E10-P

Portable Rubidium Frequency Reference

USER'S HANDBOOK

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1	1st July 2012	Initial Release	N. Law
2	18th Sept 2012	Service sections 7 & 8	N. Law
2.1	9th Oct 2012	Results sheet amended	N. Law

Contents

1 Safety Considerations

1.1 General

This product and related documentation must be reviewed for familiarisation before operation. If the equipment is used in a manner not specified by the manufacturer, the protection provided by the instrument may be impaired.

1.1.1 Before Applying Power

Verify that the product is set to match the available charger and the correct fuse is installed.

1.1.2 Before Cleaning

Disconnect the product from operating power before cleaning.

WARNING

Bodily injury or death may result from failure to heed a warning. Do not proceed beyond a warning until the indicated conditions are fully understood and met.

CAUTION

Damage to equipment, or incorrect measurement data, may result from failure to heed a caution. Do not proceed beyond a caution until the indicated conditions are fully understood and met.

1.1.3 Safety WARNINGS for Lithium Polymer Batteries

This is equipment is fitted with two Lithium Polymer Battery Packs

WARNING

Lithium-ion and lithium polymer cells and battery packs may get hot, explode or ignite and cause serious injury if exposed to abuse conditions. Be sure to follow the safety warnings listed below:

Do not place the battery in fire or heat the battery.

Do not install the battery backwards so the polarity is reversed.

Do not connect the positive terminal and negative terminal of the battery to each other with any metal object (such as wire).

Do not carry or store battery together with necklaces, hairpins or other metal objects.

Do not pierce the battery with nails, strike the battery with a hammer, step on the battery or otherwise subject it to strong impacts or shocks.

Do not solder directly onto the battery.

Do not expose battery to water or salt water, or allow the battery to get wet.

WARNING

Do not disassemble or modify the battery. The battery contains safety and protection devices, which, if damaged, may cause the battery to generate heat, explode or ignite.

The protection circuit module provided with battery packs is not to be used as a substitute for a shut-off switch.

WARNING

Do not place the battery in or near fire, on stoves or other high temperature locations. Do not place the battery in direct sunlight or use or store the battery inside cars in hot weather. Doing so may cause the battery to generate heat, explode or ignite. Using the battery in this manner may also result in a loss of performance and a shortened life expectancy.

WARNING

When the battery is worn out, insulate the terminals with adhesive tape or similar materials before disposal.

WARNING

Immediately discontinue use of the battery if, while using, charging or storing the battery, the battery emits an unusual smell, feels hot, changes colour or shape, or appears abnormal in any other way. Contact Quartzlock if any of these problems are observed.

WARNING

Do not place the battery in microwave ovens, high-pressure containers or on induction cookware.

WARNING

In the event the battery leaks and the fluid gets into one's eye, do not rub the eye. Rinse well with water and immediately seek medical care. If left untreated, the battery fluid could cause damage to the eye.

Whenever it is likely that the protection has been impaired, the instrument must be made inoperative and be secured against any unintended operation.

Instructions for adjustments while the covers are removed and for servicing are for use by service-trained personnel only. To avoid dangerous electrical shock, do not perform such adjustments or servicing unless qualified to do so.

For continued protections against fire, replace the line fuse(s) with fuses of the same current rating and type (for example, normal blow time delay). Do not use repaired fuses of short-circuited fuse holders.

1.2 Voltage, Frequency and Power Characteristics

1.2.1 Universal Full Range AC Input Power Adaptor

Class II power (no earth)

Overvoltage, short circuit & over temperature protection

GS, UL/cUL & CE approval

Voltage 100 - 240V AC

Frequency 50 - 60Hz

Power characteristics 600mA Max

Output Voltage 15V DC 1.2A

1.2.2 Unit Power Requirements

Input Voltage	11Vdc – 18Vdc
Input Current	1.7A max

1.3 Environmental Conditions

1.3.1 Temperature

Operating (ambient)	-20^{o}C to +50^{o}C
Charging	0^{o}C to +45^{o}C
Storage	-20^{o}C to +40^{o}C

1.3.2 Magnetic Field

Sensitivity	$\leq 2x10^{-11}$/ Gauss
Atmospheric Pressure	-60m to 4000m
	$<1x10^{-13}$/ mbar

1.4 Replaceable Fusing Characteristics

1.5 Cleaning Instructions

To ensure long and trouble free operation, keep the unit free from dust and use care with liquids around the unit.

Be careful not to spill liquids onto the unit. If the unit does get wet, turn the power off immediately and let the unit dry completely before turning it on again.

Never spray cleaner directly onto the unit or let liquid run into any part of it. Never use harsh or caustic products to clean the unit.

2 Portable Rubidium Frequency Reference

2.1 Rubidium Frequency Reference

A Rubidium frequency reference owes its outstanding accuracy and superb stability to a unique frequency control mechanism. The resonant transition frequency of the Rb 87 atom (6,834,682,614 Hz) is used as a reference against which an OCXO output is compared. The OCXO output is multiplied to the resonance frequency and is used to drive the microwave cavity where the atomic transition is detected by Electro-optical means. The detector is used to lock the OCXO output ensuring its medium and long-term stability.

The first realised Rubidium frequency reference arose out of the work of Carpenter (Carpenter et al 1960) and Arditi (Arditi 1960). It was a few years until the first commercial devices came onto the market and this was primarily due to the work of Packard and Schwartz who had been strongly influenced by the work of Arditi a few years before on Alkali atoms (of which Rb 87 is one). Unlike much of the research done into frequency references at that time, practical realization of a Rubidium maser was high on the researchers' agenda. This was mainly due to an understanding that such a device would have extremely good short-term stability relative to size and price. In 1964, Davidovits brought such research to fruition, with the first operational Rubidium frequency reference.

The Rubidium frequency reference, like its more expensive cousin, the Hydrogen maser, may be operated either as a passive or as an active device. The passive Rubidium frequency standard has proved the most useful, as it may be reduced to the smallest size whilst retaining excellent frequency stability. The applications for such a device abound in the communication, space and navigation fields.

The Rubidium frequency reference may be thought of as consisting of a cell containing the Rubidium in its vapour state, placed into a microwave cavity resonant at the hyperfine frequency of the ground state. Optical pumping ensures state selection. The cell contains a buffer gas primarily to inhibit wall relaxation and Doppler broadening. The Rubidium frequency reference essentially consists of a voltage controlled crystal oscillator, which is locked to a highly stable atomic transition in the ground state of the Rb 87 atom.

There are several reasons why Rubidium has an important role to play as a frequency reference. Perhaps more important is its accuracy and stability.

Accuracy is comparable with that of the standard Caesium with an operating life approximately 5 times that of Caesium. Moreover the stability of a Rubidium frequency reference over short time-scales -100s of seconds- betters that of Caesium (Caesium is more stable over longer time periods, in the regions of hours to years).

There are, however, a few drawbacks to the use of Rubidium as a frequency reference. In the past, these included the limited life of the Rubidium lamp (since improved to >10 years), The Caesium is affected to a greater degree than this, whilst the Hydrogen Maser operates differently and is not affected. The thermal stability of Rubidium is inferior to that of Caesium or Hydrogen Masers, and the Rubidium previously required frequency access to a primary reference signal or synchronization source to maintain long-term Caesium level accuracy.

The cost of a Rubidium frequency reference is significantly cheaper than a Caesium, with a much reduced size and weight. Due to its small size, low weight and environmental tolerance the Rubidium frequency reference is ideal for mobile applications. Indeed, Rubidium atomic clocks are beginning to be implemented into the new generation of GPS satellites. This is in part due to the extended life of the Rubidium physics package compared to that of Caesium. The Rubidium is also extremely quick to reach operational performance, within 10 minutes reaching 5 parts in 10^{-11}.

3 Operating Procedure

3.1 Introduction

The basic E10-P unit contains two principal internal units:

1) The Rubidium Atomic Frequency Standard.
2) The Internal Polymer Lithium Ion Battery Pack.
3) The Associated External Power Supply.

Additionally four indicators are available on the front panel to monitor the performance and status of the instrument. These are: - Battery Charging, Battery Low, Rubidium Unlocked and External Power.

3.2 Getting Started

Check that the appropriate supply voltage is being used. Connect the external supply to the unit (at the rear) and switch on.

The 'EXT PWR' and 'CHARGING/FAULT' indicator LEDs will come on immediately the external power is connected. Both indicators should be green (Figure 1), if the 'CHARGING/FAULT' indicator is illuminating as red this indicates that there is a fault with the charging of the internal batteries (Figure 12).

The internal batteries will take approximately 4 hours before they are fully charged, once the internal batteries are fully charged the 'CHARGING/FAULT' indicator will no longer be illuminated see Figure 9.

Switch on the unit via the front panel switch, the 'ON/LOCKED' indicator LED will come on and it will remain on, initially it will be amber (Figure 2) once the rubidium is locked it will turn green (Figure 3).

The 10 MHz output is available from the appropriately labelled BNC socket on the front of the unit.

The units' warm time is approximately 5 minutes. Frequency stabilization time is up to 15 minutes depending on the detailed specification of the particular Rubidium fitted.

Whilst external power is connected to the unit, the internal batteries will be charging irrespective of whether the unit is switched on or off.

In order to maximise the battery life it is recommended that the unit is initially switched on whilst the external supply is connected and the unit allowed to warm and stabilise.

If the Low Battery LED illuminates (Figure 10) during operation then an external supply should be connected within 20 minutes in order to maintain normal operation.

If the Low Battery LED illuminates on initial switch on (Figure 11) then an external supply should be connected in order to charge the internal battery and allow for normal operation.

If the Charging/Fault LED should illuminate RED at any time then the unit must be switch off immediately and the external supply disconnected.

3.3 Front panel LED combinations

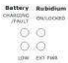


Figure 1 *OFF*


Figure 2 *ON – Rubidium Not Locked*


Figure 3 *ON – Rubidium Locked*


Figure 4 *External Power Connected*


Figure 5 *External Power Connected – Charging internal battery*


Figure 6 *ON – Rubidium Not Locked – External supply in use – Charging internal battery*


Figure 7 *ON – Rubidium Locked – External supply in use – Charging internal battery*


Figure 8 *ON – Rubidium Not Locked – External supply in use – Internal battery charged*


Figure 9 *ON – Rubidium Locked – External power in use – Internal battery charged*


Figure 10 *ON – Rubidium Locked – Low Battery* CONNECT EXTERNAL SUPPLY


Figure 11 *ON – Rubidium not locked – Low Battery* CONNECT EXTERNAL SUPPLY


Figure 12 *External Power Connected – Charging Fault*

DISCONNECT POWER EXTERNAL SUPPLY


Figure 13 *ON – Rubidium Locked – External power in use – Charging Fault*

SWITCH OFF AND DISCONNECT EXTERNAL SUPPLY


Figure 14 *ON – Rubidium Not Locked – External supply in use – Charging Fault*

SWITCH OFF AND DISCONNECT EXTERNAL SUPPLY

4 Specification

1. Output Characteristics:

a.	Frequency	10MHz Sine
b.	Impedance:	50 Ω nominal
c.	Level:	+10 dBm ±3
d.	Connector:	dBm BNC

2. Harmonics

a.	Second harmonic	<-40dBc

3. Spurious Outputs:

< -80 dBc

4. Accuracy

a.	At shipment @ 25°C	$\pm 5 \times 10^{-11}$

5. Short Term Stability:

a.	1s	8×10^{-11}
b.	10s	3×10^{-11}
c.	100s	8×10^{-12}

6. Drift

a.	1 day	5×10^{-12}
b.	1 month	5×10^{-11}

7. Phase Noise

a.	10Hz	95dBc
b.	100Hz	125dBc
c.	1kHz	135dBc

8. Input Voltage

+11Vdc to +18Vdc

9. Input Power

6W @ 12Vdc, 25°C Max 1.7A

10. Universal Power Adaptor

a.	Class II power (no earth)	
b.	Protection	Over voltage, short circuit & over temperature
c.	Approvals	GS, UL/cUL & CE

d.	Voltage	100 to 240V AC
e.	Frequency	50 to 60Hz
f.	Power characteristics	600mA Max
g.	Output Voltage	15V DC 1.2A

11. Internal Battery

a.	Run Time (fully Charged)	2 hours Typical 4 hours
b.	Charge Time	4 hours

12. Warm Time

a.	@ 25^{o}C	5 Minutes to lock

13. Retrace

$\leq\pm2x10^{-11}$

14. Magnetic Field Sensitivity

$<\pm4x10^{-11}$

15. Mechanical

a.	Size	107 x 58 x 146 mm
b.	Weight	500g

16. Warranty

24 months

17. Temperature

a.	Operating	-20^{o}C to $+50^{o}$C
b.	Charging	0^{o}C to 45^{o}C -
c.	Storage	20^{o}C to $+60^{o}$C

18. Temperature Coefficient

a.	Ambient	$2x10^{-10}$

19. MTBF

100,000 hours

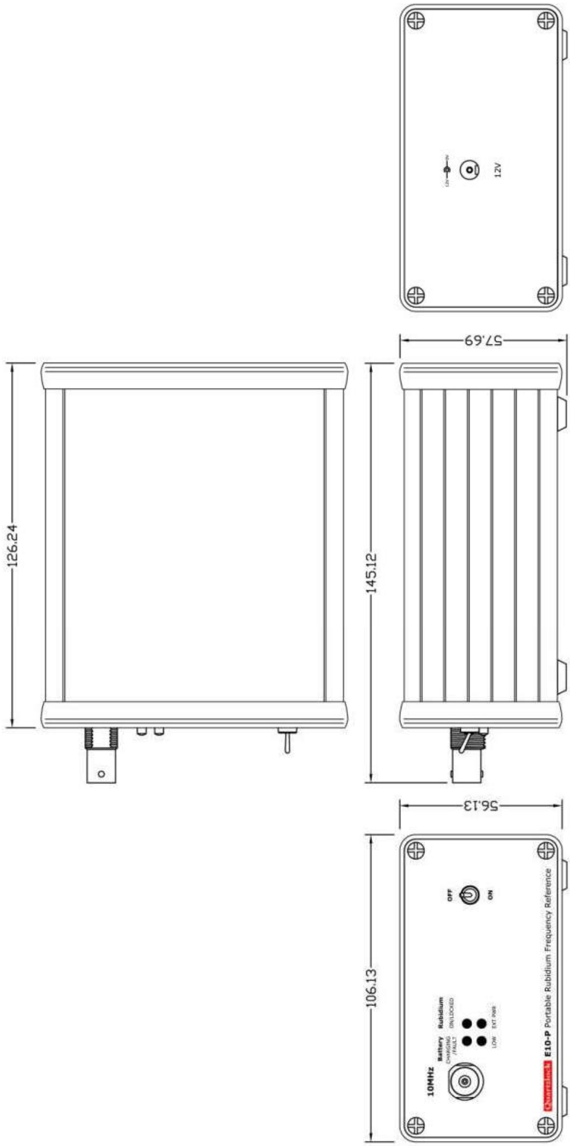
20. Environmental

RoHS

21. EMI

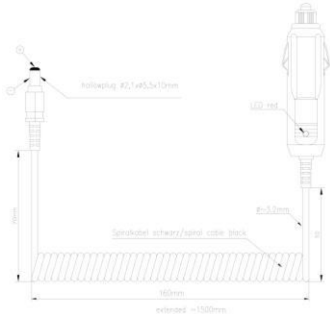
a.	Compliant to	FCC Part 15 Class B

5 Unit Outline

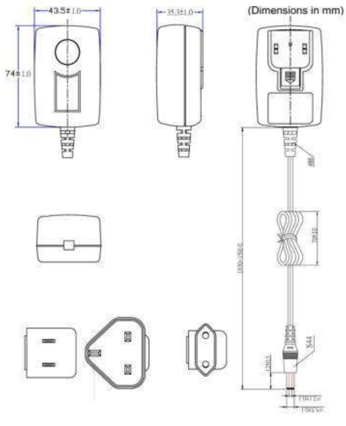


6 Accessories

6.1 Car Lighter Cable



6.2 Plug Top Supply



7 Service

7.1 Introduction

The board is initially tested with no battery connected. A power supply takes the place of the battery. This is to avoid large currents flowing due to a board fault which could damage the board or components.

7.2 Equipment required

1. PSU1 0 - 20V, 0 - 2A with current monitoring and current limit
2. PSU2 0 - 20V, 0 - 2A with current monitoring and current limit. Must be capable of sinking current, and displaying current flowing into power supply.
3. DVM Digital meter with 4 digit resolution
4. JP2 shorting plug
5. JP1 plug with cable
6. R1 120Ω 2W load resistor with crocodile clips
7. R2 12Ω 15W load resistor with crocodile clips.
8. R3 1kΩ resistor

7.3 Initial tests

7.3.1 Preliminary:

The battery over temperature thermistor must be connected between TP1 and TP2. The switch SW1 should be off.

7.3.1.1 Test 1 Chip under voltage lockout.

The LTC4110 battery backup and charger control chip has a low input voltage lockout. This occurs when the voltage on the DCIN pin (pin 1) falls below a threshold.

Procedure:

Connect PSU1 to DC input connector, J1. Set current limit to 100mA. Raise the voltage from zero volts. Monitor the input voltage with the DVM connected to TP3. Note the voltage at which D3 lights. Decrease the input voltage until D3 goes out. Note this voltage.

The Under voltage lockout entry threshold should be between 3.4 and 4.1 V, nominal 3.7V

The Under voltage exit threshold should be between 3.7 and 4.35V, nominal 4V

Note that LED2C (battery low) may also light. PSU1 current should be less than 20mA during this test.

7.3.1.2 Test 2 AC power available threshold

(Note AC power refers to DC voltage on J1)

The chip senses the presence of DC input voltage by monitoring the voltage on the DCDIV pin (pin 5). The voltage on J1 is attenuated by potential divider R18 and R19.

Procedure:

With the same connections as TEST 1, raise the voltage on J1 until LED1C (AC power ON) and LED2B (charge) lights. Decrease the voltage until LED1C and LED2B goes out. Note these voltages on the DVM

The AC present entry threshold should be between 11.26 and 11.96V, nominal 11.61V

The AC present exit threshold should be between 10.72 and 11.38V, nominal 11.05V

Note that PSU1 current should be less than 100mA during this test

7.3.2 Battery charger tests

7.3.2.1 Test 3 Preconditioning charge current

This test measures the preconditioning charge current when the battery voltage is below the bulk charge threshold (nominal 12V)

Procedure:

Connect PSU1 as in TEST 2. Set PSU1 voltage to 12V, current limit 1A. Connect PSU2 to battery connector JP1. Connect shorting plug to battery connector JP2. Set PSU2 voltage to 10V, current limit 1A. Connect 120Ω load to SW1 pin 3 and ground. Switch on SW1. Monitor voltage on TP5 with the DVM.

The following LEDS should be on:

a.	LED1B	Power ON
b.	LED1C	AC power ON
c.	LED2B	Charge
d.	LED2C	Battery low

Read the preconditioning charge current from PSU2 (will display as negative current)

Read supply current from PSU1

Preconditioning charge current should be between 71 and 133mA, nominal 102mA

Supply current should be about 300mA

7.3.2.2 Test 4 Bulk charge threshold and bulk charge current

This test measures the battery voltage at which point the chip switches into the bulk charge state.

Procedure:

With the same connections as TEST 3, raise the voltage of PSU2 slowly until the charging current jumps to about 500mA. Note the voltage on the DVM. Read the bulk charge current from PSU2.

The bulk charge threshold voltage should be between 11.2 and 12.8V nominal 12V

The bulk charge current should be between 467 and 550mA nominal 508mA

Supply current should be about 800mA

Note. Once the chip has switched into bulk charge mode, it will remain in this mode even if the battery voltage is reduced past the threshold. In order to repeat the test, reduce the battery voltage to 10V, and switch SW1 OFF and ON. This resets the chip into the preconditioning charge mode.

7.3.2.3 Test 5 Battery over temperature cut off

This test checks the over temperature charge cut off and the charge fault LED

Procedure:

With the same connections as TEST 4, with the chip in the bulk charge state, connect a 1kΩ resistor across the thermistor to simulate an over temperature condition. The charge current should drop to zero, and LED 2B (charge fault) should light. When the resistor is removed, charging should resume.

7.3.2.4 TEST 6 Float voltage

This test measures the battery float voltage at the end of the bulk charge state, and during the top up charge state. The chip switches into the top up charge timer when the bulk charge termination current is reached. There is no external evidence that this has happened. The bulk charge termination current is nominally 101mA.

Procedure:

With the same connections as TEST 4, set PSU2 voltage to 16V. With the DVM monitoring the voltage on TP5, slowly increase PSU2 voltage until the charge current drops to less than 100mA. At this point the battery voltage will equal the float voltage setting. Read this from the DVM.

The float voltage should be between 16.72 and 16.88V nominal 16.80V

7.3.3 Battery backup tests

7.3.3.1 Test 7 Battery backup function

This tests checks the battery backup function

Procedure:

With the same connections as TEST 6, set PSU2 voltage to 16V. Disconnect PSU1 from the input connector. PSU2 should now show a positive current of about 145mA as the battery (PSU2) is supplying the load. LED1B (Power ON) should be lit.

7.3.3.2 Test 8 Battery lockout

This test measures the battery lockout voltage

Procedure:

With the same connections as at the end of TEST 7, reduce PSU2 voltage slowly until all the LEDs go out. Read the voltage on the DVM. This is the battery lockout threshold.

Battery lockout threshold should be between 10.84 and 11.17V nominal 11V

Note. Once the battery lockout state has been entered, it can only be exited by applying external power to J1. The behaviour will be different depending upon whether SW1 is on or off:

1. SW1 OFF. On application of external power D3 will be lit. This shows that a battery lockout state has occurred. This state may be cleared by switching on SW1. This applies a reset pulse to the chip via C15, etc.

2. SW1 ON. On application of external power the chip will be reset by the rising voltage at TP4, and D3 will not be on.

7.3.3.3 Test 9 Battery low LED setting

The battery low LED is controlled from a comparator that is not part of the main control chip.

Procedure:

With the same connections as TEST 8, set PSU2 voltage to 14V and disconnect the external power. Monitor the voltage at TP5 with the DVM, and adjust PSU2 until the voltage at TP5 is 14.000V ± 50mV. Now adjust RV1 until LED2C (battery low) is just on.

7.3.3.4 TEST 10 Battery backup switch voltage drop

This test checks the voltage drop across the battery switch TR2 at high load currents.

Procedure:

Connect the DVM between TP4 and TP5. Connect the 12Ω load between SW1 pin 3 and ground. Set PSU2 to 15V, with current limit 1.5A. Disconnect external power. Switch on SW1. PSU2 should now be supplying the load with a current of about 1.2A. Read the voltage drop from the DVM.

The voltage drop across the battery switch should be less than 150mV

7.3.3.5 Test 11 External power switch voltage drop

This test checks the voltage drop across the external power switch TR1 with a high load current.

Procedure:

With the same connections as TEST 10, set the current limit on PSU1 to 2.0A. Connect the DVM between TP3 and TP4. Connect external power and switch on SW1. The external power should be supplying the load. The DVM should indicate the voltage drop across TR1.

The voltage drop should be less than 75mV

7.3.4 Conclusion

This concludes the E10-P board test. It is not possible to make a direct test of the various timers used by the control chip, particularly the top up charge timeout (56 minutes) which should terminate the charge cycle. Other parameters which have not been measured are the Auto Recharge Threshold Voltage, and the Battery Overvoltage Threshold. It is very improbable that these are incorrect if the other parameters have been measured correctly.

The batteries may now be connected, together with the rubidium oscillator. The final product test should include at least 1 discharge/charge cycle.

7.3.5 Result Sheet

Test No.	Description	Upper Limit	Lower Limit	Nom	Unit	Result
1	**Chip under voltage lockout**					
1.1	Under voltage lockout exit threshold	4.35	3.70	4.00	Vdc	
1.2	Supply current (PSU1)	20.00			mA	
1.3	Under voltage lockout entry threshold	4.10	3.40	3.70	Vdc	
2	**AC power available threshold**					
2.1	AC present entry threshold	11.96	11.26	11.05	Vdc	
2.2	AC present exit threshold	11.38	10.72	11.05	Vdc	
2.3	Supply current (PSU1)	100.00			mA	
3	**Preconditioning charge current**					
3.1	LED Status					Sat/Unsat
3.2	Preconditioning charge current	133.00	71.00	102.00	mA	
3.3	Supply current (PSU1)			300.00	mA	
4	**Bulk charge threshold and bulk charge current**					
4.1	Bulk charge threshold voltage	12.80	11.20	12.00	Vdc	
4.2	Bulk charge current	550.00	467.00	508.00	mA	
4.3	Supply current (PSU1)			800.00	mA	
5	**Battery over temperature cut off**					
5.1	Charge Current	10.00			mA	
5.2	LED2B on					Sat/Unsat
6	**Float voltage**	16.88	16.72	16.80	Vdc	
7	**Battery backup function**					
7.1	PSU 2 Current			145.00	mA	
7.2	LED1B on					Sat/Unsat
8	**Battery lockout**	11.17	10.84	11.00	Vdc	
9	**Battery low LED setting**					Sat/Unsat
10	**Battery backup switch voltage drop**					
10.1	PSU 2 Current			1.20	A	
10.2	Voltage drop	150.00			mV	
11	**External power switch voltage drop**	75.00			mV	

8 LTC4110 settings

a.	Basic	4 cell standard Li-Ion
b.	Soft start	default values
c.	Back drive protection	not used

1. PRECONDITIONING CHARGE

a.	Current	101mA ±30%
b.	Termination voltage	12V (11.2V to 12.8V)
c.	Timeout	56 minutes

2. BULK CHARGE

a.	Current (Constant current phase)	508mA ±8%
b.	Voltage (Constant voltage phase)	16.8V (16.72V to 16.88V)
c.	Termination current	102mA
d.	Timeout	3.72 hours

3. TOP UP CHARGE

a.	Voltage	16.8V (16.72V to 16.88V)
b.	Timeout	56 minutes

4. EXTERNAL POWER

a.	Threshold (rising)	11.61V
b.	Threshold (falling)	11.05V

5. BATTERY LOCKOUT

a.	Voltage	11.0V

6. AUTO RECHARGE

a.	Threshold voltage	15.96V

7. BATTERY LOW INDICATOR

(Not a LTC4110 setting)

a.	Threshold	14V

8. OVER TEMPERATURE CUT OFF

a.	Maximum temperature	55^{o}C

Notes:

1) If preconditioning charge timeout expires before termination voltage is reached a charge fault is indicated, and charging stops.

2) If bulk charge timeout expires before termination current is reached, a charge fault is indicated and charging stops

3) If the battery discharges below the battery lockout voltage, the load is disconnected and a backup fault is indicated. This state lights LED3 (on board) when external power is supplied to recharge the battery. This state must be cleared by switching off and on using the front panel switch.

4) If, when external power is applied, the battery voltage is above the auto recharge threshold voltage, then no charge cycle will start and the charge LED will not light.

5) If thermistor temperature rises above 55^{o}C, charge cycle will pause until temperature falls.

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