MLX90603

Tire Pressure Monitoring SiP
Low-Power Pressure Sensor

Features and Benefits

- ❑ Low-Power Microcontroller-based Pressure-Temperature-Battery monitor, ideally suited for TPMS
- ❑ Measurement of car and truck tire pressure with 1% precision
- ❑ Sleep current < 1uA during operation, Run mode < 1mA
- ❑ Delivered as a fully tested and calibrated component
- ❑ Flash version compatible with ROM package, for development and small series
- ❑ Temperature compensation of sensors and timers
- ❑ Diagnostics for system error detection
- ❑ Robust package that withstands shocks up to 2000 G
- ❑ 5 digital IO's to control the wireless RF transmitter or external IC's
- ❑ Operation with internal RC clock for low-cost, or with external RF clock for very stable data-rate
- ❑ Compatible with existing RKE systems (remote keyless entry)
- ❑ LF interface for short-range wireless communication using 125KHz

Applications

- ❑ Continuous car and truck Tire Pressure Monitoring System (TPMS)
- ❑ Low-Power Wireless Pressure-Temperature-Battery sensor

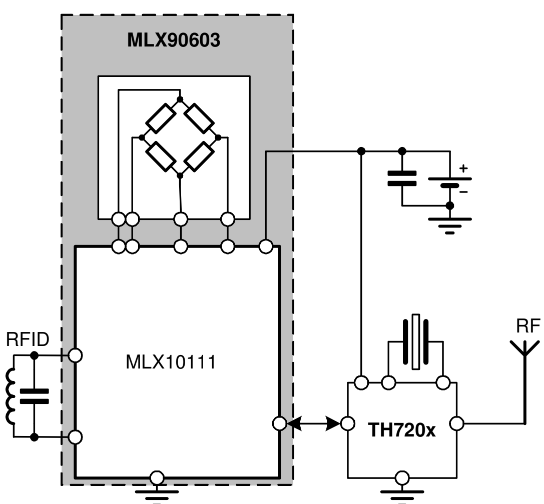
Ordering Information

Part No.	**Temperature Code**	**Package Code**	**Memory code**(*)	**Absolute Pressure range**(**)
MLX90603	K (-40°C to 125°C)	DF (SO-wide)	BF (FLASH)	B (0 – 700 kPa)
			XX (ROM)	C (0 – 1500 kPa)

(*) dedicated ROM code is assigned after customer ROM order
(**) other pressure ranges are available on demand

Delivery Form
1500 pc/T&R

1 Functional diagram



2 General description

The MLX90603 is a System in a Package (SIP) pressure sensor, combining an analog pressure sensor and a low-power sensor interface with micro-controller MLX10111, in a plastic SO16 package.
Its primary use is in wireless TPMS applications, using any RF transmitter, the system can be made compliant with existing Remote Keyless Entry (RKE) systems.
Power consumption in standby is less than 1uA, power during periodic sensing is reduced with the low-power microcontroller (typical <1mA).
The MLX90603 offers 1% Full Scale accuracy. Pressure ranges of 7 and 15 Bar are available, other ranges are on demand. The robust sensor has a burst pressure >50 bar.

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3 Glossary of Terms

VLFO	VERY LOW FREQUENCY OSCILLATOR.
LFO	LOW FREQUENCY OSCILLATOR:
HFO	HIGH FREQUENCY OSCILLATOR
POR	POWER ON RESET/POWER DOWN
MFD	MEDIUM FIELD DETECTOR
SFD	STRONG FIELD DETECTOR
SIP	SYSTEM IN A PACKAGE
RESOLUTION	2.5□ NOISE LEVEL
ACCURACY	ABSOLUTE ACCURACY INCLUDING NON-LINEARITIES, OFFSETS AND RESOLUTION.

1 bar = 14.5038 psi (Pound per square inch) = 750.0639973 mmHg (height mercury) = 100 kPa

4 Absolute maximum ratings

Parameter.	Units
Supply Voltage, V_{DD} (overvoltage)	6V
Supply Voltage, V_{DD} (operating)	3.6V
Reverse Voltage Protection	-0.5V
Supply Current, I_{DD}	4mA
Operating Temperature Range, T_{amb}	-40 to +125°C
Operating Temperature Range, T_{amb}, 10 hours	+125 to 150°C
Storage Temperature Range, T_S	150°C
ESD Sensitivity (AEC Q100 002)	1kV
ESD Sensitivity on COIL1 COIL2 pins (AEC Q100 002)	1kV

Table 1: Absolute maximum ratings

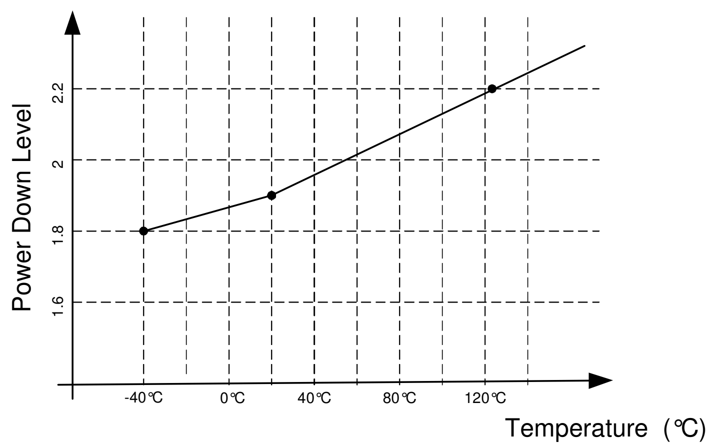
Exceeding the absolute maximum ratings may cause permanent damage. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

5 Specifications

5.1 Power down/Up specification

Parameter.	Symbol	Test Conditions	Min	Typ	Max	Units
Power down Reset	V_{PDR-40}	-40°C			1.8	V
	V_{PDR25}	25°C			1.9	V
	V_{PDR85}	85°C			2.1	V
	V_{PDR125}	125°C			2.2	V
Power up Hysteresis	V_{PUR_hyst}	Power Up level – Power Down Level			0.2	V

Table 2: Power Down/Up specifications



Note: the Power down level is the lowest voltage at which IC operates

5.2 General Current Consumption

DC Operating Parameters T_A = -40°C to 125°C, V_{DD} = 1.8V (*) to 3.6V (unless otherwise specified)

Parameter.	Symbol	Test Conditions	Min	Typ	Max	Unit
SHELF MODE current	I_{SHELF}	No clock active, [-40, 70] °C		100	220	nA
SLEEP MODE current	I_{SLEEP}	VLFO clock active, VDD=3V, [-40, 70] °C (**)		300	520	nA
SLEEP MODE current HighT	I_{SLEEP_HT}	VLFO clock active, VDD=3V, [70, 125] °C (**)		900	3400	nA
IDLE MODE current	I_{SHELF}	CPU inactive, VDD=3V, [-40, 125] °C		375	700	uA
RUN MODE current	I_{RUN}	CPU active at 1MHz, VDD=3V, [-40, 125] °C		0.8	1.4	mA

Table 3: Electrical specifications

(*) See 5.1: minimum operating voltage V_{DD} > 1.8V at higher temperature
(**) See 7.3: graphs with sleep current change over voltage supply and temperature range

5.3 Timing Specifications

DC Operating Parameters T_A = -40°C to 125°C, V_{DD} = 1.8V (*) to 3.6V (unless otherwise specified)

Parameter.	Symbol	Test Conditions	Min	Typ	Max	Unit
High Frequency Oscillator tolerance	f_{HFO_tol}	1 MHz		+/-3%	+/-7.5%	
Low Frequency Oscillator tolerance	f_{LFO_tol}	32 kHz		+/-6%	+/-10%	
Very Low Frequency Oscillator tolerance	f_{VLFO_tol}	2 kHz		+/-10%	+/-20%	
Sleep time with VLFO timer	Tsleep	VLFO+ Sw temp compensation		+/-5%	+/-10%	

Table 4: Timing specifications

Notes:
(*) See 5.1: minimum operating voltage V_{DD} > 1.8V at higher temperature

5.4 Sensor Specific Specifications

DC Operating Parameters T_A = -40°C to 125°C, V_{DD} = 2.2V to 3.6V (unless otherwise specified)

Parameter.	Symbol	Test Conditions	Min	Typ	Max	Units
Battery Voltage Measurement Specific Specifications						
Voltage sensor resolution	V_{RES}	2.5σ noise		5	10	mV
Voltage sensor accuracy	V_{ERR1}	[-20, 70] °C			50	mV
Voltage sensor accuracy	V_{ERR2}	[-40, 125] °C			100	mV
Temperature Measurement Specific Specifications						
Temperature sensor resolution	T_{RES}	2.5σ noise – 12bit ADC reading		±0.25	±0.5	°C
Temperature sensor accuracy	T_{ERR1}	[-20, 70] °C after sw temp correction			±2.5	°C
Temperature sensor accuracy	T_{ERR2}	[-40, 125] °C			±4	°C
MLX90603KDFxxB -- Full Scale (FS) = 700kPa, Pressure Measurement Specific Specifications						
Pressure sensor resolution	P_{RES}	2.5σ noise – 12bit ADC reading		0.3	0.5	%F.S.
Pressure sensor accuracy	P_{ERR1}	[-20, 70] °C, [300, 500] kPa			1	%F.S.
Pressure sensor accuracy	P_{ERR2}	[-40, 125] °C			2.5	%F.S.
Pressure sensor G-error	P_{ERR_CENTR}	Extra rotation error, per 1000G		0.9	1.1	%F.S.
MLX90603KDFxxC -- Full Scale (FS) = 1500kPa, Pressure Measurement Specific Specifications						
Pressure sensor resolution	P_{RES}	2.5σ noise – 12bit ADC reading		0.3	0.5	%F.S.
Pressure sensor accuracy	P_{ERR1}	[-20, 70]] °C, [100, 1200] kPa			1	%F.S.
Pressure sensor accuracy	P_{ERR2}	[-40, 125] °C, [100, 1300] kPa			2	%F.S.
Pressure sensor accuracy	P_{ERR3}	[-40, 125] °C, [1300, 1500] kPa			4	%F.S.
Pressure sensor G-error	P_{ERR_CENTR}	Extra rotation error, per 1000G		0.4	0.5	%F.S.

Table 5: Specifications after linearization by the microcontroller

Parameter.	Symbol	Test Conditions	Min	Typ	Max	Units
Power consumption						
P Measurement Power	P_{MEASP}	Raw ADC value available		0.72	1.00	uAs
P Linearisation Power	P_{LINP}	Linearized value available		0.87	1.22	uAs
P Coeff (T) calc Power	P_{COEFP}	Calc. of the calibr. coeff as a function of Temp.		0.2	0.27	uAs
T Measurement Power	P_{MEAST}	Raw ADC value available		0.72	1.00	uAs
T Linearisation Power	P_{LINT}	Linearized value available		0.96	1.35	uAs
V Measurement Power	P_{MEASV}	Raw ADC value available		0.72	1.00	uAs
V Linearisation Power	P_{LINV}	Linearized value available		0.87	1.22	uAs
V Coeff (T) calc Power	P_{COEFV}	Calc. of the calibr. coeff as a function of Temp.		0.2	0.27	uAs

Table 6: Measurement power consumption

5.5 RFID interface Specific Specifications

DC Operating Parameters T_A = -40°C to 125°C, V_{DD} = 2.2V to 3.6V (unless otherwise specified)

Parameter.	Symbol	Test Conditions	Min	Typ	Max	Units
Current consumption medium field mode	I_{MFD}	Supply current used by MFD on top of sleep current		33	55	nA
Sensitivity level medium field	V_{DETMFD}	Absolute detection level	50	120	200	mVpp (*)
Current consumption strong field mode	$I_{LOWFIELD}$	Supply current required by SFD on top of shelf current		0	20	nA
Sensitivity level strong field	V_{DETSFD}	Absolute detection level	1	2	3	Vpp (*)

Table 7: RFID interface Specific specifications

(*)Note: Vpp means the differential voltage across the 2 coil terminals

6 Detailed Description

The MLX90603 is a System In a Package (SIP) that consists of two silicon dies:

- a MEMS absolute pressure sensor
- and a microcontroller based low power sensor interface (MLX10111),

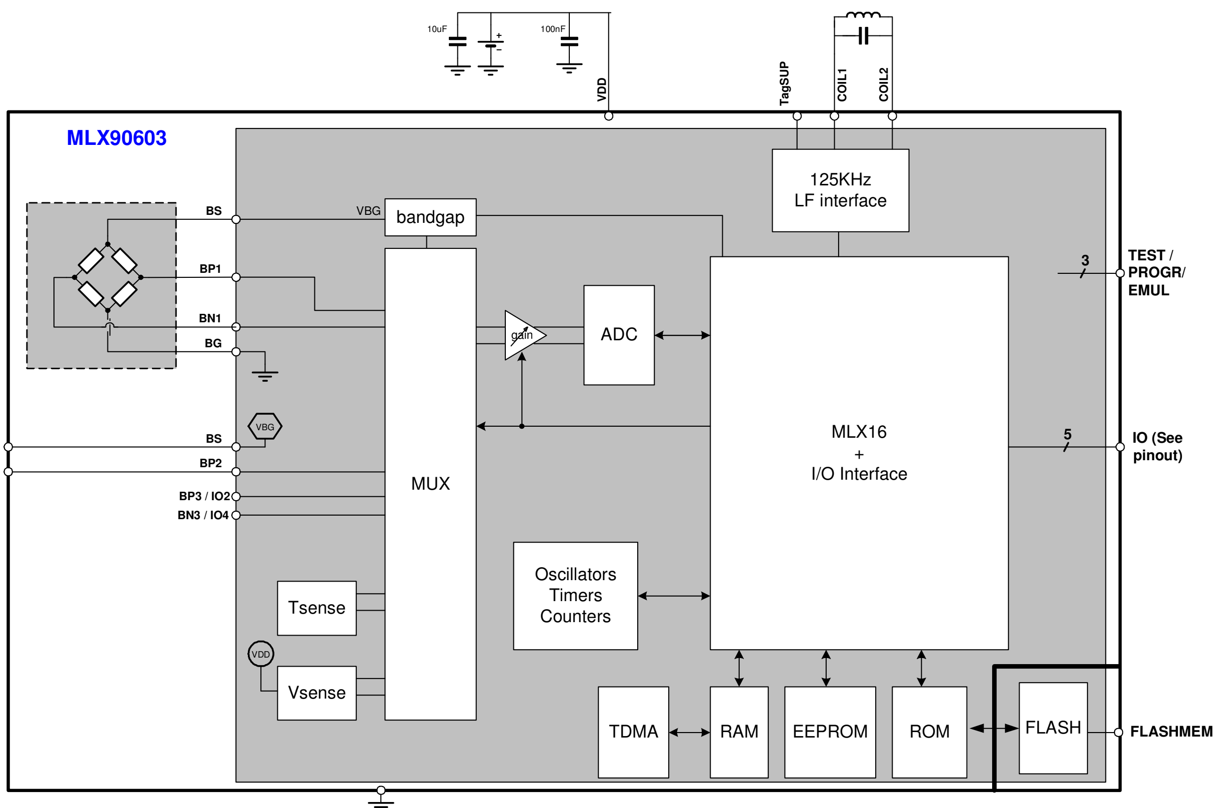
assembled in a wide body (300mils) SOIC16 compatible package.
The MLX90603 is delivered as a fully tested and calibrated device.

6.1 Architecture

The heart of the MLX90603 is the Melexis 16 bit microcontroller: MLX16. It allows software control of:

- the sensor interface
  - temperature and voltage measurements on the MLX10111
  - measurements of the analog pressure sensor bridge or a 2nd sensor bridge
- the communication interface
  - Internal RFID: 125kHz
  - External RF
  - Serial communication using 1 of the 5 digital IO's
- the power management.

The microcontroller can access RAM, EEPROM and ROM memories. Also a programmable FLASH memory is available for development and pre-production series. The standard software library with low-level routines give access to all IC's functions. Application examples offer a low-entry level introduction to the MLX16 programming.



6.2 MEMORIES

6.2.1 EEPROM

The MLX90603 has 128 bytes of EEPROM on board. Half of this memory is reserved for internal operation coefficients. The rest is available for application specific data like a sensor identification number.

6.2.2 RAM

RAM size is 256 bytes.

6.2.3 ROM/FLASH

The Program Memory size is 4K Word Instructions or 8 Kbytes.

6.3 Interrupts

A wide range of interrupt sources are available, each with their own interrupt vector address.
External interrupts include IRQ on digital IO's or from the RFID interface.
Internal interrupts include a watchdog and 2 compare timers.

6.4 Measurement functions

A bandgap is used to generate the internal voltage reference, independent of the battery voltage.
The output of the pressure, temperature and voltage sensor are differential signals that are multiplexed on the input of the signal conditioning chain.

- The actual measurement consists of the amplification of the analog value that then is converted to a digital signal by an analogue to digital converter (ADC).
- Next these ADC output values are linearized, removing the offset and adjusting the sensitivity using the calibration constants that are stored in the EEPROM. These calibration constants are measured and programmed during the production test at Melexis.

Linearization time varies depending on the sensor (see specification). During the ADC measurement, the microcontroller is switched off to reduce power consumption and noise influence during a measurement (see power consumption below).

6.4.1 Absolute Pressure sensor

The pressure sensor is a separate silicon MEMS (Micro Electro-Mechanical Structure) die based on piezo-resistive wheatstone bridge. Under the sensitive pressure membrane a vacuum cavity serves as reference.

6.4.2 Temperature sensor

The temperature sensor is part of the MLX10111.

6.4.3 Voltage sensor

The battery or supply voltage sensor is part of the MLX10111.

6.4.4 External sensor

Pin BP2 can be used to measure an extra analog sensor.
The general I/O pins IO2 and IO4 can be configured as a differential input of a 3rd sensor.

6.5 Communication interface

An external interface communication can be implemented in software, using any of the digital IO's: any serial RF/LF/SPI protocol can be programmed.

6.5.1 RF transmission

The communication protocol for RF transmission can be programmed in software, with preamble and CRC.
Normally the baud rate is generated in software, using the High Frequency Clock of the microcontroller (HFO). The temperature variation of the internal RC oscillator can be reduced by extra software compensation. As alternative, the stable external clock from the RF transmitter IC can be used for accurate baud rate generation.
The MLX90603 can be used with most commercially available transmitters and transceivers. For instance in combination with the Melexis TH720x range of RF transmitters an ASK or FSK data-stream can be generated.

6.5.2 RFID or LF interface

The RFID interface operates at 125kHz. This operating frequency is set by an external inductance and capacitor. Two sensitivity levels are available:

- A Strong Field Detector (SFD) is available in which the controller does not consume any current from the battery. This can be used to wake up the IC in production test, and to maximize shelf life.
- A Medium Field Detector (MFD), is available in which the controller is sleeping and woken-up by an external 125KHz signal, e.g. to start a measurement and do a transmission on demand.

6.6 Power management

Several hardwired features are integrated to minimize power consumption:

- Multiple power consumption operating modes: shelf mode, sleep mode, idle mode, run mode
- Optional 16bit CRC in hardware to reduce power consumption during communication
- Optional DMA mode (direct memory access) for low power RAM access during communication

6.7 Oscillators

VLFO: The Very Low Frequency Oscillator generates a 2 KHz clock that is used for the low-power Sleep Mode: the sleep time can be programmed in steps of 250ms (= 0 to 64 seconds sleep time).

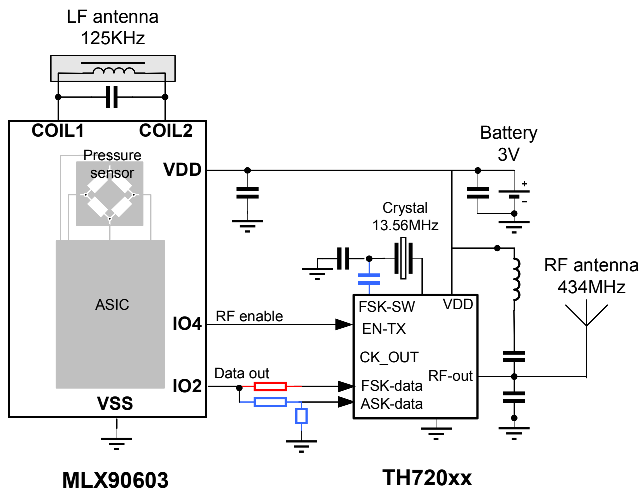
LFO: The Low Frequency Oscillator generates a 32 KHz clock that can be used for low-power DMA communication or to program short sleep periods

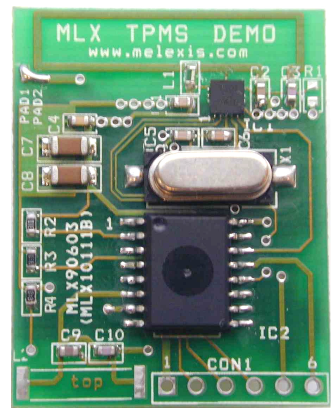
HFO: The High Frequency Oscillator is the 1MHz micro-controller clock, instructions are executed based on this clock: 4 clocks per instruction, 4us per instruction

7 Application information

7.1 Demo board

A schematic and a picture of a typical application is shown below, it uses the MLX90603 pressure sensor with the TH720xx RF transmitter. Both ASK (Red) and FSK (Blue) modes of RF transmission are possible.





7.2 Unique Features

- Automotive qualified
- Low stand-by power consumption
- Flexible software control over performance and power consumption
- Options for battery and battery-less implementation
- Small feature size of the package

7.3 Current consumption

The IC is designed for maximizing the battery life time in automotive applications. Four different operating modes are considered:

7.3.1 SHELF MODE

In Shelf Mode the battery voltage is applied, but the IC consumes very little power: only the Power-On-Reset circuit is active (note: above 80°C the consumption increases). This shelf mode is used after the TPMS module has been assembled and tested. In this mode the battery leakage is the biggest limit on battery life. The module can exit shelf mode by an external interrupt, for instance a mechanical motion switch or a strong RFID signal.

7.3.2 SLEEP MODE

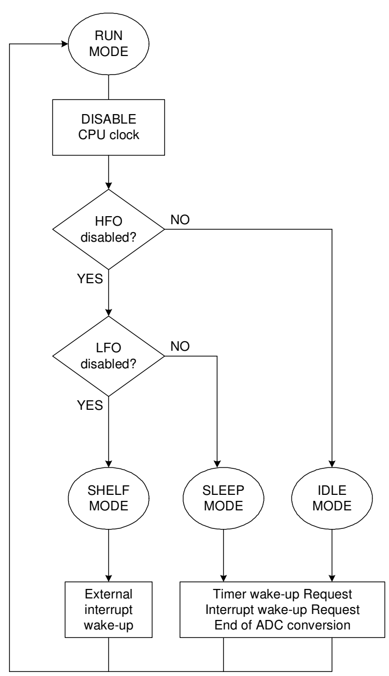
Only the VLFO Oscillator is active in sleep mode. A digital counter will wake up the microcontroller on pre-programmed VLFO time intervals, as preset in software (typical between 0 – 64 sec). During SLEEP MODE the total current consumption is $I_{SLEEP} = I_{SHELF} + I_{VLFO.}$

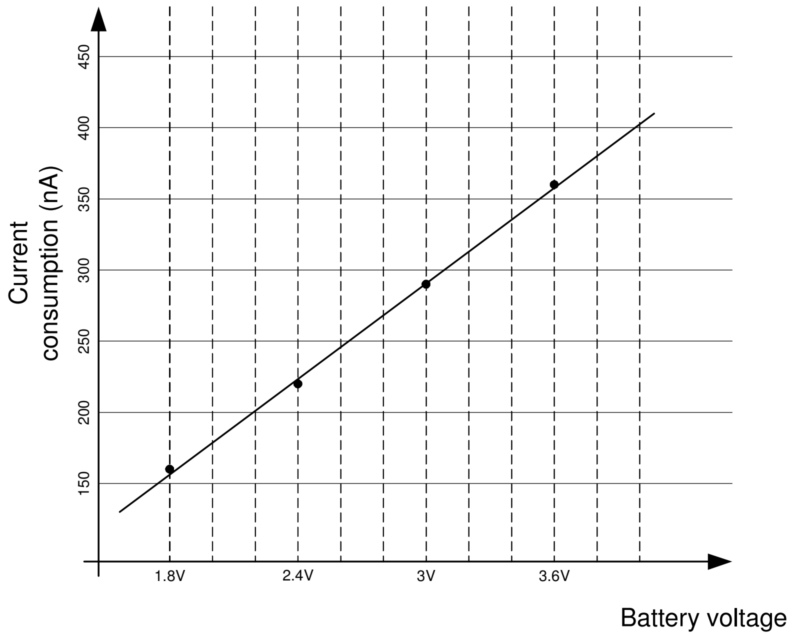
7.3.3 RUN MODE

When the microcontroller clock is running (Clock = High Frequency Oscillator = HFO), the IC is in RUN MODE and the microcontroller is executing instructions. Current consumption of the chip is now increased to Irun.

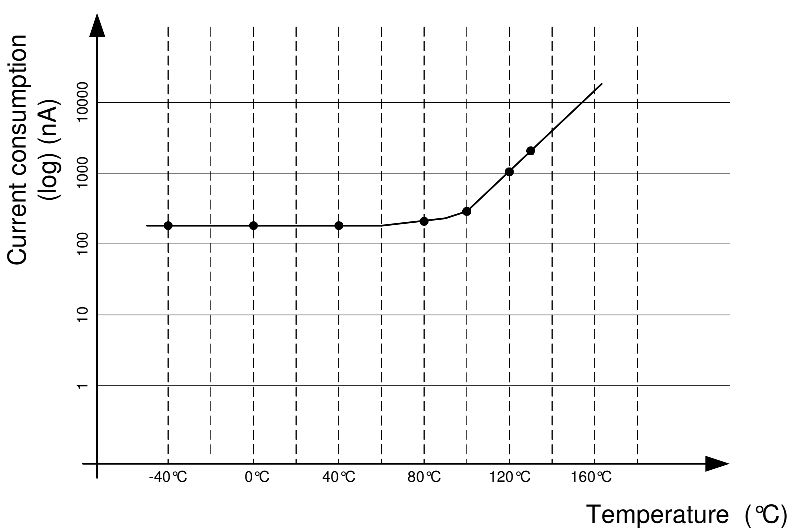
7.3.4 IDLE MODE

During measurements the microcontroller is not used. Therefore an IDLE MODE has been introduced in which only the ADC is functional, but the microcontroller is NOT executing instructions.





Typical SLEEP MODE current vs. supply voltage (at 25°C)



Typical SLEEP MODE current vs. temperature (at 3V power supply)

7.3.5 Battery life time calculation example

1. One Pressure + one Temperature measurement every 3 seconds
   ⇨ I_{MEAS} = (2.22uAs + 2.35uAs) / 3s = 1.52 uA

2. One RF transmission every 30 sec, using messages of 10 bytes (80 bits) and 10kbps FSK.
   The TH720xx transmitter at 3dBm RF power consumes 7mA and takes 1.5ms to start up.
   ⇨ consumption per message: 7ma * (8ms+1.5ms) = 66.5 uAs
   ⇨ Average transmit current: I_{TX} = 66.5uAs/30s = 2.22 uA

3. Standby current depends on the choice of motion sensor:
   a. No motion sensor: I_{SLEEP} = 0.52uA
   b. With mechanical motion switch I_{SHELF} = 0.22uA
   c. With MFD for LF initiation $I_{SLEEP+MFD}$ = 0.57uA

4. Using a CR2450 battery with 540mAH capacity.
   => assume 1%/yr leakage, this consumes I_{LEAK} = 0.62uA

In the table below the battery life time is estimated based on the above simplified example.

Wake up	Timer (no motion detect)	Mechanical switch	LF initiator	
Standby	0.52	0.22	0.57	uA
Duty cycle(*)	100%	5%	5%	
IMEAS	1.52	0.08	0.08	uA
ITX	2.22	0.11	0.11	uA
ILEAK	0.62	0.62	0.62	uA
Total average current	4.88	1.03	1.38	uA
Battery life (100% cap)	12.6	59.8	44.7	Year
Battery life (60% cap) (**)	7.6	35.9	26.8	Year

(*) Assumption that vehicle is driving during 5% of the time, so that sensor measurements and RF transmissions are active only 5% if motion detection is used. Without motion detection, the measurements and transmissions must be done 100% of the time.

(**) In typical cases not the full rated battery capacity can be used. Therefore a battery life time for 60% of the rated capacity is estimated.

7.4 Temperature shut down

The timers, the microcontroller, the ADC and the sensors are guaranteed to operate up to 150C.
The temperature sensor works monotonously up to 150C. The MLX90603 can be programmed to go to Sleep Mode without measuring, when the temperature rises above a defined value, it can restart measuring when the temperature is again below this limit.

7.5 Motion detection

Several motion detection strategies can be implemented on the MLX90603: The MLX90603 has several IO's, some with interrupt capability. Wake-up from shelf or sleep mode can be realized using the interrupt IO's.

- The MLX90603 can read a mechanical motion switch with 1 digital interrupt input.
- The MLX90603 can read an acceleration IC with an analog input and 1 output to switch IC on/off
- The MLX90603 can read a low-cost circuit with PZT shock sensor (cfr application note)

7.6 LF Initiation

The IC coil inputs can be used for LF initiation (measurement on demand). Typically the 125 KHz LF field is detected when the tire module rotates and comes close to the LF initiator in the wheel well. The wheel rotation can be detected fast and with low power, if the coil input sensing is programmed with a low duty cycle (e.g. duty cycle of 10% , 1ms on - 9ms off).

An alternative approach for very sensitive LF initiation is that the MLX90603 powers and measures an external LF detection IC that uses two LF antennas.

7.7 Tools and libraries

7.7.1 Tools

The MLX16 environment is based on the EMLX-MM emulator/programmer tool, in combination with a C compiler.

7.7.2 Standard library

A set of library functions is available to simplify the programming of the total application. A range of application notes describe the software examples.

8 Other product references

- TH720XX: RF transmitter
- TH711XX: RF receiver
- TH722XX: RF transceiver

9 Standard information regarding manufacturability of Melexis products with different soldering processes

Our products are classified and qualified regarding soldering technology, solderability and moisture sensitivity level according to following test methods:

Reflow Soldering SMD's (Surface Mount Devices)

- IPC/JEDEC J-STD-020
  Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices
  (classification reflow profiles according to table 5-2)
- EIA/JEDEC JESD22-A113
  Preconditioning of Nonhermetic Surface Mount Devices Prior to Reliability Testing
  (reflow profiles according to table 2)

Wave Soldering SMD's (Surface Mount Devices) and THD's (Through Hole Devices)

- EN60749-20
  Resistance of plastic- encapsulated SMD's to combined effect of moisture and soldering heat
- EIA/JEDEC JESD22-B106 and EN60749-15
  Resistance to soldering temperature for through-hole mounted devices

Iron Soldering THD's (Through Hole Devices)

- EN60749-15
  Resistance to soldering temperature for through-hole mounted devices

Solderability SMD's (Surface Mount Devices) and THD's (Through Hole Devices)

- EIA/JEDEC JESD22-B102 and EN60749-21
  Solderability

For all soldering technologies deviating from above mentioned standard conditions (regarding peak temperature, temperature gradient, temperature profile etc) additional classification and qualification tests have to be agreed upon with Melexis.

The application of Wave Soldering for SMD's is allowed only after consulting Melexis regarding assurance of adhesive strength between device and board.

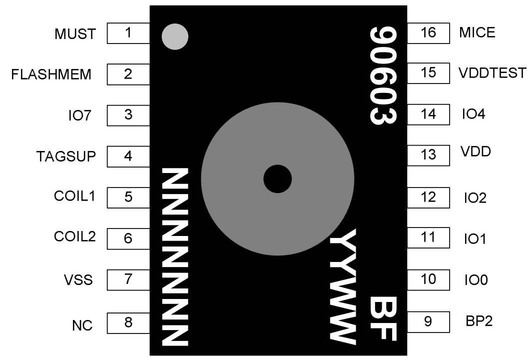
Melexis is contributing to global environmental conservation by promoting **lead free** solutions. For more information on qualifications of **RoHS** compliant products (RoHS = European directive on the Restriction Of the use of certain Hazardous Substances) please visit the quality page on our website:
http://www.melexis.com/quality.asp

10 ESD Precautions

Electronic semiconductor products are sensitive to Electro Static Discharge (ESD).
Always observe Electro Static Discharge control procedures whenever handling semiconductor products.

11 Package Information

The MLX90603 is a System-In-Package (SIP) consisting of two chips that are assembled in a custom moulded package. The package footprint is compatible with a standard SO16 wide-body IC.



NNNNNNN	LOT NUMBER
YYWW	YEAR-WEEK CODE
90603BF	PRODUCT VERSION

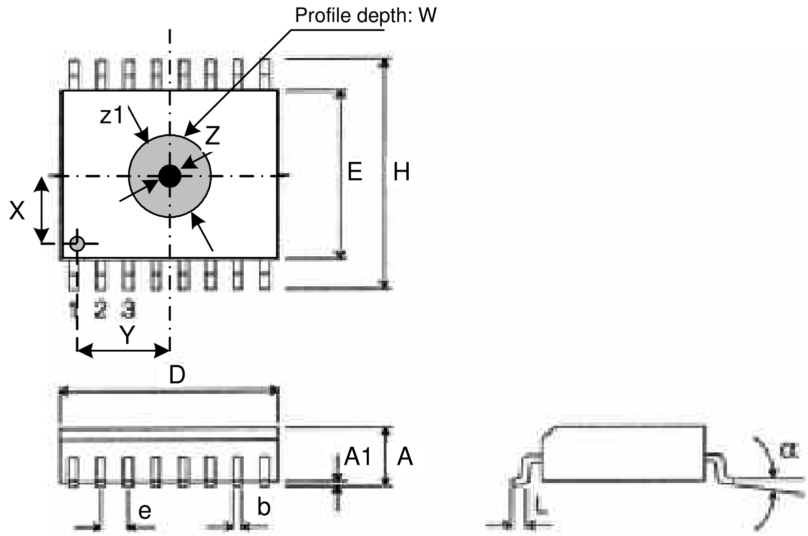
Table 8: SOIC16 pin layout

11.1 Pin description for MLX90603

	Pad Name	Function
1	MUST	Test input pin
2	FLASHMEM	FLASH memory selection (not connected in ROM version)
3	IO7	Programmable I/O pin
4	TAGSUP	Tag Supply output
5	COIL1	Coil connection1
6	COIL2	Coil connection2
7	VSS	Ground
8	NC	Not Connected
9	BP2	analog input
10	IO0	Programmable I/O pin with IRQ
11	IO1	Programmable I/O pin with IRQ
12	IO2	Programmable I/O pin
13	VDD	Power Supply
14	IO4	Programmable I/O pin
15	VDDTEST	Test supply pin
16	MICE	Test output pin

Table 9: Pin description for MLX90603

11.2 SO16 Package outline



Package type		D	E	H	A	A1	e	b	L	α	W	X	Y	Z	Z1
SO16	Min	10.10	7.40	10.00	2.35	0.10	1.27	0.33	0.40	0°	0.01	2.40	4.01	0.75	4.3
	Max	10.50	7.60	10.65	2.65	0.30		0.51	1.27	8°	0.09	2.50	4.21	0.85	4.7

Table 10: SO16 dimensions in mm, co-planarity<0.1mm

12 Disclaimer

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Or for additional information contact Melexis Direct:

Europe, Africa, Asia:
Phone: +32 1367 0495
E-mail: sales_europe@melexis.com

America:
Phone: +1 603 223 2362
E-mail: sales_usa@melexis.com