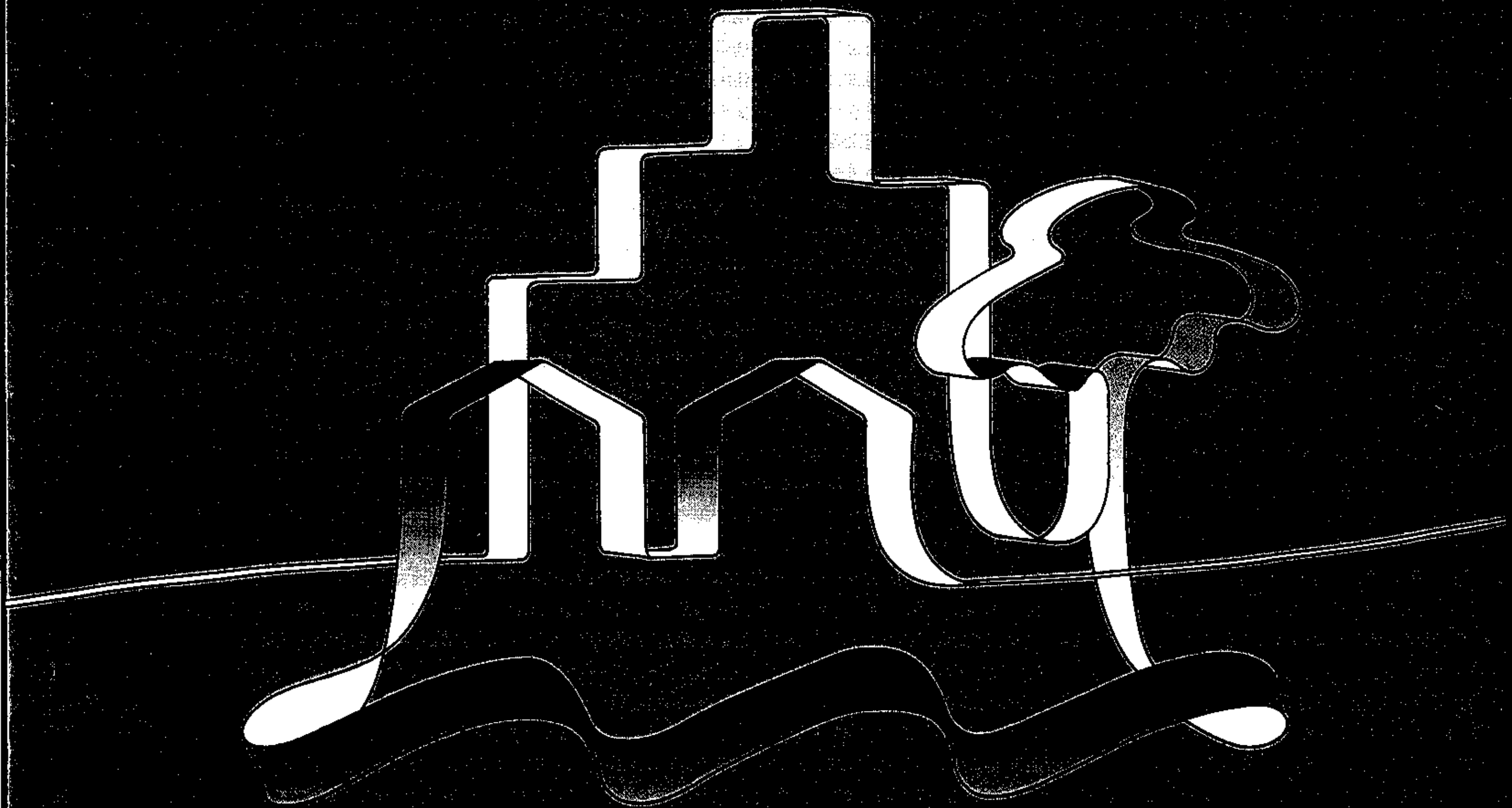
Urban Water Research Association of Australia

# Electronic Household Water Meter

## Investigation into a Cost Effective Design



Research Report No 59

## URBAN WATER RESEARCH ASSOCIATION OF AUSTRALIA

The Association was formed in 1986 following initiatives by the Australian Water Research Advisory Council and the Major Urban Water Authorities of Australia. The Association's primary role is to foster and promote a comprehensive, co-ordinated and cost-effective approach to urban water research within Australia, for both metropolitan and non-metropolitan areas.

The Association invites proposals for research work through its member authorities and allocates funding to approved projects on an annual basis. The actual research is undertaken by water authorities, research organisations, universities, consultants and government agencies.

The UWRAA Research Report series presents information resulting from research projects supported by the Association and is published as a record of the work undertaken and as a means of disseminating the research findings. The Association also encourages the presentation of findings by the researchers in professional journals and at conferences. The Association's reports are indexed on STREAMLINE, the national water data base.

For further details contact:
Executive Officer
Urban Water Research Association of Australia
C/- Melbourne Water
GPO Box 4342
Melbourne 3001 Telephone: (03) 615 5816
AUSTRALIA Fax: (03) 615 4408

Urban Water Research Association of Australia

# Electronic Household Water Meter

## Investigation into a Cost Effective Design

Zlatko Balazic and Andrew Leong
MITS Ltd

Research Report No 59
June 1993

Published for the Urban Water Research Association of Australia by the Melbourne Water Corporation.

ISBN 1 875298 60 6

Cover design by Gregory R Smith

# FOREWORD

This report is the third of three reports based on UWRAA Research Projects No IS-1 (Electronic Meter Reading: Link between water meter and house) and No IS-1(2) (Electronic Meter Reading: Link between water meter and corporate billing system, Stage 2) which commenced in March 1987. The first report was published as UWRAA Research Report No 28 in June 1991 and described the work undertaken in Project No IS-1. The second report was published as UWRAA Research Report No 52 in February 1993 and covers the link between the water meter and billing system. This third report is on the design of an electronic household water meter and completes Project No IS-1(2).

Organisational reponsibility for Project No IS-1(2) was as follows:

| | | |
|---|---|---|
| Sponsoring Authority | : | Melbourne Water Corporation |
| Project Officer | : | Mr Bernard Phey, Melbourne Water |
| Research Agency | : | MITS Ltd |
| Principal Researcher | : | Mr Z Balazic<br>Mr A Leong |

The project was funded by the Urban Water Research Association of Australia.

# SYNOPSIS

A low cost Electronic Household Water Meter has been successfully designed and two prototypes have been field trialled for five and a half weeks. The electronic meters contain a processing unit and a wire base communication scheme. The module that was created fits easily within a standard Davies Shephard 20mm KGG water meter. Efficient design and component selection has allowed the Electronic Household Water Meter to have an operational life of over 10 years with a single lithium battery.

By incorporating a processing unit within the meter, extra facilities can be included to add value to the meter. The main benefit is the use of the Electronic Household Water Meter in a full Automatic Meter Reading System. Other advantages are the ability to have flow correction for ageing water meters which can improve accuracy over existing water meters. Tamper detection can also be added to detect possible fraud and if the communications cable is cut the information is still retained within the electronic water meter.

The challenges associated with the power consumption requirements and communication methods for the Electronic Household Water Meter were highlighted during the investigation, design and trial of the prototype units. The trial revealed that the methods of lightning protection will need to be investigated in future designs.

The introduction of electronics into the water meter has suggested that production costs can be lowered so that the Electronic Household Water Meter could become a replacement for the standard water meter on the basis of cost rather than technology. This would facilitate the introduction of a full Automatic Meter Reading System which is seen as too costly at this stage.

# TABLE OF CONTENTS

# LIST OF FIGURES





# LIST OF TABLES

# LIST OF PLATES





# 1. INTRODUCTION

## 1.1 Trial Initiation

In March 1991, approval was given by the Urban Water Research Association of Australia (UWRAA) to proceed with a project titled "Electronic Meter Reading - Link between Water Meter and Data Network". This project is the second stage of the UWRAA project IS-1 and it is a result of recommendations from the first part of the project titled "Electronic Meter Reading - Link between Water Meter and Data Transmitter".

Stage one of the UWRAA project IS-1 showed that information can be successfully and reliability transmitted from the water meter to the house using a radio link. The major problem with the design was that the power consumption of the system would require the maintenance of the meters to reach impractical levels.

The second stage of IS-1 was broken up into two parts, these being

1. To further the development of the electronic water meter with special consideration given to power consumption.
2. To trial a common transmission link between the household data collection unit and the corporate data networks.

The second part of this project was called the Utilities Network Project part 2 (UNP) and has been reported on separately. This can be found in the report [Phey, Leong, Balazic, Colson and Manning (1993)].

## 1.2 Objectives

The main aim of the UWRAA project IS-1 is to develop viable ways of transmitting data from the water meters to the customer interface unit which is connected to the electricity and telephone lines. Stage two of this project looks essentially at developing an electronic water meter with low power consumption and an efficient communications method to the Customer Network Unit (CNU). To achieve the objective, research was undertaken into microcontrollers for information processing, transducers for flow detection, power supplies and communication links to develop a practical solution to an EHWM.

In the early stages of the project it was decided that an additional objective of the trial would be to make the EHWM cost effective. For the EHWM to be installed into households on a large scale, the cost of producing the meter and the cost of its maintenance would be an important factor in its introduction. The objective of developing a cost effective EHWM became the main criteria in the decision making process for the design.

## 1.3 Outline of the Report

The report details the requirements for the EHWM and which components were selected to produce a cost effective design. A description of the prototype produced for testing is given and any limitations in construction are discussed. The method of testing is described both for the laboratory and the field and an analysis on the performance is given. Estimates on pricing are given for full production and suggested additions to the design have been described. The recommendations include an evaluation of the trial and suggested steps for future EHWM designs.



# 2. EHWM DESIGN

## 2.1 Requirements

The main constituents of the EHWM are :

1. The microcontroller for information processing and protocol conversion.
2. Transducer for mechanical to electronic interface.
3. Communications interface to the Customer Network Unit.
4. Power supply for system power requirements.

The requirements for each of the components are now outlined.

### 2.1.1 Microcontroller

In order to develop a cost effective commercial Electronic Household Water Meter (EHWM) a cost effective and power efficient microcontroller is required. The microcontroller gives a high degree of flexibility to the Electronic Household Water Meter's implementation. By building into the meter some form of intelligence, the ability to provide Time Of Day Metering and Leakage Detection can be utilised. It also allows the meter to interface to other interface devices such as a Customer Network Unit (CNU) and enables the EHWM to be part of an Automatic Meter Reading (AMR) system if required.

A number of possible microcontroller and hardware configurations were considered with the conceptual design being taken from a previous development by Z Balazic [Balazic, (1990)] as this offered a cost effective solution. An investigation was made of the different microcontrollers that are produced by the large manufacturers and the ones that have met the requirements have been presented in this report. The manufacturers investigated were Dallas Semiconductor, Intel, Motorola, National Semiconductor, Philips, Texas Instruments and ZiLOG.

This section describes the initial conceptual design of the EHWM, outlines the proposed requirements for the microcontroller in terms of hardware and software and makes a final comparison of the microcontrollers.

## MICROCONTROLLER REQUIREMENTS

The following is a description of the hardware and software requirements for the microcontroller that will be used within the Electronic Household Water Meter (EHWM). The requirements were based upon the EHWM Stage 3 design from Ballarat University College. Refer to [Balazic 1990].

### Hardware

a) Input/Output

Figure 1 shows the Input/Output (I/O) requirements of the microcontroller.

22 input lines consisting of :

| | | |
|---|---|---|
| 6 | for | leakage detection |
| 12 | for | total consumption |
| 1 | for | register overflow detection |
| 1 | for | lid open detection |
| 1 | for | receive data |
| 1 | for | external clock |

8 output lines consisting of :

| | | |
|---|---|---|
| 3 | for | LCD driver |
| 1 | for | register overflow reset |
| 1 | for | lid open reset |
| 1 | for | transmit data |
| 1 | for | LCD display on/off 50uA sink |
| 1 | for | RS232 driver on/off 5-10mA sink |

1 input/output line for interrupt/acknowledge (INT/ACK)



b) Memory

The minimum internal memory requirements for the microcontroller are detailed as follows.

| | | |
|---|---|---|
| 2 Kbytes | ROM | minimum program space |
| 120 bytes | RAM | useable scratch memory for register manipulation and consumption storage |

The RAM is to be non-volatile whilst the supply is connected to the processor.

c) Modes

The microcontroller will require a minimum of two modes of operations, these being a run mode and a stop mode.

1. In run mode it is desirable that the microcontroller consume a minimal amount of current, in the order of milliamperes or less.

2. In stop or data retention mode, it is desirable that the microcontroller consume the least amount of current. There should be enough current to support the internal RAM, this being in the order of microamperes or less. The exit from stop mode should require minimal or no external support devices.

d) Asynchronous Receive Transmit Device (UART)

The microcontroller will need to contain either a UART, which will be required for the communications to and from the EHWM, or to be able to simulate a UART through software.

e) Power

It is desirable that the microcontroller have a wide operating voltage range between two and seven volts. The microcontroller may be operating from the following power supplies :-

i) Lithium battery

ii) Lithium rechargeable batteries with generator

iii) Supercapacitors with generator

iv) 3-7V DC power feed.

f) Temperature Range

The microcontroller will need to operate within the water meter environment. Initial laboratory testing has indicated that temperatures inside the water meter when water is flowing would be from around +70°C down to 0°C. See section 3.5 for more details.

**Software**

a) Memory

The minimum memory requirements for the EHWM is detailed as follows.

| | | |
|---|---|---|
| 2 Kbytes | ROM | user program space |
| 110 bytes | RAM | useable scratch memory for register manipulation |
| 10 bytes | RAM | consumption storage |
| | | 32+8 bits for present consumption |
| | | 32+8 bits for last meter reading |

b) Instruction Set

The instruction set for the microcontroller will need to have :-

i) bit manipulation

ii) arithmetic operations

iii) logical operations

iv) boolean variable manipulation

v) I/O manipulation

Figure 2 shows an operational flowchart for the EHWM.



# Microcontroller Interface Requirements

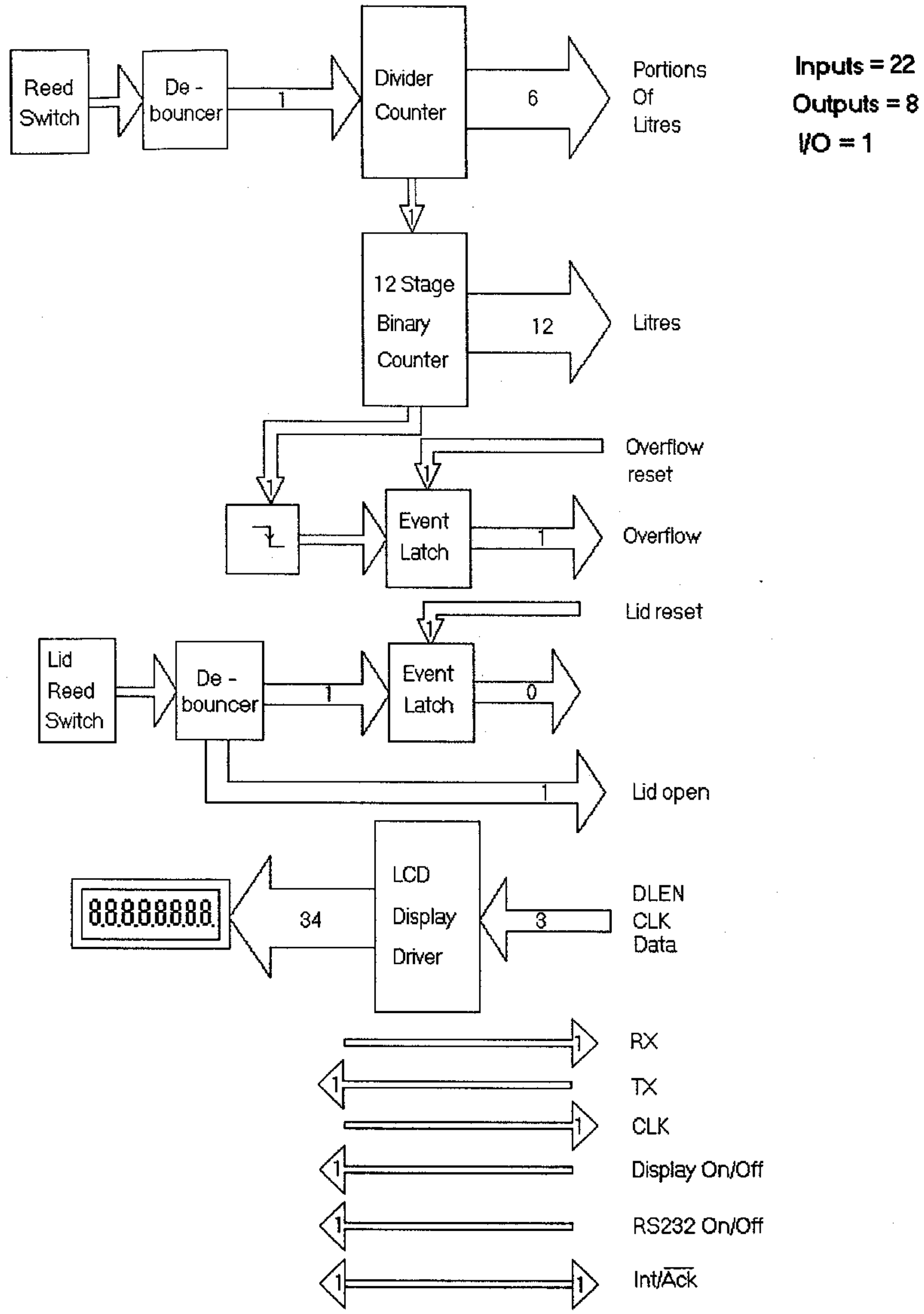



Figure 1 Proposed microcontroller interface requirements

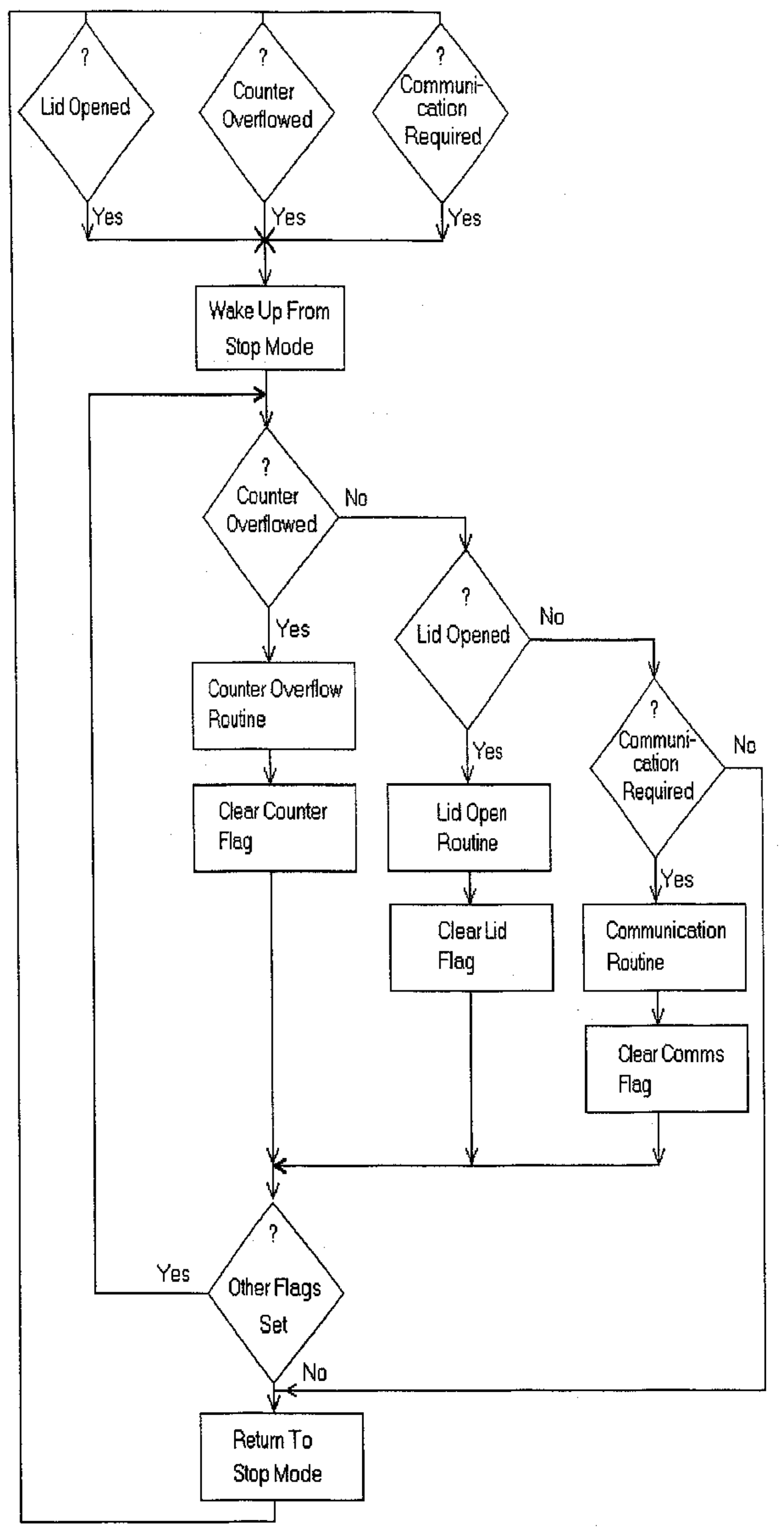



Figure 2 Proposed operational flowchart



## LONG TERM DEVELOPMENT COST:

TABLE I

LONG TERM DEVELOPMENT COSTS FOR MICROCONTROLLERS

| Device | Unit Cost @ 100K Order | Hardware & Software Development Costs | Non Recurring Engineering Cost | Operating Voltage Range | Stop mode current uA @3V | Run mode current mA, 5V @2MHz |
|---|---|---|---|---|---|---|
| Intel 80C51 US0.77$ | $4.35 | $8225 | $2750 | 4-6 | 50 | 20 |
| Dallas Semiconductor DS5000 US0.77$ | $36 | $8225 | - | 4.5- 5.5 | 80 | 43.2 |
| Motorola MC68HCL05C4 US0.77$ | $2.47 | $5038 | $2500US | 2.4-5.5 | 5 | 5 |
| National Semiconductor COP880 US0.78$ | $2.40 | $6370 | $4500US | 2-5.5 | 1 | 2 |
| Philips PCF84C633AT US0.78$ | $5.00 | $1500 | $4100 | 2.5-5.5 | 10 | 3.2 |
| Texas Instruments TMS70C20FNL US0.78$ | $2.37 | $7100 | $3500US | 2-6 | 1 | 4.8 |
| ZiLOG Z86C40 US0.78$ | $3.40 | $1495 | $3500US | 3- 5.5 | 8 | 15 |

Table I shows the corresponding costs associated with the microcontroller. The prices quoted are in Australian dollars at the conversion factors given on the left of the table unless otherwise specified. It lists the unit cost at order quantities of one hundred thousand, the development system costs and the non recurring engineering or mask charges. Other important requirements of the microcontroller such as the allowable operating voltage range, the stop mode or halt mode current consumption and the run mode operating current are listed.

The columns in order of importance are :

| | | |
|---|---|---|
| Unit Cost | : | For a cost effective solution. |
| Stop mode Current | : | For the reduction in the required power storage capacity. |
| Operating Voltage | : | For a wide operating environment. |
| Run mode Current | : | Not critical due to the short operating time but will be if in a high interrupt mode. |
| Engineering cost | : | This value would be dispersed over a large quantity of microcontrollers. |
| Development System | : | The system can be reused and the cost can be dispersed. |

**FINAL COMPARISON:**

National Semiconductor, ZiLOG, Motorola, Philips, Intel and Texas Instruments all offer cost effective solutions to the microcontroller problem. After constructing and analysing Table I weightings were given to the importance of each of the columns and the Texas Instruments microcontroller was the device which best met the criteria.

The Texas Instruments TMS70C20 offered the lowest unit cost and it featured lowest power consumption, the widest operating voltage range and the ability for future expansion and upgradability if so desired. Some of the other microcontrollers do not offer this degree of flexibility. Texas Instruments also offers the most extensive backup and support for the development of the EHWM.

Based upon the long term costs of producing an Electronic Household Water Meter (EHWM) it was recommended that the TMS70C20 microcontroller device from Texas Instruments be used within the EHWM.



### 2.1.2 Transducer

In any electronic meter there has to be a device which converts the item to be measured ( in this case water volume) into an electronic form. The present mechanical water meters being used have a displacement chamber which contains a revolving piston inside that spins one revolution for a known volume of water. The revolving piston is connected to a magnet so that they spin in unison. The mechanical meter uses the magnet to turn some gears and tumblers to enable a display. A diagram of the displacement chamber and magnet is shown in Figure 4. To enable retrofitting of existing meters and to simplify the design process, it was decided that a transducer was only required to accurately measure the number of revolutions of the revolving piston. This could be achieved by either detecting the rotating magnetic field or by mechanical action. Other transducers which electronically measure the flow of water are available but they are very costly.

**Specifications**

The requirements of the transducer are that :

- The cost be keep minimal to make the overall cost of meter as low as possible.
- The device must draw minimal current as power is limited.
- Minimum lifespan of transducer : 10 years.
- Minimum number of operations : 1x $10^8$ pulses.

  ( For an average household that consumes 300 kilolitres a year and with the piston revolving 16.575 times a litre, generating 33.15 pulses a litre, the total number of pulses over a ten year period is 1x $10^8$. )

A number of transducers options were found and these are described below.

i) Reed Switch

A reed switch is a small switch encapsulated in glass that can detect a change in magnetic field. It can be easily inserted into the water meter to detect the rotations of the magnet. A simple debounce circuit is all that is required to detect the pulse output from the reed switch so that the overall circuit including reed switch is low cost. A drawback of the reed switch is that there is a limited life due to the mechanical contact of the switch. Typical minimum life expectancy of a dry reed switch is 1x $10^8$ pulses. Wet reed switches were found to have a greater life but they were not considered because of their greater expense and size.

ii) Hall Effect Device

A Hall effect transducer has a semiconductor transistor which can switch an external device on or off when placed next to a magnetic field. This device has virtually an unlimited lifetime as there are no moving parts. The main problem with a Hall effect transducer is that it draws a constant supply current of about 6 mA which make it unsuitable for use within the EHWM with a limited power source.

iii) Pulse Wire Sensors

Pulse wire sensors consist of a compound wire, a permanent magnet wire and a pick-up coil surrounding the two wires. When exposed to an alternating magnetic field they emit voltage pulses of about 3 volts. No power supply is required and theoretically the pulse energy can drive a Light Emitting Diode (LED) though it was found after initial testing that the pulse was of insufficient duration to light the LED. The pulse wire has virtually an unlimited lifetime which makes it ideal for an EHWM. The high cost for the pulse wire makes it unsuitable at this stage for implementation into the EHWM. If the cost of the pulse wire drops, further research is required to determine its total capabilities in future EHWM designs.

iv) Wiegand Sensor

This is a ferromagnetic wire which will produce a minimum four volt pulse when there is a change in polarity of an applied magnetic field. This pulse might be sufficient to drive some CMOS circuity. No further information was available and therefore was not considered in this project.

v) Polyvinylidene Fluoride (PVDF) film sensor

This is a polymer film that has piezoelectric properties and many uses. This film can be made into a magnetic switch which produces a voltage that may be able to drive some CMOS circuitry. Initial information suggests that the mechanical strength of the PVDF switch is only marginally better than a reed switch. At this stage there is no commercially available PVDF magnetic switch for use within the EHWM so further research and development is required before it can be



considered in future designs.

(iv) Generator

One possible construction of the EHWM is to have a generator inside which would be driven by water flow. The output voltage of the generator can be used to determine how much water has flowed through the meter. At this stage the concept is only in the idea stage and further thought is required on how the idea can be implemented.

**Selection**

Of the transducers investigated, the reed switch was selected for the EHWM because of its significantly lower cost and simpler design. Its only failing is that the life expectancy only just meets the average required. One solution to this is to use a water meter that has the piston rotating fewer revolutions per litre. A warning indicator could be transmitted with the reading when the reed switch has reached its expected life to assist in the replacement.

### 2.1.3 Communications media

Water meters in Australia are uniquely positioned in that they are usually at the front of the property. This means that there can be a distance of up to fifty metres between the utility metering box and the actual water meter. The electronic water meter has to be able to communicate over this distance before a device at the house can take readings to send to a central billing centre.

For new estates, it would be possible to have the communication media put into trenches at the same time as the water pipes are installed to the house. This would most likely be the simplest solution, both in the design of the Electronic Household Water Meter and also in the cost.

For established housing estates where the owners agree to have trenches dug in their garden, then the solution to the communications problem would be similar to that of the new housing estate. When the established estate is such that digging trenches is either too costly or impractical, then another solution for communications must be found. This might be in the form of either a radio frequency link using one way or two way communications or by using fibre optic cable.

**Specifications**

•

The communications media must be capable of transmitting and/or receiving information from up to 50 metres away.

**Communications Options**

(i) Twisted pair cable

Where the owner of the property agrees to having a trench dug on the premises then the cheapest overall system would be achieved by using ordinary twisted pair cable for communications. This requires some sort of driver which can transmit up to 50 metres over twisted pair cable. One advantage of this is that power can also be delivered to the EHWM and thus solve the restrictions on power.

(ii) Radio Frequency

If trenches are unable to be dug then one alternative for communications is using radio frequency. This is a complicated technology because there are a number of issues involved such as Department Of Transport And Communications (DOTAC) approval for RF spectrum allocation, signal strengths, transmission power, broadcast duration, spread spectrum, two way or one way transmissions, protocols and circuit power consumption.

A study done by Nigel Portlock [Portlock, (1991)] outlines the effectiveness of a one way radio based transmission link using a RF Monolithics MB1003 transmitter and a RB 1003 receiver. A number of limitations were found such as signals being prone to interference due to the low powered nature of the device and difficulties of transmitting at bit rates greater than 300 bits/sec.

Another prototype and trial was done [Reid, Renwick and Prior (1991)] to determine the possibilities of using radio frequency as a method of transmitting data. The test water meter had a one way FM transmitter inside and it was successful in transmitting information but one of the major problems was that the power consumption of the meter was too high.



There are many difficulties using radio frequency for communications and further investigation needs to be done to resolve all the issues involved.

(iii) Optical Fibre.

For existing estates, it could also be possible to send an optical fibre down an existing water pipe and this could be a solution to having to dig up a customer's garden. A feasibility study has been done by Adelaide Microelectronics Centre [Pugatschew] where they determined that it is possible to use optical fibres to transmit information. A working prototype has been constructed but more investigation is required to produce a cost effective design.

**Selection**

As the main criteria for the EHWM was to produce a power efficient design it was decided that the initial prototype should concentrate on this aspect and keep the communications side simple. A wire based media was chosen for the communications as this was power efficient and it allowed for the use of two way communications using the existing research. The overall design of the EHWM allows for the addition of radio frequency or optical fibre communications when an efficient and cost effective solution is developed.

### 2.1.4 Power supply

The remoteness of the water meter from the house presents a problem in powering the EHWM in a cost effective manner. The power source has to be able to last for ten years and if there is a possibility of power failure then there must be a backup source for the duration of the power failure. The power supply can also be dependent upon the communication media. If cable or optical fibre is being used for communications then they could also be used for powering the EHWM. If radio frequency is being used for communications then the power supply must be self contained for the EHWM. The different power sources researched are listed below.

i) Primary Batteries

For a self contained EHWM, primary battery power offers the most attractive solution due to the simplicity of the design. There are a number of criteria for the selection of the battery and these are :

- shelf life of ten years.
- large capacity for supplying the required power.
- small size to fit in the water meter.
- absolute minimum voltage of two Volts over the lifetime
- stable voltage over both temperature and lifetime.

For the required battery capacity, and to be able to fit in the small compartment of the water meter it was found that lithium batteries best fits the criteria. Most of the batteries did not have an operational life of 10 years and so they were not suitable. The best solution was offered by Lithium Thionyl Chloride (LTC) batteries as they offered a 10 year shelf life, high energy density, a level voltage characteristic and a high open circuit voltage of 3.7 volts.

ii) Wire Feed Power

Where the communications media is a cable then a wire fed supply would offer the cheapest and most logical solution. This would be the case in new residential areas and where customers agree to have trenches dug in their garden. The only problem would occur during power failures where there would have to be some backup power supply in the EHWM. Secondary backup sources such as lithium rechargeables and super-capacitors are described later in the section.

iii) Three-phase Micro Hydro Generator

It has been considered that the water flow through the meter could be sufficient to drive a generator to power the EHWM. After initial investigation, design and testing of a wire-wound three phase micro hydro generator it was found that the starting torque of the generator was too great to be used. Initial investigations into a three phase printed circuit board micro hydro generator have suggested that it could be used to power the EHWM, though further design and testing is required before the generator can be practically used. Consideration would also have to be given to a secondary power source when water is not flowing such as in the cases where customers are away for extended periods.



iv) Optical Fibres

Optical fibres can be used to transmit power by using a solar cell to convert the light beamed down the fibre into electrical energy. This idea is not new and research by Geo-Centers Inc have shown that it is possible to get in excess of one watt electrical from a (silica) optical fibre. [Tabacco (1987)]. Further research on this process by Telecom Research Laboratories [Lo (1991)] has shown that while the idea is technically feasible, the cost inhibits any practical use of the process at this present stage.

v) Lithium Rechargeable Batteries

Lithium rechargeable batteries have been seen as a possible secondary power source where their small size and high capacity are attributes which are required in the EHWM environment. The rechargeable batteries could be used in conjunction with a micro-hydro generator or external charging source such as a wire feed from the house supply. Information to date has been limited, suggesting an operational life of 100 charge/discharge cycles.

vi) Super Capacitors

Super Capacitors could be used in the same way as the Lithium Rechargeable batteries would be used within the EHWM. Again a charging source is required to maintain the power above the minimum level in order to sustain full operation.

**Selection**

The cheapest and most effective solution to power a self contained EHWM at this stage would be from the Lithium Thionyl Chloride batteries. They offer a reliable, self contained power source that can last the ten year lifetime.

## 2.2 Final System Design

A number of possible designs for the EHWM were considered and a final design consisting of an elaborate power conservation scheme was selected. From the initial conceptual design it was decided that an LCD was not necessary as part of the EHWM so it was omitted from the first prototype. Refer to section 5.2 for further details. It should be noted that because the microcontroller that was selected is a masked device and it is therefore a final production device, it was impractical to use in the prototypes. A one time programmable device which closely resembles the mask version was used.

### 2.2.1 Specification

With the ultimate aim of an operational life of over ten years and to be self-powered, it was necessary for the design to be power conservative. The design philosophy adopted was to only power the minimal amount of circuitry to undertake the task or operation at hand. Therefore if no communications is required, then the communications section is powered down and so on. Figure 3 shows the block diagram representation of the final system chosen. Refer to Appendix D for a complete circuit diagram of the final design.

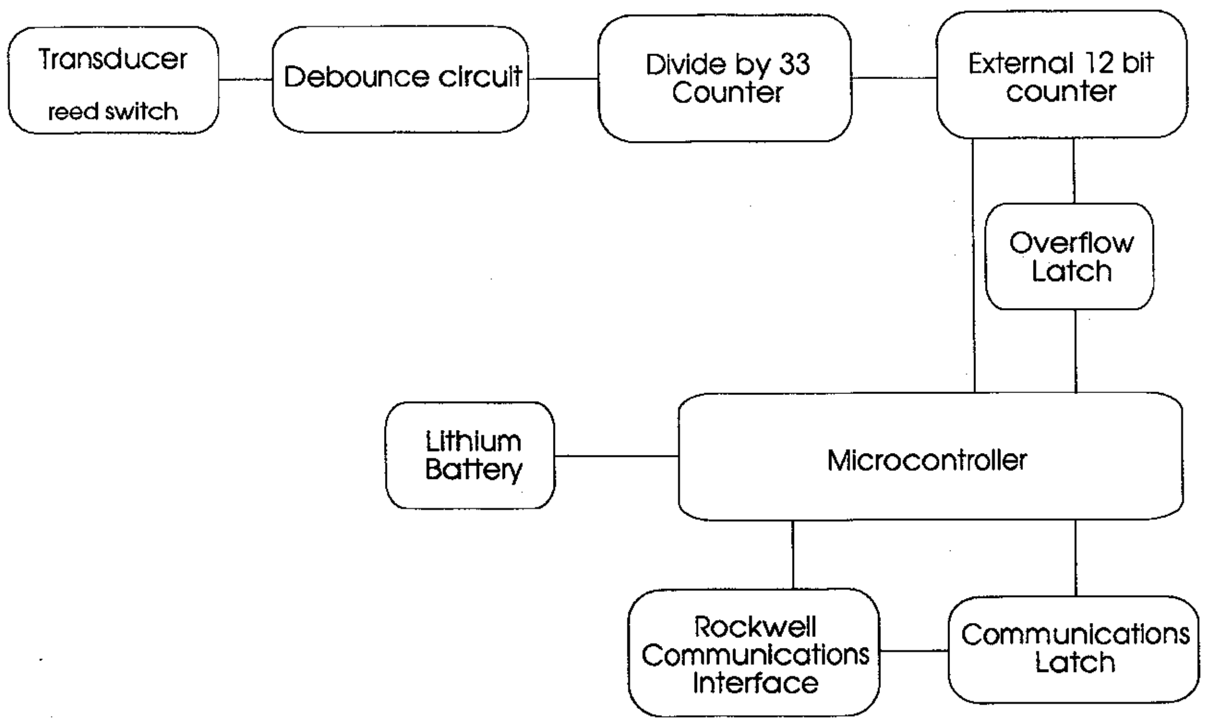



Figure 3 Final EHWM System Block Diagram

The design consists of a reed switch for the transducer which produces a contact closure for every pass of a North/South pole of the rotating magnet. A debounce circuit removes all the mechanical



contact bounce from the reed switch before passing the electronic signal to the external electronic divider circuit. The divider circuit converts the incoming pulses into a value which closely approximates litres value. The output of the divider circuit flows into the external counter. This counter can store a value of 4096 before it overflows. If the counter does overflow, the counter overflow latch is set which will interrupt the microcontroller requesting that the internal 32 bit counter register be incremented. By having the external counter circuitry it means that less power is consumed by the microcontroller giving longer life to the battery.

As the Rockwell protocol had proven to be a simple, power efficient and reliable communications protocol for the Siemens Computer Assisted Meter Reading Interface (CAMRI) unit, it was decided to adopt the same protocol for the EHWM. The hardware part of the Rockwell communications section consists of a 3 wire interface, Ground, Clock Input and Data input/output. Enhancement mode Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) were used to interface the wiring to the EHWM. These MOSFETs offer extremely low power consumption which make these the most applicable for the interfacing.

When a signal is asserted by the CNU on the Clock line, the communications latch is set. The microcontroller will then be woken up and the reading will be transmitted. When finished the microcontroller will go into sleep mode once again.

The microcontroller serves two main functions :

1. To service any request of counter overflow and increment and provide internal storage of count values in excess of 4096.
2. To send on request the total accumulation of water to the receive unit using the Rockwell protocol.

The main feature of the microcontroller is that when none of the services are required, the device is put into micro-power mode or halt mode. In this mode the device will only respond to external interrupts from either the communications or the overflow.

A Lithium Thionyl Chloride battery powers the entire circuit continuously with the microcontroller entering micro-power mode when not in full operation. Sufficient power is retained within the water meter for a life expectancy of over 10 years.

### 2.2.2 Prototyping and construction

A simple construction methodology was adopted with the ultimate aim of the EHWM module being a drop in replacement to the mechanical registers. A Davies Shephard 20mm KGG water meter was used with only the absolute minimum alterations being necessary. Three prototype units were constructed. One module was left in the laboratory for continuous testing and observation. The other two prototypes modules were housed within a KGG water meter and placed in the field.

The prototype modules were constructed on vero board which was cut round to fit into the index housing. Figure 4 shows the overall assembly method used. All of the integrated circuits were placed into sockets for ease of component replacement during field visits. It was necessary to drill a single hole in the register housing to allow a communications cable to be inserted. Silicone sealant was applied to the cable and hole to provide a water tight seal. A metal restraining ring was applied to the cable to stop the cable from being pulled out accidentally. A slot was drilled in the plastic meter cap in order to allow the cap to be removed and placed on with ease.

A plastic spring washer was placed between the metal retaining ring and the plastic meter cap so when the cap was screwed on it would directly apply pressure to the glass top and in turn to the rubber ring. The overall construction was therefore water tight. Future designs should consider vacuum sealing as well as silicone water absorption beads to absorb any moisture. Plates 1, 2 & 3 shows the prototype modules and complete Electronic Household Water Meter.



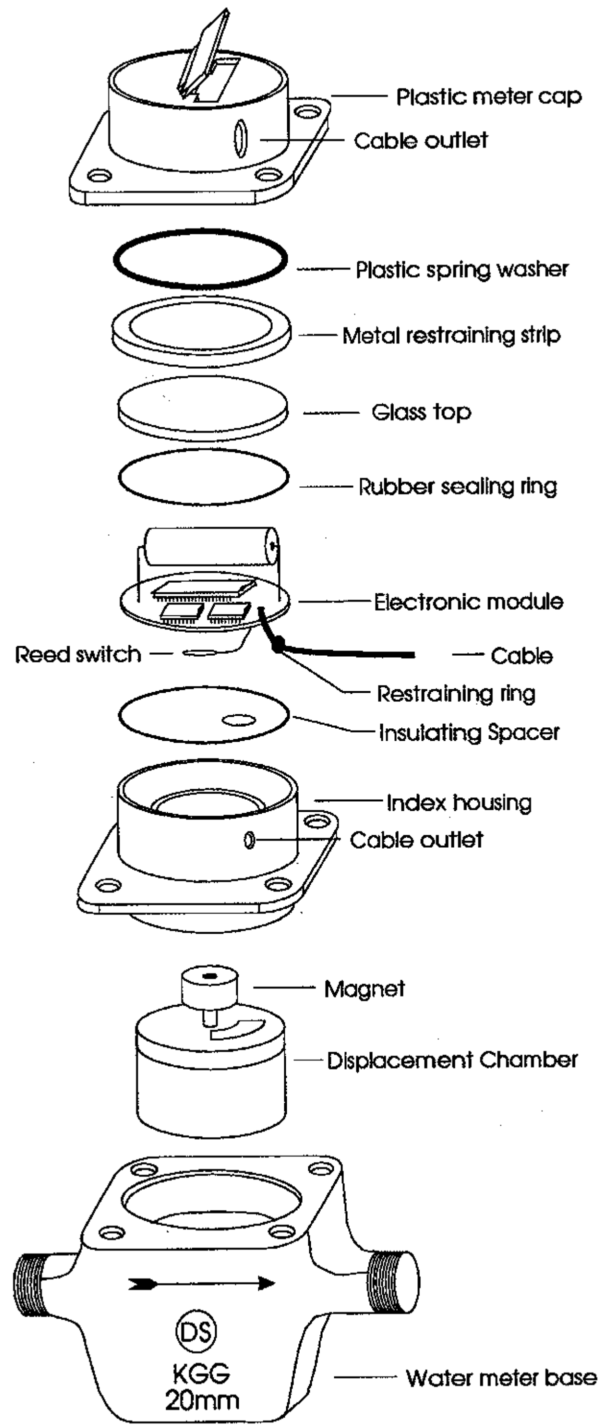



Figure 4 Prototype assembly block diagram

Future designs should also take into consideration the ease of removal and insertion of the EHWM module. Another possible location for the cable entry is through the lid although the glass will need to be drilled.

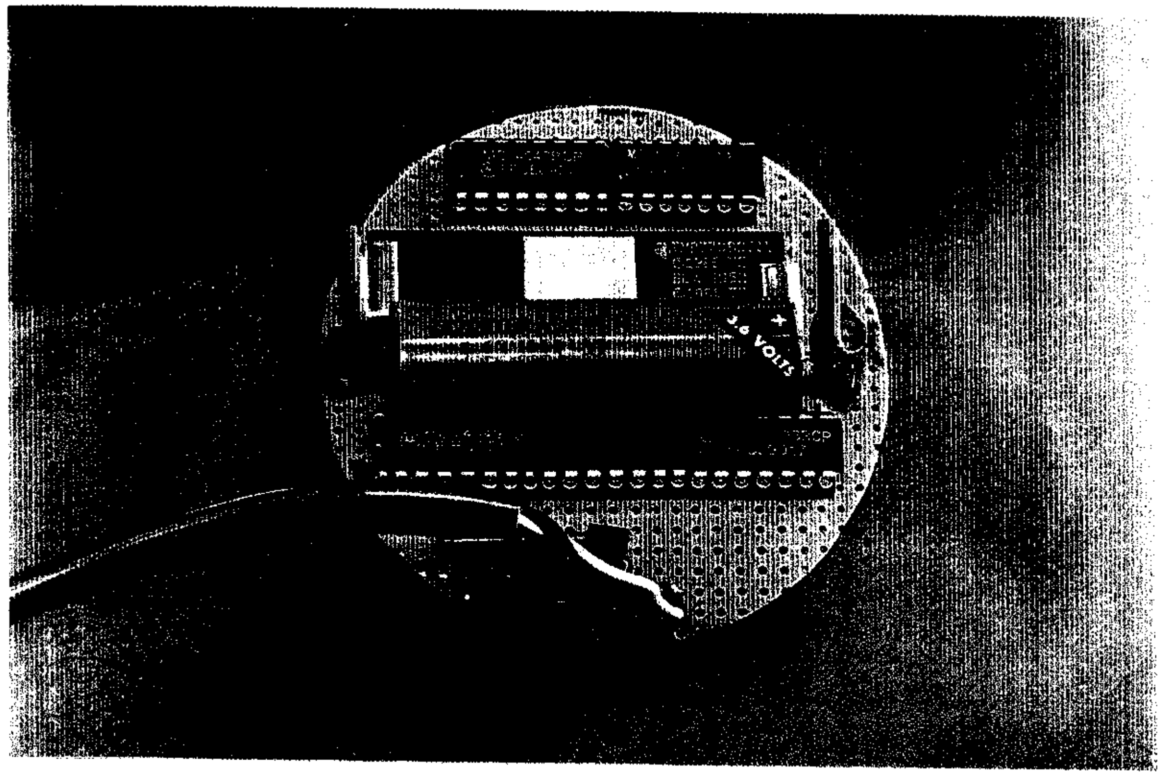


PLATE 1 - Electronic meter module

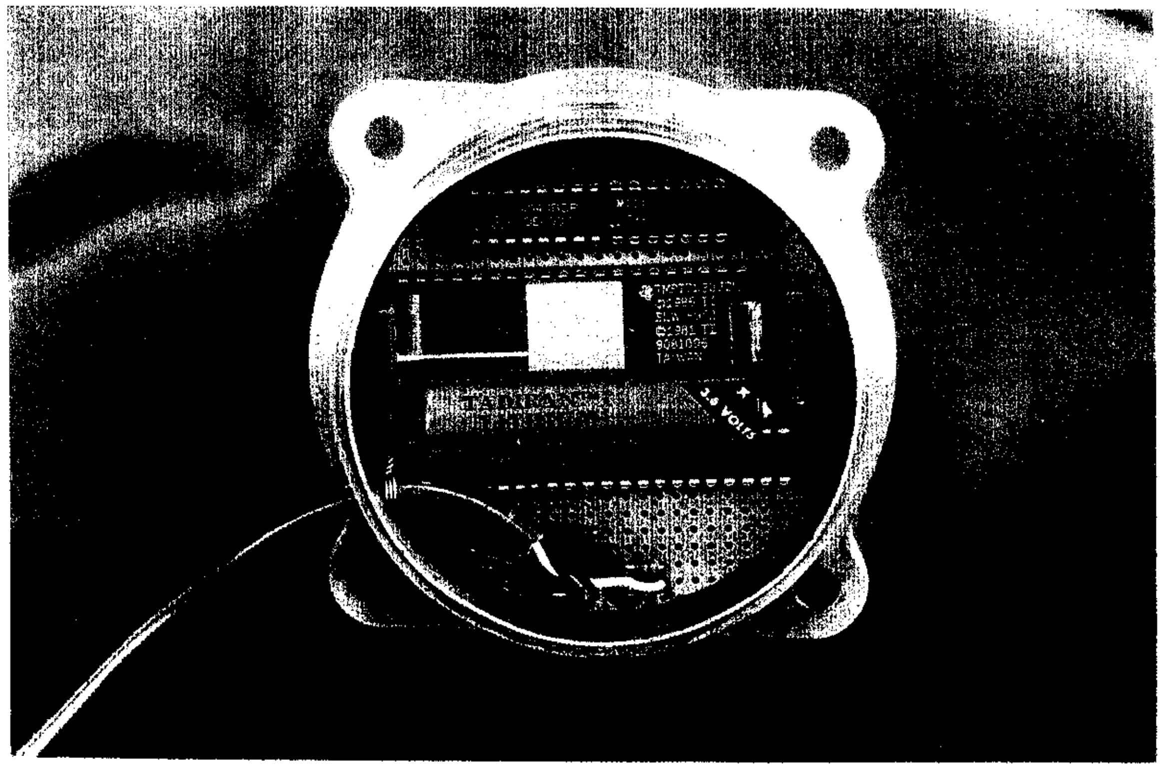


PLATE 2 - Electronic meter module inside water meter capsule

Plate 3 Complete Electronic Household Water Meter

### 2.2.3 Firmware

The software that is contained within the microcontroller consists of two major blocks.

1. Storage and compensation block.
2. Transmission block.

Figure 5 shows the base level system operation flow chart. Refer to Appendix E for the complete source listing of the microcontroller software.

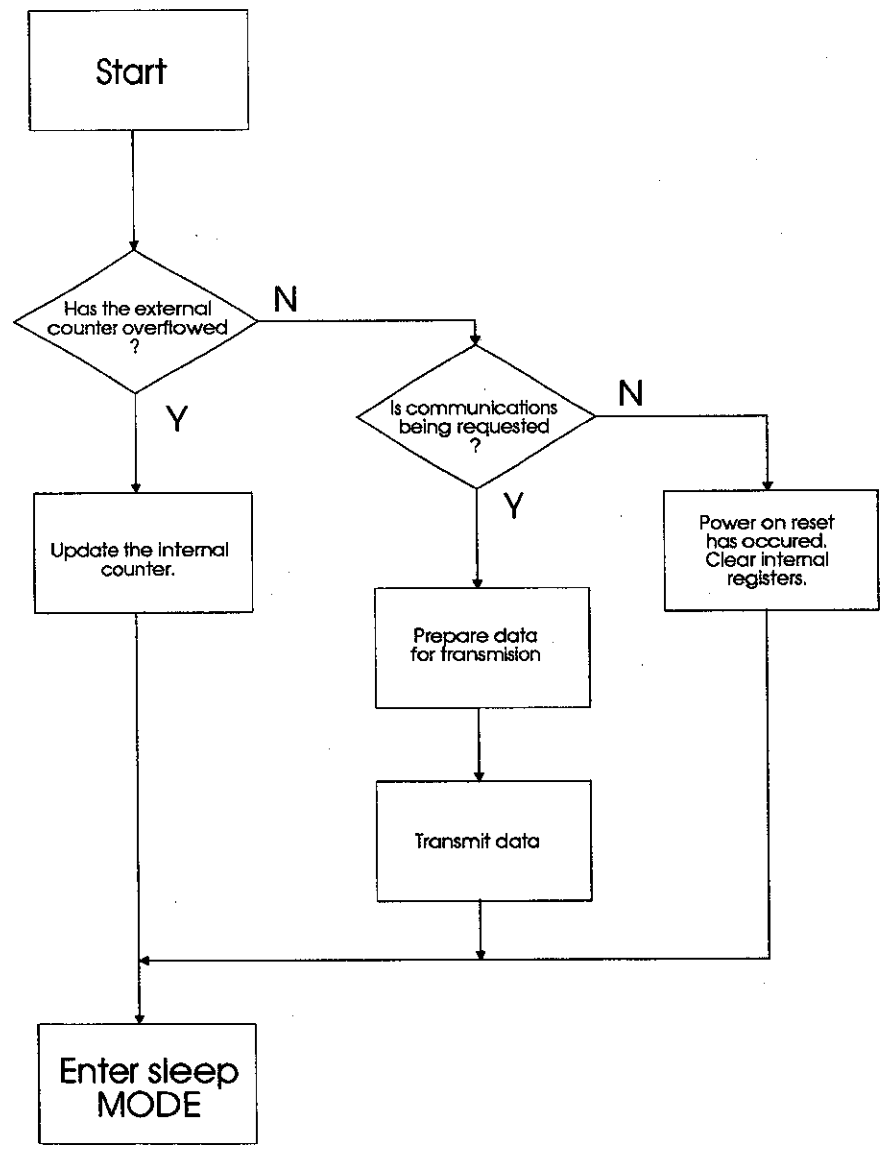



Figure 5 Base level system flow chart.

**Storage and Compensation Block**

The Storage and compensation block consists of a 32 bit counter register which is incremented every time the external counter overflows. The amount that the internal counter register is incremented is determined by the compensation value selected at programming. The compensation value is the value which the external counter value need to be adjusted in order to compensate for the external digital division error. The external digital division error exists because the water chamber is geared for 16.575 revolutions per litre which corresponds to 33.15 pulses of the reed switch per litre and because the digital circuit is dividing by 33, the additional 0.15 pulses per litre need to be compensated. A software solution was selected as this is more cost effective. The compensation software takes this error into account by dividing the total count by the compensation factor and adjusts the external counter value before adding the internal compensated value to it to produce the total accumulation.

Davies Shephard have the water meter chamber geared for 16.575 revolutions per litre but their mechanical register within the KGG meter is geared for 16.5 revolutions per litre to allow the meter to be within specification over the required flow rates with age. It was intended to have the prototype units programmed to the mechanical register value but the exact values were not available at the time of prototyping. The prototype units were programmed for 16.6 revolutions per litre which was the value given by Davies Shephard at the time.

**Transmission Block**

When a request for a meter read is received by the EHWM, the transmission block takes the 32 bit total accumulation register and converts this into an ASCII string for transmission purposes. Additional characters are added to the start and end of the ASCII consumption value to form a Rockwell protocol message.

A sample message is shown

`V;RWdddddddd;IWnn<CR>`

where V - is the beginning of the message.

; - is the delimiter of fields.

R - indicates the reading field.

I - indicates the identification field.

d - this is one digit of the total accumulation reading in ASCII format.

nn - is the water meter identification number.

W - indicates that the message is from a water meter.

<CR> - end of record (stop character).

After the consumption value is put in Rockwell message form, the transmission block then outputs the message synchronously to the clock signal supplied by the Customer Interface Unit which in this case is the CAMRI. A parity bit is also added to each character for error detection. After each bit is sent, the microcontroller is put into a wait mode to conserve power before the next bit is transferred. A timer has also been programmed into the transmission block so that if there is a long delay between clock signals such as when an error occurs then transmission is halted and the microcontroller is reset to its shutdown mode.



# 3. FIELD TRIAL AND TESTING

## 3.1 Laboratory Testing

There were three main tests performed on the EHWM in the laboratory, these tests were :

1. System power consumption testing.
2. Water accumulation testing.
3. EHWM Rockwell interface testing.

### 3.1.1 System power consumption testing

A system power consumption test was performed on the prototype EHWM's using the configurations shown in Figure 6.

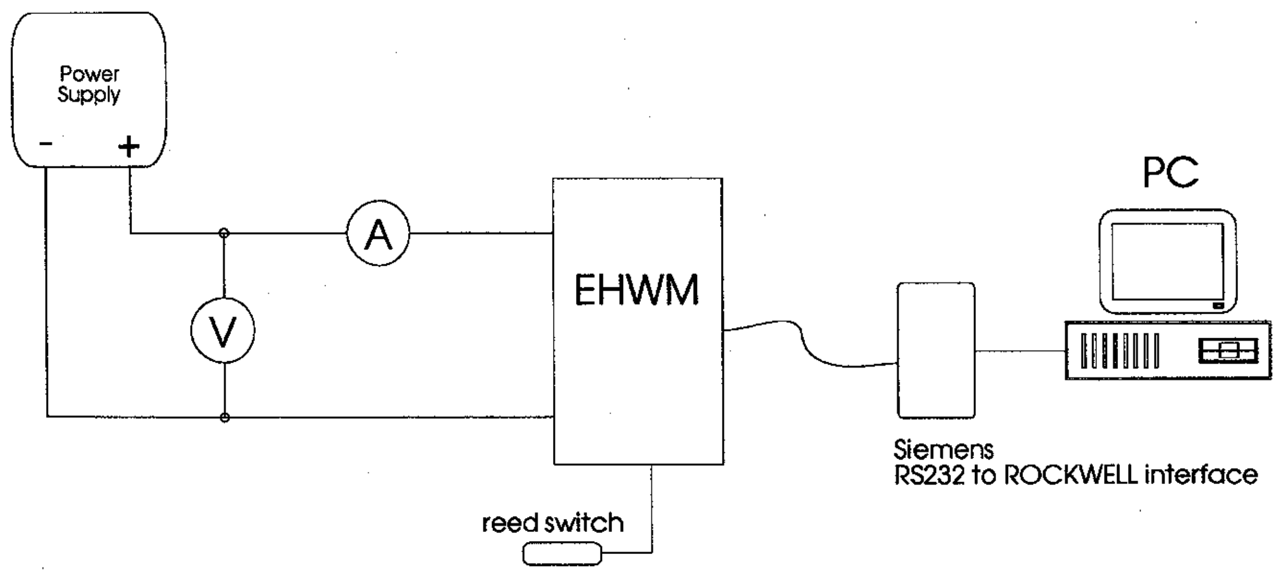



Figure 6 Power consumption testing setup.

Tests were performed on the prototype units at two voltage levels. The five volt level is what the component specifications are given at and the three point six level being the voltage output of the lithium battery used in the trial. The results of the two tests are shown in Tables II & III. As mentioned earlier, the microcontrollers used in the prototypes are not the same as the final mask versions which would be used for the final design. The characteristics of the device used are comparable. The tables show measurements for both the crystal and RC versions of the microcontrollers. This is due to the RC versions not being available at the commencement of the trial and hence the prototypes in the field contained crystal versions.

TABLE II

MAXIMUM CIRCUIT POWER CONSUMPTION TEST AT 5V LEVEL

| @5.0 Volts @20°C | XTAL Ceramic Version microcontroller @ 2MHz Ceramic resonator | | RC Plastic Version microcontroller @ 2MHz C=48pF, R=10k | |
|---|---|---|---|---|
| | Actual System Current | Theory System Current | Actual System Current | Theory System Current |
| Run mode | 11.32mA | 21.21mA | 11.60mA | 21.21mA |
| Wait mode | 1.80mA | 2.11mA | 1.50mA | 2.11mA |
| Halt mode | 696.0uA | 851.5uA | 6.3uA | 18.5uA |

The purpose of the 5V test performed was to compare the literature consumption values to the actual recorded values.

TABLE III

MAXIMUM CIRCUIT POWER CONSUMPTION TEST AT 3.6V LEVEL

| @3.6 Volts @20°C | XTAL Ceramic Version microcontroller @ 2MHz Ceramic resonator | RC Plastic Version microcontroller @ 1.5MHz C=48pF, R=10k |
|---|---|---|
| | Actual System Current | Actual System Current |
| Run mode | 3.64mA | 3.52mA |
| Wait mode | 402uA | 600uA |
| Halt mode | 272.0uA | 2.9uA |



The test at 3.6 Volts was performed in order to determine the power consumption of a circuit whilst being powered by a lithium battery.

A definition of the terms used in Tables II & III is now given.

a. Run mode - is defined as being the maximum current consumption of the EHWM when all the integrated circuits are activated and the microcontroller is operating. Activities such as counter overflow occurring or communications in progress.

b. Wait mode - is defined as being the maximum current consumption of the EHWM when the microcontroller is in wait mode or timer active mode. In wait mode the microcontrollers' timers are operating and the microcontroller is either waiting for the next clock edge of the communications line, or for the time to have expired on the timer.

c. Halt mode - is defined as being the maximum current consumption of the circuit when all the integrated circuits are activated but with the microcontroller in micro power sleep mode.

**System power consumption testing results**

It was found that the power consumption of all the components in the circuit were within manufacturers specification. The complete calculation of the theoretical power consumption of the circuit is given in Appendix C. It was found that the minimum operating voltage of the circuit to allow communications using the crystal version of the microcontroller was 2.6 volts.

### 3.1.2 Water accumulation testing

A test jig was constructed to test and compare the readings of the trial EHWM to another mechanical water meter in the laboratory. A block diagram of the test jig is shown in Figure 7.

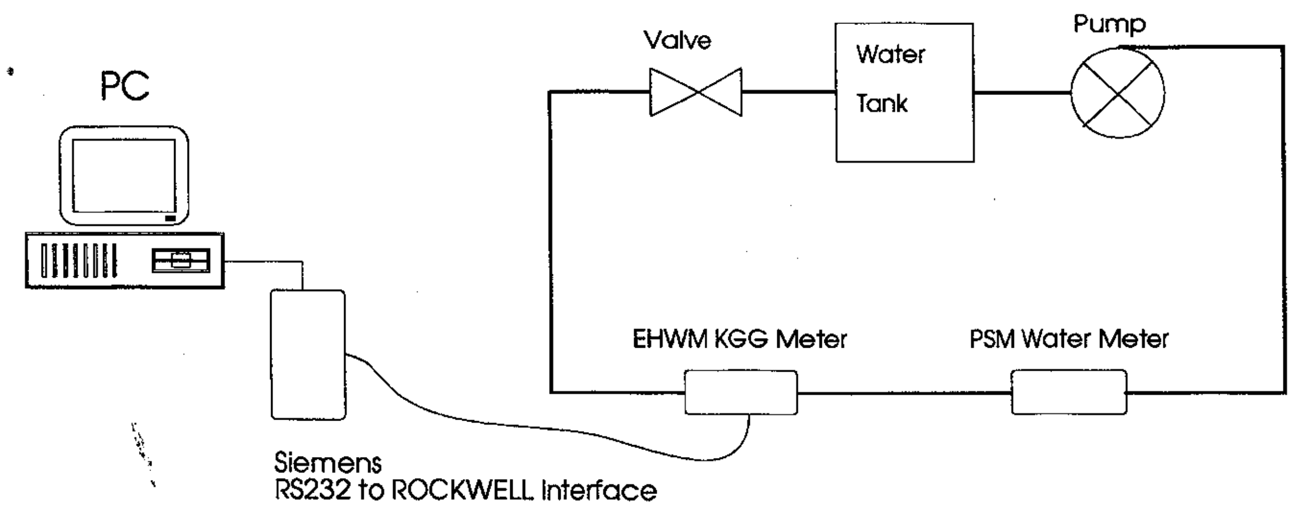



Figure 7 Water accumulation test setup.

Water was passed through the water meters at varying flow rates. Table IV shows the results of the testing.

TABLE IV

WATER ACCUMULATION TESTING RESULTS

| | Low flowrate - 5 - 30 l/hr | | High flowrate - 400 - 500 l/hr | |
|---|---|---|---|---|
| | Total accumulation | % Difference | Total accumulation | % Difference |
| Davies Kent PSM - T reference meter | 5723.6 ltr | | 17221.69 ltr | |
| EHWM compensated | 5645 ltr | -1.37% | 17027 ltr | -1.13% |



**Water Accumulation Test Results**

The outcome of the testing in the laboratory suggests that the compensation factor that was put into the software is operating correctly. From the information given by Davies-Kent (NSW) Pty Ltd the PSM - T meter reads between +1% to +1.4% above actual consumption for the same range of flowrates. Uncompensated readings for the EHWM are as low as -0.53% difference between the PSM reading.

### 3.1.3 EHWM Rockwell interface testing.

The communications interface of the EHWM was tested using two setups. Figure 8 shows a Personal Computer (PC) interface to the EHWM and Figure 9 shows a CAMRI unit connected to the EHWM.

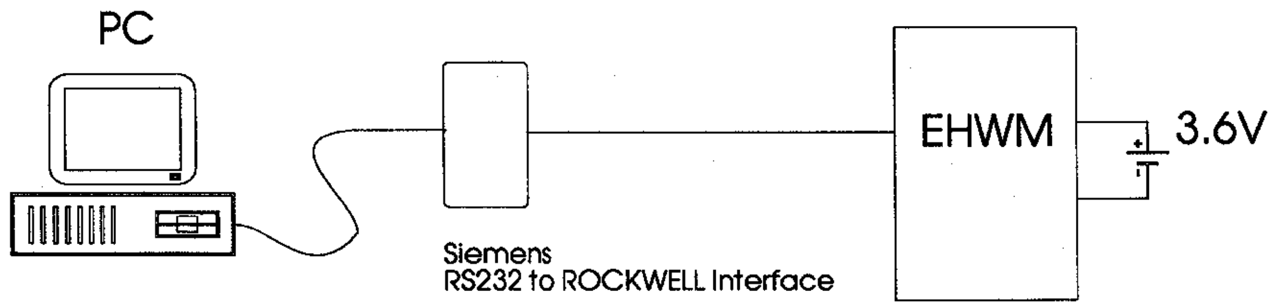



Figure 8 Rockwell interface testing setup 1 - EHWM to PC.

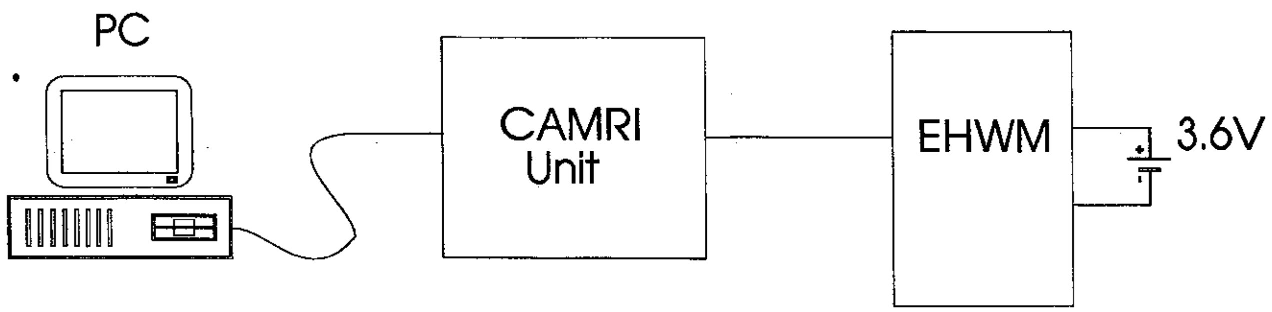



Figure 9 Rockwell interface testing setup 2 - EHWM to CAMRI.

In the case of setup one, a read was requested by the PC via a PC to Rockwell interface unit every 10 seconds, 1 minute and 10 minutes to see if the read request rate would effect the reliability of the communication. Table V shows the success rate of the communications at the specified request rate.

TABLE V

COMMUNICATIONS RELIABILITY OVER VARYING READ REQUEST RATES

| Setup 1 EHWM to PC | No of reads | Success rate |
|---|---|---|
| 10 Seconds | 3203 | 100% |
| 1 Minute | 2895 | 100% |
| 10 Minutes | 1733 | 100% |

In the case of setup 2, the EHWM was connected to a commercially available CAMRI unit from which the reads were requested every hour for the period shown. Table VI shows the reliability of the reads obtained from the EHWM when requested by the CAMRI unit.



TABLE VI

COMMUNICATIONS RELIABILITY USING A CAMRI UNIT WITH HOURLY REQUESTS

| Setup 2 EHWM to CAMRI | No of Hourly Reads | Success rate |
|---|---|---|
| 16/11/92 - 13/1/93 | 1037 | 100% |

**EHWM Rockwell Interface Testing Results**

The tests in the laboratory revealed that the communications interface is reliable. Both tests performed on the EHWM have shown that information is reliably transmitted to the device making the request.

## 3.2 Field Trial

The field trial was held for five and a half weeks which means that the testing on the EHWM was limited but long enough to determine the operation of the prototypes. In order to extensively test the meter it would need to be put under varying environmental conditions and tested for a number of years.

### 3.2.1 Trial configuration

The EHWM was installed in two properties in Mount Dandenong to enable the performance of the meters to be tested under actual environmental operating conditions. The Mt Dandenong area which is located 35km East of Melbourne, was chosen as the location for the EHWM trial as this provided ease of installation due to the existing setup of two CAMRI units from the UNP trial. Figure 10 shows a diagram of the EHWM trial configuration.

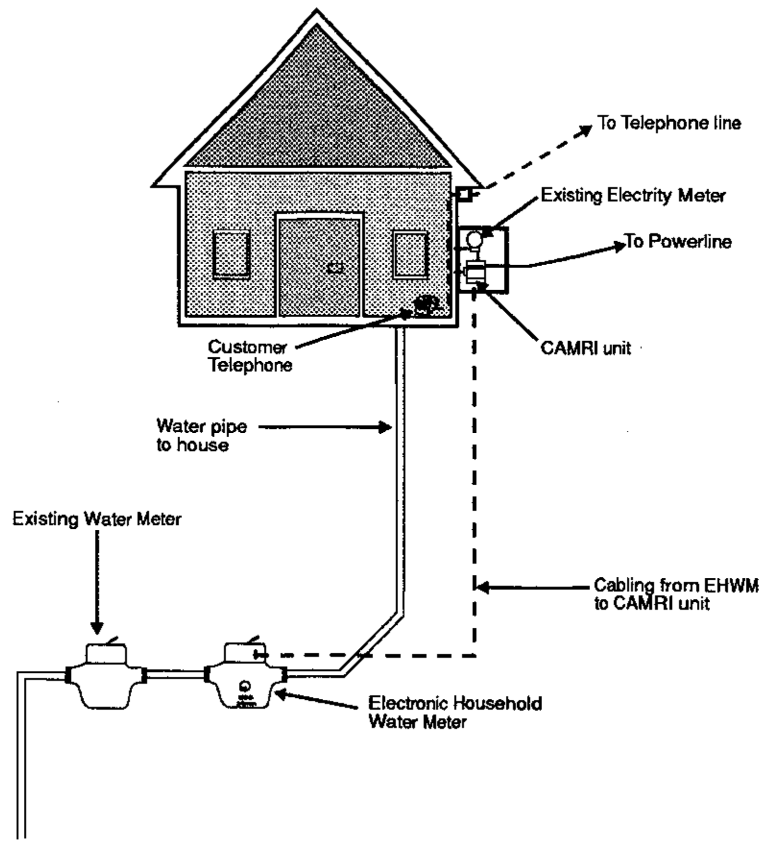



Figure 10 EHWM trial configuration block diagram



Each water meter was placed in series with the existing water meter and an underground cable was used to connect it to the CAMRI unit which is mounted in the Utility Metering Box. The CAMRI unit transmits the information from the meter over the telephone line to the billing centre.

### 3.2.2 List of problems encountered

There were a number of problems encountered with the EHWM during the field trial. One of these problems being with lightning and the other with static electricity. Midway through the trial, there was a lightning strike on both CAMRI units in the field. This resulted in the total replacement of the electronic components within the water meter. This problem will need to be looked at in future designs.

Another problem existed with static electricity. This problem is inherent with the devices used in the communications section of the circuit. Special handling was necessary in the laboratory to prevent destroying the components. MOSFETS were used and protection should be provided to make the design more robust.

### 3.2.3 Reliability

The reliability of the EHWM was determined by how successful the transmission of the reads were from the EHWM to the CAMRI unit. The reliability of the EHWM can be calculated from the number of reads requested by the CAMRI to the number being returned. The reliability of the system from the CAMRI unit to the Billing Centre was not tested here as it has been documented in [Phey, Leong, Balazic, Colson and Manning (1993)] and was found to be reliable for meter reading at 99.36%. From the data collected during the trial, the reliability of the EHWM was found to be 100%. Table VII shows the number of successful reads during the trial period.

TABLE VII

EHWM RELIABILITY

| Period | Location 1 | | Location 2 | |
|---|---|---|---|---|
| | No. of Reads | % Successful | No. of Reads | % Successful |
| 7/12/92 - 19/12/92 | 228 | 100% | 232 | 100% |
| Lightning 19/12/92 - 7/1/93 | 0 | 0% | 0 | 0% |
| 7/1/93 -25/1/93 | 347 | 100% | 327 | 100% |

### 3.2.4 Accuracy

The EHWM was connected in series with the existing Billing meter and therefore measuring the same water consumption. An exact determination of accuracy could not be done because neither the EHWM or the existing billing water meter have been recently calibrated though it can be assumed that the billing water meter meets Melbourne Water specifications. The difference between the EHWM and the existing water meter is shown in Table VIII.



TABLE VIII

EHWM METER ACCURACY

| | | Location 1 | | Location 2 | |
|---|---|---|---|---|---|
| | | EHWM No1 | WM No1 | EHWM No2 | WM No2 |
| Period 7/12/92 - 16/12/92 | Consumption | 16170 litres | 16058 litres | 7759 litres | 7190 litres |
| | % Difference | 0.697% | | 7.914% | |
| Period 23/12/92 - 7/1/93 | Consumption | 24154 litres | 23998.2 litres | 10263 litres | 10217 litres |
| | % Difference | 0.649% | | 0.450% | |
| Period 7/1/93 - 25/1/93 | Consumption | 38893 litres | 38666 litres | 14100 litres | 13953.1 litres |
| | % Difference | 0.587% | | 1.053% | |

For the period between 7/12/92 to 16/12/92 the meter at location 2 had a 7.914% difference in the reading. After a lightning strike it was necessary to replace the components including the reed switch in that particular unit. The reed switch had the contacts fused together at location 2 but not at location 1. Once all the devices were replaced the accuracy of the meter was comparable to the water meter at location 1. It was therefore concluded that there may have been a problem with the reed switch initially.

## 3.4 Hourly Results

From the information which was collected from the two sites in Mt Dandenong, hourly consumption graphs can be plotted. Figures 11 & 12 shows the consumption of water over an hour of the two customers during the same week period. The graphs shows the type of information that can be obtained using an EHWM in an AMR system. Information is missing from customer #2 on the 24/1/93 because of a problem with a CAMRI unit.

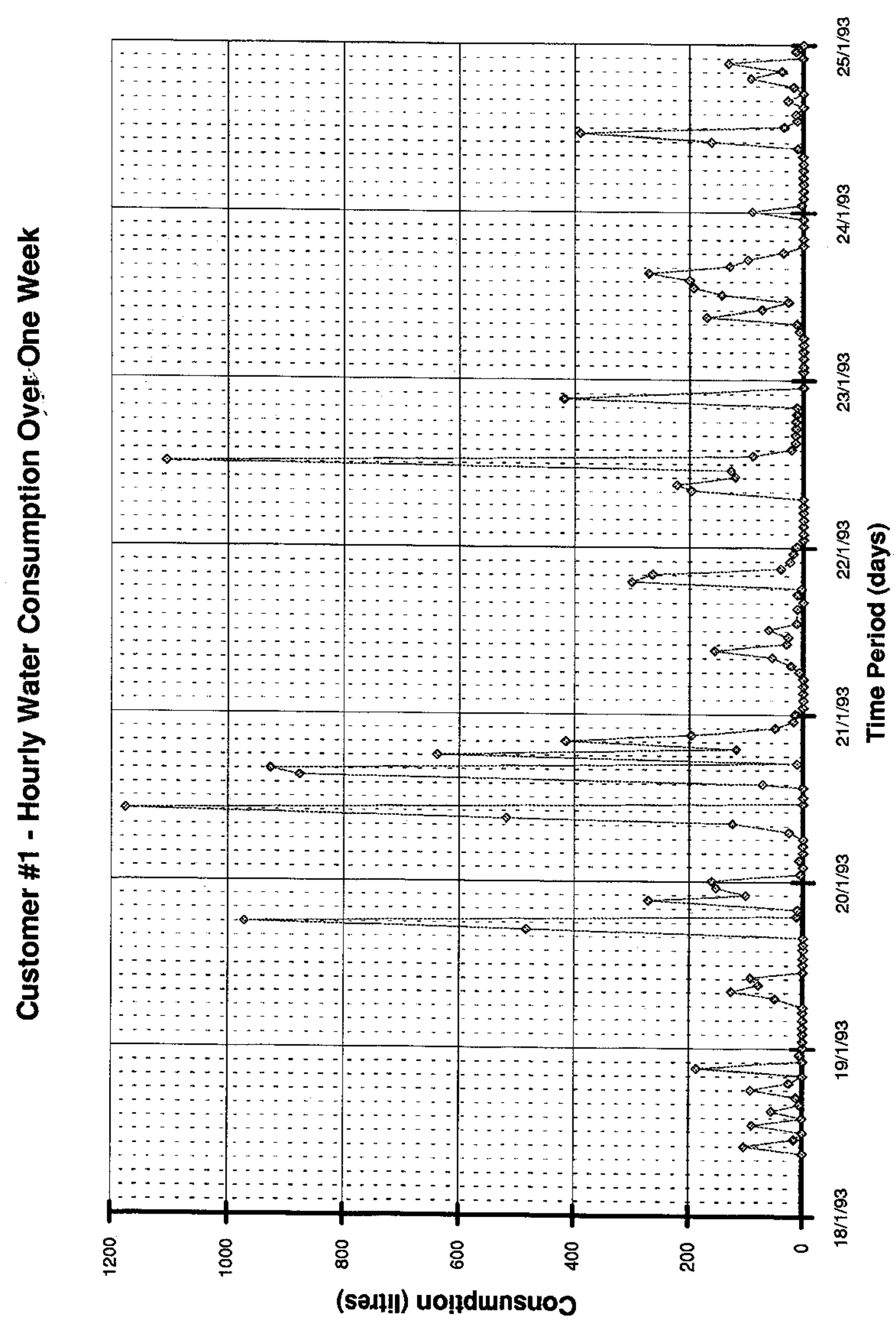



Figure 11 Consumption of water over hourly periods for customer #1



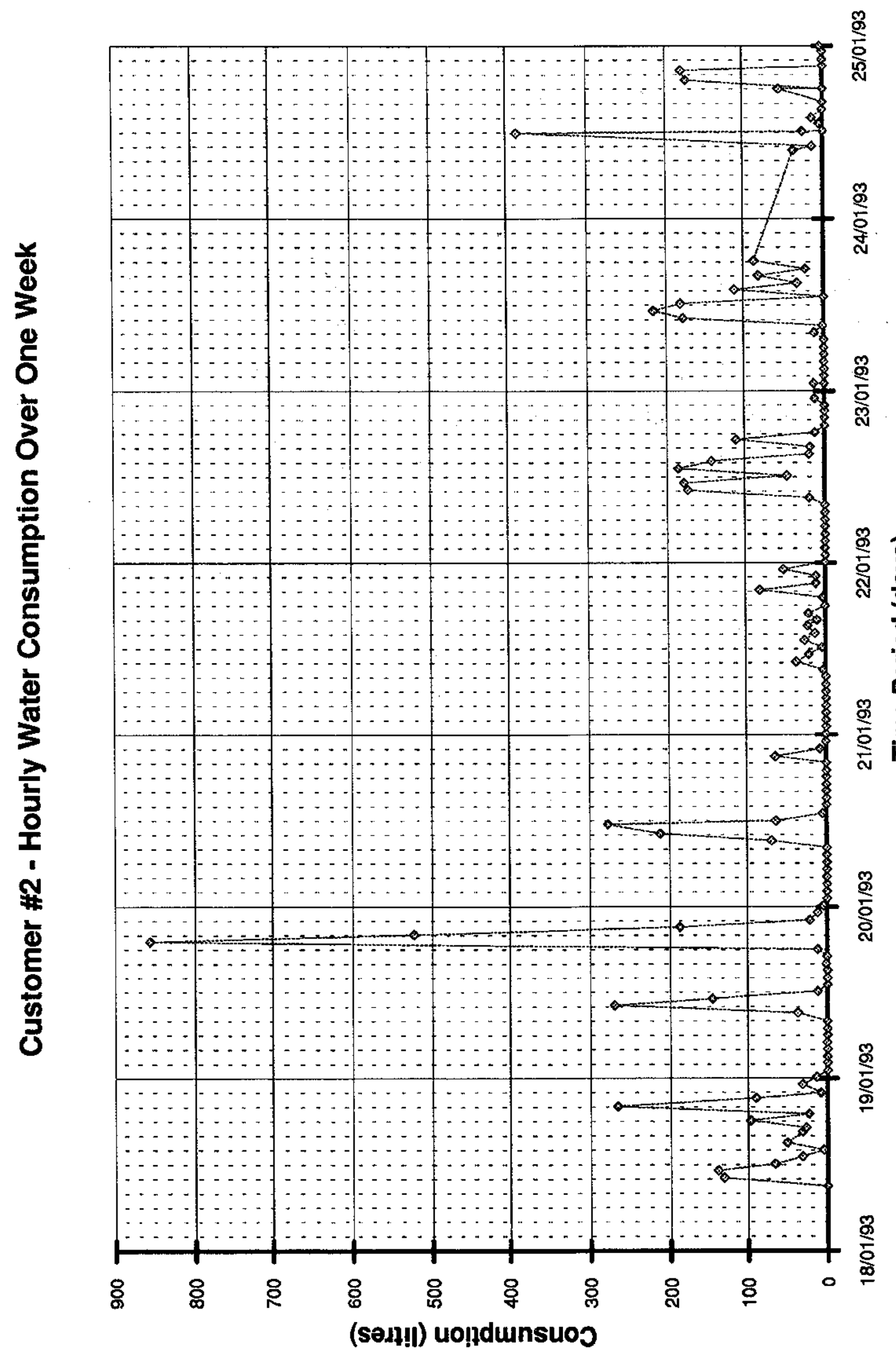



Figure 12 Consumption of water over hourly periods for customer #2

## 3.5 Further Work Necessary

As a result of the prototyping and field testing of the EHWM's, a number of adjustments to the design should be considered. One adjustment is input protection to the communications line. The other is lightning protection for the circuitry.

Further work is necessary in the area of environmental testing since the trial was very limited in that extent. Laboratory environmental testing was carried out at Ballarat University College. [Vranesic, (1989)]. The tests indicated that the maximum internal temperature experienced within the water meter with an ambient temperature of 50°C is less then 70°C. At the low end of the temperature range, the internal temperature of the meter experienced 0°C with an ambient temperature of -2°C. Further extensive environmental testing is necessary with the complete electronic water meter to determine its operation under all conditions.



# 4. ECONOMIC VIABILITY

## 4.1 Pricing Full Production

Table IX breaks down the cost of the individual components used in the design of the EHWM. Details of the pricing were obtained from the manufacturers and suppliers on a 100,000 order quantity.

TABLE IX

COMPONENT BREAKDOWN COSTING

| COMPONENT TYPE | Price @100K+ |
|---|---|
| TI micro-controller TMS70C20 | $2.37 |
| MOSFETS + IC's | $1.612 |
| Resistors + Capacitors | $0.3333 |
| Reed Switch | $1.39 |
| Lithium Battery | $2.95 |
| PCB + Construction | $3.95 |
| Davies Shephard water meter without tumblers | $50.00 |
| TOTAL UNIT COST | $62.6053 |

Further research into the components would enable better pricing as some suppliers could only give estimates at the time of writing. Additional savings could also be made if surface mounted devices were used. This would reduce the size of the total package and lower the cost of construction.

## 4.2 Price Comparison To Existing Mechanical Meters

The price of the existing water meters used by Melbourne Water is in the order of $56 which means that if you are only comparing standard water meter functions then it would suggest that an EHWM is not as yet viable. For the EHWM to be considered as a cost effective alternative, the advantages of the additional features needs to be considered. The EHWM allows for the remote reading of the water consumption where as the existing water meter does not. It also has the capability of having adjustable correction factors and detection of tampering.

Preliminary discussions with Davies Shephard have indicated that the design of the brass capsule and coverplate could be modified specifically for the EHWM which would lower the overall cost of the water meter. With the addition of an electronic display (refer to section 5.2) the EHWM could be a practical alternative with just standard existing meter functions. The additional features such as remote reading could be introduced as the need arises. Additional research is required in the production side of the EHWM to determine the cost savings that could be achieved.

## 4.3 Installation and running costs

The cost of installing an EHWM is basically the cost of installing an electronic meter and laying the cable from the EHWM to the meter box. For new estates this cost would virtually be the same as installing the existing water meter as the cable could be installed when the pipe is layed. For existing properties there needs to be a changeover of water meters and a trench dug for the cable. A rough estimate of the installation cost obtained from a contractor was $140 with most of the cost being from the trenching and laying of the cable. With a high volume of installations the price would drop dramatically.

The EHWM itself has been designed for no maintenance over its 10 year lifetime. Additional costs are incurred in installing a CNU to make the system totally automatic. These costs as well as an estimate of running costs for the system are detailed in the UNP report [Phey, Leong, Balazic, Colson and Manning (1993)].



# 5. POSSIBLE ENHANCEMENTS

Possible enhancements to the EHWM will be discussed in this section.

## 5.1 Tamper Detection

The interim Standard Part 3 - Services Interface due to be released in May 1993, deals with the issues regarding tamper detection of wire based interfaces.

In terms of the EHWM, the house unit (Master Unit) would detect a tamper if no reading can be obtained from the EHWM (Slave Unit), since the reads are instigated by the house unit. Tampering would only be detected at the point when the reads are requested. If the reads of the meter are done frequently as would be the case in a Time Of Day setup, (at least twice a day) then the tampering would be detected much sooner.

The types of tampering includes,

- destroying the module,
- opening the module,
- destroying the counter circuitry,
- breaking the reed switch,
- removal of battery,
- cutting of the communications cable.

Additional circuitry would be necessary in the EHWM in order to detect tampering of the module itself.

## 5.2 Incorporating A Liquid Crystal Display

The standard household water meter has the water consumption displayed on the meter for billing purposes and so the customer can check their own consumption. For billing purposes a display of water consumption on the EHWM is not required as information would be transferred electronically. Customers would still require some method of reading their water consumption and it is generally considered that the display be on the Customer Interface Unit as this would allow easier access. An initial problem could be customers' acceptance of taking a reading remotely from the water meter. If it is decided that displays on the electronic water meter are required in the initial introduction of automatic meter reading then the details below give an indication of the requirements and estimated costs.

**Requirements**

Because of the remote environment where the water meter is situated, the display must have a low operating voltage, low power consumption and also be able to endure the temperature range found in the water meter. A liquid crystal display best fits the criteria.

The liquid crystal display would also require a driver to enable the display to be controlled by the microcontroller. The LCD driver would have to be able to communicate with the microcontroller using a three wire serial line as the microcontroller has only a limited number of input/output ports.

Both the display and driver would need to be easily removed from the design as it is seen that in the future the meter readings would be read from the house rather than on the meter itself. The extra work required to the existing EHWM design to incorporate the display would be additional software, PCB design including extra componentry.

**Specifications**

Digit Height > 4mm
8 Digits including a decimal place to enable 1/1000 of a kl to be read.
Operating temperature : 0° to 60°
Storage temperature : -10° to 70°
Supply Voltage : 2.5 to 6 volts
Extra symbols : Battery symbol, communications symbol, kl, $m^3$.
Standard polariser reflective.
Epoxy DIL pins
Multiplex rate : This is dependent on the LCD driver. (For a Philips PCF2111) - 1: 2



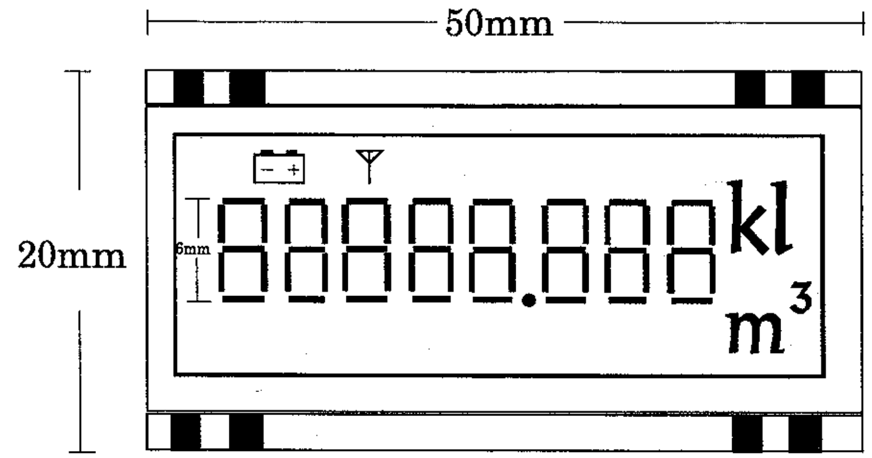



Figure 13 LCD Dimensions

**LCD Driver**

Operating temperature : 0° to 60°
Storage temperature : -10° to 70°
Supply Voltage : 2.5 to 6 volts
3 wire serial input

A number of manufacturers were found to be able to supply the required Liquid Crystal Display. To obtain the extra symbols, a custom liquid crystal display has to be designed and constructed. At present the only LCD driver able to accept a 3 wire serial input has been the Philips PCF2111. An investigation of other LCD drivers needs to be carried out and quotes obtained for them.

TABLE X
MAJOR PARTS COST
OF INCORPORATING A LIQUID CRYSTAL DISPLAY

| Component Type | Price @ 100K+ |
|---|---|
| Custom Liquid Crystal Display | $2.15 |
| LCD Driver | $3.41 |
| TOTAL | $5.56 |

Table X shows an estimate of the additional cost of the two major components for incorporating into a LCD display within the EHWM. Extra costs would be involved in other components required for the display, the printed circuit board and the construction. A rough estimate of the cost to add a LCD display to the EHWM would be $10. This would bring the total cost of the meter to $72.61. With additional research and a finalisation of the design this cost would be reduced.

## 5.3 Flow Correction

The incorporation of a microcontroller in the EHWM design permits the inclusion of additional features which are not possible in a standard water meter. As a water meter ages, the readings become less accurate due to the wearing of parts. The ability to adjust for accuracy during ageing of the meters is considered to be a definite advantage. Only a simple software adjustment is necessary to implement this feature. Correction factors could also be down loaded to the meter on a regular basis.

Because of the nature of positive displacement water meters the accuracy of the meters varies with flow rate. With an EHWM a flow compensation factor could be programmed into it to allow for the difference. A characteristic curve could be programmed into the meters and maybe even changed at a later date.



# 6. CONCLUSIONS AND RECOMMENDATIONS

From the trial it was found that the Electronic Household Water Meter functioned very successfully with the only major problem being the lack of protection against lightning. The additional cost for this protection will need to be looked at both statistically and economically. Statistically in the number of possible meter strikes. Economically in the cost of the additional lightning protection circuitry as compared to the loss of data and service crew for site visit and module replacement. Protection against static electricity would also be required to provide a more robust meter as the EHWM is likely to be treated roughly during installation.

The trial has shown that the EHWM is a very cost effective and practical design. Further extended testing would be required to determine the operation of the EHWM under all environmental conditions and to verify the theoretical life of ten years.

To enhance the capabilities of the EHWM further development can be done on the liquid crystal display and the radio frequency link. These enhancements would allow the EHWM to be installed in a greater variety of households to suit the varying conditions. The liquid crystal display would also allow the use of the EHWM as a standard meter until a full AMR system is introduced.

The work done in this trial has shown that the EHWM can be a commercially viable product. Discussions with Davies Shephard have indicated that the EHWM could actually reduce production costs which would greatly enhance its acceptance by water utilities due to its lower cost. The ability to add additional features to the standard water meter will become of greater value as the cost of delivering water and monitoring its consumption increases in the future.

It is recommended that there be further investigation into refining the construction of the EHWM to reduce the costs of production and to allow the meter to be commercially produced. At this stage with manual meter reading being very efficient and delivery costs being low, introduction of the EHWM to the average household is more likely to be achieved if the cost of the EHWM is lower than or similar to the cost of the existing mechanical meter.

# Acknowledgments

The authors would like to thank the people and organisations listed below for their invaluable contributions to make the project a success.

ACD and Texas Instruments - for the loan of the microcontroller development system and assistance in the development.

State Electricity Commission of Victoria - For the assistance in meter removal after the lightning strike.

Davies Shephard - donation of the KGG water meters and provision of information.

Ballarat University College - Construction of the test jigs.

P. & L. Mooiman - For use of their property as a trial site.

G. & K. Heenan - For use of their property as a trial site.

Peter J. Reid - Lecturer, Ballarat University College.

Ray Martin - Head of Electrical Engineering, Ballarat University College.

Nigel Portlock - Royal Melbourne Institute of Technology.

Paul Langton - Royal Melbourne Institute of Technology.

Bernard Phey - Manager, Asset Planning, Maribyrnong Region, Melbourne Water.

David Richards - Manager, MITS.

Andrew Leong - Project Engineer, MITS.

Zlatko Balazic - Project Engineer, MITS.

# References


BALAZIC, Z. (1990). Electronic Household Water Meter - Stage 3, Ballarat University College, Ballarat, Australia. (Unpublished)

LO, E.W.C. (1991). A review on the issue of powering an optical fibre customer access network. Australian Electronics Convention Proceedings pp.405 - 408. IREE, Sydney, Australia.

PHEY, B., LEONG, A.K., BALAZIC, Z., COLSON, R. and MANNING, S.N. (1993). Automatic Meter Reading : Link between meters and Billing Centre : Combined Utilities Trail,Urban Water Research Association of Australia, Report Number 52, Melbourne, Australia.

PORTLOCK, N. (1991). Radio Based Meter - Data Link Test Report, MITS, Melbourne, Australia. (Unpublished)

PUGATSCHEW, Dr. and FRIEBEL, M. (1991). Optic Fibre Based Transmission System for Water and Gas Consumption Meters. Adelaide, Australia.

REID P.J., RENWICK, J. and PRIOR, M.F. (1991). Electronic Meter Reading, Link between Water Meter and Home, Urban Water Research Association of Australia, Report Number 28, Melbourne, Australia.

TABACCO, M.B., DIGIUSEPPE T.G. and STOKES G.H. (1987). High power laser delivery through infrared transmitting optical fibers. Infrared Optical Materials & Fibers. pp.138-142. SPIE Vol 843.

VRANESIC, S. (1989). Electronic Household Water Meter - Stage 2, Ballarat University College, Ballarat, Australia. (Unpublished)


### Data Books


DALLAS. (January 1990). Dallas Semiconductor DS5000 User's Guide

INTEL. (1991). Intel 8-Bit Embedded Controllers Handbook

MOTOROLA. (1988). Motorola Microprocessor, Microcontroller and Peripheral Data Volume 1 and 2 Q3

NATIONAL SEMICONDUCTOR. (1990). National Semiconductor Microcontroller Data Book

PHILIPS. (1991). Philips 8048-based 8-Bit Microcontrollers Data Handbook IC14

TEXAS INSTRUMENTS. (1991). Texas Instruments TMS7000 family 8-Bit Microcontrollers Data Manual

ZILOG. (1991). ZiLOG Microcontrollers Handbook




# APPENDIX A.
# MEASUREMENT UNITS

The SI units of measurement are adopted in the report and the symbols used are shown below:

- Hz Hertz (Frequency measurement unit)
- V Volts (Voltage measurement unit)
- °C Centigrade (Temperature measurement unit)
- A Ampere (Current measurement unit)
- $m^3$ Cubic meter (Volume measurement unit)
- l Litre (Volume measurement unit equivalent to $1x10^{-3}m^3$)
- s Second (Time measurement unit)
- m Metre (Length measurement unit)

- m (milli) multiplier measurement unit
- u (micro) multiplier measurement unit
- n (nano) multiplier measurement unit
- p (pico) multiplier measurement unit
- k (kilo) multiplier measurement unit
- M (mega) multiplier measurement unit

# APPENDIX B
## Supplier List

**Dallas Semiconductors**

Igor Karlik
Veltec Pty. Ltd.
telephone : (03) 808 7511

**Davies Shephard**

Richard Sokol
Davies Shephard
telephone : (03) 460 3744

**Entech Products**

Don Miles
Entech Products Ltd
telephone : (08) 371 1022

**Hamlin**

Mark Peeters
Email Electronics
telephone : (03) 544 8244

**Handok**

Craig Dickeson
Davidson Ltd
telephone : (03) 555-7277

**Intel**

Bill Bourne
NSD Australia
telephone : (03) 890 0970

**Motorola**

Anthony Coffey
Motorola Semiconductor Products
telephone : (02) 906 3855

Eddie Prince
VSIP Electronics (Aust) Pty. Ltd.
telephone : (03) 543 6445

Igor Karlik
Veltec Pty. Ltd.
telephone : (03) 808 7511

**National Semiconductor**

Steve Cinquegrana
National Semiconductor
telephone : (03) 558 9999

Bill Bourne
NSD Australia
telephone : (03) 890 0970

Eric Sfyridis
GEC George Brown Group.
telephone : (03) 878 8111

**Philips**

Gary Pereira
Passive Electronic Distributors Pty.Ltd.
telephone : (03) 873 4722



**Tadiran**

Maurice E. MacMahon
Mechtric Ltd
telephone : (02) 938 3555

**Texas Instruments**

Doug Mealy
Texas Instruments Australia Limited
telephone : (03) 696 1211

Ken Pattison
Advanced Component Distributors Pty Ltd
telephone : (03) 762 7644

**ZiLOG**

Eric Sfyridis
GEC George Brown Group.
telephone : (03) 878 8111

# APPENDIX C

# Power Consumption Study For The EHWM

•

**Assumptions** a/ Communications occurs twice a day @0.5 seconds communications
b/ With the display option, 10 reads per year @15 seconds per display

**Information**

| | |
|---|---|
| Hours in ten year = | 87600 hours |
| Average water consumption = | 300000 litres/year |
| ten years = | 3000000 litres/10 years |
| | |
| average flow rate = | 34.2466 litres/hour |
| | 0.5708 litres/minute |
| | 0.0095 litres/second |
| | |
| meter pulses per litre = | 33.15 pulses/litre ie. KGG water meter |
| external divider = | 33 pulses/litre |
| | |
| average pulse rate of reed switch = | 0.3154 pulses/second ie. frequency of operation<br>0.0003 kHz |
| | |
| Counter size = | 12 Stage Binary |
| Counter range = | 4096 count |
| Overflow Rate = | 2.33e-09 kHz |
| | |
| Reed switch calculations: | |
| Reed switch operational life = | 1.00e08 pulses |
| Total switch operations = | 9.95e06 per year |
| Life span = | 10.06 years |
| Expected life span = | 10 years |

**Counter and Integrated circuit current calculations:**

| **4093 Nand gates** | |
|---|---|
| Average operating frequency = | 9.556e-06 kHz<br>ie reed switch pulse rate / 33 |
| Device quiescent current =<br>per package max @25oC @5V | 2.500e-07 Amps |
| Device dynamic current = | 4 gates per package<br>1.2 micro Amps/kHz<br>per package |
| Total device current =<br>per package max @25oC @5V | 2.500e-07 Amps |



| **4069 Inverter** | |
|---|---|
| Average operating frequency = | 3.15e-04 kHz<br>ie reed pulse rate |
| Device quiescent current =<br>per package max @25oC @5V | 2.500e-07 Amps |
| Device dynamic current = | 6 gates per package<br>0.3 micro Amps/kHz<br>per gate |
| Total device current =<br>per package max @25oC @5V | 2.506e-07 Amps |

| **4049 Inverter** | |
|---|---|
| Average operating frequency = | 3.15e-04 kHz |
| Device quiescent current =<br>per package max @25oC @5V | 1.000e-06 Amps |
| Device dynamic current = | 6 gates per package<br>1.8 micro Amps/kHz |
| Total device current =<br>per package max @25oC @5V | 1.000e-06 Amps |

| **4013 D flip flop** | |
|---|---|
| Average operating frequency = | 2.3331e-09 kHz<br>ie overflow freq |
| Device quiescent current =<br>per package max @25oC @5V | 1.00e-06 Amps |
| Device dynamic current = | 2 gates per package<br>0.75 micro Amps/kHz |
| Total device current =<br>per package max @25oC @5V | 1.00e-06 Amps |

| **4040 12 stage counter** | |
|---|---|
| Average operating frequency = | 9.51e-06 kHz |
| Device quiescent current =<br>per package max @25oC @5V | 5.00e-06 Amps |
| Counter dynamic current = | 0.42 micro Amps/kHz<br>per package |
| Total counter current =<br>per package max @25oC @5V | 5.00e-06 Amps |

| **4024 7 stage counter** | |
|---|---|
| Average Operating freq = | 3.15e-04 kHz |
| Counter quiescent current =<br>per package max @25oC @5V | 5.00e-06 Amps |
| Counter dynamic current = | 0.31 micro Amps/kHz<br>per package |
| Total counter current =<br>per package max @25oC @5V | 5.00e-06 Amps |

| | |
|---|---|
| **Total**<br>Current consumption of counters = | 1.15e-05 Amps |
| Using 4049 instead of the 4069 = | 1 .23e-05 Amps |
| | |
| **Total**<br>Power consumption of counters = | 1.0075 AmpHrs |
| Using 4049 instead of the 4069 = | 1.0732 AmpHrs |

| | |
|---|---|
| **Display** | |
| PCF2111 Philips | |
| Display consumption = | 5.00e-05 Amps |
| | |
| Servicing lid openings = | 10 times per year |
| Expected life time = | 10 years |
| Total openings during lifetime = | 100 times during life |
| | |
| Time required to service | 15 seconds |
| Lid openings = | 0.0042 hours |
| | |
| Total time spent on lid servicing = | 0.4167 hours |
| Power required to service lid openings = | 0.0020 AmpHours |

| | |
|---|---|
| **Communications** | |
| Comms device consumption = | 0.0360 milli amps<br>3.6/(Rds+100K) |
| | |
| Total communications current =<br>(ie comms + micro) | 4.8360 milli amps |
| | |
| Communications event<br>Time required to service communications event =<br>18 Characters * 10 Bits/char* 600 microsec/bit + 300mS startup =<br>0.408 seconds | 0.5 seconds<br>1.39e-04 hours |
| | |
| Number of communications =<br>events | 2 per day<br>730 per year<br>7300 during life |
| | |
| Total time spent =<br>on communication service | 1.0139 hours |
| | |
| Power required to service =<br>communications | 0.0049 AmpHrs |



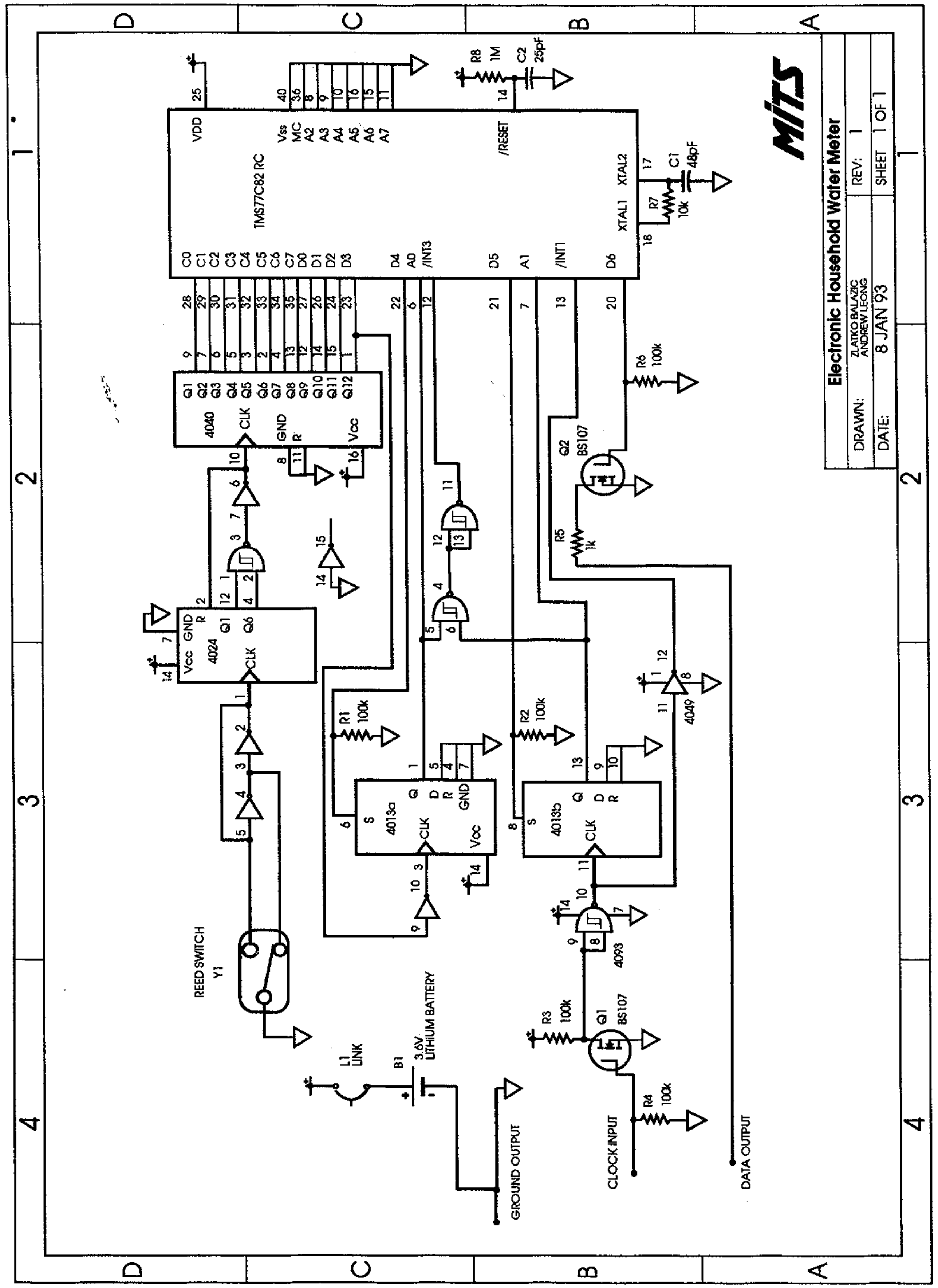
| | |
|---|---|
| **Overflow Servicing** | |
| Total number of overflows = | 732.42 in 10 years |
| Time to service an overflow = | 3.63e-04<br>seconds |
| Total time to service = | 0.2659 seconds |
| | |
| Power requirement in overflow = | 3.54e-07 Amphrs |

| **Microcontroller** | Texas Instruments TMS70C20 | Prototyping TMS77C82 RC |
|---|---|---|
| **Halt/Stop mode current =** | 1 micro Amps | 7 micro Amps |
| | | |
| Time spent in halt mode = | 87598.57 hours | 87598.57 hours |
| | | |
| Power requirement in halt mode = | 0.0876 AmpHrs | 0.6132 AmpHrs |
| | | |
| Wait - Timer active mode = | 640 micro Amps | 2.1 milli Amps |
| | | |
| **Run mode current @5V 2MHz =** | 4.8 milli Amps | 21.2 milli Amps |
| | | |
| **Time spent in run mode =** | | |
| | 0.417 hours ie display | 0.417 hours ie display |
| | 1.014 hours<br>ie communications | 1.014 hours<br>ie communications |
| | 7.39e-05 hours<br>ie service overflow | 7.39e-05 hours<br>ie service overflow |
| **Total =** | 1.4306 hours | 1.4306 hours |
| | | |
| **Power requirement in run mode =** | | |
| | 2.00e-03 Amphrs<br>ie display | 8.83e-03 Amphrs ie display |
| | 4.87e-03 Amphrs<br>ie communications | 2.15e-02 Amphrs<br>ie communications |
| | 3.54e-07 Amphrs<br>ie service overflow | 1.57e-06 Amphrs<br>ie service overflow |
| **Total =** | 6.87e-03 Amphrs<br>Display + Comms + overflows | 3.03e-02 Amphrs<br>Display + Comms + overflow |
| | | |
| **Total Microcontroller Power Requirement** | | |
| **Halt + Run =** | 0.0945 AmpHrs | 0.6435 AmpHrs ie.<br>Prototyping microcontroller used |

| Battery requirements | | | | |
|---|---|---|---|---|
| Idle mode current | | | | |
| | Consumption | Duration | Capacity | |
| counters | 1.15e-05 Amps | 87600 hours | 1.0075 AmpHrs | |
| micro | 1.00e-06 Amps | 87598.57 hours | 0.0876 AmpHrs | |
| | Capacity = 1.0951 AmpHrs | | | |
| Pulsed current | | | | |
| | Consumption | Duration | Pulsed | Capacity |
| micro | 4.8mA | 1.4306 hours | 15 seconds | 0.0069 AmpHrs |
| display | 0.05 mA | 0.4167 hours | 15 seconds | 2.08e-05 AmpHrs |
| comms | 0.0360 mA | 1.0139 hours | 0.5 seconds | 3.65e-05 AmpHrs |
| overflow | 4.8 mA | 7.39e-05 hours | 3.63e-04 seconds | 3.54e-07AmpHrs |
| | Capacity = 0.0069 AmpHrs | | | |
| **Total Required Capacity = 1.1020 AmpHrs** | | | | |
| **Voltage range -** | | | | |
| Minimum voltage | 2 V Absolute | | | |
| **Temperature range** | | | | |
| minimum | 0 oC | | | |
| maximum | 70 oC | | | |
| climate | Australia | | | |



# APPENDIX D
# Electronic Household Water Meter
# Circuit Diagram






# APPENDIX E

## Electronic Household Water Meter

## Assembler Listing

```
         ********************************************************************************
         * :EHWMR4.ASM          Electronic Household Water Meter Project                *
         *                                                                              *
         * Description:  This program calculates the total water consumption of the    *
         *               meter and transmits this value using the Rockwell protocol     *
         *               as required.                                                   *
         *                                                                              *
         *                                                                              *
         *                                                                              *
         *                                                                              *
         *                                                                              *
         * Version 4.01                                                                 *
         * By Zlatko Balazic and Andrew Leong.                                          *
         * 2/12/92                                                                      *
         *                                                                              *
         ********************************************************************************
0000
                 IDT     'EHWM-V4'
0000
         *********************************************************************************
         *                             Peripheral File                                   *
         *                                                                               *
         *********************************************************************************
0000
    0000 IOCNT0 EQU     P0                         Interrupt control 0
    0002 IOCNT1 EQU     P2                         Interrupt control 1
    0001 IOCNT2 EQU     P1                         Interrupt control 2
0000
    0004 APORT  EQU     P4                         Port A data register
    0005 ADDR   EQU     P5                         Port A data direction register
    0006 BPORT  EQU     P6                         Port B data register
    0008 CPORT  EQU     P8                         Port C data register
    0009 CDDR   EQU     P9                         Port C data direction register
    000A DPORT  EQU     P10                        Port D data register
    000B DDDR   EQU     P11                        Port D data direction register
0000
    000C T1MSB  EQU     P12                        Timer 1 data (N/A for TMS70C20)
    000D T1LSB  EQU     P13                        Timer 1 data (P2 on TMS70C20)
    000F T1CTL0 EQU     P15                        Timer 1 control 0 (P3 on TMS70C20)
    0013 T2CTL0 EQU     P19                        Timer 2 control 0 (N/A for TMS70C20)
    0015 SCTL0  EQU     P21                        Serial control register
0000
0000
         **********************************************************************************
         *                             Register File                                      *
         *                                                                                *
         **********************************************************************************
0000
         * Continuous internal count overflow register
0000
    001E MSMSW  EQU     R30     Most significant byte of the most significant word
    001F LSMSW  EQU     R31     Least significant byte of the most significant word
    0020 MSLSW  EQU     R32     Most significant byte of the least significant word
    0021 LSLSW  EQU     R33     Least significant byte of the least significant word
0000
         * Temporary storage of the total of the internal overflow register +
         *       compensated external counter value
0000
    0022 MSMSWT EQU     R34     Most significant byte of the most significant word
    0023 LSMSWT EQU     R35     Least significant byte of the most significant word
    0024 MSLSWT EQU     R36     Most significant byte of the least significant word
    0025 LSLSWT EQU     R37     Least significant byte of the least significant word
0000
         * Temporary storage of external counter value
0000
    0026 MSBEXT EQU     R38     Most significant byte of the external counter
    0027 LSBEXT EQU     R39     Least significant byte of the external counter
0000
         * Temporary external storage value - compensation value
0000
    0028 TMSBXT EQU     R40     Most significant byte of the external counter
    0029 TLSBXT EQU     R41     Least significant byte of the external counter
0000
0000
    002A MSGPTR EQU     R42     No of chars left to transmit in message.
    002B TXCNTR EQU     R43     Number of bits which has been transmitted in a char.
    002C TXPARY EQU     R44     Storage of parity for current char.
    002D TXBUFF EQU     R45     Current char being transmitted.
    002E STCNTR EQU     R46     Number of interupts left to occur before a start error.
0000
0000
```





```
         ************************************************************
         **************** Complete Rockwell message ******************
0000
         * This is a 18 byte message which actually starts at MSGEND+1.
         * The Rockwell message will be something like that below.
         * 0,CR,'1','0','W','I',';'
         * '0','0','0','0','0','0','0','0','0','W','R',';','V'
0000
    0030 MSGEND EQU     >0030     Uses registers R48->R66
    0012 MSGLEN EQU     18        The number of chars in a message.
0000
         ************************************************************
         ********************** VARIABLES ****************************
0000
    000D CR     EQU     >0D               Carriage return
    0060 STPT   EQU     >60               Stack pointer
0000
    0028 NOSTRT EQU     40                Number of interupts before a start error.
         *NOSTRT EQU    90        for a 5Mhz xtal.
0000
0000
    0000 T1MDAT EQU     >00               Data for the MSByte of Timer 1 reload register. (N/A for
                                          TMS70C20)
    00FF T1LDAT EQU     >FF               Data for the LSByte of Timer 1 reload register. TR=255
    009F T1CDAT EQU     ?10011111         T1 control data. 7-Start time,6-internal clock source,
         *                                5-Active during idle,4->0-Prescaler reload value. PR=31
0000
         * The outputs on port D6 are opposite to normal due to a transistor
         * inverting the output from the pin to the comms.
    0040 LBIT6P EQU     ?01000000         A low for Bit 6 of a port.
    FFBF HBIT6P EQU     #?01000000        A high for Bit 6 of a port.
0000
0000
         *-----------------------------------------------------------------------------------------

0000
0000
         ***************************************************************************
         * :START                          MAIN PROGRAM                            *
         *                                                                         *
         * Description: This routine when run will test for three conditions which may *
         *              exist.                                                     *
         *                     1. External counter overflow occured whereby        *
         *                              APORT bit 0 will be low.  The internal 32 bit *
         *                              overflow counter value is then incremented by *
         *                              4071 or (0FE7H).                           *
         *                     2. External communications is requested whereby     *
         *                              APORT bit 1 will be low.  The routine is then *
         *                              called to calculate the total consumption ie *
         *                              the internal accumulation value + the external *
         *                              counter value with compensation of 1 litre for *
         *                              every 166 litres consummed.  These values are *
         *                              then forwarded to the communications routine *
         *                     3. Power on reset or an external interrupt on INT3  *
         *                              where none of the states 1 and 2 are       *
         *                              active.  The internal accumulation value is *
         *                              set to zero.                               *
         *                                                                         *
         * On RESET -   Test for External Overflow, APORT bit 0 (LOW)              *
         *              Test for Communications, APORT bit 1 (LOW)                 *
         *              Test for Power on reset, APORT bit 0 and 1 both (HIGH)     *
         *                                                                         *
         * Inputs:      APORT bits 0 and 1 (LOW = ACTIVE)                          *
         *                                                                         *
         * Outputs:                                                                *
         *                                                                         *
         * Calls to:    UPINCT  Update internal counter                            *
         *              TOTCVL  Total consumption value                            *
         *              TRNFER  Transfer consumption value                         *
         *              CLROVR  Clear overflow latch                               *
         *              CLRCOM  Clear communications latch                         *
         *              HALTMD  Set microcontroller into halt mode                 *
         *                                                                         *
         * Modified:    APORT, B, STPT=60h                                         *
         * Rev 1.00     ZB - 11/11/92                                              *
         ***************************************************************************
0000
F006            AORG    >F006                    Start of main program
```

```
F006  8E  START  CALL   @INTVAR                Initialize registers
F007 F038
F009  52         MOV    %STPT,B                Set stack location as 60H
F00A  60
F00B  0D         LDSP
F00C  8E  RESTRT CALL   @SNPSHT                Take a snapshot of external registers
F00D F061
F00F  A7         BTJZP  %>01,APORT,OVRFLW      Test if Overflow condition exists
F010  01
F011  04
F012  09
F013  A7         BTJZP  %>02,APORT,COMMS       Test is Communications condition exists
F014  02
F015  04
F016  11
F017  8E         CALL   @CLRTOT                If neither comms or overflow then battery connected
F018 F0B4
F01A  E0         JMP    SHTDWN                 Shutdown the system
F01B  19
F01C  8E  OVRFLW CALL   @UPINCT                If overflow update the internal count value
F01D F054
F01F  8E         CALL   @CLROVR                Clear the external overflow latch
F020 F0BD
F022  A7         BTJZP  %>02,APORT,RESTRT      Test if communications is requested
F023  02
F024  04
F025  E6
F026  E0         JMP    SHTDWN                 If not then shutdown the system
F027  0D
F028  8E  COMMS  CALL   @TOTCVL                If communications is requested update the total
                                               counter
F029 F08A
F02B  8C         BR     @TRNSFR                Convert and send the reading
F02C F0DC
F02E  8E  ENDTRN CALL   @CLRCOM                Clear the external communication latch
F02F F0C4
F031  A7         BTJZP  %>01,APORT,RESTRT      Test if overflow is requested
F032  01
F033  04
F034  D7
F035  8C  SHTDWN BR     @HALTMD                If not then shutdown the system
F036 F0CB
          *                                    Run the haltmode routine
          *      End of the main program
F038
F038
          ***************************************************************************
          * :INTVAR                             INITIALIZE                          *
          *                                                                         *
          * Description: This routine     1. Clears the interrupt flags to a known state *
          *                               2. Sets the Input/output ports            *
          *                                                                         *
          * Inputs:                                                                 *
          *                                                                         *
          * Outputs:      IOCNT0  2A      Single chip mode, Clear and disable int3,2,1  *
          *               IOCNT1  0A      Clear and disable int5,4                  *
          *               IOCNT2  02      Set int1 edge sensitive active low        *
          *               ADDR    00      Set port A as inputs                      *
          *               CDDR    00      Set port C as inputs                      *
          *               DDDR    F0      Set port D as outputs and inputs          *
          *               APORT   00      Clear port A                              *
          *               BPORT   FF      Set all port B pins                       *
          *               DPORT   0X      Clear port D Most significant nibble      *
          *                                                                         *
          * Modified:     All listed in outputs                                     *
          *                                                                         *
          * Rev 1.00                                                                *
          * ZB - 11/11/92                                                           *
          *                                                                         *
          ***************************************************************************
F038
F038  A2  INTVAR        MOVP   %?00101010,IOCNT0      Single chip mode, Clear and disable int3,2,1
F039  2A
F03A  00
F03B  A2                MOVP   %?00001010,IOCNT1      Clear and disable int5,4
F03C  0A
F03D  02
F03E  A2                MOVP   %?00100010,IOCNT2      Set int1 & int3 edge sensitive active low
```





```
F03F  22
F040  01
F041  A2                MOVP   %?11111111,APORT       Clear port A settings
F042  FF
F043  04
F044  A2                MOVP   %?00000000,ADDR        Set port A as all inputs
F045  00
F046  05
F047  A2                MOVP   %?11111111,BPORT       Set port B outputs to all 1's
F048  FF
F049  06
F04A  A2                MOVP   %?00000000,CDDR        Set port C as all inputs
F04B  00
F04C  09
F04D  A2                MOVP   %?11110000,DDDR        Set port D MSN as outputs LSN as inputs
F04E  F0
F04F  0B
F050  A2                MOVP   %?00000000,DPORT       Set port D MSN to low
F051  00
F052  0A
F053  0A                RETS
F054
F054
      ***************************************************************************
      * :UPINCT                         UPDATE INTERNAL COUNTER                 *
      *                                                                         *
      * Description: This routine increments the internal accumulation value by 4071 *
      *                      which is 4096 - a compensation value of 25 ie 1 in 166  *
      *                      4096/166=24.6                                      *
      *                                                                         *
      * Inputs:      LSLSW, MSLSW, LSMSW, MSMSW                                 *
      *                                                                         *
      * Outputs:     LSLSW+E7H, MSLSW+0FH, LSMSW+C, MSMSW+C                     *
      *                                                                         *
      * Modified:    LSLSW, MSLSW, LSMSW, MSMSW                                 *
      * Rev 1.00     ZB - 11/11/92                                              *
      ***************************************************************************
F054
F054  78  UPINCT ADD    %>E7,LSLSW
F055  E7
F056  21
F057  79         ADC    %>0F,MSLSW
F058  0F
F059  20
F05A  79         ADC    %>0,LSMSW
F05B  00
F05C  1F
F05D  79         ADC    %>0,MSMSW
F05E  00
F05F  1E
F060  0A         RETS
F061
F061
      ***************************************************************************
      * :SNPSHT                         SNAP SHOT                               *
      *                                                                         *
      * Description: This routine reads the external 12 bit counter.  The least *
      *                     significant byte of the counter is read from port C and *
      *                     is stored in LSBEXT.  The most significant nibble of *
      *                     the counter is read from port D with the unused part *
      *                     being masked out.                                   *
      *                                                                         *
      * Inputs:      CPORT Least significant byte of the 12 bit external counter *
      *              DPORT D0-D3 most significant nibble of the external counter *
      *                                                                         *
      * Outputs:     LSBEXT Least significant byte of the 12 bit external counter *
      *              MSBEXT D0-D3 most significant nibble of the external counter *
      *                                                                         *
      * Modified:    A, B, LSBEXT, MSBEXT                                       *
      * Rev 1.00     ZB - 11/11/92                                              *
      ***************************************************************************
F061
F061  80  SNPSHT MOVP   CPORT,A
F062  08
F063  D0         MOV    A,LSBEXT               Read least significant byte of the external counter
F064  27
F065  91         MOVP   DPORT,B
F066  0A
F067  D1         MOV    B,MSBEXT               Read most significant byte of the external counter
```

```
     F068   26
     F069   73         AND     %?00001111,MSBEXT       Mask off most significant nibble of the most
                                                       significant byte
     F06A   0F
     F06B   26
     F06C   0A         RETS
     F06D
     F06D
                ******************************************************************************
                * :CMPVLA                           COMPUTE COMPENSATION VALUE                 *
                *                                                                              *
                * Description: This routine calculates the compensation value which will be    *
                *                       subtracted from the external counter value to          *
                *                       compensate for the additional 0.2 pulses per litre.    *
                *                                                                              *
                *      Water meter                                                             *
                *      16.6 revolutions per litre                                              *
                *      33.2 pulses / litre     =>      1 litre passes 33.2 pulses are received *
                *      1000 litres = 33200 pulses                                              *
                *                                                                              *
                *      Electronic circuit                                                      *
                *      33 pulses per 1 litre recorded                                          *
                *      1000 litres = 33000 pulses                                              *
                *                                                                              *
                *      33200 pulses => 33200 / 33 = (1006.06\) litres  ie over registered      *
                *                                                         by (6.06\) litres    *
                *                                                                              *
                *      Over registering by (33.2-33)/33.2 = (0.2)/33.2 = 1/166                 *
                *             ie 1 litre in every 166 recorded                                 *
                *             compensation value = (1006.06\) / 166 = (6.06\) litres           *
                *             error = [{(1006-6)-1000}/1000]*100 = 0%                          *
                *                                                                              *
                *      eg For a consumption of 10000 litres                                    *
                *             10000*33.2  = 332000 pulses generated                            *
                *             332000/33   = 10060.(60\) litres stored                          *
                *             10060/4096  = 2 overflows                                        *
                *                                                                              *
                *             2*(4096-25)      = 8142  litres stored internally                *
                *             10060-(2*4096)  = 1868  litres stored externally                 *
                *             1868/166         = 11    litres compensation factor external     *
                *             1868-11          = 1857  litres actual consumption external      *
                *             8142+1857        = 9999  litres recorded eletronically           *
                *                                                                              *
                *             Error = [(9999-10000)/10000]*100 = -0.01%                        *
                *                                                                              *
                * Inputs:     MSBEXT  Most significant nibble of the external 12 bit counter   *
                *             LSBEXT  Least significant byte of the external 12 bit counter    *
                *                                                                              *
                * Outputs:    CMPVAL  Compensation value to be added to external counter       *
                *                                                                              *
                * Modified:   A, B, LOPCNT, CMPVAL                                             *
                *                                                                              *
                * Rev 1.00                                                                     *
                * ZB - 10/11/92                                                                *
                *                                                                              *
                ******************************************************************************
     F06D
          000A  LOPCNT EQU     R10
          00A6  DIVSOR EQU     166
          000B  CMPVAL EQU     R11
     F06D
     F06D   12  CMPVLA MOV     MSBEXT,A                A Contains dividend MSB
     F06E   26
     F06F   32         MOV     LSBEXT,B                B Contains divedend LSB
     F070   27
     F071   72  BINDVD MOV     %8,LOPCNT               Set loop counter to 8
     F072   08
     F073   0A
     F074   CF  DVDLP  RLC     B                       Multiply divedend by 2
     F075   BF         RLC     A
     F076   E7         JNC     SKIP1
     F077   05
     F078   2A         SUB     %DIVSOR,A
     F079   A6
     F07A   07         SETC
     F07B   E0         JMP     DIVEND
     F07C   06
     F07D   2D  SKIP1  CMP     %DIVSOR,A               Is MSB of divedend > divisor
     F07E   A6
     F07F   E7         JNC     DIVEND
     F080   02
     F081   2A  SUBIT  SUB     %DIVSOR,A               If so divedend = dividend - divisor
```





```
     F082   A6
     F083   DA  DIVEND DJNZ    LOPCNT,DVDLP            C=1 gets folded into next rotate
     F084   0A
     F085   EE
     F086   CF         RLC     B
     F087   D1         MOV     B,CMPVAL                Store quotient into COMPVAL variable
     F088   0B
     F089   0A         RETS
     F08A
     F08A
                ******************************************************************************
                * :TOTCVL                COMPUTE TOTAL CONSUMPTION VALUE                       *
                *                                                                              *
                * Description: This routine calculates the 32 bit total consumption value     *
                *                        including the compensation value.                     *
                *                                                                              *
                * Inputs:       LSBEXT  The external counter least significant byte            *
                *               MSBEXT  The external counter most significant nibble           *
                *                                                                              *
                *                       32 bit total accumulation                              *
                * Outputs:      LSLSWT  Least significant byte of the least significant word   *
                *               MSLSWT  Most significant byte of the least significant word    *
                *               LSMSWT  Least significant byte of the most significant word    *
                *               MSMSWT  Most significant byte of the most significant word     *
                *                                                                              *
                * Calls to:     CMPVLA  Compute compensation value for the external counter    *
                *                                                                              *
                * Modified:     TLSBXT, TMSBXT, LSLSWT, MSLSWT, LSMSWT, MSMSWT                 *
                * Rev 1.00      ZB - 11/11/92                                                  *
                ******************************************************************************
     F08A
     F08A   8E  TOTCVL CALL    @CMPVLA Calculate amount of compensation required
     F08B F06D
     F08D
     F08D   42         MOV     LSBEXT,TLSBXT   Make a copy of the external counter values
     F08E   27
     F08F   29
     F090   42         MOV     MSBEXT,TMSBXT
     F091   26
     F092   28
     F093
     F093   4A         SUB     CMPVAL,TLSBXT   Subtract the compensation factor from the external counter
                                               value
     F094   0B
     F095   29
     F096   E3         JC      CONTIN          Carry is set TO 0 if borrow is required
     F097   03
     F098   7A         SUB     %>1,TMSBXT      If borrow is required then subtract 1 from the most
                                               significant nibble
     F099   01
     F09A   28
     F09B
     F09B   42  CONTIN MOV     MSMSW,MSMSWT    Make a copy of the internal counter storage value
     F09C   1E
     F09D   22
     F09E   42         MOV     LSMSW,LSMSWT
     F09F   1F
     F0A0   23
     F0A1   42         MOV     MSLSW,MSLSWT
     F0A2   20
     F0A3   24
     F0A4   42         MOV     LSLSW,LSLSWT
     F0A5   21
     F0A6   25
     F0A7
     F0A7   48         ADD     TLSBXT,LSLSWT          Add the compensated external value to the internal
                                                      values
     F0A8   29
     F0A9   25
     F0AA   49         ADC     TMSBXT,MSLSWT
     F0AB   28
     F0AC   24
     F0AD   79         ADC     %>0,LSMSWT
     F0AE   00
     F0AF   23
     F0B0   79         ADC     %>0,MSMSWT
     F0B1   00
     F0B2   22
     F0B3   0A         RETS                           Return with total consumption values
     F0B4
     F0B4
```

```
                ************************************************************************
                * :CLRTOT                       CLEAR THE INTERNAL CONSUMPTION VALUE          *
                *                                                                              *
                * Description: This routine will clear the internal accumulation value        *
                *                                                                              *
                *                          32 bit internal overflow accumulation value        *
                * Inputs:        MSMSW   Most significant byte of the most significant word   *
                *                LSMSW   Least significant byte of the most significant word  *
                *                MSLSW   Most significant byte of the least significant word  *
                *                LSLSW   Least significant byte of the least significant word *
                *                                                                              *
                * Outputs:       MSMSW   Most significant byte of the most significant word   =0 *
                *                LSMSW   Least significant byte of the most significant word  =0 *
                *                MSLSW   Most significant byte of the least significant word  =0 *
                *                LSLSW   Least significant byte of the least significant word =0 *
                *                                                                              *
                * Modified:      MSMSW, LSMSW, MSLSW, LSLSW                                    *
                * Rev 1.00       ZB - 11/11/92                                                 *
                ************************************************************************

F0B4
F0B4   D5  CLRTOT CLR     MSMSW               Clear all internal count values
F0B5   1E
F0B6   D5         CLR     LSMSW
F0B7   1F
F0B8   D5         CLR     MSLSW
F0B9   20
F0BA   D5         CLR     LSLSW
F0BB   21
F0BC   0A         RETS
F0BD
F0BD
                ************************************************************************
                * :CLROVR                 CLEAR EXTERNAL OVERFLOW LATCH                        *
                *                                                                              *
                * Description:  This routine sends a high to low pulse to port pin D4 to clear *
                *                       the overflow latch.                                    *
                *                                                                              *
                * Inputs:                                                                      *
                *                                                                              *
                * Outputs:      DPORT   %?00010000 then %?11101111                             *
                *                                                                              *
                * Modified:     DPORT                                                          *
                * Rev 1.00      ZB - 11/11/92                                                  *
                ************************************************************************
F0BD
F0BD   A4  CLROVR ORP     %?00010000,DPORT        High on D4
F0BE   10
F0BF   0A
F0C0   A3         ANDP    %?11101111,DPORT        Low on D4
F0C1   EF
F0C2   0A
F0C3   0A         RETS
F0C4
F0C4
                ************************************************************************
                * :CLRCOM                 CLEAR EXTERNAL COMMUNICATIONS LATCH                  *
                *                                                                              *
                * Description: This routine sends a high to low pulse to port pin D5 to clear  *
                *                       the communications latch.                              *
                *                                                                              *
                * Inputs:                                                                      *
                *                                                                              *
                * Outputs:      DPORT   %?00100000 then %?11011111                             *
                *                                                                              *
                * Modified:     DPORT                                                          *
                * Rev 1.00      ZB - 11/11/92                                                  *
                ************************************************************************
F0C4
F0C4   A4  CLRCOM ORP     %?00100000,DPORT        High on D5
F0C5   20
F0C6   0A
F0C7   A3         ANDP    %?11011111,DPORT        Low on D5
F0C8   DF
F0C9   0A
F0CA   0A         RETS
F0CB
```





```
                ************************************************************************
                * :HALTMD                           ENTER INTO HALT MODE                       *
                *                                                                              *
                * Description:  This routine will place the TMS77C82 microcontroller into HALT *
                *                       mode and will require either an external reset to exit *
                *                       or a negative going edge on the INT3 line.             *
                *                                                                              *
                * Inputs:                                                                      *
                *                                                                              *
                * Outputs:      T1CTL0  Timer 1 halted           >20                           *
                *               T2CTL0  Timer 2 halted           >20                           *
                *               SCTL0   Serial port halted       >80                           *
                *               IOCNT0  Interrupt 3 enabled, disable intl & int2               *
                *               IOCNT1  Interrupt 5 and int4 disabled                          *
                *                                                                              *
                * Modified:     T1CTL0,T2CTL0,SCTL0, IOCNT0, IOCNT1                            *
                *                                                                              *
                * Rev 1.0                                                                      *
                * ZB - 11/11/92                                                                *
                *                                                                              *
                ************************************************************************
F0CB
F0CB   A2  HALTMD MOVP    %>20,T1CTL0             Timer 1 halted
F0CC   20
F0CD   0F
F0CE   A2         MOVP    %>20,T2CTL0             Timer 2 halted
F0CF   20
F0D0   13
F0D1   A2         MOVP    %>80,SCTL0              Serial port halted
F0D2   80
F0D3   15
F0D4   A2         MOVP    %?00111010,IOCNT0       Clear and Enable int3, disable intl & int2
F0D5   3A
F0D6   00
F0D7   A2         MOVP    %?00001010,IOCNT1       Disable int5 & 4
F0D8   0A
F0D9   02
F0DA   05         EINT                            Enable interrupts
F0DB   01         IDLE                            Enter idle state
F0DC
F0DC
F0DC

                ************************************************************************
                * :TRNSFR             TRANSFER INFORMATION TO COMMUNICATIONS PORT              *
                *                                                                              *
                * Description: This routine takes a 4 byte meter reading and converts it into  *
                *              a Rockwell message. The timers and interrupts are initialised   *
                *              and the microcontroller is put in wakeup mode so that the       *
                *              Rockwell message may be output.                                 *
                *                                                                              *
                *              On INT1 program control is given to routine TRANSM for the      *
                *              message to be output.                                           *
                *              On INT2 program control is given to routine TRANER to check     *
                *              that a clock signal is still being sent.                        *
                *                                                                              *
                * Inputs:                                                                      *
                *                                                                              *
                * Outputs:                                                                     *
                *                                                                              *
                * Calls to:     BN2BCD - 32 Bit binary to BCD conversion                       *
                *               BCDASC - BCD to ASCII conversion                               *
                *               ADRKWL - Add Rockwell protocols                                *
                *               TMINIT - Transmission initialisation                           *
                *                                                                              *
                *                                                                              *
                * Modified:                                                                    *
                *                                                                              *
                * Rev 1.00                                                                     *
                * AL - 6/11/92                                                                 *
                *                                                                              *
                *                                                                              *
                ************************************************************************
F0DC
F0DC   8E  TRNSFR CALL    @BN2BCD
F0DD F0EA
F0DF   8E         CALL    @BCDASC
F0E0 F112
F0E2   8E         CALL    @ADRKWL
F0E3 F163
F0E5   8E         CALL    @TMINIT
F0E6 F19F
```

```
F0E8  05           EINT
F0E9  01           IDLE
F0EA
F0EA
F0EA
F0EA
F0EA
           ******************************************************************************
           * :BN2BCD          32 Bit Binary to BCD conversion                           *
           *                                                                            *
           * Description:  This routine converts a 32 bit binary word to a packed       *
           *               10 Nibble value.                                             *
           *                                                                            *
           * Inputs: LSBLSWT - Byte 0 of 32 bit binary read.                            *
           *         MSBLSWT - Byte 1 of 32 bit binary read.                            *
           *         LSBMSWT - Byte 2 of 32 bit binary read.                            *
           *         MSBMSWT - Byte 3 of 32 bit binary read.                            *
           *                                                                            *
           * Outputs: R2,R3,R4,R5,R6 - DIGITs 0 to 9 of 10 digit packed BCD read        *
           *                                                                            *
           * Modified: R7                                                               *
           *                                                                            *
           *                                                                            *
           * Rev 1.00                                                                   *
           * AL - 5/11/92                                                               *
           *                                                                            *
           ******************************************************************************
F0EA
F0EA
F0EA  D5   BN2BCD     CLR    R2       Clear registers.
F0EB  02
F0EC  D5              CLR    R3       Clear registers.
F0ED  03
F0EE  D5              CLR    R4       Clear registers.
F0EF  04
F0F0  D5              CLR    R5       Clear registers.
F0F1  05
F0F2  D5              CLR    R6       Clear registers.
F0F3  06
F0F4  72              MOV    %32,R7   Set counter to 32 times for loop
F0F5  20
F0F6  07
F0F7  DF   LOOP32     RLC    LSLSWT   Shift MS binary bit out into next byte
F0F8  25
F0F9  DF              RLC    MSLSWT   Shift MS binary bit out into next byte
F0FA  24
F0FB  DF              RLC    LSMSWT   Shift MS binary bit out into next byte
F0FC  23
F0FD  DF              RLC    MSMSWT   Shift MS binary bit out to carry
F0FE  22
F0FF  4E              DAC    R6,R6    Double the number and add the carry.
F100  06
F101  06
F102  4E              DAC    R5,R5    Double the number and add the carry.
F103  05
F104  05
F105  4E              DAC    R4,R4    Double the number and add the carry.
F106  04
F107  04
F108  4E              DAC    R3,R3    Double the number and add the carry.
F109  03
F10A  03
F10B  4E              DAC    R2,R2    Double the number and add the carry.
F10C  02
F10D  02
F10E  DA              DJNZ   R7,LOOP32       Do this 32 times, once for each bit
F10F  07
F110  E6
           *                                     of the binary number.
F111  0A              RETS
F112
```





```
                 ******************************************************************************
                 * :BCDASC       Packed 10 Nibble BCD to ASCII conversion                     *
                 *                                                                            *
                 * Description:  This program converts a packed 10 Nibble value into an eight *
                 *               digit ASCII number stored at location MSGEND. The 2 MS digits*
                 *               are not transmitted.                                         *
                 *                                                                            *
                 * Inputs: R2,R3,R4,R5,R6 - 10 digit packed BCD.                              *
                 *         MSGEND - Address of last byte in message.                          *
                 *                                                                            *
                 * Outputs: 8 byte ASCII read from memory location MSGEND+9 to MSGEND+2       *
                 *                                                                            *
                 * Modified: A                                                                *
                 *                                                                            *
                 * Rev 3.00                                                                   *
                 * AL - 6/11/92                                                               *
                 *                                                                            *
                 ******************************************************************************
F112
        F112     BCDASC  EQU     $
F112      12     DIGIT0          MOV    R6,A          Move LS BCD to Acc.
F113      06
F114      23                     AND    %>0F,A        Mask byte to leave lower nibble
F115      0F
F116      28                     ADD    %>30,A        Convert to ASCII.
F117      30
F118      8B                     STA    @MSGEND+7     Store digit 0 in memory
F119    0037
F11B      D7                     SWAP   R6            Exchange Nibbles in register.
F11C      06
F11D      12                     MOV    R6,A          Move LS BCD to Acc.
F11E      06
F11F      23                     AND    %>0F,A        Mask byte to leave lower nibble
F120      0F
F121      28                     ADD    %>30,A        Convert to ASCII.
F122      30
F123      8B                     STA    @MSGEND+8     Store digit 1 in memory
F124    0038
F126      12     DIGIT2          MOV    R5,A          Move LS BCD to Acc.
F127      05
F128      23                     AND    %>0F,A        Mask byte to leave lower nibble
F129      0F
F12A      28                     ADD    %>30,A        Convert to ASCII.
F12B      30
F12C      8B                     STA    @MSGEND+9     Store digit 2 in memory
F12D    0039
F12F      D7                     SWAP   R5            Exchange Nibbles in register.
F130      05
F131      12                     MOV    R5,A          Move LS BCD to Acc.
F132      05
F133      23                     AND    %>0F,A        Mask byte to leave lower nibble
F134      0F
F135      28                     ADD    %>30,A        Convert to ASCII.
F136      30
F137      8B                     STA    @MSGEND+10    Store digit 3 in memory
F138    003A
F13A      12     DIGIT4          MOV    R4,A          Move LS BCD to Acc.
F13B      04
F13C      23                     AND    %>0F,A        Mask byte to leave lower nibble
F13D      0F
F13E      28                     ADD    %>30,A        Convert to ASCII.
F13F      30
F140      8B                     STA    @MSGEND+11    Store digit 4 in memory
F141    003B
F143      D7                     SWAP   R4            Exchange Nibbles in register.
F144      04
F145      12                     MOV    R4,A          Move LS BCD to Acc.
F146      04
F147      23                     AND    %>0F,A        Mask byte to leave lower nibble
F148      0F
F149      28                     ADD    %>30,A        Convert to ASCII.
F14A      30
F14B      8B                     STA    @MSGEND+12    Store digit 5 in memory
F14C    003C
F14E      12     DIGIT6          MOV    R3,A          Move LS BCD to Acc.
F14F      03
F150      23                     AND    %>0F,A        Mask byte to leave lower nibble
F151      0F
F152      28                     ADD    %>30,A        Convert to ASCII.
F153      30
F154      8B                     STA    @MSGEND+13    Store digit 6 in memory
F155    003D
```

```
F157   D7               SWAP     R3              Exchange Nibbles in register.
F158   03
F159   12               MOV      R3,A            Move LS BCD to Acc.
F15A   03
F15B   23               AND      %>0F,A          Mask byte to leave lower nibble
F15C   0F
F15D   28               ADD      %>30,A           Convert to ASCII.
F15E   30
F15F   8B               STA      @MSGEND+14      Store digit 7 in memory
F160 003E
F162   0A               RETS
F163
F163
       ****************************************************************************
       * :ADRKWL       Add Rockwell Protocols                                     *
       *                                                                          *
       * Description:  This program adds the necessary Rockwell protocols to a    *
       *               8 digit ASCII number stored at location MSGEND+9 to MSGEND+2.*
       *                                                                          *
       * Inputs: MSGEND - Address of last byte in message.                        *
       *         MSGEND - Address of last byte in message.                        *
       *                                                                          *
       * Outputs: 13 byte ASCII message from memory location MSGEND+13 to MSGEND+1 *
       *          TXCNTR - Initialise to zero bit to be transmitted.              *
       *          MSGPTR - Length of message.                                     *
       *                                                                          *
       * Modified: A                                                              *
       *                                                                          *
       *                                                                          *
       * Rev 2.00                                                                 *
       * AL - 12/11/92                                                            *
       *                                                                          *
       ****************************************************************************
F163
F163   22  ADRKWL       MOV      %CR,A           Load <CR> into the Acc
F164   0D
F165   8B               STA      @MSGEND+1       Store as the end of message
F166 0031
F168   22               MOV      %'1',A          Load 'W' into the Acc
F169   31
F16A   8B               STA      @MSGEND+2       Identifies read as water
F16B 0032
F16D   22               MOV      %'0',A          Load 'R' into the Acc
F16E   30
F16F   8B               STA      @MSGEND+3       Identifies that message is a read.
F170 0033
F172   22               MOV      %'W',A  Load ';' into the Acc
F173   57
F174   8B               STA      @MSGEND+4       Delimiter of fields
F175 0034
F177   22               MOV      %'I',A          Load 'V' into the Acc
F178   49
F179   8B               STA      @MSGEND+5       Identifies beginning of a record.
F17A 0035
F17C   22               MOV      %';',A          Load 'V' into the Acc
F17D   3B
F17E   8B               STA      @MSGEND+6       Identifies beginning of a record.
F17F 0036
F181
F181   22               MOV      %'W',A          Load 'W' into the Acc
F182   57
F183   8B               STA      @MSGEND+15      Identifies read as water
F184 003F
F186   22               MOV      %'R',A          Load 'R' into the Acc
F187   52
F188   8B               STA      @MSGEND+16      Identifies that message is a read.
F189 0040
F18B   22               MOV      %';',A          Load ';' into the Acc
F18C   3B
F18D   8B               STA      @MSGEND+17      Delimiter of fields
F18E 0041
F190   22               MOV      %'V',A          Load 'V' into the Acc
F191   56
F192   8B               STA      @MSGEND+18      Identifies beginning of a record.
F193 0042
F195
F195   72               MOV      %>00,TXCNTR     Initialise TXCNTR to the 0 bit
F196   00
F197   2B
F198   72               MOV      %MSGLEN,MSGPTR  Initialise the no of chars in the message
F199   12
```





```
F19A   2A
F19B   72               MOV      %NOSTRT,STCNTR    Number of INT before start error.
F19C   28
F19D   2E
F19E
F19E   0A               RETS
F19F
F19F
       ****************************************************************************
       *:TMINIT         TRANSMISSION INTITIALISATION                              *
       *                                                                          *
       * Description:  This routine initialises the interupts and the timer ports for *
       *               communications.                                            *
       *               INT1 - enabled and negative edge sensitive. Actually detects *
       *                      rising edge of PWR/CLK signal                       *
       *               INT 3,4,5 - disabled                                       *
       *               INT2 -  enabled for countdown timer.                       *
       *                      timer interval = t(CLK)x(PR+1)x(TR+1)               *
       *                               with PR=255 & TR=31                        *
       *                      timer interval = t(CLK)x8192                        *
       *                                                                          *
       *                      For TMS70Cx0 T(CLK) = 16/f(osc)                     *
       *                                       PR = T1LDAT                        *
       *                               timer interval = 65.5ms @ 2MHz             *
       *                               timer interval = 32.8ms @ 4MHz             *
       *                                                                          *
       *                      For TMS70Cx2 T(CLK) = 4/f(osc)                      *
       *                                       PR = T1MDAT & T1LDAT               *
       *                               timer interval = 16.38ms @ 2MHz            *
       *                               timer interval =  8.19ms @ 4MHz            *
       *                                                                          *
       * Inputs:       T1MDAT - MSByte of the Reload register. Used in TMS70Cx2 only *
       *               T1LDAT - LSByte of the Reload register.                    *
       *               T1CDAT - Flags and prescaler.                              *
       *                                                                          *
       * Outputs:      IOCNT0, IOCNT1, IOCNT2                                     *
       *               T1CTL0, T2CTL0, SCTL0                                      *
       *               T1MSB, T1LSB                                               *
       *                                                                          *
       * Modified:                                                                *
       *                                                                          *
       *                                                                          *
       * Rev 1.00                                                                 *
       * AL - 5/11/92                                                             *
       *                                                                          *
       ****************************************************************************
F19F
F19F   A2  TMINIT       MOVP     %?00101111,IOCNT0    INT3 disabled, INT1&2 enabled.INTs cleared.
F1A0   2F
F1A1   00
F1A2   A2               MOVP     %?00001010,IOCNT1    INT4&5 disabled.
F1A3   0A
F1A4   02
F1A5   A2               MOVP     %?00000010,IOCNT2    INT1 negative edge sensitive.
F1A6   02
F1A7   01
F1A8
F1A8   A2               MOVP     %?00100000,T2CTL0    Turn off timer2 (P19)
F1A9   20
F1AA   13
F1AB   A2               MOVP     %?10000000,SCTL0     Turn off serial port (P?)
F1AC   80
F1AD   15
F1AE   A2               MOVP     %T1MDAT,T1MSB        MS Byte T1 reload register. (T1MSB)
F1AF   00
F1B0   0C
F1B1   A2               MOVP     %T1LDAT,T1LSB        LS Byte T1 reload register. (T1LSB)
F1B2   FF
F1B3   0D
F1B4   A2               MOVP     %T1CDAT,T1CTL0       Reload Prescaler, internal clock source
F1B5   9F
F1B6   0F
       *                           Timer 1 active, Prescaler-32. Min Delay > 3.8ms
F1B7   0A               RETS
F1B8
F1B8
```

```
                ****************************************************************************
                *:TRANSM         TRANSMIT MESSAGE                                          *
                *                                                                          *
                * Description:  This program transmits an ASCII messaage stored at location *
                *               MSGEND using the Rockwell protocol. Every time there is a  *
                *               rising edge on the PWR/CLK signal, an interupt is generated. *
                *                                                                          *
                *               On INT1 the routine below transmits the next bit of information *
                *               until the whole message is sent. A character is made up of  *
                *               1 start bit, 7 bits data(LSb first), Even parity and a stop bit. *
                *               The micro is put into Wakeup mode between the transmission of *
                *               each bit to conserve power.                                 *
                *                                                                          *
                * On INT1  - TRANSM                                                        *
                *                                                                          *
                * Inputs:       TXCNTR - No of bits transmitted. Must be 0 to start.       *
                *               MSGPTR - No of chars left to transmit.Initialy 13.         *
                *               TXPARY - Storage of parity for current char.               *
                *               TXBUFF - Current char being transmitted.                   *
                *               MSGEND - Last byte-1 of message being transmitted.         *
                *               HBIT6P - Output a high for comms on Bit 6 of a port.       *
                *               LBIT6P - Output a low for comms on Bit 6 of a port.        *
                *                                                                          *
                * Outputs:      DPORT - Port address of (D6) where message is sent.        *
                *                       ANDP (10111111) to clear port.                     *
                *                       ORP (01000000) to set port.                        *
                *                                                                          *
                * Calls to:     WAKEUP - Put micro into wakeup mode.                       *
                *               ENDTRN - End of transmission. Return to main program.      *
                *                                                                          *
                * Modified: A,B,SP                                                         *
                *                                                                          *
                *                                                                          *
                * Rev 1.20                                                                 *
                * AL - 11/11/92                                                            *
                *                                                                          *
                ****************************************************************************
F1B8
F1B8    06  TRANSM      DINT                            Disable interupts
F1B9    7D              CMP     %>00,TXCNTR             Is this bit 0 of message.
F1BA    00
F1BB    2B
F1BC    E2              JEQ     STRTBT
F1BD    1F
F1BE    7D              CMP     %>08,TXCNTR             Is this bit 8 of message.
F1BF    08
F1C0    2B
F1C1    E2              JEQ     PARITY
F1C2    2B
F1C3    7D              CMP     %>09,TXCNTR             Is this bit 9 of message.
F1C4    09
F1C5    2B
F1C6    E2              JEQ     STOPBT
F1C7    36
F1C8
F1C8    45  DATABT      XOR     TXBUFF,TXPARY           Build up parity bit
F1C9    2D
F1CA    2C
F1CB    77              BTJZ    %>01,TXBUFF,TRANS0      Send a 1 or a 0 for the data.
F1CC    01
F1CD    2D
F1CE    05
F1CF    A3  TRANS1      ANDP    %HBIT6P,DPORT           Output a high for comms through port D6
F1D0    BF
F1D1    0A
F1D2    E0              JMP     NXTBIT
F1D3    03
F1D4    A4  TRANS0      ORP     %LBIT6P,DPORT           Output a low for comms through port D6
F1D5    40
F1D6    0A
F1D7    DC  NXTBIT      RR      TXBUFF                  Rotate to next bit of char to transmit.
F1D8    2D
F1D9    D3              INC     TXCNTR                  Increment to next bit of message
F1DA    2B
F1DB    E0              JMP     WAKEUP
F1DC    41
F1DD
F1DD    A4  STRTBT      ORP     %LBIT6P,DPORT           Transmit a low for the startbit.
F1DE    40
F1DF    0A
```





```
F1E0    72              MOV     %>00,TXPARY             Initialise Parity to Zero.
F1E1    00
F1E2    2C
F1E3    D3              INC     TXCNTR                  Increment to next bit of message
F1E4    2B
F1E5    32              MOV     MSGPTR,B                Move message pointer to index pointer.
F1E6    2A
F1E7    AA              LDA     @MSGEND(B)              Load Acc with Char from index address.
F1E8  0030
F1EA    D0              MOV     A,TXBUFF                Move the Char into the transmission buffer.
F1EB    2D
F1EC    E0              JMP     WAKEUP
F1ED    30
F1EE
F1EE    77  PARITY      BTJZ    %>01,TXPARY,PRTY0       Check output for Even Partity
F1EF    01
F1F0    2C
F1F1    05
F1F2    A3  PRTY1       ANDP    %HBIT6P,DPORT           Output a high through port D6
F1F3    BF
F1F4    0A
F1F5    E0              JMP     ENDPAR
F1F6    03
F1F7    A4  PRTY0       ORP     %LBIT6P,DPORT           Output a low through port D6
F1F8    40
F1F9    0A
F1FA    D3  ENDPAR      INC     TXCNTR                  Increment to next bit of message
F1FB    2B
F1FC    E0              JMP     WAKEUP
F1FD    20
F1FE
F1FE    A3  STOPBT      ANDP    %HBIT6P,DPORT           Transmit a high for a stopbit.
F1FF    BF
F200    0A
F201    D2              DEC     MSGPTR                  Decrement Message pointer to the next character.
F202    2A
F203    E2              JZ      TRANSE                  Goto end of transmission.
F204    05
F205    72              MOV     %>00,TXCNTR             Reset Bit counter for next character.
F206    00
F207    2B
F208    E0              JMP     WAKEUP
F209    14
F20A
F20A    8C  TRANSE BR   @ENDTRN                 Finished transmission. Return to main program.
F20B  F02E
F20D
F20D
F20D
F20D

                ****************************************************************************
                *:TRANER          TRANSMISSION ERROR                                       *
                *                                                                          *
                * Description:  This routine determines if the power/clock signal has been *
                *               removed before the end of the message or if there is no PWR/CLK *
                *               signal after the inital power up.                          *
                *               If an error has occurred then the micro will be put back to *
                *               sleep.                                                     *
                *               The interval time before an interupt occurs is set in routine *
                *               TMINIT.                                                    *
                *               For a startup error the time elapsed before error is       *
                *                       STCNTR * interupt interval.                        *
                *               This must be greater than 300ms                            *
                *                                                                          *
                *               For a clock signal error the time elapsed before error is  *
                *                       the interupt interval.                             *
                *               This must be greater than 3.8ms                            *
                *                                                                          *
                * On INT1  -    TRANSM                                                     *
                *                                                                          *
                * Inputs:       MSGLEN - The length of the message.                        *
                *               MSGPTR - No of chars left to transmit.Initialy 13.         *
                *               TXCNTR - Number of bits which have been transmitted in the char. *
                *               STCNTR - No of timer intervals left before a start error occurs. *
                *                                                                          *
                * Outputs:                                                                 *
                *                                                                          *
                * Calls to:     WAKEUP - Put the micro in wakeup mode.                     *
                *               SHUTDN - Shut down the micro and put to sleep.             *
                *                                                                          *
                * Modified:     SP                                                         *
                *                                                                          *
                * Rev 1.00                                                                 *
                * AL - 5/11/92                                                             *
                *                                                                          *
                ****************************************************************************
```

```
F20D
F20D   06  TRANER          DINT
F20E   7D                  CMP     %MSGLEN,MSGPTR  Has message started and so past the startup time
F20F   12
F210   2A
F211   E7                  JNC     SHUTDN          Error-No more clock sync for data.ShutDown micro
F212   13
F213   7D                  CMP     %0,TXCNTR       Has a number of bits of 1st char been sent?
F214   00
F215   2B
F216   E6                  JNZ     SHUTDN          Error-No more clock sync for data.ShutDown micro
F217   0E
F218   D2                  DEC     STCNTR          Decrement no of timer intervals.
F219   2E
F21A   E2                  JZ      SHUTDN          Error-Clock sync not started after >300ms
F21B   0A
F21C   E0                  JMP     WAKEUP          Still waiting for Clock sync.
F21D   00
F21E
F21E
           ******************************************************************************
           * :WAKEUP                Put the Micro-controller into WAKEUP mode.          *
           *                                                                            *
           * Description: This sub-routine resets the stack pointer to the start and    *
           *              initialises the timers and interupts before putting the micro *
           *              into wakeup mode.                                             *
           *                                                                            *
           *                                                                            *
           * Inputs:      STPT - Location of stack pointer.                             *
           *                                                                            *
           * Outputs:     SP - Stack pointer reset to STPT.                             *
           *                                                                            *
           * Modified:                                                                  *
           *                                                                            *
           * Rev 1.00                                                                   *
           * AL - 5/11/92                                                               *
           *                                                                            *
           ******************************************************************************
F21E
F21E   8E  WAKEUP          CALL    @TMINIT Initialise all the timers.
F21F F19F
F221   52                  MOV     %STPT,B
F222   60
F223   0D                  LDSP                    Reset the stack pointer.
F224   05                  EINT                    Enable interupts.
F225   01                  IDLE                    Put micro into wakeup mode.
F226
F226
           ******************************************************************************
           * :SHUTDN      Prepare the Micro-controller to be put in halt mode.          *
           *                                                                            *
           * Description: This sub-routine resets the stack pointer to the start and    *
           *              returns back to the main program.                             *
           *                                                                            *
           *                                                                            *
           * Inputs:      STPT - Location of stack pointer.                             *
           *                                                                            *
           * Outputs:     SP - Stack pointer reset to STPT.                             *
           *                                                                            *
           * Modified:                                                                  *
           *                                                                            *
           * Rev 1.20                                                                   *
           * AL - 2/12/92                                                               *
           *                                                                            *
           ******************************************************************************
F226
F226   52  SHUTDN MOV      %STPT,B
F227   60
F228   0D                  LDSP                    Reset stack pointer to STPT.
F229   8C                  BR      @ENDTRN Put micro into haltmode.
F22A F02E
F22C
F22C
           ************************************************************
           ******************** Interupt Vectors **********************
FFF8                AORG    >FFF8
FFF8 F006           DATA    START
FFFA F20D           DATA    TRANER
FFFC F1B8           DATA    TRANSM
FFFE F006           DATA    START
0000
                    END

NO ERRORS, NO WARNINGS
```



# UWRAA RESEARCH REPORTS

| Report Number | Title | Author |
|---|---|---|
| 1 | Trickling filter – solids contact process: Pilot plant studies. | M. Laginestra |
| 2 | A model of water pricing for Melbourne, Sydney and Perth | P. B. Dixon<br>P. M. Norman |
| 3 | Taste generation associated with chloramination | M. Kerslake |
| 4 | Bacterial regrowth in water supplies | K. Power<br>L. A. Nagy |
| 5 | Leakage management: Assessing the effect of pressure reduction on losses from water distribution systems | B. Horvath |
| 6 | Improving communication with the public on water industry policy issues | B. E. Nancarrow<br>G. J. Syme |
| 7 | Water use efficiency of domestic appliances | I. J. Beith<br>D. J. Horton |
| 8 | Pilot plant study of fermentation units to increase degradable COD fraction in sewage. | P. J. Bliss<br>D. Barnes<br>P. R. Evans<br>I. Law |
| 9 | Artificial destratification of water storages in Australia. | T. F. McAuliffe<br>R. S. Rosich |
| 10 | Taste thresholds of mono-chloramine and chlorine in water | R. O'Halloran<br>C. Veres |
| 11 | Chromatographic analysis of chloramines using electro-chemical detection | R. O'Halloran<br>Hai Lin Ge<br>P. Spizziri |
| 12 | Glass reinforced plastic bore casing for large diameter and deep bores | R. Bowyer |
| 13 | A guide to improving communication with the public on water industry policy issues | B. E. Nancarrow<br>G. J. Syme |
| 14 | Fouling and cleaning of fine bubble ceramic dome diffusers | K. J. Hartley |
| 15 | Chloramination of Water Supplies | P. M. Thomas (ed) |
| 16 | The 1988 Australian Winter Storms Experiment: Report on aircraft observations | J. B. Jensen |
| 17 | Pipeline assets: Life cycle management and economic life | R. Vass<br>M. Anderson<br>R. Lewis<br>D. Samson |
| 18 | Development of empirical model for tradewaste discharges to small treatment plants | Camp Scott Furphy |
| 19 | PRELIM users guide (Amended): Australian Version | Camp Scott Furphy |
| 20 | Chemical regeneration of activated carbon: Preliminary studies | G. Newcombe |
| 21 | Management and display of dam surveillance data | D. M. Stirling<br>G. L. Benwell<br>A. B. Murnane |
| 22 | Evaluation and demonstration facilities for primary sensors | J. A. Lanaway<br>M. Cavey |
| 23 | Modelling and design of reservoir aeration destratification systems | D. P. Lewis<br>J. C. Patterson<br>J. Imberger<br>R. P. Wright<br>S. G. Schadlow |
| 24 | Modelling optimum conditions for reservoir destratification using mechanical mixers | R. M. A. Velzeboer<br>J. A. Cugley<br>J. C. Patterson |
| 25 | Methods for detection of *Giardia* and *Cryptosporidium* in water: A preliminary assessment | C. A. Bee<br>P. E. Christy<br>B. E. Robinson |
| 26 | Toxic cyanobacteria in water supplies: Analytical techniques | D. J. Flett<br>B. C. Nicholson |
| 27 | Tracing toxic discharges to sewers by analysis of biofilms | D. Oliver<br>T. Watson |
| 28 | Electronic meter reading: Link between water meter and house | P. J. Reid<br>J. S. Renwick<br>M. F. Prior |
| 29 | Identification of common noxious cyanobacteria: Part 1 – Nostocales | P. Baker |
| 30 | Forecasting water demand using weather data | M. N. Viswanathan |
| 31 | Effects of controls on water consumption | M. N. Viswanathan |
| 32 | Biological removal of iron from groundwater: Preliminary studies | M. N. Viswanathan |
| 33 | Statistical modelling of water main failures | E. Tsui<br>G. Judd |
| 34 | Stratification, mixing and water quality in Darwin water supply reservoirs | R. Lukatelich<br>D. Robertson<br>K. Boland<br>J. Imberger<br>J. Patterson |
| 35 | Performance auditing in the Australian urban water industry | S. O'Kane<br>I. Parry<br>D. Blunden<br>D. Herring |
| 36 | Microbiological studies on enhanced removal of phosphates from sewage | R. C. Bayly<br>J. W. May<br>G. Vasiliadis<br>G. N. Rees |
| 37 | Magnetite and microwaves in sewage effluent treatment | D. R. Dixon<br>A. J. Ware |
| 38 | Polymer based electrode for the selective detection of dichloramine | Y. Lin<br>G. G. Wallace |
| 39 | Current cost asset valuation: Methodology | J. Dyke |

# UWRAA RESEARCH REPORTS

| Report Number | Title | Author |
|---|---|---|
| 40 | Community analysis of household water pressure satisfaction | G. J. Syme<br>B. E. Nancarrow<br>B. J. Bishop<br>P. VanderWal |
| 41 | Assessment of coagulants for water treatment | C. Donati |
| 42 | Coagulants for water treatment: A generic guide | ACWQR |
| 43 | Optimal prices for urban water: A general equilibrium model applied to Melbourne | P.B. Dixon<br>D.J. Baker |
| 44 | Applications of the Streaming Current Detector in water treatment | W. Barron<br>D. R. Dixon<br>M. Pascoe |
| 45 | Sydney coastal stormwater study | W. G. Rowlands et.al. |
| 46 | Identification of common noxious cyanobacteria: Part 2 – Chroococcales and Oscillatoriales | P. Baker |
| 47 | Levelling using the Global Positioning System | A. P. Armstrong<br>P. A. Collier<br>F. J. Leahy |
| 48 | Allocation of sewerage costs to customer segments | R. Hood<br>P. Geary |
| 49 | Impact of urban lawns on nutrient contamination of an unconfined aquifer | M. L. Sharma<br>D. E. Herne<br>P. G. Kin<br>J. D. M. Byrne |
| 50 | Early warning system for hazardous substances in sewage | R. O'Halloran<br>B. A. Sexton<br>N. H. Pilkington |
| 51 | Management model for trade waste discharges to small treatment plants (including PRELIM VERSION 4.0 Users Guide) | Camp Scott Furphy |
| 52 | Automatic meter reading: Link between meters and billing centre (Combined utilities trial) | B. Phey<br>A. Leong<br>Z. Balazic |
| 53 | Prediction of perceived odour strength and type from composition of sewage odour mixtures | D. G. Laing<br>A. Eddy<br>D. J. Best |
| 54 | Tracer studies using bacteriophage to predict the fate of viruses in the marine community: Preliminary assessments | B. J. Richardson<br>A. L. Charlton<br>S. Currie<br>P. Ashton<br>I. Lowther |
| 55 | Development of a water quality analyser suitable for unattended use in rivers and streams | G. W. Skyring<br>I. A. Johns<br>J. A. Cugley |
| 56 | Enhancement of nitrification in wastewater lagoons | P. M. Gross |
| 57 | Identification of critical water supply assets | PPK Consultants |
| 58 | Water in Our Environment: Education Project | H. Breidahl<br>D. Cliffe<br>H. Henderson |

| Report Number | Title | Author |
|---|---|---|