CAVEAT EMPTOR

The PMEL MTR (Miniature Temperature Recorder) was developed at NOAA's Pacific Marine Environmental Laboratory to fulfill the needs of various in-house research programs. The capability to measure temperature in the deep ocean for year-long periods at low cost did not exist commercially. The cost factor was critical and resulted in a unit that is void of features normally found on modern oceanographic instruments. However, it is cheap—and it works! Good Luck.

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MTR SUMMARY SPECIFICATIONS

Temperature sensor	
Accuracy:	±0.02°C/6 months
Range:	–2 to +34°C
Resolution:	0.0013 @ 0°C
	0.0007 @ 15°C
	0.0004 @ 30°C
Clock	
Initial Accuracy:	±5 min/yr
Temperature effect:	–.035 ppm/°C^2
Aging:	5 min first year, max
Sampling Interval	
Minimum:	1 second
Maximum	18 hours
Increment:	1 second
Data Capacity	
118.5 kBytes usable RAM	
56,880 temperature samples	
Power/Life	
Battery	
main:	2 AA lithium
back-up:	20 mm coin cell
Quiescent:	35 μA
Sampling:	20 mA for 200 msecs/sample
Back-up mode:	6 μA
Physical Parameters	
Material:	6 Al-4V Titanium
Depth rating:	15,000 meters
Diameter:	2.0 in (5.1 cm)
Length:	5.4 in (13.7 cm)
Weight in air:	1.41 lbs (640 gm)
Weight in water:	0.78 lbs (358 gm)
Thermal time constant:	4 min

OVERVIEW

The MTR measures temperature with a YSI 46006 thermistor and a voltage-to-frequency converter. The system timing and sampling is controlled with a Motorola 68HC11 microprocessor. Current date and time, starting date and time, and sample interval must be entered to configure the unit, and it must be calibrated to relate counts to temperature. The data, as raw counts, is stored along with system software in battery backed up RAM.

1. PREPARING FOR DEPLOYMENT

In order to prepare an MTR for deployment, the following steps should be followed:

1.1. REMOVING FROM THE PRESSURE CASE

To remove the MTR from its pressure case, pull on the string until the velcro disengages, and the instrument slides out of the case. Be careful not to allow the electronic components to come in contact with the pressure case.

1.2. CHANGING THE BATTERY

1.2.1. *General Precautions*

When the electronics is completely out of the pressure case, be aware that grasping the board tightly near the clock oscillator components, (X1, C6 area) can cause the clock oscillator to stop until the board is released. This causes the clock to lose an amount of time equal to the period that the oscillator is stopped. This is nothing to be alarmed about, as the date and time should be reinitialized before deployment anyway. However, prudent practice dictates that all configuration for deployment be done after the battery changing is done, the clock accuracy is checked (if required), and the electronics is back in the pressure case. Also, it is wise to avoid touching the electronics as much as possible when changing batteries, by using the end pieces for holding on to the electronics. Black tape in the area of the oscillator components will not cause a problem.

When removing or installing the coin cell be careful not to bend the spring so much that it does not grip the new battery tightly.

1.2.2. *Battery*

The battery is made from two Electrochem CSC93 lithium AA cells connected in series. The voltage must be greater than 6 volts. A piece of artboard should be placed between the battery and the pc board for insulation, and a wrap of electrical tape holds the battery to the board. The onboard RAM backup battery (20 mm coin cell type) retains the memory in the event of the main battery being discharged or disconnected, and should be replaced every 2 years. The backup battery DOES NOT retain the correct time in the clock.

CAUTION: The MTR software is stored in the battery-backed-up RAM. Removing both the system power and the backup battery at the same time will cause loss of the program.

1.3. MONITORING THE CLOCK OSCILLATOR

Now is the time to monitor the clock oscillator, if clock errors must be backed out of the time record. Refer to section 4. Be careful of the electronics while it is out of the pressure case.

1.4. INSTALLING INTO THE PRESSURE CASE

Before the MTR is installed into the pressure case, apply an amount of thermally conductive compound on the thermistor, sufficient to make thermal contact between it and the pressure case. Insert the electronics into the case until the velcro can be felt to engage, being careful not to allow the components to contact the pressure case.

1.5. MTR SERIAL INTERFACE (MSI)

The MSI is used between the MTR and a terminal or computer. It supplies power to the MTR when it is connected to save batteries, and converts voltage levels to allow RS232 communications. The reset button is used to wake up the MTR. The MSI is powered by an internal 9VDC battery or a wall plug-in power transformer. It draws power only when it is connected to an MTR. There is no on/off switch for confusion.

1.6. ENTERING CONFIGURATION DATA

The MTR must be configured by the user prior to deployment. For this purpose it uses an MTR SERIAL INTERFACE to talk to a terminal. The terminal settings should be 9600 baud, 8 data bits, 1 stop bit, no parity, and CAPS LOCK must be ON. In the following discussion of MTR commands the command to be entered will be enclosed in [ ] brackets. The brackets are not to be entered as part of the command, but rather are merely a way of delineating the command from the rest of the text. All spaces and periods shown in the [ ] brackets must be entered as shown. Leading zeroes on numerical values may be omitted. It is assumed that all commands will be followed by depressing the ENTER key unless specifically stated otherwise. BE CAREFUL!! As currently realized, the MTR does NOT make any checks as to the validity of any configuration data. It relies on the user to enter correct data.

1.6.1. [CONFIG=]

This command shows the format of the other commands used to configure the MTR.

1.6.2. [DATE= space mm dd yy] current?

This command is used to enter the date: ?
mm is the month from 1 to 12;
dd is the date;
yy is the last 2 digits of the year.

1.6.3. [TIME= space hh mm ss]

This command is used to enter the time:
hh is the current hour;
mm is the current minute;
ss is the second at which the ENTER key will be depressed.

1.6.4. [SD= mm dd yy]

This command tells the MTR the date to start logging data:
mm is the start month;
dd is the start date;
yy is the start year.

1.6.5. [ST= hh mm ss]

This command tells the time at which logging will start:
hh is the start hour;
mm is the start minute;
ss is the start second.

1.6.6. [SAMPLE= hh mm ss]

This command tells the MTR how long to wait between samples in hours minutes, seconds. Any value from 00 00 01 (1 second) to 18 00 00 (eighteen hours) in 1-second increments is acceptable as a sample interval.

1.7. VERIFYING CONFIGURATION DATA

There are several commands which can be used to verify the configuration of the MTR.

1.7.1. [CONFIG]

This command shows the current configuration data of the MTR. If any of the data is incorrect it should be reentered using the appropriate command, and rechecked using the [CONFIG] command.

1.7.2. [STATUS]

This command gives the same information as the CONFIG command. In addition, it gives the unit's serial number, the software version number, the number of data records currently in memory, and the number of samples in the last record.

1.7.3. [DATE]

Shows the current date.

1.7.4. [TIME]

Shows the current date and time.

START

1.7.5. [SD]

Shows the date on which logging will start.

1.7.6. [ST]

Shows the time at which logging will start.

1.7.7. [SAMPLE]

Shows the current sample interval.

1.8. ENTERING DATA LOGGING MODE

There are two data logging commands, LOG and GO.LOG. Either command will ask if you want to lose the data currently in the RAM buffer. Since the MTR starts logging at the beginning of the RAM buffer, and destroys the previous data, be sure a copy of the old data exists before continuing with data logging. Only a response of Y will cause logging to begin, with the consequent loss of previously acquired data.

1.8.1. [LOG]

This command waits until the start date and time, as given by the *[SD]* and *[ST]* commands, before commencing data logging.

1.8.2. [GO.LOG]

This command automatically sets the start date and time to be 5 seconds from the current time and then continues the same as the *[LOG]* command. *[GO.LOG]* is envisioned primarily for bench testing, and/or calibration procedures, but can be used for field deployments, if desired.

1.9. DETERMINING SAMPLE INTERVAL

For a given sample interval, the number of hours of data that can be gathered (for simplicity, called here the logging period) will be limited by either battery life or data storage capacity. Thus,

$$T_{BL} = \frac{1}{35\times10^{-6} + (1.1\times10^{-6})(SAMPLES/HR)}$$

$$T_{DC} = \frac{56,800}{SAMPLES/HR}$$

where T_{BL} is the hours of battery life available;
and T_{DC} is the hours of data capacity available.

The smaller of T_{BL} and T_{DC} is the number of hours of data that can be logged at the given sample interval. The following table shows some examples of the relationship between sample interval, battery life, and data capacity.

Sample interval	Battery Life	Data Capacity
00 00 01	250 hours	15.8 hours
00 01 00	412.5 days	39.5 days
00 10 00	1001.6 days	395 days
01 00 00	1138 days	2370 days

1.10. SEALING THE PRESSURE CASE

Before the pressure case is sealed, purging with a dry gas or insertion of a desiccant is recommended. The o-ring and its seating surfaces should be thoroughly cleaned and lightly lubricated with a suitable o-ring grease. Screw the pressure case endcap on until it is securely seated.

1.11. DEPLOYMENT

The instrument can be secured with clamps, tape, bailing wire, or bubble gum to whatever the user chooses. Be careful not to have any other metal in contact with the case, as most metals are sacrificial to the titanium. For instance, if stainless hose clamps are used, insulate them from the case with heat shrink tubing or electrical tape.

2. POST-RECOVERY PROCEDURES

2.1. FRESH WATER RINSE

The MTR should be rinsed thoroughly with fresh water, and dried around the cap before opening. Allowing the unit to come to ambient temperature before opening will prevent condensation from forming on the board.

2.2. OPENING THE CASE

If water leaked into the pressure case during deployment, or if the lithium battery decided to make a mess, potentially dangerous pressure could be built up inside. No need to worry, as the case can hold the pressure, and as soon as the cap is opened enough to unseat the o-ring, the pressure will be discharged through the safety groove in the cap threads.

2.3. RECOVERING THE DATA

The data can be recovered using the MTR SERIAL INTERFACE to connect the MTR to a terminal. The settings are 9600 baud, 8 data bits, 1 stop bit, no parity, and CAPS LOCK must be on. The MTR will recognize XON-XOFF protocol, so be sure that your computer is set accordingly. Depress the reset switch, and respond with Y to the question about going to CONFIG mode. Put the system being used as a terminal into capture mode so that the data is being saved to a disk file at the same time it appears on the screen.

2.3.1. *[READ DATA]*

This command will read all data stored in the RAM since the last time that the RAM was initialized. The MTR will proceed to dump the data at 9600 baud, and will continue until either all data has been dumped, or until the reset button is depressed. If all 128K bytes are filled, then this process should take approximately 10 minutes. Data reading occurs in a non-destructive manner, allowing as many tries as necessary.

2.4. EXAMINING THE DATA

If it seems necessary to inspect the data before dumping it all to a disk, such as when testing or calibrating, use the following commands which allow non-destructive inspection of the data in RAM.

2.4.1. *[REWIND]*

This command moves the data pointer to the start of the data buffer.

2.4.2. *[READ n RECORDS]*

This command displays n records, starting at the data pointer. When finished, the data pointer will point to the start of the $(n+1)$th record.

2.4.3. *[SKIP n RECORDS]*

This command skips n records, starting at the data pointer.

2.4.4.

The preceding commands can be combined to make commands such as [REWIND SKIP 210 RECORDS READ 10 RECORDS].

2.5. DATA RECORD FORMAT

Data records are a fixed size of 250 bytes, allocated as follows:
6 bytes for date and time;
2 bytes for Vishay data;
240 bytes for temperature data (120 samples);
2 bytes for checksum.

The data is printed out in the following format:

```
mmddyyhhmmssvvvv
111122223333444455556666777788889999aaaabbbbcccc
(9 more rows like row 2)
ckck
```

where each character represents a hex digit, and
mm is the month in binary coded decimal (BCD);
dd is the date in BCD;
yy is the year in BCD;
hh is the hour in BCD;
mm is the minute in BCD;
ss is the second in BCD;
vvvv is the Vishay sample in hexadecimal;
1111 is the first temperature sample, made at the date/time given at the start of the record. The data is in hex;
2222 is the second temperature sample made 1 sample period after sample 1. The data is in hex;
etc. for all 120 temperature samples;
ckck is the checksum, consisting of the least significant 4 hex digits of the sum of the rest of the data record, summed as 16 bit words. The checksum value is in hex.

3. CALIBRATION

3.1. CALIBRATION EQUATIONS

The following equations are given under the assumption that all values of components, etc. are ideal. Accommodations to the real world are taken care of in the determination of the calibration coefficients.

3.1.1. *MTR EQUATIONS*

The MTR converts thermistor resistance to counts according to:

$$R = (4 \times 10^8) / N.$$

where R is thermistor resistance in ohms, and
N is the decimal value of the data.

This expression for R must then be used in the Steinhart-Hart equation to get T as a function of N.

3.1.2. *THE STEINHART-HART EQUATION*

The Steinhart-Hart equation for T as a function of the resistance R of a negative temperature coefficient thermistor is;

$$T = \frac{1}{a + b\,(\ln R) + c(\ln R)^3} - 273.15$$

where T is the temperature in °C, and
a, b, and c are coefficients derived from the calibration process.

Substituting for R using equation (4), the S-H equation takes the form:

$$T = \frac{1}{a + b\left(\ln\frac{4\times10^8}{N}\right) + c\left(\ln\frac{4\times10^8}{N}\right)^3} - 273.15\ .$$

where N is the decimal value of the data logged by the MTR.

3.2. CALIBRATION PROCEDURE

The MTR must be calibrated in a controlled temperature bath with a minimum of 5 points over the temperature range in question. The T and N pairs from these points are then used in the Steinhart-Hart equation, as described in section 3.1.2. to make M equations in 3 unknowns, where M is the number of calibration points taken, and 3 is the number of coefficients in the S-H equation. These equations are then solved using the least-squares method to arrive at the 3 calibration coefficients for the MTR in question.

3.3. UTILIZING THE VISHAY DATA

The Vishay resistor is 12.0K ohms, and is highly stable over both temperature and time. It is substituted for the thermistor once per data record and a data value for it is logged. Any changes in this data are due to either temperature effects on, or component aging in, the interface portion of the electronics. The Vishay data can be used to remove these changes from the data record. One method would be to convert the Vishay data to a temperature value, using the predeployment calibration. In each record, an amount equal to the change in the Vishay "temperature" would be subtracted (or added, depending on the sign of the change) from the data temperature values.

4. CLOCK CALIBRATIONS

As designed, the MTR clock should be accurate to ±5 minutes per year at 25°C. The effects of being deployed for extended periods at temperatures close to 0°C on the accuracy of the clock may need to be accounted for by the user.

4.1. MEASURING THE CLOCK OSCILLATOR FREQUENCY

4.1.1. [TEST.CLOCK]

This command causes the clock oscillator frequency to be present on TP1, the test point pin near the center of the board. Use pin one on the serial interface connector for ground. Measure the period with an accurate frequency counter to a resolution of .01 nanoseconds using the period average mode on the counter. This should be done both at room temperature and at a temperature within 1 or 2° of the expected deployment temperature. The entire procedure should be performed both before and after deployment in order to check for clock errors due to aging.

4.2. DETERMINING ERROR RATE DUE TO AGING

The error due to aging is:

$$E_A = \frac{E_2 - E_1}{T}$$

where E_A is the aging error in ppm per unit time;
E_1 is the clock frequency error in ppm at room temp before deployment;
E_2 is the clock frequency error in ppm at room temp after deployment;
and T is the time between the two measurements.

4.3. DETERMINING CLOCK ERROR

The clock error at any given time during the deployment period will be:

$$E = (E_{RT})(T_{RT}) + (E_{DT})(T_{DT}) + (E_A)(T_A)^2$$

where E_{RT} is the clock frequency error at room temp in ppm;
T_{RT} is the time the MTR is at room temperature;
E_{DT} is the clock frequency error at deployment temp in ppm;
T_{DT} is the time at deployment temp;
E_A is the frequency error due to aging in ppm per unit time;
T_A is the time since the predeployment measurements were made. All the time values should be in the same units.

5. RELOADING THE PROGRAM

If the program is inadvertently lost, it must be reloaded. The MTR SYSTEM DISK provided should be installed in any Macintosh computer and the MTR SERIAL INTERFACE unit connected to the MTR. Open the disk icon and double click on the MAX DEV SYS 3 icon. Allow the application to load. In MAX DEV SYS 3 pull down the file menu and click on either open or print. When the dialogue box appears, double click on the READ ME file. Follow the directions in this file for reloading the software. This file also contains useful information on auto-loading CONFIG data into the MTRs.

NOTE: Software to allow program reloading on a PC computer using MIRROR is currently being considered.