

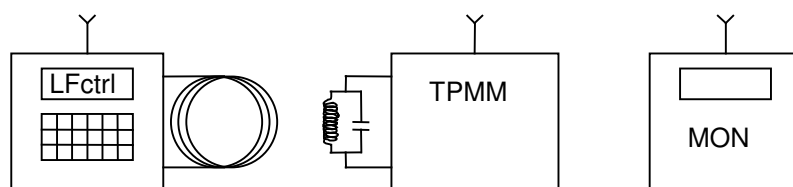
1 Purpose

This document is intended to give hints on how to use the Intersema pressure sensors in a low cost tire pressure monitoring system (TPMS).

2 Introduction

A TPMS monitors the pressure and temperature inside an automobile's tire. There are three main parts involved in a complete tire pressure monitoring system:

- The measurement system, (Tire Pressure Measurement Module ,TPMM) inside the tire
- The monitor (MON) displaying the status of the tires
- The Low Frequency control equipment (LFctrl) for maintenance and configuration of the TPMM.



The tire pressure measurement module is built into each tire and is responsible for intelligent tire pressure and temperature monitoring. The module can be configured through the LFctrl unit. Results during operation are transmitted to the monitor unit (MU) through an RF link.

- The main features are:
 - unique module number for identification
 - low battery detector (End of life)
 - frequently measurements of the tire pressure and temperature
 - depending on the result, transmit the measurement by the RF link to the MU
- Operating conditions are:
 - automotive -40°C to 125°C
 - low power device (battery operated, lifetime about 10 years)

The monitor unit is built into the car dashboard, giving the driver the status of the tires. A warning is generated if the tire pressure is below a minimum, over a maximum or if the tire starts to loose pressure with a bigger gradient than allowed. A warning is generated if the tire temperature exceeds a certain threshold.

- The main features are
 - observing the tire pressure and temperature
 - give a warning in case for pressure and temperature are out of the operating range
 - give a warning in case of low battery of a TPM module
- Operating conditions are:
 - automotive -40°C to 125°C

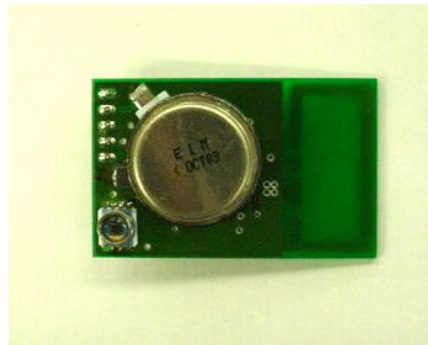
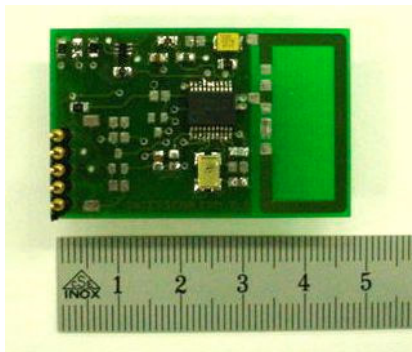
The low frequency control equipment is the so-called hand held control device used to configure the tire pressure module by a low frequency magnetic link. The results from the TPMM are transmitted back by its RF link. The main features of the LFctrl block are:

- Setup of parameters in the TPMM:
 - tire position (FL, FR, BL, BR)
 - reset min/max pressure during operation
 - reset min/max temperature during operation

- During fabrication store the parameters into the TPMM
 - unique ID code
 - fabrication date
- Readout of the TPMM data:
 - fabrication date
 - min/max pressure during operation
 - min/max temperature during operation

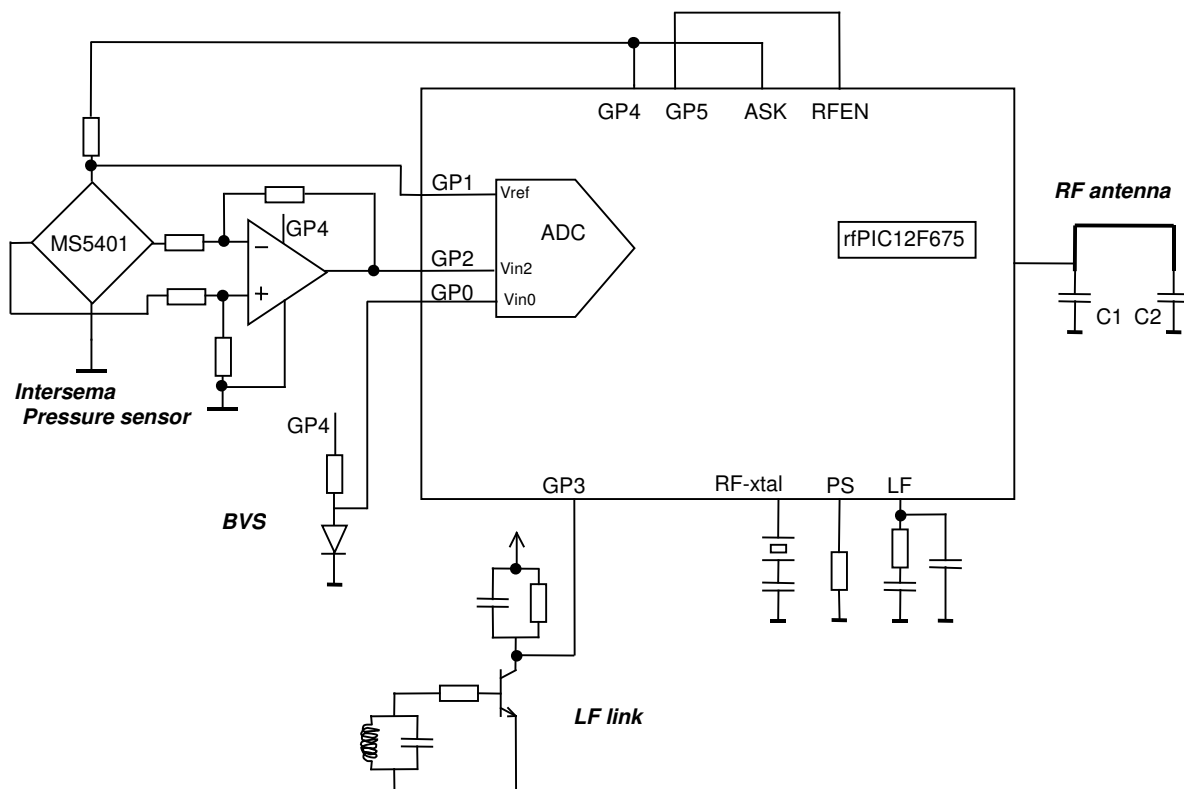
This document concentrates on the design of the Tire Pressure Measurement Module (TPMM), and especially on the interfacing of the pressure sensor with widely available 10 bit ADC converters found in most microcontrollers.

3 System overview



The TPMM consists of the following main blocks:

- RfPIC12F675 Microcontroller with integrated 434 MHz RF transmitter for data transmission and 10bit AD converter for pressure & temperature measurements, 6 I/O pins for system control.
- Simple interface electronic for interfacing the pressure sensor to the AD converter (LMV341 operational amplifier)
- Battery voltage survey (BVS) (small signal diode)
- Low frequency link for calibration and setup commands (inductance and transistor)



4 Pressure/Temperature measurement

Both pressure and temperature values can directly be measured on the pressure sensor bridge:

- for the pressure measurement, the differential output voltage from the pressure sensor is converted pre-amplified and converted
- for the temperature measurement, the sensor bridge resistor is sensed through a resistor and converted

In order to reduce power consumption, the sensor will only be switched on for a very short time. When not measuring, all IO ports are at low output, which shut down the sensor and the pre-amplifier.

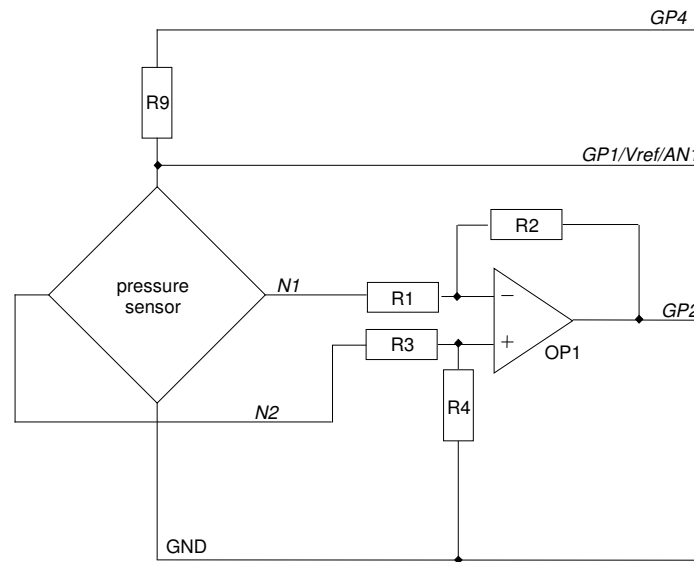


Fig.1 Schematic of simple sensor interface circuit

During pressure measurement the IO pins of the microcontroller are in following states:

- GP1 output pin pulls the bridge directly to Vdd. GP1 is also used as the reference for the ADC conversion. This way the internal port resistance in the microcontroller has so no influence on the ADC result, even if it does not pull the bridge exactly to vdd.
- GP2 is used to measure the differential pressure voltage through the preamplifier with the AD converter. The gain of the preamplifier is chosen to have maximal resolution, and ensuring that the signal will not saturate with sensor process variation, pressure and temperature variations.
- GP4 serves as output to pull up the temperature measurement resistor to avoid current flowing through R9, which is not used for pressure measurements. GP4 is also used to enable the LMV341 operational amplifier.

During temperature measurement the IO pins of the microcontroller are in following states:

- GP4 pulls up the sensor over the serial resistor R9. The pressure sensor bridge and R9 form a resistive divider, which is temperature dependent, since the pressure sensor resistors have a quite large temperature coefficient (3000 ppm/°C).
- GP1 serves as analog input of the AD converter. This time, Vdd serves as Vref. The parasitic serial resistance (output resistance of the port) is not cancelled and care has to be taken the parasitic resistance of the port, which is about 200 Ohm. For this reason, the serial resistor R9 has to be chosen quite large (about 10k), to minimise the influence of the parasitic port resistance.

5 Battery voltage survey (BVS)

Battery voltage survey is performed by converting the forward voltage of a low power small signal diode with the integrated ADC. The forward voltage of a diode is not much dependent of the polarisation current. Since the reference voltage of the AD converter is the battery voltage, the result will be reflect the battery voltage.

Required forward current for the MMBD1701A diode is of 10uA, thus it can be biased at every pressure/temperature measurement. The voltage survey requires an extra AD conversion (with the bridge powered). It is only required in the last measurement before transmission of the pressure and temperature values to the monitor unit.

Variation of the diode's forward voltage (process tolerances) are compensated at first power-up of the module, when battery voltage is at about 3.45 +/- 0.2V (100uA load). Adding 50 LSB to the ADC result gives the calibration data for the BVS. Low battery level is then about 2.5V +/- 0.1V.

6 RF transmitter

The RfPic allows to modulations: ASK (amplitude modulation) or FSK (frequency modulation). The ASK modulation is used in this design, but FSK modulation could be used too.

For best transmission efficiency, the antenna's resonance frequency has to be at transmission frequency (434MHz), and it's impedance has to match the output impedance of the transmitter inside the RfPIC (about 300 Ohm at 434MHz). For this matching, two capacitors are placed in the loop of the antenna:

- C1 (transmitter output to ground): this capacitor strongly affects the impedance of the antenna. For the actual antenna design, it is about 19 pF.
- C2 (antenna output to gnd): this capacitor determines the resonance frequency of the antenna together with the inductance and the resistance of the antenna itself. For actual antenna design it is about 4pF.

To avoid trimming of the capacitors during production, the quality factor of the antenna can be reduced. Of course effective transmission power will be reduced and usable range will be shorter. To decrease the Q (quality factor) of the antenna, a resistor can be placed between the transmitter output and Vdd. Decreasing this resistance reduces the Q.

The inductance from transmitter output to Vdd is for DC polarisation of the antenna.

7 LF – link

The LF link is used as receiver of the TPMM. Since the TPMM can be in sleep mode during data arrival, the LF link must be able to wake up the processor without adding current consumption during sleep mode.

Simplest way would be to use the internal comparator of the microcontroller. Unfortunately the reference resistor string of that comparator does take too much power ($V_{dd}/48 \text{ kOhm} = 62.5 \text{ uA @ } 3.0 \text{ V}$) to keep it on all the time and so the comparator cannot be used.

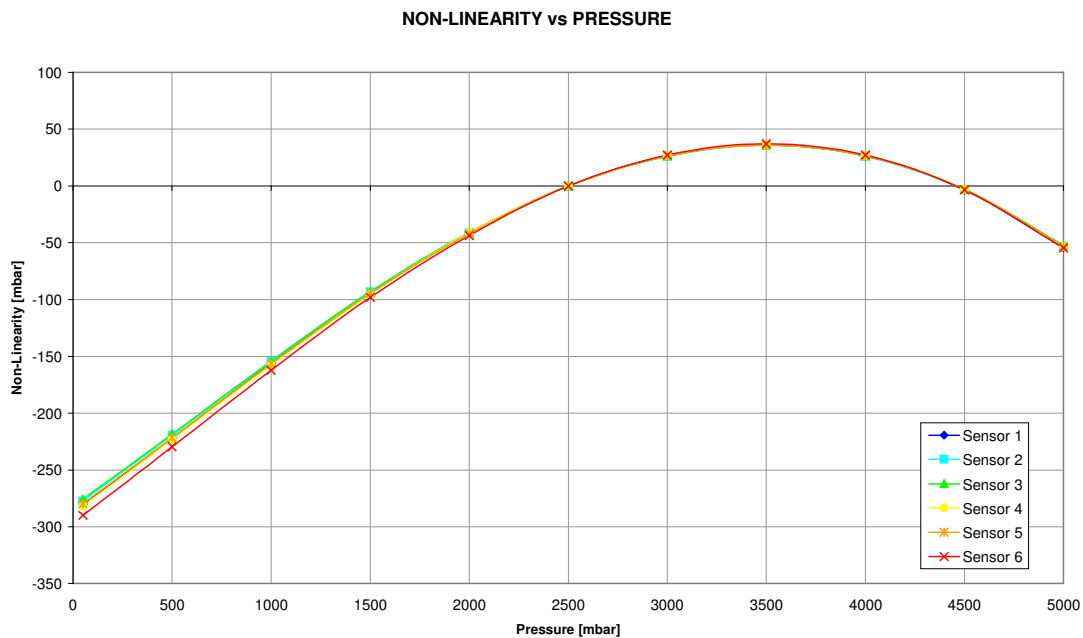
The LC tank must so be able to generate a quite high voltage ($\gg V_{dd}/2$), so that the controller can be waked up from the sleep mode through a simple interrupt on GP3 pin.

An ideal operating frequency is somewhere between 10 kHz to 200 kHz, perhaps a bit higher frequency is better suited for a faster transmission (shorter on time saves power)

8 System performance

Following performance can be achieved with the presented tire pressure monitoring system, by calibrating the system at 4 points (1.2bar, 3.0bar and 20°C, 70°C):

Parameter	Conditions	Typ	Unit
Pressure resolution	With MS5401-BM sensor, Pre-amplification = 9	4	mbar
Temperature resolution	10k temperature measurement resistor	2	°C
Pressure non-linearity	2bar – 5 bar	< 50	mbar



8.1 Power consumption

During operation, the system can be in one of 7 modes. Several system components have to be switched ON and OFF with the same control lines, as we only have 6 I/O lines. This does not increase the power consumption significantly, as the system is only active during a very short time, before re-entering the very low power consuming sleep mode.

Mode	Microcontroller state	Sensor state	Amplifier state	Voltage survey	Transmitter state
Sleep	sleep	off	off	off	off
Active	active	off	off	off	off
Pressure measurement	sleep, ADC on	on	on	on	off
Temperature measurement	sleep, ADC on	on	on	on	off
Voltage survey	sleep, ADC on	on	on	on	off
Trans. "0"	active	off	off	off	on
Trans. "1"	active	on	on	on	off

Typical current consumption for each mode:

Mode	Typ. current [mA]	Duration [ms]
Sleep	0.003	
Active	0.5	3.0
P-measurement	1.6	0.08
T-measurement	1.2	0.08
Voltage survey	1.2	0.08
Transmitting "0"	3.0	8
Transmitting "1"	10.0	8

Average current consumption of the module:

Mode	Average current [uA]
1 measurement / s, no transmission	4.7
1 measurement /s, transmitting every 60 s, 9600 baud	6.5

With the TL4986 lithium cell from Sonnenschein (370 mAh), a typical lifetime of 6 years should be achieved.

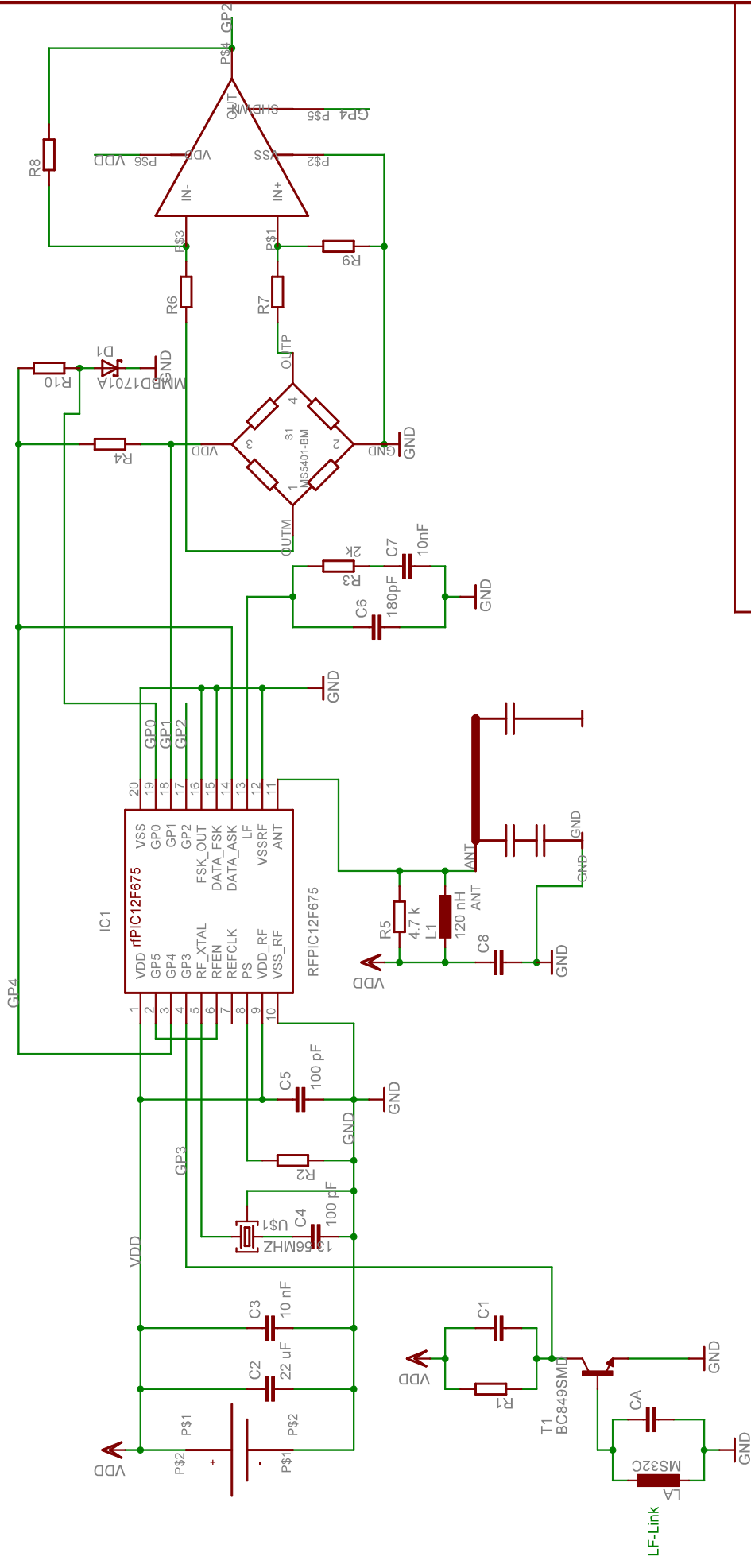
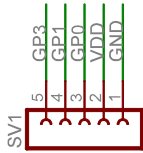
9 Bill of material

Part	Qty	Description	Part number	Source	Price / 500k
	1	Pressure Sensor	MS5401-BM	Intersema	\$2.00
	1	Microcontroller with RF transmitter	rfPIC12F575	Microchip	\$1.20
	1	SMD 5.0x3.2 13.56MHz Crystal Unit	TZ0259A-MC	Taisaw	\$0.41
	1	Lithium battery	TL4986/D	Sonnenschein	\$1.50
	1	Operational amplifier	LMV341MG	National	\$0.25
	1	small signal diode	MMBD1701A	Fairchild	\$0.04
		Discrete			\$0.15
	1	PCB			\$0.30
	1	Assembly			\$1.00
	1	Calibration			\$1.00
		Total			\$7.85

For additional cost saving for high volume production, a direct chip on board with Intersema's sensor dies can be investigated.

Additional costs for the LF-link:

Part	Qty	Description	Part number	Source	Price / 500k
	1	Inductance			\$0.45
	1	Transistor			\$0.05
		discrete			\$0.05
		Total			\$0.55



TirePressureModule with rPIC12F675	
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REVISION HISTORY

Date	Revision	Type of changes
July 8th, 2004	V1.0	Initial release

FACTORY CONTACTS

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