A1000

Rubidium Time & Frequency Standard

USER'S HANDBOOK

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1	1st May 2013	Initial Release	N. Law
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3	17th July 2017	Layout change, Command update	N. Law
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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 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 Voltage, Frequency and Power Characteristics

Voltage 90-240V AC Frequency 40-50Hz

Power characteristics 500mA Max

1.3 Environmental Conditions

1.3.1 Temperature

Operating (ambient)	-20°C to +60°C
Storage	-20°C to +70°C

1.3.2 Magnetic Field

Sensitivity	≤2×10^{-11}/ Gauss
Atmospheric Pressure	-60m to 4000m
	<1×10^{-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

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 A1000 unit contains two principal internal units:

1) The Rubidium Atomic Frequency Standard.
2) The Associated power supply.

Additionally a small indicator is fitted to the front panel to monitor performance of the Rubidium.

Other options may also be fitted to suit customer requirement, for example:

a) Sine-TTL conversion board.
b) Universal Output Board.
c) 2048kHz generator board.
d) 6 Output.

3.2 Getting Started

1) Check that the AC mains voltage selector is appropriate to the supply voltage being used. Connect the mains supply to the unit (at the rear), the ‘AC’ green indicator LED will come on. Then switch on the unit.
2) The ‘ON/OFF’ blue indicator LED and ‘Rb Lock Status’ red indicator LED will come on immediately the power is switched on, ‘Rb Lock Status’ indicator LED will remain on initially and it will turn off once the Rubidium is locked.
3) The 10 MHz (or option) is available from the appropriately labelled BNC/SMA socket(s) at the rear of the unit.
4) The units’ warm time is approximately 20 minutes. Frequency stabilisation time is up to 45 minutes depending on the detailed specification of the particular Rubidium fitted.
5) All outputs are fed to the rear mounted BNC/SMA socket(s), which are appropriately labelled.

4 Specification

1. **Output Characteristics:**

a. Frequency	10MHz Sine
b. Impedance:	50 Ω nominal
c. Level:	+10 dBm ±2 dBm
d. Connector:	BNC/SMA
e. Number	1, 6 or 12

2. **Harmonics**

a. Second harmonic	<-30dBc

3. **Spurious Outputs:** < -80 dBc

4. **Accuracy**

a. At shipment @ 25°C	$\pm 5\times10^{-11}$

5. **Short Term Stability:**

a. 1s	5×10^{-12}
b. 10s	6×10^{-12}
c. 100s	8×10^{-12}

6. **Drift**

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

7. **Phase Noise**

a. 1Hz	-105dBc
b. 10Hz	-130dBc
c. 100Hz	-140dBc
d. 1kHz	-155dBc

8. **Input Voltage** 100 to 240AC

9. **Warm Time**

a. @ 25°C	6 Minutes to lock

10. **Retrace** $\leq\pm 2\times10^{-11}$

11. **Magnetic Field Sensitivity** $<\pm 2\times10^{-11}$

12. **Mechanical**
    a. Size: 480 x 257 x 44mm
    b. Weight: <2Kg

13. Warranty

24 months

14. Temperature

a. Operating — -20°C to +60°C
b. Storage — -20°C to +80°C

15. Temperature Coefficient

a. Ambient — 1×10^{-9}

16. MTBF

100,000 hours

17. Environmental

RoHS

18. EMI

a. Compliant to — FCC Part 15 Class B

5 Specification (Optional)

1. Input Characteristics

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

2. Output Characteristics:

a) Frequency	10MHz Sine
b) Impedance:	50 Ω nominal
c) Level:	+10 dBm ±2 dBm
d) Connector:	BNC
e) Number	1, 6 or 10

3. PLL Bandwidth

Adaptive/Automatic

4. Short Term Stability:

a) 1s	$\leq 2x10^{-12}$
b) 100s	$\leq 4x10^{-12}$

5. Phase Noise (Typical)

a) 1Hz	-108dBc/Hz
b) 10Hz	-130dBc/Hz
c) 100Hz	-140dBc/Hz
d) 1kHz	-155dBc/Hz

6. Input Voltage

100 – 240A ac 50Hz

7. Remote System Interface

RS232
Remote control and interrogation of all instrument functions and parameters

8. Mechanical

a) Size	H x W x D (mm) 89 x 483 x 280 mm

9. Temperature

a) Operating	-20°C to +60°C
b) Storage	-40°C to +85°C

10. Warranty

2 Year as standard

6 RS-232 Control Commands

Note:

The Control codes are provided for monitoring purposes only, any modification to the DPLL parameters could significantly affect the performance of the Quartzlock A1000 and should only be modified by a qualified Quartzlock Engineer.

1PPS Locking Commands

OS **Overall Status (1PPS locking)**

OS? returns overall status bytes:

aa bb cc dd e f

	aa	is test status byte:	bits set:	bit0:	200PPS output (default 1PPS)
				bit1:	200PPS input (default 1PPS)
				bit2:	NU
				bit3:	disable 1PPS output
				bit4:	disable 1PPS input timetag
				bit5:	disable frequency correction (Kalman filter updated)
				bit6:	disable Kalman filter update
				bit7:	disable state control
	bb	is lockstatus byte:	bits set:	bit0,1,2:	state (0 to 7)
				bit3:	normalise DACs (cleared automatically)
				bit4:	Rubidium warmed up
				bit5:	loop locked
				bit6:	NU
				bit7:	zero clock on next 1PPS capture
*	cc	is output status byte:	bits set:	bit0:	1PPS base = last input time tag
				bit1:	1PPS base = Kalman phase estimate otherwise 1PPS base is zero
				bit2:	Disable user 1PPS offset calculation(enables PO command)
				bit3:	NU
				bit4,7:	NU
*	dd	is autocal byte:	bits	(set to FF on loading new firmware)	
				bit0:	set loads EEPROM default 0, then cleared
				bit1:	set initiates auto rubidium calibration, then cleared
				bit2:	set when Rb cal is in progress
				bit3:	NU
				bit4,7:	last EEPROM default number

e (decimal string) is OCXO current 0 to 660mA

* f (decimal string) is running time 0 to 5962 hours

OSTaa write new test status byte
OSLbb write new lockstatus byte
OSPcc write new output 1PPS status byte
OSAdd write new autocal byte

PO **1PPS OUT**

PO? returns current status of 1PPS output

a b c d

a (decimal string)	modulo200 counter (5ms) range 0 to 199
b (decimal string)	main counter (100ns) range 0 to 49999
c (decimal string)	delay setting (50ns) range 0 to 1
d (decimal string)	vernier (0.25ns) range 0 to 255

POAaa (hex)	write new modulo200 counter
POBbbbb (hex)	write new main counter
POCcc (hex)	write new delay setting
PODdd (hex)	write new vernier

PD **1PPS OUT**

PD? returns current user 1PPS offset in decimal ns

a

* a (decimal sting) last user 1PPS offset, -500,000,000 to 499,999,999 ns

PD(space)(string)(carriage return) inputs new user 1PPS offset in seconds (floating point format)

TO **TIMETAG**

TO? returns last time tag parameters

a b c

a (decimal string)	last time tag (ns)
b (decimal string)	last capture
c (decimal string)	last increment

TO+ write TO? to command repeat stack

PM **PERFORMANCE MEASURE**

PM? returns last time tag in decimal ns, and other performance indicators

a b c d e f g

a (floating point)	Corrected time tag
b (floating point)	Last Kalman phase estimate
c (decimal string)	Mean square measurement error (ns squared)
d (decimal string)	Filtered performance indicator 0 to 32768
e (decimal string)	S1 multiplier
f (floating point)	Last frequency estimate
g (floating point)	Mean of frequency estimate

Notes:
The performance indicator is the square of the current fractional frequency estimate divided by the P22 element of the error covariance matrix multiplied by 2048. The normal running value is 0 to 100 The mean square measurement error is the (Kalman phase estimate minus the current time tag)^2 and filtered in an 6th order exponential filter. Units are ns^2.

The S1 multiplier is the constant used to multiply the S1 system noise parameter(random walk FM). This results in a recalculation of the Q matrix (system covariance matrix). This adjusts the filter for expected increased drift rate of the controlled oscillator.

The mean of the frequency estimate is the Kalman frequency estimate filtered by a 5th order exponential filter

PM+ write PM? to command repeat stack

KP **Kalman filter parameters**

* KP? returns current state vector and "P" matrix

X1	X2	X3	
P11	P12	P13	
	P22	P23	
		P33	in floating point format

KP+ write KP? to command repeat stack

KSx(space)(string)(carriage return) inputs a new floating point value where x is the matrix element

---

KZ **Measurement parameters**
* KZ? returns the latest measurement, and the current measurement noise parameter

Z(corrected) Timetag R

Note: Z is the corrected measurement in seconds, Timetag is the uncorrected timetag in ns.
R is the expected variance of the measurement noise in seconds squared.

KZ1 (space) (string) (carriage return) inputs a new R
KZ+ Write KZ? to command repeat stack

OC **Oscillator control parameters**

* OC? returns latest oscillator control constant and maximum tuning voltage

OC1 OC2 S1 S2 S3

Note OC1 is oscillator tuning constant in fractional frequency /volt, and OC2 is the maximum tuning voltage in volts, assumed 0V minimum.
Note S1 is the level of white FM noise, and S2 the level of random walk FM noise, and S3 the level of random run FM noise. These are fixed parameters that describe the oscillator being modelled.

OCx (space)(string)(carriage return) inputs new OC1, OC2,S1 or S2 where x is the item number

OT **Oscillator tuning control**

OT? returns tuning word and DAC values

aaaaaa bbbb cccc

*	aaaaaa	(hex)	24 bit tuning word
	bbbb	(hex)	coarse tuning DAC value
	cccc	(hex)	fine tuning DAC value

OTTaaaaaa inputs new tuning word
OT+ writes OT? to command repeat stack

CA **1PPS time tag parameters**

a b c d e

a (decimal string)	capture
b (decimal string)	uncorrected increment
c (decimal string)	filtered 100ns calibration measurement
d (decimal string)	filtered 200ns calibration measurement
e (decimal string)	modulo200 counter

CA+ writes CA? to command repeat stack

TR **Test Ramp**

TR? returns simulated drift rate in fractional frequency / second

TR (space) (floating point string)(carriage return)

Inputs new simulated drift rate

Digital PLL Commands

UA **User adjust**

UA? returns user parameters

aa b

*	aa	is bandwidth control: bits set:	bit0,1,2:	bandwidth (0 to 7)
			bits 3 to 6:	NU
			bit 7:	controlled oscillator negative slope

* b (decimal string) is elapsed time , 0 to 5962hours

UABaa write new bandwidth control byte

PS **Overall Status (digital PLL)**

PS? returns overall status bytes:

aa bb cccc dd ee

*	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:	NU
				bit7:	inhibit state control
			bits 2,1,0:	000	no test output, fine tune DAC used for tuning
				001	Isample (filtered)
				010	Qsample (filtered)
				011	PLL Integrator upper 16 bits
				100	Phase result
				101	last Isample
				110	last Qsample
				111	|I| + |Q| (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 DC amp AGC setting

PSTaa	Write new test status byte
PSLbb	Write new lock status byte
PSGcccc	Write new PLL control
PSDdd	Write new quadrature setting
PSQee	Write new DC 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

XD Phase detector

XD? returns phase detector parameters

aaaa bbbb c d

aaaa	Last phase result, 2s complement
bbbb	Last mod[I] +mod[Q]
c (decimal string)	mod (phase result) (filtered) in radians
d (decimal string)	mod(freq offset) (filtered) in radians/second

XD+	write PD? to command repeat stack

EU **EEPROM update** (backed up values from RAM)

ED **load EEPROM and RAM with default values**

EDa loads EEPROM with default a

a=0 default automatically loaded after new firmware
a=1,2....9 parameters for other oscillator types(defined in firmware)

SR **Software Reset**

ER **EEPROM read**

ERCaaaabb returns bb bytes from starting address aaaa as ASCII characters
ERNaaaabb returns bb bytes from starting address aaaa as hexadecimal numbers(character pairs)

RI **Repeat Interval**

RI? returns command repeat interval

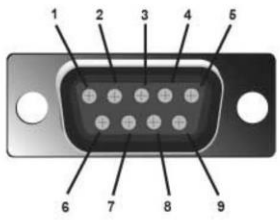
aa

aa 8 bit command repeat interval multiplier. Range 1 to 255. Command

repeat interval is 1sec x aa

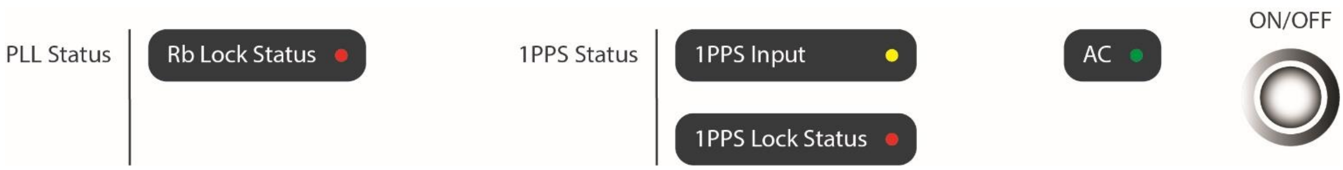
RI0aa write new command repeat interval
RID cancel command repeat and clear command repeat stack

7 RS-232 Configuration



Pin No.	Function	Description
1	10MHz Lock Status	10MHz lock status – Locked = Low / Unlocked = High
2	RXD (PLL)	Serial data receive
3	TXD (PLL)	Serial data transmit
4	1PPS Lock Status	1PPS Synch lock status – Locked = Low / Unlocked = High
5	GND	Ground
6	-	-
7	-	-
8	-	-
9	-	-

8 LED Indicator and Status



Indicator	Colour	Condition	Description
ON/OFF	**White**	ON	The unit is ON.
		OFF	The unit is OFF.
AC	**Green**	ON	The AC power is ON.
		OFF	The AC power is OFF.
Rb Lock Status	**Red**	ON	The Rubidium is not locked.
		Flashing	The Rubidium is locked and is fine tuning the frequency.
		OFF	The Rubidium is locked.
1PPS Input	**Yellow**	Flashing	1PPS input is present.
		OFF	1PPS input is not present.
1PPS Lock Status	**Red**	ON	Not locked to external 1PPS.
		Flashing	Locked to external 1PPS and is fine tuning the frequency, or is in Holdover Mode due to the removal of the external 1PPS.
		OFF	Locked to external 1PPS.

Quartzlock

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