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Design of Direct-Type Tire-Pressure Monitoring System Based on SP37 Sensor

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Abstract: Tire pressure monitoring system (TPMS) can be effective in preventing tire burst. However, traditional TMPS mostly uses the combination of pressure sensor, microcontroller and radio frequency (RF) transmitter, with excessive discrete components, low integration, poor reliability and high power consumption. The use of special TPMS sensor chip SP37 to design tire pressure monitoring module can overcome these shortcomings. Direct-type tire pressure monitoring module was designed based on SP37, and central receiving module was designed using microcontroller ATMEGA16 and RF receiving chip MC33594. Thus, the real-time monitoring of tire pressure and temperature is achieved. SP37 working mode can be flexibly configured *via* software, and power management implemented by low-frequency arousal technology and software greatly reduces system power consumption. Moreover, integrated RF transmitter improves anti-interference capability to protect communication reliability. *Copyright © 2013 IFSA.*

Keywords: Wireless communication, TPMS, SP37.

1. Introduction

TPMS is a monitoring system used to monitor perspective blind area: tire pressure and temperature during vehicle driving. The low pressure, high pressure and high temperature of tire are the main reasons for tire burst. Sudden tire burst accidents accounted for above 70% within major traffic accidents on Chinese highway. Moreover, there are 260 thousand traffic accidents caused by high tire pressure or leakage in the U.S. every year. Therefore, the TPMS products for real-time tire-pressure detection came into being. The U.S. Congress on November 1, 2000 made law requiring new finished cars after November, 2003 taking TPMS as standard configuration, while the EU also made similar provisions [1]. TPMS mostly uses sensor+RF+MCU+antenna+cell solution at present with disadvantages such as low integration, small reliability, large volume and high power consumption. The pressure sensor chip SP37 of Infineon integrates not only pressure/temperature/acceleration sensor modules and MCU module, but also RF transmitter module. Therefore, the use of SP37 sensor to design TPMS clearly has a natural advantage. This work selected SP37 as tire pressure sensor and RF transmitter, Maxim MAX1473 as receiving chip and independent Philips CAN bus-controller SJA1000 to design a new TPMS.

2. Overall TPMS Scheme

There are two kinds of common TPMSs [2]. One is Wheel-Speed Based TPMS (abbreviation: WSB TPMS, or called indirect-type TPMS). This system monitors 4 wheel speed signals through the wheel

speed sensor of ABS system. Tire diameter becomes large or small when certain tire pressure is too high or low, while wheel speed also correspondingly changes. Monitoring system will compare wheel speed change with previously stored standard value, and then it will give an alarm if tire pressure is too high or insufficient. Such system cannot judge the situation of more than two tires being lack of gas at the same time or speed exceeding 100 km/h, with complex system calibration. Failure tire positioning is not precise enough, and pressure values cannot be reflected visually and accurately. The other is Pressure-Sensor Based TPMS (abbreviation: PSB TPMS, or called direct-type TPMS). This system uses pressure sensor installed in each tire to directly measure tire pressure to display and monitor it. System will automatically turn on alarm when tire pressure is too low or there is leakage. Driver can intuitively understand every tire pressure condition through direct-type TPMS. In contrast, direct-type TPMS is superior to indirect-type TPMS in function and performance, so this system used the direct-type TPMS. It mainly consisted of four SP37 tire pressure monitoring modules installed in car and a central receiver module installed on driving platform. Four SP37 tire-pressure monitoring modules real-timely measured tire pressure, temperature and acceleration, and the measured signals were transmitted after modulated into high frequency signals. Central receiving module received the signals and displayed the received tire pressure, temperature data on the screen for driver to refer to. If tire pressure and temperature abnormalities occur, then central receiving module will give relevant alarm signal to remind driver to take necessary measures. System block diagram is shown in Fig. 1.

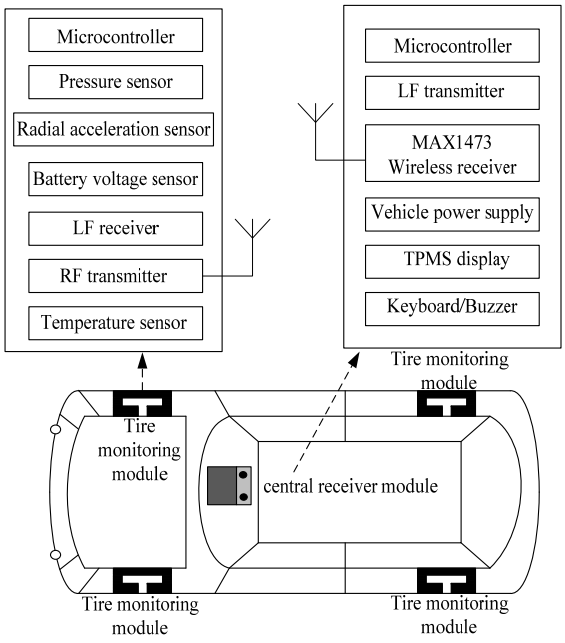


Fig. 1. Tire pressure monitoring system block diagram.

3. TPMS Hardware Design

3.1. Application of TPMS Sensor SP37

SP37 is highly-integrated monolithic TPMS sensor [3], with low-voltage power supply, built-in microcontroller and wireless FSK/ASK UHF transmitter. SP37 has integrated pressure sensor produced by Micro Electro Mechanical System (MEMS) technology, acceleration sensor chip and digital signal processing ASIC chip, as shown in Fig. 2. The ASIC chip includes temperature sensor, battery voltage detection, internal clock, ADC, sampling/holding (S/H), SPI interface, sensor data calibration, data management, ID code and other functions. A pressure/temperature importing hole left on upper packaging can directly import pressure into the stress film of pressure sensor and ambient temperature into semiconductor temperature sensor, as shown in Fig. 3.

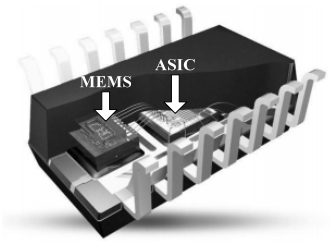


Fig. 2. MEMS sensor packaging with ASIC

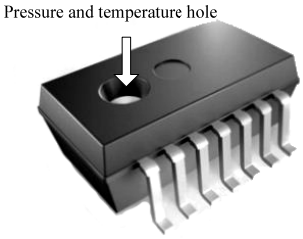


Fig. 3. The hole for measuring pressure/temperature.

SP37 has main advantages as follows: 1) Hardware: There are acceleration detecting sensor, pressure sensor, temperature sensor, thermal shutdown sensor, voltage detecting sensor and RF transmitting module. Peripheral circuit elements are less, and circuit volume smaller. Sensitive 125 kHz low-frequency arousal, freely-set RF transmit mode, ASK/FSK modulation mode and fully-integrated VCO and PLL synthesizer make transmission frequency stabilized at set value. There are also three I/O ports with multiplex function, Manchester encoder with hardware, Manchester low-frequency detector and so on. 2) Software: There are random number generator to avoid data conflicts and cyclic redundancy check (CRC). Interior has standard library functions that have been cured by

manufacturers with pressure, temperature, acceleration, thermal shutdown, power voltage value, pressure compensation, temperature compensation, etc. The software writing and debugging of TPMS transmitter part are relatively easy to implement. 3) Low power consumption: Current consumption is less than 0. 7μA under dormant state, and interval timer can be set by software to extend system life.

The main performance of SP37 sensor is shown in Table 1, and schematic diagram of tire pressure monitoring circuit based on SP37 is shown in Fig. 4.

Table 1. Performance of sensor SP37.

	Pressure	Temperature	Acceleration	Voltage
Measuring range	100~450 KPa	-40~125 °C	-12~115 g	1.8~3.6 V
Measuring accuracy	1.37 KPa	1 °C	0.5 g	0.0184 V
Measuring time	6 ms	1.5 ms	6 ms	17 ms

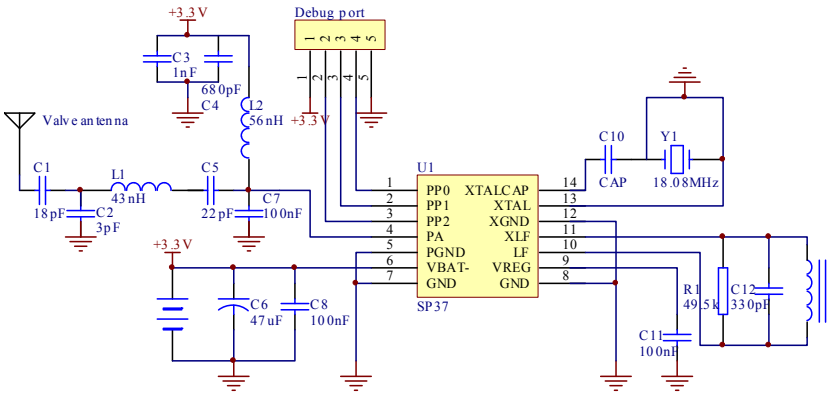


Fig. 4. SP37 Application circuit.

The circuit mainly includes three parts: power filter circuit, high-frequency crystal-oscillating circuit and low-frequency antenna matching circuit. Filter capacitances are configured near power pins in order to suppress noise and improve reliability since RF chip is very sensitive to electromagnetic noise of car. The high working frequency of system used appointed band 433.92 MHz in Europe TPMS, and high SP37 frequency is 24 times of external crystal frequency. Therefore, 18.08 MHz passive crystal and 8 pF load capacitance were selected. ASK is poor in noise immunity and susceptible to interference, so this system used FSK modulation. RF PA transmitting units were integrated inside SP37, with 15.02+j53.219 Ω output impedance. Chamber valve was used as antenna, and π-type matching circuit for impedance matching. Inductance and capacitance values were optimized through ADS software. Antenna can be matched to the output impedance 500Ω of power amplifier SP37 to suppress harmonics and improve antenna performance.

SP37 receives low-frequency information *via* low-frequency circuit so that it can be aroused by central receiving module. Low-frequency antenna consisted of parallel resistors, capacitors and inductors. The resonant frequencies of inductors and capacitors were designed as 125 kHz low carrier frequency, exactly the same as low SP37 frequency. Thus optimal low-frequency receiving sensitivity can be achieved. Low-frequency inductance is 4.77 mH, and capacitance [4].

$$C=\left(\frac{1}{2\pi f_c}\right)^2/L=\left(\frac{1}{2\times 3.14\times 125\times 10^3}\right)^2/4.77\times 10^{-3}= \\ =3.398\times 10^{-10}\approx 330\ pF \quad (1)$$

3.2. Hardware Design on Central Receiving Module

Central receiving module informs driver of whether current tire pressure and temperature are abnormal through flashing or liquid crystal display. Central receiver module is located at automobile cab, and tire working environment is bad when car is driving at a high speed. Thus, signal drift and sporadic instability appear due to the shielding, interference and other issues of other electronic products. Therefore, it is particularly necessary to make efforts to solve signal transmission stability during driving at a high speed. The central receiving system is mainly composed of wireless reception section, main controller and peripheral associated devices, as shown in Fig. 5. Radio receiving section consists of highly-integrated UHF receiver MC33594 and its matching network. MC33594 can exchange data with main controller ATmega16 through its SPI bus interface, with functions of receiving and

demodulating Manchester coding data modulated by ASK or FSK [5] [6].

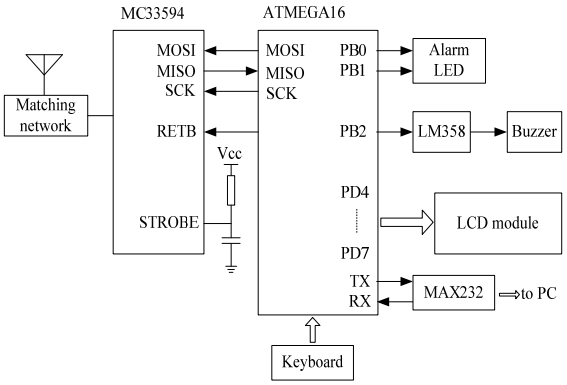


Fig. 5. Center receiver module hardware diagram.

This system used FSK receiving mode with 433.92 MHz operating frequency, and the signals received by antenna were amplified and mixed by MC33594 then filtered by ceramic filter. System sent data by Manchester, and receiving control system used ATmega16 for decoding, data processing, controlling LCD displaying pressure and temperature values and alarm. Alarm includes overpressure alarm, undervoltage alarm, over-temperature alarm, gas leakage alarm, weak current alarm and no signal alarm. In addition, this module also designed keyboard module and serial communication interface with computer to query and facilitate parameter set and computer to analyze tire pressure data.

4. TPMS Software Design

4.1. Data Frame Format

This system used Manchester coding, FSK signal modulation and 9600bps transmission rate. Transmission system transmitted data in the form of data frame and ensured reliable data reception by CRC8 method. MCU first aroused SP37 by sending leading bit and then sent data frame for each communication. Data frame format transmitted by SP37 is shown in Table 2. receiving module for display until counted up to a certain threshold. This method can greatly reduce system power consumption [6].

Table 2. SP37 data frame format.

Pressure	Temperature	Voltage	Acceleration	Synchronization code	Tire ID	Status bit	Alarm bit	Correction value	CRC8
1 byte	1 byte	1 byte	1 byte	2 byte	3 byte	1 byte	1 byte	1 byte	1 byte

4.2. Software Design on Tire Pressure Monitoring Module

SP37 first performed power-up initializing program and then entered sleep mode for power saving. Car was considered moving when acceleration sensor detects car acceleration exceeding set threshold, then SP37 processor was aroused by external interrupt and executed starting-up detection program. SP37 sequentially detected the pressure, temperature, battery voltage and other information in tire. Then, it compared the detected values with predetermined alarm values to determine whether there was an exception and then performed appropriate warning action. SP37 returned to sleep mode when car stopped. Program flow chart is shown in Fig. 6.

SP37 RF emission needs a lot of power consumption which can be greatly reduced through the decrease of its transmitting frequency. System will process tire data after tire pressure monitoring module finishes the data detection to determine whether there is tire failure. If a failure occurs, then system immediately transmits data to notice central receiving module give an alarm, otherwise timer does counting up. Data are not transmitted to the central

Signal collision phenomenon is inevitable when four tire pressure monitoring modules transmit data to a central receiving module. Therefore, this design used time-sharing method to transform point-to-multipoint communication into point-to-point communication.

4.3. Software Design on Central Receiving Module

The main function of central receiving module is to set SP37 transmitting time and send tire data from SP37 to display module. Central receiving-module system leaves RF wireless receiving chip MC33594 in receiving state to wait for wireless signal from SP37 after power-up initialization. Then, MC33594 determines whether the received signal is a noise or data through data frame preamble "0xFFFF". Moreover, it will continue to receive if it is data. It is necessary to determine whether SP37 transmitting time setting is needed for received data, and SP37 will enter its setting process, if necessary. SP37 can conduct the setting after reset and do not need setting again. Moreover, each SP37 transmits tire data according to it. If signal collision phenomenon occurs during setting, then central receiving module should

immediately loop back. Moreover, it should retransmit command to allow different SP37 to retransmit tire data according to different delays and reset transmitting time [7]. Normal work flow is shown in Fig. 7. Data frame can be sent through serial port for the receiving and storage of external data, if necessary.

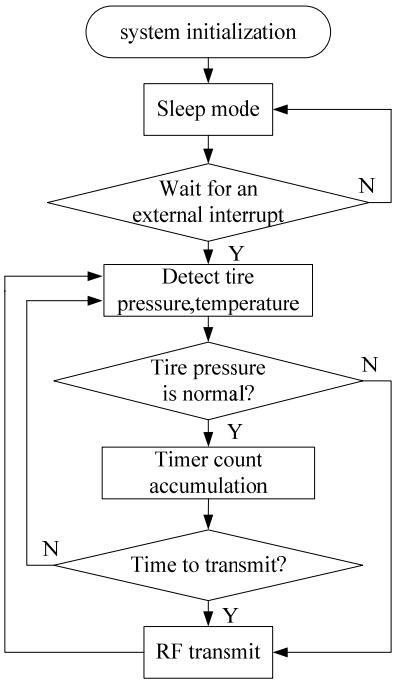


Fig .6. Flowchart of tire monitoring module.

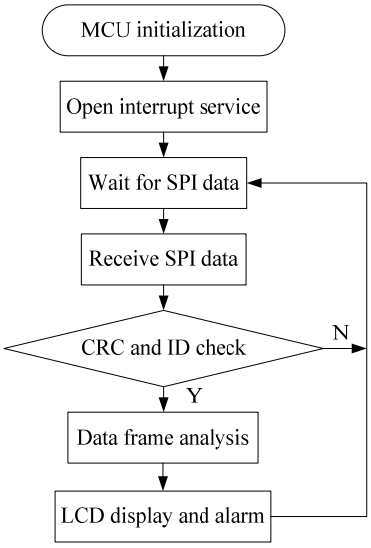


Fig .7. Flowchart of center receiver module.

5. TPMS Performance Test

This system was installed in car for actual measurements and run, obtaining performance indicators as follows:

1) Tire pressure monitoring range is 0~450 KPa, and resolution is 2.0 KPa. Normal driving tire pressure is generally between 200~280 KPa.

2) Temperature detection range is -30~120 °C, and resolution is 2.0 °C.

TPMS lithium battery of FANSO ER2450,
Nominal capacity 1000 mAh,
Nominal voltage 3.6V,
Operating temperature range -40~+125 °C.

3) Transmitter module can work more than 8 years with the normal traffic for 10 hours a day.

The resulting relationship between temperature and tire pressure in the actual test is shown in Fig. 8.

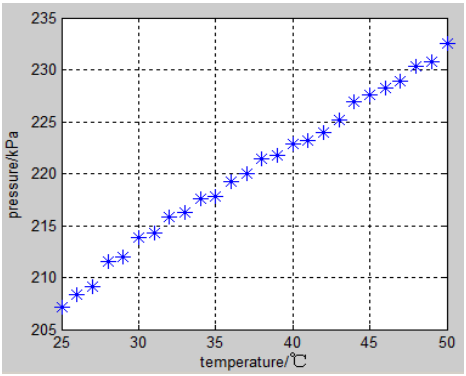


Fig.8. The relation of tire pressure and temperature.

6. Conclusions

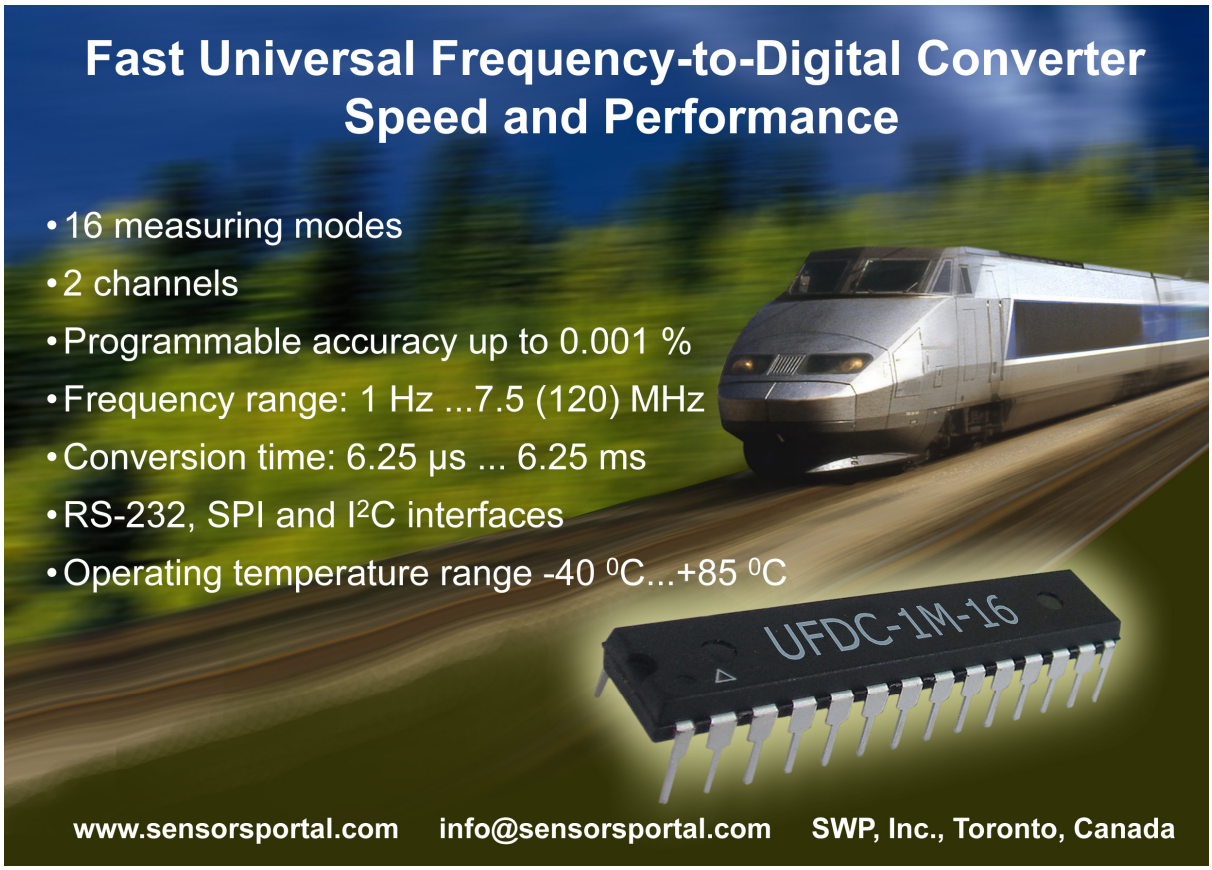
The real-time monitoring of car tire pressure and temperature is achieved through SP37. SP37 has integrated temperature sensor, pressure sensor, acceleration sensor, microcontroller and RF transmitter. Therefore, the use of SP37 to design TPMS has advantages including high integration, high reliability, small size and low power consumption. SP37 can control the working mode through software to further reduce power consumption. The adding of CAN bus controller into central receiving module is proposed, thus making TPMS become automotive CAN bus node and share data with other devices. Besides, TPMS life can be further improved if the mechanical energy of tire movement can be employed to supply power to sensor without battery.

References

[1]. S. Bulbeck, RFID and MEMS for tire pressure monitoring systems, *Smart Labels Analyst*, Vol. 10, Issue 21, 2002, pp. 22-23.

[2]. National Highway Traffic Safety Administration. Federal Motor Vehicle Safety Standards, Tire Pressure Monitoring Systems. Controls and Displays. Federal Register, 67, 108, 2002, pp. 38703-38749.

[3]. C. Kolle, W. Scherr, D. Hammerschmidt, et al., Ultra Low-Power Monolithically Integrated Capacitive

Pressure Sensor for Tire Pressure Monitoring, *IEEE*, 2, 2004, pp. 244-247.
[4]. Infineon. Tire Pressure Monitoring Sensor SP37 datasheet [EB/OL], http://www.infineon.com/cms/en/product, 2010.
[5]. MC33594/D PLL Tuned UHF Receiver for Data Transfer Applications, Rev. 1.1, Note 5: 21.
[6]. PLL tuned UHF receiver for data transfer applications, MC33594, Datasheet, 2002.
[7]. M. Kowalewski, Monitoring and managing tire pressure, *Potentials, IEEE*, Vol. 23, Issue 3, 2004, pp. 8-10.

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