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Measurement report of ST L9780 with Bosch LSU-4.9 and LSU-ADV Wide Band Lambda Sensors

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Background

On the basis of the common validation plan of ST and Bosch (ref.1) to certify operation of the ST L9780 Wide Range Air/Fuel Sensor Interface IC with the Bosch LSU-4.9 and LSU-ADV Wide Range Lambda Sensors, ST has evaluated the most suitable setup for L9780 and Bench test described on a previous document (ref.2). In the following of this document there is a description of the results of the measurement demonstrating the compatibility of L9780 with both LSU 4.9 and LSU ADV wide range lambda sensor.

ref1: "*L9780_Bosch Validation Proposal 22-Nov-10*"
ref2: "*L9780_Bosch setup Proposal 16-03-11"*

Static Lambda Measurements

In order to execute this measurement the system was setup as described in ref.2. Regarding the engine setup we have considered the following point:

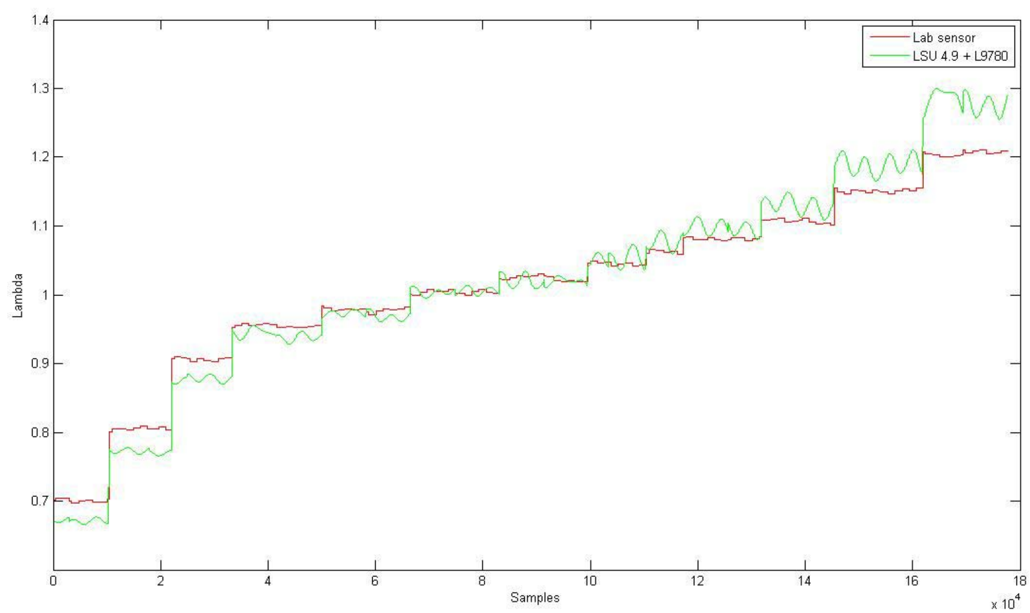
- Motorized throttle open 5%
- RPM 1500
- Feedback control of lambda operated using ST developed dSpace Engine control System (see appendix A)

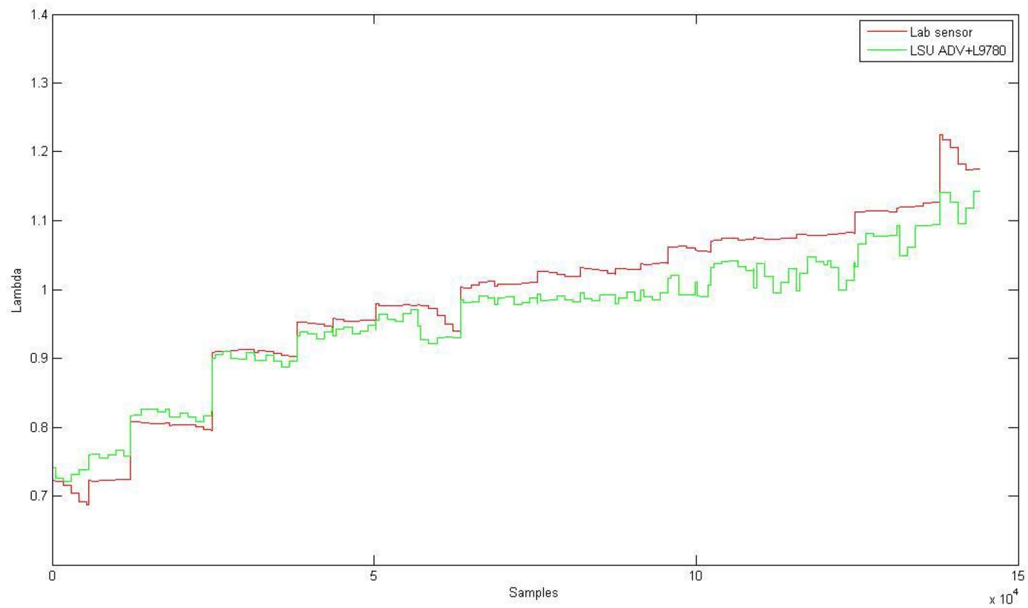
The lambda value is measured in the same moment with laboratory lambda sensor and with the system (L9780+Bosch sensor) while the reference lambda is maintained constant. The reference lambda points considered are the following:

[0.7 0.8 0.9 0.95 0.96 1 1.02 1.04 1.06 1.08 1.1 1.15 1.2]

For both the sensor a 61.9 ohm shunt resistor was used.

In the figures below you can look the results for LSU-4.9 + L9780 and LSU-ADV + L9780

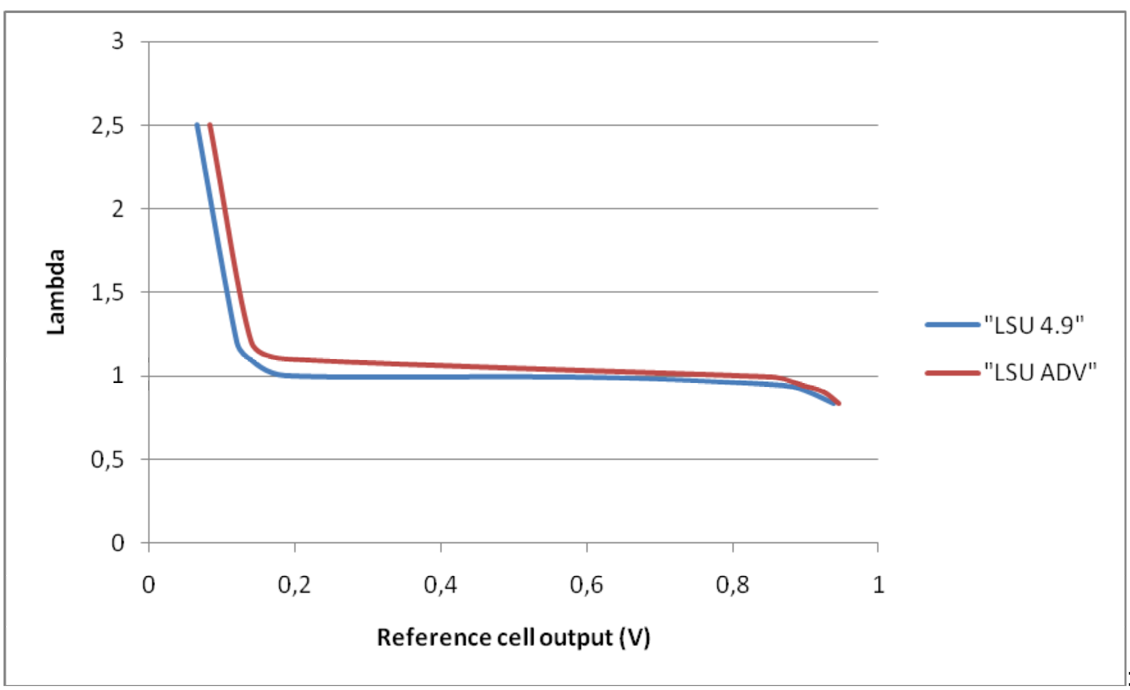




The data was acquired with dSpace with the following settings:

- Sampling time :6*10^-6 s
- Length of each lambda step measurement: 0.8 s
- The lambda value measured by L9780+LSU4.9 is digitally filtered with an IIR lowpass filter 4^{th} order, cut frequency 100 Hz
- The Lambda value is sampled once a revolution at -90° TDC (Top Dead Center)

Besides these we also have carry out some measurement in order to determine the Reference Cell Curve (Lambda/V). The results are shown in the following figure:



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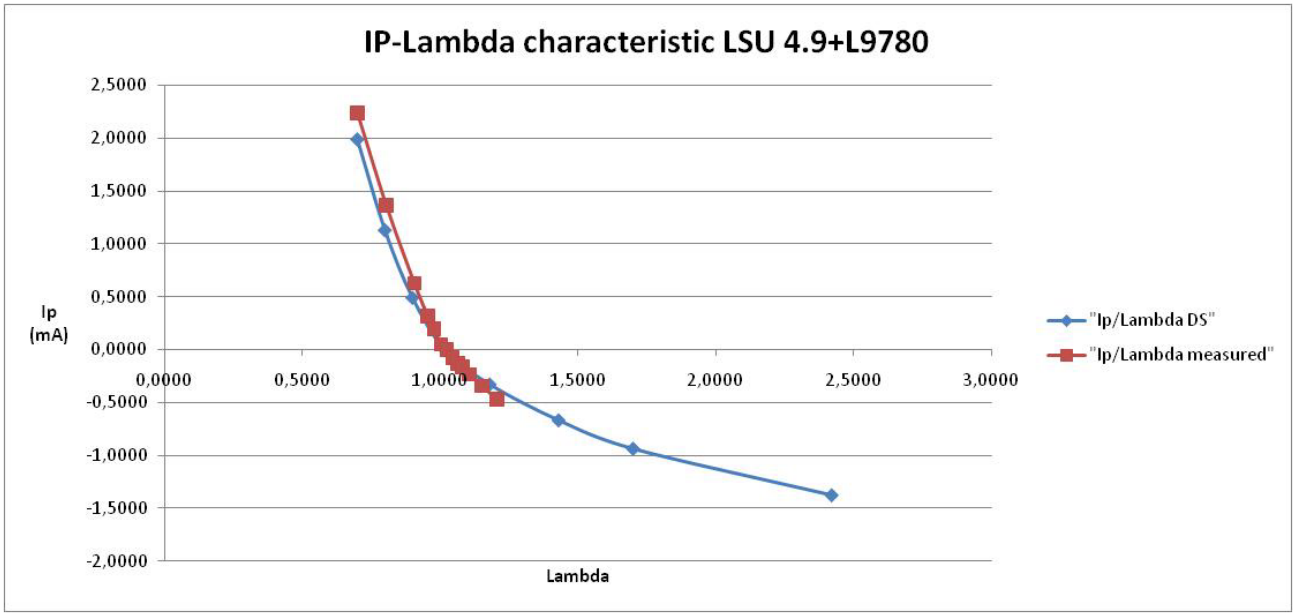
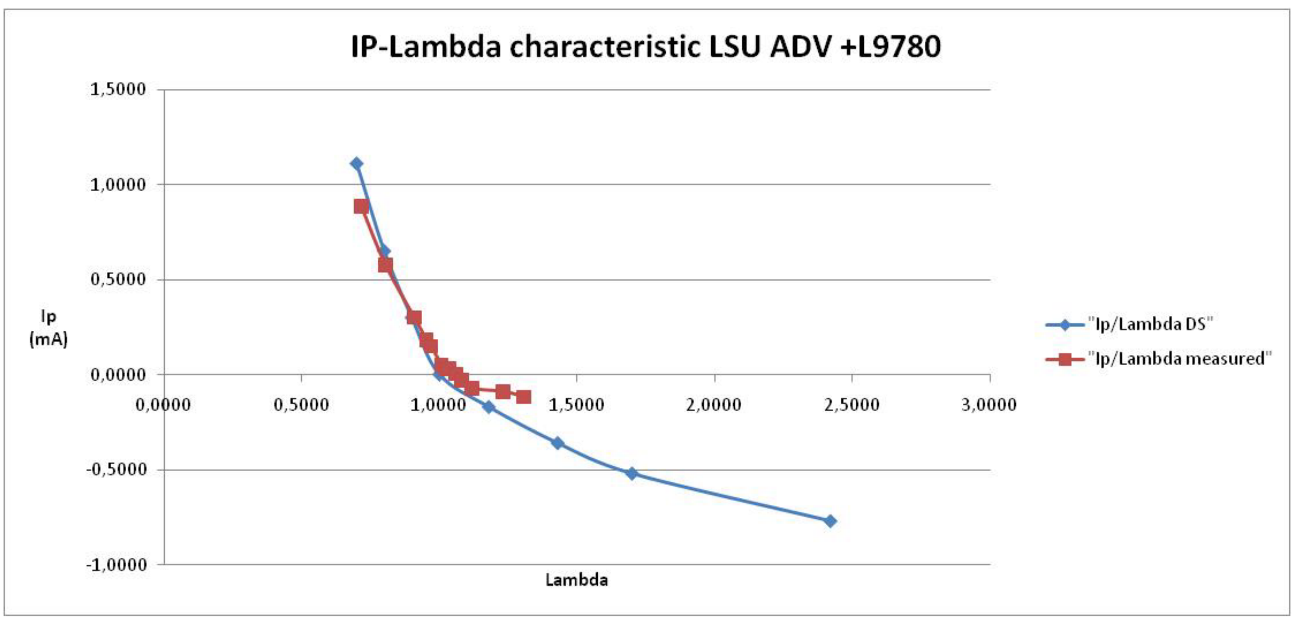
The following charts are a comparison between the Ip/Lambda characteristic present in the LSU 4.9 and LSU ADV DS and the one measured in the laboratory:

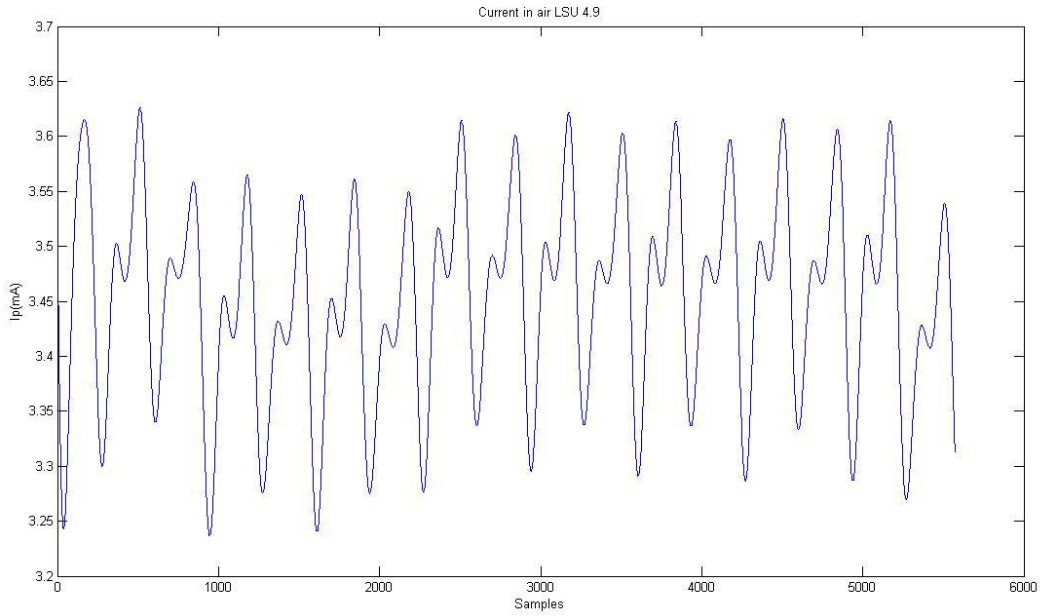


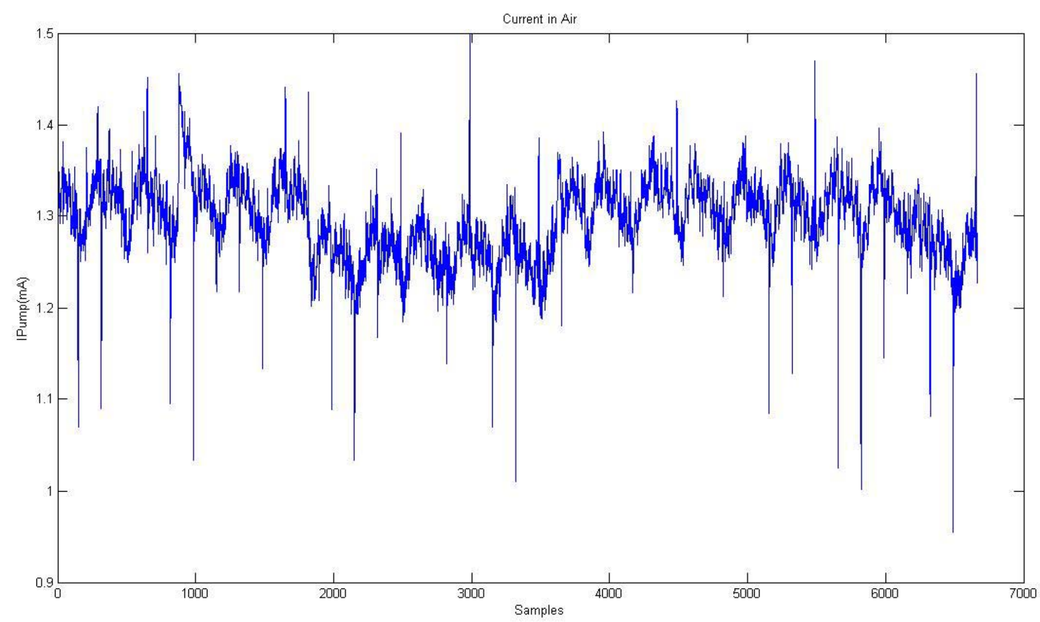


Output of Lambda Measurements in air

A test in air was especially carried out in order to evaluate the pump current necessary to control the sensor when it is in air.

The resulting control currents are shown in the following figures:





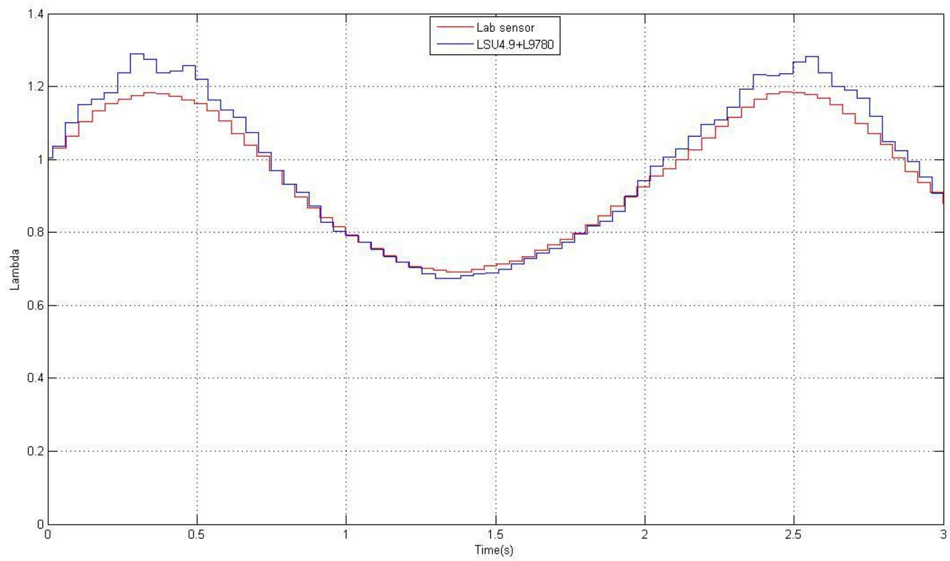
In average for LSU 4.9 the pumping current is 3,45 mA that results higher than the one certified in the datasheet. Bosch is executing some test in their Germany laboratory to check if this is due to some problem of the specific sensor sample. For LSU ADV the average current is 1.3 mA in accordance with the Datasheet value.

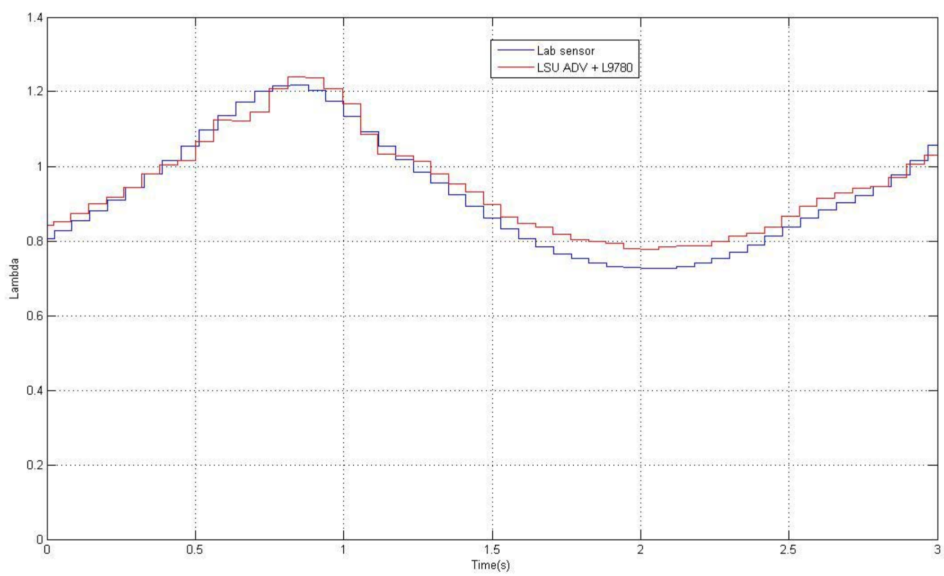
Dynamic Lambda Measurements

The goals of this test are:

- Measure lambda in transient condition
- Measure transition from $\lambda = 0.7$ to $\lambda = 1.2$
- Transition time is 3 seconds

In order to execute this test the value of injection time was varied automatically with a sinusoidal shape whose maximum and minimum value was chosen in accordance with the particular engine working condition (1500 rpm, 5% throttle opening).
In the following figures the results of the test for LSU 4.9 and LSU ADV:

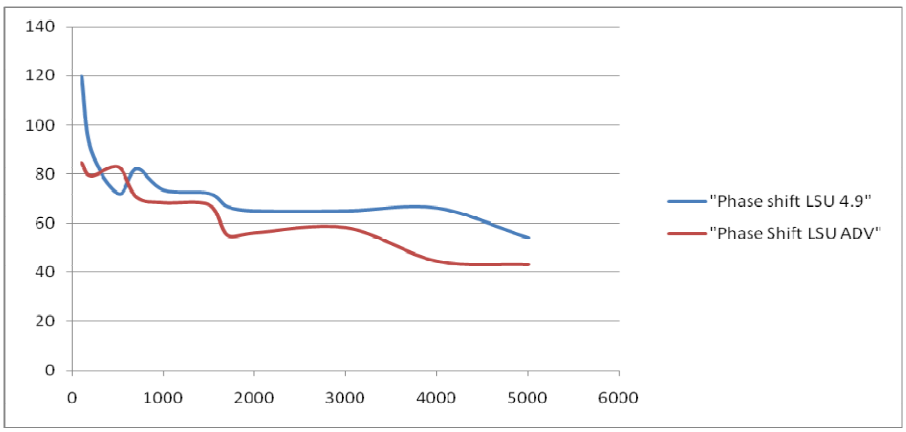




Sine wave injection test

In this test a sine wave across the reference cell node with the sensor connected will be applied. The sine wave frequency will span from 100 Hz to 5KHz and the signal amplitude will be 20mV The output of the system was mapped in order to observe the phase shift introduced from the system. The test was carried out in air.
In the following tables the phase shift for both LSU4.9 and LSU ADV sensors + L9780

LSU 4.9		
F(Hz)	dT (s)	Theta (°)
100	3,33E-03	119,88
200	1,25E-03	90
500	4,00E-04	72
700	3,26E-04	82,152
1000	2,04E-04	73,44
1500	1,34E-04	72,171
1700	1,09E-04	66,708
2000	9,03E-05	65,016
3000	6,02E-05	65,0052
4000	4,60E-05	66,24
5000	3,00E-05	54



LSU ADV		
F(Hz)	dT (s)	Theta (°)
100	2,35E-03	84,6
200	1,10E-03	79,2
500	4,60E-04	82,8
700	2,80E-04	70,56
1000	1,90E-04	68,4
1500	1,25E-04	67,5
1700	9,00E-05	55,08
2000	7,80E-05	56,16
3000	5,40E-05	58,32
4000	3,10E-05	44,64
5000	2,40E-05	43,2

Appendix A
Brief Description of the system used to make the tests

The engine under test was a four stroke, four cylinders, 1995cc gasoline engine. The engine has been installed in the ST test bench room at CNR-Naples in order to develop a prototypal ECU based on ST Power Drivers, Signal Conditioning and Logic Unit.

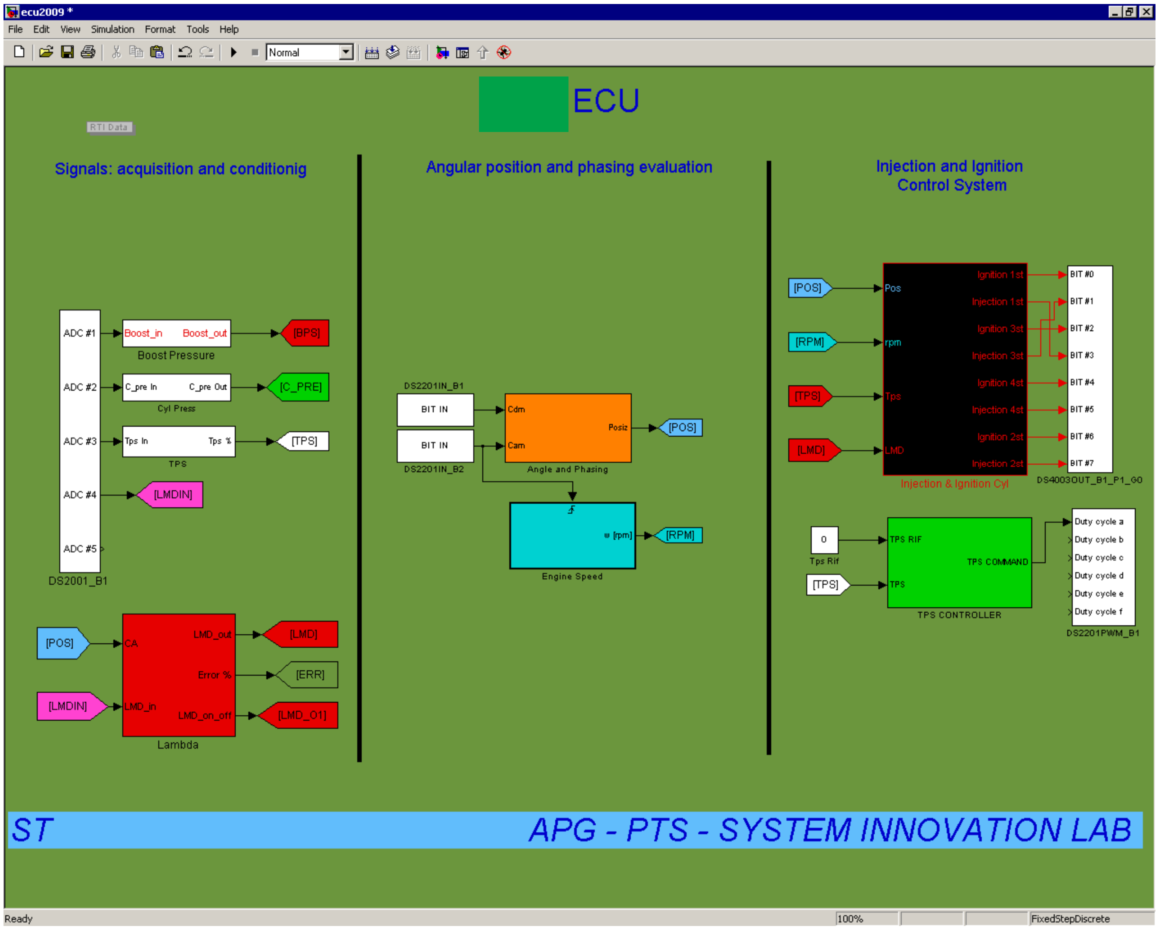
The main features of the engine under test were the following:
- Port Fuel Injection engine
- Four Ignition coils, one for each spark plug
- Catalytic converter with lambda sensor
- Throttle body with throttle motored with position sensor
- Crankshaft ferromagnetic ring provided with 60-2 teeth and pick up sensor for engine speed and engine angular position detection
- Cam sensor for phase detection
- IMAP sensor for intake air pressure and air temperature measurement
- In-cylinder pressure sensor

In order to test and calibrate the engine a dSPACE experiment has been developed. dSPACE is a rapid prototyping system which is able to test directly on the engine the control strategies. The Logic Control has been developed in Simulink environment and, thanks to a Synoptic interface, we were able to monitor every engine signals (engine position, engine speed, lambda value, boost pressure, throttle position etc…) and to set up for every engine operating point the engine inputs like injection duration and ignition timing (basic maps). The system also allowed to drive the actuators (fuel pump, injector, ignition coil, etc…). Regarding the motored throttle body, we set a closed loop control with a PI controller based on the throttle position sensor signal.

In the next two paragraphs, the meaning of each simulink block and the virtual instruments used in control desk layout (graphic interface) have been briefly explained.

Simulink Engine control model

The Simulink model has been divided in three groups of blocks, see figure 1:
- “Signals: acquisition and conditioning”
- “Angular position and phasing evaluation”
- “Injection and Ignition control System”



The intake manifold pressure, the in-cylinder pressure sensor signal, the lambda signal and throttle position signal were acquired using DS2001 dSPACE board, which is the board used for analog signals; on the contrary the engine speed sensor signal and Cam sensor signal were acquired by means of DS2201 dSPACE board, used for on/off signals. The project has been implemented in just one task that can be divided in several steps:

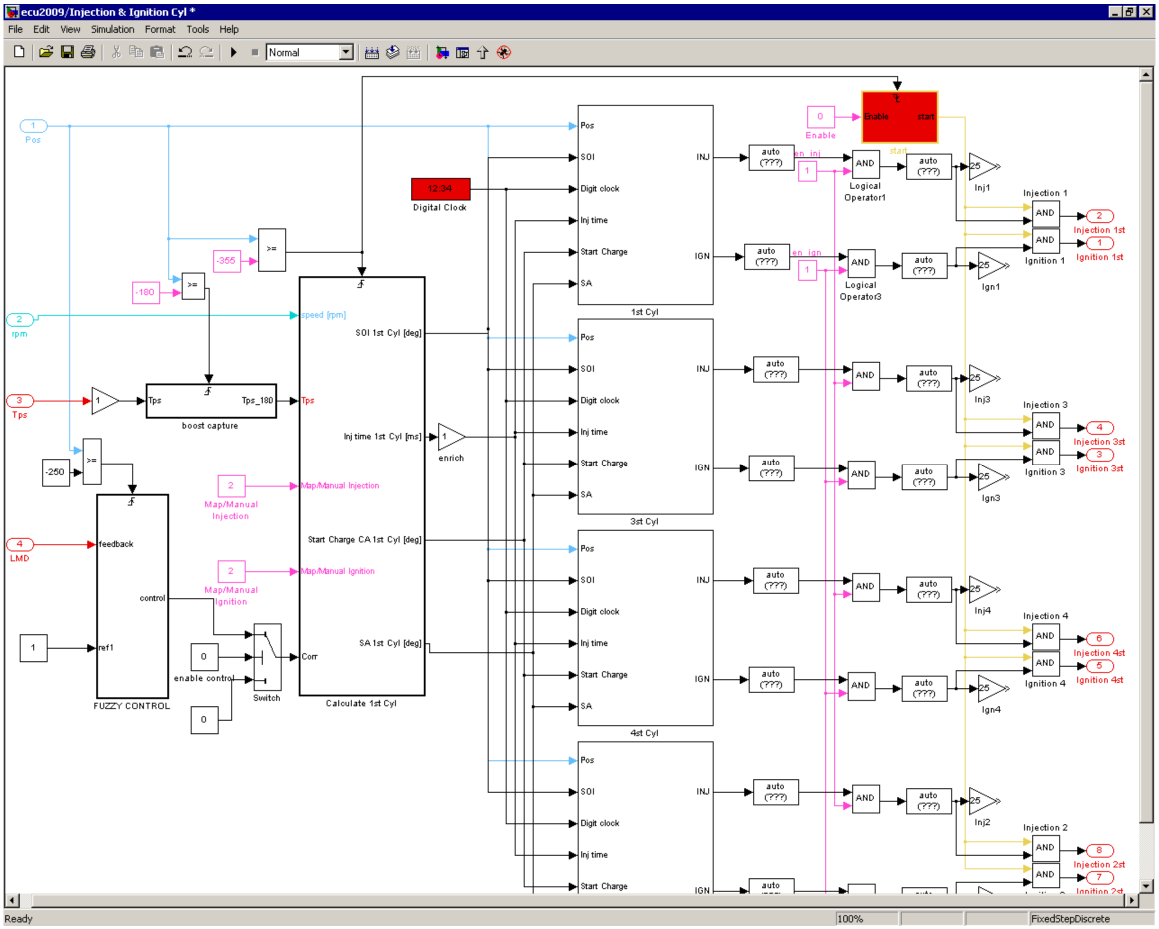
Step1: The ‘Angle and Phasing’ block uses the crankshaft speed sensor signal (BIT IN_B1) and cam sensor signal (BIT IN_B2). It calculates a relative engine absolute angular position (POS)

Step2: The “Engine Speed” block has as input the cam sensor signal and as output the engine speed.

Step3: In function of the engine operating point (engine speed and throttle position sensor), the ‘ECU’ block reads the injection time and spark advance from the basic maps for the four cylinders and provides the commands for the injectors and ignition coils through the DS4003 dSPACE board.

The Throttle Body is driven through DS2201PWM board in function of driver requiring and PI controller.

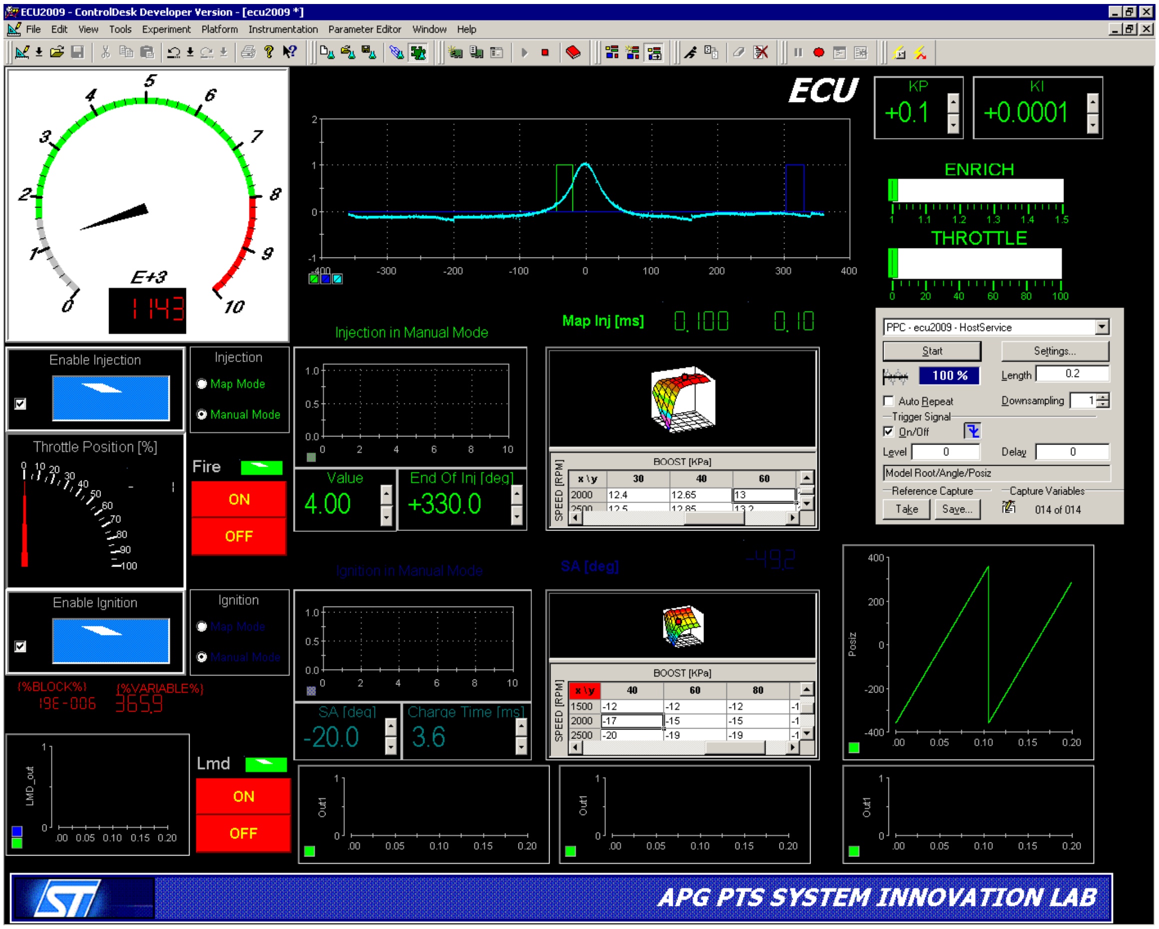
In the following picture, the ‘injection and ignition coil’ block is shown. The injection duration and ignition timing maps are referred to the first cylinder, the map values for the other cylinders are actuated with a delay depending on the cylinder firing sequence (1-3-4-2).



When the engine is warmed and the lambda sensor is ready to use, the ‘Lambda’ block filters the lambda signal, evaluates the error referred to the reference value (=1 typically), and gives these values to ‘ECU’ block that using a fuzzy controller modifies the injection duration in order to have a lambda = 1.

Engine ControlDesk interface

The User Interface Layout is the following:



The “Kp” and “Ki” numeric inputs (on the top-right of the layout) allow to set the PI controller for motored throttle body. The “THROTTLE” slider allows to modify the throttle opening.

The tachymeter in the picture shows the actual engine speed, the saw teeth on the bottom right of the Layout represents the actual engine angular position which varying between -360 CA and +360 CA.

On the *xy* plot at the top and centre of the Layout the in combustion pressure and the injection and ignition signals for the first cylinder are monitored on angular basis. The light blue signal is a typical in-combustion pressure signal shape when the engine run in motored condition. The green pulse is the ignition signal, determines the charge phasing of the coil, when (spark advance) this charge ends the spark plug fires.

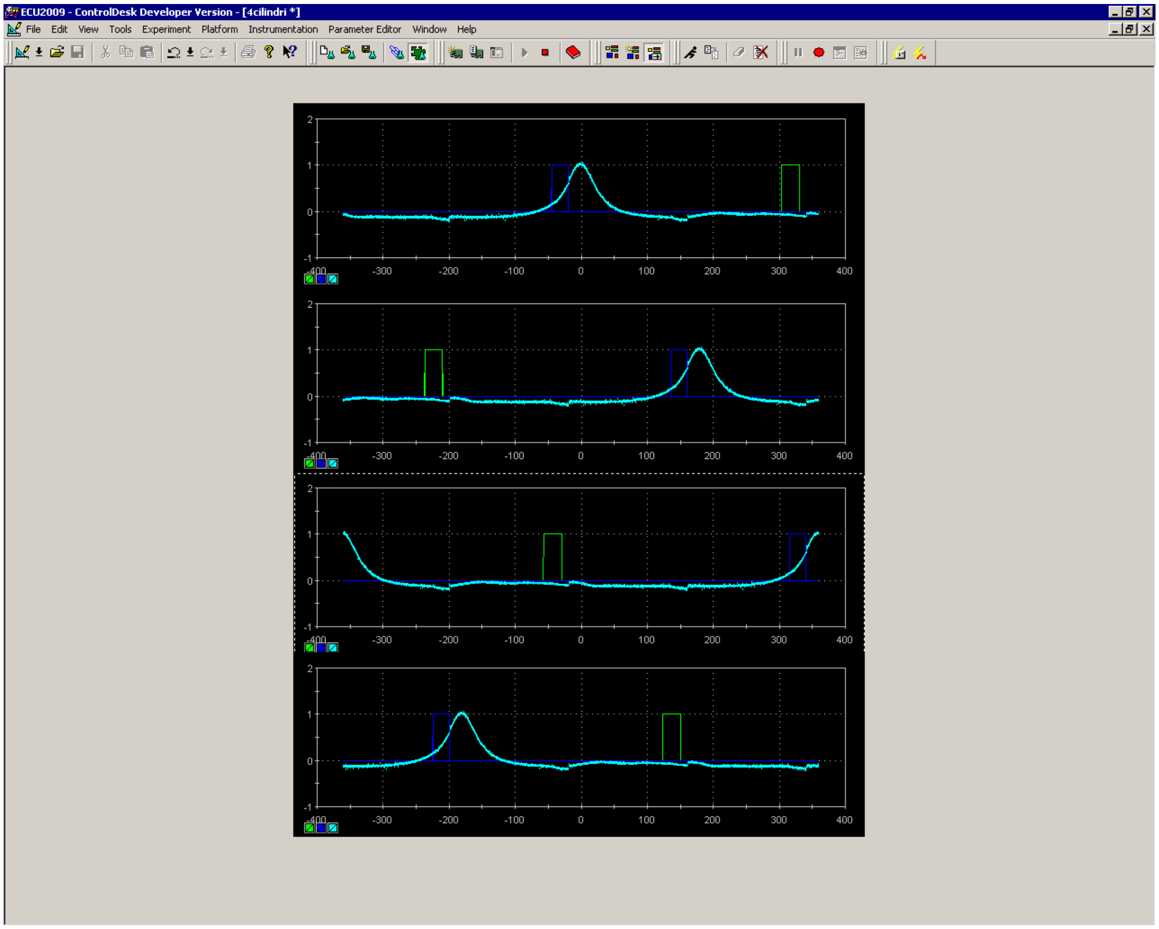
The blue signal is the injection signal, when the signal is high the injector is opened and the fuel is injected in the intake manifold. The amount of injected fuel depends on the injection duration signal and injector characteristics; the injection timing, for each engine operating, is fixed imposing that the end of injection point happens before intake valve opening. .

Thanks to ‘Enrich’ slider the operator is able to grew the quantity of fuel injected in percentage until 50, its necessary for a cold startup.

The two colored surfaces are the injection time and spark advance maps, thanks to the button on the left we can enable/disable the output and decide if to work in map or manual mode.

The manual mode can us to construct the maps because we can decide the injection time and spark advance in every engine point using the numeric input under the shape of signal (‘VALUE’ and ‘SA’). In this way we can create two look up table for injection time and Spark Advance and download them on the DSP of the dSPACE.

In the map mode the value of injection time and spark advance depend from throttle position sensor and engine revolution and are red from the look up tables.



In the picture below the same *xy* plot related the different cylinders in the sequence 1-3-4-2 are shown. The combustion pressure sensor is installed only in 1st cylinder camera, so the other shapes are obtained from this one with a delay of 180° from the previous.

Appendix B
List of test equipments in ST CNR-IM Engine testbench lab

In the following list the main instruments present in the engine testbench room of ST:

- Asynchronous Dynamometer AVL APA 100 (Power 120 kW);
- Test bed and instrumentation automation system AVL PUMA 6.5.2;
- Fast prototyping control system (dSpace);
- AVL Fuel Balance with fuel conditioner;
- Advanced Indicating System AVL Indiset 631;
- Air flow meter;
- Lambda measurement system LMS-2 produced by TAG Electronics;
- Exhaust gas analyzer AVL Digas .
- AVL in cylinder pressure sensor with amplifier.
- Optical encoder.