Precise Time and Frequency, Inc

ptf 4220A Rubidium Standard

Operation and Maintenance Manual

Document #: 10282
Revision: D

Certificate of Conformance

This certificate confirms that the following equipment :

Unit type : ***ptf*** 4220A Rubidium Standard

Serial Number : ___________________________

has successfully passed a FINAL ACCEPTANCE TEST and conforms in all respects of form, fit, and function to current specifications, including regulatory requirements and certifications.

Inspected and verified by: Date:

______________________ ______________________

For Precise Time and Frequency, Inc

Introduction

Congratulations on your purchase of the ***ptf*** 4220A Disciplined Rubidium frequency standard !

This product meets the highest standards of quality and reliability, and Precise Time and Frequency, Inc wants to insure that you enjoy the maximum benefits and functionality that this unit can provide.

The technology within this unit uses the decades of experience in time and frequency applications of our engineering team, to give a product that is highly advanced, and provides an extremely stable and accurate reference for your timing and frequency application,

Operation of the unit is straightforward and the contents of this manual are designed to provide a basic understanding of the product, set-up and functionality, and procedures for maintenance and repair.

If you have any questions or concerns, please do not hesitate to contact our technical service department who will be pleased to provide assistance.

Please help us to live up to our stated objectives, our company motto is:

KNOW THE NEEDS AND EXPECTATIONS OF YOUR CUSTOMER…THEN DELIVER!

Once again, thank you for purchasing our product, and we look forward to you utilizing Precise Time and Frequency, Inc. for your future time and frequency instrumentation needs.

President
Precise Time and Frequency, Inc.

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1. Rubidium Atomic Module

The heart of the ***ptf*** 4220A is a high performance rubidium module that provides a highly accurate and stable 10MHz reference.

The atomic standard operates by disciplining an internal quartz crystal oscillator to a hyperfine transition at 6.834,682,612 GHz in the rubidium. A photo detector is used to detect the amount of light (transmitted by a rubidium discharge lamp) that is transmitted through a resonance cell.

Typically the received light will drop by approximately 0.1% when the rubidium vapor in the resonance cell is exposed to microwave power near the transition frequency. The internal crystal oscillator is then disciplined by monitoring the transmitted light drop while sweeping an RF frequency synthesizer through the transition frequency.

The module uses a microprocessor to control the complex functions of the unit, including disciplining control of the crystal oscillator via a high precision DAC.

The 10MHz output comes directly from a 3^{rd} overtone stress-compensated (SC cut) ovenized crystal oscillator and a dual loop RF synthesizer is used to generate the required rubidium transition frequency at 6.834 GHz.

This method eliminates spurious components while insuring excellent inherent phase noise characteristics out of the module, especially useful when requiring generating high performance outputs such as those provided by the ***ptf*** 4220A.

2. ***ptf* 4220A Rubidium Standard - Technical Overview**

The ***ptf*** 4220A takes the inherently good performance of the internal rubidium module, and improves it to the high level by adding an additional high performance oven controlled crystal oscillator (OCXO) which is phase locked to the rubidium 10MHz.

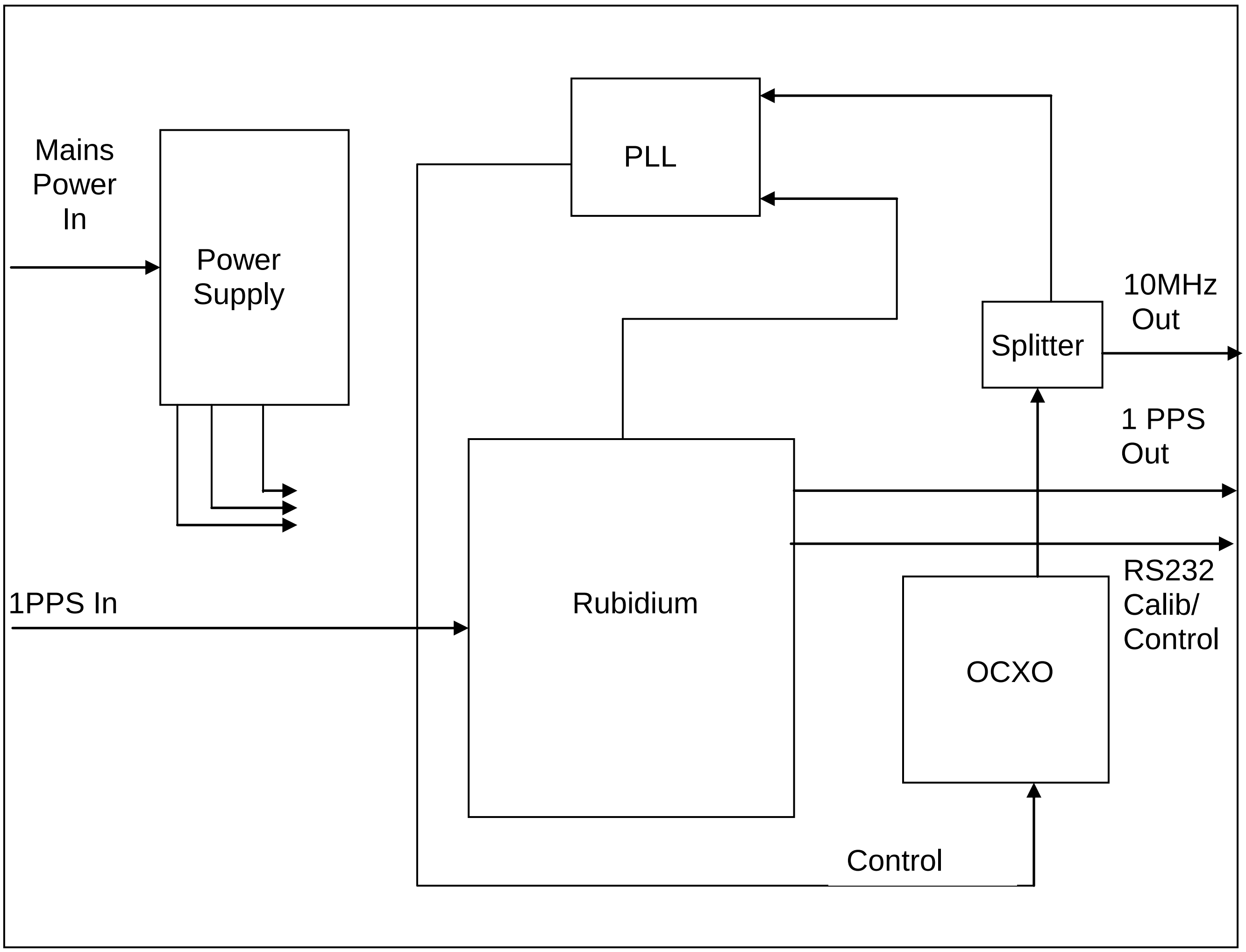


Figure 1. ***ptf*** 4220A Rubidium Standard Schematic

2.1. Technical Description

The ***ptf*** 4220A High Performance Rubidium Standard has an inherent stability due to the atomic reference, which is suitable as a stand-alone reference for many demanding applications.

In addition, the unit comes complete with an external 1PPS input which can be used to lock the ***ptf*** 4220A to another external reference, for example a GPS receiver, which may have excellent long term stability but is unable to provide the short and medium term stability and phase noise performance of the ***ptf*** 4220A.

The external 1PPS input is fed directly to the rubidium module and, if present, is used internally within the module to “lock” the rubidium 10MHz output to the 1PPS input. The time constant of this adjustment can be adjusted by means of the RS232 remote control input, over a period of 5 minutes to 18 hours, to accommodate different quality levels of the external reference. This capability is also an excellent means of calibrating the ***ptf*** 4220A if a higher accuracy reference is available.

Additionally, the 1PPS output, which comes directly from the internal rubidium module, can be offset relative to the 1PPS input by up to 1 second minus 1 ns, with a step resolution of 1 nano second, via the external RS232 interface.

The 10MHz output from the rubidium module is fed to a very high quality OCXO to deliver improved phase from the unit (–108 dBc at 1Hz offset from the 10MHz carrier, down to a floor of –165dBc at 10kHz offset and above). The high performance OCXO is phase locked to the rubidium module to provide improved accuracy and medium term stability.

Any adjustments required (e.g. calibration, frequency offset etc.) are applied directly to the rubidium module, which in turn adjusts the output OCXO by means of the phase locked loop.

Details of input commands etc. available via the RS232 calibration/control connector can be found in section 5 of this manual.

3. *ptf* 4220A Rubidium Standard - Specifications

3.1. Electrical

RF Output	
Frequency	10MHz (sine wave)
Amplitude	>7dbM (max.+10dBm)
	0.5V rms
1PPS Output	TTL Level
Stability (Allan Deviation)	
1 second	2E-11
10 seconds	1E-11
100 seconds	2E-12
Aging	
after 30 days of operation	<5E-11/month
per year	<5E-10
Accuracy at shipment	<5E-11
Phase Noise	
Offset from (10MHz) carrier	Phase Noise (dBc)
1Hz	-108
10Hz	-128
100Hz	-150
1000Hz	-160
10,000Hz	-165
Spurious signals (100k Hz bw)	-80 dBc
Input Power requirements	110 to 240 V AC / 50-60 Hz

3.2. Mechanical/Environmental

Dimensions	2U(3.5”)high x 19”wide x 12” deep
Temperature	
Operating	0 to 50 degrees Celsius
Storage	-10 to +70 degrees Celsius
Humidity	0 to 95%, non-condensing
Weight	< 15 lbs

4. Unpacking/Inspection/Installation

4.1. Unpacking/Inspection

The ***ptf*** 4220A Rubidium Standard together with accessories, is shipped in a custom designed package. Upon receipt the equipment should first be visually inspected for any signs of visible damage.

If visible damage is apparent immediate notification should be given to both Precise Time and Frequency, Inc., and the carrier responsible for shipment. Do not discard the shipping container that should be made available for inspection by the carrier.

For purposes of unit reference, the unit serial number located on the rear panel of the unit should be quoted in all communications.

4.2. Chassis Installation

The ***ptf*** 4220A Rubidium Standard chassis is supplied with rack ears ready for simple installation into a standard 19-inch rack frame/cabinet.

For adequate support when mounted into the rack, a rear supporting bar or tray should be used as the rack ears are designed to secure the unit in the rack, NOT to support the full weight of the unit.

Attention should be given to the internal rack environment to insure the unit operates within it’s specified operating temperature range of 0 to 50 deg. C also noting that the unit relies upon convection for cooling, so there should be sufficient air flow to accommodate this.

4.3. Connections

A diagram showing the connectors is provided in section 4.3.4 at the end of this section.

4.3.1. Power Connection

Power is supplied by connecting the supplied ac power cable to and ac source, at 120 or 230 V ac, +/-15%. The ac input is a universal input – no range switching is required.

4.3.2. Timing Input/Output Connections

BNC connectors are provided for the standard ***ptf*** 4220A Rubidium Standard outputs, the 10MHz sine wave, 1 pulse per second (PPS), and the 1 pulse per second (PPS) input.

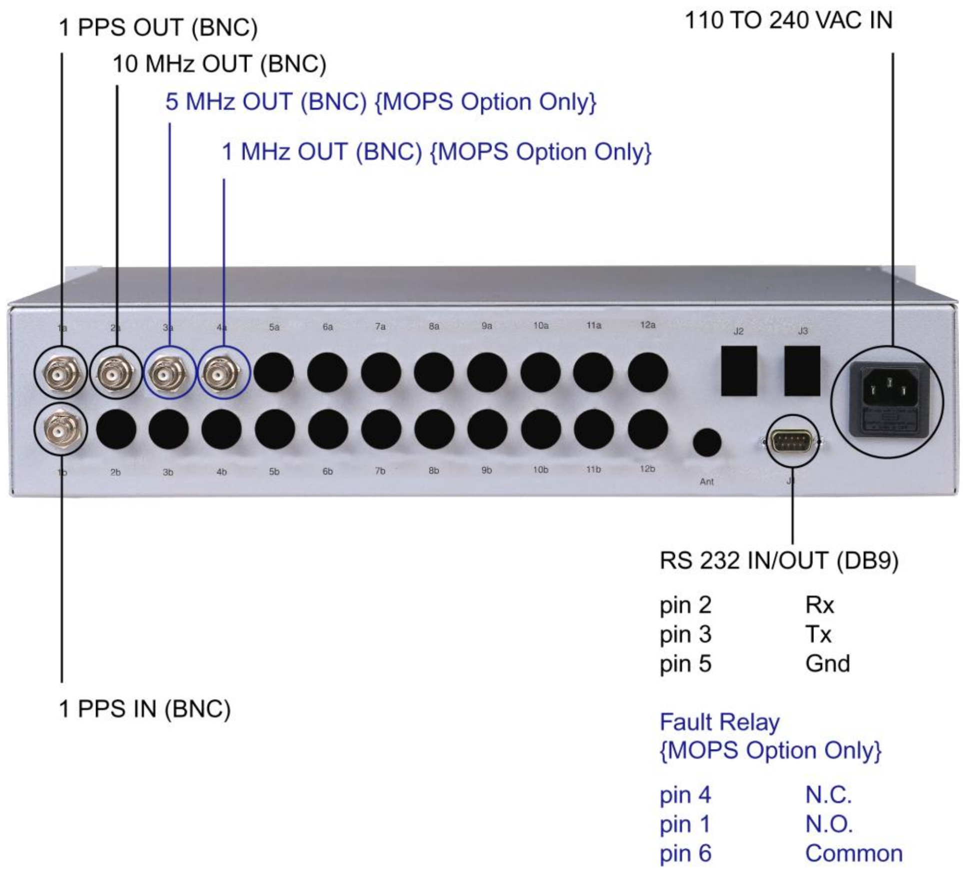
4.3.3. Calibration/Control Connections

Control and monitoring is available through an RS232 port (female 9-contact D connector). The RS232 port is configured as DCE, receiving data on pin 3 and transmitting data on pin 2. Pin 5 is chassis ground, and the other lines are unused. The 2 RJ-11 connectors are not used in this unit.

4.3.4. Diagram of connections

4.3.2.1 Multiple Output Module (Optional)

The ***ptf*** 4220A equipped with an optional **Multiple Output Module (MOPS)** provides both 1MHz *and* 5MHz output capabilities.



5. ***ptf*** 4220A Rubidium Standard – Operation

5.1. Initialization

Warm up.

When first powered on the unit will take approximately 5 minutes to warm up and achieve lock on the rubidium.

Also, the 1PPS Output will be high (+5V) until lock is achieved. Following lock, the 1PPS output will pulse high for 10 microseconds each second.

5.2. Operation

5.2.1. Normal Use

For many applications, powering on is all that is required as the unit is used in its default configuration. For applications requiring more flexible or complex set-up, the RS 232 calibration/monitor port may be used

5.2.2. RS 232 Configuration

The RS232 port factory default setting is 9600-8N1.

A brief description of syntax and summary of the instruction set available on the Calibration/Monitor port is shown in the next section.

5.2.3. Calibration/Monitor Summary Instruction Set

5.2.3.1. Command List

Commands consist of two-letter ASCII mnemonics. A command may be followed one or more numeric values, and punctuation. Command sequences end with a carriage return (ASCII 1310). All commands are case insensitive. Spaces (ASCII 3210) and linefeeds (ASCII 1010) are ignored.

A command followed by a value is used to set a parameter to the value. A command followed by an exclamation point (! or ASCII 3310) indicates that the current value should be saved to EEPROM to be used as the initial value after the next reset. A command followed by a question mark (? or ASCII 6310) is used to request that the current value be returned. A command followed by an exclamation point and a question mark is used to return the EEPROM value.

For example, the gain parameter determines the time constant used to lock the 10MHz oscillator to the rubidium hyperfine transition.

Examples of the four forms of the gain parameter command are:

GA? ;returns the current value of the frequency lock loop gain parameter.

GA7 ;sets the frequency lock loop gain parameter to 7.

GA! ;writes the value of the gain parameter to EEPROM for use after reset.

GA!? ;returns the value of the gain parameter which is stored in EEPROM.

All strings returned by the unit are terminated with a carriage return (ASCII 1310). In the verbose mode, strings are preceded with a linefeed (ASCII 1010) and terminated with a carriage return and a linefeed. If more than one value is returned by a command the values will be separated by a comma (ASCII 4410).

Only commands in **bold type** are available to the end-user. The other commands are factory only commands, which are disabled at the factory.

5.2.4. Instruction Set Summary

Query Value	Set Value or Activate	Write EEPROM	Query EEPROM	Description
Initialize				
RS?	**RS 1**			Restart
VB?	**VB** ***value***			Verbose mode
ST?				Read six status values
LM?	**LM** ***value***	**LM!**	**LM!?**	Lock pin mode
	RC 1	RC!		Recall factory calibration
Freq. Lock				
LO?	**LO** ***value***			Frequency lock loop status
FC?	**FC** ***high,low***	**FC!**	**FC!?**	Frequency control values
DS?				Read detected signals (ω and 2ω)
SF?	**SF** ***value***			Set frequency offset
SS?	SS ***value***	SS!	**SS!?**	Set Slope (SF calibration)
GA?	**GA** ***value***	**GA!**	**GA!?**	FLL Gain parameter
PH?	PH ***value***	PH!	**PH!?**	Phase angle parameter
SP?	**SP** ***r,n,a***	**SP!**	**SP!?**	Set synthesizer parameters
Magnetic Tuning				
MS?	**MS** ***value***			Magnetic switching
MO?	**MO** ***value***	**MO!**	**MO!?**	Magnetic Offset
MR?				Magnet read
1PPS Lock				
TT?				Time-tag (1pps input)
TS?	TS ***value***	TS!	**TS!?**	Time slope cal. (1pps input)
TO?	**TO** ***value***	**TO!**	**TO!?**	Time-tag offset
	PP ***value***			Place pulse (1pps output)
PS?	PS ***value***	PS!	**PS!?**	Pulse slope cal. (1pps output)
PL?	**PL** ***value***	**PL!**	**PL!?**	Phase lock (to 1pps input)
PT?	**PT** ***value***	**PT!**	**PT!?**	Phase lock time constant
PF?	**PF** ***value***	**PF!**	**PF!?**	Phase lock stability factor
PI?	**PI** ***value***			Phase lock integral term

Query Value	Set Value	Write EEPROM	Query EEPROM	Description
D/A Control				
SD0?	SD0,*value*	SD0!	**SD0!?**	Set DAC (RF amplitude)
SD1?	SD1,*value*	SD1!	**SD1!?**	Set DAC (1pps delay)
SD2?	SD2,*value*	SD2!	**SD2!?**	Set DAC (lamp intensity)
SD3?	SD3,*value*	SD3!	**SD3!?**	Set DAC (lamp temperature)
SD4?	SD4,*value*	SD4!	**SD4!?**	Set DAC (crystal temperature)
SD5?	SD5,*value*	SD5!	**SD5!?**	Set DAC (cell temperature)
SD6?	SD6,*value*	SD6!	**SD6!?**	Set DAC (10 MHz amplitude)
SD7?	SD7,*value*	SD7!	**SD7!?**	Set DAC (RF deviation)
Analog Test	(12-bit values)			
AD0?				Spare (J204)
AD1?				+24V(heater supply) / 10.
AD2?				+24V(electronics supply) /10
AD3?				Drain voltage to lamp FET / 10
AD4?				Gate voltage to lamp FET / 10
AD5?				Crystal heater control voltage
AD6?				Resonance cell heater control
AD7?				Discharge lamp heater control
AD8?				Amplified ac photosignal
AD9?				Photocell's I/V converter / 4
AD10?				Case temperature (10 mV/°C)
AD11?				Crystal thermistors
AD12?				Cell thermistors
AD13?				Lamp thermistors
AD14?				Frequency calibration pot
AD15?				Analog ground
Analog Test	(8bit values)			
AD16?				VCXO varactor voltage
AD17?				VCO varactor voltage
AD18?				AGC for RF
AD19?				RF PLL lock signal

5.2.5. Calibration

Specialized equipment is required for calibration of the unit, and therefore it is recommended that the unit be returned to the factory for calibration.

If the user has available the necessary equipment, including a primary reference stand (e.g. caesium standard) phase monitor etc. calibration may be accomplished using the units software controls. Note: in order to adjust the frequency using the SF command, the units 1PPS PLL must be disabled by sending a PL 0 command. For example: SF 1 changes the frequency by +1e-12, SF1000 changes the frequency by +1e-9 and SF -100 changes the freq. by -1e-10.

Magnetic field Control

A magnetic field coil inside the resonance cell is used to tune the apparent hyperfine transition frequency. The magnetic field is controlled by a 12-bit DAC. Increasing the magnetic field will increase the hyperfine transition frequency, which will increase the frequency of the 10 MHz output. The transition frequency may be tuned over about ±3 x 10E-9 by the magnetic field, which corresponds to ±0.030 Hz at 10 MHz.

The output frequency (at 10 MHz) tunes quadratically with field strength, and d□f(Hz) = □ 0.08 * $(DAC/4096)^2$.

A minimum magnetic field should always be present to avoid locking to the wrong Zeeman component of the hyperfine transition, so the 12-bit DAC may be set from 1000 to 4095 with 3000 being the nominal midscale value. (A DAC value of 1000 corresponds to about 6% of the full-scale frequency tuning range, 3000 corresponds to about 53%, while 4095 is 100% of the full-scale range.)

To help cancel frequency shifts due to external magnetic fields, the current in the coil is switched at a 5 Hz rate. The frequency lock-loop averages over a full period of the switch rate to avoid injecting a spur at 5 Hz onto the 10 MHz control signal. The switching of the magnetic field is enabled at power-on and restart, but may be turned on or off by RS-232 command. (see MS command.)

The commands associated with magnetic field control (MO, MS, and MR) allow direct control of the magnetic field circuitry.

For software control of the unit's calibration, use the SF commands, which disable the (internal) analog control and allow the frequency to be adjusted over a range of ±2000x10E-12. (The program will linearize the magnetic field control of the frequency offset)

MS?
MS{0 or 1}
Magnetic switching. The MS command is used to turn off or on the 5Hz switching of the frequency tuning magnetic field. Magnetic switching is enabled when the unit is powered-on or after a restart. (Since the UNIT is calibrated with the field switching enabled, turning off the field switching may alter the calibration.)
Example: MS 1 will turn on the magnetic field switching, and **MS 0** will turn it off. **MS?** will return a .1. if the field switching is currently enabled.

MO?
MO{value} 2300 □≤value≤3600
MO!
MO!?

Magnetic offset. The magnetic offset is the value, determined when the unit is calibrated, which calibrates the unit to 10 MHz. The restricted range is necessary to allow room for user calibration via the internal frequency calibration pot or by an external voltage. If the unit cannot be calibrated to 10 MHz within the allowed range of MO values, then a different setting for the frequency synthesizer is required. (See SP command and the table in Appendix A.
Example: MO 3000 sets the magnetic offset to 3000, which is its nominal (mid-linear scale) value. The **MO?** command reads back the current value of the magnetic offset. **MO!** is used to store the current value of the magnetic offset parameter to EEPROM for use after the next restart. **MO!?** may be used to query the value stored in EEPROM. This value is used on power-up or restarts.

MR?
Magnetic read. This command returns the value that the 12-bit DAC is using to control the magnetic field. This value is computed from the magnetic offset value (see MO command) and the position of the internal frequency calibration pot, external calibration voltage, or value sent by the SF command.

The value is computed from the equation DAC = $\sqrt{(SF*SLOPE + MO^2)}$ where SF is the desired frequency offset in parts per 10E-12(from the cal pot position, the SF command, or the 1pps PLL and is in the range .2000 < SF < 2000), SLOPE is the SF calibration factor with a nominal value of 1450 (see SS command), and MO is the magnetic offset value. The returned value should be in the range of 1000 to 4095.

Example: MR? would return a value of 3450 if the magnetic offset is at 3000, the SF command requested an offset of +2000 x 10-12, and the SS CAL factor has the nominal value of 1450.

6. Maintenance

6.1. Overview

The ***ptf*** 4220A Rubidium Standard uses highly advanced technology components together with some specialty components such as the internal OCXO oscillator.

Advanced techniques with highly sophisticated equipment, are used for assembly and test of the unit.

Due to the above, very little periodic maintenance of the unit is required and the units can be expected to deliver many years of trouble free operation. The sections below describe the few items that may require periodic maintenance.

Any maintenance or service of the unit should be performed at a Precise Time and Frequency, Inc. authorized facility, to insure the appropriate equipment and expertise is available.

6.2. Local Oscillator

The superior phase noise performance of the ***ptf*** 4220A Rubidium Standard is delivered by an high performance Oven Controlled Crystal Oscillator (OCXO).

In normal operation, the Rubidium module phase locks the OCXO to the to the rubidium output, and in turn, if used, the one pulse per second input signal.

Due to aging characteristics of the local oscillator, over a period of time the control voltage used for disciplining moves in one direction, and after a very long period (>10 years) may reach the limit of it's control voltage.

If this occurs, the unit will cease to control the OCXO, and lock will be lost from the PLL. In this situation the unit should be returned for mechanical adjustment to "center" the control voltage.

7. Contact Information – Technical Assistance

   The Precise Time and Frequency, Inc service department normal hours of operation are from Monday to Friday, between the hours of 8.00 a.m. and 5.00 p.m. US Eastern Standard Time.

   24 hour, 7-day technical assistance is available under special contract.

   Before returning any equipment for service or repair please contact our service department for an RMA number.

   Tel: (+1) 781 245 9090
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   e-mail: service@ ptfinc.com

   Shipping address is:

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