MICROCHIP

TB1092

Designing Heat Meters using PIC16F9XX Microcontrollers

Author: Rodger Richey and Ezana Haile
Microchip Technology Inc.

INTRODUCTION

Heat in many parts of the world is supplied to rooms using hot water and radiators. A boiler in a basement or adjoining building heats water and pumps it throughout the building. Radiators in each room use convection and radiation to distribute heat. By changing the flow of water through the radiator, the amount of heat also varies proportionally. This technical brief will show the basic details to building an electronic heat meter.

HEAT METER FUNDAMENTALS

Water is heated by a boiler of some type. It is then pumped to the rooms in a building and then returns to the boiler to start the process over again. The idea behind a heat meter is to measure the amount of energy dissipated in the building by the hot water radiators. To measure this energy consumption, the heat meter must measure three parameters:

- Incoming temperature of water
- Outgoing temperature of water
- Mass flow rate of water

We can obtain the temperature of the incoming and outgoing water using RTDs, thermocouples or similar devices. The mass flow rate can come from standard residential water meters. Once we know these parameters, we can calculate the amount of energy dissipated in the building using the following equation:

$$Q = m \times cp \times \Delta T$$

Where:

Q	=	heat transfer rate (Watts),
m	=	mass per time (kg/s),
cp	=	specific heat (J/g°C)
ΔT	=	is the differential temperature (°C)

Water meters output in three forms: cubic feet, gallons or cubic meters. We need to calculate the mass flow rate in terms of kilograms per second for use in our heat transfer equation. The following list shows the conversion factors from each of the three water meter outputs into kilograms. The electronic heat meter would then need to record this measurement over a particular time period. The specific heat and density of water change as a function of the temperature of the water and therefore depends on the output temperature of the boiler. For the examples below, lets assume that the boiler outputs hot water at a temperature of 40°C. Table 1 shows both the density and specific heat of water over temperature. At 40°C, the density of water is.991 grams/cm^3. Table 1 shows the density of water versus temperature.

$$1\ ft^3 \text{ of water} = 28{,}316.8467117 cm^3 \text{ x } 0.991\ gram/cm^3 \text{ x } 1\ kg/1000\ grams = 28.061995\ kg$$

$$1 \text{ gallon of water} = 3{,}785.4118\ cm^3 \text{ x } 0.991\ gram/cm^3 \text{ x } 1kg/1000\ grams = 3.751343\ kg$$

$$1\ m^3 \text{ of water} = 1{,}000{,}000\ cm^3 \text{ x } 0.991\ gram/cm^3 \text{ x } 1kg/1000\ grams = 991\ kg$$

The most common residential water meters are designed to measure mass flow rates of 0-20 gallons per minute. This would equate to 1.25043 kg/s (20 gpm * 3.751343 kg/gal * 1m/60s). As an example, lets calculate the energy usage when the mass flow rate is 5 gallons per minute with an incoming temperature of 40°C and an outgoing temperature of 34°C.

Calculate the mass flow rate:

$$5\ gpm \times 3.751343\ kg/gal \times 1m/60s = 0.31261\ kg/s$$

Use specific heat of water 4.179 Joules/gram °C at a temperature of 40°C (Table 1).

Calculate the differential temperature:

$$40\ °C - 34\ °C = 6\ °C$$

Calculate the heat transfer rate:

$$\begin{aligned} Q &= 0.31261\ kg/s \times 4.179\ J/g\ °C \times 6\ °C \\ &= 7.83843\ J/s \text{ or } W \end{aligned}$$

In this example, we are transferring ~8W of heat into the room every second or 28.2 kW/hr.

HEAT METER DESIGN

Figure 1 shows an example heat meter circuit based on a PIC16F913 microcontroller. This device has an integrated 10-bit A/D converter and LCD module. The LCD module is capable of driving up to 4 COMs x 15 SEGs for a total of 60 pixels. Typical water and energy meters have 6 numeric digits for a total of 48 pixels leaving 12 pixels for other icons. The circuit will use relatively high resistors (~750 kΩ) in the resistor ladder of the LCD module. This will help to minimize the current consumption of the circuit.

This example uses two Type K thermocouples to measure the incoming and outgoing temperatures. Two MCP602 operational amplifiers (op amps) are used to create an instrumentation amplifier to signal condition the thermocouple outputs. These outputs are connected to the RA0 and RA1 analog inputs to the integrated 10-bit A/D. Timer1 is used to set up the periodic sample rate for temperature.

The water flow meter will have one of two type outputs typically. The first is a shaft where the speed of rotation is proportional to water flow. For this type of meter, a slotted wheel is attached to the shaft and an opto-reflector is used to output a pulse every time the slot passes. The second type is where the meter has a magnet that circulates with the flow. A Hall effect sensor is used to detect the presence of the magnet and outputs a digital pulse stream. Both of these outputs can be tied to the clock input of a counter on the microcontroller. The T0CKI input on the PIC16F913 device has a Schmitt Trigger input buffer which helps to filter out any noise on these pulse outputs. Timer0 is used to count the number of pulses from the water meter. Every time the PIC16F913 samples the A/D inputs, the value of Timer0 is captured. The difference between the current value and the last value provides the flow rate for that time period.

Once we have all three measurements, the microcontroller calculates the energy usage and updates the display. The PIC16F913 microcontroller also has integrated data EEPROM which can be used to save the energy usage periodically.

CONCLUSION

Using a relatively simple circuit, a cost effective heat meter can be designed using a low-cost, low power microcontroller with LCD display. The PIC16F91X microcontrollers with integrated 10-bit A/D converter and LCD module are perfect for not just heat meters, but also gas, water and energy meters.

REFERENCES:

1. AN649: Yet Another Clock Featuring the PIC16C924, Rodger Richey, 1997.
2. AN658: LCD Fundamentals Using PIC16C92X Microcontrollers, Rodger Richey, 1997.
3. AN679: Temperature Sensing Technologies, Bonnie C. Baker, 1999.
4. AN684: Single Supply Temperature Sensing with Thermocouples, Bonnie C. Baker, 1999.
5. AN685: Thermistors in Single Supply Temperature Sensing Circuits, Bonnie C. Baker, 2004.
6. AN687: Precision Temperature Sensing with RTD Circuits, Bonnie C. Baker, 2004.

FIGURE 1: EXAMPLE HEAT METER SCHEMATIC

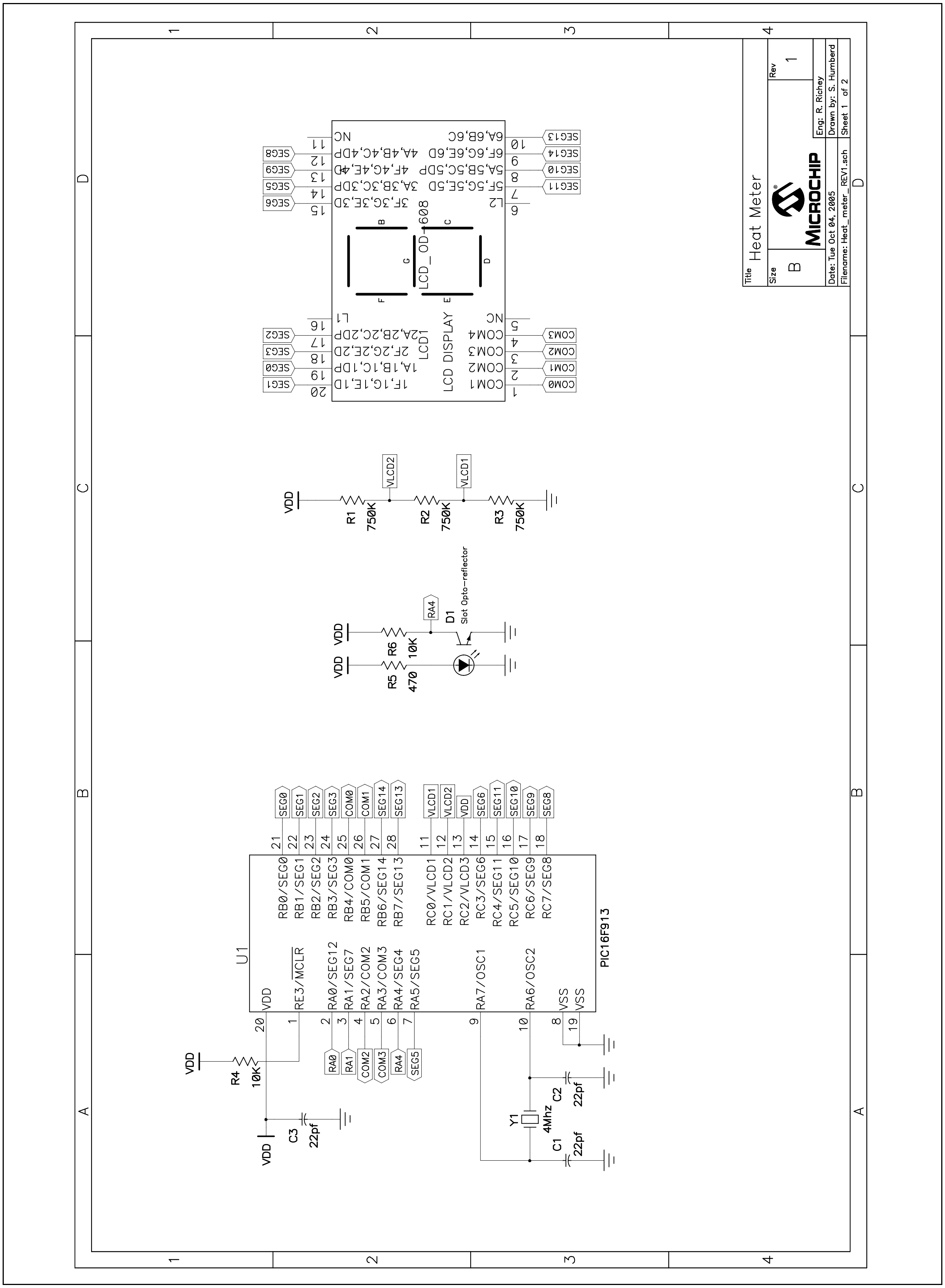

FIGURE 1: EXAMPLE HEAT METER SCHEMATIC (CONTINUED)

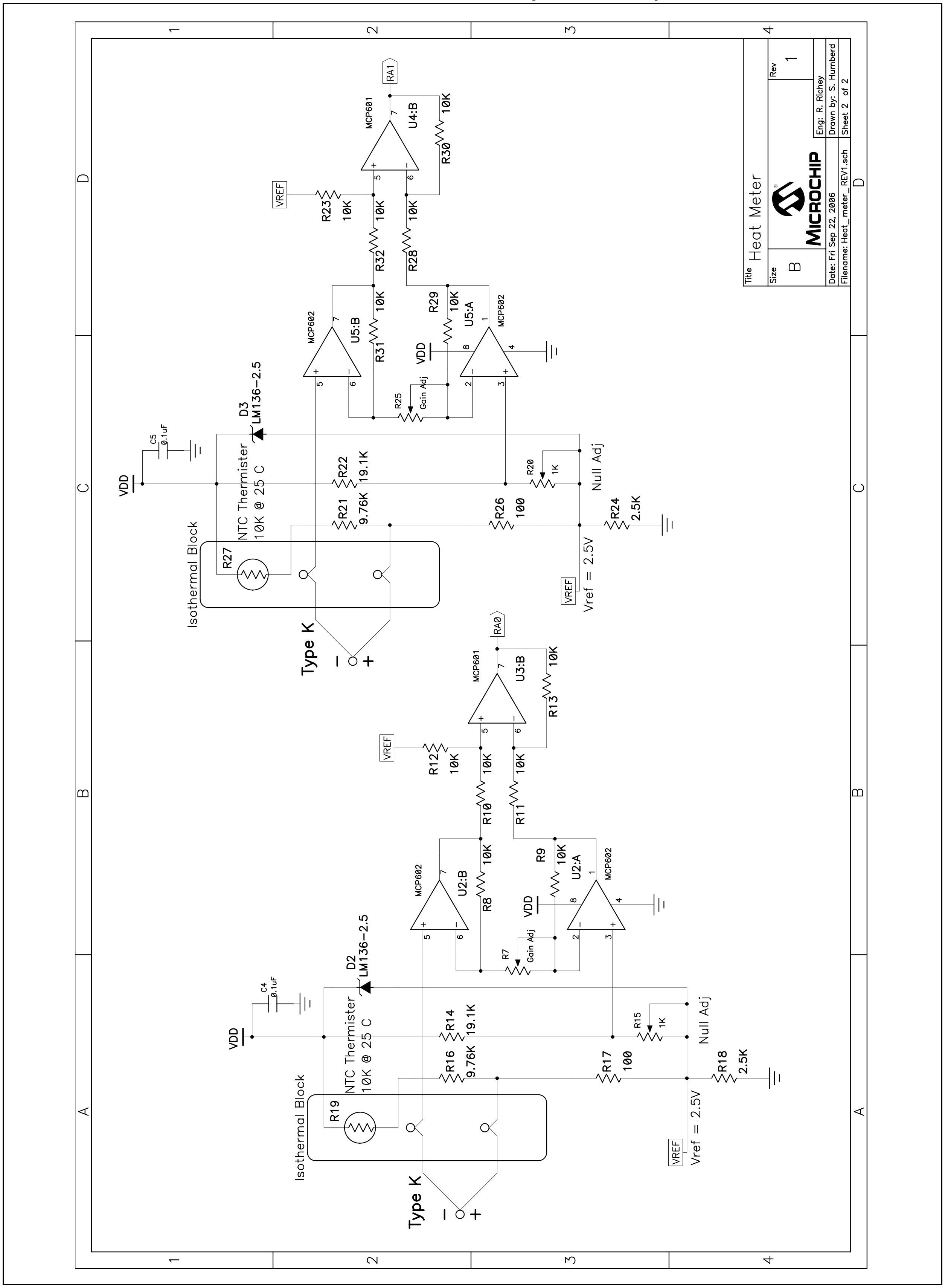

TABLE 1: SPECIFIC HEAT AND DENSITY OF WATER VERSUS TEMPERATURE

Temperature – T (°C)	Density – ρ (kg/m^3)	Specific Heat – C_P (kJ/kg°C)
0	1000	4.217
5	1000	4.204
10	1000	4.193
15	999	4.186
20	998	4.182
25	997	4.181
30	996	4.179
35	994	4.178
40	991	4.179
45	990	4.181
50	988	4.182
55	986	4.183
60	980	4.185
65	979	4.188
70	978	4.190
75	975	4.194
80	971	4.197
85	969	4.203
90	962	4.205
95	962	4.213
100	962	4.216

NOTES:

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:
http://support.microchip.com
Web Address:
www.microchip.com

Atlanta
Alpharetta, GA
Tel: 770-640-0034
Fax: 770-640-0307

Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

Detroit
Farmington Hills, MI
Tel: 248-538-2250
Fax: 248-538-2260

Kokomo
Kokomo, IN
Tel: 765-864-8360
Fax: 765-864-8387

Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608

Santa Clara
Santa Clara, CA
Tel: 408-961-6444
Fax: 408-961-6445

Toronto
Mississauga, Ontario,
Canada
Tel: 905-673-0699
Fax: 905-673-6509

ASIA/PACIFIC

Asia Pacific Office
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Habour City, Kowloon
Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

Australia - Sydney
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

China - Beijing
Tel: 86-10-8528-2100
Fax: 86-10-8528-2104

China - Chengdu
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

China - Fuzhou
Tel: 86-591-8750-3506
Fax: 86-591-8750-3521

China - Hong Kong SAR
Tel: 852-2401-1200
Fax: 852-2401-3431

China - Qingdao
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

China - Shanghai
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

China - Shenyang
Tel: 86-24-2334-2829
Fax: 86-24-2334-2393

China - Shenzhen
Tel: 86-755-8203-2660
Fax: 86-755-8203-1760

China - Shunde
Tel: 86-757-2839-5507
Fax: 86-757-2839-5571

China - Wuhan
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

China - Xian
Tel: 86-29-8833-7250
Fax: 86-29-8833-7256

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-4182-8400
Fax: 91-80-4182-8422

India - New Delhi
Tel: 91-11-4160-8631
Fax: 91-11-4160-8632

India - Pune
Tel: 91-20-2566-1512
Fax: 91-20-2566-1513

Japan - Yokohama
Tel: 81-45-471- 6166
Fax: 81-45-471-6122

Korea - Gumi
Tel: 82-54-473-4301
Fax: 82-54-473-4302

Korea - Seoul
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or
82-2-558-5934

Malaysia - Penang
Tel: 60-4-646-8870
Fax: 60-4-646-5086

Philippines - Manila
Tel: 63-2-634-9065
Fax: 63-2-634-9069

Singapore
Tel: 65-6334-8870
Fax: 65-6334-8850

Taiwan - Hsin Chu
Tel: 886-3-572-9526
Fax: 886-3-572-6459

Taiwan - Kaohsiung
Tel: 886-7-536-4818
Fax: 886-7-536-4803

Taiwan - Taipei
Tel: 886-2-2500-6610
Fax: 886-2-2508-0102

Thailand - Bangkok
Tel: 66-2-694-1351
Fax: 66-2-694-1350

EUROPE

Austria - Wels
Tel: 43-7242-2244-3910
Fax: 43-7242-2244-393

Denmark - Copenhagen
Tel: 45-4450-2828
Fax: 45-4485-2829

France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781

Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340

Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

UK - Wokingham
Tel: 44-118-921-5869
Fax: 44-118-921-5820

08/29/06