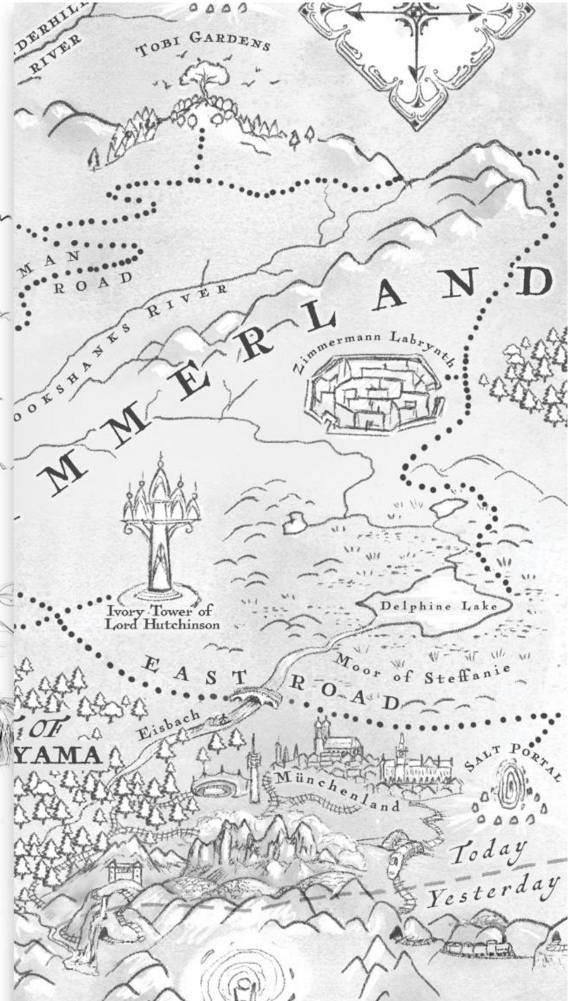

THRECS

Operating Manual

Fathom Scientific Ltd.

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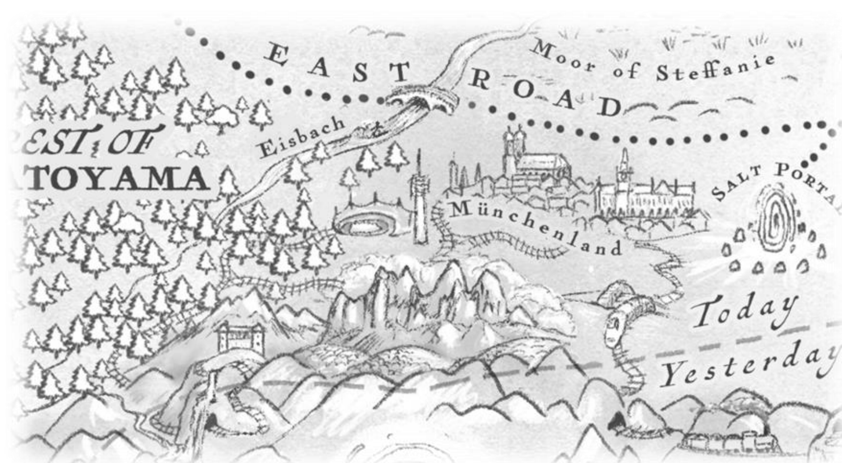
CHAPTER 1

Introduction

In which the Reader *is* Guided
Through the realm to *where the* T-HRECS roam



The T-HRECS can be found hunting in a pack
in the mountains just south of the Eisbach.

1. INTRODUCTION

1.1. SUMMARY

The Temperature – High Resolution Electrical Conductivity Serial (T-HRECS) device is a high resolution (0.001 µS/cm) device for measuring Electrical Conductivity (EC), Temperature (T), and calculating Electrical Conductivity – Temperature Compensated (EC.T). The device accuracy is stated as ±1% over the range 0-2000 µS/cm, provided that the four point calibration is done over the range of interest. There are currently 5 versions of the T-HRECS available:

- RS232*: A Modified RS232 interface with 5V power on pin 9.
- Radio: Xbee Radio device
- SDI-12: Serial Digital Interface-1200 Baud compliant with Version 1.3 of the standard.
- DL: Datalogger unit designed to work autonomously with the AutoSalt system and featuring LoRa radio communication.
- 4to20: 4-20mA output
- MR: MultiRange SDI-12 device featuring high and low ECT ranges (0-2,000, and 2,000-200,000 μS/cm)

Table 1 compares the T-HRECS variants currently available. All devices are:

- Rated at IP67 dust and waterproof. This standard stipulates waterproof in 1m of water up to 30mins.
- Lightning and ElectroStatic Discharge (ESD) protected
- Galvanically Isolated to avoid ground loops

Each T-HRECS is composed of four parts:

1. The probe itself has an inner and outer electrode made of titanium. On older probes, the outer electrode was tightened by hand on a fine-thread base. The inner electrode is fixed and also in contact with an internal high accuracy thermistor
2. The anodize aluminum shroud protects the electrodes from damage while still allowing water to freely flow around the electrodes.
3. The cable is sheathed in nylon to protect, identify, and assist in handling.
4. The device driver is housed in an electronics box. Inside each housing is the driving circuit (including lightning and ESD protection), galvanic isolation, and conversion to the desired output.

Figure 1: The T-HRECS probe

The probe is composed of two parts:1. The electrical conductivity cell has an inner and outer electrode with a k value of 0.1 and 2. The anodized aluminum shroud protects the electrode from damage, allowing water to easily flow around it. Hand tighten the shroud on the probe before each use.

1.2. THEORY OF OPERATION

The T-HRECS is a conductivity and temperature measurement device. Temperature is measured using an NTC thermistor. Conductivity is calculated as $1/\rho$ where ρ is the specific resistivity. The specific resistivity is resistance between two (inner and outer in our case) electrodes and compensated for the distance between them, L and the Area of the surfaces, S.

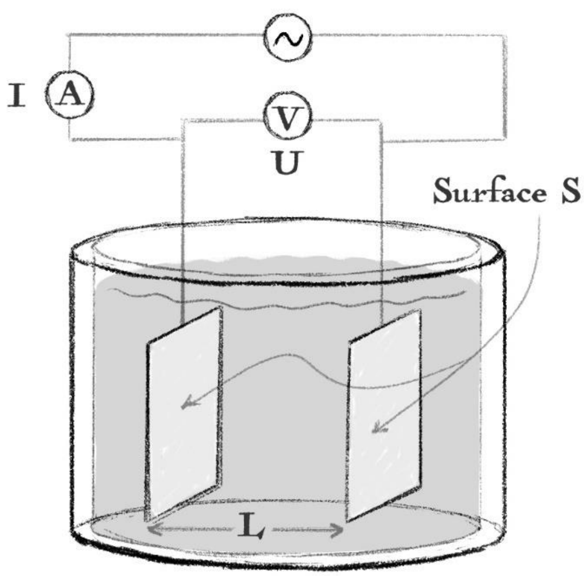


Figure 2: Principle of measuring resistivity between two cells.

An alternating voltage is applied and the resistance calculated

The specific resistivity is given by

$\rho = \frac{S}{L}R$

Typically, S/L is not calculated exactly, but calibrated using a solution with a known specific conductance, ρ *. If the resistance of this solution is R*, then the Cell constant is given by :

$$\mathrm{C} = \frac{R^*}{\rho *}$$

The cell constant of most T-HRECS (except MR) is ~0.1. This gives the highest stability and accuracy at the lower ranges (<2000 μ S/cm). The conductivity is given by the reciprocal of the specific resistance

$$EC = \frac{1}{\rho^*} = \frac{C}{R}$$

The T-HRECS uses a 3-point polynomial to then fine-tune the EC through a calibration procedure outlined in Section 2.1.3. We therefore do not save a C value for each probe, but rather two sets of polynomial coefficients. The first set is for the lower range (user defined, but generally 0-2000 μ S/cm) and another for the upper range (user defined, but generally 0-10,000 μ S/cm).

Conductivity is dependent on temperature. Temperature Compensated EC, or EC.T, is the EC normalized to a temperature of 25°C. We use the nlf [1] compensation which is the most accurate when temperatures drop below 10°C.

[1] Non-Linear Function (nlf) compensation is based on European standard (ÖNORM EN 27888 1993) to 25°C. Above 10°C, this is essentially 2.0%/°C and at 0°C it is reduced to 1.9%/°C.

T-HRECS	TM7-RS232	TM7-XB	TM7-SDI12	TM7-DL	TM7-4to20	TM7-MR
Parameters	EC, T, EC.T (nlf)					
EC Resolution	0.001 µS/cm				0.015 µS/cm	0.001 µS/cm
EC Range§	0 to 10,000 µS/cm					0 to 200,000 µS/cm
EC Accuracy¥	(0-2,000 µS/cm) ±1% of value					
	(2-10 mS/cm) ±10% of value					(2-200 mS/cm) ±3% of value
EC Stabilityψ	0.01% of value					
T Resolution	0.001 °C				0.002 °C	0.001 °C
T Range	-55°C ~ 80°C					
T Accuracy	(-10°C to 40°C) 0.1°C					
T Stability	0.01% of value					
Power	5V via Pin 7,9	Internal LiPo	9-14V	4xD-Cell	9-14V	9-14V
Int. Batt. Life^	-	>24 hours	-	>3 months	-	-
Comms	RS-232	ZigBee	SDI-12	SD Card Logging	4-20mA	SDI-12
Comm Range	15m	100m	230 m[ł]	-	5,000mꭓ	230 m[ł]

§ All models but the MR (Multi Range) probes utilize a continuous 4-point calibration on a K=0.1 probe. The MR probe uses both a K=0.1 and K=10 sensor. All models will report values outside of the stated range but calibration is only up to that point.

¥ Accuracy is the 95%ile. The MR model reports EC and ECT for both the K=0.1 and K=10 probe. Accuracy is best for k=0.1 for EC < 2 mS/cm; k=10 EC>2 mS/cm.

ψ This metric is most relevant to Salt Dilution measurements and determines the derived Q uncertainty.

ł The SDI-12 bus is capable of having at least 10 sensors connected to it, each with 61m of cable. With fewer sensors, longer cable lengths are possible. Due to impedance, the maximum cable length depends on the capacitance of all cables connected to the data line. In the field we used runs of up to 230 meters with three sensors.

ꭓ for best results use 5conductor wire (+12V Inst. +12V Pwr, Gnd, ECT Sig, and Temp Sig.)

* EC.T uses nlf based on EU standard 27888 at 25°C

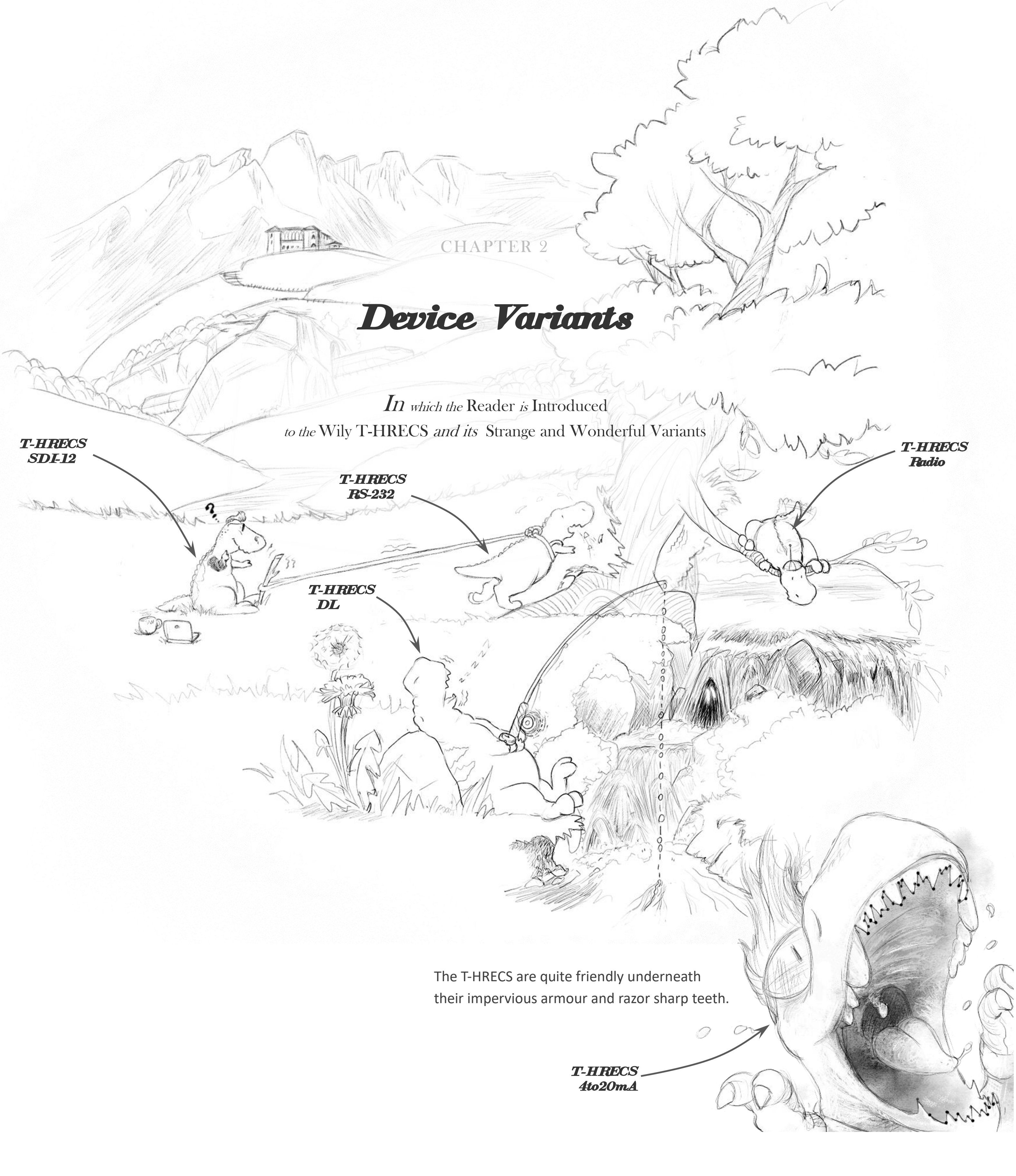
^ Based on 5 second sampling rate in moderate temperatures.

Table 1. Comparison of T-HRECS Variants.

CHAPTER 2

Device Variants

In which the Reader *is* Introduced
to the Wily T-HRECS *and its* Strange and Wonderful Variants



The T-HRECS are quite friendly underneath their impervious armour and razor sharp teeth.

2. DEVICE VARIANTS

This section describes the variations of the T-HRECS instrument. The operation of the RS232 and Radio devices are essentially the same, but the method of communication differs between the two. The SDI-12, MR, and 4-20mA devices are slave devices waiting for measurement commands. The DL device is a self-contained Datalogger with menu mode access to the embedded EC-T sensor menu. The cartoon depictions within filmstrips alludes to the changing nature of the device as we work to improve and adapt each device. This manual is a snapshot of the devices at the time of writing.

2.1. T-HRECS RS232

Figure 3: This T-HRECS is on a short tether; always collecting data whatever the weather.

The RS232 version of the instrument is used exclusively with the QiQuac Flow Measurement system. This is because its power comes from pin 9 on the QiQuac DB9 device. The various levels, eg, Tx and Rx, are RS232 compliant, ie ±6V.

Through the QiQuac Serial Terminal, you can access all the settings in the T-HRECS EC-T Instrument such as Set broadcasting Interval, Calibrate EC, Restore defaults, etc. This menu set is only available in the serial devices RS232, Radio, and through the DL. In order to calibrate the SDI-12, 4-20, or MR, you will need access to a serial interface device available from Fathom Scientific.

2.1.1. FEATURES

- High resolution EC.T (0.001 µS/cm)
- High resolution Temperature (0.001°C)
- IP67 Waterproof
- Lightning and ESD protection
- Serial Features
    - Galvanically isolated serial communication.
    - Low Power consumption
    - Powered by QiQuac datalogger through pin 9

2.1.2. OPERATION

1. Plug in DB9 to QiQuac-Power Source.
2. T-HRECS will send a comma delimited measurement string every broadcast Interval. The MEAS indicator will flash green when taking a measurement.

2.1.3. MENU MODE

To access the Menu mode, you must use a serial terminal. There is a serial terminal built into the QQ under Setup > Serial Term. You can also use a PC based terminal program such as Real-Term, TerraTerm, or Hyperterminal. To enter the T-HRECS Menu Mode, you must send the unit a "1" followed by a <CR>.

Select the menu option within 10 seconds. Once a valid selection is made, there is no time limit.

The Main Menu selections are:

1) Cal EC (Initiate sequential EC calibration routine)

2) Cal Temp (Initiate sequential temperature calibration routine)

3) Select Th Dev (Set thermal device)

4) Set Int (Set reporting interval between 1 and 3600 seconds)

5) Factory Reset (Restore factory defaults)

6) Advanced Menu (Go to Secondary Menu)

7) Exit and Save (Select to Save settings, including calibrations)

To select an option from the Main Menu, enter the number followed by a Carriage Return (CR). On the QQ, rotate the dial clockwise to select the number and push the dial, then rotate counterclockwise to select the ¶ symbol. The “SEND” label will invert in colour. Push the dial to send the string to the serial port.

1) CALIBRATE EC

The T-HRECS should be calibrated from time to time (annually) or when the following condition applies: 1) a new EC.T probe is used, 2) the derived CF.T is consistently greater than 0.50 or less than 0.46, or 3) deviation from another EC.T meter is noticed. The calibration is a 4 point (dry, low EC, Mid EC, and high EC) calibration. The Low and Mid solutions should span the range of interest, such as 50 μS/cm and 2000 μS/cm. Validation tests should be within 1% of a reference solution or probe. The High EC extends the useful range up to 10,000 μS/cm, but only to an accuracy of +/-10%. Use a secondary probe with a reliable calibration to attain the EC. If using another T-HRECS, it will need to be connected to a second terminal program to see the raw EC values. Any calibrated EC meter can be used, or two std solutions of known EC and temperature. **Note that we are calibrating EC, not EC.T**.

For each calibration step, the T-HRECS will display the current voltage between the electrodes (this is ~0.32V in dry air), followed by the reference voltage, also ~0.32 in dry air). Wait for the first voltage to stabilize within 3 values in the 5^{th} decimal place (i.e. ±0.00002 between consecutive readings)

1. Select “1) Calibrate EC” from the Main Menu.

2. When “Dry Cal” appears, ensure the probe electrodes are dry by blowing on them or using a hot air gun on Low setting. Push the dial again to send a ¶ to the T-HRECS (you can send “1¶” or any number followed by ¶ and the T-HRECS will ignore the number.

3. When “Enter Low Cal” appears, place the probe in the low EC solution and stir. Ensure no bubbles are on the electrodes by knocking it on the container walls. Attain the EC (not EC.T) from the reference meter, or read the EC from the standard bottle for the measured temperature. Dial in the raw EC (not EC.T) into the QQ, or enter it into the terminal program, and send to the serial port with a CR.

4. When “Enter Mid Cal” and “Enter High Cal” appears, repeat step 3 for Mid and High EC solutions. The value of the Low, Mid, and High EC solutions is not critical, but should represent the values of interest and be approximately equally spaced. For example, if the user will be measuring in 50 μS/cm, 200 μS/cm, and up to 800 μS/cm, the calibration solutions should be roughly these values.

5. The T-HRECS will report that the settings are saved and enter the Main Menu.

6. Select “Exit & Save to begin the measurement program.

*From here on, selection of the ¶ symbol and dial push to send the string will simply be denoted by “Select” or “Enter”.

2) CALIBRATE TEMPERATURE

The temperature should not require calibration after the initial calibration. However, if the unit is reset, or a new probe is attached, calibration may be required. Temperature calibration is more time-consuming than EC calibration because the probe must reach equilibrium with the water. It also requires three water baths 1) near zero degrees, 2) an arbitrary temperature between zero and ~40 degrees, and 3) a third equal to twice the difference between 1 and 2. If an AD590 probe is used, the calibration is a simple single arbitrary temperature entry.

1. Select “2) Calibrate Temperature” from the Main Menu.

2. When “1)AD590 or 2)Thermistor” appears, select the correct temperature sensor. (Factory Default is Thermistor)

3. When “Calibrate? 0=no 1=yes” enter 0 to use the default calibration and begin measurements, or 1 to perform the calibration procedure.

4. If AD590 is selected, when “Enter Temp” appears, enter the temperature from the reference meter. Go to step 8.

5. If Thermistor is selected, when “Enter Low Temp” appears, place the probe in the low temperature solution and stir. This should be an ice bath and the temperature should be near zero. Attain the temperature from the reference meter. Enter the low temperature.

6. When “Enter Med Temp” appears, repeat step 3 in a solution around room temperature.

7. When “Use High Temp:” appears, followed by a required temperature, ensure the temperature bath is equal to the required temperature within 0.1° and send a CR.

8. The T-HRECS will report the current temperature. Send a CR to enter the measurement program.

3) SELECT THERMAL DEVICE

Select the thermal device being used. In most cases this is a 10k NTC Thermistor

4) SET INTERVAL

This is the measurement interval in seconds. Factory default is 5 seconds.

5) FACTORY RESET

Use this option to reset the T-HRECS to factory defaults, including the temperature calibration

6) ADVANCED MENU

1) Set Probe K (Set the probe k constant. Factory default is 0.1)

2) Set Dec Places (Set the decimal places to report. Factory default is 5)

3) CMD Mode (Set the T-HRECS into Command Mode used for SDI-12, 4-20, DL, and MR)

4) Cal Values (Print the current calibration values)

5) Exit Menu

7) EXIT AND SAVE

Changes to the settings are not saved until this item is selected

Figure 4: The T-HRECS RS232

This probe comes with 5m of sheathed cable, an IP67 watertight aluminum housing, probe, and anodized aluminum shroud. This device requires 5V and up to 40mA on Pin 5 to power the galvanically isolated circuit. The T-HRECS SDI-12 and 4-20mA, probes look the same, but come with 10m cable standard between the probe and housing.

2.2. T-HRECS Radio

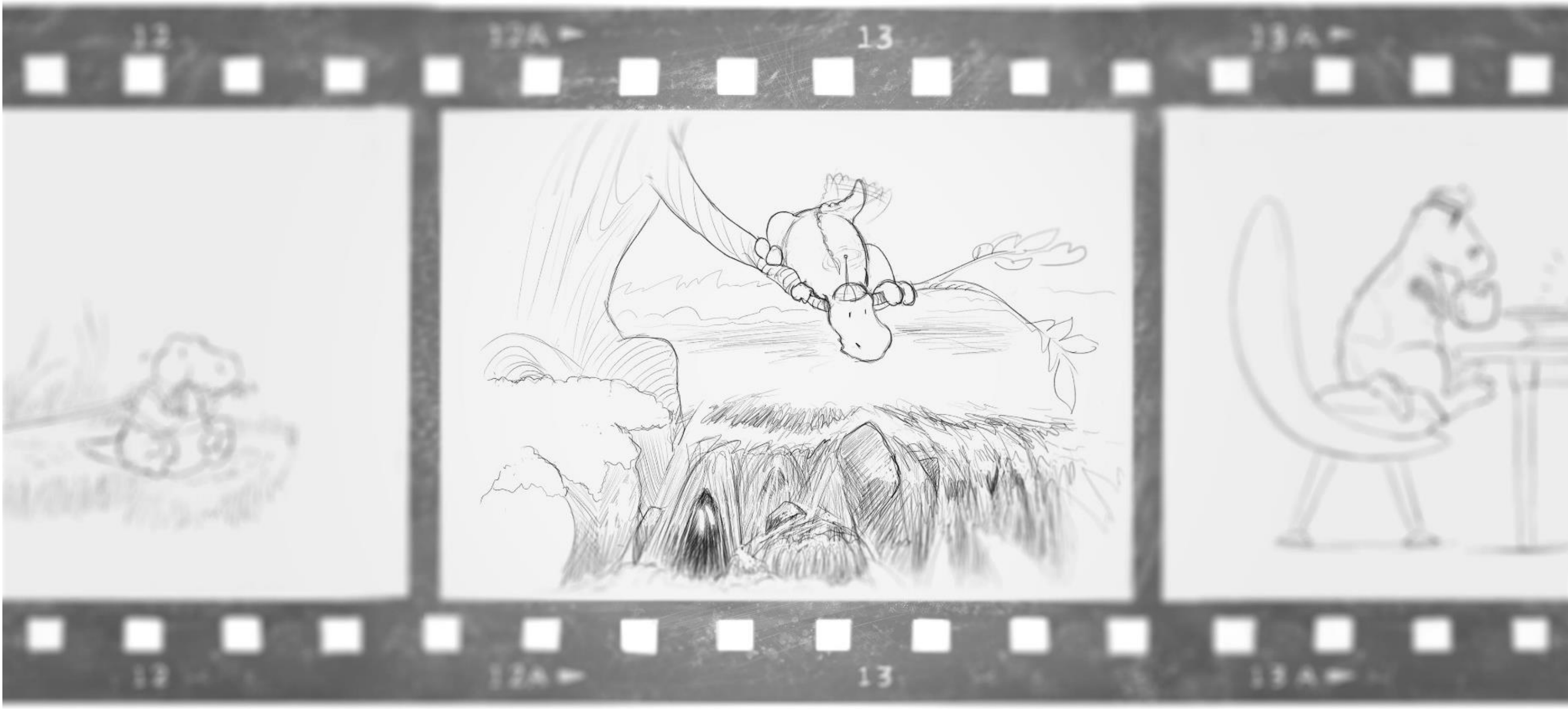


Figure 5: The Radio T-HRECS is hunting for flows. Whether he catches one nobody knows

The Radio version of the instrument is used exclusively with the QiQuac Flow Measurement system. This is because it connects to the QiQuac via a paired XBee radio from Digi International. It may be possible to connect to the same radio installed in another device, but that functionality is not supported. If a new T-HRECS Radio is used for an existing QiQuac kit, it may be necessary to swap the XBee radio from one device to another since they are paired. Instructions will be provided by Fathom Scientific to undertake this task.

Power for the Radio device comes from an internal LiIon rechargeable battery.

The XBee radio is FCC and CE approved. For a full list of country certifications see: https://www.digi.com/resources/certifications

Through the QiQuac Serial Terminal, you can access all the settings in the T-HRECS EC-T Instrument such as Set broadcasting Interval, Calibrate EC, Restore defaults, etc. This menu set is only available in the serial devices RS232, Radio, and through the DL. In order to calibrate the SDI-12, 4-20, or MR, you will need access to a serial interface device available from Fathom Scientific.

2.2.1. FEATURES

- High resolution EC.T (0.001 µS/cm)

- High resolution Temperature (0.001°C)
- IP67 Waterproof
- Lightning and ESD protection
- Serial Features
    - Galvanically isolated radio communication.
    - Low Power consumption

2.2.2. OPERATION

1. Switch on Radio Device.
2. T-HRECS will send a comma delimited measurement string every broadcast Interval. The Green LED MEAS indicator will flash green when taking a measurement. The Red MENU LED indicates the unit is either in menu mode, or trying to pair with it's host XBee radio.
3. When the T-HRECS Radio is turned on, the Blue Charge State LEDS will illuminate for 12s and then go off. When a USB cord is plugged in, the portion of the battery capacity being charged will flash.
4. The Radio Link LED indicates the Radio connection status and signal strength. 5 consecutive flashes is 100%. A single flash is the lowest strength. A sold LED indicates no connection.
5. For 3rd U/S Sensor enabled devices, holding your finger on the injection button until the "Injection Made" LED is lit will send a "-100" value for ECT to the QiQuac which interprets it as an injection event.

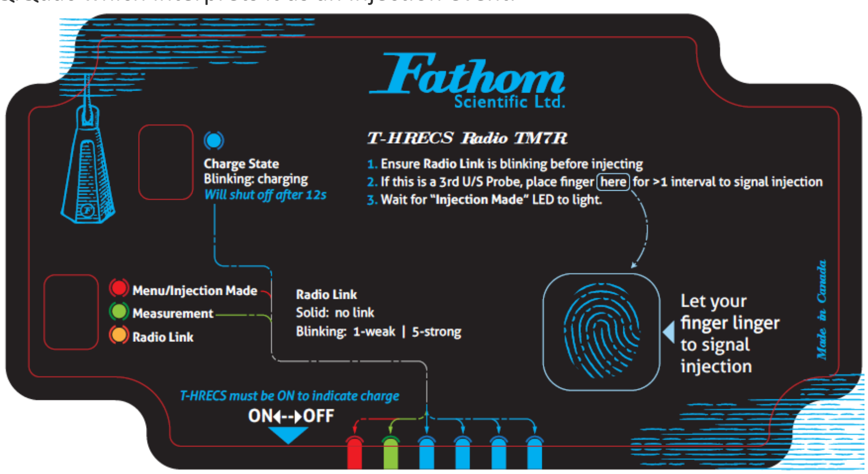


Figure 6: The Radio T-HRECS Sticker

2.2.3. MENU MODE

The Menu Mode for the Radio device is the same as for the RS232 device, see Section 2.1.3. A Red LED will be illuminated while the device is in Menu Mode.

2.2.4. CHARGING AND POWER MANAGEMENT

To charge the internal battery, insert a custom (grey) USB mini cable with elongated casing. This custom modification allows the mini USB plug to be fully inserted into the IP67 USB connection. Using a standard mini cable will not fully engage the data-contacts, but may still charge the unit. The Radio unit must be switched ON to indicate charging state. The unit will still charge if turned off, but the charge state indicator will not be accurate.

There are 4 blue LEDs visible through a portlight into the Radio device and indicate charge state as 25%, 50%, 75%, and 100% charged. A flashing blue LED indicates this capacity level is being charged.

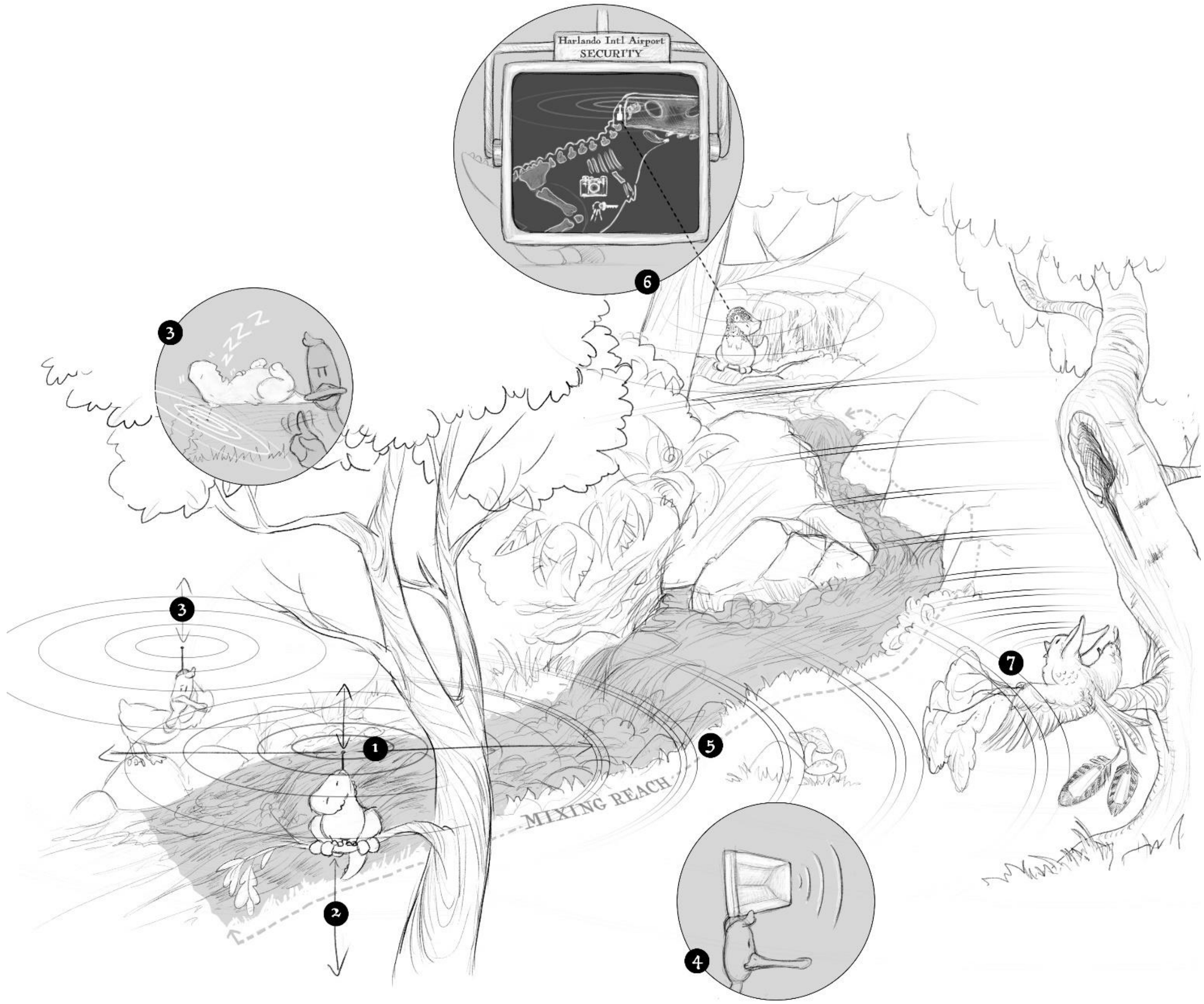
The battery life of the T-HRECS Radio when fully charged should exceed 24hours of continual 5s measurement. Contact Fathom Scientific if this longevity is not achieved.

2.2.5. RADIO CONNECTION

The XBee radio has two states: Affiliated and Searching. When the XBee is affiliated with its pair (usually in a QiQuac) this red LED will flash. Solid illumination indicates searching mode. To determine the range of the current setup, ensure the radio is paired before walking away with the radio. The Radio Link LED will flash continuously at first, and the then flash the number of times relative to the signal strength, from 1 to 5 (or continuous). Note when the Red LED stops flashing. Move back into range for the radios to re-affiliate.

Figure 7: The Radio T-HRECS

The best range will be attained when dipole antennas are vertical and the plastic radio T-HRECS is horizontal, as shown in Figure 8.



DOWNSTREAM SITE

1) Keep radio dipole antenna vertical

2) Lift device off ground and away from objects if possible: consider putting T-HRECS in a tree

3) Keep Dipole Antenna vertical for longer range

4) YAGI antenna is directional

UPSTREAM SITE

6) Mixing Reach: vegetation and obstacles will reduce range

5) T-HRECS TM7.2 has an internal antenna that is vertical when T-HRECS is horizontal

7) The T-Ekho Radio Repeater can be located midway between D/S and U/S sites to transmit longer distances, around corners, or over hills

Keep clear of antenna for longer range

Figure 8: Radio Placement

2.3. T-HRECS SDI-12

Figure 9: The SDhI-12 T-HRECS is too hip and cool, waiting for notes to be passed on the bus after school.

The SDI-12 version of the instrument is compliant with the SDI-12 standard V1.3 It outputs 3 measurements, EC, Temperature, and ECT. It is not possible to calibrate the SDI-12 unit without a Serial Interface such as the DL, RS232, or Radio modules. Even so, special firmware must be used to do so. Secondary calibration can be undertaken by the user if the calibration drifts out of spec.

2.3.1. FEATURES

- High resolution EC.T (0.001 µS/cm)
- High resolution Temperature (0.001°C)
- Lightning and ESD protection
- IP67 Waterproof
- Serial Features
    - Galvanically isolated serial communication.
    - Low Power consumption

2.3.2. WIRING

The T-HRECS SDI-12 requires 9-14 V on the Red wire, Gnd on the Black Wire, and outputs 0-3.3V on the White SDI-12 Bus line.

2.3.3. OPERATION: SDI-12 Commands

The SDI-12 unit supports the following commands:

- a!: Acknowledge Active Command
- aM!: Single Measurement Command
- aC!: Concurrent Measurement Command
- aD0!: Get Data 0 Command
- aXR!: Extended Command Continuous Measurement Mode
- aXM!: Extended Command Single Measurement Mode
- aR0!: Retrieve Last Continuous Data 0
- aI!: Identification
- aAb!: Change Address

Where a is the current device address.

The T-HRECS SDI-12 sensor should return 3 variables, EC, Temp, and EC.T after 1 second. Testing has confirmed that up to 2 units can support Continuous Measurement Mode (aXR! Command) at 1s interval on a single SDI-12 bus, but only 1 unit in Single Measurement mode at 1s interval due to SDI-12 overhead. More than 2 Units can run on a single bus if longer than 1s interval is used.

2.4. T-HRECS 4to20 mA

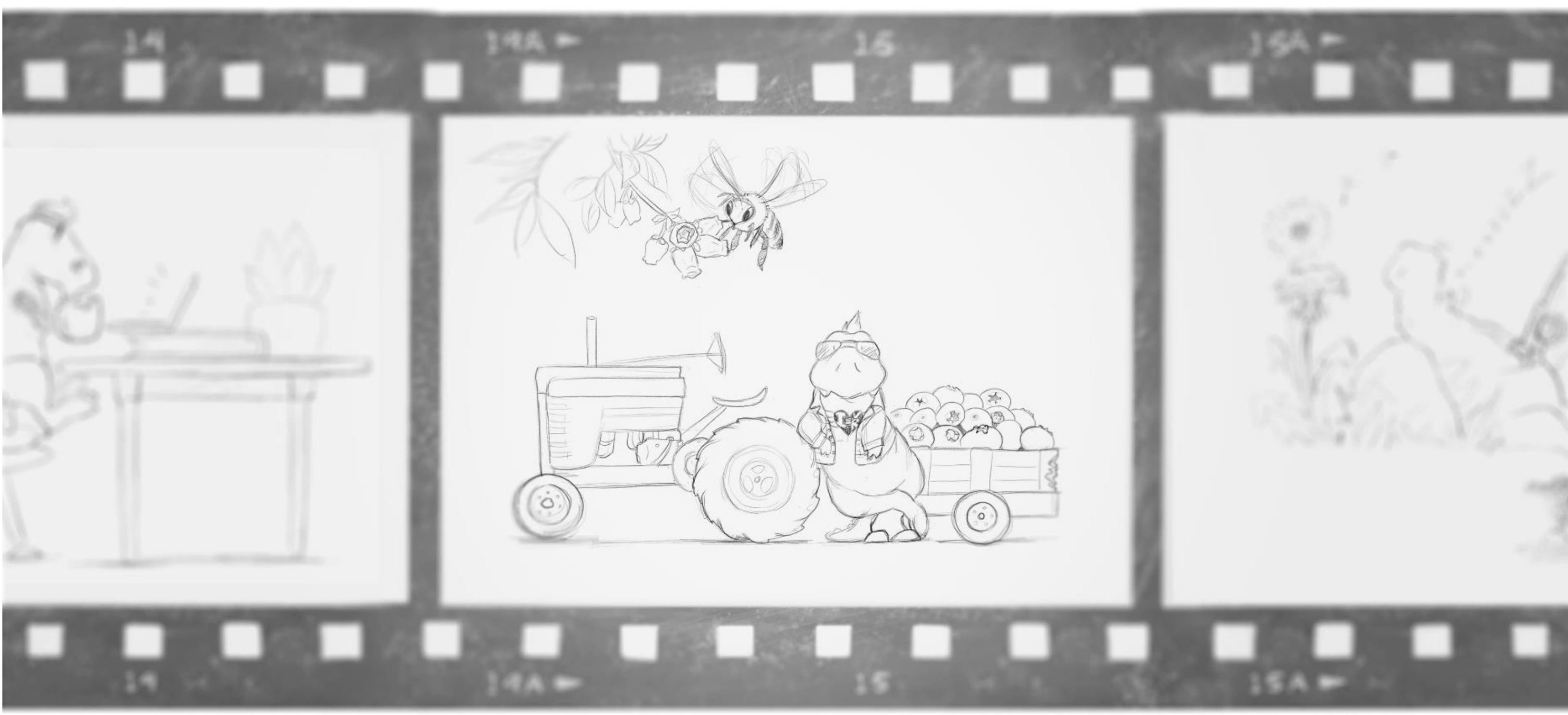


Figure 10: This old-skool cat knows how to start a tractor: V=IR is easy enough to refactor!

The 4to20 version of the instrument provides a standard output of Temperature and ECT over large distances. It does not have as fine a resolution as the SDI-12 unit due to the process of converting the digital ECT measurement to an analog output. There are also more wires than a usual 4to20mA device: Instrument Power, Device Power, Gnd, Temperature Output, and ECT Output. A calibration is performed after conversion to 4to20mA based on the range specified in the order and an equation to convert mA to measured values is provided with the unit.

It is not possible to calibrate the 4-20mA unit without a Serial Interface such as the DL, RS232, or Radio modules. Even so, special firmware must be used to do so. Secondary calibration can be undertaken by the user if the calibration drifts out of spec, i.e. perform calibration and generate an equation to apply to the device output.

2.4.1. FEATURES

- High resolution EC.T (0.0015 µS/cm)
- High resolution Temperature (0.002°C)
- Lightning and ESD protection
- IP67 Waterproof
- Serial Features
    - Galvanically isolated serial communication to the 4-20mA conversion IC.
    - Low Power consumption

2.4.2. WIRING

The T-HRECS 4-20mA sonde requires 9-14V power. To reduce noise caused by measurement, there is an Instrument Power and Device Power. This is to reduce the very small drawdown of the reference voltage during a measurement. They can be connected to the same source at the supply side, but should have separate conductors on the run to the sensor to maintain accuracy. Wiring is:

- Red+White 9-14V
- Black: GND
- Green: ECT
- Blue: Temp

2.4.3. OPERATION

Connect the power to the 4-20mA sensor. The sensor will sample once per second and post the appropriate voltage to the Digital to Analog (DAC) converter, which in turn generates the appropriate current.

2.5. T-HRECS DL

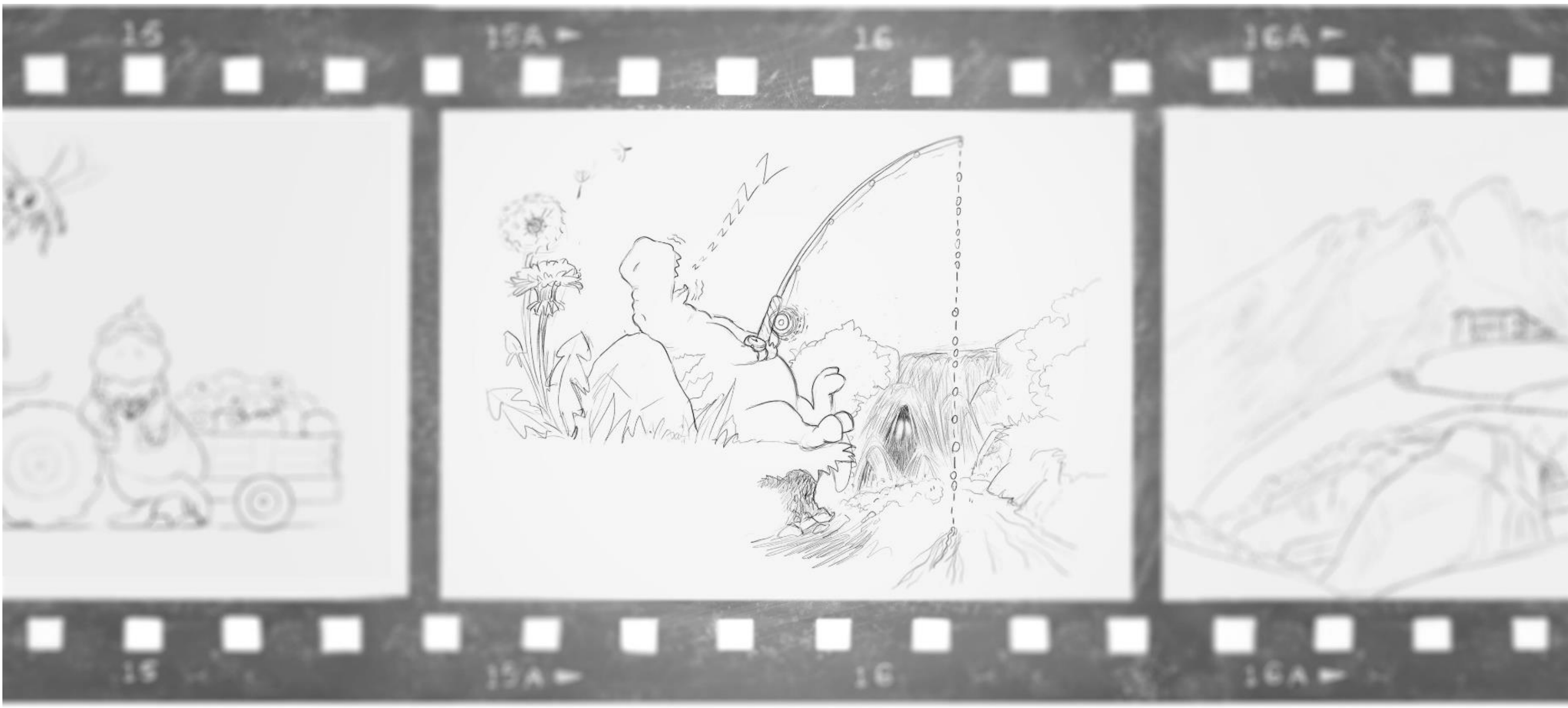


Figure 11: : The T-HRECS DL's naps are respectable, Though his clock and memory are impeccable.

The T-HRECS-DL (Datalogger) is a self-contained EC.T datalogger and LoRa Radio device. It was designed to be used with the AutoSalt system for continuous high frequency (ie 5sec) and high resolution (0.001 μ S/cm) monitoring. The 4xD-Cell batteries contain up to 20Ah of capacity and can last up to 3 months at a 5 second interval. This life is reduced depending on the LoRa duty cycle.

Unlike the other T-HRECS, the electronics of the DL are suspended in a foam moulding within a waterproof enclosure. The user must replenish the desiccant regularly within the case or corrosion of the electronics can occur.

The T-HRECS DL has a modular circuit board design; each layer on the stack performs a different function.

- The lowest layer is the EC-T sensing board. With the power off, it's alright to carefully remove the upper layers to access the screw terminals of the lower layer.
- The second layer is the EC Interface board which provides access to the EC circuit for a higher level MCU that manages the Datalogging. This layer also contains an FTDI USB-Serial chip to allow access to the T-HRECS DL Menu system via mini-USB cable. This same port is used to update the firmware.
- The third layer is the Datalogging module with Real Time Clock (RTC) and CR1220 battery, and SD Card holder.

- The fourth layer is the Atmel 1284 (3.3V, 16MHz) microcontroller and LoRa interface. Connected via the grey 10 conductor cable is the the LoRa radio. Disconnect this cable to reduce power consumption if LoRa is not needed.

In general, layers are interchangeable between T-HRECS. This allows faster troubleshooting or replacement. To swap a layer first ground your hands to something metal to remove excess static electricity built up in your body. Next ensure the power is off, and carefully pull apart the stack. To replace a layer, ensure the pins are lined up and compress the stack. It's also necessary to expand the stack to swap the CR1220 coin cell if the RTC loses its date-time.

The SD Cards are the Push-Push type, meaning push to eject and also push to insert.

2.5.1. FEATURES

- High resolution EC.T (0.001 µS/cm)
- High resolution Temperature (0.001°C)
- IP67 Waterproof
- Lightning and ESD protection
- Real Time Clock
- SD Card Datalogging
- 20 Ah D-Cell battery holder for up to 3 months of 5second datalogging
- LoRa Radio for Connection with AutoSalt System

2.5.2. OPERATION

Flip the toggle switch to ON. A red light on MCU board indicates power is supplied to the microcontroller. The red light by the SD Card indicates a log to SD Card. A Green flash on the lowest layer indicates an EC-T measurement.

T-HRECS_DL will save the data to the SD card in files labeled with the unit's serial ID (i.e. AT05) followed by the file number (i.e. 003) and timestamp the file with the last write operation. The file is a .csv file with columns:

- DT: Date Time. We recommend always setting this to PST or non-daylight savings time in your area to avoid future confusion.
- RTCTmp: The RTC measures its own temperature for accurate timekeeping. This is a proxy for air temperature and is recorded.
- RawV: The Voltage supplied to the unit. You can attach up to 16V to this unit.
- EC: The Electrical Conductivity in µS/cm.
- PrbTmp: Probe Temperature in °C.
- EC.T: Electrical Conductivity Temperature Compensated using nlf based on EU standard 27888 at 25°C in µS/cm.

To replace batteries, turn off T-HRECS. Replace batteries.

To download data, turn off T-HRECS. Remove SD Card and download data.

MENU MODE

To access the Menu mode, you must use a PC based terminal program such as Real-Term or Hyperterminal. These instructions are for RealTerm. To enter the T-HRECS Menu Mode, you must send the unit a "1" followed by a <CR>.

Open RealTerm and set the Display> Rows to 80 to allow more rows of transmissions to show.

Select Port>9600, 8N1, and the port corresponding to the T-HRECS. Click Open.

You should see:

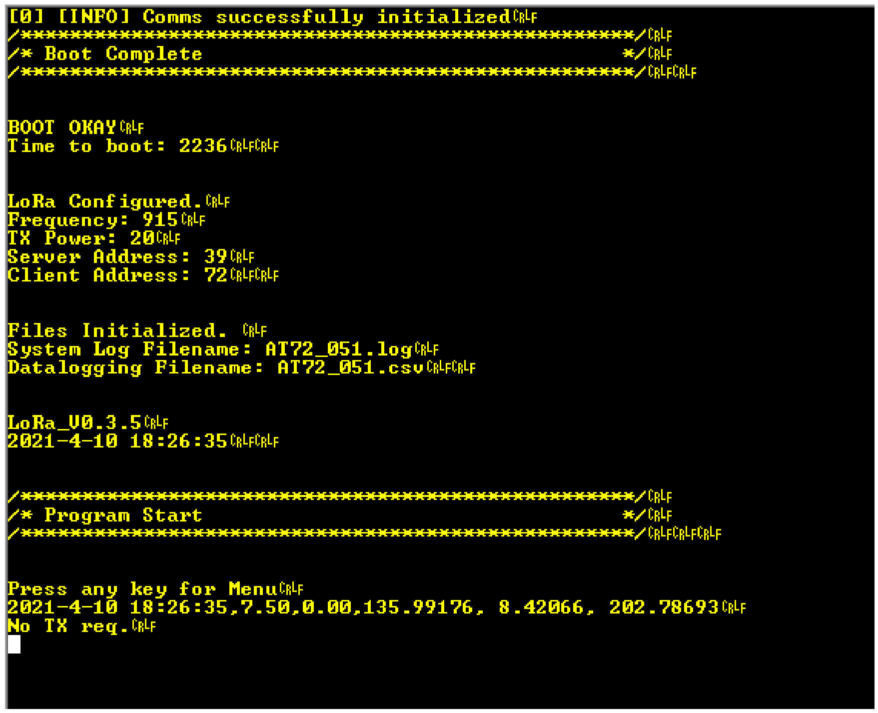


Figure 12: T-HRECS DL (AT72) Startup Screen

To access the menu, select the Send tab and send a 1 as an ASCII with a CR. Use the Send window for sending multiple digits, but the terminal screen will work for single digits. The Main Menu selections are:

0. Save&Exit
1. Set Clock
2. Set Interval
3. Set LoRa Power
4. Set LoRa Frequency
5. Set AQ server address
6. Diagnostic mode
7. Factory Reset
8. T-HRECS Comm
9. Set LoRa Tx Mode

To select an option from the Main Menu, enter the number followed by a Carriage Return (CR).

0) Save&Exit

Changes to the settings are not saved until this item is selected.

1) Set Clock

Select “1) Set Clock” from the Main Menu by sending a 1<CR> to the serial port.

Use the Send tab of RealTerm, with EOL = “+CR” checked and send ASCII for each prompt. You can also enter the data into the terminal window.

When prompted, select “Y” or “y” to send the new date-time to the T-HRECS.

2) Set Interval

This is the measurement interval in seconds. Factory default is 5 seconds. The current version of T-HRECS-DL will only allow 1-29 second intervals. This is because logging occurs on the second of the clock corresponding to the interval, for example if 5 seconds is selected, a log will occur at 12:00:05, 12:00:10. If 4 seconds is chosen, 12:00:04, 12:00:08, etc. For this reason, a maximum interval of 29 seconds allowed.

3) Set LoRa Power

The LoRa Power is the transmission power of the LoRa Radio. This can be set to meet local LoRa regulations. For example, in Europe this is +14 dBM at 868 MHz. In North America it is +30dBM at 915MHz, as shown in Table 1.

4) Set LoRa Frequency

This can be set to meet local LoRa regulations, shown in Table 2.

5) Set AQ server address

The T-HRECS DL is a LoRa client. It must be paired to a LoRa Server, usually the AutoSalt controller. Set this value to the Address of the LoRa Server and likewise set the LoRa Server Channel ID to this unit’s Serial Number. For example, if the Serial Number is AT072, then set the LoRa Channel ID in the AutoSalt Controller to 72.

	Europe	North America	China	Korea	Japan	India
Frequency band	867-869MHz	902-928MHz	470-510MHz	920-925MHz	920-925MHz	865-867MHz
Channels	10	64 + 8 +8	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee
Channel BW Up	125/250kHz	125/500kHz				
Channel BW Dn	125kHz	500kHz				
TX Power Up	+14dBm	+20dBm typ (+30dBm allowed)				
TX Power Dn	+14dBm	+27dBm				
SF Up	7-12	7-10				
Data rate	250bps- 50kbps	980bps-21.9kpbs				
Link Budget Up	155dB	154dB				
Link Budget Dn	155dB	157dB				

Table 2. LoRa Power and Frequency Regulations from LoRa Alliance.

6) Diagnostic mode

Turn Diagnostic Mode On or Off to see verbose diagnostic messages on the terminal screen.

7) Factory Reset

Select this to restore factory defaults. This should have been set to the local LoRa regulations for your area in the firmware.

8) T-HRECS Comms

The T-HRECS DL is a compound instrument with two MCUs. The Main Menu is handled by the Atmel AT1284 MCU on the top of the stack. To access the T-HRECS EC board on the bottom layer, it's necessary to enter into a transparent communication mode. Select 8 to enter this mode. The T-HRECS DL will respond with

Enter E to Exit

The T-HRECS EC board is set to CMD mode, and will only responde to 'r<CR>' for read sensors or '1<CR>' to enter the EC menu. Once inside the T-HRECS EC Main Menu, follow the instructions in Section 2.1.3.

NOTE: In the current version of the T-HRECS DL firmware, the Main Menu of the DL does not require a <CR> after each command, but the T-HRECS EC board does.

After completing your interaction with the T-HRECS EC board, select 7) Exit & Save then enter ‘E’ to enter the T-HRECS DL menu again.

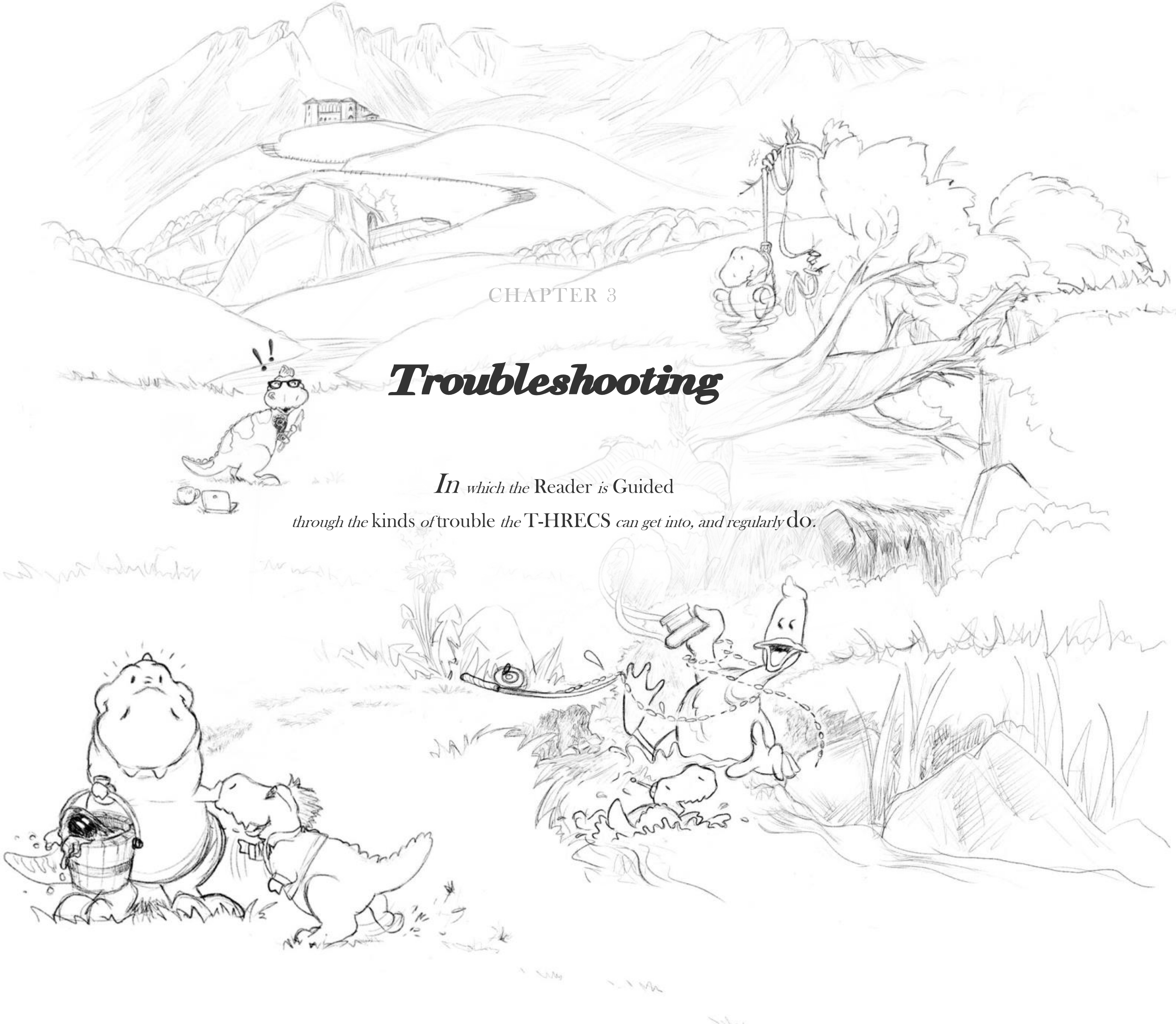
9) Set LoRa Tx Mode

The T-HRECS DL can be set to Constant Tx mode, which uses more power but avoids complications or failed handshaking sessions with the AutoSalt Controller. This mode may also exceed local LoRa regulations for Duty Cycle. Set this to ‘1’ to use Constant Tx Mode and ‘0’ to use Handshaking mode.

Figure 13: The T-HRECS DL (Shh, it's sleeping)

This device contains everything needed to record 5 sec data for months at a time. Housed in a watertight box, data is downloaded from the SD Card and 4-D Cells power the unit

.



CHAPTER 3

Troubleshooting

In which the Reader *is* Guided
through the kinds *of* trouble *the* T-HRECS *can get into, and regularly* do.

We may need to seek psychotherapy
while T-HRECS seek maximum entropy

3. TROUBLESHOOTING

No T-HRECS Signal

Power the T-HRECS unit and check for the following.

- Radio: Blue LEDs should light up to indicate battery power. The Red LED should be on for 30 seconds after the unit is powered up and the Green LED should continually flash for every measurement.
  - If both LEDs are operating normally, the Radio may have become detached. Open the box and check; likewise for the QiQuac.
  - If there are no LEDs on, the Battery or Power Management component may be detached or failed. Follow steps below.
- All models: The Red LED should come on after the unit is powered up and the Green LED should continually flash for every measurement.
  - If neither LED has turned on, then open the T-HRECS box and check:
    - Has the circuit board has likely been disconnected?
    - Is there a broken wire? Are the wires firmly secured in the screw terminal? Pull lightly on connections with tweezers to see if any wires are loose.
    - Are there any signs of corrosion or water damage.
  - RS232 on QiQuac: If the green LED is flashing for each measurement,inse open the QiQuac Setup>Serial Term>CH0 and look at the readings. If a reasonable csv file is present (Voltage, EC, Temp, ECT, VEC, VRef) then it's possible that the QiQuac is not interpreting the data correctly. On older QiQuacs ensure T-HRECS is selected under Setup>Device Settings>Ch0 Device. On new units, turn off both the QiQuac and T-HRECS. Next turn on the QiQuac then the T-HRECS.

Noisy, drifting, or erratic signal

- During a Measurement in water: Put the probe is a controlled water sample, such as in a bucket or flask. Is the signal stable? If so, the insitu site in the moving water may be the problem:
  - Ensure there are no air bubbles trapped within the electrode housing.
  - Ensure there is no upstream inflow of water with a different EC
  - Ensure the probe is not in a backeddie or pool with variable flow paths.
- If the probe signal is still noisy or errative:
  - Check the Temperature Values. If they are not reasonable and stable, then the problem is likely the thermistor and not the EC probe which uses the temperature to generate the ECT. If it's a thermistor problem, see below.
  - Check to see if the probe's outer electrode is tight. It will screw on and off. It should be as hand-tight as possible. You may want to add a drop of Loctite Blue Thread Locker or Teflon tape to the threads and then screw the outer electrode back on handtight.

  - Check for signs of wear in the probe wire, especially near the box and near the probe. Are there signs of abrasion or wear? Does the ECT signal jump around when you move the wire around? Is the wire going into the box secured at the cable gland? If yes to any of these see below.
- If tightening the electrode or moving the probe in the water does not solve the problem, there may be a loose or broken wire or water damage. Either contact FSL or open the box and look for signs of moisture damage or loose or damaged wires. Attempt to repair if that's in your wheelhouse.
- If the calibration is drifted out of spec, then the electrode surface may be fouled by sediment or algae and cleaning the probe may bring it back to within specification:

Cleaning Probe Electrodes

- If you find the CF.T has drifted between probes, or is significantly different than 0.486 (see Richardson et al.), or if there are signs of fouling (from permanent installations) then it may be time to clean the electrode surface. This will often bring the T-HRECS back into calibration without the need to calibrate.
- Mix warm water with a small amount of surfactant (a few drops in a bowl of warm water) such as Dawn dish soap.
- Rinse probe electrodes in the warm soapy water.
- Scrub the inside of the outer electrode and inner electrode with a Q-tip or something similar.
- If the electrodes are badly tarnished, soak them in acetone for 2 hours. Make sure the probe's plastic housing does not contact the acetone.

T-HRECS DL Specific Issues:

- RTC Date-Time set to 2000-01-01: The RTC Coin Cell is likely dead. To replace it you will need a CR1220 3V Coin cell. Remove the top (4th) and 3rd (Datalogger) layers. Push the CR1220 out with the tip of a pen, a small screwdriver, or tweezers. Check the voltage to ensure it's the battery that's the problem. Replace with a new CR1220. Replace the circuit board layers being careful to line up the pins.
- SD Card Error: The Red LED will flash if it fails to initialize. First try to power cycle the device to see if this repairs it. If not, you may need a new SD Card or to format the existing SD Card. To avoid SD Card failures in the future, try not to remove the card or shut off the power during a possible SD Card write operation. This will occur immediately after a Green LED Measurement event.
- LoRa Radio failure. Check the connection on both the 1284MCU board and the LoRa board. Connect to the DL unit with a mini-USB cable and using Realterm or other terminal program, check the failure message for more information.

SDI-12 Specific Issues:

- When the SDI-12 program code is not working, try to send the T-HRECS SDI-12 commands directly.
- Sampling at 1s should be possible with most Dataloggers with a single T-HRECS on the bus. Adding more T-HRECS will not allow 1s sampling in Measurement Mode. To address this, try to sample in SDI-12 Continuous Mode. To enter continuous mode, use the command aXR!: where a is the address. To collect the last measured values, use the command xR0!. If you try to use aM! and aC0! Commands while in continuous mode, this will cause a delay in processing and reporting. To enter back into single measurement mode, use aXM!
- If the SDI-12 unit is slow in responding to aM! and aC0!, ensure it is in Single Measurement mode (aXM!).
- If SDI-12 issues persist, it may be interference from another SDI-12 unit on the same bus. Try to remove all other instruments from the bus and try again.

Power Consumption Issues:

- SDI-12 and 4-20mA: It may seem as though the SDI-12 and 4-20mA boards draw more power than other instruments. This is likely due to the power required for the galvanic isolation circuit, which draws 20mA even when asleep. This is necessary to avoid ground loops. If low power consumption is a higher priority than ground isolation, then it may be possible to remove this circuit if the proper precautions are in place.
- Radio Power: The internal LiIon battery may be depleted or the charging circuity may have failed. Ensure the Power Switch is ON to charge. Contact FSL.

3.1. FREQUENTLY ASKED QUESTIONS

Q: Why do you report 3 decimal places when your accuracy is far more coarse? And why don't you autorange?

A: Good question. For many applications, such as Salt Dilution measurements, high resolution, repeatability, linearity and stability are more important attributes than absolute accuracy in Electrical Conductivity. This is because we are more interested in the relative change of the ECT.

Q: Why are all your product acronyms so hard to spell?

A: Ummm. IDK. IMHO it's OK.

Q: Why use a 2 electrode EC Cell rather than 4?

A: 2 electrode with a low k value are more sensitive at the lower conductivity ranges where most active turbulent watercourses exist. We are working on a 4 electrode cell

Q: In your other FAQs, there more jokier Questions, why are these so serious.

A: We fired the guy writing those "Jokier" FAQs. We are a serious company that demands to be taken seriously.

Q: Why aren't you wearing pants?

A: This FAQ is OVER!