pin 50-CC3IO	P2.3	D18	D17	Pin 5-CC3IO	5
	INJPI_A	Pin 51-CC4IO	P2.4	C19	C18	Pin 6-CC4IO	6
	INJI_B1	Pin 52-CC5IO	P2.5	D19	D18	Pin 7-CC5IO	7
	INJI_B2	Pin 53-CC6IO	P2.6	C20	C19	Pin 8-CC6IO	8
	INJPI_B	Pin 54-CC7IO	P2.7	D20	D19	Pin 9-CC7IO	9
	INJI_C1	Pin 57-CC8IO	P2.8	C21	C20	Pin 10-CC8IO	17
	INJI_C2	Pin 58-CC9IO	P2.9	D21	D20	Pin 11-CC9IO	18
	INJPI_C	Pin 59-CC10IO	P2.10	C22	C21	Pin 15-CC10IO	19
SPI signals	SCK	Pin 80- SCLK0	P3.13	D25	D24	Pin 45- SCLK0	14
	/CS	Pin 73	P3.6	D27	D26	Pin 36	13
	DIN	Pin 76-MTSR0	P3.9	C26	C25	Pin 41-MTSR0	15
	DOUT	Pin 75-MRST0	P3.8	D26	D25	Pin 40-MRST0	16
UART signals	TxD0	Pin 77-TxD0	P3.10			Pin 42-TxD0	
	RxD0	Pin 78-RxD0	P3.11			Pin 43-RxD0	
	TxD1	Pin 16-TxD1	P8.7				
	RxD1	Pin 15-RxD1	P8.6				

Note: 1 For ST10F276, connect ASC0 or ASC1 to L9707 via serial port cable.

2 For ST10F252, connect only ASC0 to L9707 via serial port cable.

3 F276_SH board made by ShangHai BPT&S Lab APG China. (ST10F27X EVA v1.0)*

4 F276_FS board made by FORTH-SYSTEME (EVA27X_0)*

To power the ST10 board directly from the L9707 board also connect the respective Vdd and Gnd PIN (for more information see the schematic of L9707 board and ST10 board).

3.2 Default jumper configuration

Table 2 shows the standard configuration for the jumper present on the L9707 board to work connected with the ST10 board.

Table 2. Standard configuration for the jumper present on L9707 board

Jumper name	Position
J1	ON
J2	OFF
J3	OFF
J4	ON
J5	ON
J6	N.C.
J7	1-2
J8	N.C.
J9	1-2

Table 3 gives the settings of micro-switches S4 and S3 for the ST10 board; for further information refer to the board user manual and microcontroller user manual.

Table 3. Setting of micro-switches S4 and S3 for ST10 board

Switch	S4	S3
1	OFF	OFF
2	OFF	OFF
3	ON	OFF
4	OFF	OFF
5	OFF	ON(1)
6	ON	ON
7	ON	ON
8	OFF	OFF

1. OFF in programming phase.

3.3 DC/DC boost converter frequency setting

In order to respect the L9707 specification, the switching frequency for the DC/DC converter has to be in the range 15-21 kHz. Trimmer R25 is used to set the required frequency. Connect an oscilloscope on test point TP10 and adjust R25 until the frequency of the triangle wave reaches the frequency range defined in the datasheet.

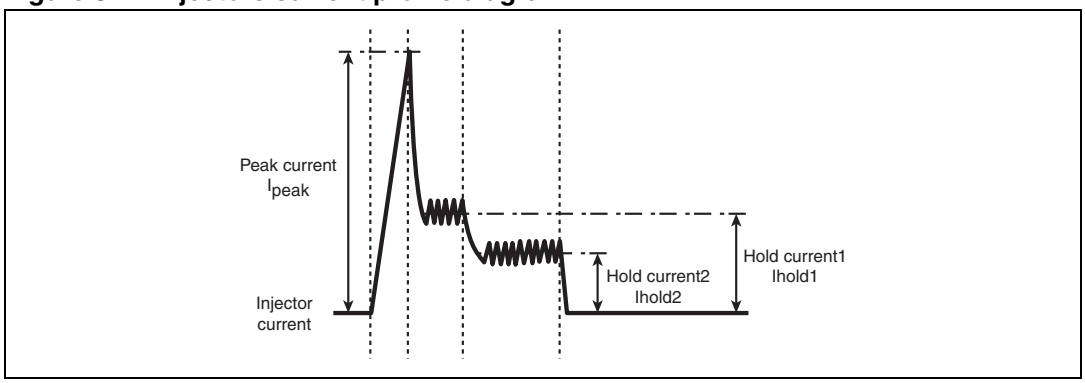
3.4 DC/DC boost converter voltage setting

Considering the specification of the particular injector used by the customer application, it is necessary to set the maximum voltage of the DC/DC boost converter. Trimmer R8 can be adjusted to set the voltage value in the range of 40 to 80 volts. To check the value needed, measure the VH using the test point TP5VH near the power connector,.

3.5 Injectors current profile setting

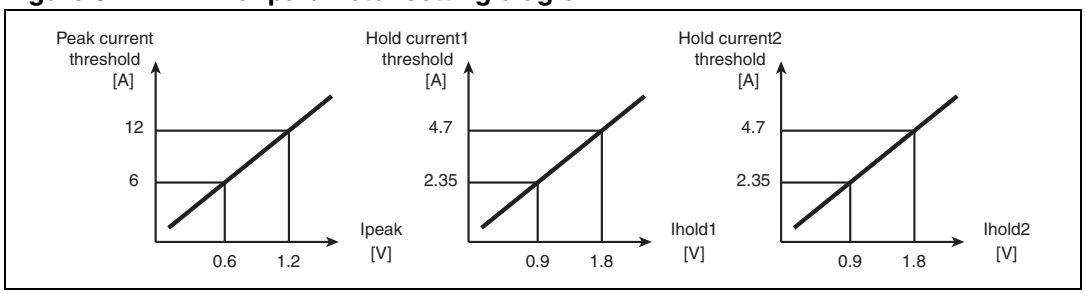
Considering the specification of the particular injector used by the customer application, it is necessary to set the current profile relevant value. In *Figure 2*, Ipeak represents the peak value of the current, Ihold1 represents the first upper current level and Ihold2 the second lower current level.

Figure 8. Injectors current profile diagram



Three trimmers are present on the L9707 board to set these parameters: Ipeak is set using R14, Ihold1 using R15 and Ihold2 using R16. The correct setting can be achieved considering the the three diagrams in *Figure 9* (taken from L9707 datasheet).

Figure 9. Trimmer parameter setting diagram



It is possible to check the voltage value for the settings using the test points Ipeak, Ihold1 and Ihold2 available near the trimmer on the L9707 board.

3.6 Detailed connectors description

Table 4. Detailed connectors description

Connector name	Pin	Name	Function	Note
P3-P4-P6-P7-P8-P9	1-2		Injectors output	
P1	1	VB	Positive battery input	
P1	2	VH	Boost converter output	
P1	3	GND	Power ground	
P2	1	Vcc	5V Vcc	max 200 mA
P2	2	VDD	5V Vdd	max 50 mA
P2	3	WD	Watchdog input	see L9777 datasheet
P2	4	GND	Ground	
P2	5	Vcc	5V Vcc	max 200 mA
P2	6	RESET	RESET output	see L9777 datasheet
P2	7	NMI	Non maskable interrupt output	see L9777 datasheet
P2	8	GND	Ground	
P5	1	Vcc	5V Vcc	
P5	2	/STDBY	L9707 Standby	
P5	3	ENA	L9707 Enable	
P5	4	INJIA1	Bank 1 injector 1 command	
P5	5	INJIA2	Bank 1 injector 2 command	
P5	6	INJPI_A	Bank 1 pick command	
P5	7	INJIB1	Bank 2 injector 1 command	
P5	8	INJIB2	Bank 2 injector 2 command	
P5	9	INJPI_B	Bank 2 pick command	
P5	10	GND	Ground	
P5	11	Vcc	5V Vcc	
P5	12	/FAULT	L9707 fault flag	
P5	13	/CS	L9707 SPI Chip Select	
P5	14	CLK	L9707 SPI Clock	
P5	15	DIN	L9707 SPI DataIn	
P5	16	DOUT	L9707 SPI DataOut	
P5	17	INJIC1	Bank 3 injector 1 command	
P5	18	INJIC2	Bank 3 injector 2 command	
P5	19	INJPI_C	Bank 3 pick command	
P5	20	GND	Ground	

3.7 Detailed jumper description

Table 5. Detailed jumper description

Jumper name	Name	Function
J1	WD	L9777 Watchdog output
J2	Vdd_EN	Enables Vdd regulator of L9777
J3	WD_En	Enables Watchdog of L9777
J4	DC_OUT	DC/DC MOSFET control signal
J5	RADJ_Disable	Undervoltage threshold disable
J6	/STDBY	3-2 L9707 activated, 1-2 L9707 deactivated
J7		3-2 /STDBY controlled by J6, 1-2 controlled by microcontroller
J8	ENA	3-2 L9707 injector driver activated, 1-2 L9707 injector driver not active
J9		3-2 ENA controlled by J8, 1-2 ENA controlled by microcontroller

4 Software description

4.1 Introduction

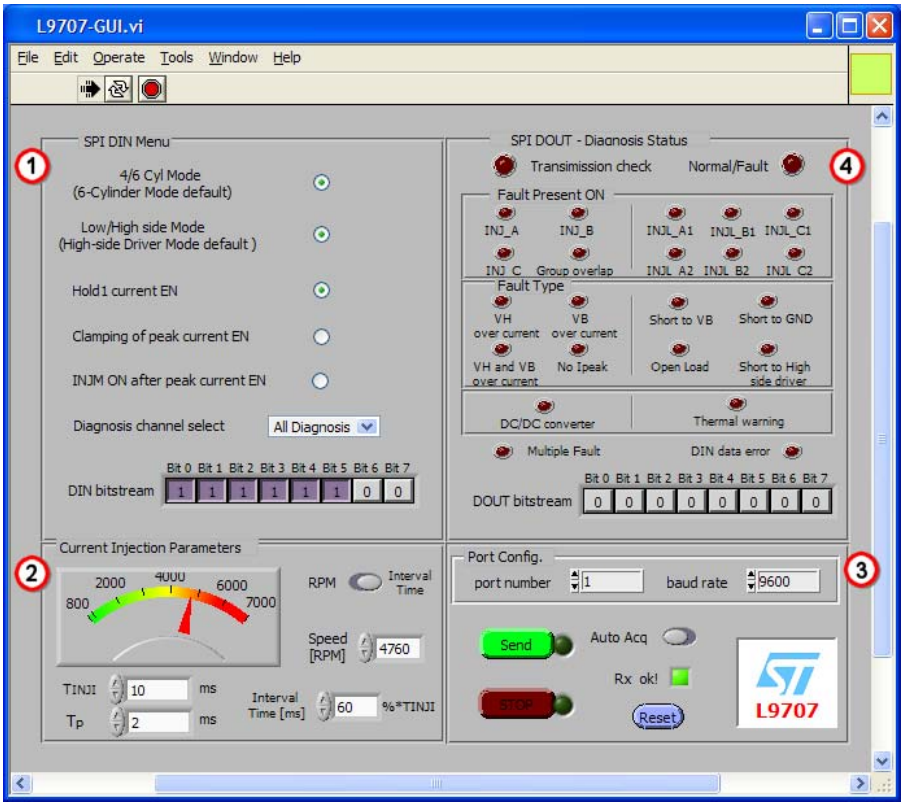
This section of the document explains how to work with the L9707 GUI (Graphical User Interface).

4.2 General description

The L9707 GUI consists of four fields:

- 3 control fields
  - SPI DIN Menu
  - Current Injection Parameters
  - Port Config. & command
- 1 indication field
  - SPI DOUT-Diagnosis Status

Figure 10. L9707 GUI general view



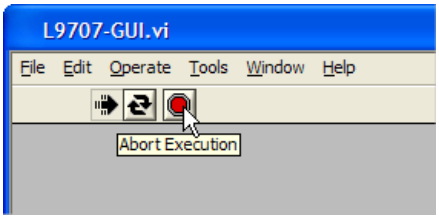
4.3 Running L9707 GUI

After opening the L9707 GUI, click on the "Run" or the "Run Continuously" button. Unlike other GUIs, the L9707 GUI runs manually. In general, the user selects "Run Continuously" to continue running the L9707 GUI. Click the "Abort Execution" button to stop the L9707 GUI. The L9707 GUI can be configured only while it is running.

Figure 11. L9707 GUI "Run" command

Figure 12. L9707 GUI "Run Continuously" command

Figure 13. L9707 GUI "Abort Execution" command



4.4 Configuring L9707 GUI

4.4.1 SPI DIN menu

The frequency of SPI is 1 kHz with CPU frequency 40 MHz.

This field is used to configure the Operation mode of L9707. The DIN command is sent to the L9707 by the ST10 via SPI.

4/6 Cyl Mode

Description:	4-Cylinder or 6-Cylinder Select		
Value:	4-Cylinder	-> Clicked	-> 1
	6-Cylinder	-> Uclicked	-> 0
Default:	6-Cylinder	-> Uclicked	-> 0
SPI-DIN Bit:	b0		

When 4-Cylinder is selected, Group A (INJI_A1, INJI_A2, INJPI_A) and Group B (INJI_B1, INJI_B2, INJPI_B) work, Group C (INJI_C1, INJI_C2, INJPI_C) doesn't generate waveform (cylinders 5 & 6 are disabled).

Low/High side Mode

Description:	Low-Side Driver Mode or High-Side Pre-Driver Mode		
Value:	Low-Side Driver Mode	-> Clicked	-> 1
	High-Side Pre-Driver Mode	-> Uclicked	-> 0
Default:	High-Side Driver Mode	-> Uclicked	-> 0
SPI-DIN Bit:	b4		

Hold1 current EN

Description:	Hold1 Current Enabled or Disabled		
Value:	Hold1 Current Enabled	-> Clicked	-> 1
	Hold1 Current Disabled	-> Uclicked	-> 0
Default:	Hold1 Current Disable	-> Uclicked	-> 0
SPI-DIN Bit:	b5		

Clamping of peak current EN

Description:	Clamping of Peak Current Enabled or Disabled		
Value:	Clamping of Peak Current Enabled	-> Clicked	-> 1
	Clamping of Peak Current Disabled	-> Uclicked	-> 0
Default:	Clamping of Peak Current Disabled	-> Uclicked	-> 0
SPI-DIN Bit:	b6		
Rules:	When Hold1 current is enabled, clamping of peak current is always disabled.		

INJM ON after peak current EN

Description: INJM ON after Peak Current Enabled or Disabled
Value: INJM ON after Peak Current Enabled -> Clicked -> 1
INJM ON after Peak Current Disabled -> Uclicked -> 0
Default: INJM ON after Peak Current Disabled -> Uclicked -> 0
SPI-DIN Bit: b7
Rules: When Hold1 current is enabled, INJM ON after peak current is always disabled.

Diagnosis channel select

Description: Channel Select of Diagnosis
Value: All Diagnosis Select -> 1 1 1
Thermal Warning Select -> 0 0 0
Channel A1 Select -> 0 0 1
Channel B1 Select -> 0 1 0
Channel C1 Select -> 0 1 1
Channel A2 Select -> 1 0 0
Channel B2 Select -> 1 0 1
Channel C2 Select -> 1 1 0
Default: All Diagnosis Select -> 1 1 1
SPI-DIN Bit: b1 b2 b3
Rules: When High-Side Mode is selected, All Diagnosis Select is always selected.

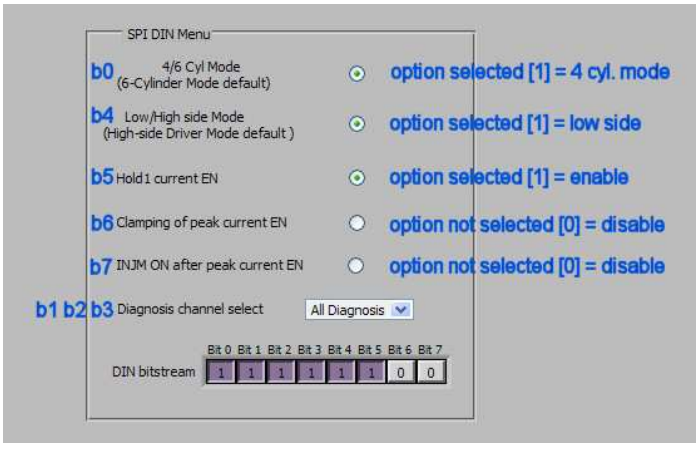
DIN bit stream

Description: Corresponding SPI DIN command was displayed
Value: b0 b1 b2 b3 b4 b5 b6 b7
Reset Value: 0 0 0 0 0 0 0 0

Example

Click the button means set the bit. Unclick the button means reset the bit.

Figure 14. SPI DIN menu example



DIN bit stream field displays the SPI-DIN byte once the "Send" button is clicked.

The rules mentioned previously work once the "Send" button is clicked.

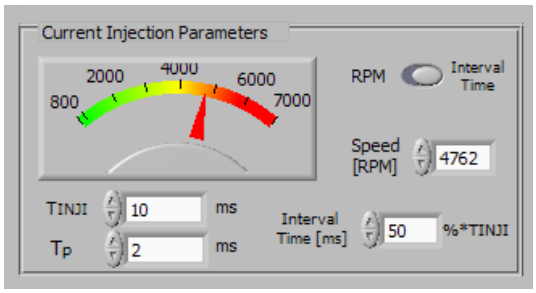
For more information about the SPI DIN map, please refer to the L9707 datasheet.

4.4.2 Current injection parameters

This field is used for configuring the time duration for INJI_x and INJPI_x. The Total Injection period or interval time is provided for more selection flexibility.

The user should first toggle the "RPM-Interval Time" switch to select RPM or Interval Time. If Interval Time is selected, the user enters the Interval Time [ms] and the Speed [RPM] is calculated automatically once the "Send" button is clicked.

Figure 15. Current injection parameters



T_{INJI}

Description: Time duration for each INJI_x
Range: [2 - 10] ms
Step: 0.001 ms
Default: 10 ms

T_p

Description: Peak-hold1 duration (INJPI_x)
Range: [0.25 - T_{INJI}] ms
Step: 0.001 ms
Default: 2 ms

“RPM - interval time" switch

Description: For more flexibility, the user not only configures the total injection time period T_{INJ} but can also configure the interval time between two sequential INJI_x.
This is implemented by the "RPM - Interval Time" switch to select either RPM or Interval Time.
The relation regarding Speed RPM and interval time is provided in the following formula:

$$(\text{Cylinder} - 1) * (\text{Interval Time}\% * T_{INJI}) + T_{INJI} + 0.2 = T_{INJ}\ (\text{ms})$$

$$T_{INJ}\ (\text{ms}) = 2*60*\ 1000 / \text{Speed}$$

0.2 is interval space between each period cycle.

Value: RPM -> Select Speed RPM
Interval Time -> Select Interval Time

Default: Interval Time

Speed RPM

Description: Speed selection will set the frequency of the injection (the total injection time period) according to this formula:

$$T_{INJ} = 2 \cdot \frac{60}{\text{Speed[RPM]}}$$

Range: [800, 7000] RPM

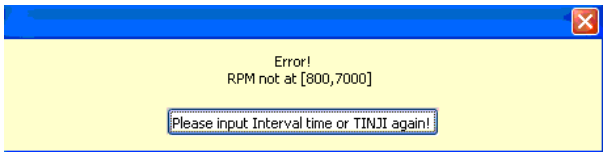
Step: 10 RPM

Default: 800 RPM

Note: 1 When selecting "Interval Time" via RPM-Interval Time Switch, "Speed [RPM]" is indicator.

2 If calculated Speed is not at range [800, 7000], the error warning below appears once "Send" button is clicked.

Figure 16. Speed RPM error warning



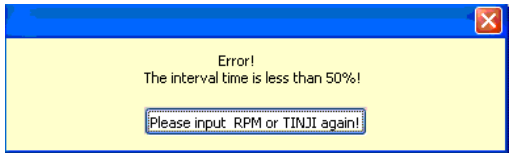
Interval time

Description: The interval time at two sequential INJI_x.
Expression: Percentage of T_{INJI}
Range: [50, …] % * T_{INJI}
Step: 1 %
Default: 50 %

Note: 1 When selecting "RPM" via RPM-Interval Time Switch, "Interval Time" is indicator

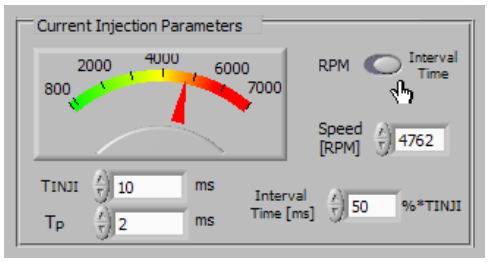
2 If calculated interval time is less than 50%, the error warning below appears once "Send" button is clicked.

Figure 17. Interval time error warning



RPM-Interval time example

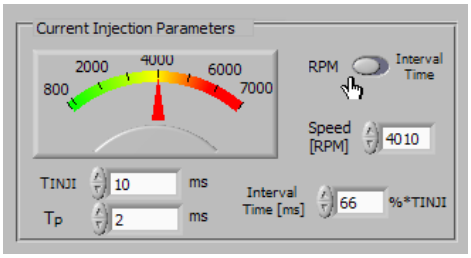
Figure 18. Interval time switch example



RPM-Interval time: Interval Time
T_{INJI}: 10 ms
T_p: 2 ms
Interval time: 50 %* T_{INJI} = 5 ms

Once "Send" button is clicked, the Speed [RPM] indicates the calculated result.
Cylinder = 4; T_{INJ}= 3*5+10+0.2 (ms) = 25.2 ms RPM = 2*60*1000 / 25.2 = 4762.

Figure 19. Speed RPM switch example



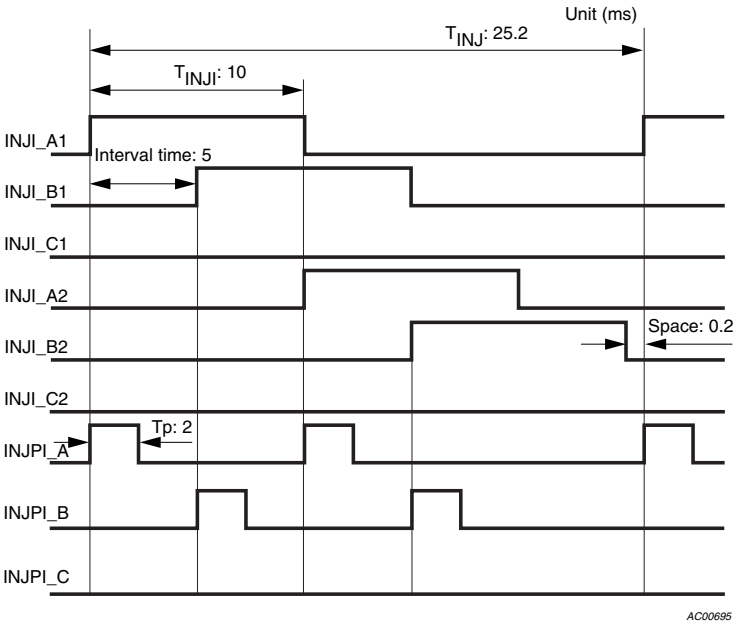
RPM-Interval time: RPM
T_{INJI}: 10 ms
T_p: 2 ms
Speed: 4010 RPM

Once "Send" button is clicked, the Interval Time [ms] indicates the calculated result.
Cylinder = 4; T_{INJ} = 2*60*1000/ 4010 = 30 ms Interval Time = (30-10-0.2)/3/10 = 66%.

INJI_x, INJPI_x waveform example

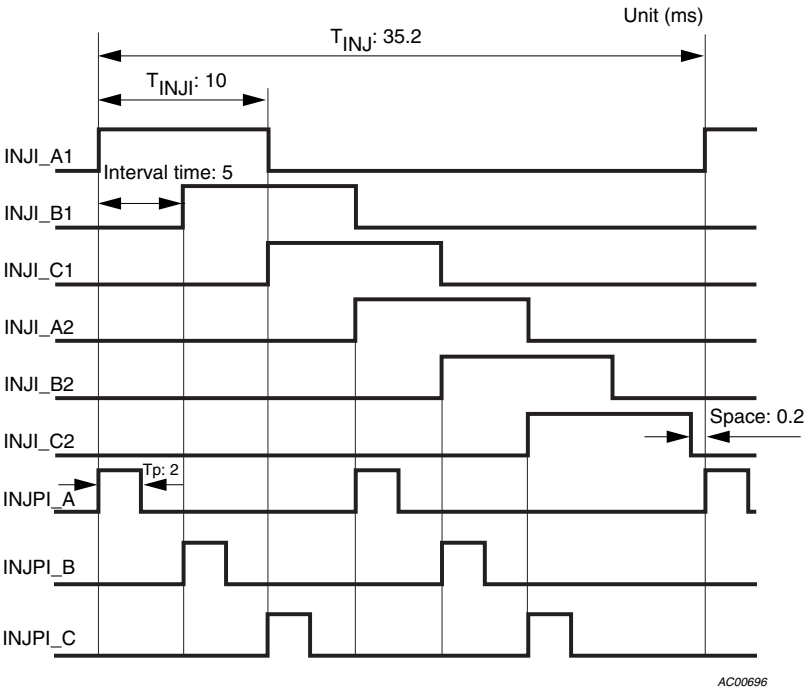
RPM-Interval time: Interval Time
T_{INJI}: 10 ms
T_p: 2 ms
Interval time: 50 %* T_{INJI} = 5 ms

Figure 20. 4-cylinder waveform



4-Cylinder: T_{INJ} = 3*5 + 10 +0.2 = 25.2 (ms)

Figure 21. 6-cylinder waveform

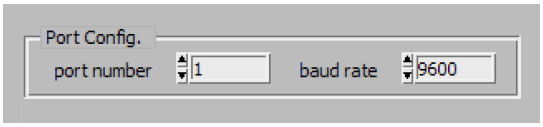


6-Cylinder: T_{INJ} = 5*5 + 10 +0.2 = 35.2 (ms)

4.4.3 Port configure

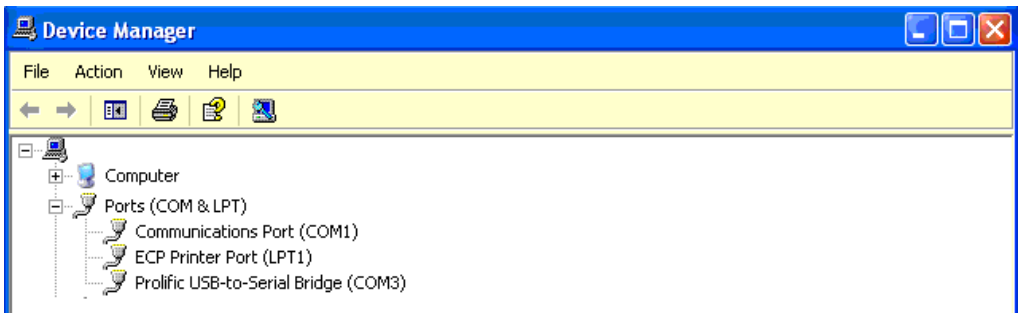
Baud rate: 9600

Figure 22. Port configuration



Port number: (COM Number - 1)

Figure 23. COM number

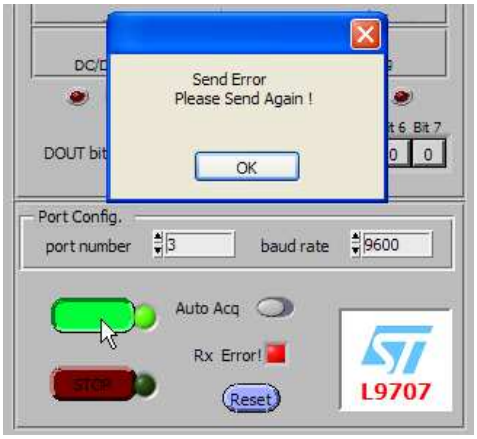


Example: For COM1 port configure: "0" port number should be selected

For COM3 port configure: "2" port number should be selected

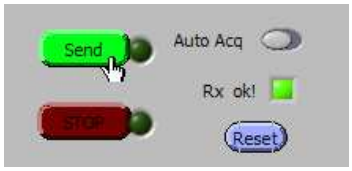
If the Port configure fails, the error warning below appears once "Send" button is clicked, and the Rx status light changes from GREEN "Rx ok!" to RED "Rx Error!"

Figure 24. Serial port configure error



4.4.4 Command field

Figure 25. Command field



"Send" button

After all the parameters are configured, clicking the "Send" button performs the following operations.

1. Estimate if the item "Diagnosis channel select" met the item "Low / High side" mode
2. Estimate if the item "Clamping of peak current EN" and the item "INJM on after peak current EN" met the item "Hold1 current EN".
3. DIN bit stream displayed the SPI DIN command the user has configured.
4. Estimate if the "T_{INJI}" at the range
5. Estimate if the "T_p" at the range
6. Estimate if the "Speed" at the range
7. Estimate if the Interval Time at the range
8. Estimate if calculated "Speed RPM" at the range, when "Interval Time" was selected
9. Estimate if calculated "Interval Time" at the range, when "RPM" was selected
10. Estimate if Port was configured successfully

If all the previous checks passed succesfully, the SPI DIN & time parameters are sent to ST10 MCU via UART. In turn the ST10 MCU performs the following operations:

- make STDY signal & EN signal HIGH level to L9707
- send SPI DIN to L9707 via SPI and get SPI OUT
- INJI_x, INJPI_x waveform generation
- send SPI OUT back to PC-GUI via serial port

Note: The indicator light to the right of the "Send" button comes on once the bytes are sent to the serial port. Release the "Send" button when this light comes on.

"STOP" button

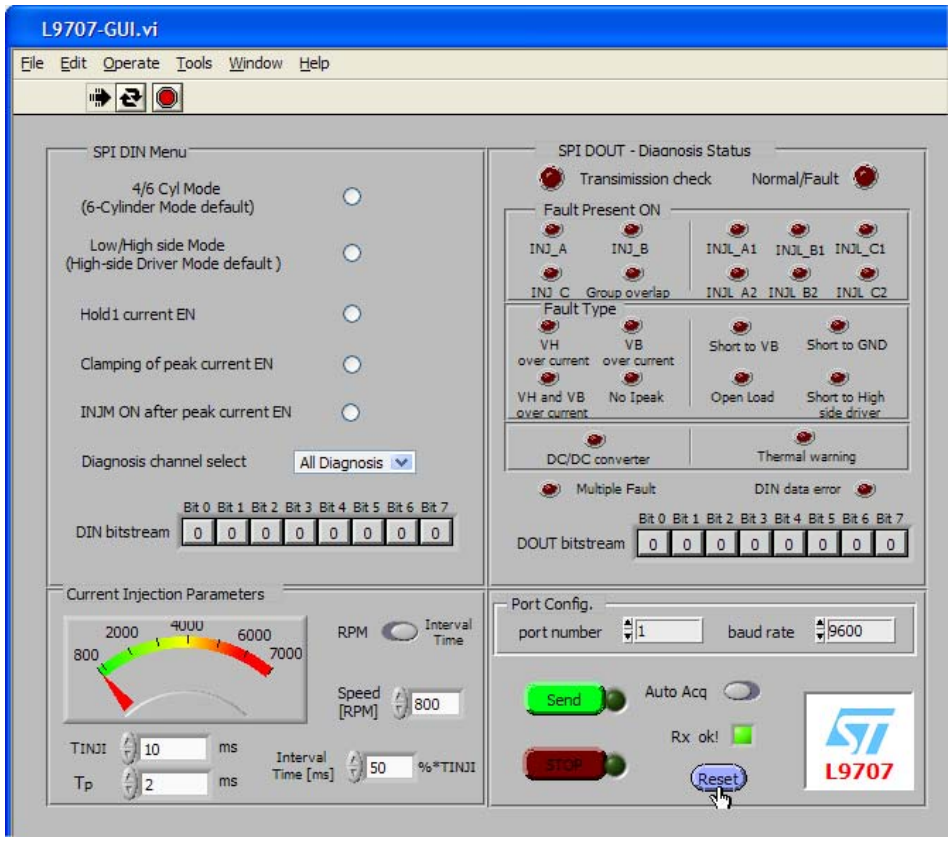
When the "STOP" button is clicked, the EN signal to L9707 goes to LOW level to stop the operation.

Note: The indicator light to the right of the "STOP" button comes on once the bytes are sent to the serial port. Release the "STOP" button when this light comes on.

"Reset" button

Click the "Reset" button will reset each item as shown in *Figure 26*.

Figure 26. Reset value



"Auto Acq" Switch

Toggling the switch to the left turns on the auto acquisition serial port data function. The SPI OUT bytes will automatically read to display by L9707 GUI.

Toggling the switch to the right turns off the auto acquisition serial port data function.

"Rx ok" indicator

When reading the serial port, if it failed, the "Rx ok!" indicator turns RED, otherwise it turns GREEN.

4.4.5 SPI OUT indication field

This field indicates the diagnosis status.

The SPI OUT diagnosis byte is displayed at DOUT bit stream.

The DOUT bit map for High-Side mode and Low-Side mode are shown in *Figure 27*:

Figure 27. DOUT bit map - high-side injection pre-driver diagnosis output mode

<table>
<tr><th colspan="2" rowspan="2">DOUT fault code</th><th colspan="8">Bits</th></tr>
<tr><th>b0</th><th>b1</th><th>b2</th><th>b3</th><th>b4</th><th>b5</th><th>b6</th><th>b7</th></tr>
<tr><td rowspan="2">Information</td><td>No fault</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Fault</td><td>1</td><td colspan="7">see cells below</td></tr>
<tr><td colspan="2"></td><td></td><td colspan="5" rowspan="2"></td><td rowspan="2">0/1</td><td rowspan="2">0/1</td></tr>
<tr><td></td><td>High-side pre-driver mode</td><td></td></tr>
<tr><td>Fault present on</td><td>INJ_A</td><td></td><td>0</td><td>0</td><td rowspan="4">see cells below</td><td rowspan="8"></td><td rowspan="8">Multiple Fault</td><td rowspan="8"></td></tr>
<tr><td></td><td>INJ_B</td><td></td><td>0</td><td>1</td></tr>
<tr><td></td><td>INJ_C</td><td></td><td>1</td><td>0</td></tr>
<tr><td></td><td>Group overlap</td><td></td><td>1</td><td>1</td></tr>
<tr><td>Type of fault</td><td>VH over current</td><td></td><td rowspan="4">see cells above</td><td>1</td><td>0</td></tr>
<tr><td></td><td>VB over current</td><td></td><td>0</td><td>1</td></tr>
<tr><td></td><td>VH and VB over current</td><td></td><td>0</td><td>1</td></tr>
<tr><td></td><td>No Ipeak</td><td></td><td>1</td><td>0</td></tr>
<tr><td>DC/DC converter</td><td>Normal</td><td></td><td colspan="3" rowspan="2"></td><td>0</td></tr>
<tr><td></td><td>Over voltage</td><td></td><td>1</td></tr>
<tr><td colspan="2"></td><td>Even parity bit</td><td colspan="6"></td><td>0/1</td></tr>
<tr><td colspan="2">DIN data Error</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table>

Figure 28. DOUT bit map - low-side injection driver diagnosis output mode

<table>
<tr><th colspan="2" rowspan="2">DOUT fault code</th><th colspan="8">Bits</th></tr>
<tr><th>b0</th><th>b1</th><th>b2</th><th>b3</th><th>b4</th><th>b5</th><th>b6</th><th>b7</th></tr>
<tr><td rowspan="2">Information</td><td>No fault</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Fault</td><td>1</td><td colspan="7">see cells below</td></tr>
<tr><td colspan="2">Thermal warning</td><td></td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td></td><td>Low-side driver mode</td><td></td><td colspan="5"></td><td></td><td></td></tr>
<tr><td>Fault present on</td><td>INJL_A1</td><td></td><td>0</td><td>0</td><td>1</td><td rowspan="6" colspan="2">see cells below</td><td>0/1</td><td>0/1</td></tr>
<tr><td></td><td>INJL_B1</td><td></td><td>0</td><td>1</td><td>0</td><td rowspan="7">Multiple Fault</td><td rowspan="6"></td></tr>
<tr><td></td><td>INJL_C1</td><td></td><td>0</td><td>1</td><td>1</td></tr>
<tr><td></td><td>INJL_A2</td><td></td><td>1</td><td>0</td><td>0</td></tr>
<tr><td></td><td>INJL_B2</td><td></td><td>1</td><td>0</td><td>1</td></tr>
<tr><td></td><td>INJL_C2</td><td></td><td>1</td><td>1</td><td>0</td></tr>
<tr><td>Type of fault</td><td>Short to VB</td><td></td><td rowspan="4" colspan="3">see cells above</td><td>1</td><td>1</td></tr>
<tr><td></td><td>Short to GND</td><td></td><td>0</td><td>1</td></tr>
<tr><td></td><td>Open load</td><td></td><td>1</td><td>0</td></tr>
<tr><td></td><td>Short to high-side driver</td><td></td><td>0</td><td>0</td></tr>
<tr><td>Transmission check</td><td>Even parity bit</td><td colspan="6"></td><td>0/1</td></tr>
<tr><td colspan="2">DIN data Error</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table>

Note: 1 Fault is 0, the number of faults is 1 or 0.
When Multiple Fault is 1, the number of faults is more than 1.

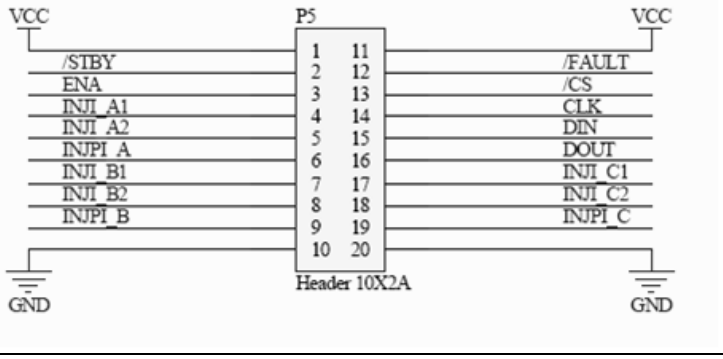
2 In the event of multiple faults, the diagnosis word with the highest priority is outputted. The priority decreases from Group Overlap to INJ_A then INJL_C2 to INJL_A1.

3 "DIN Data Error" indicates that the number of SCK pulses does not equal 8, or DIN data is not valid.

For more diagnosis information, please refer to L9707 data sheet in detail.

Appendix A Interface schematic between L9707 board and ST10 board

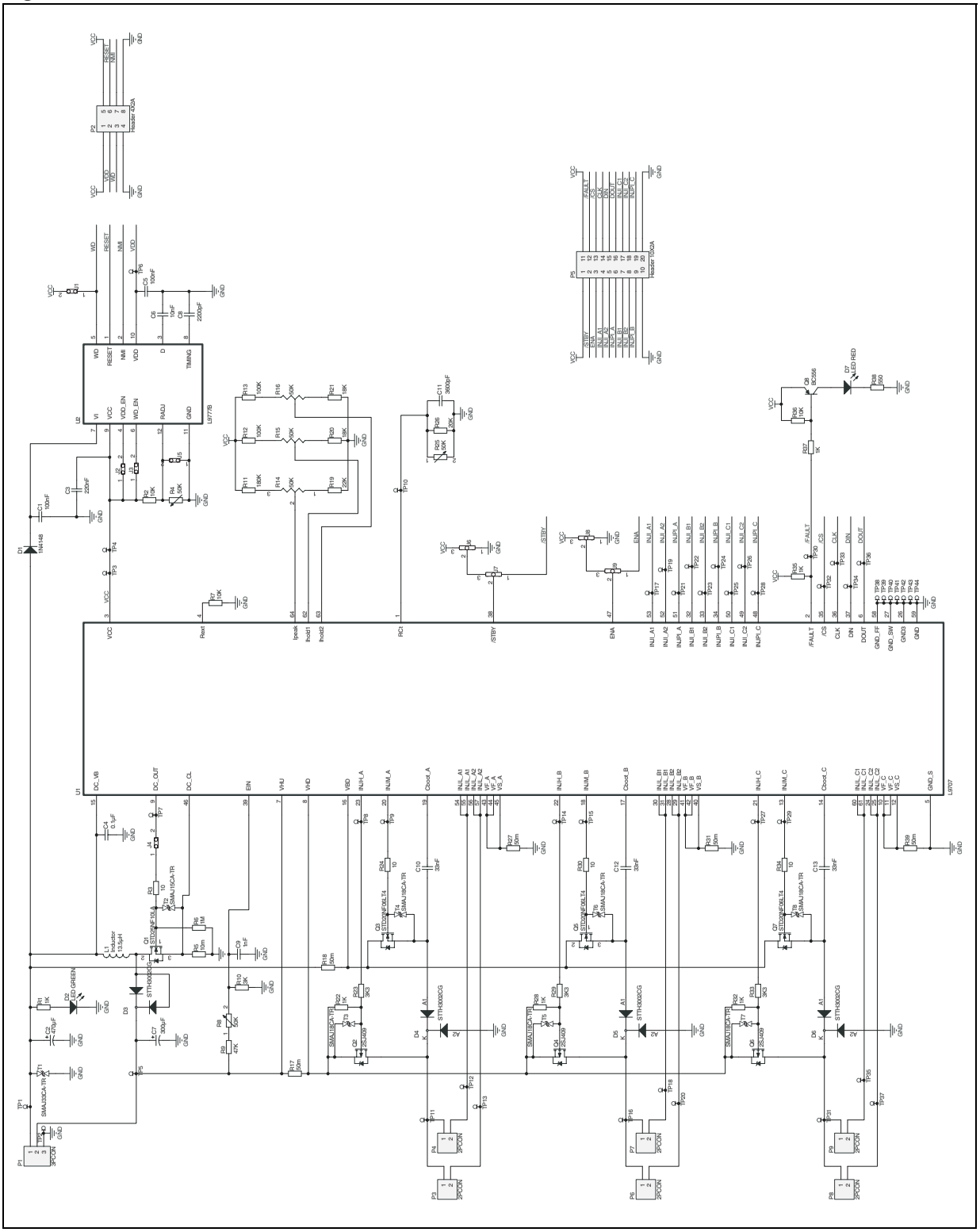
Figure 29. Connection interface



For more information, please refer to the L9707 demo board schematic.

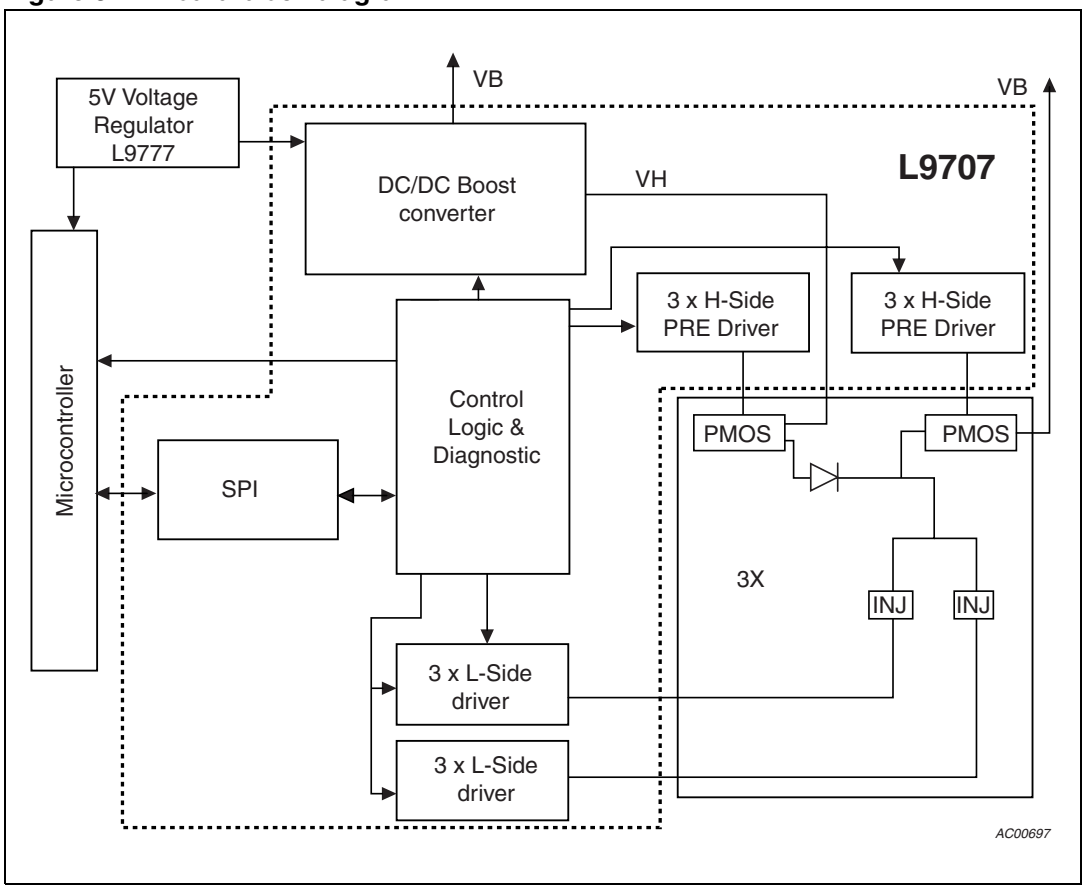
Appendix B L9707 board schematic

Figure 30. L9707 board schematic



Appendix C Board block diagram

Figure 31. Board block diagram



Appendix D Applications

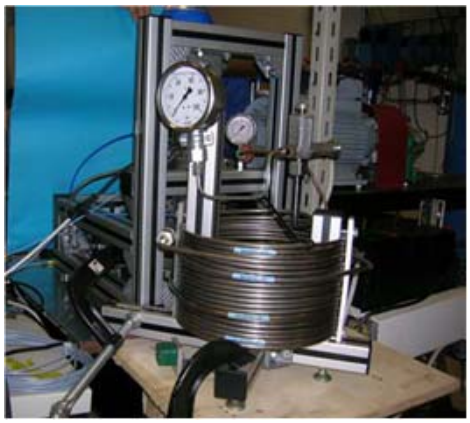
D.1 Using L9707 board for driving single-hole injectors

The L9707 evaluation board was used to drive a single-hole, hollow-cone Bosch GDI injector. The injector is shown in *Figure 32* and it has the following electrical characteristics:

- Max voltage: 70 V
- Equivalent inductance: 150 µH
- Equivalent resistance: 1.2 ohm

Figure 32. Bosch GDI single-hole injector

Figure 33. Bosch tube system

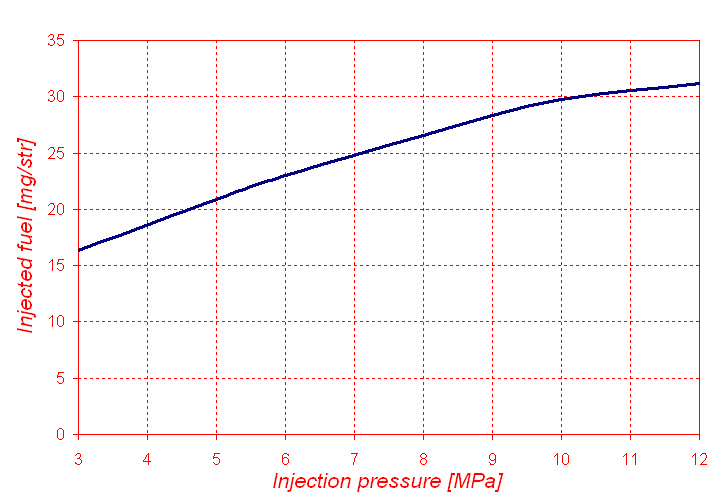


Different injection strategies have been tested. The amount of injected fuel and the fuel mass flow rate have been measured by means of a fuel injection meter system (the so called Bosch tube) shown in *Figure 33*

The L9707 evaluation board succeeded in generating the current profile (see *Figure 34*) required to drive the GDI injector.

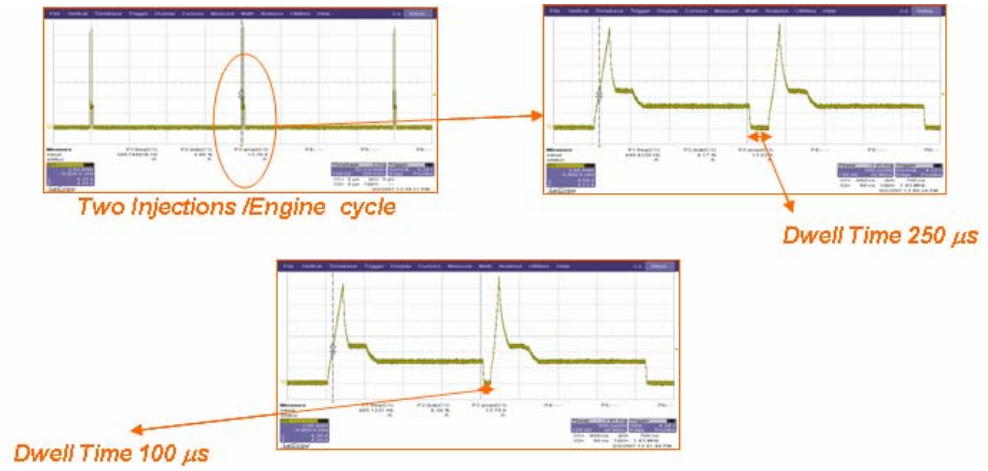
Figure 34. Current command for a GDI injector

Figure 35. Injected fuel in function of injection pressure



In *Figure 35* the amount of injected fuel based on the fuel pressure is shown. The figure refers to the injector driven with a trigger current by means of L9707 evaluation board.

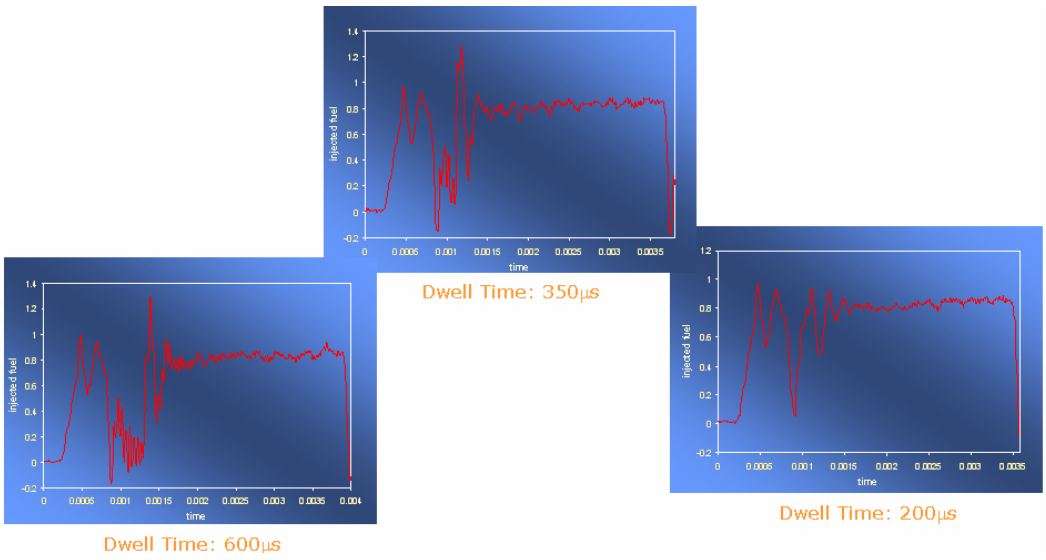
Figure 36. Multiple injection driving



Tests were also conducted with L9707 evaluation board to determine its capability for driving multiple injections (see*Figure 36*). In particular, two consecutive injections with different dwell times have been generated by means of the L9707 evaluation board. These tests

confirmed that the L9707 is able to generate a proper trigger current in the case of multiple injections without limitations on the duration of dwell time between consecutive injections (dwell times lower than 100 µs are allowed). The choice of dwell times that are too short between consecutive injections is only limited by the mechanical characteristics of GDI injectors: the injector needle has no time to close before the subsequent opening for dwell times that are too short. In fact, as shown in *Figure 37*, for a current command with a dwell time lower than 350 µs, the fuel is not split in two separate injections.

Figure 37. Instantaneous injected fuel based on dwell time



D.2 Using the L9707 board for driving multi-hole injectors

How to use the L9707 demo board for drivng a Bosch GDI multi-hole injector is described here.

The injector electrical characteristics are:

Max voltage: 65 V

Equivalent inductance: 2.3 mH (1 kHz)

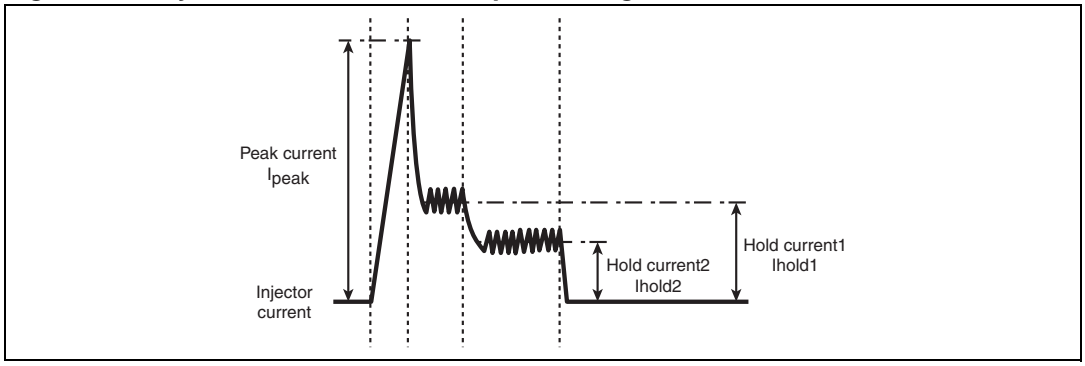
Equivalent resistance: 1,5 ohm

Figure 38 shows a photograph of this injector.

Figure 38. Electric injector

Figure 39 illustrates the standard injector current profile used in this application.

Figure 39. Injectors standard current profile diagram



The current requirements are given in *Table 6*.

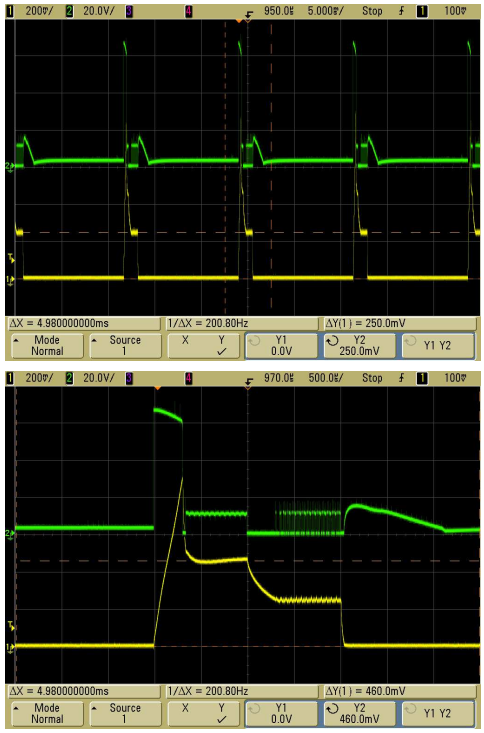
Table 6. Current requirements

Name	Value (A)
IPeak	9
IHold1	5
IHold2	2.5

Using the L9707 evaluation board, the current was set as explained in *Section D.1: Using L9707 board for driving single-hole injectors* and the maximum BH voltage was set to 65 V.

The images in Figure 38 show the injector current commands generated by the L9707 evaluation board. The results show the perfect of the requirements.

Figure 40. Injector current commands generated by L9707 evaluation board.



5 Revision history

Table 7. Document revision history

Date	Revision	Changes
10-Apr-2008	1	Initial release.