



AN238

Tire Pressure Monitoring (TPM) System

*Authors: Ruan Lourens
Microchip Technology Inc.
Curtis Kell
Kell Laboratories*

An auto-location system can dynamically detect the position of a specific sensor, which is useful when tires are rotated. The heart of the TPM system is the Sensor/Transmitter (S/TX) device and it is based on Microchip's rfPIC12F675.

INTRODUCTION

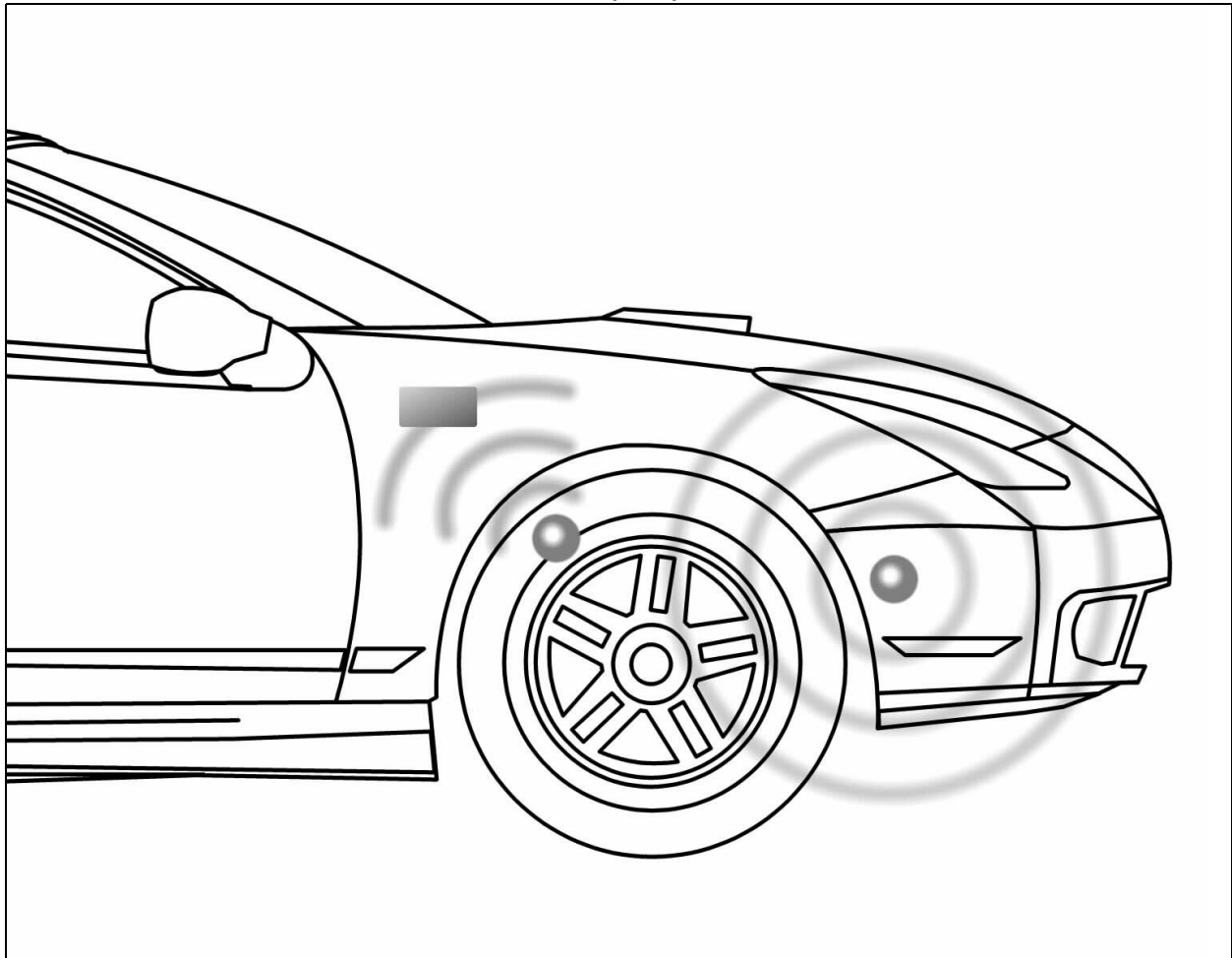
This document explains a typical tire pressure monitoring (TPM) system specifically intended for automotive use. It serves as a reference to design a real-world system based on various Microchip products. A TPM system primarily monitors the internal temperature and pressure of an automobile's tire. There is a variety of system approaches to follow, although this one is a rather comprehensive auto-location system.

SYSTEM COMPONENTS

The TPM system consists of the following major component.

- Sensor/Transmitter Device
- RF Receiver Module
- Low Frequency (LF) Commander Device
- Control Unit
- Pressure Vessel (Tire)

FIGURE 1: TIRE PRESSURE MONITORING (TPM) SYSTEM



Sensor/Transmitter (S/TX) Device

There are typically five S/TX units per vehicle, one per wheel, and the spare tire. Each unit has a unique serial number enabling the system to distinguish between each tire. When mounted within a vehicle tire, the S/TX periodically measures internal tire pressure, temperature and battery condition. It then sends a RF signal composed of the measured information to a central receiver. The device described in this document is based on Microchip's rPIC12F675 and the pressure and temperature sensing is performed by the Sensoror SP-13, a sensor IC (www.sensoror.com). The unit is also equipped with a LF receiver unit, used to communicate to the S/TX device and to enable it from a Sleep state.

RF Receiver Module

A central RF receiver module receives transmissions from the individual S/TX devices. The receiver can also be used as a remote keyless entry receiver, saving on overall system cost. The design of the RF receiver module falls beyond the intent of this document. A functional RF receiver module is assumed.

LF Commander Device

The LF commander is designed to send specific commands to the S/TX unit via a 125 kHz ASK modulated signal. The LF link communicates over a short distance (1 meter or less), thus making it capable of communicating with the wheel in its immediate range. LF magnetic communications is well suited for sending commands to the S/TX devices. These commands, when received by the S/TX device, instruct it to carry out specific tasks.

Control Unit

The control unit is responsible for initiating communications, interpreting received data and reporting the relevant information back to the vehicle. The unit will only be treated from a system overview perspective.

Pressure Vessel

The pressure vessels (tires) are the measurement subjects, with pressure and temperature values measured and reported.

TPM Sensor/Transmitter

TECHNICAL SPECIFICATIONS

- Modulation Format: ASK
- Operating Voltage: 2.5-3.6V
- Low Voltage Alert Threshold: 2.5V
- Quiescent Current: TBD

RF Specific:

- Transmit Frequency: 315 MHz
- Transmit Interval: 60, 15 or 5 seconds (LF selectable)
- Power Output: +9 dBm into 50 Ω load
- Operating Current – Transmit: 12.5 mA at max RF power

LF Specific:

- Input Frequency: 125 kHz
- Input Sensitivity: TBD

Pressure Sensor Specific:

- Pressure Sensor Range: 50-637 kPa absolute
- Temperature Sensor Range: -40–125°C

The schematic for the TPM S/TX is shown in **Appendix A: "Schematics"**.

THEORY OF OPERATION

The S/TX device comprises two integrated circuits:

- Microchip's rPIC12F675 MCU/RF transmitter IC
- Sensoror SP-13 (pressure, temperature and low-voltage sensor IC)

In addition, the S/TX also includes LF input circuitry. This circuitry allows the S/TX device to receive special commands via the LF link. Refer to **Appendix A: "Schematics"** for additional circuit detail.

rfPIC12F675 Transmitter IC

The rPIC™, based on the PIC12F675, was chosen as the heart of the S/TX for several reasons. First, the PIC12FXXX series of microcontrollers are widely used for transmitter applications and millions of PICmicro® microcontroller devices are currently used in transmitter applications today. Second, this device features an internal RC oscillator, thereby reducing the external component count which, directly reduces module cost as well as circuit board size. Third, this device includes the RF transmitter circuitry, which again reduces external component count, cost and overall size of the circuit board. The rPIC12F675 also has an internal comparator which plays an important role in decoding the information from the LF link. The internal comparator helps reduce overall part count, thereby further reducing module cost and circuit board size. Lastly, the rPIC12F675 features a 10-bit Analog-to-Digital converter, allowing the designer to use analog output pressure sensors.

The rPIC performs three functions. It monitors the data line from the SP-13 sensor IC and from the LF input, and assembles and transmits a RF message at periodic intervals.

After application of power, the rfPIC executes an initialization procedure and goes into a Sleep mode until a state change is detected on either the SP-13 data line or the LF input. Either of these inputs generates a wake-up, causing the rfPIC to transition into the Run mode. If the wake-up was generated by the SP-13, the rfPIC reads the incoming data, assembles the data into an appropriate message, and transmits the message via the RF transmitter. Once the RF message is sent, the rfPIC reenters the Sleep mode. If the wake-up was generated by the LF input, the rfPIC interprets the LF message, executes the command and then reenters the Sleep mode.

RF Circuitry

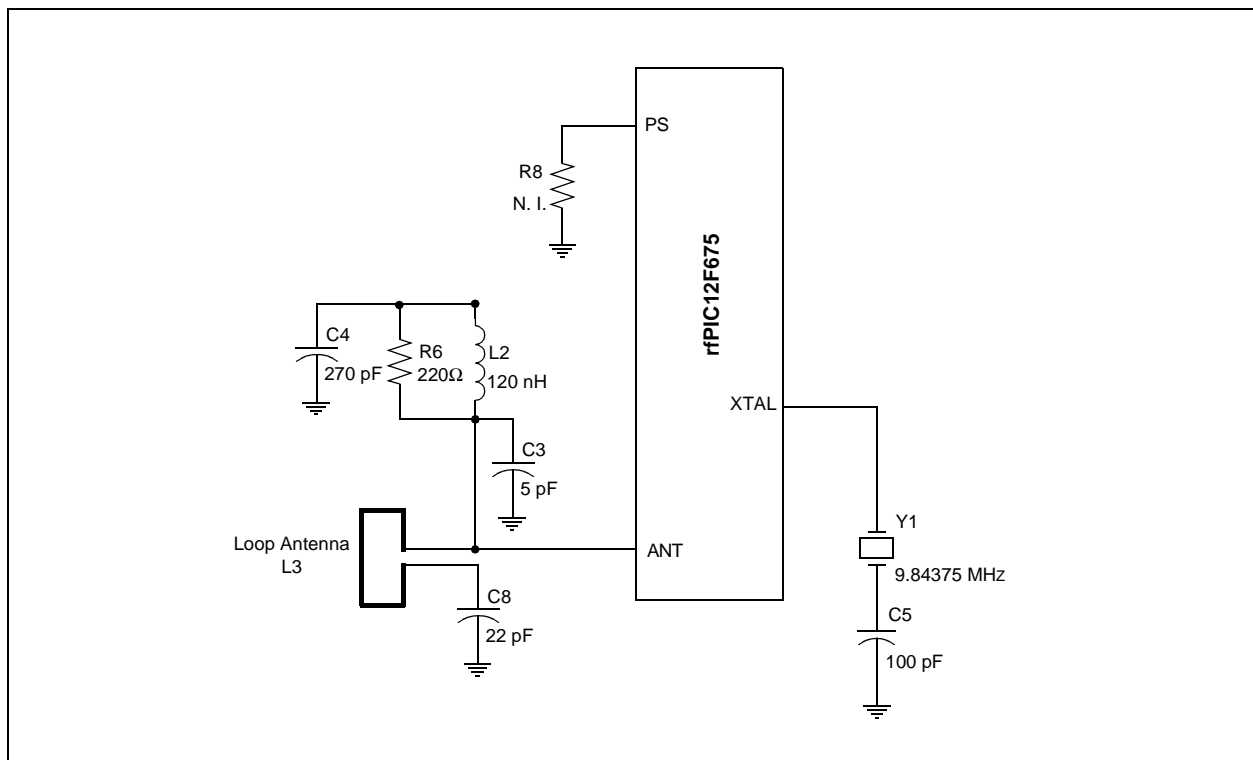
The PLL style transmitter within the rfPIC requires minimum external components to complete the RF transmitter. The fundamental frequency of the transmitter is determined by Y1. To derive the appropriate crystal frequency, simply divide the desired transmit frequency by 32. For example, if the desired transmit frequency is 315 MHz, the crystal frequency is 9.84375 MHz.

Loop antenna L3 is matched to the single-ended RF driver via C3 and C8, which also form the resonant tank. Refer to the "Matching Small Loop Antennas to rfPIC™ Devices" Application Note AN831 (DS00831) and "Designing Loop Antennas for the rfPIC12F675" Application Note AN868 (DS00868) for additional technical detail on selecting the appropriate component values for your RF application.

Capacitor C4 is selected to provide decoupling for the 3V supply. Be sure the components selected for your application have a self-resonant frequency well above the desired transmit frequency. The filter formed by L2 and R6 further help decouple the high frequency energy from the rest of the circuitry. The R6 also de-Q's the antenna.

The output power of the transmitter circuit can be adjusted via R8, maximum power is obtained when it is left an open circuit. The transmit power can be changed per the "Power Select Resistor Select" table located in the "rfPIC12F675" Data Sheet (DS70091). This is also useful when trying to certify a product to FCC regulations.

FIGURE 2: RF CIRCUITRY



Sensoror SP-13 Sensor IC

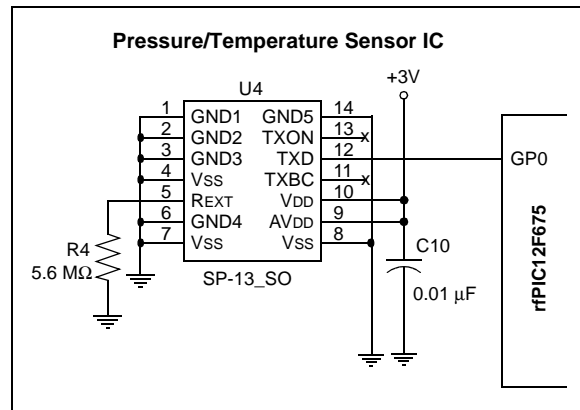
The SP-13 sensor IC performs several functions. It measures pressure, temperature, and generates a flag when the battery voltage drops below a predetermined threshold. The SP-13 has five unique modes:

1. **Storage mode:** If the pressure is below 1.5 bar, pressure is measured every 60 seconds but no data is sent. If the pressure increases above 1.5 bars, the component shifts into the Initial mode.
2. **Initial mode:** This mode occurs at power on or if the pressure increases above 1.5 bar from Storage mode. In this mode, pressure is measured every 0.85 seconds and data is sent every 0.85 seconds. This sequence is repeated 256 times. After the sequence is repeated 256 times, the device shifts into the Normal mode only if pressure is above 1.5 bar. If the pressure is below 1.5 bar, the device will shift into the Storage mode.
3. **Normal mode:** Pressure is measured every 3.4 seconds and data is transmitted every 60 seconds. If the measured pressure differs by more than 200 mbar from the reference taken every 60 seconds, the device enters a Pressure Alert mode.
4. **Pressure Alert mode:** It is the same measurement and transmitting pattern as the Initial mode.
5. **High Temp Alert mode:** If the temperature exceeds 120°C, the SP-13 device enters into the same measurement and transmitting pattern as the Initial mode.

The SP-13 also includes a 32-bit identification number that is programmed into the device at the time of manufacture. This unique ID, when used by the central receiver, allows differentiation between S/TXs.

Sensoror, as well as several other manufacturers, continue to offer enhanced pressure sensing devices of varying functionality. Therefore, it is recommended that a TPM developer thoroughly research the market prior to making a final pressure sensor selection.

FIGURE 3: SENSOROR SP-13 SENSOR IC

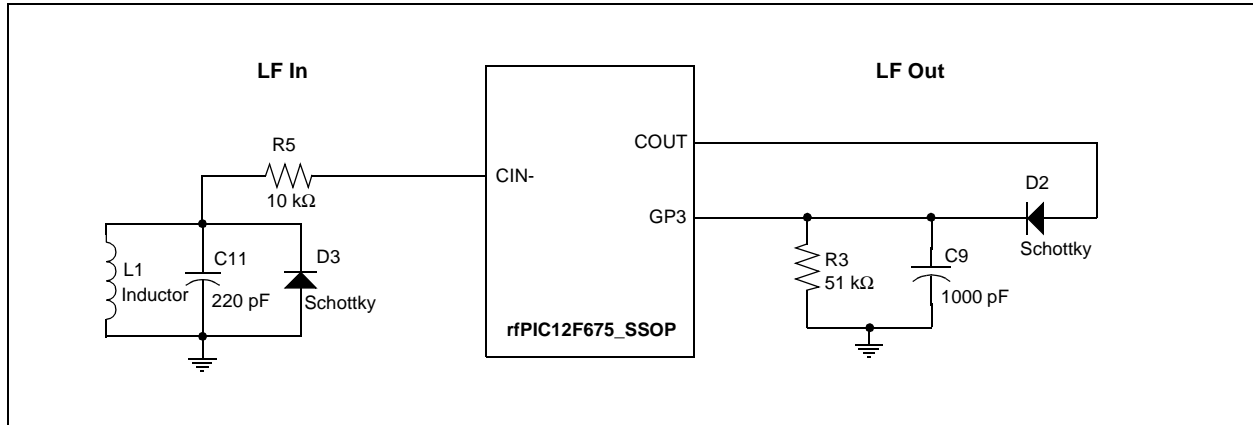


LF Input Circuitry

The LF input is designed to receive and demodulate a 125 kHz signal and transform the received data into a specific command. The LF input circuitry makes use of the internal comparator of the rPIC, thereby reducing cost, module size and quiescent current. The LF input circuitry features a LC tank circuit that is tuned to 125 kHz. The LF sensing input comprises L1 and C11. L1 is specially designed by Coilcraft for this type of application. It provides good sensitivity in a compact package. A conventional coil could be used in its place, but overall circuit sensitivity or range would be reduced. Schottky diode D3 is used to clamp the voltage developed across the LC tank to safe levels. The output of the LC tank circuit, after passing through current limiting resistor R5, is fed into the rPIC comparator's negative input. The comparator's positive input is configured as VREF through the rPIC12F675's VREF module. The output of the comparator is then fed into an envelope detector consisting of Schottky diode D2, capacitor C9 and resistor R3. C9 and R3 are selected to provide adequate filtering of the LF frequency without rounding the edges of the desired data signal. The output of the envelope detector is then fed directly into a port pin on the rPIC and used to process the LF data.

Without a limiting diode, the LF input circuit may be prone to being overdriven when strong LF fields are present. This can be seen when the LF commander device is in close proximity to the S/TX device. The envelope detection circuit can be abandoned to reduce cost, but doing so would require additional data extraction software.

FIGURE 4: LF CIRCUITRY

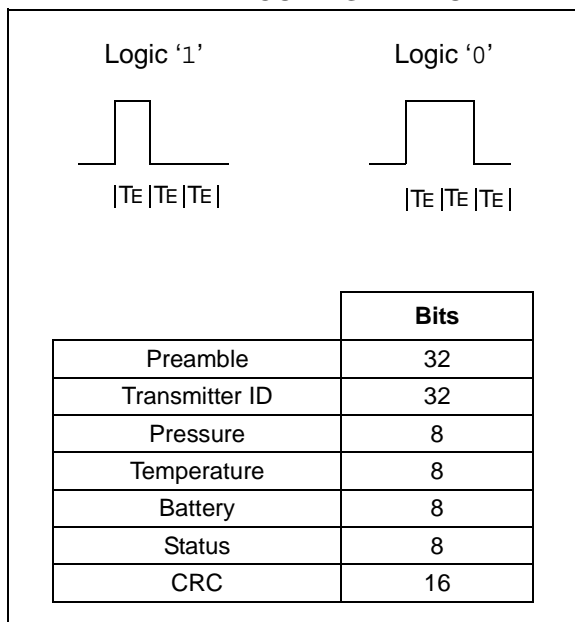


Details of the LF transmission format and the specific commands can be found in the Section, "LF Commander".

RF Transmission Format

The encoding method used for this demonstration system is the 1/3-2/3 PWM format with T_E (basic pulse element) time of 400 μ s and a bit period of $3 \times T_E$ or 1.2 ms.

FIGURE 5: RF TRANSMISSION ENCODING METHOD



Preamble: The preamble is a series of 31 logic '1' bits followed by a single logic '0' bit. The preamble allows the receiver to recognize the RF transmission as a valid S/TX message. The preamble also allows the receiver to synchronize to the RF message, thereby compensating for any oscillator inaccuracies within the transmitter. The system designer may vary the number of preamble bits based on system requirements. Longer preamble bit lengths may be appropriate where receiver quiescent current is an issue. Shorter preamble bit lengths may be appropriate where S/TX battery usage is a concern. In either case, it is purely a trade-off between receiver quiescent current and battery power consumed by the S/TX device.

Transmitter ID: The 32 transmitter ID bits are used to uniquely identify each S/TX. A frame of 32 bits insures that there is a very low probability that any two S/TXs will have the same ID.

Pressure: The pressure in kPa is obtained by multiplying the unsigned binary value of this byte by 2.5.

Temperature: The temperature in degrees C is obtained by subtracting 40 from the unsigned value of byte 8.

Battery: Bit 7 of this byte indicates the battery condition. A logic '1' is considered normal while a logic '0' indicates a low battery voltage.

Status: This status byte contains the following information:

Bits 0 and 1: Indicate operating state of sensor IC

00 = Initial or Storage mode

01 = Normal mode

10 = Pressure Alert mode

11 = Temperature Alert mode

CRC (2 bytes): Implement according to CCITT standards.

LF Commander

THEORY OF OPERATION

The system proposed in this document is based on an auto-location system, enabling it to detect the position of a specific S/TX device. This requires a LF commander device at each wheel arc and possibly at the spare tire mounting position.

Having a handheld LF commander unit can enable a lower cost system. Although, this would require that the system be manually relearned after a tire rotation, the S/TX device is able to detect tire rotation or some other system to engage data transmission. The LF commander device is capable of sending commands to the S/TX device via a LF transmission such as:

- Enable RF transmissions
- Disable RF transmissions
- Transmit an immediate message
- Transmit at 60-second intervals
- Transmit at 15-second intervals
- Transmit at 5-second intervals

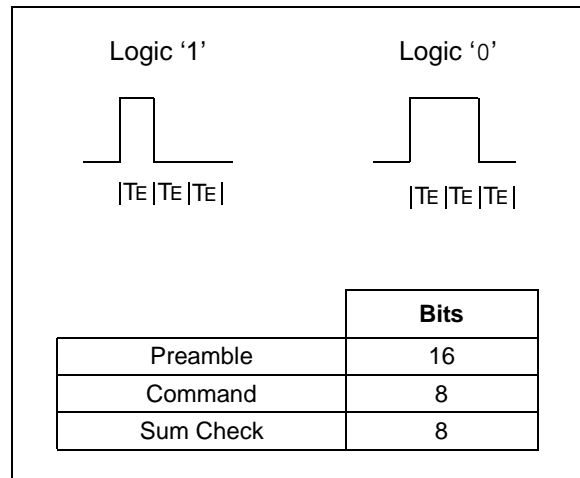
The LF commander unit is based on the PIC16F628 MCU device. Communication between the LF commander and the S/TX is accomplished via magnetic field. When the LF commander is transmitting a message, it is essentially creating a magnetic field by exciting a series LC circuit. The LC circuit is excited by the PICmicro's PWM port. This port is set up to generate a 50% duty cycle at 125 kHz. The command data is then modulated on this 125 kHz signal in the form of ASK modulation. Functionally, this is accomplished by instructing the PICmicro to toggle the PWM port between 0% and 50% duty cycle at the rate of the data.

LF TRANSMISSION FORMAT

The encoding format used in the LF link is a 1/3 - 2/3 PWM format with $400\ \mu\text{s}$ TE (basic pulse element). Selecting $400\ \mu\text{s}$ TE or greater insures the magnetic field generated by the series LC circuit has adequate time to rise and decay, without requiring too much wave shaping of the recovered square wave in the S/TX circuitry.

The transmission data format for the LF link is shown in Figure 6.

FIGURE 6: LF TRANSMISSION ENCODING METHOD



Preamble: The preamble is a series of 15 logic '1' bits and 1 logic '0' bit. This reduces the chance of the S/TX receiving erroneous data from electronic devices that generate strong 125 kHz fields. Computer CRT's and switching power supplies are examples of such devices.

Command: These 8 bits of data contains the specific command that the S/TX is being asked to perform. Table 1 illustrates the various commands (MSB is left most column).

TABLE 1: BIT FUNCTIONS

Bits	Function
01101101	Enable RF transmissions
10010010	Disable RF transmissions
10101010	Transmit an immediate RF message
10110110	Transmit at 60-second interval
11001100	Transmit at 15-second interval
11010011	Transmit at 5-second interval

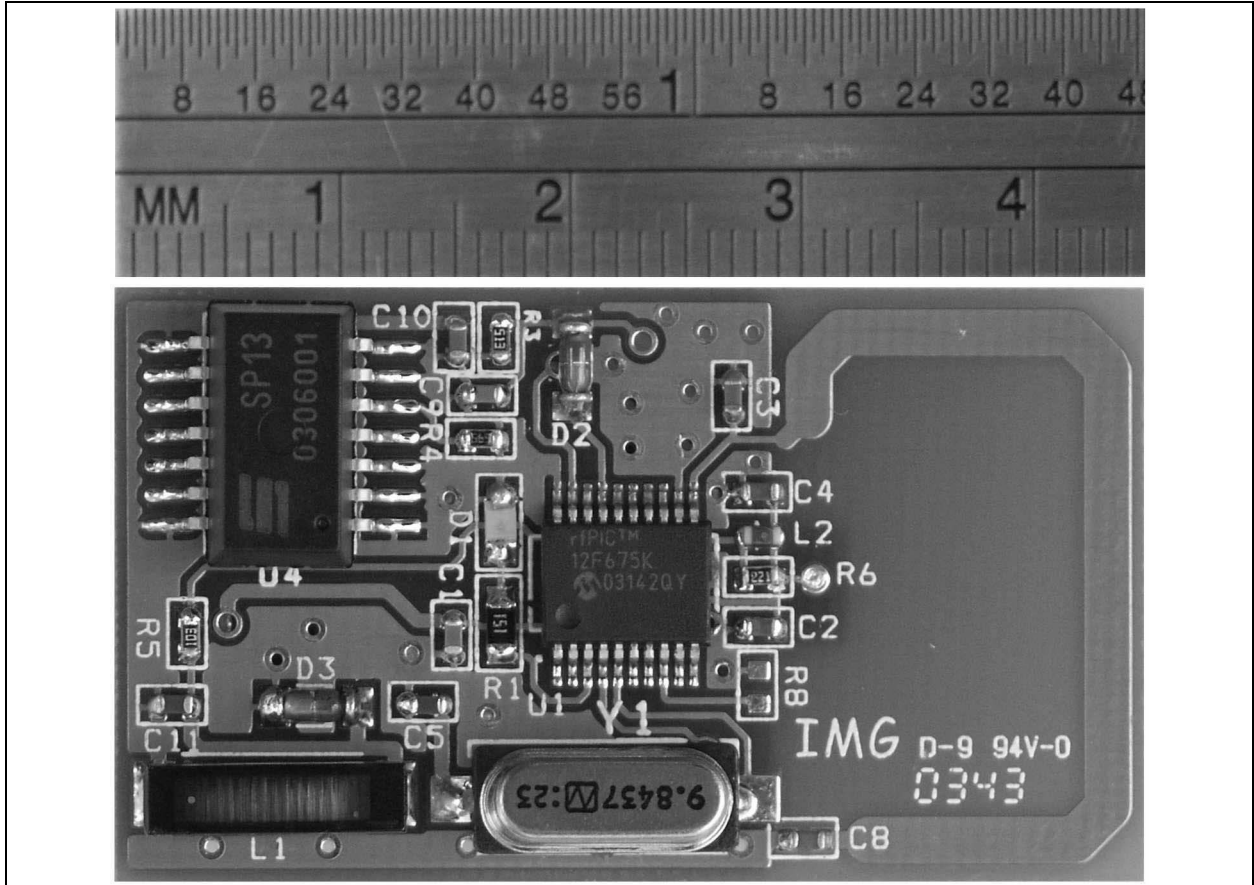
Sum Check: Calculated by adding contents of the command byte with '10101010'.

SUMMARY

TPM use in the automotive industry is growing, driven by customer demand, improved safety, and possible compulsory-usage legislation. Microchip's low-cost rfPIC devices are well suited for the application and help reduce the overall TPM system cost.

The use of rfPIC based S/TX makes for a flexible solution that allows for the merging with existing systems such as security, PKE, RKE and more.

FIGURE 7: PHOTOGRAPH OF SENSOR/TRANSMITTER DEVICE



REFERENCE DOCUMENTS

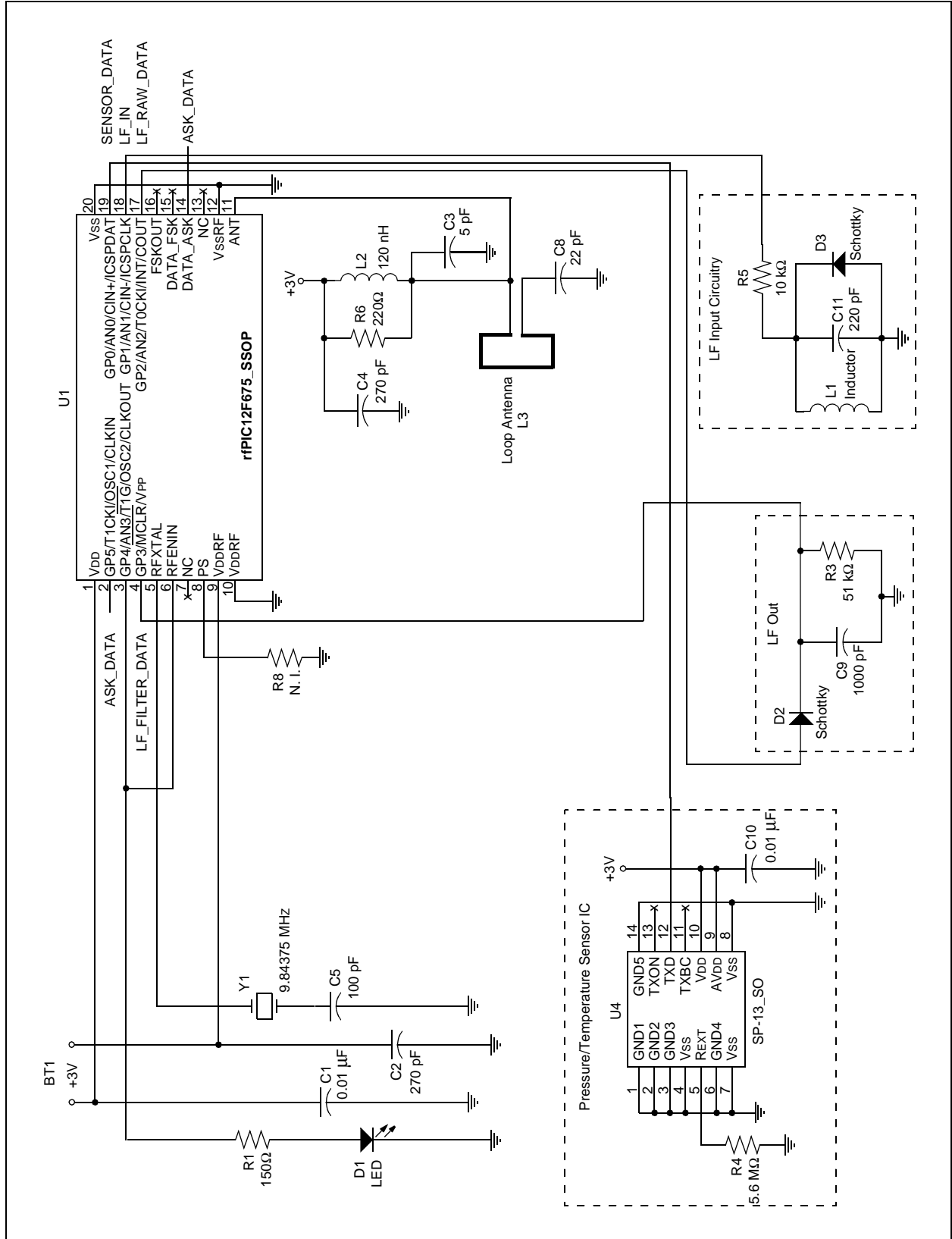
The following reference documents are available from Microchip's web site at www.microchip.com.

1. "Low Frequency Magnetic Transmitter Design" Application Note (AN232), DS00232; Microchip Technology Inc.
2. "Designing Loop Antennas for the rfPIC12F675" Application Note (AN868), DS00868; Microchip Technology Inc.
3. "Matching Small Loop Antennas to rfPIC Devices" Application Note (AN831), DS00831; Microchip Technology Inc.
4. "Magnetic Tuning of Resonant Resistors and Methods for Increasing Sensitivity" Application Note (AN832), DS00832; Microchip Technology Inc.
5. "Optimizing PLL Filters for the rfPIC12C509A and rfHCS362" Application Note (AN846), DS00846; Microchip Technology Inc.
6. "rfPIC12F675" Data Sheet, DS70091; Microchip Technology Inc.

Note: Microchip has a confidential Application Note on Magnetic Sensors, "Magnetic Tuning of Resonant Resistors and Methods for Increasing Sensitivity" Application Note, DS00832. Contact Microchip for a Non-Disclosure Agreement in order to obtain this application note.

APPENDIX A: SCHEMATICS

FIGURE A-1: TPM SENSOR/TRANSMITTER SCHEMATIC



AN238

NOTES:

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is intended through suggestion only and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. No representation or warranty is given and no liability is assumed by Microchip Technology Incorporated with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Use of Microchip's products as critical components in life support systems is not authorized except with express written approval by Microchip. No licenses are conveyed, implicitly or otherwise, under any intellectual property rights.

Trademarks

The Microchip name and logo, the Microchip logo, Accuron, dsPIC, KEELOQ, MPLAB, PIC, PICmicro, PICSTART, PRO MATE and PowerSmart are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.


AmpLab, FilterLab, microID, MXDEV, MXLAB, PICMASTER, SEEVAL, SmartShunt and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Application Maestro, dsPICDEM, dsPICDEM.net, dsPICworks, ECAN, ECONOMONITOR, FanSense, FlexROM, fuzzyLAB, In-Circuit Serial Programming, ICSP, ICEPIC, Migratable Memory, MPASM, MPLIB, MPLINK, MPSIM, PICKit, PICDEM, PICDEM.net, PICtail, PowerCal, PowerInfo, PowerMate, PowerTool, rLAB, rPIC, Select Mode, SmartSensor, SmartTel and Total Endurance are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

Serialized Quick Turn Programming (SQTP) is a service mark of Microchip Technology Incorporated in the U.S.A.

All other trademarks mentioned herein are property of their respective companies.

© 2004, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

 Printed on recycled paper.

**QUALITY MANAGEMENT SYSTEM
CERTIFIED BY DNV
== ISO/TS 16949:2002 ==**

Microchip received ISO/TS-16949:2002 quality system certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona and Mountain View, California in October 2003. The Company's quality system processes and procedures are for its PICmicro® 8-bit MCUs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.



MICROCHIP

WORLDWIDE SALES AND SERVICE

AMERICAS

Corporate Office

2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: <http://www.microchip.com>

Atlanta

3780 Mansell Road, Suite 130
Alpharetta, GA 30022
Tel: 770-640-0034
Fax: 770-640-0307

Boston

2 Lan Drive, Suite 120
Westford, MA 01886
Tel: 978-692-3848
Fax: 978-692-3821

Chicago

333 Pierce Road, Suite 180
Itasca, IL 60143
Tel: 630-285-0071
Fax: 630-285-0075

Dallas

4570 Westgrove Drive, Suite 160
Addison, TX 75001
Tel: 972-818-7423
Fax: 972-818-2924

Detroit

Tri-Atria Office Building
32255 Northwestern Highway, Suite 190
Farmington Hills, MI 48334
Tel: 248-538-2250
Fax: 248-538-2260

Kokomo

2767 S. Albright Road
Kokomo, IN 46902
Tel: 765-864-8360
Fax: 765-864-8387

Los Angeles

18201 Von Karman, Suite 1090
Irvine, CA 92612
Tel: 949-263-1888
Fax: 949-263-1338

San Jose

1300 Terra Bella Avenue
Mountain View, CA 94043
Tel: 650-215-1444
Fax: 650-961-0286

Toronto

6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC

Australia

Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

China - Beijing

Unit 706B
Wan Tai Bei Hai Bldg.
No. 6 Chaoyangmen Bei Str.
Beijing, 100027, China
Tel: 86-10-85282100
Fax: 86-10-85282104

China - Chengdu

Rm. 2401-2402, 24th Floor,
Ming Xing Financial Tower
No. 88 TIDU Street
Chengdu 610016, China
Tel: 86-28-86766200
Fax: 86-28-86766599

China - Fuzhou

Unit 28F, World Trade Plaza
No. 71 Wusi Road
Fuzhou 350001, China
Tel: 86-591-7503506
Fax: 86-591-7503521

China - Hong Kong SAR

Unit 901-6, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

China - Shanghai

Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xia Road
Shanghai, 200051
Tel: 86-21-6275-5700
Fax: 86-21-6275-5060

China - Shenzhen

Rm. 1812, 18/F, Building A, United Plaza
No. 5022 Binhe Road, Futian District
Shenzhen 518033, China
Tel: 86-755-82901380
Fax: 86-755-8295-1393

China - Shunde

Room 401, Hongjian Building, No. 2
Fengxiangnan Road, Ronggui Town, Shunde
District, Foshan City, Guangdong 528303, China
Tel: 86-757-28395507 Fax: 86-757-28395571

China - Qingdao

Rm. B505A, Fullhope Plaza,
No. 12 Hong Kong Central Rd.
Qingdao 266071, China
Tel: 86-532-5027355 Fax: 86-532-5027205

India

Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O'Shaughnessy Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan

Benex S-1 6F
3-18-20, Shinyokohama
Kohoku-Ku, Yokohama-shi
Kanagawa, 222-0033, Japan
Tel: 81-45-471- 6166 Fax: 81-45-471-6122

Korea

168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea 135-882
Tel: 82-2-554-7200 Fax: 82-2-558-5932 or
82-2-558-5934

Singapore

200 Middle Road
#07-02 Prime Centre
Singapore, 188980
Tel: 65-6334-8870 Fax: 65-6334-8850

Taiwan

Kaohsiung Branch
30F - 1 No. 8
Min Chuan 2nd Road
Kaohsiung 806, Taiwan
Tel: 886-7-536-4818
Fax: 886-7-536-4803

Taiwan

Taiwan Branch
11F-3, No. 207
Tung Hua North Road
Taipei, 105, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE

Austria

Durisolstrasse 2
A-4600 Wels
Austria
Tel: 43-7242-2244-399
Fax: 43-7242-2244-393

Denmark

Regus Business Centre
Lautrup høj 1-3
Ballerup DK-2750 Denmark
Tel: 45-4420-9895 Fax: 45-4420-9910

France

Parc d'Activite du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - Ier Etage
91300 Massy, France
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany

Steinheilstrasse 10
D-85737 Ismaning, Germany
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy

Via Quasimodo, 12
20025 Legnano (MI)
Milan, Italy
Tel: 39-0331-742611
Fax: 39-0331-466781

Netherlands

P. A. De Biesbosch 14
NL-5152 SC Drunen, Netherlands
Tel: 31-416-690399
Fax: 31-416-690340

United Kingdom

505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44-118-921-5869
Fax: 44-118-921-5820

01/26/04