

# High Accuracy Digital Tire Pressure Gauge

## Description of High Accuracy Digital Pressure Gauge Design

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### INTRODUCTION

This application note describes one possible implementation of a high accuracy tire pressure gauge with a digital readout.

### HARDWARE

#### SYSTEM CONCEPT

From a systems point of view, a tire pressure gauge is relatively simple (see Figure 1). The heart of the application is the microcontroller. It reads data out of the pressure sensor and remembers the maximum value. This value is then shown on the attached display. The user can power-on the application or clear the display (reset the maximum value) by depressing the push button.

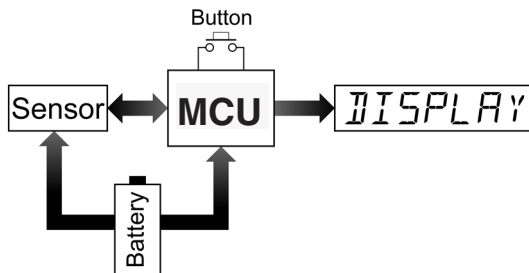


Figure 1. System Concept

Since the whole application is handheld and needs to be powered by a small battery, the power consumption is critical. Another important factor which governs selection of components is size — the application needs to be small in dimensions and lightweight.

For the pressure sensor, the CMOS absolute pressure sensor designed for tire pressure monitoring is a perfect match. The power consumption in stand-by mode is below 1.2  $\mu\text{A}$  (typically around 0.6  $\mu\text{A}$  in ordinary temperature range). The sensor features very small dimensions (10 x 7.5 x 4.2 mm) and is available in different pressure ranges. This makes the application easily adaptable for different tire pressure ranges by simply exchanging the sensor.

Selection of the microcontroller is also driven by low power consumption and a small package. In addition, it needs to have enough GPIO pins to interface to the sensor and the display. MC68HC908GR8 was chosen for the first prototype: it features very low power consumption in stop mode (below 3  $\mu\text{A}$ , 1  $\mu\text{A}$  typ.) and the 32-pin LQFP package is small enough while providing just enough I/O pins. MC68HC908JL3 with the RC-based oscillator can also be used to lower cost of the application.

Because of power consumption limitations of the system, an LCD was chosen as the display.

The choice of battery which powers the unit is a compromise between size and weight and available capacity. The CR2032 lithium coin cell with a capacity of 210 mAh was chosen. Since the system will typically draw only 1.6  $\mu\text{A}$  in stand-by mode, the battery would be capable of delivering the stand-by current for approximately 15 years. Measurements on the prototype showed that when the application is running the system power consumption is around 2.2 mA. The expected lifetime of one battery under different conditions is shown in Table 1.

**Table 1: Expected Lifetime of One Battery**

| Conditions and Usage  | Lifetime  |
|---|-----------|
| Typical power consumption values, frequent check of pressure in 4 tires (once per 10 days)    | >15 years |
| Typical power consumption values, heavy usage (every day checking of pressure in 4 tires)     | >15 years |
| Typical power consumption values, extra heavy usage (check of 40 tires per day)               | 3.1 years |
| Worst case power consumption values, frequent check of pressure in 4 tires (once per 10 days) | 5.5 years |
| Worst case power consumption values, heavy usage (every day checking of pressure in 4 tires)  | 4.3 years |
| Worst case power consumption values, extra heavy usage (check of 40 tires per day)            | 1.3 years |

It can be seen that with the selected battery the product is suitable for home usage, however professional usage might require larger battery capacity. A battery holder was used in the prototype for easier testing and to enable the user to replace the battery after it is exhausted.

**SCHEMATICS**

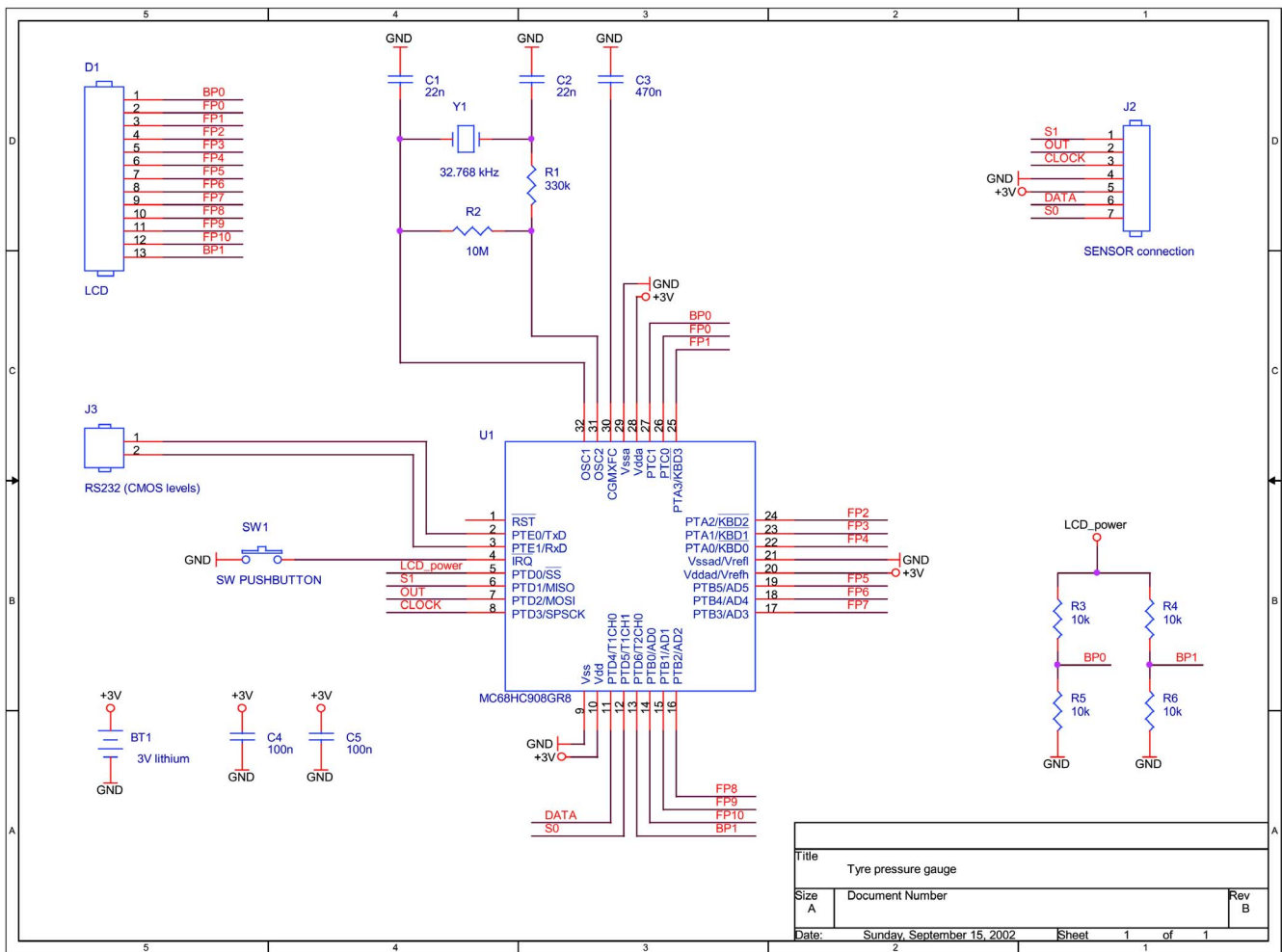
Based on the component selection made earlier, we can now look at the detailed schematic diagram of the application (see Figure 2).

The LCD and the sensor are connected to GPIO pins of the microcontroller. The LCD drive waveforms and SPI

communication interface for the sensor are created in software.

The CPU is clocked by an external oscillator. To further reduce the overall system cost, the oscillator can be replaced by a low-cost resonator since accurate timing is not required or the CPU can be replaced by MC68HC908JL3 (as mentioned above).

The push button is connected to the  $\overline{IRQ}$  pin of the CPU. Button depression can wake-up the CPU from low power stop mode even when the oscillator is stopped to minimize the power consumption.



**Figure 2. Schematic Diagram**

During SW debugging, the code of the application is downloaded to the CPU through the SCI port (RS-232 protocol) by utilizing the serial bootloader. This path can also

be used for future firmware upgrades.  
The bill of materials is shown Table 2.

**Table 2: Bill of Materials**

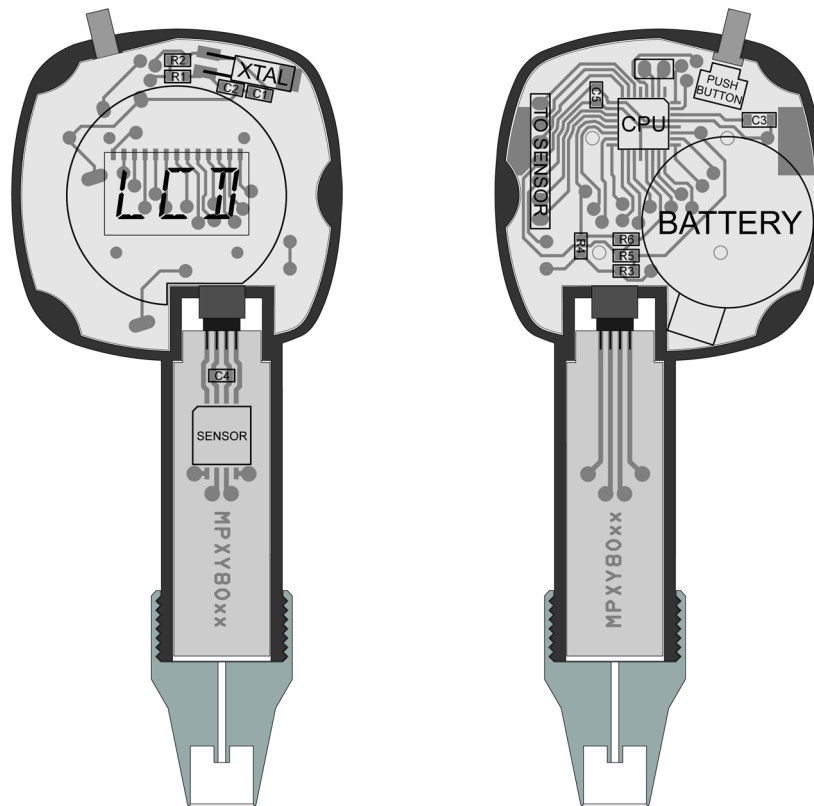
| Item | Quantity | Reference      | Part                    |
|------|----------|----------------|-------------------------|
| 1    | 1        | BT1            | CR2032, 3 V Lithium     |
| 2    | 2        | C2, C1         | 22n                     |
| 3    | 1        | C3             | 470n                    |
| 4    | 2        | C4, C5         | 100n                    |
| 5    | 1        | D1             | LCD, 2 x 11 Segments    |
| 6    | 1        | J2             | Connectors and MPXY8010 |
| 7    | 1        | J3             | Header for Debugging    |
| 8    | 1        | R1             | 330k                    |
| 9    | 1        | R2             | 10M                     |
| 10   | 4        | R3, R4, R5, R6 | 10k                     |
| 11   | 1        | SW1            | Push Button             |
| 12   | 1        | U1             | MC68HC908GR8            |
| 13   | 1        | Y1             | Crystal, 32.768 kHz     |

**CONSTRUCTION DETAILS**

Since the MPXY80xx family sensors perform absolute pressure measurements, the sensor itself must be physically separated and enclosed in a hermetic chamber, which is pressurized during measurement. Current atmospheric pressure needs to be subtracted in software from the tire

pressure indicated by the sensor to display correct differential tire pressure.

Mechanical construction of the first prototype is shown in Figure 3.

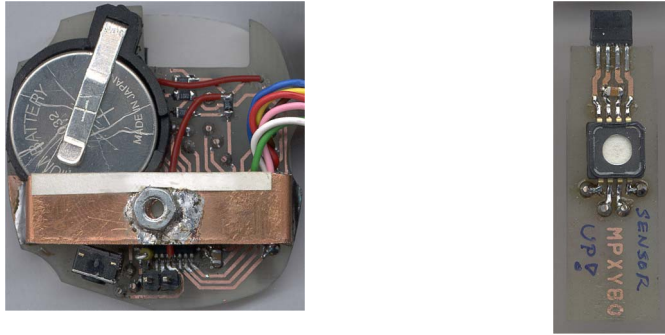


**Figure 3. Mechanical Construction (Top and Bottom View)**

The sensor, with its power supply decoupling capacitor, is placed on a separate PCB. Connection between the main board and the sensor PCB is achieved by a miniature connector pair. This enables easy sensor PCB extraction and replacement in the prototype system. The main PCB is

secured in the enclosure by a single M3 screw, while the sensor PCB is held in position only by the connector friction. Photographs of the actual prototype PCBs can be seen in Figure 4.

Actual width of the main PCB is approximately 38mm.



**Figure 4. Prototype PCBs**

A photograph of the assembled gauge is shown in Figure 5.



**Figure 5. Assembled Tire Pressure Gauge**

**SECOND GENERATION PROTOTYPE**

After the concept was proven on the initial prototype, the application was redesigned for easier manufacturing of the small series.

**SCHEMATICS**

The initial prototype used an LCD display targeted for a low-cost digital watch. Testing of the prototype revealed that the larger display should be used for improved readability. Since the design was not meant for mass production, ordering

a custom made LCD display was not adequate and the design had to use an industry standard LCD display. The display which was chosen does not use the multiplexed driving scheme and therefore requires a higher number of I/O pins. To match this requirement, the MC68HC908GP32 microcontroller was chosen and later exchanged for pin-compatible MC68HC908GT8 which features an internal clock generator unit and does not require an external crystal.

The schematic diagram of the redesigned application can be seen in Figure 6.

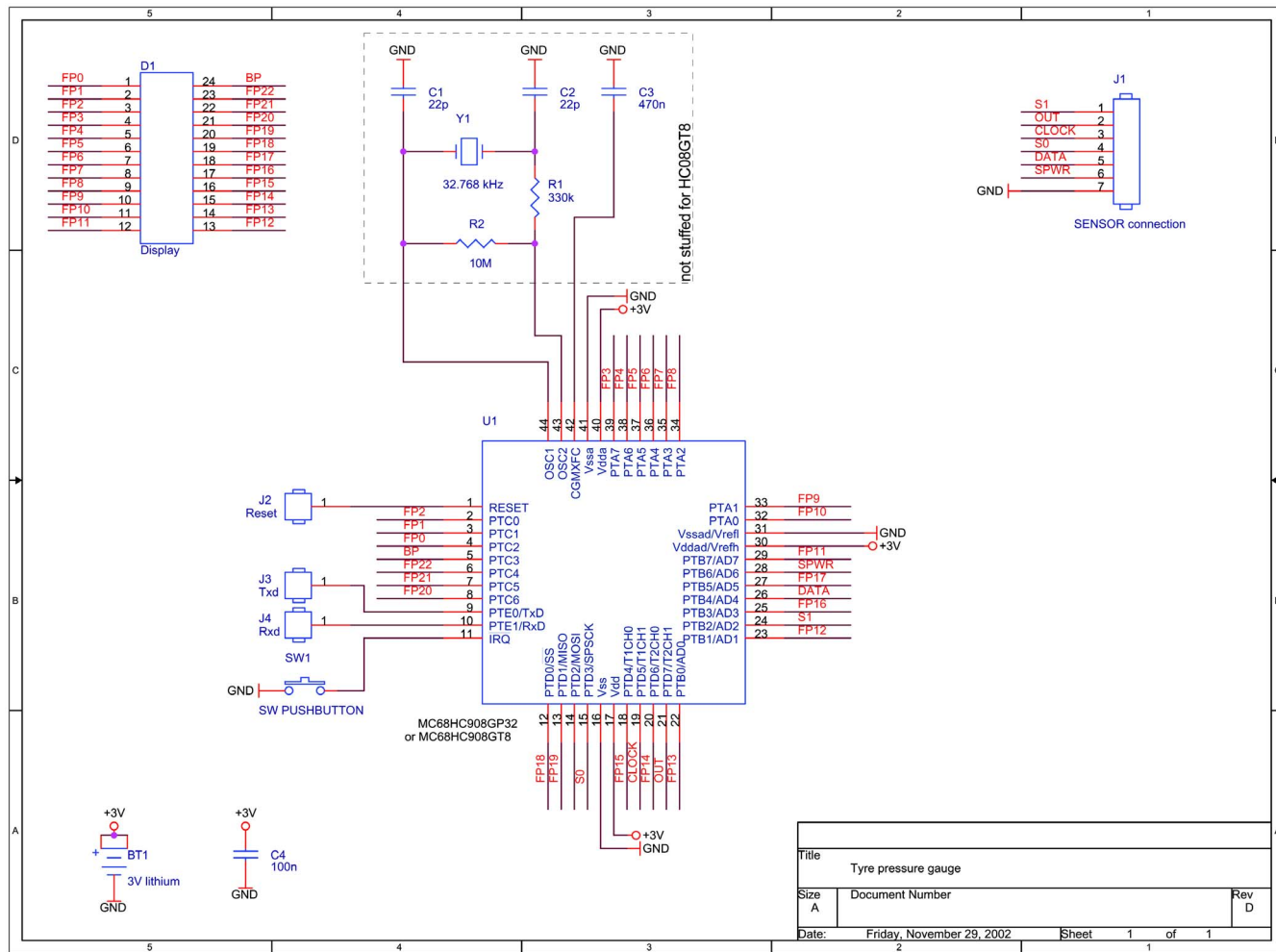


Figure 6. Schematic Diagram After Redesign

The bill of materials is shown in Table 3.

Table 3: Bill of Materials

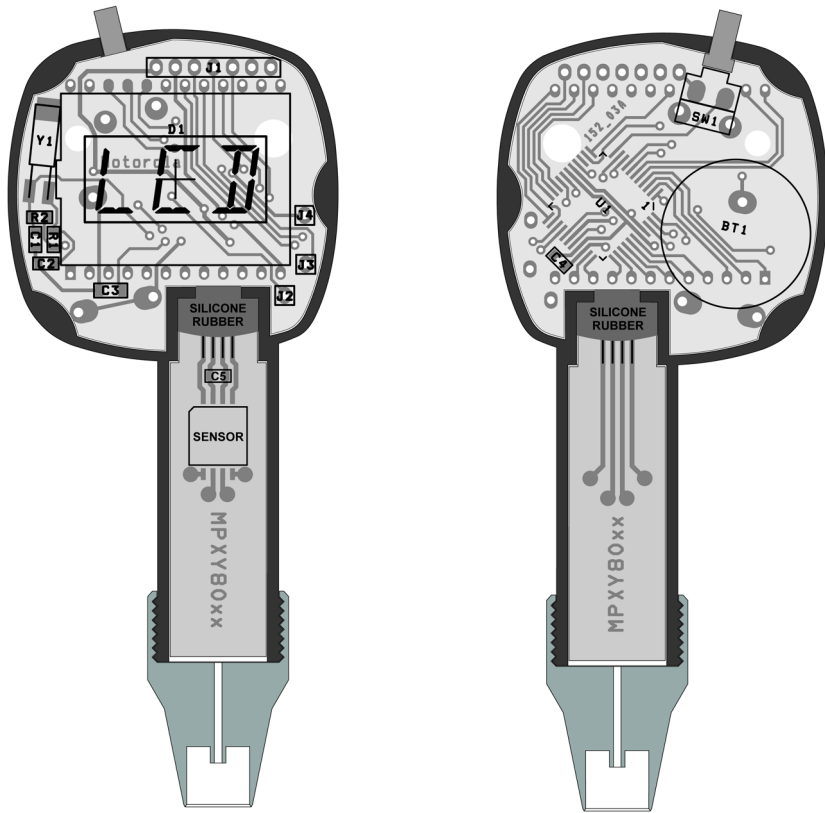
| Item | Quantity | Reference  | Part                          |
|------|----------|------------|-------------------------------|
| 1    | 1        | BT1        | CR2032, 3 V Lithium           |
| 2    | 2        | C4, C5     | 100n                          |
| 3    | 1        | D1         | LCD, 23 x 1 Segments          |
| 4    | 1        | J1         | Connecting Wires and MPXY8020 |
| 5    | 3        | J2, J3, J4 | Headers for Debugging         |
| 6    | 1        | SW1        | Push Button                   |
| 7    | 1        | U1         | MC68HC908GT8                  |

**CONSTRUCTION DETAILS**

To simplify the design, the miniature connector between the main board and the sensor board was removed. The interconnecting wires are directly soldered to both boards and the hole is sealed by silicone rubber. To cut cost, the main PCB

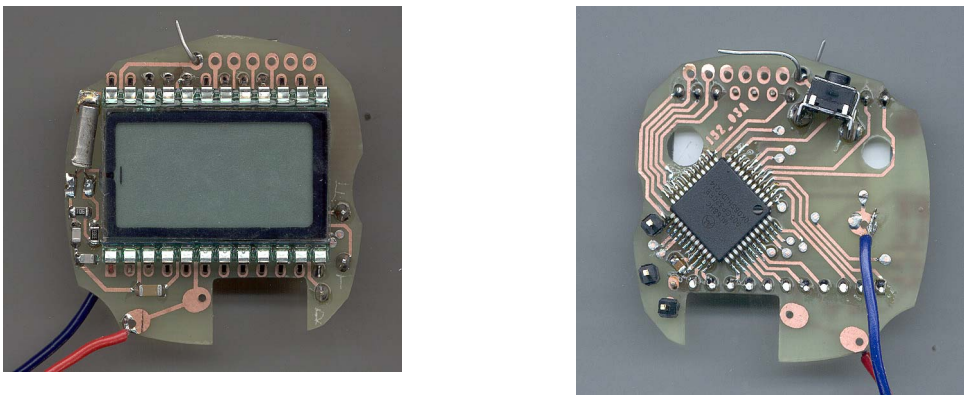
is held in position by glue rather than a screw and a battery with pins was used in place of the battery holder.

The mechanical construction of the improved design is shown in Figure 7.



**Figure 7. Mechanical Construction (Top and Bottom View)**

The photographs of the actual PCB are shown in Figure 8.



**Figure 8. Prototype PCB of the Improved Design (Top and Bottom View)**

The photographs of the assembled gauge are shown in Figure 9.



Figure 9. Assembled Tire Pressure Gauge with and Without the Front Plexiglass

**MANUFACTURING STEPS OF THE SECOND GENERATION PROTOTYPE**

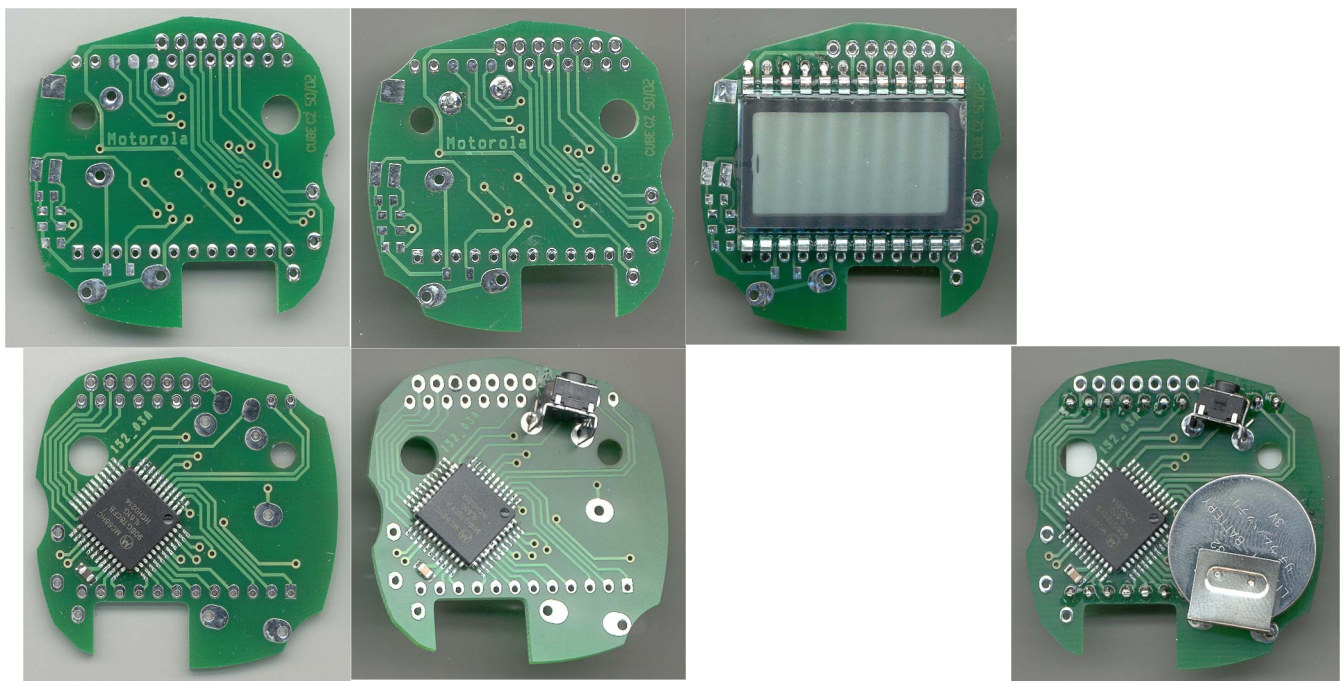


Figure 10. PCB During Low Volume Manufacturing (Top and Bottom View)

## SOFTWARE

### OPERATIONAL INSTRUCTIONS

When the gauge is not used it stays in “sleep mode” — the microcontroller is in stop mode with oscillator disabled. The user can wake-up the gauge by depressing the button momentarily.

After the button is depressed, the gauge will display “- - -” and perform a calibration measurement. During this calibration, the gauge measures atmospheric pressure which is subtracted from the sensor data in consecutive measurements (the sensor measures pressure against reference vacuum, while the tire pressure is normally expressed as differential against atmospheric pressure). After the calibration is complete, the gauge will display “0” (kPa) or “0.0” (PSI) and start the actual measurement.

During measurement, the display shows the maximum pressure observed by the sensor. The user can reset the display back to zero by depressing the button momentarily.

### REFERENCES

MC68HC908GR8/D, *M68HC08 Microcontrollers: MC68HC908GR8 and MC68HC908GR4 Technical Data*  
 MC68HC908GT16/D, *M68HC08 Microcontrollers: MC68HC908GR16 and MC68HC908GT8 Technical Data*

The gauge is capable of displaying the pressure in kPa (no decimal point is shown on the display) or PSI (the decimal point is shown between the last two digits). The user can switch the units of measurement by holding the button depressed for 1 second. The units of measurement are remembered during idle sleep mode and used again on the next wake-up.

The gauge will enter the sleep mode if the button is not depressed for 15 seconds.

### POSSIBLE IMPROVEMENTS

The MPXY80xx pressure sensors are capable of measuring temperature as well as pressure. Future versions of the software can be extended to also display the temperature.

The tire pressure changes with ambient temperature. The software can be modified to provide for compensation of these pressure changes according to temperature measured by the sensor.



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