LCD Mini: The Intelligent

TECHNICAL MANUAL

V1.0e

FOR LCD Mini/DataSource/Wireless Mini mask revision 1.0

Revision history

1.0 JAL 12/5/04 - Renamed & edited LCD DataSource manual 1.8
1.0b JAL 7/9/04 - Bit 4 of User flags ($31 in EEPROM) set = Ext sensor
1.0c AS 04-05-2005 – Product Code definition
1.0d WCH 1/8/5 - RF f/w ver. stored in EEPROM
1.0e WCH 21/9/5 - List of features updated

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1.0 General

The LCD Mini is very similar to the LCD DataSource and has been redesigned to fit in a new case with DB9 serial comms connector.

Its core features are as follows:

- Four digit LCD
- One momentary action push-button switch
  - pressing and holding the button for more than one second will start logging
  - pulsing the button will cycle the display
- RS232 communications using
  - a simple DB9 extension if logger not plugged directly onto computer
  - 2400 baud transmission rate
- Single thermistor based temperature sensor covering a -40°F to +158°F range (-40°C to +70°C)
- Accuracy of ±1.0°F (±0.5°C)
- Temperature displayed in either units of Celsius or Fahrenheit
- 18 month operating life from a user-replaceable battery
- Low battery indication (only on PC or chartreader)
- 1868 logs stored in non-volatile memory
- Individually configurable over and under temperature alarms
- Consecutive and non-consecutive alarm settings
- Background logging mode (must not be enabled due to patent infringement)
- Programmable start delay
- Programmable log interval and number of logs
- Lease option to inhibit indefinite use of the logger
- Security code to protect against program change
- Unique electronic serial number
- Trip counter
- Real time clock
- 16 characters of user programmable device description
- No sound
- No LEDs

Product code:
[FF] - [XX] - [R(R)] - [M] - [Options]

[FF] Family
MI- Intelligent Mini (LCD Mini or Wireless Mini)

[XX] Sensor combination
IN Internal sensor
OE No internal but external sensor on cable

[R(R)] Temperature Range
D D-Range

[M] Memory size
2 1868 readings (2KB)

[Options]
L LCD
LR8 LCD & 868 MHz
LR9 LCD & 916 MHz

Example:
Wireless Mini 916 MHz, external sensor: MI-OE-D-2-LR9

1.1 Hardware

The LCD Mini is based around the 4-bit OKI MSM64162A microcontroller. This controller is specifically designed for battery powered electronic temperature measurement so has a significant amount of the required hardware built in. As well as the CPU core, it incorporates the LCD drivers, ADC and battery check circuit.

External to the controller are a 2k I^2C EEPROM (24LC16), the LCD, a 3V 550mAH disc cell (CR2450), and the thermistor sensor (10K3A1B).

The 64162 uses the thermistor as the resistive component in an RC oscillator and uses the measured frequency to determine the resistance. A full description of how this method is implemented can be found in Appendix B.

The EEPROM is guaranteed for one million write-cycles. As many variables are written to EEPROM every time a log is taken and it is possible to set the logger to log once per minute almost continuously, a worst case scenario is that the EEPROM could fail after 1.9 years.

1.2 Low battery indication

The logger uses a circuit built into the microcontroller to measure its battery level. This is only an approximate test and is really a 'marketing feature' rather than accurate and reliable information. Among other things, it is temperature dependent and the trip level has been set for operation at 25°C.

This internal circuit is used due to low cost, and will require the selection of two external resistors based on a measurement of the microcontroller's characteristic. The circuit compares the level of a voltage divider (the two external resistors) with the level of a diode drop below the supply level. As the supply level decreases the constant diode drop decreases faster than the voltage divided level, and the cross over point determines the trigger level for the circuit. The value of the diode drop is not precise and will require measurement on a microcontroller batch basis. Using software to compensate for variation in this circuit is possible but not practical.

The battery level is not displayed on the LCD and a reading can only be instigated by a PC (or a chartreader).

1.3 Reset

The design ideology has been to keep running if at all possible. All operation variables are backed up to EEPROM and reloaded when and if the microcontroller is reset.

The real time clock is not backed up so if this gets corrupted in RAM then the problem can only be corrected by PC software.

The microcontroller has a watch dog timer which attempts to ensure that if the main code crashes then the watch dog code will be executed. The reset pin of the micro is tied to an output port and the watch-dog interrupt has been set up such that a software crash will drive this pin low resulting in a full hardware reset.

The PC or chartreader can trigger a partial reset by clearing an active low flag called NotSemiInit. This has the same effect as a full reset except it does not set up the port directions and it does not specifically reset any special function registers (including stack pointer).

If the device has operational comms then the PC or chartreader can also force a hard reset. This is a dubious feature - the tidy way of doing this has been removed to free up some code space. (To force a reset the PC or chartreader must write the address of the watchdog code over the return vector in the stack area, then allow the comms function to time out and return.)

1.4 Scalability

Little attention has been paid to future proofing the design. Most notably a change in memory size will not be possible without creating another mask for the microcontroller.

1.5 Time management

The logger manages time in the form of two seconds registers and a 3-byte minutes register. (3 byte minutes = 16,777,215 minutes = 32 years)

The time datum is arbitrary (and not stored on the logger) but is intended to be midnight December 31 1999.

The 6-nibble TimeNow register holds the number of minutes elapsed since the time datum in binary form. The SecondsCounter0 register holds the number of seconds.

The SecondsCounter1 register holds a measure of seconds elapsed since the program was started. When the button is pressed and held for exactly one second this counter is loaded with the value 58. When this counter rolls over from 59 to 00 the first log is taken (or the delayed start initiated).

2.0 Communications

Mode	:	RS232 2400 baud, 1 start bit, 1 stop bit, 8 bits data, No parity
TX (Host->Logger) minimum inter-character delay	:	500µs
RX (Logger->Host) maximum inter-character delay	:	1ms
Recommended RX timeout (waiting for reply)	:	10ms
Recommend Retry Count	:	5

The comms are performed by bit-bashing two GPIO port pins.

Because the OKI-64162 is 4-bit, its code efficiency is quite low and therefore can't achieve acceptable comms rates while running from a 32kHz clock. However, it has a high-speed mode where it operates from a 400kHz RC oscillator and the comms takes advantage of this.

To initiate communications the communicating device must first send a 'kick start' character. Activity on the Rx line triggers an interrupt in the microcontroller which in turn tells it to wake up, switch to high speed mode, calibrate the RC oscillator against the more accurate 32k768Hz crystal, then start polling the Rx line for a start bit.

This takes a maximum of 400ms then the micro will remain polling the comms for 875ms. If, at any stage, there is no comms activity for 875ms the comms function will time out and the processor will slow down and go to sleep again. Once a packet has been received (either correctly of incorrectly) and a reply has been sent (if the packet was valid), the 875ms time out period is restarted.

It is imperative to keep the real time clock running continuously which means that a 1Hz interrupt must be momentarily enabled after each packet is received. This can cause the detection of the next start bit to be unacceptably delayed and the subsequent packet misread and rejected. From the PC or chartreader's point of view this means occasionally packets won't get through, and, in the absence of a reply from the logger, must be resent. In addition to this if comms are initiated part way through an A/D conversion then the loggers response will be delayed by up to a second and it will miss any packets sent during this time. If however, the scenario is reversed and the logger is in comms mode while the "time to take a log" flag becomes set, then the actual taking of the log is deferred until the comms function times out. Care should therefore be taken, as this means it is possible for a log to be skipped if comms takes longer than the log interval.

2.1 Packet structure

There are only two possible commands that can be written to the logger. These are read memory and write memory. The PC or chartreader software has free access to every EEPROM and RAM location (including stack area etc.). To trigger an action such as force the device to perform a conversion the software must 'fiddle' the logger's internal registers. The internal memory structure has been designed with this in mind.

2.1.1 Write packet

byte 0	Start character (A3)
byte 1 bits 4 to 7	Command nibble (0 = write)
byte 1 bits 0 to 3	The total number of bytes in the packet
byte 2	Low byte of destination address
byte 3 bit 7	Memory bank (1 = RAM, 0 = EEPROM)
byte 3 bits 0 to 6	High 'byte' of destination address
byte 4	Number of bytes to write
bytes 5 to end-1	Data bytes
final byte	Check sum

2.1.2 Write reply packet

byte 0	Start character (A3)
byte 1 bits 4 to 7	Write reply nibble (1)
byte 1 bits 0 to 3	The total number of bytes in the packet (3)
byte 2	Check sum (B6)

2.1.3 Read packet

byte 0	Start character (A3)
byte 1 bits 4 to 7	Command nibble (8 = read)
byte 1 bits 0 to 3	The total number of bytes in the packet (6)
byte 2	Low byte of source address
byte 3 bit 7	Memory bank (1 = RAM, 0 = EEPROM)
byte 3 bits 0 to 6	High 'byte' of source address
byte 4	Number of bytes required
byte 5	Check sum

2.1.4 Read reply packet

byte 0	Start character (A3)
byte 1 bits 4 to 7	Read reply nibble (9)
byte 1 bits 0 to 3	The total number of bytes in the packet
bytes 2 to end-1	Data bytes
final byte	Check sum

The logger makes no attempt to verify any data that is written to it however for a packet to be accepted it must have a correct start character, length, and check sum. The check sum is simply the 8-bit summation of all the bytes in the packet.

The maximum packet length is 16 bytes. Attempting to write packets longer than this will result in them being ignored and asking for more data than will fit in a read reply packet will result in a corrupt packet being sent.

2.2 Accessing EEPROM

It is not practically possible to fit 16 data bytes into a comms packet, so due to the banked nature of the EEPROM, logs will need to be up loaded in groups of 8. With the packet overhead, this will take roughly 30 seconds to up load the entire 2k memory.

The 'banked nature' of the EEPROM refers to fact that data in EEPROM is read and written using a packet structure. The packet has a start address followed by up to 16 bytes of data however any single read or write *cannot cross a 16 byte page boundary*. Attempting to will result in wrap around ie. If the start address of a read packet is $2D and the data length is 5 then the data will be read from addresses $2D, $2E, $2F, $20, $21.

2.3 Accessing RAM

RAM is organised as nibbles and the comms structure is based around bytes so some compromises are required. The RAM address to read or write should be the nibble address as shown in Appendix A.2 but should always be even. Note that the high 'byte' of the address (bits 0 - 6 of byte 3 in the packet) is simply ignored. The data length field in the comms packet is always in bytes so nibbles can only be read and written to RAM in pairs.

Although the 64162 memory architecture is banked in a similar fashion to the EEPROM this has been made transparent to comms so restrictions on page boundaries do not apply.

WARNING! Because of the flexible nature of the comms, it is possible to crash the logger by writing to the stack area. It is desirable to avoid doing this.

2.4 Reading the firmware version

Because no status request command exists the firmware version is stored in RAM and can be directly read from there. The RTC interrupt updates this location once per second with the hard coded version number so it is effectively a read only address.

The firmware version is stored as a byte. The lower nibble represents the sub-revision, the upper nibble represents the revision and if there is any response at all then this represents the LCD Mini.

2.5 Reading the battery status

The logger will not check the battery of its own accord. To find out the battery status, the software must ensure that the BatteryStatus flag in ActionFlags1 in RAM is cleared. The software must then trigger the logger to take a reading by resetting the active low 'NotCheckBattery' flag in this nibble.

For the battery test to occur the logger must exit comms mode by timing out (after 875ms). The battery will be subsequently checked (taking just less than 30ms) and the BatteryStatus flag set if the battery voltage is above the specified threshold. If the battery is below the threshold this flag is not explicitly cleared but remains unchanged (which is why the PC or chartreader must ensure it's cleared initially). The software must then read the ActionFlags1 nibble from RAM and interrogate this bit.

3.0 Program operation

3.1 General

The logger is controlled by a program loaded into it using a PC (or rearmed by a chartreader).

The user can either start the logger program using the PC or chartreader or set it to be started using the push button.

When the program begins the logger waits for a variable length start delay to elapse before taking the first log. This delay can be set to any integer number of minutes from 0 to 255.

The logger also records the time of day to an accuracy of 1 minute when the program is started. The TimeNow field in RAM is copied to the StartLogTime field in EEPROM immediately prior to the first log being taken. If a delayed start is programmed, the time is copied after the delay has elapsed.

Once the start delay has elapsed, the logger will record the temperature periodically at the programmed log interval. The log interval can be set to any integer number of minutes from 1 to 256.

The logger will continue this cycle until it has taken the specified number of logs then it will stop recording. The specified number of logs can be set to any number, which must be from 1 to 1868 to avoid overwriting earlier recorded data.

The logger program cannot be stopped prematurely without using a PC or a chartreader.

3.2 Background logging

The logger can optionally have a background-logging mode enabled. In this case, the logger will continuously record the temperature at the specified log interval (the same interval used for the program) prior to the program being started.

When the program is started the logger will suspend background logging and begin the program as described above. If a delayed start has been programmed, no logs will be recorded during the delay period.

At the completion of the program, background logging will remain suspended and no further readings will be taken.

If the program is not started, background logging will continue indefinitely.

The logger can record a maximum of 1868 logs so if more than this number of logs are taken in background logging mode, the oldest logs will be overwritten with the most recent logs.

3.3 Setting a program

All set up for the program can be done by writing only to EEPROM. However, some EEPROM stored values are echoed in RAM (to reduce processing overhead each time they're needed), so it is necessary to trigger the micro to copy them over. This is done by clearing the active low NotSemiInit flag in the ActionFlags1 in RAM. This in turn will copy all relevant data to RAM and will reset the display mode to Main. It will also measure the battery level but this can be ignored.

The program sequence is controlled by the LogStatus register.

3.3.1 LogStatus register

Bit	Name	Description
7	Celsius	Set to display temperatures in Celsius. Clear for Fahrenheit.
6	Wrapped	This flag gets set when the NextLogAddress wraps from 07FF to 00B4. The f/w never clears it.
5	LogStartType	This flag is ignored by the firmware but is reserved for external software to set to indicate a switch start, or clear otherwise.
4	ReadDelay	Internal flag - set in the button interrupt to tell the foreground to copy the start delay from EEPROM to RAM.
3	NotStopped	Active low - Indicates that the program has finished and no further logs should be taken. This bit over-rides bits 0 -2.
2	NotCurrentlyLogging	Active low - indicates that the logging cycle of the program is active, i.e. the start delay has finished.
1	ProgramRunning	Active high - Indicates that program has been started, i.e. the program is in some state other than ready.
0	NotBackgroundLogging	Active low - Sets background logging mode. This bit over-rides bits 1 and 2.

To correctly set a program the above register should have the relevant bits set (e.g. $2D or $AD for a normal program with button start and background logging disabled) as well as the relevant values written to the NumberOfLogsToTake, StartDelay, and LogInterval registers.

An "Immediate" start is effected by setting the BeginProgram bit instead of clearing the NotSemiInit flag. In this case, the startup delay is re-read from EEPROM regardless of the setting of the ReadDelay flag above. If this value is not zero, the startup delay will commence.

If background logging is to be used then the value in CurrentLogAddress should be set to the start of the log buffer ($00B4) first, so that it is known where to extract the data from if needed. In addition, the Wrapped flag should be cleared so that wrapping can be detected if it occurs.

3.3.2 StartDelay register

The start delay register defines a period of N minutes inactivity between the start of the program and the first log being taken. During this time, no readings are taken even if background logging is enabled. There are no flags to turn this feature off - to start immediately simply write a value of zero to this register.

3.3.3 LogInterval register

The log interval register defines the period between consecutive logs. This timing is used both for normal program operation as well as for background logging. The period is in minutes. A value of zero represents 256 minutes.

3.3.4 NumberOfLogsToTake register

This register is self-explanatory, however it's important to note that it's a 16-bit register and there's only memory space for 1868 logs. Writing a value of zero to this register has the same effect as writing 1 to it.

3.3.5 Celsius / Fahrenheit

The logger has the ability to record and display temperature in either Celsius or Fahrenheit. The logger does not convert one to the other. If Celsius is selected (the Celsius bit in LogStatus is set) then a Celsius calibrated look up table must also be present in EEPROM. If Fahrenheit is selected (the Celsius bit cleared) then a Fahrenheit calibrated look up table must be present in EEPROM. Only one table can reside in memory at once so changing from Celsius to Fahrenheit or vice versa involves uploading the corresponding table overwriting the existing one.

The recorded values are scaled differently.

The recorded value in Celsius mode corresponds to twice the temperature in degrees Celsius plus 88. For example, a value of 113 corresponds to (113 - 88) / 2 = 12.5°C.

The recorded value in Fahrenheit mode corresponds to the temperature in degrees Fahrenheit plus 48. For example, a value of 113 corresponds to 113 - 48 = 65°F.

Note that 65°F ≠ 12.5°C.

This has been done to simplify the code involved and results in different sized look up tables. The Celsius table has five more words in it than the Fahrenheit table, so if Fahrenheit is used then there are 10 spare EEPROM locations from 00AA to 00B3 inclusive.

An explanation of how a measure of temperature is derived from the A/D conversion and the look up tables can be found in Appendix C.

4.0 Alarms and Statistics

Alarms are visually indicated by the HIGH ALARM 1 and/or LOW ALARM 1 sections of the LCD.

The alarms are controlled by the flags in the lower nibble of the AlarmControl register as well as the AlarmDelays register. The alarm status can be read by the PC or chartreader by examining the upper nibble of the AlarmControl register and Upper and Lower alarms counts registers.

The firmware does not initialise any of these flags or registers when the program is started so initialisation must be performed by the PC or chartreader.

4.1 AlarmControl register

Bit	Name	Description
7	PreviousLogUnder	Internal flag - used to determine if consecutive errors have occurred
6	PreviousLogOver	Internal flag - used to determine if consecutive errors have occurred
5	NotLowAlarmOn	Active low - Indicates the low alarm has been triggered
4	NotHighAlarmOn	Active low - Indicates the high alarm has been triggered
3	ConsecutiveDisable	Active low - Clearing this flag enables consecutive alarm triggering
2	Non-consecutiveDisable	Active low - Clearing this flag enables non-consecutive alarm triggering
1	LowerAlarmEnable	Active high - Enables testing for under range conditions
0	UpperAlarmEnable	Active high - Enables testing for over range conditions

4.2 AlarmDelays register

Bit	Name	Description
4-7	ConsecutiveDelay	Indicates one less than the number of consecutive out of range conditions that must have occurred before an alarm is tripped - must be non-zero.
0-3	Non-consecutiveDelay	Indicates the total number of out of range conditions that must have occurred before an alarm is tripped - must be non zero.

The UpperAlarmCounts and LowerAlarmCounts registers are the same format as the AlarmDelays register and record the number of consecutive and non-consecutive out of range conditions that have occurred for the respective alarm. The alarm is turned on when a nibble in one of these registers becomes equal to the corresponding nibble in the AlarmDelays register.

4.3 Upper and Lower alarm levels

The UpperAlarmLevel and LowerAlarmLevel registers hold the values that define the valid temperature range. These levels are specified in either degrees Fahrenheit + 48, i.e. the value 50 corresponds to 2°F OR in twice the degrees Celsius + 88, i.e. the value 50 corresponds to -19°C. The levels indicate the maximum and minimum safe levels - the measured value must fall outside this range to trigger the alarm.

4.4 TimeOverTemperature / TimeUnderTemperature

The time spent over and under temperature is counted and displayed on the LCD. The display resolution only goes down to tens of minutes but the units of minutes are recorded to maintain accuracy. The format is shown in the EEPROM memory map. These registers are not initialised by the firmware so must be by the PC or chartreader.

These values do not include logs taken during background logging, but do include the time spent outside the valid range prior to the relevant alarm being tripped. These registers are only incremented if the associated alarms are enabled.

If the very first log is out of range, it is not included in the time count. This is because if a log is out of range then it is assumed that the temperature was out of range for the entire log interval preceding that log, and this assumption cannot be made for the very first log. The NotFirstLog flag is used to determine this and should never be cleared by PC or chartreader. Setting this flag cannot cause a problem.

4.5 Statistics

The logger displays the Highest log, Lowest log and Average log on the LCD. These values do not include logs taken during background logging. They are not initialised when the program is started so the PC or chartreader must do this. The initial value for the Average log can start at anything but a value of 0°F (48) or 0°C (88) is recommended.

The highest and lowest logs are only updated if a higher or lower reading is taken. The Highest log must therefore be initialised to -40°F or -40°C, and the lowest log must be initialised to +158°F or +70°C. Note that for Fahrenheit -40°F -> 8 & +158°F -> 206, and for Celsius -40°C -> 8 & 70°C -> 228.

The Average Log is calculated by dividing the SumOfAllLogs by the NumberOfLogsTaken, and all three of these registers are updated each time a reading is taken (outside of background logging mode). It is therefore necessary for the PC or chartreader to also initialise the SumOfAllLogs to 0. Note that the NumberOfLogsTaken *is* initialised when the program is started to avoid the possibility of a divide by zero error.

5.0 User options

The firmware is oblivious to all the features described in this section. Space has been reserved in EEPROM which the firmware avoids, leaving all functionality to be controlled by the PC or chartreader.

5.1 Lease option

The UDATA area is defined with a lease control byte that allows the logger to support a lease situation where the logger is to be leased to a user for up to 127 trips. After the number of lease trips have been performed, reprogramming is not possible until either the lease option is disabled or more trips are enabled.

Note that the LCD Mini controls the lease option slightly differently to other Escort products.

Set up of the lease option is performed by a separate piece of software.

The lease byte is comprised of a 7-bit cycle count value and a single enable bit. When a logger is set up for lease, the cycle count value is loaded with the number of trips (typically 1) of the lease.

During programming the PC or chartreader reads the Lease control byte and if enabled compares the cycle count to 0. If equal then reprogramming is blocked. If non-zero the cycle count is decremented by 1. The PC or chartreader must only decrement the cycle count if the LogStatus register indicates that the previous program has been started at some stage.

5.2 Security code

Two bytes are reserved for a security code. The intended format is for a four-digit BCD number.

The items which the password protects are defined by the User Flags as shown in Appendix A.1.

5.3 Trip Count

The logger reserves memory for a Trip counter. This is not updated by firmware so the PC must increase this numbber when a new program is loaded and the previous program had been started.

6.0 LCD operation

6.1 Basic functionality

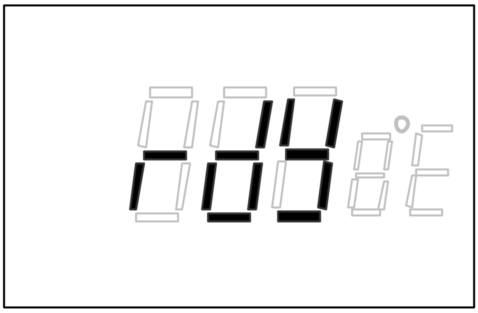
The LCD Mini has three states of display, namely Main, Statistics and Alarms. The single momentary action push button will cycle through the three states, switching to the next state each time it is pressed. If the button is pressed and held down for more than one second it will start the logger and will not cycle the display. Once started the logger will not be able to be stopped by the press of the button.

If one minute elapses without the button being pressed then the logger will automatically revert to the Main state.

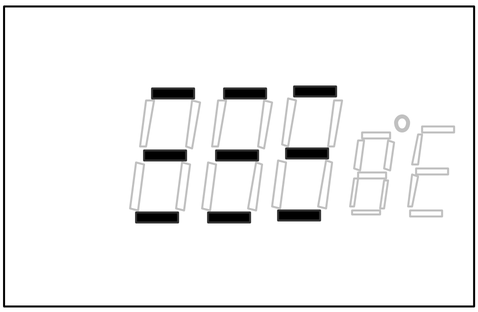
6.2 Main state

The Main display state shows which step in the program the logger is up to (including the latest measurement if the logger is currently logging), as well as 'HIGH ALARM 1' if an over temperature alarm has been triggered, and 'LOW ALARM 1' for the under temperature alarm.

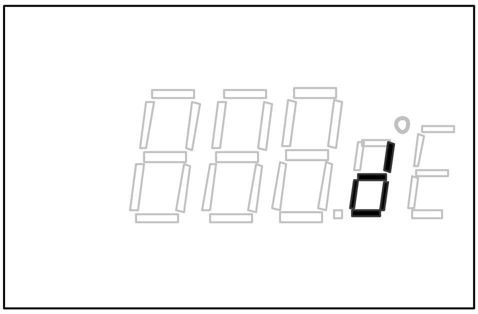
When the logger has a program loaded and is ready to start the following is displayed.



When the logger latches the start command (push button pressed and held for more than one second) the following pattern is displayed for more than 1 second and less than 2, then the logger will either begin logging if the DelayedStart register is set to 0 or enter the delayed start mode if not.

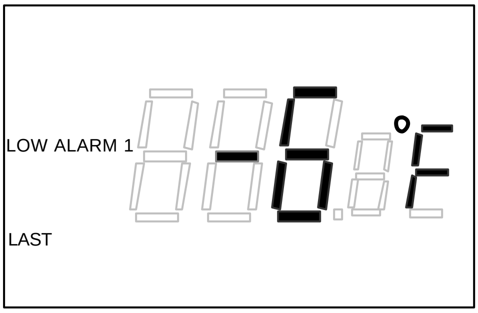


When the logger has been activated and is in the delayed start mode the following pattern is displayed.

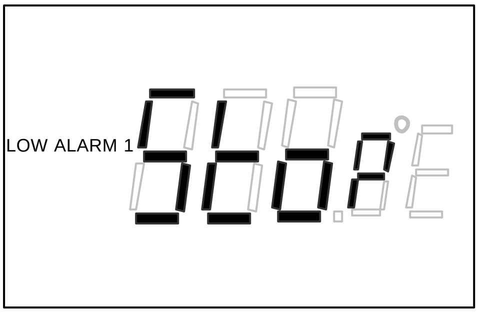


When the logger is in its active logging mode the latest temperature reading is displayed as shown. 'High Alarm 1' and/or 'LOW ALARM 1' will be displayed if the respective alarm is triggered. A low alarm condition has been shown.

When in this mode the word 'LAST' will flash at a one-second rate to indicate activity.



When the logger has finished its program and has stopped logging the following pattern is displayed. If an alarm condition occurred and was latched during logging, it will continue to be displayed. A low alarm condition has been shown.

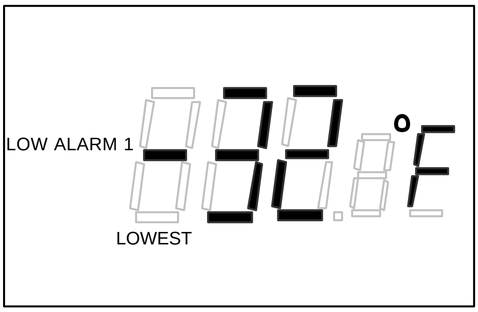


6.3 Statistics State

The statistics display state shows the highest temperature recorded, the lowest temperature recorded and the average temperature over the entire journey. The display will continuously cycle through the three pieces of information, displaying them for two seconds each. The lowest reading has been shown.

Readings taken during background logging, if enabled, are not included in the statistics.

The user is not inhibited from cycling through the three display states prior to activating the program. In this case, the initialised values of 0 °F for average temperature, -40 °F for highest temperature and 158 °F for lowest temperature will be displayed.



6.4 Alarms State

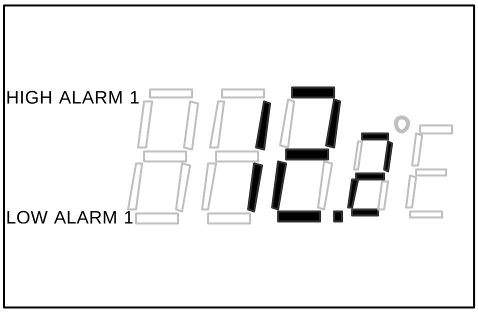
The alarm display state shows the total time that the logger has spent at temperatures above the high alarm level and below the low alarm level. This includes the time prior to either alarm being tripped. The display will continuously cycle through the two pieces of information, displaying them for two seconds each. When the time spent over temperature is displayed the words 'HIGH ALARM 1' are shown, and the words 'LOW ALARM 1' are shown when the under temperature time is displayed.

The time is displayed in hours with the fractional digit representing 10-minute intervals; e.g. the following example shows 12 hours and 20 minutes. The time is always rounded down so this example indicates a time between 12:20 and 12:29 inclusive.

If the high alarm is not enabled then the time spent over temperature remains unchanging at 000.0. The same applies for the low alarm.

The longest time that can be displayed is 999.5 hours or 41? days. Times longer than this are displayed unchanging as 999.5.

This will be moved and changed to say "HOURS"



Appendix A

A.1 EEPROM Memory Map.

Location	Size	Name	Description / Format
0 ($00)	16	Description text	Owner or Cargo Description.
16 ($10)	1	LogInterval	Log interval in minutes (1-255, 0=256)
17 ($11)	1	UpperAlarmLevel	Byte value of upper specification alarm trigger
18 ($12)	1	LowerAlarmLevel	Byte value of lower specification alarm trigger
19 ($13)	1	CaseType	Lower nibble only used 0 = DataSource 1 = Mini
20 ($14)	3	StartLogTime	Time that the first log was taken (3 bytes of minutes count - MSB @ $16)
23 ($17)	2	NumberOfLogsToTake	Word indicating the number of logs to take - does not include background logging
25 ($19)	2	NumberOfLogsTaken	The number of logs taken so far (not including background logs)
27 ($1B)	1	LogStatus	bit 7 - Celsius (1 = °C, 0 = °F) bit 6 - Wrapped (1 = memory has wrapped) bit 5 - LogStartType (1 = button, 0 = PC/CR) bit 4 - ReadDelay (internal flag) bit 3 - NotStopped (0 = stopped) bit 2 - NotCurrentlyLogging (0 = actively logging) bit 1 - ProgramRunning (1 = logging or delay) bit 0 - NotBackgroundLogging (0 = BGL)
28 ($1C)	2	CurrentLogAddress	The address in EEPROM where the next log to be taken should be stored
30 ($1E)	2	FirstLogAddress	The address in EEPROM where the first log was stored (not including background logs)
32 ($20)	1	AlarmControl	bit 7 - NotPreviousLogUnder (internal flag) bit 6 - NotPreviousLogOver (internal flag) bit 5 - NotLowAlarmOn (0 = low alarm triggered) bit 4 - NotHighAlarmOn (0 = high alarm triggered) bit 3 - ConsecDisable (0 = enabled) bit 2 - Non-consecDisable (0 = enabled) bit 1 - LowerAlarmEnable (1 = enabled) bit 0 - UpperAlarmEnable (1 = enabled)
33 ($21)	1	AlarmDelays	Nibble orientated register for Number of logs in alarm before alarm generation. Upper Nibble Non-consecutive alarm delay (1-15) Lower Nibble: Consecutive alarm delay (1-15)
34 ($22)	1	UpperAlarmCounts	Nibble orientated register to record the number of logs so far for upper alarm generation. Upper nibble Non-consecutive alarm count (0~15) Lower nibble: Consecutive alarm count (0~15)
35 ($23)	1	LowerAlarmCounts	Same as upper alarm counts but for the lower alarm.
36 ($24)	3	TimeOverTemperature	Sum of the time spent above the upper alarm level. BCD-ish format. $24 - minutes units (0 - 9) $25 lower nibble - minutes tens (0 - 5) $25 upper nibble - hours units (0 - 9) $26 lower nibble - hours tens (0 - 9, "A" = blank) $26 upper nibble - hours hundreds (0 - 9, "A" = blank))

39 ($27)	3	TimeUnderTemperature	Sum of the time spent under temperature - format as per time over temperature.
42 ($2A)	1	HighestLog	The highest log recorded so far (not including background logs)
43 ($2B)	1	LowestLog	The lowest log so far (not including BGL)
44 ($2C)	1	AverageLog	The average of all the logs taken so far (not including BGL)
45 ($2D)	3	SumOfAllLogs	The binary sum of all the logs taken so far (not including BGL) - used in the average calculation
48 ($30)	1	StartDelay	Start up delay for log start after button pressed. 0 = no start delay. 1-255 = delay in minutes.
49 ($31)	1	UserFlags	bit 7 - 1 = Description is protected (not editable) bit 6 - Data protected by PIN bit 5 - Program protected by PIN bit 4 - 1 = Sensor is "external" bits 0-3 - UDATA version = 0
50 ($32)	1	LeaseControl	bits 0-6 - 7 bit cycle count value bit 7 - 1 = Lease logger, 0 = not lease.
51 ($33)	1	TimeZone	bit 7 - 1 = Enabled bit 6 - Daylight saving in sender time zone bits 0-5 - Signed number of 30min intervals from GMT for sender
52 ($34)	4	SerialNumber	Format: DL-YY-DDD-III Of the 32 bits with MSB at $37; Bit 31 = 0 for DataSource (DL), 1 for Mini (MI) Bits 24 to 30 = year code (00 - 99) Bits 12 to 23 = day of year (1 - 366) Bits 0 to 11 = index (0 - 999) All fields are binary (not BCD). Year portion of serial number is displayed in user software as 'AI' for 98,AJ for 99,BA for 00, BB for 01, CA for 10 etc.
56 ($38)	2	SecurityCode	Four-digit BCD number to protect against unauthorised access.
58 ($3A)	1	SUM_INC	Summary Increment, unsigned value
59 ($3B)	1	BattTypeAndRF	Lower nibble frequency, 0=non-RF, 1=916, 2=868, 3=433MHz Bit 7 battery type: 0=coin, 1=½AA
60 ($3C)	1	Battery usage counter (LSB)	0=new battery (Only for Intelligent Min)
61 ($3D)	1	For Intelligent Mini: Battery usage counter (MSB)	
		For Wireless Mini: PIC firmware version	0x17 = version 1.7 etc.
62 ($3E)	2	TripCount	Trip counter - incremented by software
64 ($40)	116	Look up table	Used in ADC conversion to linearise thermistor and convert its resistance to temperature (See appendix C for specific values)
180($B4)	1868	Log buffer start	The recorded data

NOTE: All multi-byte quantities are orientated with the MSB at the highest address.
NOTE: Shading in cells means that these locations are read into RAM by clearing the "NotSemiInit" flag. (StartDelay $48 is also copied if bit 4 ReadDelay in LogStatus is set.)

A.2 RAM Memory Map

Note size and location refer to nibbles not bytes.

Location	Size	Name	Description / Format
$80	12	Temp0 - Temp11	Temporary working registers.
$8C	2	C400kHz	Two nibbles used to calibrate the 2400-baud comms timing.
$8E	2	DelayedStartCounter	Counter used to count down the number of minutes until the next log.
$90	2	SecondsCounter0	Seconds counter for RTC - rolls over to zero after counting to 59.
$92	2	SecondsCounter1	Additional seconds counter to synchronise logging with the press of the button.
$94	6	TimeNow	3 byte sum of minutes for RTC.
$9A	2	Log interval	RAM image of what's stored in EEPROM.
$9C	2	UpperAlarmLevel	RAM image of what's stored in EEPROM.
$9D	2	LowerAlarmLevel	RAM image of what's stored in EEPROM.
$A0	2	AlarmControl	RAM image of what's stored in EEPROM.
$A2	2	LogStatus	RAM image of what's stored in EEPROM.
$A4	1	ActionFlags0	bit 3 - BeginProgram bit 2 - NotSemiInit bit 1 - NotIncomingComms bit 0 - NotTakeALog
$A5	1	ActionFlags1	bit 3 - BatteryStatus (not an action, 1 = OK) bit 2 - NotFirstLog (internal, never clear this) bit 1 - spare bit 0 - NotCheckBattery
$A6	2	LatestLog	The latest log reading.
$A8	1	DisplayFlags0	Display mode - 0 = Main, 1 = Stats, 2 = Alarms
$A9	1	DisplayFlags1	Display cycling bit 3 - spare bit 2 - 1 = upper alarm, 0 = lower alarm bit 0,1 - 0 = Avg, 1 = Highest, 2 = Lowest
$AA	1	DisplayFlags2	bit 3 - DisplayDataNotValid bit 2 - NotUpdateDisplay bit 1 - Positive (± for displaying numbers) bit 0 - Flash (the 'LAST' word)
$AB	1	Counter	General purpose counter
$AC	2	FirmwareVersion	Upper nibble - f/w revision Lower nibble - f/w sub-revision
$AE	2	ButtonAndDisplayTimer	Controls automatic cycling of the display as well as timing how long the button is pressed for.
$B0	32	ByteStore0.0 - 16.1	RAM area where comms packets are assembled as well as I^2C transfers and a few other things.
$D0	48	stack	Do *NOT* write to here.
$FF		end of RAM	

NOTE: All multi-nibble quantities are orientated with the most significant nibble at the highest address.

Appendix B - ADC operation

The analogue to digital conversion is performed internal to the microcontroller by an oscillation process. The basic procedure is

- A precision reference resistor and a capacitor are switched into the feedback path of a digital oscillator.

- The oscillator is set running with the resistor and capacitor establishing the frequency.

- A defined number of cycles of this frequency (in this case 3000 cycles) sets a gate time during which cycles of the 32768Hz clock are counted.

- The precision resistor is then switched out of the circuit and the thermistor is switched in.

- The cycle count from the first measurement is then used to set the gate time for a second measurement. This time the gate time is based on the 32768Hz clock.

- The number of cycles of the ADC oscillator is now counted over this time and this count is inversely proportional to the resistance of the thermistor.

The maths of this are shown below:

$$\text{FirstGateTime} = (R_{Ref} \times C \times 2.2) \times 3000$$

$$\text{Counter A} = 32768 \times \text{FirstGateTime}$$

$$\text{SecondGateTime} = 1/32768 \times \text{CounterA}$$

$$\text{Counter B} = \text{SecondGateTime} / (R_{Therm} \times C \times 2.2)$$

$$= 1/32768 \times \text{CounterA} / (R_{Therm} \times C \times 2.2)$$

$$= 1/32768 \times 32768 \times \text{FirstGateTime} / (R_{Therm} \times C \times 2.2)$$

$$= 1/32768 \times 32768 \times (R_{Ref} \times C \times 2.2) \times 3000 / (R_{Therm} \times C \times 2.2)$$

$$= (R_{Ref} \times C \times 2.2) \times 3000 / (R_{Therm} \times C \times 2.2)$$

$$= (R_{Ref} \times 3000) / R_{Therm}$$

$$R_{Therm} = (3000 / \text{Counter B}) \times R_{Ref}$$

Note: The "2.2" is just a constant relating to the mechanics of the oscillator - it gets divided out.
C = 1000pF.

The resistance of the thermistor ranges from 2kΩ at 70°C to 335kΩ at -40°C so in practice in order to maintain accuracy over the whole range two conversions are sometimes taken. An initial gate time of 3000 cycles is used and if the final count comes out less than 4096 then the conversion is done a second time using an initial gate time of 12000 (4 x 3000).

At no stage is R_{Therm} actually calculated. Instead, a look up table is used to convert the final count straight to temperature. The index to the LUT is the temperature in degrees Fahrenheit (or

Celsius) and the table holds word values corresponding to the expected final count. Just to complicate things (and reduce the size of the table) every fourth degree F (or every second degree C) is stored and temperatures in between are linearly interpolated. For example, the word stored at LUT index 1 is 430 corresponding to -40°F, and the word stored at LUT index 2 is 495 corresponding to -36°F. A final count of 440 is therefore found to correspond to -39°F.

The equation given by OKI for calculating the resistance of the thermistor as measured by their internal ADC circuit is approximate and although highly accurate mid range, is as much as 7% out at the extremes of the range. Due to this (and also heavily implied by their documentation) the translation from the ADC count number to an actual temperature reading has been worked out empirically.

The look up table has been stored in EEPROM and can be reloaded at any stage. It appears, based on just the few sample devices tried so far, that only one standard LUT for Fahrenheit and one for Celsius will be needed, however if production spread is larger than expected then each logger can be individually calibrated. This can be achieved by a 10 second automated process in which perhaps three precision resistance values are measured and a table is chosen from a suite of pre-calculated tables based on the readings obtained. Down load time for the table as well as other initialisation data is around 3 seconds.

There is a spare byte in EEPROM that can be used to record which table is required if a user wishes to change between the units on the fly.

At the completion of an A/D conversion the RAM locations Temp8, Temp9, Temp10 & Temp11 hold the raw count. An immediate conversion can be triggered by loading the DelayedStartCounter with 0 and the SecondsCounter1 with 59 while ensuring the logger is in its active logging mode.

A.3 ADC Look-up tables

Address	°C count	°C	°F count	°F
0040	0000	< -40	0000	< -40
0042	01AE	-40	01AE	-40
0044	01E9	-38	01EF	-36
0046	0229	-36	0238	-32
0048	0271	-34	0289	-28
004A	02C0	-32	02E5	-24
004C	0319	-30	034D	-20
004E	037B	-28	03BF	-16
0050	03E6	-26	0440	-12
0052	045D	-24	04D1	-8
0054	04E2	-22	0575	-4
0056	0575	-20	062A	0
0058	0618	-18	06F5	4
005A	06CD	-16	07D4	8
005C	0791	-14	08D1	12
005E	086C	-12	09EA	16
0060	095D	-10	0B1A	20
0062	0A64	-8	0C6B	24
0064	0B7F	-6	0DEB	28
0066	0CB8	-4	0FA2	32
0068	0E17	-2	10D8	36
006A	0FA2	0	12B9	40
006C	10B9	2	14C6	44
006E	1259	4	1711	48
0070	1429	6	1984	52
0072	1626	8	1C36	56
0074	184B	10	1F27	60
0076	1A98	12	2265	64
0078	1D18	14	25ED	68
007A	1FCD	16	29BB	72
007C	22C0	18	2DE3	76
007E	25ED	20	3242	80
0080	295A	22	36EE	84
0082	2D0E	24	3C00	88
0084	30F2	26	416F	92
0086	3510	28	4750	96
0088	3977	30	4D92	100
008A	3E2C	32	5475	104
008C	4332	34	5B9A	108
008E	4890	36	6339	112
0090	4E42	38	6B5E	116
0092	5475	40	7400	120
0094	5AE3	42	7D35	124
0096	61B3	44	8707	128
0098	68EC	46	9152	132
009A	708C	48	9C5F	136
009C	789A	50	A7BE	140
009E	8123	52	B3FB	144
00A0	8A1E	54	C0A6	148
00A2	9388	56	CE54	152
00A4	9D82	58	DC8F	156
00A6	A7BE	60	EB53	160
00A8	B2C2	62	FFFF	> 160
00AA	BE1D	64	FFFF	
00AC	CA3A	66	FFFF	
00AE	D6DE	68	FFFF	
00B0	E3F1	70	FFFF	
00B2	FFFF	> 70	FFFF	

Values are in hexadecimal. MSB is at higher address.

Appendix C - Firmware revision history

F/W Ver	sub ver	Release Date	Products Supported	Primary Revision Purpose	Hex File name	Hex Chksum	µP	PCB revisions				
								1				
1	1	2002	all	Initial			'162A	•				

TBR = yet to be released   M = Can be used with modified PCB