...escale Semiconductor
Application Note

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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.

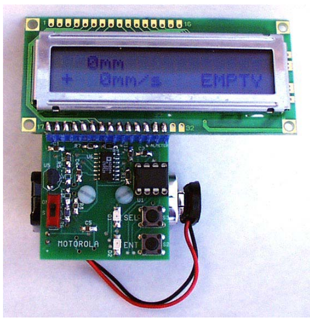

Figure 1. Water Level Reference Design Featuring a Pressure Sensor

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.

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

(5.0 V/ 10 V) x 25 mV = 12.5 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.

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

12.5 mV * 40% = 5.0 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.

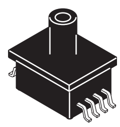

Figure 2. A Ported Pressure Sensor

Table 1. MPXM2010D OPERATING CHARACTERISTICS (V_S = 10 V_{DC}, T_A = 25°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:

Gain = (Max Output needed) / (Max Sensor Output and Initial Offset) = 5.0 V / (0.005 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:

$$V_A = (1+R8/R6) * V_4$$
$$= (1+10/1000) * V_4$$
$$= (1.001) * V_4$$

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.

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

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.

$$VC = (R12/R11) * (V_B - V_A)$$
$$= (500\ K/1K) * (V_B - V_A)$$
$$= 500 * (V_B - V_A)$$

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:

Count = (V_{OUT} – VRL) / (VRH – VRL) x 255

where V_{Xdcr} = Transducer Output Voltage

V_{RH} = Maximum A/D voltage

V_{LH} = Minimum A/D voltage

Count (0 mm H20) = (2.5 – 0) / (5.0 – 0) * 255 = 127

Count (40 mm H20) = (5.0 – 0) / (5.0 – 0) * 255 = 255

Total # counts = 255 – 127 = 127 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:

Resolution = mm of water / Total # counts

= 400mm/127 counts = 3.1 mm per A/D count

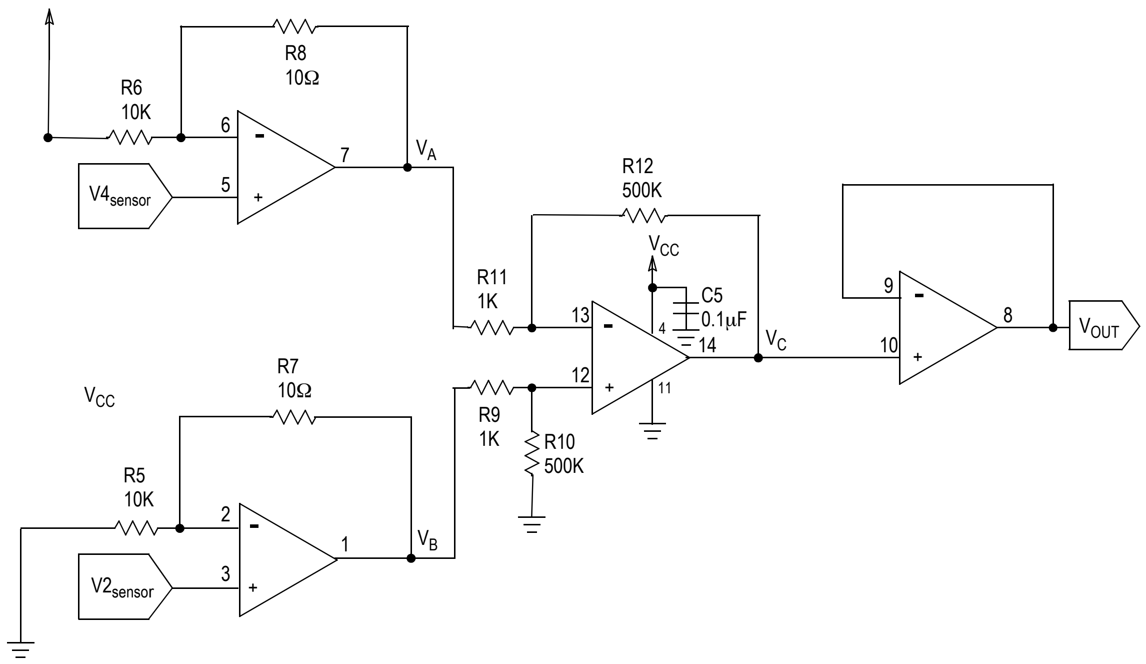

Figure 3. Amplification Scheme

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

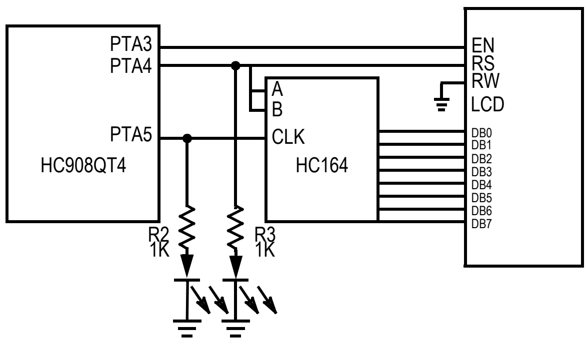

Figure 4. Multiplexed LCD Circuit

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	0.1μf	Generic	—
C2	1	Op-Amp Cap	0.1μf	Generic	—
C3	1	Shift Register Cap	0.1μf	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 Registor	—	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.

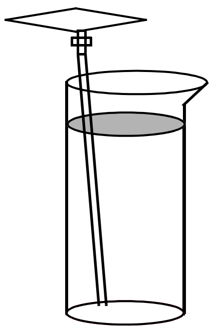

Figure 5. Water Level System Set-Up for Demonstration

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.

$$P = Pa + \rho\, g\, \Delta h$$

where P = pressure

Pa = pressure

ρ = mass density of fluid

g = 9.8066 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:

$$\Delta h = P \backslash \rho\, g$$

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 H20

N2 is the A/D Value at 160 mm H20

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.

wrflash and ersflsh Functions

The *wrflash* 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 *lcdcmdo* and *lcdchro* both send a byte of data. The function *shiftA* is called by both *lcdcmdo* 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
adiclk   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 wrflash & 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:   ldx   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
         brclr  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
        ldx   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
        ldx    #$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
        ldx    #$0A           ;divide by 10
        div
        jsr    lcdnibo        ;display "tens" digit
        lda    #'.'
        jsr    lcdchro        ;display decimal point
        pshh
        pula
        jsr    lcdnibo        ;and first decimal
        lda    UnitType       ;check for cm ($A0) vs. in (#3F)
        cmp    #$3F
        beq    dsplIN

dsplCM: lda    #'c'
        jsr    lcdchro
        lda    #'m'
```

```
        jsr   lcdchro       ;display "cm" for centimeters
        bra   goflow

dsplIN: 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   dsplINf

dsplCMf: lda  #'c'
        jsr   lcdchro
        lda   #'m'
        bra   reusef
```

```
dsplINf:  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 wrflash 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
  rolRB
    rol NB
  rolRB
  rol NA
  rolRB
  rol DC
  rolRB
  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,adiclk ;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
pgmflsh: 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 ---------------------------------------------
;       adcbyti: gets single A/D reading from PTA0 and returns it in A
;       -------
adcbyti:  mov    #$00,adscr     ;ADC set to PTA0
        brclr  7,adscr,*      ;wait for ADC reading
        lda    adr            ;result in adr
        rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       adcbyta: gets averaged A/D reading from PTA0 and returns it in A
;       -------
adcbyta:  clr    CNT            ;average 256 readings
        clr    RB             ;will be addint them up
        clr    RA             ;in RB:RA
do256a:   bsr    adcbyti
        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
isdta:  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 = '@'
```

```
        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.

NOTES

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