

Water Level Monitoring

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INTRODUCTION

Many washing machines currently in production use a mechanical sensor for water level detection. Mechanical sensors work with discrete trip points enabling water level detection only at those points. The purpose for this reference design is to allow the user to evaluate a pressure sensor for not only water level sensing to replace a mechanical switch, but also for water flow measurement, leak detection, and other solutions for smart appliances. This system continuously monitors water level and water flow using the temperature compensated MPXM2010GS pressure sensor in the low cost MPAK package, a dual op-amp, and the MC68HC908QT4, eight-pin microcontroller.

SYSTEM DESIGN

Pressure Sensor

The pressure sensor family has three levels of integration — Uncompensated, Compensated and Integrated. For this design, the MPXM2010GS compensated pressure sensor was selected because it has both temperature compensation and calibration circuitry on the silicon, allowing a simpler, yet more robust, system circuit design. An integrated pressure sensor, such as the MPXV5004G, is also a good choice for the design eliminating the need for the amplification circuitry.

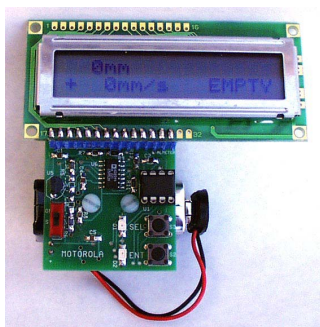


Figure 1. Water Level Reference Design Featuring a Pressure Sensor

The height of most washing machine tubs is 40 cm, therefore the water height range that this system will be

measuring is between 0–40 cm. This corresponds to a pressure range of 0–4 kPa. Therefore, the MPXM2010GS was selected for this system. The sensor sensitivity is 2.5 mV/kPa, with a full-scale span of 25 mV at the supply voltage of 10 V_{DC}. The full-scale output of the sensor changes linearly with supply voltage, so a supply voltage of 5 V will return a full-scale span of 12.5 mV.

$$\left(\frac{V_{S \text{ actual}}}{V_{S \text{ spec}}} \right) * V_{\text{OUT full-scale spec}} = V_{\text{OUT full-scale}}$$

$$(5.0 \text{ V} / 10 \text{ V}) * 25 \text{ mV} = 12.5 \text{ mV}$$

Since this application will only be utilizing 40 percent of the pressure range, 0–4kPa, our maximum output voltage will be 40 percent of the full-scale span.

$$V_{\text{OUT FS}} * (\text{Percent}_{\text{FS Range}}) = V_{\text{OUT max}}$$

$$12.5 \text{ mV} * 40\% = 5.0 \text{ mV}$$

The package of the pressure sensor is a ported MPAK package. This allows a tube to be connected to the sensor and the tube is connected to the bottom of the tub. This isolates the sensor from direct contact with the water. The small size and low cost are additional features making this package a perfect fit for this application.

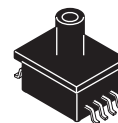


Figure 2. A Ported Pressure Sensor

Table 1. MPXM2010D OPERATING CHARACTERISTICS ($V_S = 10 V_{DC}$, $T_A = 25^\circ C$ unless otherwise noted, $P1 > P2$)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|-----------------|-----------|------|-----|-----|-------------|
| Pressure Range | P_{OP} | 0 | — | 10 | kPa |
| Supply Voltage | V_S | — | 10 | 16 | Vdc |
| Supply Current | I_O | — | 6.0 | — | mAdc |
| Full Scale Span | V_{FSS} | 24 | 25 | 26 | mV |
| Offset | V_{off} | -1.0 | — | 1.0 | mV |
| Sensitivity | DV/DP | — | 2.5 | — | mV/kPa |
| Linearity | — | -1.0 | — | 1.0 | % V_{FSS} |

Amplifier Induced Errors

The sensor output needs to be amplified before being inputted directly to the microcontroller through an eight-bit A/D input pin. To determine the amplification requirements, the pressure sensor output characteristics and the 0-5 V input range for the A/D converter had to be considered.

The amplification circuit uses three op-amps to add an offset and convert the differential output of the MPXM2010GS sensor to a ground-referenced, single-ended voltage in the range of 0–5.0 V.

The pressure sensor has a possible offset of ± 1 mV at the minimum rated pressure. To avoid a nonlinear response when a pressure sensor chosen for the system has a negative offset (V_{OFF}), we added a 5.0 mV offset to the positive sensor output signal. This offset will remain the same regardless of the sensor output. Any additional offset the sensor or op-amp introduces is compensated for by software routines invoked when the initial system calibration is done.

To determine the gain required for the system, the maximum output voltage from the sensor for this application had to be determined. The maximum output voltage from the sensor is approximately 12.5 mV with a 5.0 V supply since the full-scale output of the sensor changes linearly with supply voltage. This system will have a maximum pressure of 4 kPa at 40 cm of water. At a 5.0 V supply, we will have a maximum sensor output of 5 mV at 4 kPa of pressure. To amplify the maximum sensor output to 5.0 V, the following gain is needed:

$$\text{Gain} = (\text{Max Output needed}) / (\text{Max Sensor Output and Initial Offset}) = 5.0 \text{ V} / (0.005 \text{ V} + 0.005) = 500$$

The gain for the system was set for 500 to avoid railing from possible offsets from the pressure sensor or the op-amp.

The Voltage Outputs from the sensor are each connected to a non-inverting input of an op-amp. Each op-amp circuit has the same resistor ratio. The amplified voltage signal from the negative sensor lead is V_A . The resulting voltage is calculated as follows:

$$\begin{aligned} V_A &= (1+R8/R6) * V_4 \\ &= (1+10/1000) * V_4 \\ &= (1.001) * V_4 \end{aligned}$$

The amplified voltage signal from the positive sensor lead is V_B . This amplification adds a small gain to ensure that the positive lead, V_2 , is always greater than the voltage output from the negative sensor lead, V_4 . This ensures the linearity of the differential voltage signal.

$$\begin{aligned} V_B &= (1+R7/R5) * V_2 - (R7/R5) * V_{CC} \\ &= (1+10/1000) * V_2 + (10/1000)*(5.0 \text{ V}) \\ &= (1.001) * V_2 + 0.005 \text{ V} \end{aligned}$$

The difference between the positive sensor voltage, V_B , and the negative sensor voltage, V_A is calculated and amplified with a resulting gain of 500.

$$\begin{aligned} VC &= (R12/R11) * (V_B - V_A) \\ &= (500 \text{ K}/1\text{K}) * (V_B - V_A) \\ &= 500 * (V_B - V_A) \end{aligned}$$

The output voltage, V_C , is connected to a voltage follower. Therefore, the resulting voltage, V_C , is passed to an A/D pin of the microcontroller.

The range of the A/D converter is 0 to 255 counts. However, the A/D Values that the system can achieve are dependent on the maximum and minimum system output values:

$$\text{Count} = (V_{OUT} - V_{RL}) / (V_{RH} - V_{RL}) * 255$$

where V_{Xdcr} = Transducer Output Voltage

V_{RH} = Maximum A/D voltage

V_{LH} = Minimum A/D voltage

$$\text{Count (0 mm H20)} = (2.5 - 0) / (5.0 - 0) * 255 = 127$$

$$\text{Count (40 mm H20)} = (5.0 - 0) / (5.0 - 0) * 255 = 255$$

$$\text{Total \# counts} = 255 - 127 = 127 \text{ counts.}$$

The resolution of the system is determined by the mm of water represented by each A/D count. As calculated above, the system has a span of 226 counts to represent water level up to and including 40 cm. Therefore, the resolution is:

$$\begin{aligned} \text{Resolution} &= \text{mm of water} / \text{Total \# counts} \\ &= 40\text{mm}/127 \text{ counts} = 3.1 \text{ mm per A/D count} \end{aligned}$$

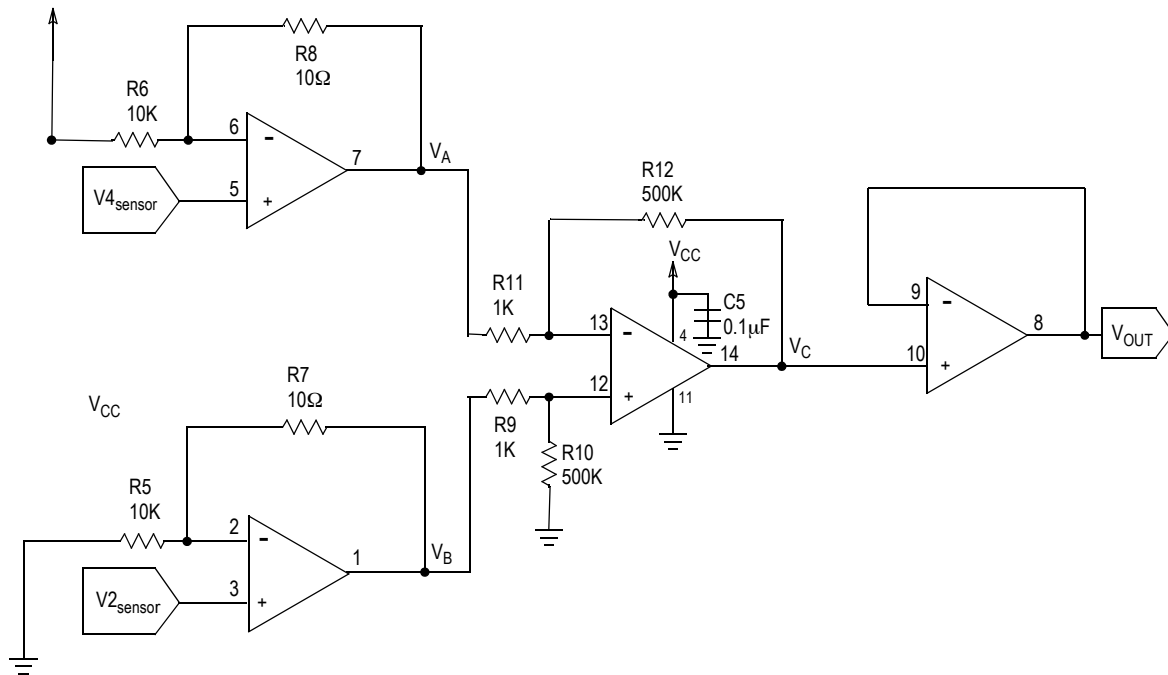


Figure 3. Amplification Scheme

Microprocessor

To provide the signal processing for pressure values, a microprocessor is needed. The MCU chosen for this application is the MC68HC908QT4. This MCU is perfect for appliance applications due to its low cost, small eight-pin package, and other on-chip resources. The MC68HC908QT4 provides: a four-channel, eight-bit A/D, a 16-bit timer, a trimmable internal timer, and in-system FLASH programming.

The central processing unit is based on the high performance M68HC08 CPU core and it can address 64 Kbytes of memory space. The MC68HC908QT4 provides 4096 bytes of user FLASH and 128 bytes of random access memory (RAM) for ease of software development and maintenance. There are five bi-directional input/output lines and one input line shared with other pin features.

The MCU is available in eight-pin as well as 16-pin packages in both PDIP and SOIC. For this application, the eight-pin PDIP was selected. The eight-pin PDIP was chosen for a small package, eventually to be designed into applications as the eight-pin SOIC. The PDIP enables the customer to reprogram the software on a programming board and retest.

Display

Depending on the quality of the display required, water level and water flow can be shown with two LEDs. If a higher quality, digital output is needed, an optional LCD interface is provided on the reference board. Using a shift register to hold display data, the LCD is driven with only three lines outputted from the microcontroller: an enable line, a data line, and a clock signal. The two LEDs are multiplexed with the data line and clock signal

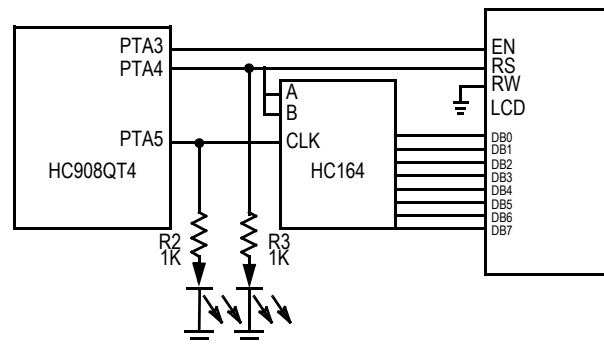


Figure 4. Multiplexed LCD Circuit

Multiplexing of the microcontroller output pins allows communication of the LCD to be accomplished with three pins instead of eight or 11 pins of I/O lines usually needed. With an eight-bit shift register, we are able to manually clock in eight bits of data. The enable line (EN) is manually accepted when eight bytes have been shifted in, telling the LCD the data on the data bus is available to execute.

The LEDs are used to show pressure output data by displaying binary values corresponding to a pressure range. Leak detection, or water-flow speed, is displayed by blinking a green LED at a speed relating to the speed of water flow. The red LED displays the direction of water flow. Turning the red LED off signifies water flowing into the tub. Turning the red LED on signifies water flowing out of the tub, or alternatively, there is a leak.

Digital values for water height, rate of water flow, and calibration values are displayed if an LCD is connected to the board

OTHER

This system is designed to run on a 9.0 V battery. It contains a 5.0 V regulator to provide 5.0 V to the pressure

sensor, microcontroller, and LCD. The battery is mounted on the back of the board using a space saving spring battery clip.

Table 2. Parts List

| Ref. | Qty | Description | Value | Vendor | Part No. |
|---------|-----|--------------------|-------------|-------------------|--------------|
| U2 | 1 | Pressure Sensor | 1 | Freescale | MPXM2010GS |
| C1 | 1 | Vcc Cap | 0.1 μ f | Generic | — |
| C2 | 1 | Op-Amp Cap | 0.1 μ f | Generic | — |
| C3 | 1 | Shift Register Cap | 0.1 μ f | Generic | — |
| D1 | 1 | Red LED | — | Generic | — |
| D2 | 1 | Green LED | — | Generic | — |
| S2, S3 | 2 | Pushbuttons | — | Generic | — |
| U1 | 1 | Quad Op-Amp | — | ADI | AD8544 |
| U3 | 1 | Voltage Regulator | 5.0 V | Fairchild | LM78L05ACH |
| U4 | 1 | Microcontroller | 8-pin | Freescale | MC68HC908QT4 |
| R1 | 1 | ¼ W Resistor | 22 K | Generic | — |
| R2 | 1 | ¼ W Resistor | 2.4 K | Generic | — |
| R3, R6 | 2 | ¼ W Resistor | 1.2 M | Generic | — |
| R4, R5 | 2 | ¼ W Resistor | 1.5 K | Generic | — |
| R7, R8 | 2 | ¼ W Resistor | 10 K | Generic | — |
| R9, R10 | 2 | ¼ W Resistor | 1.0 K | Generic | — |
| U6 | 1 | LCD (Optional) | 16 x 2 | Seiko | L168200J000 |
| U5 | 1 | Shift Register | — | Texas Instruments | 74HC164 |

Smart Washer Software

This application note describes the first software version available. However, updated software versions may be available with further functionality and menu selections.

Software User Instructions

When the system is turned on or reset, the microcontroller will flash the selected LED and display the program title on the LCD for five seconds, or until the select (SEL) button is pushed. Then the menu screen is displayed. Using the select (SEL) pushbutton, it is easy to scroll through the menu options for a software program. To run the water level program, use the select button to highlight the *Water Level* option, then press the enter (ENT) pushbutton. The Water Level program will display current water level, the rate of flow, a message if the container is *Filling*, *Emptying*, *Full*, or *Empty*, and a scrolling graphical history displaying data points representing the past forty level readings.

The Water Level is displayed by retrieving the digital voltage from the internal A/D Converter. This voltage is converted to pressure in millimeters of water and then displayed on the LCD.

Calibration and Calibration Software

To calibrate the system, a two-point calibration is performed. The sensor will take a calibration point at 0 mm and at 40 mm of water. Depressing both the SEL and ENT

buttons on system power-up enters the calibration mode. At this point, the calibration menu is displayed with the previously sampled offset voltage. To recalibrate the system, expose the sensor to atmospheric pressure and press the SEL button (PB1). At this point, the zero offset voltage will be sampled and saved to a location in the microcontroller memory. To obtain the second calibration point, place the end of the plastic tube from the pressure sensor to the bottom of a container holding 40 mm of water. Then press the ENT button (PB2). The voltage output will be sampled, averaged and saved to a location in memory. To exit the calibration mode, press the SEL (PB1) button.

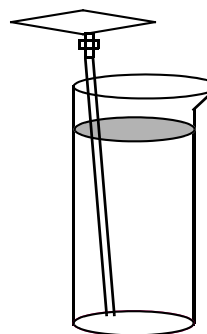


Figure 5. Water Level System Set-Up for Demonstration

Converting Pressure to Water Level

Hydrostatic pressure being measured is the pressure at the bottom of a column of fluid caused by the weight of the fluid and the pressure of the air above the fluid. Therefore, the hydrostatic pressure depends on the air pressure, the fluid density and the height of the column of fluid.

$$P = P_a + \rho g \Delta h$$

where P = pressure

P_a = pressure

ρ = mass density of fluid

$g = 9.8066 \text{ m/s}^2$

h = height of fluid column

To calculate the water height, we can use the measured pressure with the following equation, assuming the atmospheric pressure is already compensated for by the selection of the pressure sensor being gauge:

$$\Delta h = P / \rho g$$

Software Function Descriptions

Main Function

The main function calls an initialization function *Allinit* calls a warm-up function, *Warmup*, to allow extra time for the LCD to initialize, then checks if buttons PB1 and PB2 are depressed. If they are depressed concurrently, it calls a calibration function *Calib*. If they are not both pressed, it enters the main function loop. The main loop displays the menu, moves the cursor when the PB1 is pressed and enters the function corresponding to the highlighted menu option when PB2 is depressed.

Calibration Function

The calibration function is used to obtain two calibration points. The first calibration point is taken when the head tube is not placed in water to obtain the pressure for 0 mm of water. The second calibration point is obtained when the head tube is placed at the bottom of a container with a height of 160 mm. When the calibration function starts, a message appears displaying the A/D values for the corresponding calibration points currently stored in the flash. To program new calibration points, press PB1 to take 256 A/D readings at 0 mm of water. The average is calculated and stored in a page of flash. Then the user has the option to press PB1 to exit the calibration function or obtain the second calibration point. To obtain the second calibration point, the head tube should be placed in 160 mm of water, before depressing PB2 to take 256 A/D readings. The average is taken and stored in a page of flash. Once the two readings are taken, averaged, and stored in the flash, a message displays the two A/D values stored.

Level Function

The Level function initializes the graphics characters. Once this is complete, it continues looping to obtain an average A/D reading, displaying the Water Level, the Water Flow, and a Graphical History until simultaneously depressing both PB1 and PB2 to return to the main function.

The function first clears the 40 pressure readings it updates for the Graphical History. The history then enters the loop first displaying eight special characters, each containing five data points of water level history. The function *adcbyta* is called to obtain the current averaged A/D value. The function *LfNx* is called to convert the A/D value to a water level. It is then compared to the calibration points, the maximum and minimum points, to determine if the container is full or empty. If true, then it displays the corresponding message. The current water level is compared to the previous read and displays the message *filling* if it has increased, *emptying* if it has decreased, and *steady* if it has not changed.

The water level calculation has to be converted to decimal in order to display it in the LCD. To convert the water level calculation to decimal, the value is continually divided with the remainder displayed to the screen for each decimal place. To display the Rate of Water Flow, the sign of the value is first determined. If the value is negative, the one's complement is taken, a negative sign is displayed, and then the value is continually divided to display each decimal place. If the number is positive, a plus sign.

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The most complicated part of this function is updating the graphics history display. The characters for the 16x2 LCD chosen for this reference design are 8x5 pixels by default. Therefore, each special character that is created will be able to display five water level readings. Since the height of the special character is eight pixels, each vertical pixel position will represent a water level in increments of 20 mm.

$$\text{Resolution} = (H1 - H0) / D$$

where H1 and H2 are the maximum and minimum water levels respectively and D is the possible datapoints available per character.

Resolution = (160mm– 0mm) / 8.0 = 20 mm / data point.

The graphical history is displayed using the eight special characters. To update the graphics, all the characters have to be updated. The characters are updated by first positioning a pixel for the most recent water level reading in the first column of the first character. Then the four right columns of the first character are shifted to the right. The pixel in the last column of that character is carried to the first column of the next character. This column shifting is continued until all 40 data points have been updated in the eight special characters.

LfNx Function

The LfNx function calculates the water level from the current A/D pressure reading. The A/D Pressure value is stored in Register A before this function is called. Using the A/D value and the calibration values stored in the flash, the water level is calculated from the following function:

$$RBRA = (NX - N1) * 160 / (N2 - N1),$$

where NX is the current A/D Value

N1 is the A/D Value at 0 mm H2O

N2 is the A/D Value at 160 mm H2O

To simplify the calculation, the multiplication is done first. Then the function *NdivD* is called to divide the values.

NdivD Function

The *NdivD* function performs a division by counting successive subtractions of the denominator from the numerator to determine the quotient. The denominator is subtracted from the numerator until the result is zero. If there is an overflow, the remainder from the last subtraction is the remainder of the division.

wflash and ersflsh Functions

The *wflash* and *ersflsh* functions are used to write to and erase values from the flash. For more information regarding flash functionality, refer to Section Four, Flash Memory from the *MC68HC908QY4/D* Databook.

ALLINIT Function

The *Allinit* function disables the COP for this version of software, sets the data direction bits, and disables the data to the LCD and turns off the LCD enable line. It also sets up the microcontroller's internal clock to half the speed of the bus clock. See Section 15, Computer Operating Properly, of the *MC68908QT4* datasheet for information on utilizing the COP module to help software recover from runaway code.

WARMUP Function

The *Warmup* function alternates the blinking of the two LEDs ten times. This gives the LCD some time to warm up. Then the function *warmup* calls the LCD initialization function, *lcdinit*.

bintasc Function

The *binasc* function converts a binary value to its ascii representation.

A/D Functions

The A/D functions are used to input the amplified voltage from the pressure sensor from channel 0 of the A/D converter. The function *adcbyti* will set the A/D control register, wait for the A/D reading and load the data from the A/D data register into the accumulator. The function *adcbyta* is used to obtain an averaged A/D reading by calling *adcbyti* 256 times and returning the resulting average in the accumulator.

LCD Functions

The LCD hardware is set up for multiplexing three pins from the microcontroller using an eight-bit shift register. Channels three, four, and five are used on port A for the LCD enable (E), the LCD reset (RS), and the shift register clock bit, respectively. The clock bit is used to manually clock data from channel four into the eight-bit shift register. This is the same line as the LCD RS bit because the MSB of the data is low for a command and high for data. The RS bit prepares the LCD for instructions or data with the same bit convention. When the eight bits of data are available on the output pins of the shift register, the LCD enable (E) is toggled to receive the data.

The LCD functions consist of an initialization function *lcdinit* which is used once when the system is started and five output functions. The functions *lcmdmo* and *lcdchro* both send a byte of data. The function *shiftA* is called by both *lcmdmo* and *lcdchro* to manually shift eight bits of data into the shift register. The function *lcdnibo* converts the data to binary before displaying. The *lcdnibo* displays a byte of data by calling *lcdnibo* for each nibble of data. The function *lcdnibo* enables strings to be easily added to the software for display. The function accepts a comma-delimited string of data consisting of 1–2 commands for clearing the screen and positioning the cursor. It then continues to output characters from the string until the @ symbol is found, signally the end of the string.

CONCLUSION

The water level reference design uses a MPXM2010GS pressure sensor in the low cost MPAK package, the low cost, eight-pin microcontroller, and a quad op-amp to amplify the sensor output voltage. This system uses very few components, reducing the overall system cost. This allows for a solution to compete with a mechanical switch for water level detection but also offer additional applications such as monitoring water flow for leak detection, and the other applications for smart washing machines.

SOFTWARE LISTING

```
;NitroWater 2.0 24Jan03
;-----
;
;
;Water Level Reference Design
;*****
; - uses 908QT4 (MC68HC908QT4) and MPAK (MPXM2010GS)
; CALIB: 2-point pressure calibration (0mm and 160mm)
; LEVEL: displays water level, flow, and graphics
; UNITS: allows user to select between cm and inches
;
;
;-----
ram    equ    $0080    ;memory pointers
rom    equ    $EE00
vectors equ    $FFDE
;-----
porta  equ    $00      ;registers
ddra   equ    $04
config2 equ    $1E
config1 equ    $1F
tsc    equ    $20
tmodh  equ    $23
icgcr  equ    $36
adscr  equ    $3C
adr    equ    $3E
adickl equ    $3F
flcr   equ    $FE08
flbpr  equ    $FFBE
;-----
        org    $FD00    ;flash variables
N1     db    $96      ;1st calibration pt. = 0mm
        org    $FD40
N2     db    $F6      ;2nd calibration pt. = 160mm
        org    $FD80
;-----
        org    vectors
        dw    cold    ;ADC
        dw    cold    ;Keyboard
        dw    cold    ;not used
        dw    cold    ;not used
        dw    cold    ;not used
        dw    cold    ;not used
        dw    cold    ;not used
        dw    cold    ;not used
        dw    cold    ;not used
        dw    cold    ;not used
        dw    cold    ;TIM Overflow
        dw    cold    ;TIM Channel 1
        dw    cold    ;TIM Channel 0
        dw    cold    ;not used
        dw    cold    ;IRQ
        dw    cold    ;SWI
        dw    cold    ;RESET ($FFFE)
;-----
        org    ram
BB     ds    1        ;variables
flshadr ds    2
flshbyt ds    1
memSP  ds    2
mem03  ds    2
```

```

CNT    ds    1
Lgfx   ds    1
weath  ds    1
UnitType ds  1
UnitDiv ds    1
UnitEmpt ds  1
UnitFull ds  1
ram0   ds    1
NC     ds    1
NB     ds    1
NA     ds    1
DC     ds    1
DB     ds    1
DA     ds    1
MB     ds    1
MA     ds    1
OB     ds    1
OA     ds    1
RB     ds    1
RA     ds    1
P0C    ds    1
P0B    ds    1
P0A    ds    1
NPTR   ds    1
ramfree ds 80      ;used both for running RAM version of wflash & storing 40 readings
:
:
:
org rom
cold:  rsp          ;reset SP if any issues (all interrupt vectors point here)
      jsr ALLINIT   ;general initialization
      jsr WARMUP    ;give LCD extra time to initialize

      brset 1,porta,nocalib
      brset 2,porta,nocalib
      jmp CALIB     ;only do calibration if SEL & ENT at reset

nocalib: ldhx #msg01      ;otherwise skip and show welcome messages
         jsr lcdstro     ;"Reference Design" msg
         jsr del1s       ;wait 1s
         ldhx #msg01a    ;"Water Level" msg
         jsr lcdstro
         jsr del1s       ;wait 1s

initCM: ldhx #A014      ;initialize default units to cm ($A0=cm, $3F=in)
         sthx UnitType   ;UnitType set to $A0; UnitDiv set to $14
         ldhx #039E
         sthx UnitEmpt   ;UnitEmpt set to $03; UnitFull set to $9E

MENU:  ldhx #msg01b
         jsr lcdstro     ;Menu msg
         clr RA          ;menu choice=0 to begin with
         lda #$0D
         jsr lcdcmdo     ;blink cursor on menu choice

luke:  ld  RA          ;get current menu choice
        clrh
        lda menupos,x   ;and look up corresponding LCD address
        jsr lcdcmdo     ;reposition cursor

```



```

warm:  brclr 1,porta,PB1 ;check for SEL
       bclr 2,porta,PB2 ;or for ENT
       bclr 4,porta ;otherwise
       bset 5,porta ;turn on "SEL" LED
       jsr del100ms ;delay
       bset 4,porta ;toggle LEDs
       bclr 5,porta ;"ENT" now on: means choice is SEL ***or*** ENT
       jsr del100ms ;delay and repeat until SEL or ENT
       bra warm

PB1:   inc RA ;***SEL*** toggles menu choices
       lda RA
       cmp #$02 ;menu choices are $00 and $01
       bne PB1ok
       clr RA ;back to $00 when all others have been offered
PB1ok: bclr 4,porta
       bclr 5,porta ;LEDs off
       jsr del100ms ;wait a little bit
       brclr 1,porta,PB1ok ;make sure they let go of SEL
       bra luke

PB2:   bclr 4,porta ;***ENT*** confirms menu choice
       bclr 5,porta ;LEDs off
       lda RA ;get menu choice
       bne skip00
       jmp LEVEL ;do ===LEVEL=== if choice=$01
skip00: jmp UNITS ;do ===UNITS=== if choice=$00
:
:
CALIB: lda #$01
       jsr lcdcmdo
       clr ram0

       ldhx #msg05 ;===CALIB=== 2-point calibration
       jsr lcdstro ;Calibration current values
       lda N1 ;0mm
       jsr lcdbyto
       lda #'
       jsr lcdchro
       lda N2 ;160mm
       jsr lcdbyto
       bset 4,porta
       bset 5,porta ;LEDs on
lego1: brclr 1,porta,lego1
lego2: brclr 2,porta,lego2
       bclr 4,porta
       bclr 5,porta ;LEDs off when both SEL & ENT are released
       jsr del1s
       jsr del1s ;wait 2s
       ldhx #msg05a
       jsr lcdstro ;show instructions
waitPB1: brset 2,porta,no2 ;if ENT is not pressed, skip
        jmp nocalib ;if ENT is pressed then cancel calibration
no2:    brclr 1,porta,do1st ;if SEL is pressed then do 1st point cal
        bra waitPB1 ;otherwise wait for SEL or ENT
do1st: ldhx #msg05b ;1st point cal: show values
       jsr lcdstro
       clr CNT ;CNT will count 256 A/D readings
       clr RB
       clr RA ;RB:RA will contain 16-bit add-up of those 256 values

```

```

do256: lda #$C9
        jsr lcdcmdo    ;position LCD cursor at the right spot
        lda CNT
        deca
        jsr lcdbyto    ;display current iteration $FF downto $00
        lda #'.'
        jsr lcdchro
        jsr adcbyti    ;get reading
        add RA
        sta RA
        lda RB
        adc #$00
        sta RB        ;add into RB:RA (16 bit add)
        jsr lcdbyto    ;show RB
        lda RA
        jsr lcdbyto    ;then RA
        dbnz CNT,do256 ;and do 256x
        lsl RA        ;get bit7 into carry
        bcc nochg     ;if C=0 then no need to round up
        inc RB        ;otherwise round up
nochg:  lda RB        ;we can discard RA: average value is in RB
        ldhx #N1      ;point to flash location
        jsr wrflash   ;burn it in!
        ldhx #msg05c  ;ask for 160mm
        jsr lcdstro
waitPB2: brset 2,porta,waitPB2 ;wait for ENT
        ldhx #msg05d  ;2nd point cal: show values
        jsr lcdstro
        clr CNT      ;ditto as 1st point cal
        clr RB
        clr RA
do256b: lda #$C9
        jsr lcdcmdo
        lda CNT
        deca
        jsr lcdbyto
        lda #'.'
        jsr lcdchro
        jsr adcbyti
        add RA
        sta RA
        lda RB
        adc #$00
        sta RB
        jsr lcdbyto
        lda RA
        jsr lcdbyto
        dbnz CNT,do256b
        lsl RA
        bcc nochg2
        inc RB
nochg2: lda RB
        cmp N1        ;compare N2 to N1
        bne validcal ;if different, we are OK
        ldhx #msg05e  ;otherwise warn of INVALID CAL!
        jsr lcdstro
        jsr del1s
        jsr del1s
        jsr del1s     ;wait 2s
        jmp CALIB     ;try cal again

```

```

validcal: ldhx #N2
          jsr wrflash      ;burn N2 into flash
          ldhx #msg05      ;and display new current cal values from flash
          jsr lcdstro
          lda N1           ;0mm value
          jsr lcdbyto
          lda #'
          jsr lcdchro
          lda N2           ;160mm value
          jsr lcdbyto
          jsr del1s
          jsr del1s
          jmp nocalib      ;done!
:
:
LEVEL:   lda #01          ;===LEVEL=== main routine: displays level, flow & graphics
          jsr lcdcmdo      ;clear screen
          lda #0C
          jsr lcdcmdo      ;cursor off

          lda #88          ;position cursor at LCD graphics portion
          jsr lcdcmdo      ;(2nd half of first line)
          clra             ;and write ascii $00 through $07
fillgfx: jsr lcdchro      ;which contain the graphics related to
          inca             ;40 different readings
          cmp #08          ;do all 8
          bne fillgfx

LVL:     ldhx #ramfree    ;point to 40 pressure readings
          lda #28          ;count down from 40
purge:   clr 0,x          ;clear all those locations
          incx             ;next (H cannot change: we are in page0 RAM)
          dbnza purge
          jsr adcbyta      ;get averaged A/D reading (i.e. NX)
          jsr LfNx         ;convert to level and
          sta Lgfx        ;store in "Level graphics"

LVLwarm: bset 4,porta
          bset 5,porta     ;LEDs on during this cycle

          ldhx #ramfree    ;point to 40 pressure readings
          mov #27,RA       ;count down from 39
shiftgfx: lda 1,x         ;take location+1
          sta 0,x          ;and move to location+0, i.e. shift graphics left
          incx             ;next X (once again: we are in page 0, no need to worry about H)
          dbnz RA,shiftgfx ;do this 39x

          jsr adcbyta      ;get averaged A/D reading (i.e. NX)
          jsr LfNx         ;LX:=(NX-N1)*ConversionValue/(N2-N1)
          mov RA,OA        ;store result in OA

          clr RB           ;RB will contain graphic pixels (default=$00)
          cmp UnitEmpt     ;if <UnitEmpty (preset value = empty or almost)
          bcs Lzero        ;then "empty" (no pixels)
          cmp UnitFull     ;if >=UnitFull (preset value = full or almost)
          bcc Lsat         ;then "full" (pixel $80=bit 7)
          clrh             ;otherwise determine one of 8 graphic values
          idx UnitDiv      ;UnitDiv is roughly full range/8
          div              ;in order to give 8 values
          mov #01,RB       ;but now value has to be converted to pixel

```

```

    cmp  #$01      ;if result is $01
    beq  Lzero     ;then display it directly
makeRB  lsl  RB      ;otherwise shift 1 pixel bit to the right place
        dbnza  makeRB  ;by counting down result of division
        bra  Lzero
Lsat:   mov  #$80,RB ;if full then position highest pixel
Lzero:  lda  RB
        ldhx  #ramfree+$27 ;last of the 40
        sta  0,x      ;put it at then end of the 40 bytes (new value), all others were shifted left

        clr  weath    ;weath will contain dynamic change based also on value of RB
        lda  RB
        beq  donew    ;if RB=$00 then weath=$00: "empty"
        cmp  #$80
        bne  notfull  ;
        mov  #$01,weath ;if $80 then weath=$01: "full"
        bra  donew
notfull mov  #$02,weath ;prepare for "steady" if L(i)=L(i-1)
        lda  OA      ;get current level value L(i)
        cmp  Lgfx    ;compare to previous level value L(i-1)
        beq  donew
        mov  #$03,weath ;"filling" if L(i)>L(i-1)
        bcc  donew
        mov  #$04,weath ;"emptying" otherwise

donew:  lda  OA      ;current level L(i)
        sub  Lgfx    ;minus previous level L(i-1)
        sta  MA      ;establishes rate: L(i)-L(i-1)
        mov  RA,Lgfx ;update L(i-1)
;-----
golevel: lda  #$80   ;***** now let's display the level in decimal *****
        jsr  lcdcmdo ;start on 1st character of 1st line

        lda  OA      ;get current level value
        clrh
        idx  #$64    ;and divide by 100
        div
        bne  over100 ;if result is >0 then handle "hundreds"
        lda  #$20    ;otherwise display space (remove leading 0)
        jsr  lcdchro
        bra  lnext
over100: jsr  lcdnibo ;display "hundreds" digit
lnext:  pshh
        pula      ;move remainder into A
        clrh
        idx  #$0A    ;divide by 10
        div
        jsr  lcdnibo ;display "tens" digit
        lda  #'      ;
        jsr  lcdchro ;display decimal point
        pshh
        pula
        jsr  lcdnibo ;and first decimal
        lda  UnitType ;check for cm ($A0) vs. in (#3F)
        cmp  #$3F
        beq  dspIIN

dspICM: lda  #'c'
        jsr  lcdchro
        lda  #'m'

```

```

    jsr lcdchro    ;display "cm" for centimeters
    bra goflow

dspIIN: lda #'i'
    jsr lcdchro
    lda #'n'
    jsr lcdchro    ;display "in" for inches
;-----
goflow: lda #$C0      ;***** now let's display the flow in decimal *****
    jsr lcdcmdo     ;position cursor on 1st character 2nd line
    lda MA          ;get flow
    lsla           ;test sign of rate (in MA)
    bcc positiv    ;if positive, then it's easy

    lda MA         ;otherwise 1's complement of MB
    coma
    inca
    sta MA
    cmp #$64      ;check to see if >100
    bcs not2lo    ;if not we are OK
    lda #'<'     ;otherwise display that we exceeded min rate
    jsr lcdchro   ;that LCD can display (<9.9)
    lda #$63      ;force value to 99
    sta MA
    bra goconv

not2lo: lda #'-'
    jsr lcdchro   ;display that minus sign
    bra goconv

positiv: lda MA
    cmp #$64      ;check to see if >100
    bcs not2hi    ;if not we are OK
    lda #'>'     ;otherwise display that we exceeded max rate
    jsr lcdchro   ;that LCD can display (>9.9)
    lda #$63      ;force value to 99
    sta MA
    bra goconv

not2hi: lda #'+'
    jsr lcdchro   ;display the plus sign (to keep alignment)

goconv: lda MA    ;get flow
    clrh
    ldx #$0A      ;and divide by 10
    div
    jsr lcdnibo   ;display "tens" digit
    lda #'.'
    jsr lcdchro   ;display decimal point
    pshh
    pula
    jsr lcdnibo   ;and first decimal
    lda UnitType  ;check for cm ($A0) vs. in (#3F)
    cmp #$3F
    beq dspIINf

dspICMf: lda #'c'
    jsr lcdchro
    lda #'m'
    bra reusef

```

```

dspIINf: lda #'i'
        jsr lcdchro
        lda #'n'
reusef:  jsr lcdchro
        lda #'/'
        jsr lcdchro
        lda #'s'
        jsr lcdchro
;-----
gfxupdt: lda #$40      ;===== Graphics Update: tough stuff =====
        jsr lcdcmdo   ;prepare to write 8 bytes into CGRAM starting at @ $40
ldhx#ramfree;point to 40 pressure readings (this reuses wflash RAM)
        mov #$08,DA   ;DA will count those 8 CGRAM addresses
cg8:     lda 0,x
        sta NC
        lda 1,x
        sta NB
        lda 2,x
        sta NA
        lda 3,x
        sta DC
        lda 4,x
staDB;readings 0-4 go into NC,NB,NA,DC,DB and will form 1 LCD special
character
        mov #$08,RA   ;RA will count the 8 bits
fill:clrRB;start with RB=0, this will eventually contain the data for CGRAM
        rol NC
        rol RB
        rol NB
        rol RB
        rol NA
        rol RB
        rol DC
        rol RB
        rol DB
rolRB;rotate left those 5 values and use carry bits to form RB (tough part)
        lda RB
jsrlcdchro;and put it into CGRAM
dec RA      ;do this 8 times to cover all 8 bits
bne fill
        incx
        incx
        incx
        incx
incx ;now point to next 5 values for next CGRAM address (5 values per
character)
        dec DA      ;do this for all 8 CGRAM characters
        bne cg8

ldaweath;get weather variable and decide which message to display
        cmp #$04
        bne try3210
        ldhx #msg02e ;if $04
        bra showit
try3210: cmp #$03
        bne try210
        ldhx #msg02d ;if $03
        bra showit
try210:  cmp #$02

```

```

    bne try10
    ldhx #msg02c    ;if $02
    bra showit
try10: cmp #01
    bne try0
    ldhx #msg02b    ;if $01
    bra showit
try0:  ldhx #msg02a    ;otherwise this one
showit: jsr lcdstro
    jsr del1s    ;1s between pressure/altitude readings
    brset 1,porta,contin ;exit only if SEL
    brset 2,porta,contin ;and ENT pressed together
    jmp MENU
contin: jmp LVLwarm
:
LfNx:  sub N1    ;*** PX=f(NX,N2,N1) ***
    ldx UnitType    ;$A0=160 for cm, $3F=63 for in
    mul
    sta NA
    stx NB
    clr NC    ;NCNBNA:=(NX-N1)* (conversion value: 160 or 63)

    lda N2
    sub N1
    sta DA
    clr DB
    clr DC
    jsr NdivD    ;RBRA:=(NX-N1)*(conversion value)/(N2-N1)

    lda RA
    cmp #C8    ;check to see if result is negative
    bcs noovflw    ;if <$C8 we are OK
ovflw: clr RA    ;otherwise force level to 0!
noovflw: lda RA
    rts
:
NdivD: clr RA    ;RBRA:=NCNBNA/DCDBDA
    clr RB    ;destroys NCNBNA and DCDBDA
keepatit: lda RA
    add #01
    sta RA
    lda RB
    adc #00
    sta RB    ;increment RB:RA
    lda NA
    sub DA
    sta NA
    lda NB
    sbc DB
    sta NB
    lda NC
    sbc DC
    sta NC    ;NC:NB:NA:=NC:NB:NA-DC:DB:DA
    bcc keepatit    ;keep counting how many times until overflow
    lda RA
    sub #01
    sta RA
    lda RB
    sbc #00
    sta RB    ;we counted once too many, so undo that

```

```

    lsr  DC
    ror  DB
    ror  DA      ;divide DC:DB:DA by 2
    lda  NA
    add  DA
    sta  NA
    lda  NB
    adc  DB
    sta  NB
    lda  NC
    adc  DC
    sta  NC      ;and add into NC:NB:NA
    lsla
    bcs  nornd   ;if carry=1 then remainder<1/2 of dividend
    lda  RA
    add  #$01
    sta  RA
    lda  RB
    adc  #$00
    sta  RB      ;otherwise add 1 to result
nornd:  rts
:
:
:
UNITS:  brclr 2,porta,UNITS ;let go of ENT first
        lda  #$01          ;===UNITS=== Allows user to select units: inches or cm
        jsr  lcdcmdo       ;clear screen

        ldhx #msg03
        jsr  lcdstro       ;Unit Choice menu
        jsr  del100ms
        clr  RA            ;menu choice=0 to begin with
        lda  #$0D
        jsr  lcdcmdo       ;blink cursor on menu choice

uluke:  ldx  RA            ;get current menu choice
        clrh
        lda  menupos,x     ;and look up corresponding LCD address
        jsr  lcdcmdo       ;reposition cursor

uwarm:  brclr 1,porta,uPB1 ;check for SEL
        brclr 2,porta,uPB2 ;or for ENT
        bclr 4,porta      ;otherwise
        bset 5,porta      ;turn on "SEL" LED
        jsr  del100ms     ;delay
        bset 4,porta      ;toggle LEDs
        bclr 5,porta      ;"ENT" now on: means choice is SEL ***or*** ENT
        jsr  del100ms     ;delay and repeat until SEL or ENT
        bra  uwarm

uPB1:   inc  RA            ;***SEL*** toggles menu choices
        lda  RA
        cmp  #$02         ;menu choices are $00 and $01
        bne uPB1ok
        clr  RA           ;back to $00 when all others have been offered
uPB1ok: bclr 4,porta
        bclr 5,porta     ;LEDs off
        jsr  del100ms    ;wait a little bit
        brclr 1,porta,uPB1ok ;make sure they let go of SEL
        bra  uluke

```



```

uPB2:  bclr 4,porta    ;***ENT*** confirms menu choice
        bclr 5,porta    ;LEDs off
        lda  RA        ;get menu choice
        bne  SelIN

SelCM:  ldhx #A014     ;initialize default units to cm ($A0=cm, $3F=in)
        sthx UnitType ;UnitType set to $A0; UnitDiv set to $14
        ldhx #039E
        sthx UnitEmpt ;UnitEmpt set to $03; UnitFull set to $9E
        lda  #01
        jsr  lcdcmdo   ;clear LCD
        ldhx #msg03a
        jsr  lcdstro   ;and show choice selection to be cm
        jsr  del1s     ;wait 1s
        jmp  LEVEL     ;let's do LEVEL now...

SelIN:  ldhx #3F08     ;initialize default units to in ($A0=cm, $3F=in)
        sthx UnitType ;UnitType set to $3F; UnitDiv set to $08
        ldhx #033D
        sthx UnitEmpt ;UnitEmpt set to $03; UnitFull set to $3D
        lda  #01
        jsr  lcdcmdo   ;clear LCD
        ldhx #msg03b
        jsr  lcdstro   ;and show choice selection to be in
        jsr  del1s     ;wait 1s
        jmp  LEVEL     ;let's do LEVEL now...

;-----
;-----
;-----

*****
*****
***** GENERAL Routines *****
*****
*****

;----- INITIALIZATION Routines -----
;
; ALLINIT: initializes HC08, sets I/O, resets LCD and LEDs
;
;
ALLINIT: bset 0,config1 ;disable COP
        mov  #38,ddra   ;PTA0=MPAK,PTA1=SEL,PTA2=ENT,PTA3=E,PTA4=RS,PTA5=clk
        mov  #30,adick  ;ADC clock /2
        bclr 3,porta    ;E=0
        bclr 4,porta    ;grn=OFF; RS=0
        bclr 5,porta    ;red=OFF; CLK=0
        rts

;-----
;
; WARMUP: waits half a second while it flashes LEDs, and allows LCD to get ready
;
;
WARMUP: bclr 4,porta
        bclr 5,porta    ;LEDs off
        lda  #0A        ;prepare to do this 10x
tenx:   jsr  del25ms    ;delay
        bclr 4,porta
        bset 5,porta    ;alternate on/off
        jsr  del25ms
        bset 4,porta
        bclr 5,porta    ;and off/on
        dbnza tenx     ;10 times so the LCD can get ready (slow startup)
        jsr  lcdinit   ;now initialize it

```

```

    bclr 4,porta
    bclr 5,porta    ;LEDs off
    rts
;----- WRITE TO EEPROM Routines -----
;
;   wrflash: burns A into flash at location pointed by H:X
;
;-----
wrflash: sthx  flshadr    ;this is the address in the flash
        sta  flshbyt    ;and the byte we want to put there
        tsx
        sthx  memSP      ;store SP in memSP, so it can be temporarily used as a 2nd index register
        ldhx  #ramfree+1 ;SP now points to RAM (remember to add 1 to the address!!!, HC08 quirk)
        txs
        ;SP changed (careful not to push or call subroutines)
        ldhx  #ersflsh   ;H:X points to beginning of flash programming code
doall:  lda  0,x         ;get 1st byte from flash
        sta  0,sp        ;copy it into RAM
        aix  #$0001      ;HX:=HX+1
        ais  #$0001      ;SP:=SP+1
        cphx #lastbyt    ;and continue until we reach the last byte
        bne  doall
        ldhx  memSP      ;once done, restore the SP
        txs
        jsr  ramfree     ;and run the subroutine from RAM, you cannot write the flash while
        rts              ;running a code in it, so the RAM has to take over for that piece
;-----
;***** THE FOLLOWING CODE WILL BE COPIED INTO AND WILL RUN FROM RAM *****
ersflsh: lda  #$02      ;textbook way to erase flash
        sta  flcr
        lda  flbpr
        clra
        ldhx flshadr
        sta  0,x
        bsr  delayf
        lda  #$0A
        sta  flcr
        bsr  delayf
        lda  #$08
        sta  flcr
        bsr  delayf
        clra
        sta  flcr
        bsr  delayf
pgmfish: lda  #$01      ;textbook way to program flash
        sta  flcr
        lda  flbpr
        clra
        ldhx flshadr
        sta  0,x
        bsr  delayf
        lda  #$09
        sta  flcr
        bsr  delayf
        lda  flshbyt
        ldhx flshadr
        sta  0,x
        bsr  delayf
        lda  #$08
        sta  flcr
        bsr  delayf
        clra
        sta  flcr

```

```

        bsr delayf
        rts
delayf: ldhx #0005      ;wait 5x20us
        mov #36,tsc    ;stop TIM & / 64
        sthx tmodh    ;count H:X x 20us
        bclr 5,tsc    ;start clock
delayfls: brclr 7,tsc,delayfls
        rts          ;this RTS will move from RAM back into EEPROM
lastbyt: nop
;***** END OF CODE THAT WILL BE COPIED INTO AND WILL RUN FROM RAM *****
;----- DELAY Routines -----
;
; del1s: generates a 1s delay
;
; -----
del1s: pshh
        pshx
        ldhx #C350    ;1 second delay=C350=50000 x 20us
        bra delmain
;-----
;
; del100ms: generates a 100ms delay
;
; -----
del100ms: pshh
        pshx
        ldhx #1388
        bra delmain
;-----
;
; del50ms: generates a 50ms delay
;
; -----
del50ms: pshh
        pshx
        ldhx #09C4
        bra delmain
;-----
;
; del25ms: generates a 25ms delay
;
; -----
del25ms: pshh
        pshx
        ldhx #04E2
        bra delmain
;-----
;
; del5ms: generates a 5ms delay
;
; -----
del5ms: pshh
        pshx
        ldhx #00FA
        bra delmain
;-----
;
; del1ms: generates a 1ms delay
;
; -----
del1ms: pshh
        pshx
        ldhx #0032
        bra delmain
;-----
;
; del100us: generates a 100us delay
;
; -----
del100us: pshh
        pshx
        ldhx #0005
        bra delmain
;-----

```

```

; delmain: main delay routine; generates delay equal to H:X x 20us
;
; -----
delmain: mov  #$36,tsc    ;stop TIM & / 64
        sthx tmodh      ;count H:X x 20us
        bclr 5,tsc      ;start clock
delwait: brclr 7,tsc,delwait ;wait for end of countdown
        pulx
        pulh
        rts            ;this RTS serves for all delay routines!
;----- A/D Routines -----
;
; adcpyti: gets single A/D reading from PTA0 and returns it in A
;
; -----
adcpyti: mov  #$00,adscr ;ADC set to PTA0
        brclr 7,adscr,*  ;wait for ADC reading
        lda  adr        ;result in adr
        rts
;-----
;
; adcpyta: gets averaged A/D reading from PTA0 and returns it in A
;
; -----
adcpyta: clr  CNT      ;average 256 readings
        clr  RB        ;will be addint them up
        clr  RA        ;in RB:RA
do256a: bsr  adcpyti
        add  RA
        sta  RA
        lda  RB
        adc  #$00
        sta  RB        ;16-bit add into RB:RA
        dbnz CNT,do256a ;do all 256
        lsl  RA        ;if RA<$80
        bcc  nochga    ;then RB result is correctly rounded
        inc  RB        ;otherwise round off to next value
nochga: lda  RB
        rts
;----- LCD Routines -----
;
; lcdinit: initializes LCD
;
; -----
lcdinit: lda  #$3C     ;set 8-bit interface, 1/16 duty, 5x10 dots
        bsr  lcdcmdo
        lda  #$0C     ;display on, cursor off, blink off
        bsr  lcdcmdo
        lda  #$06     ;increment cursor position, no display shift
        bsr  lcdcmdo
        lda  #$01     ;clear display
        bsr  lcdcmdo
        rts
;-----
;
; lcdcmdo: sends a command to LCD
;
; -----
lcdcmdo: bsr  shiftA
        bclr 4,porta   ;RS=0 for command
        bset 3,porta
        bclr 3,porta   ;toggle E
        bsr  del5ms    ;some commands require 2ms for LCD to execute
        rts           ;so let's play it safe
;-----
;
; lcdchro: sends a character (data) to LCD
;
; -----
lcdchro: bsr  shiftA
        bset 4,porta   ;RS=1 for data

```

```

    bset 3,porta
    bclr 3,porta    ;toggle E
    bsr  del100us    ;data only requires 40us for LCD to execute
    rts
;-----
;   shiftA: shifts A into shift register and provides 8-bits to LCD
;   -----
shiftA:  psha
        mov  #$08,BB    ;will be shifting 8 bits
all8:   lsla    ;get bit
        bcc  shift0    ;if bit=0 then shift a 0
shift1: bset  4,porta    ;otherwise shift a 1
        bra  shift
shift0: bclr  4,porta    ;bit 4 is data to shift register
shift:  bclr  5,porta    ;bit 5 is shift register clock
        bset  5,porta
        bclr  5,porta    ;toggle CLK
        dbnz  BB,all8    ;do all 8 bits
        pula
        rts
;-----
;   lcdnibo: displays 1 character (0-9,A-F) based on low-nibble value in A
;   -----
lcdnibo: psha            ;convert 4 bits from binary to ascii
        add  #$30        ;add $30 (0-9 offset)
        cmp  #$39        ;is it a number (0-9) ?
        bls  d0to9b      ;if so skip
        add  #$07        ;else add $07 = total of $37 (A-F offset)
d0to9b: bsr  lcdchro
        pula
        rts
;-----
;   lcdbyto: displays 2 characters based on hex value in A
;   -----
lcdbyto: psha
        psha            ;remember A (for low nibble)
        lsra            ;shift right 4 times
        lsra
        lsra
        lsra
        bsr  lcdnibo    ;high nibble
        pula
        and  #$0F
        bsr  lcdnibo    ;low nibble
        pula
        rts
;-----
;   lcdstro: displays message ending in '@', but also sends commands to LCD
;   -----
lcdstro: psha
        lda  0,x
lcon:   cmp  #$80        ;if ASCII >=$80
        bhs  iscmd
        cmp  #$1F        ;or <=$1F then
        bls  iscmd      ;assume it is a command to LCD
isdt:   bsr  lcdchro    ;otherwise it is data to LCD
reuse1: aix  #$0001     ;next character
        lda  0,x        ;indexed by x
        cmp  #$40        ;continue until
        bne  lcon       ;character = '@'

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pula          ;we are done
bclr 4,porta  ;so
bclr 5,porta  ;turn off LEDs
rts
iscmd: bsr lcdcmdo
bra reuse1
;----- ROM DATA: contains all LCD messages -----
msg01 db $01,$80,*MPAK & 908QT4* '
db $C0,'Reference Design','@'
msg01a db $01,$80,'Water Level & '
db $C0,'Flow v2.0','@'
msg01b db $01,$80,'1:Level/Flow '
db $C0,'2:Set Units ','@'
msg05 db $01,$80,* Calibration! *
db $C0,'Curr lo/hi:','@'
msg05a db $01,$80,'1st point: 0mm'
db $C0,'SEL:cal ENT:quit','@'
msg05b db $01,$80,'Calibrating... '
db $C0,' 0mm: ','@'
msg05c db $01,$80,'2nd point: 160mm'
db $C0,'ENT:continue ','@'
msg05d db $01,$80,'Calibrating... '
db $C0,' 160mm: ','@'
msg05e db $01,$80,'INVALID '
db $C0,'CALIBRATION! ','@'
msg02a db $C8,' EMPTY','@'
msg02b db $C8,' FULL','@'
msg02c db $C8,' steady','@'
msg02d db $C8,' H20 in','@'
msg02e db $C8,' H20 out','@'
msg03 db $01,$80,'1: unit=cm H20 '
db $C0,'2: unit=in H20 ','@'
msg03a db $80,'Unit is now: cm','@'
msg03b db $80,'Unit is now: in','@'
menupos db $80,$C0

end

```

REFERENCES

- Baum, Jeff, "Frequency Output Conversion for MPX2000 Series Pressure Sensors," Application Note AN1316/D.
- Hamelain, JC, "Liquid Level Control Using a Pressure Sensor," Application Note AN1516/D.



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