Front End Manual

Content

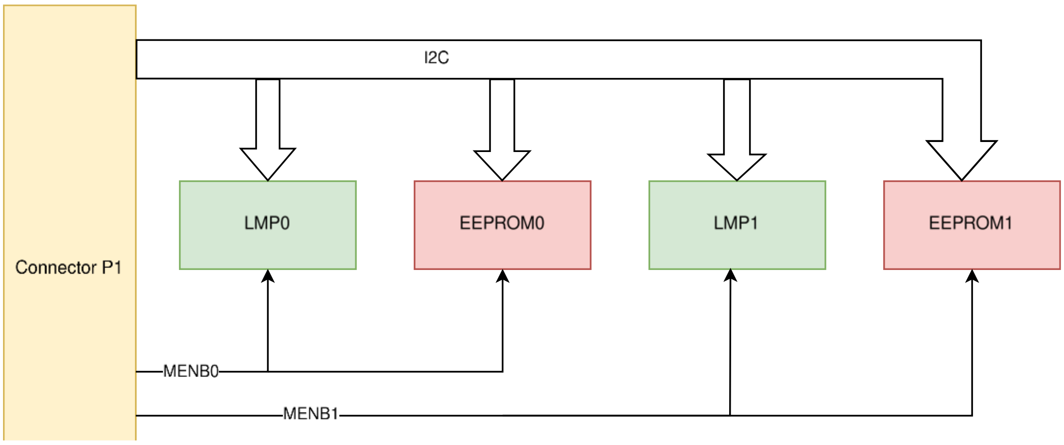
MEMBRAPOR AG, Birkenweg 2, 8304 Wallisellen, Switzerland
Phone +41 43 311 72 00 | Fax +41 43 311 72 01 |
E-Mail: sensor@membrapor.ch | Website: www.membrapor.ch

1. Overview

The Front End hardware consists of two Potentiostat devices for low-power chemical sensing applications as well as two EEPROM's, that can be used to store calibration- and user-settings.

All devices can be configured using an I2C-bus.

1.1. Blockdiagram



MEMBRAPOR AG, Birkenweg 2, 8304 Wallisellen, Switzerland
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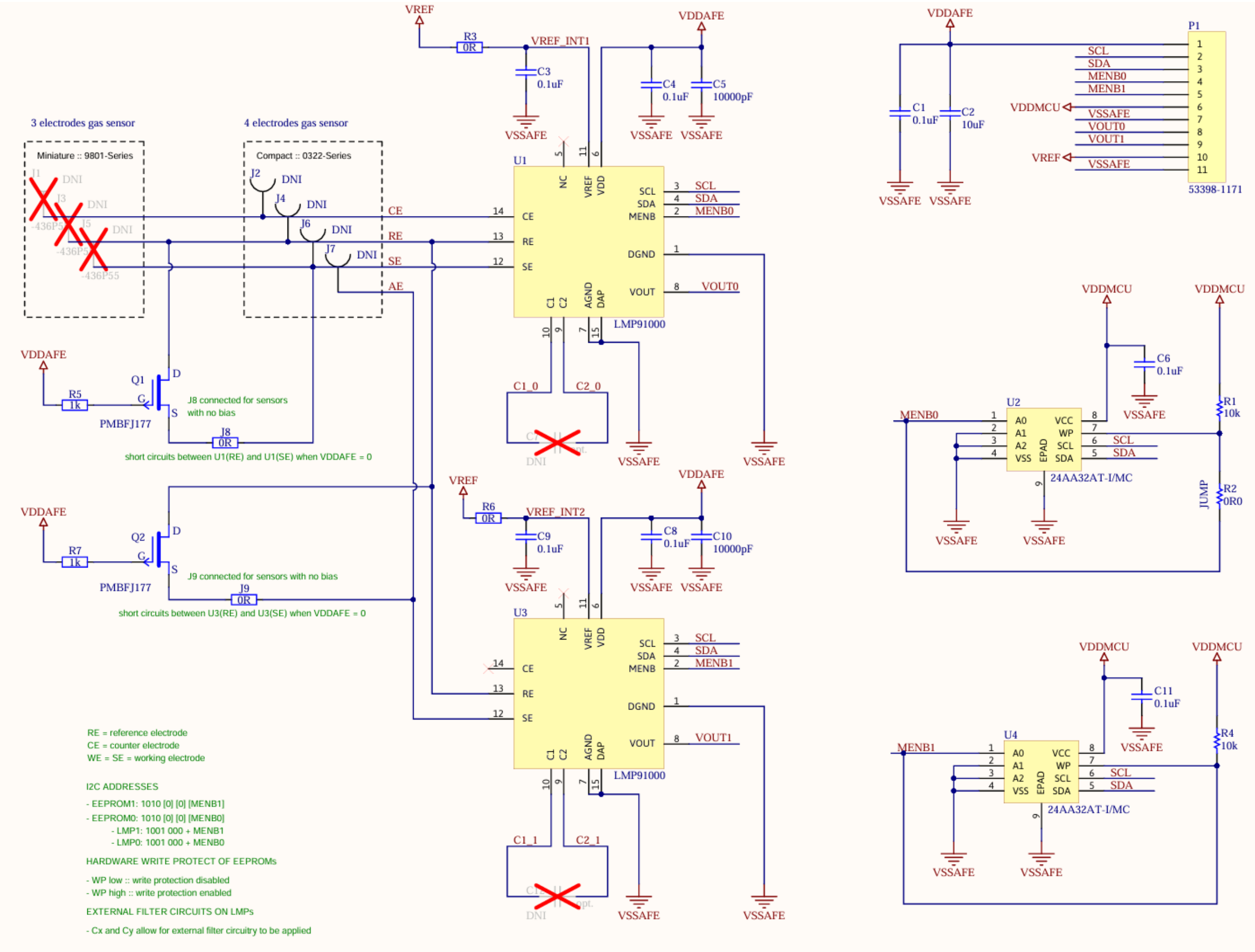
E-Mail: sensor@membrapor.ch | Website: www.membrapor.ch

1.2. Electrical Schematic



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1.3. Connector Pin-out

Pin	Name	Color	Description
1	VDDAFE	RED	Supply voltage for Front End
2	SCL	BROWN	Clock for I2C bus (max. clock-frequency: 100kHz)
3	SDA	GREEN	Data for I2C bus
4	MENB0	YELLOW	Selection Pin for LMP's and EEPROMS
5	MENB1	BLUE	Selection Pin for LMP's and EEPROMS
6	VDDMCU	RED	Supply voltage for digital components (EEPROM)
7	VSSAFE	BLACK	Ground for Front End
8	VOUT0	PURPLE	Analog output voltage of LMP0
9	VOUT1	GRAY	Analog output voltage of LMP1
10	VREF	WHITE	Reference voltage for Front End (typ. 2.5V)
11	VSSAFE	BLACK	Ground for Front End

1.4. Supply voltage

Name	Range (V)	Typical value (V)
VDDAFE	2.7 - 5.25	3.3
VDDMCU	1.7 - 5.5	3.3

1.5. Output voltage

Name	Range (V)
VOUT0	0 ≤ VOUT0 ≤ VDDAFE
VOUT1	0 ≤ VOUT1 ≤ VDDAFE

2. I2C-Interface

Both EEPROMs as well as the Front End Potentionstats are connected to the same I2C-bus. To select which LMP to communicate with, the signals MENB0 and MENB1 are used:

Table 1: LMP selection

MENB1	MENB0	Active LMP
0	0	Invalid configuration
0	1	LMP1 is selected
1	0	LMP0 is selected
1	1	Neither LMP is selected

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The same signals are also used to select the EEPROM. Additionally, MENB0 and MENB1 are used to protect the EEPROM from unintentional write access:

Table 2: EEPROM selection

MENB0	MENB1	EEPROM0	EEPROM1
0	0	Invalid configuration	
0	1	I2C-address 0x50 (writable)	I2C-address 0x51 (write protected)
1	0	I2C-address 0x51 (write protected)	I2C-address 0x50 (writable)
1	1	Invalid configuration (both EEPROM's are write protected)	

Please Note that the maximum I2C clock-frequency is limited by the LMP's to 100kHz.

2.1. LMP communication

In order to read or write from an LMP register, the following procedure has to be followed:

1. Set MENBx low (see Table 1: LMP selection)
2. Generate a start-condition on the I2C-bus, followed by the 7 Bit slave-address of the LMP (0x90) and the read/write-bit set to low.
3. Transmit the internal register address of the register to be read/written (see chapter 4.b).
4. Depending on whether it's a read or write access:
    a. Write-access: send the register-value to be written
    b. Read-access: generate a Repeat-Start-Condition on the bus, followed by the 7 bit slave-address with the read/write-bit set to high, and read the register-value from the LMP.

2.2. EEPROM communication

In order to read or write from/to an EEPROM, the following procedure has to be followed:

To read from an EEPROM:

1. Set MENBx low (see Table 2: EEPROM selection)
2. Generate a start condition on the I2C bus, followed by the 7 Bit slave address of the EEPROM (0x50 or 0x51) and the read/write-bit set to low.
3. Send the address of the byte(s) you wish to read, with the MSB first (example: to read from address 0x204 send the bytes 0x02, 0x04)
4. Generate a Repeat-Start-Condition on the bus, again followed by the 7 bit slave-address with the read/write bit set to 1 (indicating read access)
5. Read the desired number of bytes from the EEPROM
6. Generate stop-condition on the bus.

MEMBRAPOR AG, Birkenweg 2, 8304 Wallisellen, Switzerland
Phone +41 43 311 72 00 | Fax +41 43 311 72 01 |
E-Mail: sensor@membrapor.ch | Website: www.membrapor.ch

To write to an EEPROM:

1. Set MENBx low (see Table 2: EEPROM selection)
2. Generate a start condition on the I2C bus, followed by the 7 Bit slave address of the EEPROM (0x50 or 0x51) and the read/write-bit set to low.
3. Send the address of the byte(s) you wish to write, with the MSB first (example: to write to address 0x204 send the bytes 0x02, 0x04)
4. Send the desired number of bytes to write to the EEPROM
5. Generate stop-condition on the bus.

Please Note the following restriction when writing to the EEPROM:
The EEPROM has an internal page buffer of 32 bytes, and a write must not span a page boundary. This means that the maximum number of bytes that can be written at once is 32.
Additionally, if you want to write, for example, the bytes from address 20 to 40, two writes are necessary: the first from address 20 to 31, the second from address 32 to 40.

3. LMP Registers

Both LMP91000 Potentiostats provide the following registers:

Address	Name	Power on default	Access	Lockable?
0x00	STATUS	0x00	Read-only	No
0x01	LOCK	0x01	R/W	No
0x02 … 0x09	Reserved	n/a	n/a	n/a
0x10	TIACN	0x03	R/W	Yes
0x11	REFCN	0x20	R/W	Yes
0x12	MODECN	0x00	R/W	No
0x13 … 0xFF	reserved	n/a	n/a	n/a

3.1. STATUS – Address 0x00

The status bit is an indication of the LMP91000's power-on status. If its readback is "0", the LMP91000 is not ready to accept other I2C commands.

Bit	Name	Function
[7:1]	RESERVED	
0	STATUS	Status of Device 0 Not Ready (default) 1 Ready

MEMBRAPOR AG, Birkenweg 2, 8304 Wallisellen, Switzerland
Phone +41 43 311 72 00 | Fax +41 43 311 72 01 |
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3.2. LOCK – Address 0x01

The lock bit enables and disables the writing of the TIACN and the REFCN registers. In order to change the content of the TIACN and the REFCN registers the lock bit needs to be set to “0”.

Bit	Name	Function
[7:1]	RESERVED	
0	LOCK	Write protection 0 Registers 0x10, 0x11 in write mode 1 Registers 0x10, 0x11 in read only mode (default)

3.3. TIACN – Address 0x10

The parameters in the TIA control register allow the configuration of the transimpedance gain (RTIA) and the load resistance (RLoad).

Bit	Name	Function
[7:5]	RESERVED	
[4:2]	TIA_GAIN	TIA feedback resistance selection **000 External resistance (default)** 001 2.75kΩ 010 3.5kΩ 011 7kΩ 100 14kΩ 101 35kΩ 110 120kΩ 111 350kΩ
[1:0]	RLOAD	RLoad selection 00 10Ω 01 33Ω 10 50Ω **11 100Ω (default)**

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3.4. REFCN – Address 0x11

The parameters in the Reference control register allow the configuration of the Internal zero, Bias and Reference source. When the Reference source is external, the reference is provided by a reference voltage connected to the VREF pin. In this condition the Internal Zero and the Bias voltage are defined as a percentage of VREF voltage instead of the supply voltage.

Bit	Name	Function
7	REF_SOURCE	Reference voltage source selection **0 Internal (default)** 1 external
[6:5]	INT_Z	Internal zero selection (Percentage of the source reference) 00 20% **01 50% (default)** 10 67% 11 Internal zero circuitry bypassed (only in O2 ground referred measurement)
4	BIAS_SIGN	Selection of the Bias polarity **0 Negative (VWE – VRE)<0V (default)** 1 Positive (VWE –VRE)>0V
[3:0]	BIAS	BIAS selection (Percentage of the source reference) **0000 0% (default)** 0001 1% 0010 2% 0011 4% 0100 6% 0101 8% 0110 10% 0111 12% 1000 14% 1001 16% 1010 18% 1011 20% 1100 22% 1101 24%

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3.5. MODECN – Address 0x12

The Parameters in the Mode register allow the configuration of the Operation Mode of the LMP91000.

Bit	Name	Function
7	FET_SHORT	Shorting FET feature **0 Disabled (default)** 1 Enabled
[6:3]	RESERVED	
[2:0]	OP_MODE	Mode of Operation selection **000 Deep Sleep (default)** 001 2-lead ground referred galvanic cell 010 Standby 011 3-lead amperometric cell 110 Temperature measurement (TIA OFF) 111 Temperature measurement (TIA ON)

4. EEPROM

Each Front End contains two EEPROMS with 32kbits (4kBytes) each. They can be used to store calibration or configuration data for the host MCU. The Front End itself, i.e. the Potentiostats do not make use of the EEPROM's themselves.

Please note that certain address ranges of the EEPROM's contain manufacturer programmed calibration data.

Reserved Range for EEPROM0 and EEPROM1:

From	To	Content
0x00	0x200	Factory calibration data

4.1. Memory map of EEPROM 0

Address	Content
0x00	TIACN of LMP0
0x01	TIACN of LMP1
0x02	REFCN of LMP0
0x03	REFCN of LMP1
0x04	MODECN of LMP0
0x05	MODECN of LMP1
0x06	Number of pins (3 or 4 electrodes)
0x07	Selection of ppm calculation
0x08	Current loop unit
0x09	Ppm @ 20mA
0x0d	Loop-current at 20mA
0x11	Enable buzzer-alarm
0x12	Alarm trigger-value

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0x16	External reference voltage
0x80	Calibration: IOut LMP0 @ GA0 and GB0
0x84	Calibration: IOut LMP1 @ GA0 and GB0
0x88	Calibration: IOut LMP0 @ GA1 and GB1
0x8C	Calibration: IOut LMP1 @ GA1 and GB1
0x90	Calibration: IOut LMP0 @ GA2 and GB2
0x94	Calibration: IOut LMP1 @ GA2 and GB2
0x98	Calibration: Temperature
0x9C	Calibration: GA1 in ppm
0xA0	Calibration: GA2 in ppm
0xA4	Calibration: GB2 in ppm
0xC3	Calibration: Temp.-compensation TCZ enable
0xC4	Calibration: Temp.-compensation TCS enable
0xC5	Calibration: Temp.-compensation TCG enable
0xC6	Calibration: Temp.-compensation TCL enable
0xC7	Calibration: TCZ coefficient a0
0xCB	Calibration: TCZ coefficient a1
0xCF	Calibration: TCZ coefficient a2
0xD3	Calibration: TCZ coefficient a3
0xD7	Calibration: TCS coefficient a0
0xDB	Calibration: TCS coefficient a1
0xDF	Calibration: TCS coefficient a2
0xE3	Calibration: TCS coefficient a3
0xE7	Calibration: TCG coefficient a0
0xEB	Calibration: TCG coefficient a1
0xEF	Calibration: TCG coefficient a2
0xF3	Calibration: TCG coefficient a3

1.1. Memory map of EEPROM 1

Address	Content
0x40	TIACN of LMP0
0x41	TIACN of LMP1
0x42	REFCN of LMP0
0x43	REFCN of LMP1
0x44	MODECN of LMP0
0x45	MODECN of LMP1
0x46	Number of pins (3 or 4 electrodes)
0x47	Selection of ppm calculation
0x48	Current loop unit
0x49	ppm @ 20mA
0x4d	Loop-current at 20mA
0x51	Enable buzzer-alarm
0x52	Alarm trigger-value
0x56	External reference voltage

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0x10C	Calibration: IOut LMP0 @ GA0 and GB0
0x110	Calibration: IOut LMP1 @ GA0 and GB0
0x114	Calibration: IOut LMP0 @ GA1 and GB1
0x118	Calibration: IOut LMP1 @ GA1 and GB1
0x11C	Calibration: IOut LMP0 @ GA2 and GB2
0x120	Calibration: IOut LMP1 @ GA2 and GB2
0x124	Calibration: Temperature
0x128	Calibration: GA1 in ppm
0x12C	Calibration: GA2 in ppm
0x130	Calibration: GB2 in ppm
0x14F	Calibration: Temp.-compensation TCZ enable
0x150	Calibration: Temp.-compensation TCS enable
0x151	Calibration: Temp.-compensation TCG enable
0x152	Calibration: Temp.-compensation TCL enable
0x153	Calibration: TCZ coefficient a0
0x157	Calibration: TCZ coefficient a1
0x15B	Calibration: TCZ coefficient a2
0x15F	Calibration: TCZ coefficient a3
0x163	Calibration: TCS coefficient a0
0x167	Calibration: TCS coefficient a1
0x16B	Calibration: TCS coefficient a2
0x16F	Calibration: TCS coefficient a3
0x173	Calibration: TCG coefficient a0
0x177	Calibration: TCG coefficient a1
0x17B	Calibration: TCG coefficient a2
0x17F	Calibration: TCG coefficient a3

5. Sample equations

5.1. Gain resistance selection

Assuming

- Measurement concentration range = 0 … 10 ppm → i_sensor = 0 … 5 uA, and
- The highest allowed output voltage, max(U_{out}) = 2.5 V
- Internal zero / bias = 0.5 V

The LMP91000 features the selectable gain resistor values stated in section 3.3. The relation between output voltage, U_{out}, and gain resistance, R_{gain}, is described by

$$U_{out} = U_0 + R_{gain} \cdot (i_0 + i_{sensor}) \rightarrow R_{gain} \leq \frac{U_{out,max} - U_0}{i_{sensor,max} + i_{0,max}}$$

where U_0 is the bias and i_0 is the baseline current.

MEMBRAPOR AG, Birkenweg 2, 8304 Wallisellen, Switzerland
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Starting with the assumption of a small i_0, the ideal gain resistor that maximizes sensitivity while keeping the voltage within specifications is

$$R_{gain} \leq \frac{2.5\ \mathrm{V} - 0.5\ \mathrm{V}}{5\ \cdot 10^{-6}\mathrm{A}} = 400\ \mathrm{k\Omega}$$

The nearest lower gain resistance is 350 kΩ.

For a more precisely set gain resistance, taking i_0 into account, we recommend measuring the output voltage for two gain resistances and then computing the baseline current

$$U_1 = U_0 + R_1 i_0$$

$$U_2 = U_0 + R_2 i_0$$

$$\rightarrow$$

$$i_0 = \frac{U_2 - U_1}{R_2 - R_1}$$

And subsequently calculate

$$R_{gain} \leq \frac{2.5\ \mathrm{V} - 0.5\ \mathrm{V}}{5\ \cdot 10^{-6}\mathrm{A} + \mathrm{i}_0}$$

5.2. Calculating ppm with three electrodes – Calc_3

Formula	**Explanation**
$ppm = \left(\frac{I_s - I_{s,0}}{a}\right) \cdot TCS(T) + TCZ(T)$	Calculation of the gas concentration in 3-electrode operation.
$a = \frac{I_{s,1} - I_{s,0}}{GA_1}$	Calculation of the sensitivity.

Expression	**Description**	**Source**
I_s	Current at the sensing electrode (sensing)	Measuring-Signal
$I_{s,0}$	Baseline of the sensing electrode	Calibration zero point
$I_{s,1}$	Current at the sensing electrode during exposure with calibration gas	Calibration point 1
a	Sensitivity of the sensing electrode	Calibration point 1
GA_1	Concentration of the calibration gas A	Calibration point 1

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$TCS(T)$	Temperature compensation of the sensitivity
$TCZ(T)$	Temperature compensation of the baseline

5.3. Calculating ppm with four electrodes – Calc_4

Formula	Explanation
$ppm = \left(\frac{(I_s - I_{s,0}) - G \cdot (I_a - I_{a,0}) \cdot TCG(T)}{S}\right) \cdot TCS(T) + TCZ(T)$	Calculation of the gas concentration in 4-electrode operation.
$a = \frac{I_{s,1} - I_{s,0}}{GA_1}$	Calculation of the sensitivity.
$c = \frac{I_{a,1} - I_{a,0}}{GA_1}$	Calculation of the sensitivity of the auxiliary electrode.
$b = \frac{(I_{s,2} - I_{s,0}) - a \cdot GA_2}{GB_2}$	Calculation of the cross-sensitivity of the sensing electrode.
$d = \frac{(I_{a,2} - I_{a,0}) - c \cdot GA_2}{GB_2}$	Calculation of the cross-sensitivity of the auxiliary electrode.
$G = \frac{b}{d}$	Gain of the cross-sensitivity compensation.
$S = (a - G \cdot c)$	Calculation of the sensor sensitivity.

Expression	Description	Source
I_s	Current at the sensing electrode (sensing)	Measuring-Signal
I_a	Current at the sensing electrode (auxiliary)	Measuring-Signal
$I_{s,0}$, $I_{a,0}$	Baseline of the sensing and auxiliary electrodes	Calibration zero point
$I_{s,1}$, $I_{a,1}$	Current at the sensing and auxiliary electrodes during exposure of calibration gas	Calibration point 1
a , c	Sensitivity of the sensing and auxiliary electrodes	Calibration point 1
GA_1	Concentration of the calibration gas A	Calibration point 1
$I_{s,2}$, $I_{a,2}$	Current at the sensing and auxiliary electrodes	Calibration point 2

MEMBRAPOR AG, Birkenweg 2, 8304 Wallisellen, Switzerland
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	during exposure of calibration gas	
GA_2 , GB_2	Concentrations of calibration gases A and B	Calibration point 2
$TCG(T)$	Temperature compensation of the gain	
$TCS(T)$	Temperature compensation of the sensitivity	
$TCZ(T)$	Temperature compensation of the baseline	

5.4. Pseudo-code, Front End Initialization and Operation

The following pseudo-code illustrates the intended access sequence and register configuration flow. It is provided for guidance only and does not define timing, settling behavior, or application-specific algorithms.

```
// -----------------------------------------------------------
// Definitions
// -----------------------------------------------------------
MENB0, MENB1     // GPIO pins for device selection
I2C_Write(addr, reg, value)
I2C_Read(addr, reg) -> value

LMP_I2C_ADDR     = 0x90
EEPROM_ADDR_0    = 0x50
EEPROM_ADDR_1    = 0x51

// -----------------------------------------------------------
// Select device helpers
// -----------------------------------------------------------
Select_LMP0():
   MENB1 = 1
   MENB0 = 0

Select_LMP1():
   MENB1 = 0
   MENB0 = 1

Select_EEPROM0_Writable():
   MENB1 = 0
   MENB0 = 1

Select_EEPROM1_Writable():
   MENB1 = 1
   MENB0 = 0
```


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```
Deselect_All():
  MENB1 = 1
  MENB0 = 1

// -------------------------------------------------------------
// LMP Initialization
// -------------------------------------------------------------
Init_LMP(lmp_index):

  if lmp_index == 0:
    Select_LMP0()
  else:
    Select_LMP1()

  // Wait until LMP is ready
  do:
    status = I2C_Read(LMP_I2C_ADDR, STATUS_REG)
  while (status & 0x01) == 0

  // Unlock TIACN and REFCN registers
  I2C_Write(LMP_I2C_ADDR, LOCK_REG, 0x00)

  // Configure TIA (gain, load)
  I2C_Write(LMP_I2C_ADDR, TIACN_REG, TIACN_VALUE)

  // Configure reference, internal zero, bias
  I2C_Write(LMP_I2C_ADDR, REFCN_REG, REFCN_VALUE)

  // Configure operating mode
  I2C_Write(LMP_I2C_ADDR, MODECN_REG, MODECN_VALUE)

  // Optionally re-lock configuration
  I2C_Write(LMP_I2C_ADDR, LOCK_REG, 0x01)

  Deselect_All()

// -------------------------------------------------------------
// EEPROM Read Example
// -------------------------------------------------------------
Read_EEPROM(addr, mem_address):

  Select_EEPROM0_Writable()   // or EEPROM1 depending on use

  I2C_Write(addr, HIGH_BYTE(mem_address))
  I2C_Write(addr, LOW_BYTE(mem_address))
```


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```
  value = I2C_Read(addr)

  Deselect_All()
  return value

// ------------------------------------------------------------
// EEPROM Write Example (single page only)
// ------------------------------------------------------------
Write_EEPROM(addr, mem_address, data[]):

  Select_EEPROM0_Writable()   // or EEPROM1

  I2C_Write(addr, HIGH_BYTE(mem_address))
  I2C_Write(addr, LOW_BYTE(mem_address))

  for each byte in data:
    I2C_Write(addr, byte)

  Deselect_All()
``
```


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