

# Freescale Tire Pressure Monitor System Demo

by: Jeff Burgess

## TIRE PRESSURE MONITORING SYSTEM REFERENCE DESIGN

As a result of recent legislation in the U.S. (namely the Transportation Recall Enhancement, Accountability, and Documentation, or "TREAD" act), quite a large market for tire pressure monitor (TPM) systems has been created. To fulfill the large demand, Freescale has developed a comprehensive chipset for directly measuring temperature and pressure from within a tire. The chipset utilizes radio frequency (RF) technology, Freescale's HCXX series of Flash microcontroller units (MCUs), and a new capacitive pressure sensor element. Its method of direct pressure measurement (as opposed to "indirect," anti-lock brake-based systems) is the most reliable form of monitoring pressure and temperature inside a tire.

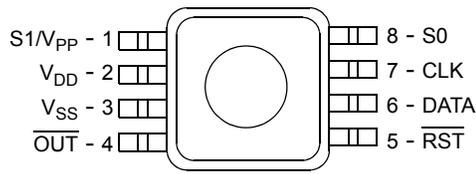
This document details the implementation from the top down of a real-world system for gathering pressure and temperature data from within the tires. It utilizes a very energy-efficient algorithm for measurement and transmission within the tire and is theoretically very similar to a system that might be put into production. This reference design demonstrates many functions that could be used in a production system. However, aside from the obvious customizations to the software and power-saving algorithms, the main difference between this and a marketable solution is related to laws and regulations overseeing RF radiation. The transmitter antenna is very efficiently matched to the transmitter output; however, the matching network is a high-pass filter, so that all of the upper harmonics of the intended signal are radiated. For a mass-production version using this chipset, the antenna

would be required to be redesigned to meet regulations, which may affect the radiated power.

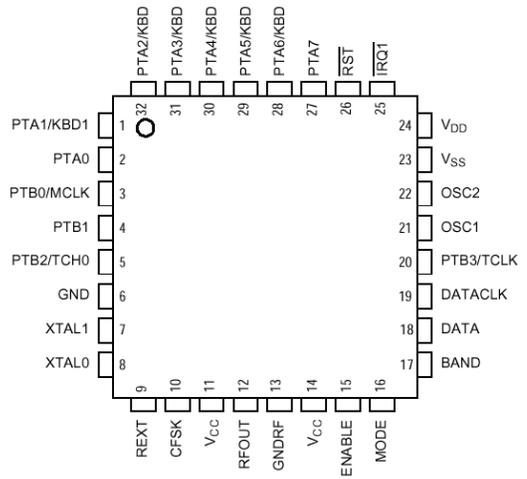
## FREESCALE TPM CHIPSET

The TPM chipset consists of the following four items.

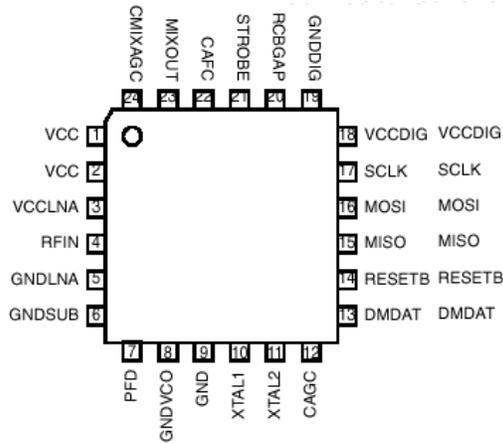
1. MPXY80xx – This is a surface micromachined, capacitive micro-electromechanical system (MEMS) pressure sensor. The MPXY80xx includes the pressure transducer, a positive temperature coefficient-diffused resistor temperature sensor, and all the necessary circuitry to produce a calibrated 8-bit digital output for pressure and temperature, all on a single die.
2. MC68HC908RF2 – Also known as RF2, this package consists of two dice. The first is a 2 KB Flash HC08 MCU (identical to part number MC68HC908RK2). The second is an RF transmitter capable of transmitting digital data for several hundred meters in free space (identical to part number MC33493).
3. MC33594 – This is the receiver compatible with the RF2. MC33594 is capable of receiving and demodulating Manchester-encoded data and outputting it on a common serial peripheral interface (SPI).
4. MC68HC908KX8 – Also known as KX8, this MCU is rather arbitrarily chosen for this demo. Freescale offers a wide selection of MCUs suitable for automotive usage.



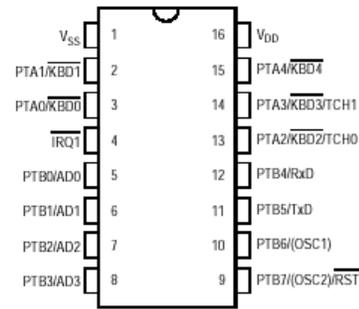
**MPXY8020/8040 Pressure and Temperature Sensor**



**MC68HC908RF2 Flash MCU and UHF Transmitter**



**MC33594 UHF Receiver**



**MC68HC908KX8 Flash MCU (Many Freescale MCUs can be substituted)**

**Figure 1. Freescale TPM Chipset**

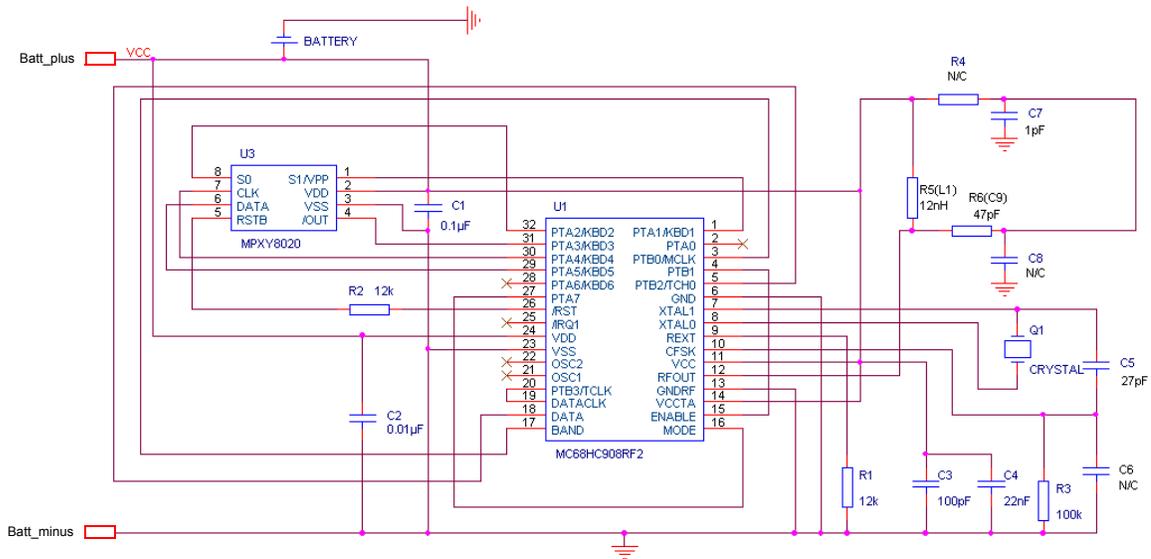
## HARDWARE IMPLEMENTATION

The Tire Pressure Monitoring System Reference Design consists of five modules: four tire modules and a receiver module. The tire modules consist of the MPXY80xx, the RF2, a battery, several discrete components, and a printed antenna. The receiver module has the MC33954, the KX8,

five LEDs to display the status, a battery, a power supply connection, and an RS-232 serial interface.

### Tire Module

The tire module's electrical schematic is shown in **Figure 2**.



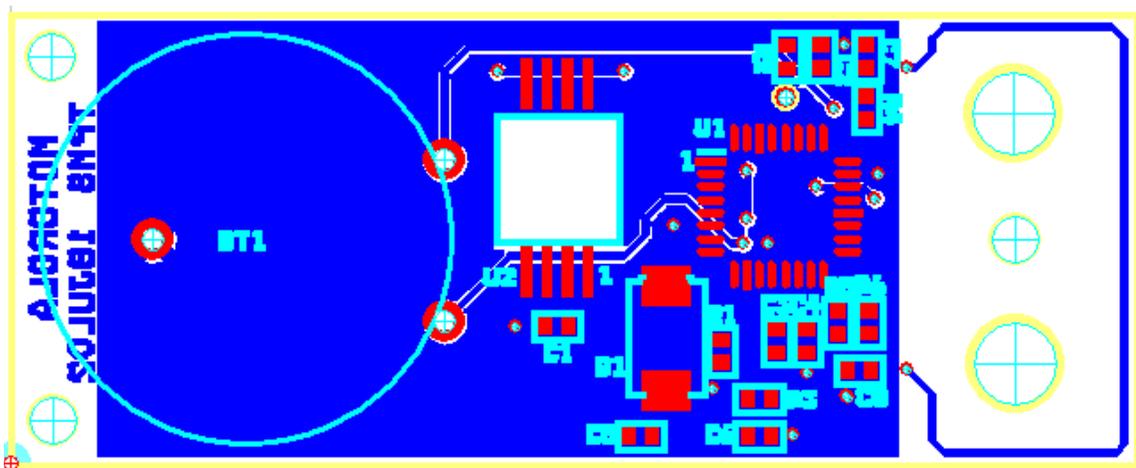
**Figure 2. TPM Tire Module Schematic**

Clearly, the MPXY80xx and the RF2 require very few external components for operation. A crystal is not required for MCU operation because the RF2 includes an internal clock generator (note pins 21 and 22 are left open). The transmitter uses the crystal as a reference oscillator for its phase lock loop (PLL). This demo uses a 13.56 MHz crystal that provides a transmission carrier frequency of 433.92 MHz. This schematic is a simple adaptation of the example application schematic in the RF2 specification for RKE<sup>1</sup>. Open I/O pins have been

connected to the MPXY80xx, and a matching network for the antenna has been added.

The module utilizes frequency shift keying (FSK), which is a more reliable modulation scheme than on-off keying (OOK) for the TPM application. This schematic is appropriate for either OOK or FSK, and the MCU can actually switch between these forms of modulation on the fly.

The layout of the tire module is shown in **Figure 3**.



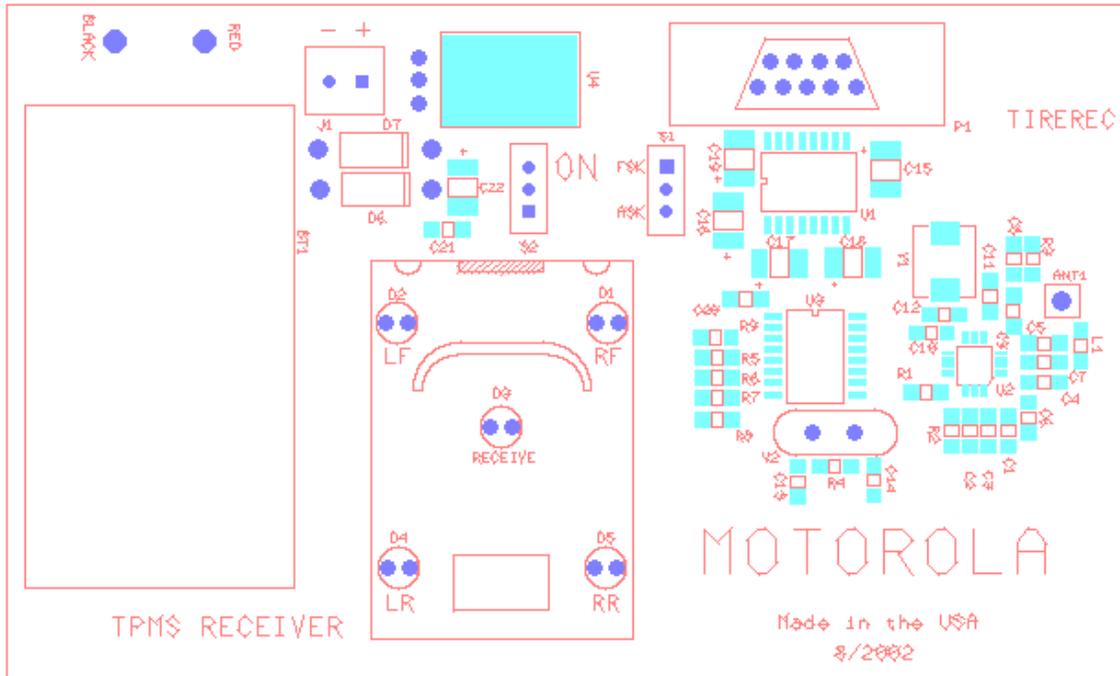
**Figure 3. TPM Tire Module Layout**



The MC33594 is connected exactly as it appears in its example application schematic<sup>2</sup>. The tuning circuit for the receiver antenna comes directly from the specification<sup>3</sup>. This demo does not utilize the receiver's strobe oscillator, so in this schematic R1 is replaced with a 0-ohm resistor.

Along with the information conveyed by the LEDs, the exact pressure and temperature values and the tire module status are sent through a 9-pin RS-232 serial interface. This interface also allows configuration information to be sent to the KX8 from a PC.

The layout of the receiver module is shown in **Figure 6**.



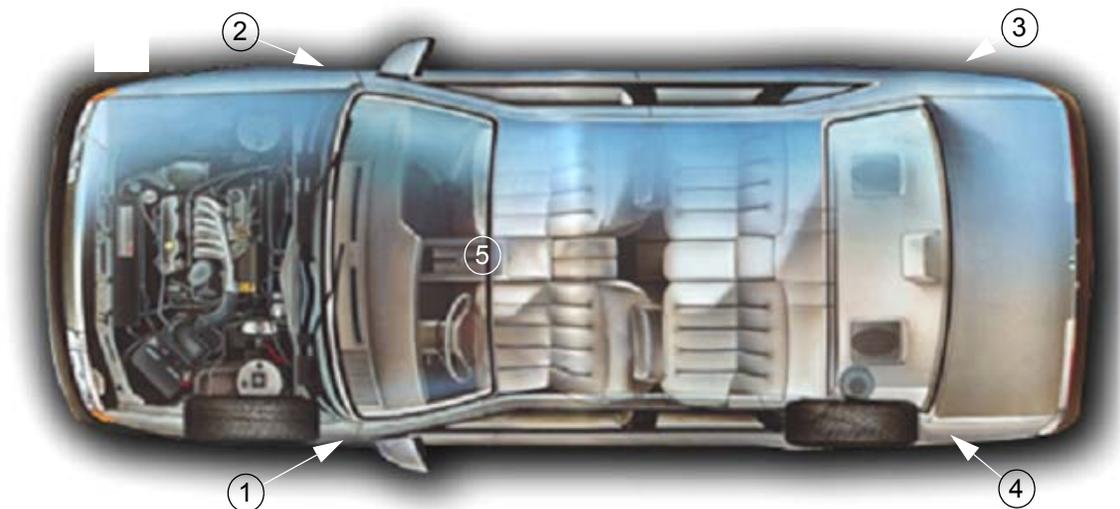
**Figure 6. TPM Receiver Module Layout**

To make the tire identification easier for the user, a diagram that represents a car has been drawn onto the PCB. Although the KX8 has an internal clock generator like the RF2, the serial communication interface (SCI) demands very accurate timing, so an external crystal oscillator is used. The Romeo2 has its own PLL that requires it to use another crystal (here at 13.580625 MHz for a 434-MHz carrier).

The bill of materials for both the transmitter and receiver modules appears in Appendix A.

### HARDWARE DISPLAY

To simulate a real application, a portable display is provided with basic tire pressure warning functionality. This display includes five LEDs that should be read as follows:



**Figure 7. LED Display**

LEDs 1-4 represent the left-front, right-front, right-rear, and left-rear tires. Each of these lights has the same functionality with the receiver power on:

- LED off – Pressure information okay.
- LED flashing – Tire module requires service. Either one of two circumstances would bring about this state:
  - LVIOU or LOWV bits in the status byte are set, which indicates that the battery is low in that tire.
  - No data received from that tire for greater than approximately 7.5 minutes.
- LED on constant – Received pressure data indicates that the pressure in that tire is low or at or below the threshold. This threshold defaults to an absolute pressure of 105 kPa (or 15.23 PSI) and can be easily changed through the serial port if so desired.

LED 5 is the indicator for the general status of the system:

- LED blink – One frame has been received in normal (not fast) transmission mode.
- LED on constant – At least one tire module has gone into fast transmission mode, which indicates that the

measured pressure within a tire has changed by at least 12 kPa within the last 27 seconds. This usually indicates an abnormal leak and also lights when inflating the tire.

### PARKING/DRIVING MODE

In a real-world application, the receiver module may receive information from the rest of the vehicle (for example, the ignition switch) regarding whether it should be configured in driving mode or parking mode. Other algorithms may be used for rolling detection on the receiver side of the system as well. For this demonstration module, there is a switch (or jumper) that selects between parking and driving modes.

When the switch is toggled from one mode to the other, and after a sufficient software debounce routine, the receiver MCU reconfigures the receiver for the appropriate modulation and data rate.

The current version of the tire module does not include an inertial switch and always transmits in driving mode. For this reason, it is recommended to leave the parking/driving switch in the driving, or FSK position.

**Table 1. Driving versus Parking Mode**

	Driving Mode	Parking Mode
Modulation	FSK	ASK
Data Rate	9600 bps	4000 bps

### RS232 INTERFACE

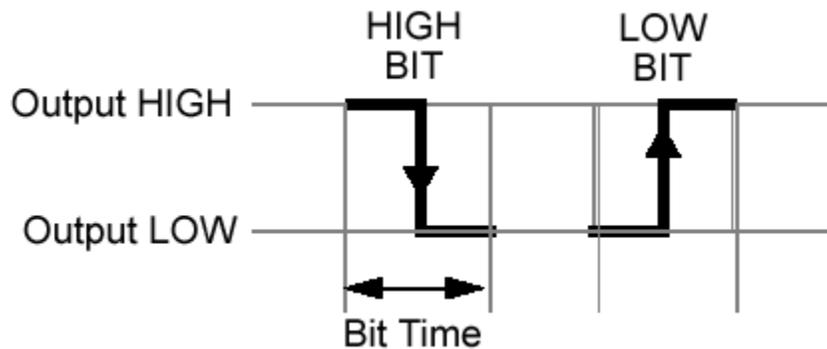
The bidirectional serial RS232 interface is used mainly for data acquisition. However, some user-defined data can be input to the receiver to override its default configuration. The data sent is raw hexadecimal data.

Each time that the receiver MCU determines that one of its four tire modules sent a data frame that was not corrupted, the entire data frame (tire ID through checksum) is sent to the serial port. The user-programmable information that can be sent through the serial interface includes the low-pressure

threshold (used to determine whether to turn on the tire's LED) and each of the four 32-bit tire IDs.

### DATA FORMAT

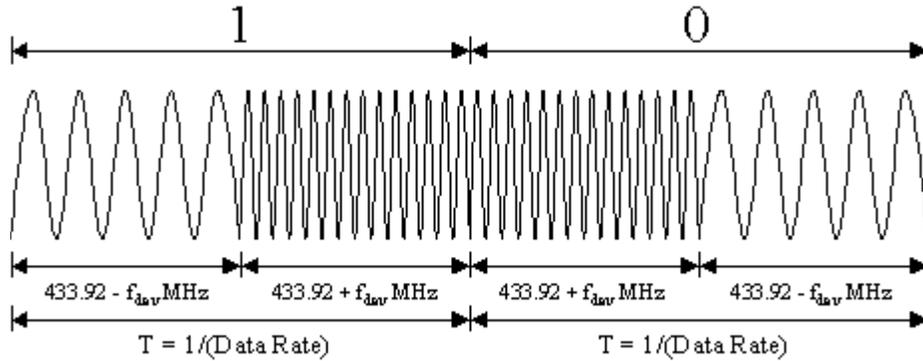
Together, the transmitter and receiver are programmed to support a simple protocol for communication. The data is sent at 9600 bps and is Manchester encoded using FSK modulation. Manchester encoding is described as a digital signal whose value transitions between high and low halfway through each bit period. A digital 0 is represented by the first half low and the second half high, while a 1 is high then low.



**Figure 8. Manchester Encoding**

FSK is defined as a signal whose frequency shifts between two values to represent a digital high and low signal. In this system a digital high is a lower frequency and a digital low is a higher frequency. In other words, if the carrier frequency is

433.92 MHz and the total frequency deviation is defined as  $\pm f_{dev}$ , then a digital high is at  $433.92 - f_{dev}$  MHz and a digital low is at  $433.92 + f_{dev}$  MHz.



**Figure 9. Diagram of the Carrier Wave with FSK and Manchester Encoding**

The receiver is already set up to demodulate and decode this data format with its Data Manager. After the proper wake-up information is sent when the Data Manager is enabled, the data it receives is sent to the MCU by a serial peripheral interface.

The tire modules send the data in packets called data frames. When the tire module MCU decides that it is time to transmit its data frame, it wakes up the receiver, sends the data, and goes back to sleep. The data frame is formatted as in **Table 2** that follows.

**Table 2. Data Frame Format**

Preamble	Device ID	Pressure	Temperature	Status	Checksum	Stop Bits
16 bits	32 bits	8 bits	8 bits	8 bits	8 bits	2 bits

### Preamble

The preamble is 16 bits in length and is always set to 0xFB86. This is for three purposes:

- 0xF (1111): The receiver requires at least four bits as a preamble to wake it up and let its internal circuitry settle.
- 0xB8 (1100 1000): Configuration Register 2 in the receiver is to be programmed as 0xB8, such that the data of 0xB8 in the preamble is recognized and turned on the Data Manager.
- 0x6 (0110): The header is to be enabled in the receiver, which indicates that the real data follows (beginning with the device ID).

Since the header data (0x6) is the last part of the preamble, this part of the transmitted data (the preamble) is not sent to the rest of the receiver module on the receiver SPI. The first data that the receiver MCU detects is the device ID.

### Device ID

The device ID is 32 bits in length. When each TPM tire module MCU (the RF2) is flashed, the device ID is programmed into address 0x7800 – 0x7803. This ID can be used for many purposes in a real-world application, such as

manufacturer information; however, for this demonstration it serves exclusively as tire identification. All four bytes of ID are checked after each received data frame; if the ID does not match, the data frame is ignored.

When the receiver finds an ID match, it modifies the status byte to indicate the tire position. This makes it much simpler for the software receiving the data from the serial port to determine the position of the tire that sent the current data frame. For more information, refer to the **Status** section on page 8.

### Pressure

The pressure data is 8 bits, which represents the pressure as measured by the MPXY80xx. When using the MPXY8020A, the relationship is 2.5 kPa/count. This data is to be monitored by the receiver MCU (the KX8) to determine whether that tire's pressure is below the programmed threshold, which then indicates a low-pressure warning.

### Temperature

The temperature data is 8 bits, which represents the temperature as measured by Daytona. The receiver MCU ignores this data and passes it through the SCI.

## Status

The status data is 8 bits, which is represented by the following table.

**Table 3. Status Bit Contents**

Status Bit								
	7	6	5	4	3	2	1	0
Received (RF)	RF2 LVIOUT	RF2 LOWV	N/A	Fast Tx Mode	N/A	N/A	N/A	N/A
Sent (SCI)	RF2 LVIOUT	RF2 LOWV	N/A	Fast Tx Mode	LF	RF	LR	RR

The following list describes the terms used in the table:

- LVIOUT high indicates that VDD on the tire module has fallen below approximately 1.85 volts for a certain period of time<sup>4</sup>.
- LOWV high indicates that VDD on the tire module has fallen below approximately 2.0 volts. See the RF2 specification for more details<sup>4</sup>.
- Fast TX Mode high indicates that the measured pressure for that tire module has changed at least 12 kPa within the last 9 measurements (approximately 27 seconds). When this bit is high, the TPM tire module begins its fast transmission mode where it transmits one data frame with new pressure and temperature data every 800 to 900 ms.
- LF, RF, LR, RR: the receiver MCU determines these bits after the frame is received. The corresponding tire's bit is set when an ID match is found for that tire and the modified status byte is sent over the serial port. This is done so that the computer receiving the data from the serial port is not required to duplicate the effort of the receiver MCU that checks the tire ID bytes.

## Checksum

The checksum is an 8-bit value dependent on the prior transmitted data. Its purpose is to decrease the probability that a data error caused by either the tire module MCU, RF noise, or receiver MCU is interpreted as valid data.

The checksum is calculated by summing each of the previous bytes of data without the carry bit that would be sent on the SPI out of the receiver. These include ID [4:0], pressure, temperature, and status. The result of the addition is negated by two's complement, and this value is stored in checksum. This way, summing (using an 8-bit register without the carry bit) all bytes from the ID to the checksum results in 0 if no corruption occurred.

## Stop Bits

Two stop bits end the TPM System data frame and are NRZ (non return-to-zero) encoded. This data does not appear at the output of the receiver SPI; however, the two stop bits are there as an indication that the data frame has ended.

## SOFTWARE

### Transmitter

The entire algorithm within the TPM tire module is based upon battery charge conservation. The module is required to last for a very long time, but its weight is also critical, so a large battery is not an option. The Freescale components within the tire module use very little energy and are designed just for these challenges. The sensor has a speedy response to inquiries for pressure and temperature, and the capacitive pressure sensor leads the industry in its minimal current requirements. The MPXY80xx operates in four modes, shown in **Table 4**.

**Table 4. The MPXY80xx Tire Pressure Monitoring Sensor Current Draw**

Mode	Typical VDD Supply Current	Typical Time in this Mode for One Measurement
Idle	600 nA	N/A
Measure Pressure	1.5 mA	500 $\mu$ s
Measure Temperature	500 $\mu$ A	150 $\mu$ s
Output Read <sup>(1)</sup>	500 $\mu$ A	1.25 ms each (P and T)

1. Calculated time for performing an 8-bit successive approximation routine using the internal clock generator running at 2 MHz (ICGMR = 0x1A).

Clearly, pressure measurement is the critical parameter for power consumption with the MPXY80xx, so measuring pressure as infrequently as possible while still providing the driver with adequate pressure warning information is necessary. The MPXY80xx is held in idle mode for most of its lifetime.

Since its stop mode current draw is phenomenally low, the RF2 is excellent for this type of application which demands long battery life. Its current usage for the MCU portion is displayed in **Table 5**.

**Table 5. RF2 MCU Current Draw**

Mode	Typical VDD Supply Current
Run	4.3 mA
Wait	1.2 mA
Stop	10 nA

**Table 6** shows the UHF transmitter module's current usage.

**Table 6. RF2 Transmitter Current Draw**

Mode	Typical VDD Supply Current	Typical Time in This Mode for One Transmission
Standby	0.1 nA	N/A
Transmission	11.6 mA	12.5 ms

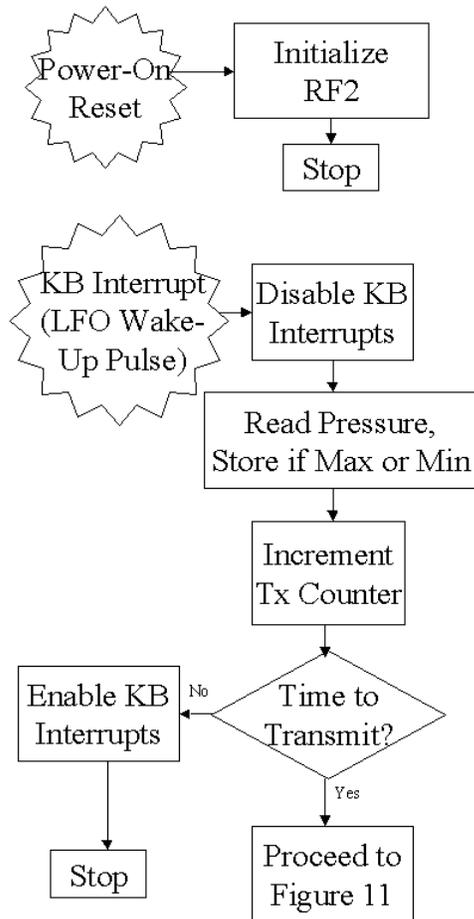
Transmission by the RF2, while still very energy efficient, is the greatest concern for long battery life. A smart algorithm reduces the number of transmissions to the minimum required for worry-free TPM usage. The MCU stop mode is also key and should be used as much as possible.

The algorithm chosen for this demo follows, beginning with **Figure 10**.

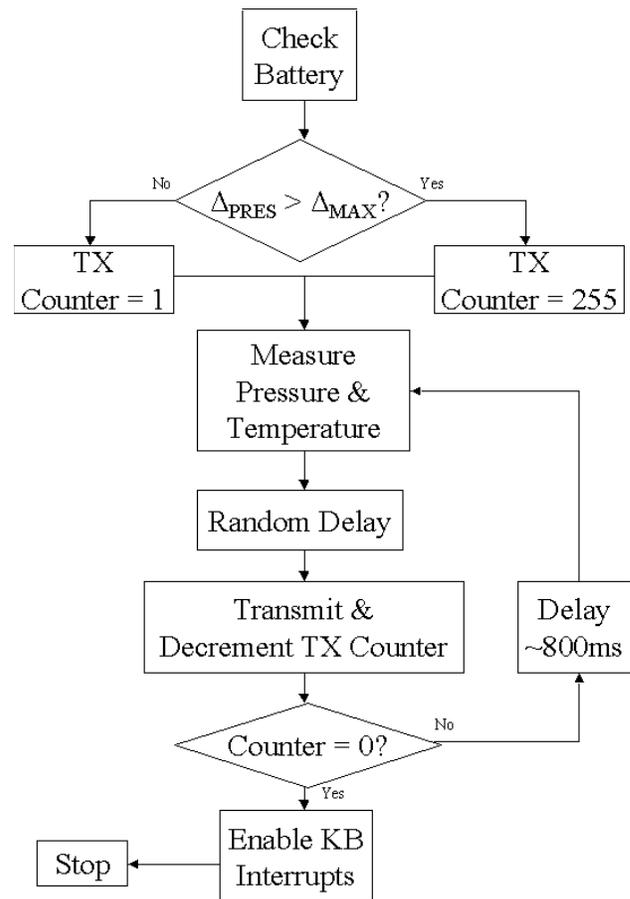
When in idle mode, the MPXY80xx sends a wake-up pulse (timed by its internal low-frequency oscillator, or LFO) every three seconds. This wake-up pulse is connected to a keyboard interrupt pin on the RF2 that allows it to come out of stop mode. Every time it wakes up, it measures the pressure. If the value it receives is a new maximum or minimum (during this period between transmissions), it stores the value in RAM; otherwise, it usually increments a counter and returns to stop mode. After 10 successive wake ups (30 seconds), the module transmits its status to the receiver.

**Figure 11** displays the algorithm for a transmission.

After looking at the low-voltage detection circuit within the RF2, the module analyzes the difference between the maximum and minimum stored pressure values. If the difference exceeds a maximum difference stored in the ROM ( $\Delta_{MAX}$ ), the module goes into "fast transmission mode." In fast transmission mode, it transmits 255 data frames that are spaced between 800 to 900 ms. This greatly increases the likelihood that the receiver gets the data, and if the large pressure change indicates a fast leak in the tire, the driver is warned within an adequate time to stop the car safely.



**Figure 10. Tire Module Main Program Flowchart**



**Figure 11. Tire Module Transmission Program Flowchart**

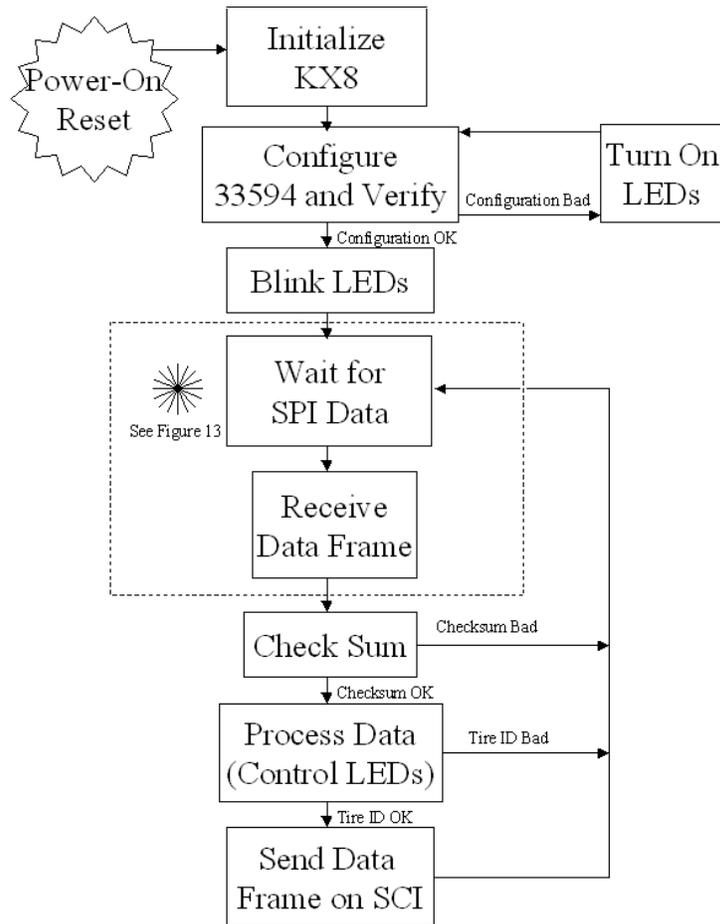
## Receiver

The general program flow for the receiver appears in **Figure 12**.

After power on, the MCU initializes itself, then configures the receiver. Upon verification that the receiver is configured properly, the LEDs all blink once to inform the user that the module is ready.

Most of the processing time is spent within the dotted line box, when the MCU is waiting for the receiver to send a data

frame. More detail about the data frame reception is shown in **Figure 12**. After a data frame is received, the checksum is recalculated and compared with the one received. After verification, the tire ID is compared with the four IDs stored in the KX8 memory. If an ID match is found, the data is processed and the proper tire LED is lit, if necessary. Finally, the data frame is sent through the serial interface for outside data acquisition and storage.

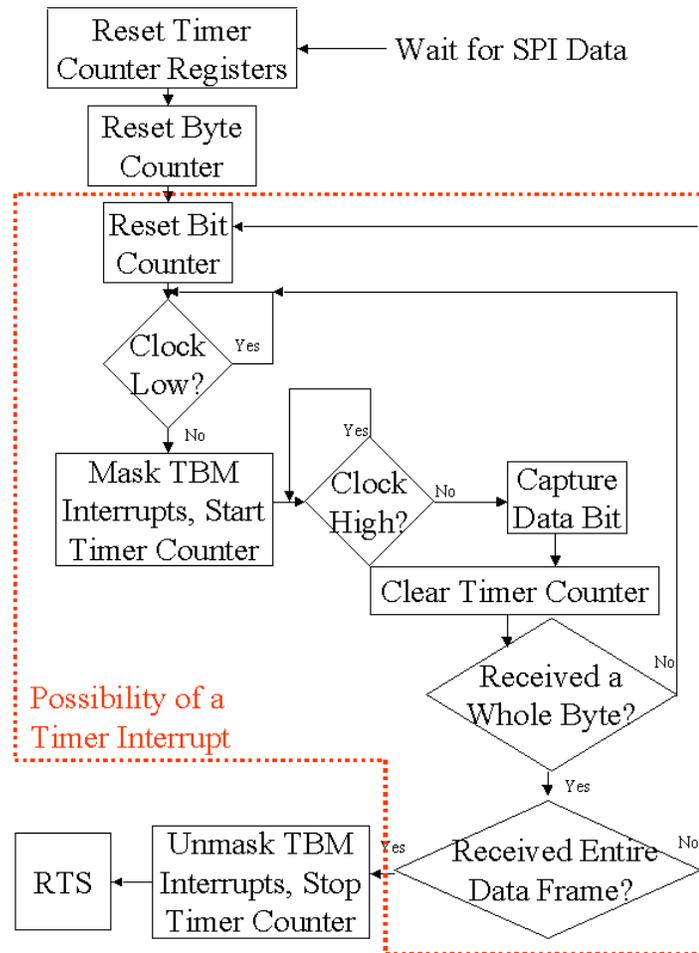


**Figure 12. Main Receiver Program Flowchart**

As the KX8 does not have a hardware SPI, the data acquisition from the receiver is performed in software. The flowchart in **Figure 13** shows how the software SPI works.

Because a TPM must operate in a very harsh environment, there is a chance that some RF interference could interrupt

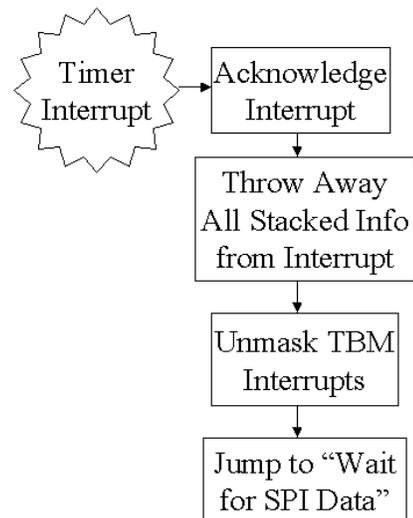
the data frame during transmission. This could cause the receiver SPI to shut down in the middle of a data frame. To prevent a partial data frame from confusing the microcontroller, the timer is used to verify that the data is entering at approximately 9600 bps.



**Figure 13. Software SPI Flowchart**

The timer is started upon the first rising clock edge, and the timer counter registers are cleared each time the clock falls. If the data frame is cut off before an entire data frame is received, the timer reaches its overflow value and an interrupt is triggered. This causes the partial data frame to be ignored, so the program simply waits for the next data frame.

The data rate during driving mode is 9600 bps. This means that the clock period is  $1/9600 = 104$  microseconds. For this demonstration, the timer overflow has been programmed to 1 millisecond so that it is certain that an interrupt is not triggered prematurely.



**Figure 14. Timer Interrupt Service Routine Flowchart**

## REAL-TIME INTERRUPTS

The HC908KX8 timebase module is used to generate periodic interrupts every 32768 clock cycles (6.67 milliseconds). The timebase interrupt service routine determines how long it has been between single tire data receptions for the “no data received” condition (flashing tire LED) and interrogates the SCI to determine whether new threshold/ID information has been received from the serial

port. If new data (low-pressure threshold and tire IDs) has been sent, then it is stored and burned into Flash.

The LEDs are also functional and are used to confirm that something changed within the receiver module. If a new threshold and set of tire IDs is sent, the LEDs confirm that the change is completed. If the driving/parking mode switch is thrown, the LEDs confirm that the receiver has verified the change occurred correctly.

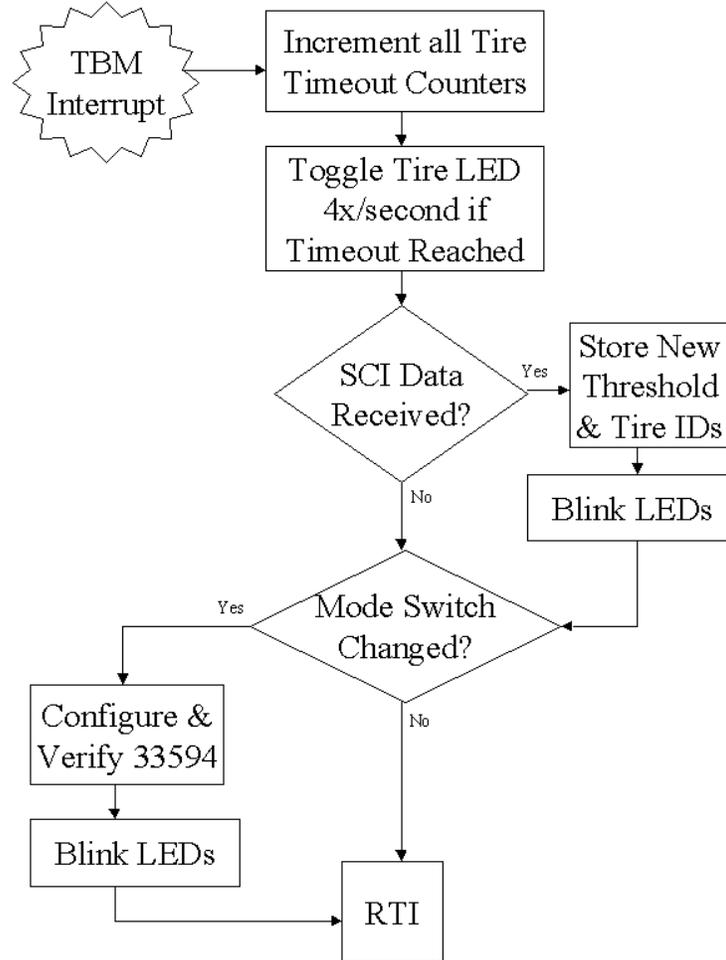


Figure 15. Timebase Module Interrupt Service Routine Flowchart

## USER INTERFACE

A user interface for this program has been created in National Instruments LabView. This program communicates with the serial port by receiving the data and displaying it as shown in **Figure 16**. It also allows reconfiguration of the receiver's low-pressure threshold and all four bytes of the tires' IDs.

The data is written to an ASCII text file, and appended to the end of each data frame is the word "Moving" or "Stopped."

This is for testing purposes, for the user to set each time the vehicle starts or stops driving, which verifies the change in data that occurs (temperature and pressure both increase dramatically when driving).

This effect may eventually lead to an algorithm to switch between driving and parking modes without the usage of an inertial switch or accelerometer, which reduces the system cost even further.

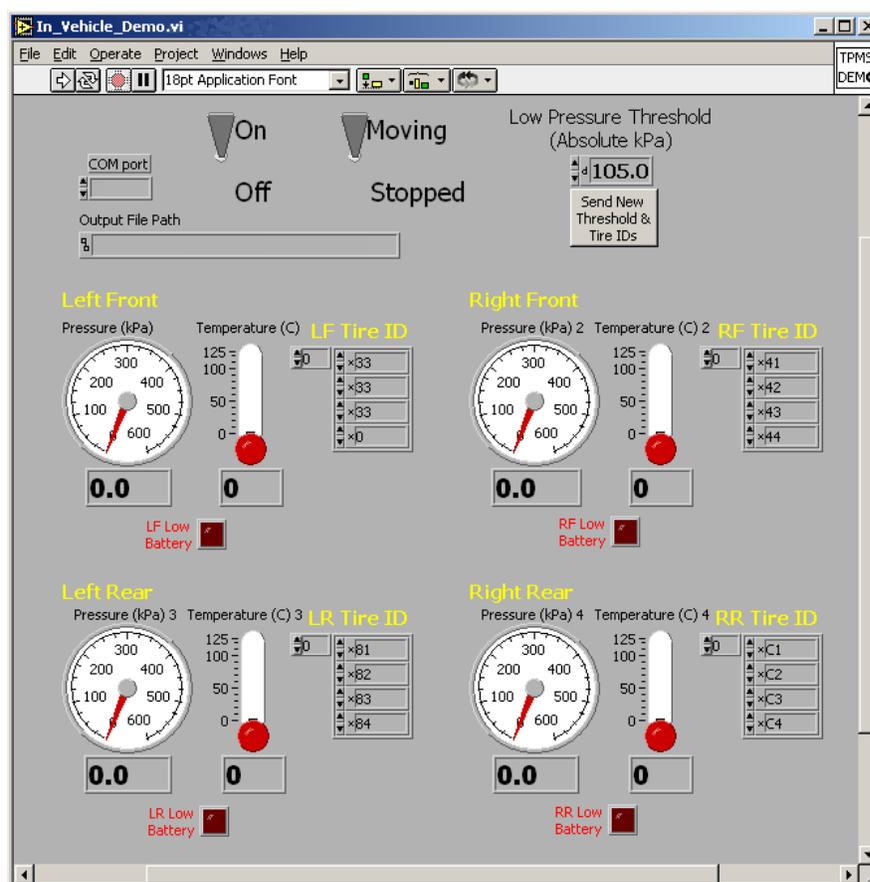


Figure 16. LabView Graphical User Interface

## REFERENCES

<u>Document Number</u>	<u>Description</u>
1 MC68HC908RF2	MC68HC908RF2 Advance Information, Rev 1: Figure 16-5, Page 230.
2 MC33594	PLL Tuned UHF Receiver for Data Transfer Applications, Rev 1.1: Figure 17, Page 25.
3 MC33594	PLL Tuned UHF Receiver for Data Transfer Applications, Rev 1.1: Note 5, Page 21.
4 MC68HC908RF2	MC68HC908RF2 Advance Information, Rev 1: Chapter 12: Low-Voltage Inhibit (LVI) Functional Description.

## APPENDIX A - BILL OF MATERIALS

Item	Qty	Item	Qty
Crystal 13.56 MHz (NDK NX8045GB)	1	0603 Inductors	
Crystal 13.580625 MHz (NDK NX8045GB)	1	12 nH	1
Receiver PCB	1		
Tire Module PCB	1	1206 Resistors	
5-Volt Regulator (MC7805)	1	0 $\Omega$	1
4.9152-MHz Crystal	1	470 $\Omega$	5
9-Volt Battery Clip and 3 Screws	1	1 k $\Omega$	1
2-Way Switch	2	180 k $\Omega$	1
Red LED	4	1 M $\Omega$	1
Yellow LED	1		
Diode (1N4001)	2	1206 Capacitors	
DB9 Female Connector and 2 Screws	1	1.5 pF	1
Terminal Connector	1	40 pF	2
Nylon Screws	4	10 pF	1
Nylon Posts	4	100 pF	3
RS232 IC (MAX232IDW)	1	390 pF	1
Receiver MCU (MC68HC908KX8CDW)	1	4.7 nF	1
Receiver IC (MC33594FTA)	1	0.01 $\mu$ F X7R	3
Transmitter/MCU (MC68HC908RF2MFA)	1	0.1 $\mu$ F X7R	3
Pressure Sensor (MPXY8020A6U)	1		
		1206 Inductors	
0603 Resistors		68 nH	1
12 k $\Omega$	2		
100 k $\Omega$	1	1710 Capacitors	
		0.1 $\mu$ F	6
0603 Capacitors			
1 pF	1		
27 pF	1		
100 pF	1		
22 nF	1		
0.01 $\mu$ F	1		
0.1 $\mu$ F	1		



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Technical Data Sheet

Product 5293

Worldwide Version, September 1996

**PRODUCT DESCRIPTION**

LOCTITE® Product 5293 is a UV curing and moisture curing silicone conformal coating which is sensitive to both ultraviolet light and moisture. Upon exposure to ultraviolet light or moisture, this material will cure to an elastomeric film; without the evolution of acidic by-products.

**TYPICAL APPLICATIONS**

Product 5293 is designed to provide environmental protection for printed circuit boards and other sensitive electronic components.

**PROPERTIES OF UNCURED MATERIAL**

	Value	Typical Range
Chemical Type	Alkoxy Silicone Rubber	
Appearance	Clear yellow liquid	
Specific Gravity @ 25°C	1.0	
Viscosity @ 25°C, mPa.s (cP)		
Brookfield RVT		
Spindle 1 @ 50 rpm	600	400 to 800
Flash Point (TCC), °C	>93	

**TYPICAL PROPERTIES OF CURED MATERIAL**

(60 secs. /side @ 70 mW/cm<sup>2</sup> (365nm) using Glass Filtered Metal Halide then post cured 7 days @ RT 50% RH)

**Physical Properties**

Coefficient of thermal expansion, ASTM E228, K <sup>-1</sup>		3 x 10 <sup>-4</sup>
Coefficient of thermal conductivity, ASTM C177, W.m <sup>-1</sup> K <sup>-1</sup>		0.18
Hardness, ASTM D2240, Shore 00		70
Non-volatile content, +%		90
Glass transition temperature, ASTM E228, °C		-40
Water vapor transmission, ASTM E96, Method A, gms/hr/m <sup>2</sup>	1.30	1.23 to 1.37

**Electrical Properties**

	Constant	Loss
Dielectric constant & loss, ASTM D150 @ 100 Hz	4.55	0.005
	@ 1 kHz	4.10
	@ 1 MHz	4.50
Volume resistivity, ASTM D257, Ω.cm		1 x 10 <sup>14</sup>
Dielectric Strength, ASTM D149, kV/mm		16

**PERFORMANCE OF CURED MATERIAL**

(After 7 days @ 25±2°C, 50±10% RH)

	Typical Value
Tensile strength, ASTM D412, N/mm <sup>2</sup> : (psi)	0.4 (60)
% Elongation to break, ASTM D412:	15

**GENERAL INFORMATION**

This product is not recommended for use in pure oxygen and/or oxygen rich systems and should not be selected as a sealant for chlorine or other strong oxidizing materials.

For safe handling information on this product, consult the Material Safety Data Sheet, (MSDS).

**Directions for use**

Thoroughly clean and dry all substrates prior to application. Apply the product by using either the dip or spray method.

For potting applications either pressure/time or positive displacement application equipment can be used.

To achieve a tack free surface this material requires 20 to 40 seconds UV exposure at 70 mW/cm<sup>2</sup>. This material responds best to a broad band UV light spectrum such as that emitted by a medium pressure mercury arc lamp.

Depending upon relative humidity, unexposed areas will begin to moisture cure in about 5 minutes, and cure tack free in 2 to 6 hours.

**Storage**

Product shall be ideally stored in a cool, dry location in unopened containers at a temperature between 2°C to 8°C (36°F to 46°F) unless otherwise labeled. Optimal storage is at the lower half of this temperature range. To prevent contamination of unused product, do not return any material to its original container. For further specific shelf life information, contact your local Technical Service Center.

**Data Ranges**

The data contained herein may be reported as a typical value and/or range (based on the mean value ±2 standard deviations). Values are based on actual test data and are verified on a periodic basis.

**Note**

The data contained herein are furnished for information only and are believed to be reliable. We cannot assume responsibility for the results obtained by others over whose methods we have no control. It is the user's responsibility to determine suitability for the user's purpose of any production methods mentioned herein and to adopt such precautions as may be advisable for the protection of property and of persons against any hazards that may be involved in the handling and use thereof. In light of the foregoing, **Loctite Corporation specifically disclaims all warranties expressed or implied, including warranties of merchantability or fitness for a particular purpose, arising from sale or use of Loctite Corporation's products. Loctite Corporation specifically disclaims any liability for consequential or incidental damages of any kind, including lost profits.** The discussion herein of various processes or compositions is not to be interpreted as representation that they are free from domination of patents owned by others or as a license under any Loctite Corporation patents that may cover such processes or compositions. We recommend that each prospective user test his proposed application before repetitive use, using this data as a guide. This product may be covered by one or more United States or foreign patents or patent applications.

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## APPENDIX C - TPM MODULES

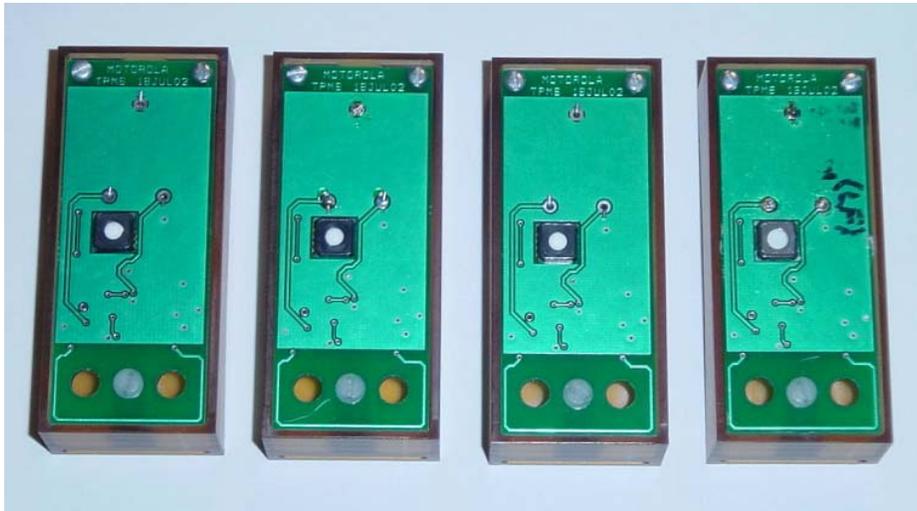


Figure 17. TPM Tire Modules

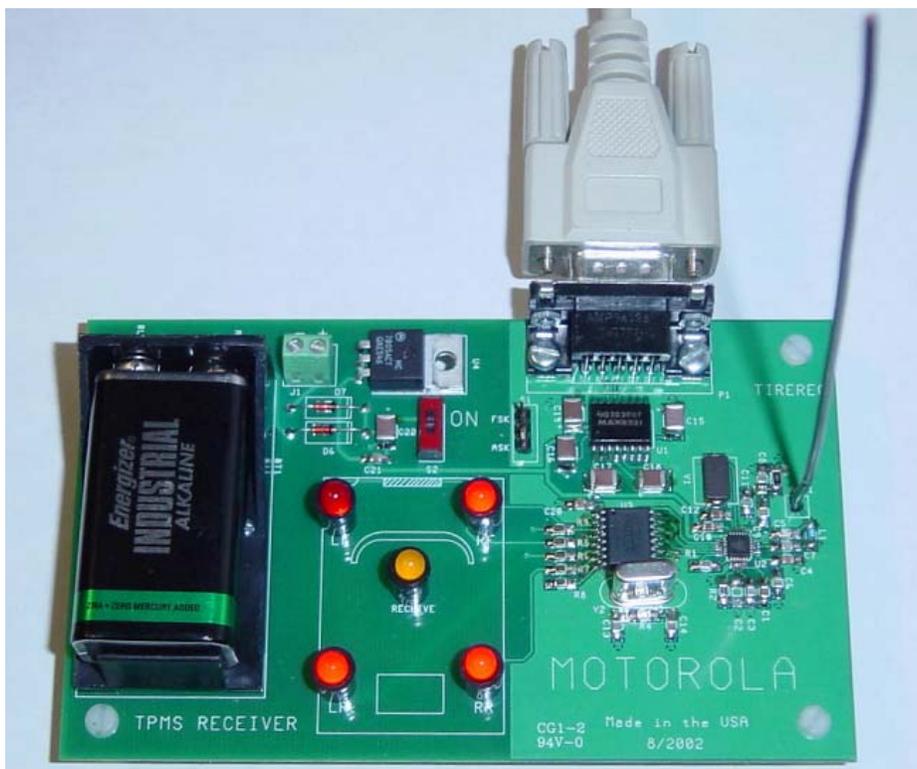


Figure 18. TPM Receiver Module

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