E10-LN

Low Noise Miniature Rubidium Oscillator Module

USER'S HANDBOOK

Revision	Date	Description	By
1	1st May 2013	Initial Release	N. Law
2	21st May 2013	Board Test Provisional for: - Board Issue 1.00 Firmware Revision 1.00	N. Law
3	12th January 2017	Pin layout re-arrangement	O. Khorremy

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.

1.2 Voltage, Frequency and Power Characteristics

1.2.1 Module Power Requirements

Input Voltage	12Vdc – 18Vdc
Input Current	1.7A max

1.3 Environmental Conditions

1.3.1 Temperature

Operating (ambient)	-20°C to +50°C
Storage	-40°C to +85°C

1.3.2 Magnetic Field

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

1.4 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 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-LN module contains two principal internal units:

1) A Rubidium Atomic Frequency Standard.
2) An Oven Controlled Crystal Oscillator used to provide a clean low noise output.
3) The Associated External Power Supply.

Additionally 2 indicators are available to monitor the status of the instrument. These are: Rubidium Unlocked and Power.

3.2 Getting Started

Check that the appropriate supply voltage is being used. Connect the external supply to the unit either via JP1 P2 +Vdc P3 GND or JP2 P1 +Vdc P2 GND.

The 'ON' indicator LED will come on and it will remain on. The 'UNLOCKED' indicator will initially come on.

The 10 MHz output is available from the SMA socket on the side of the module.

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. Once the rubidium has locked the 'UNLOCKED' indicator LED will turn off and will remain off as long as the instrument is performing correctly.

4 Specification

1. Output Characteristics:

a. Frequency	10MHz Sine	
b. Impedance:	50 Ω nominal	
c. Level:	+7 dBm ±2 dBm	
d. Connector:	SMA	
e. Number	1	

2. Harmonics

a. Second harmonic	<-30dBc	

3. Spurious Outputs:

< -80 dBc

4. Accuracy

a. At shipment @ 25°C	0.05ppb	$\pm 5x10^{-11}$

5. Short Term Stability:

a. 1s	0.002ppb	$2x10^{-12}$
b. 10s	0.005ppb	$5x10^{-12}$
c. 100s	0.002ppb	$2x10^{-12}$

6. Drift

a. 1 day	0.003ppb	$3x10^{-12}$
b. 1 month	0.04ppb	$4x10^{-11}$

7. Phase Noise

a. 1Hz	-110dBc/Hz	
b. 10Hz	-140dBc/Hz	
c. 100Hz	-145dBc/Hz	
d. 1kHz	-155dBc/Hz	

8. Input Voltage

+12Vdc to +15Vdc

9. Input Power

6W @ 12Vdc, 25°C Max 1.7A @ Warm up

10. Warm Time

a. @ 25°C	5 Minutes to lock	

11. Retrace

0.02ppb $\leq \pm 2x10^{-11}$

12. Magnetic Field Sensitivity

0.02ppb $< \pm 2x10^{-11}$

13. Mechanical

a. Size	96 x 60 x 40 mm	
b. Weight	300g	

14. Warranty

24 months

15. Temperature

a. Operating	-20°C to +50°C	
b. Storage	-40°C to +85°C	

16. Temperature Coefficient

a. Ambient	0.3ppb $3x10^{-10}$	

17. MTBF

100,000 hours

18. Environmental

RoHS

19. EMI

a. Compliant to	FCC Part 15 Class B	

PLL Locks

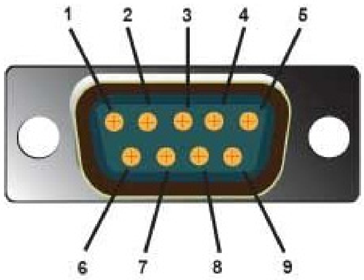
Ensure that the "UNLOCKED" indicator goes off within the allocated lock time.

4.1 Connector

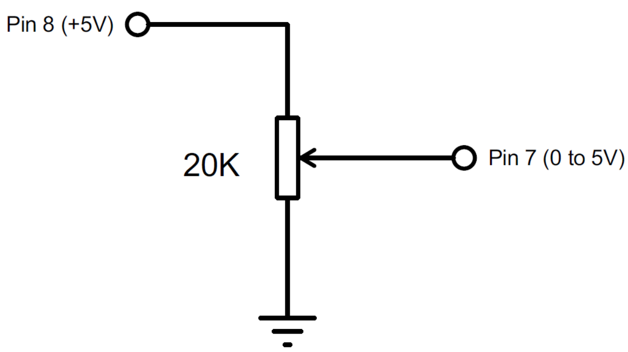
SMA

10MHz RF Output RA SMA

D9 Connector



Pin No.	Function	Description
1	Lock Status	OFF: locked, ON: not locked
2	RXD	Serial data receive
3	TXD	Serial data transmit
4	Power Supply	Input power supply between +12 to 15V
5	GND	Ground
6	GND	Ground
7	Frequency adjustment	Apply 0-5 volt to adjust the frequency
8	Voltage reference	+5V supply voltage to be used for frequency adjustment
9	Not used	Not used



5 RS232 Control Codes

RS232 control codes (all values following command or returned from the microcontroller are hexadecimal)

* = backed up in EEPROM

UA **User adjust**

UA? returns user parameters

aa bbbb

	aa	*is bandwidth control: bits set:*	*bit0,1, 2:*	*bandwidth (0 to 7)*
			bit3 to 6:	*not used*
			bit7:	*controlled oscillator negative slope*
*	*bbbb*	*is clock registers 3 and 4 (elapsed time)*		
	UABaa	write new bandwidth control byte		

OS **Overall Status**

OS? returns overall status bytes:

aa bb cccc dd ee ff gg hhhh

*	*aa*	*is test status byte:*	*bits set::*	*bit0,1,2:*	*bits 0 to 2 DAC output select*
				bit3:	*no integrator update*
				bit4:	*no proportional term*
				bit5:	*AGC off*
				bit6:	*not used*
				bit7:	*inhibit state control*

bits 2,1,0:	
000	*no test output, fine tune DAC used for tuning*
001	*sub sampled I*
010	*sub sampled Q*
011	*PLL Integrator upper 16 bits*
100	*Phase result*
101	*I sample (filtered)*
110	*Q sample (filtered)*
111	*reference CH6 (filtered)*

	bb	*is lock status byte:*	*bits set*	*bit0 to 2:*	*State control, states 0 to 7*
				bit3:	*set to normalise tuning DACs (cleared automatically)*
				bit4:	*OCXO warmed up*
				bit5:	*Loop locked*
				bit6:	*narrow range phase detector in use*
				bit7:	*set to inhibit auto load of PLL gain parameters*
	cccc	*is PLL control:*	*bits set*	*bit0,1,2,3*	*subsample rate*
				bit4, 5, 6, 7	*exp filter order*
				bit8, 9, 10, 11	*integrator gain*
				bit12, 13, 14, 15	*proportional gain*
*	*dd*	*is quadrature delay line setting*			
*	*ee*	*is tune voltage span (FFh min,00h max) 0 to 5.8V (FFh), and 0 to 10V (00h):*			
	ff	*is Q amp AGC setting*			
	gg	*is I amp AGC setting*			
	hhhh	*is OCXO current*			

OSTaa	write new test status byte
OSLbb	write new lock status byte
OSGcccc	Write new PLL control
OSDdd	Write new quadrature setting
OSSee	Write new tuning span
OSQff	Write new Q amp AGC byte
OSIgg	Write new I amp AGC byte

PL **Phase lock loop**

PL? returns current status of PLL

aaaa bbbb cccccccc dddd eeee

	aaaa	*last value of I sample(filtered) , 2s complement, 16 bit*
	bbbb	*last value of Q sample(filtered), 2s complement 16 bit*
*	*cccccccc*	*last value of PLL integrator (32 bit integer)*
	dddd	*Coarse tune DAC 16 bit integer*
	eeee	*Fine tune DAC 16 bit integer*

PLIcccccccc	write new PLL integrator
PLCdddd	write new coarse tune DAC
PLFeeee	write new fine tune DAC
PL+	enter command PL? into repeat stack

PD **Phase detector**

PD? returns phase detector parameters

aaaa bbbb cccc dddd eeee

aaaa	*Last phase result, 2s complement*
bbbb	*Last mod[I] +mod[Q]*
cccc	*2.5V reference (filtered)*
dddd	*mod (phase result) (filtered) lsb=0.763ps*
eeee	*mod(freq offset) (filtered) lsb = 5.82E-15*

PD+ write PD? to command repeat stack

EU EEPROM update (backed up values)

SR Software Reset

ER EEPROM read

ERCaabb	returns bb bytes from starting address aa as ASCII characters
ERNaabb	returns bb bytes from starting address aa as hexadecimal numbers (character pairs)

EW EEPROM write

EWCaabbccccc------c

writes bb characters to starting address aa. Correct number of characters must be included in string

EWNaabbcccc------c

Writes bb bytes to starting address aa. Character pairs cc etc. are interpreted as hexadecimal numbers.

RI Repeat Interval

RI?	returns command repeat interval
aa	
aa	*8 bit command repeat interval multiplier. Range 1 to 255. Command repeat interval is 50ms x aa*
RI0aa	write new command repeat interval
RID	cancel command repeat and clear command repeat stack

Quartzlock

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