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Setup proposal for Validation Plan of ST L9780 with Bosch LSU-4.9 and LSU-ADV Wide Band Lambda Sensors

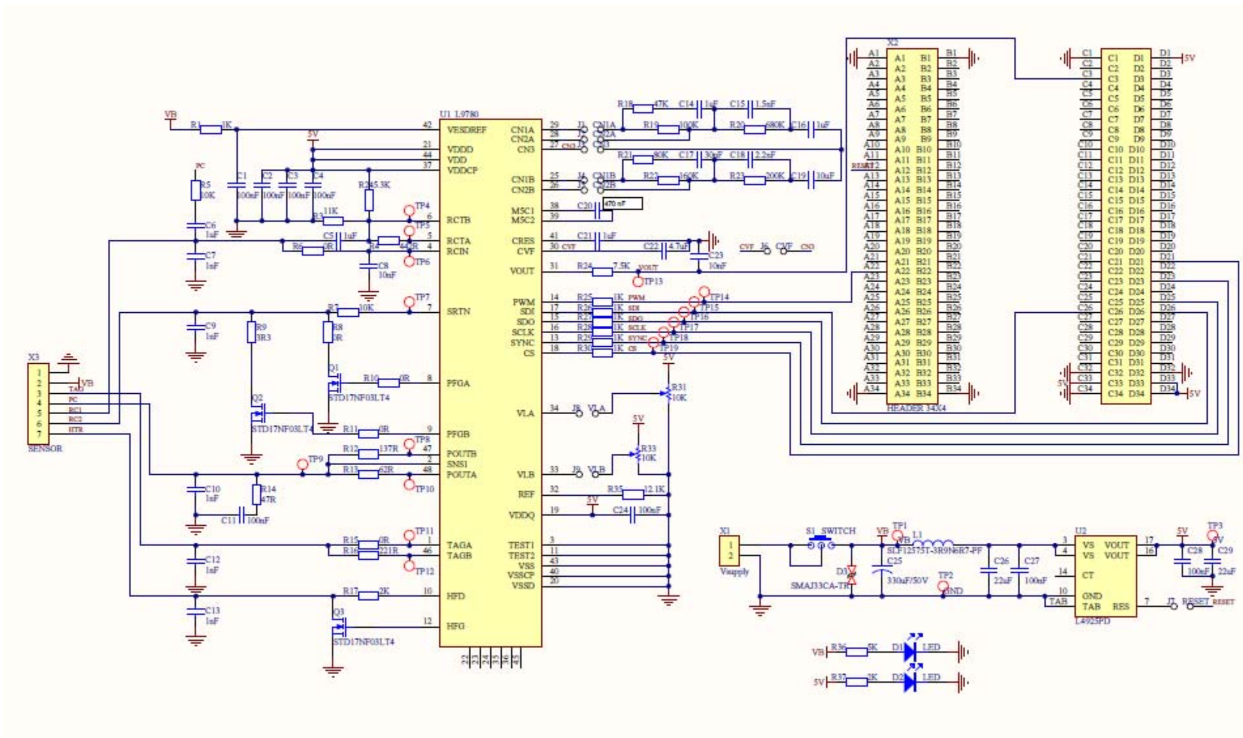
March 15, 2011

Background

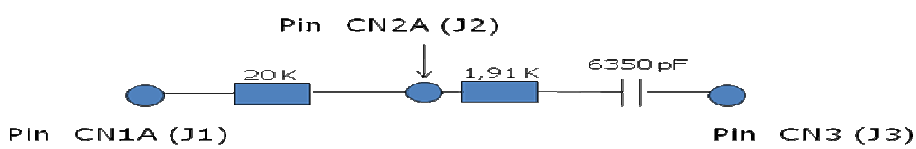
On the basis of the common validation plan of ST and Bosch to certify operation of the ST L9780 Wide Range Air/Fuel Sensor Interface IC with the Bosch LSU-4.9 and LSU-ADV Wide Range Lambda Sensors, ST has evaluated the most suitable setup for L9780 and Bench test. In the following of this document there is a description of this proposal submitted here for Bosch's review and approval.

Circuit setup proposal

In order to perform the tests will be used an evaluation board developed conjointly with the Shanghai application lab with the following schematic :



Considering the information coming from Bosch and Delphi regarding the compensation network for L9780 the following setup will be considered for both LSU4.9 and LSU ADV sensor:



The sensors will be connected to the board as described in the following table

LSU 4.9 pin	LSU ADV pin	L9780 Input	Board connector
1 IP (Red)	1 IP (Red)	OUT1	PC
5 CalR (Green)	-	TG1	TAG
2 IPN (yellow)	2 IPN (yellow)	SR	RC2
6 RE (black)	6 RE (black)	RCT1	RC1
3 H- (white)	3 H- (white)	HD	HTR
4 H+ (grey)	4 H+ (grey)	VB	VB

L9780 SPI setup

The L9780 contemplate several SPI setup in order to customize the behavior of the control loop and of the safety and diagnostic feature. In this section will be deeply discussed the proposed setup.

Considering the Bosch LSU4.9 application diagram on the datasheet we understood that the correct resistor to be used as TAGA resistor is 0 ohm that corresponds on the Shanghai board to R13. This means that the correct setting in the SPI is:
BIT 55 (TGEN) = 1
BIT 53 (VCCSOUT) = 0

Regarding the LSU ADV, considering that this kind of sensor doesn't have a TAG resistor the correct setup is:

BIT 55 (TGEN) = 0
BIT 53 (VCCSOUT) = 0

The integrator capacitor value is related to the loopback stability and then cannot be varied without taking into account the mounted sensor or the sensor itself can be damaged. The correct value of capacitance that need be used for ensure the stability of the loopback is related to the RS value where RS= Rcs(OUT1)//(Rf(TG1)+RC). Rcs is the series resistor on OUT1 pin of L9780, in our case is 61,9 ohm (as the LSU4.9 DS stated), Rf(TG1)=0 as discussed before and RC is the sensor resistor between PIN5(TG1) and PIN1(OUT1), in our case RC=133,8 ohm for LSU4.9 sensor. Considering these values Rs=42,32 ohm. Considering table 6 of L9780 datasheet the correct Cint value is Cint=6pF, so the correct setting is:

Bit 39-34 (VCCSCAP) = 000110

In the case of LSU ADV, taking into account that there is not the TAG resistor, the Rs=Rcs(POUTA)=61,9 ohm, and then the correct Cint value is Cint=9pF so the correct setting is:

Bit 39-34 (VCCSCAP) = 001001

The device is able to clamp the voltage on SNS to a selectable voltage CL1 or CL2. This is done in case of saturation of the pump cell. In our case, as suggested by Bosch, will be considered a symmetrical clamping of value CL1=2V selected by the trimmer R31 in the board schematic. The SPI stetting will be the following:
Bit 50 (CLAMPEN)=1
Bit 49 (CLAMPPCL)=0
Bit 48 (CLAMPSIM)= 0
This setup is valid both for LSU4.9 and LSU ADV. In the following, if not especially asserted in the following, all the setting will be considered common for both the LSU 4.9 and LSU ADV sensors.

If not especially needed in the testing phase the INRC pull-down current will be switched off for both sensor setup. The purge current will be enabled during normal operation with a value of -14 uA, so the SPI setting is:

Bit 58 (INRCPD) = 0
Bit 46-43 (CCS) =0001

Similarly If not especially needed in the testing phase the VCCS pull down resistor will be not enabled in normal operation condition. The SPI setting is:

Bit 52 (VCCSPD) = 0

The compensation network described in the previous paragraph will be mounted on the channel A of L9780, consequently the SPI setup will be:

Bit 51 (COMPSEL) = 0

The reference cell amplifier gain will be set to the value 4.2 so the corresponding SPI setup will be:

Bit 56 (INRCGAIN) = 0

The gain for scaling and FVOUT amplifier will be set to 12 that correspond to an SPI setup:

Bit 42-40 (SAMP) = 111

Regarding the measurement timing, will be selected a free running mode so the timing state machine is continuously running. The SPI setup is:

BIT 23 (SNC) = 0

Considering the state machine timing diagram on the L9780 Datasheet Figure 7 we will consider the following setup considering that Tosc is 250 ns using an internal oscillator frequency of 4 MHz:

- Measurement clock period: 40000 Tosc --> SPI setup Bit 33-32 (MCP) = 00
- RCT1 switch time pulse duration (tR) = 25 Tosc --> SPI setup Bit 30-24 (ITPT)= 0011001 (suggest by Delphi)
- RCT1 bandgap switch time pulse duration (tB) = 42 Tosc --> SPI setup Bit 22-16 (CBT) = 0101010 (suggest by Delphi)
- INRC switch time pulse duration (tINRC) = 0 --> SPI setup Bit 10-8 (ISPT)=000

The L9780 has several setups for protection and diagnostic of the sensor and the heater portion. In our tests the setup will be the following:

- Short to GND diagnostic on pin INRC enabled --> SPI setup Bit 57 (STGINRC) = 0 in the starting phase and then 1 after a little delay when VCCS (bit 54) is asserted to 1. This procedure is needed to avoid false INRC short to Ground diagnose (suggest by Delphi and confirmed by experiment).
- Heather short to battery threshold = 250 mV --> SPI setup Bit 31 (STBHTH) = 0
- Heather short to battery fault time duration = 80 Tosc --> SPI setup Bit 12-11 (STBHFT) = 00
- Protection FET on Channel 2 disabled --> SPI setup Bit 7 (PG2EN) = 0
- Protection FET on Channel 1 Enabled --> SPI setup Bit 6 (PG1EN) = 1
- Don't clear latched fault --> SPI setup Bit 47 (CLEARFLT) = 0

As content of SO register we will choose the status register in normal operation and then the SPI setting is the following:

Bit 59 (REG) = 0

The L9780 have a special part of the SPI word (bit 15 and 14) used to check the integrity of SPI data channel, these bits should be always Bit15 (CB1)=1 and Bit 14 (CB0) =0, if is not that means that a fault is present.

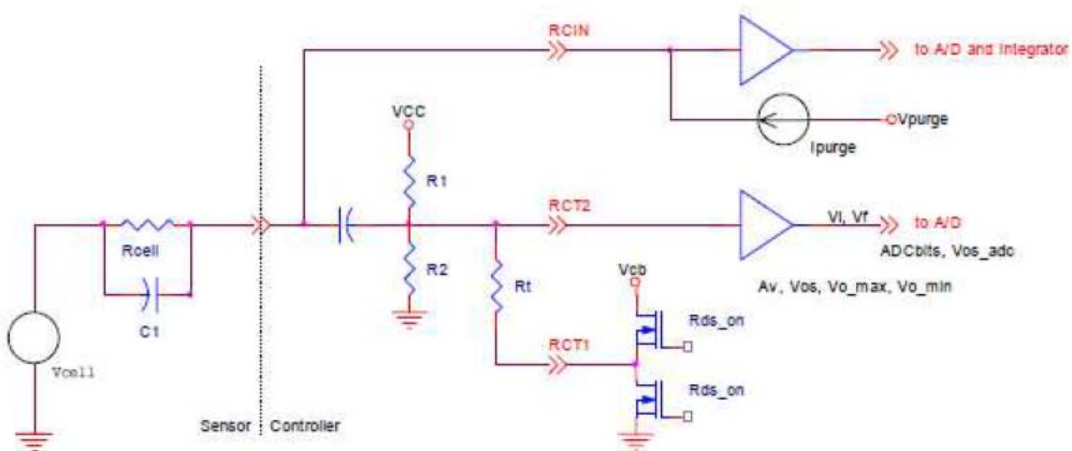
The last bit to be discussed is Bit 54 (VCCSEN) that need be considered carefully. This bit enable the functioning of VCCS so, in fact, enables all the operation needed for the lambda sensor control and measurement of lambda value. Considering the DS of Lambda sensor for safe operation the VCCS should be activated only if the internal resistance is <= 1Kohm. Our SW interface is able to measure and control the value of the internal sensor resistance using the heating in a closed loop configuration. Our operative target will be internal resistance of Lambda sensor = 300 ohm. Considering that we are not interested in a fast switch on of the sensor we will switch on VCCS only if the internal resistance of the sensor is around 300 ohm.

In conclusion the SPI control word will be respectively:

- 0x028407187F7F8040 for LSU 4.9
- 0x020407247F7F8040 for LSU ADV

Reference cell impedance measurement

The L9780 is able to make measurement in order to evaluate the impedance of the reference cell. Referring to the DS of L9780 and to the previous board schematic we consider the following setup:



Where:
Rcell=Reference cell impedance
Rt=Pull-down test resistor
R1&R2=Bias network
Rds_on=on-resistance of test switch
Av=Gain of ref cell amplifier
Vos=output offset of ref cell amplifier
Vo_max, Vo_min=Ref cell amplifier saturation voltage
ADCbits, Vos_adc=A/D conversion resolution and error

The Rcell is calculated with the following formula automatically by our interface SW:

$$R_{cell(calc)} = \frac{K_{Rdiv} * K_{Rt}\left(\frac{ADC_i - ADC_f}{ADC_f}\right)}{K_{Rdiv} - K_{Rt}\left(\frac{ADC_i - ADC_f}{ADC_f}\right)}$$

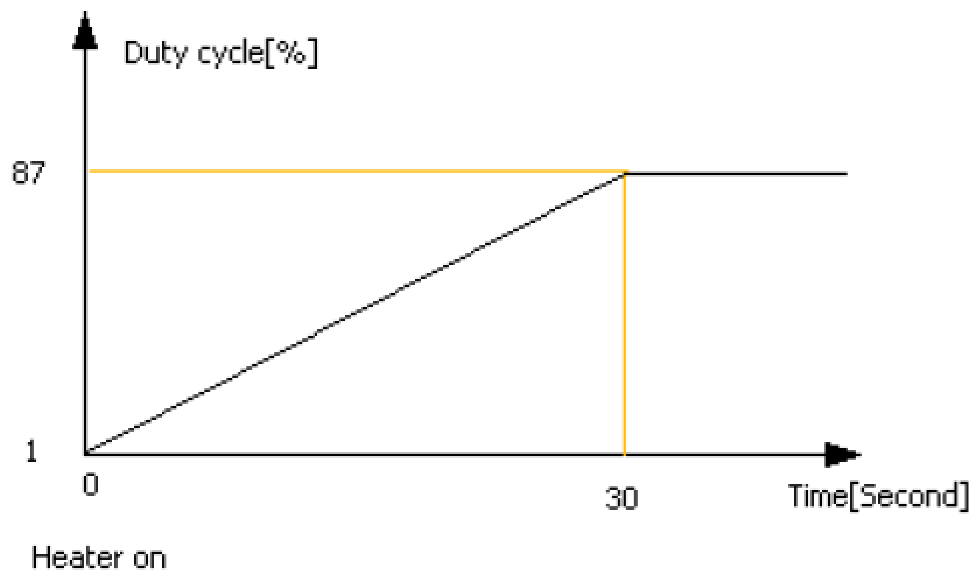
Where:

$$K_{Rt} = (R_t + R_{ds\_on})_{nominal}$$

$$K_{Rdiv} = \left(\frac{R_1 * R_2}{R_1 + R_2}\right)_{nominal}$$

Heating control

Our SW has the possibility to control in closed loop, varying the PWM duty cycle of the signal on the heather, the reference cell impedance. The SW guaranties a soft heating startup following the figure below:



Setting the heater soft start duration the PWM duty cycle changes from 1% to the dedicated duty cycle, for Example, if the dedicated duty cycle is 87%, and the soft Start duration is 30 Second, then the PWM duty cycle can be changed as in figure when heater is switched on(from 1% to 87% within 30 second). Considering the info in the lambda sensors DS we will use exactly the timing in figure in order to respect a ramp rate < 0,4V/s. The PWM frequency can be adjusted in a range of 100-1000 Hz. In our experiment we will use a 200Hz frequency.

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 1 Hz to 10KHz and the signal amplitude will span from 50mV to 100 mV. The output of the integrator will be mapped in order to observe the decaying at the increasing of the frequency. The test will be carry out in air.