PRECISION RUBIDIUM OSCILLATOR

Addendum To
Designer's Reference

1PPS Disciplining

Symmetricom

C/O/106031 ADD

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Scope

This document describes how to connect a one pulse per second (1PPS) source such as a commercial GPS receiver to an X72 to achieve long term accuracy and excellent holdover or flywheeling performance. The following are the only required connections:

- Power
- GPS antenna
- 1PPS from the source to the X72

No serial port communication is required for initial setup unless the user wants to make changes from the factory default settings . Information on setup, operation and integration is provided.

This document is applicable to X72's manufactured after November 2003 with customer firmware versions 5.02 or higher. See the table on page 9 for applicable versions.

Background

GPS technology has made possible time and frequency synchronization world wide. Connecting the 1PPS output from a commercial (civilian) GPS receiver to an X72 provides a cost effective system that maintains highly accurate time and frequency even when GPS signals become unavailable (e.g. jamming, during antenna maintenance, etc.).

The GPS system provides worldwide 1PPS signals with extremely good long term stability. (i.e. <1e-12 averaged over 24 hours). However the short term stability of this signal is often compromised by various noise sources (e.g. man-made, atmospheric conditions, crosstalk, RF multi-path or inter-symbol interference, and GPS receiver oscillator limitations).

Symmetricom has pioneered the use of rubidium oscillators in telecommunications applications. Telecommunications applications often require long term and short term stability beyond the range of free running quartz oscillators. For example, cellular CDMA systems often require 1PPS signals to be synchronized within 2us over very long periods of time even when GPS signals are not available. To achieve this performance system designers must combine the benefits of short term stability (such as from a rubidium or low noise OCXO) with long term stability (such as from GPS, Loran-C, Glonass, or Cesium). Symmetricom is the leader in system products with microprocessor driven circuitry that use the GPS 1PPS system to steer various oscillators (Cesium, Rubidium, and Quartz). These products make it possible to combine the short term with long term stability. Now with X72 the solution can be even more cost effective. The X72 when used with a GPS receiver can provide telecommunications system performance levels that rival levels obtained using Cesium oscillators.

X72 1PPS Functions

The X72 can be configured to:

- Generate a rubidium controlled 1PPS signal
- Measure the difference between an incoming 1PPS signal and the X72 1PPS
- Synchronize X72's frequency and 1PPS output to the incoming 1PPS and provide very long holdover times.

Figure 1 shows the X72 1PPS disciplining block diagram.

When an externally generated 1PPS signal is applied to pin 19 of the J1 26 pin connector on a properly configured X72 the unit can provide the time interval error difference between the 1PPS input and the 1PPS generated inside of the X72 *(See Figure 1).* The difference is read via the RS232 communications "j" command. The "j" command displays the difference between the 1PPS input and the 1PPS generated internally by the X72. The "j" command produces a number representing the number of TICS in a delta register. If the X72 has a 60 MHz crystal, each TIC is 16.7 ns (1.67E-8). Note that this number is in hex format.

A more convenient configuration is to allow X72 to be disciplined by the incoming 1PPS signal. Figure 2 shows the test bench setup. The 1PPS disciplining mode is enabled by default. It can be temporarily disabled by issuing the "g" command followed by a "1" (see The "g" Command on page 8). Typical performance data for this configuration is shown in figures 3 and 4 on pages 10 and 11.

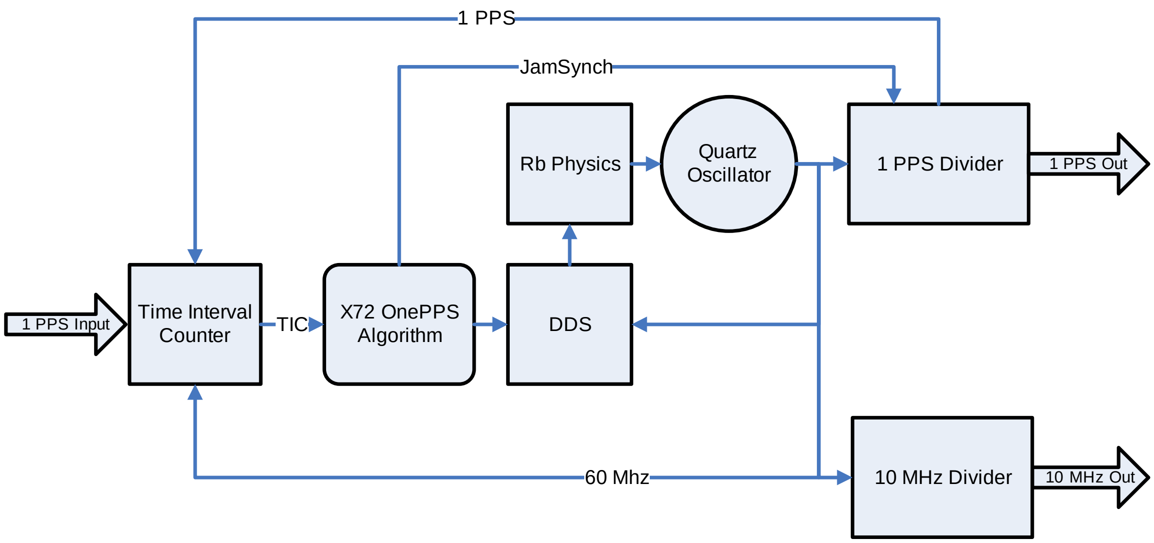

Figure 1 – X72 Time and Frequency Control System

System Requirements

The following are requirements:

- X72 with 1PPS output enabled.
- GPS receiver with less than 300 ns noise.
- One pulse per second input signals must have repeatable rise time with minimal ringing and must conform to the following:
  - 1PPS input can be driven by a standard 3.3 volt logic, 5 volt CMOS, or 5 volt TTL with normal operation at:
    - Input voltage logic high: 2.00V minimum
    - Input voltage logic high: 5.50V maximum
    - Input voltage logic low: 0.00V minimum
    - Input voltage logic low: 0.80V maximum
  - Maximum DC overshoot must be limited to 5.5V or 10mA, whichever is easiest to achieve.
  - Maximum DC undershoot must be limited to –0.5V or 10mA, whichever is easiest to achieve.
  - Minimum pulse width (or hold time) of 50 ns.
  - Input impedance is >100Kohm allowing the user to terminate the 1PPS at the input to the X72 however he wants…50 ohms at the X72 input pin or drive the X72 high impedance directly with a low impedance source such as 50 ohms or any ACMOS gate as long as input voltage level at the X72 pin are met as described above.
- X72 rubidium oscillator subsystem must be locked to achieve synchronization.
- X72 must be set up with the proper time constant and damping factor.
- X72 adapter kit (106495-001) is recommended to facilitate setup.
- PC with Microsoft Windows ™ with Hyperterm ™ . (57600bps, 8 bits with no parity).

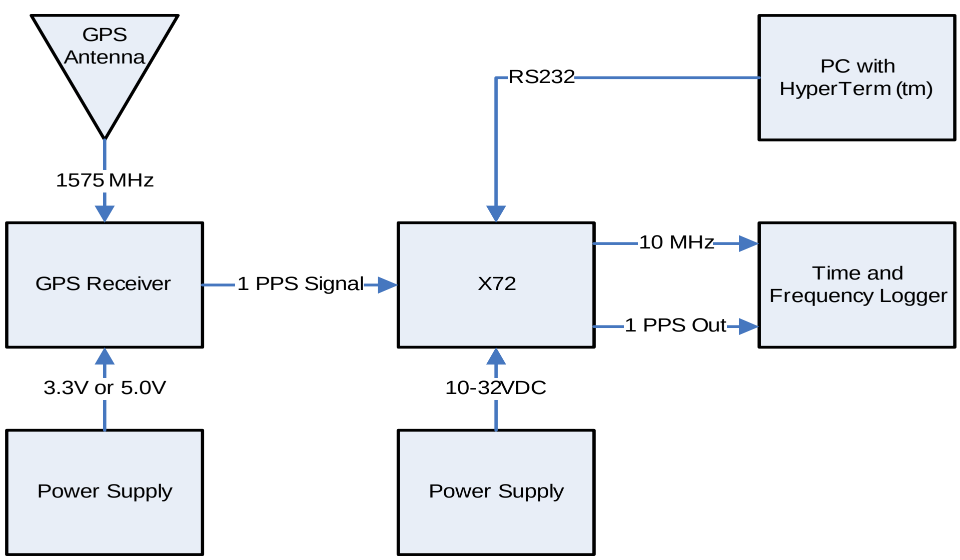

Figure 2 – Test Bench setup

X72 1PPS Algorithm Operation

There are two parameters that can be modified by the user for 1PPS synchronization using the “y” command – Damping Factor and Tau.

- Damping factor - determines the relative response time and ringing in response to each step. Values should be between 0.25 and 4. Values less than 0.25 will default to 0.25 while values over 4 will default to 4.

- Tau (or time constant) - expressed in seconds and determines the time constant of the PLL for following a step in phase for the reference. The range of Tau is 5-100,000 seconds. Values outside this range will cause both the Damping Factor and Tau to change to the factory default settings.

Factory Default

The factory default requires no inputs to the rubidium oscillator from the user. The default value for Damping Factor is 1 and the default Tau is 400. These values are a good starting point and will work well for most GPS applications.

Setting the X72 for 1PPS Synchronization

The following assumes the X72 has a 1PPS enabled Customer version of firmware at revision 5.02 or greater installed.

- Connect the X72 to the Adaptor Test Board of the Developer’s Kit or to a correctly configured equivalent system. (See Appendix C in the main X72 Designers Reference)

- Ensure that Hyperterm ™ is configured to 57,600 BPS, 8 bits, no parity, no flow control and that the keyboard caps lock is off. All input should be lower case.

- Apply power to the system. You will see header information from the X72 displayed similar to the following where you should confirm the firmware version (It is not necessary for the X72 to be locked to enter the 1PPS configuration commands, but it must be locked for actual synchronization to occur):

```
X 7 2   by Symmetricom, Inc., Copyright 2004
SDCP Version 5.02 of 4/2004; Loader Version 2
  Mode CN1B  Flag 0005 Unit serial code is 0311BB0198-h, current tuning state is 6
Crystal: 3938700hz, ACMOS: 989680.00000000hz, Sine: 989680.00000000hz
Ctl Reg: 0204, Res temp off: BFC53F7D., Lamp temp off: C003B7E9.
FC: disabled, Srvc: low
r>
```

Changing the "y" Coefficients

- At the "r>" prompt, press the y key, then the 1 key, then press Enter. (the 1 indicates that you wish to input the Damping Factor).
- Input a value between 0.25 and 4 and then press Enter. See Note 3 below and the previous section on *X72 1PPS Algorithm Operation*.
- At the "r>" prompt, press the y key, then the 2 key, then press Enter. (the 2 indicates that you wish to input the Time Constant).
- Input a value between 5 and 100000 and then press Enter. See Note 3 below and the previous section on *X72 1PPS Algorithm Operation*.
- At the "r>" prompt, press the z key. This saves the 1PPS configuration data to non-volatile memory. If the y coefficients are not saved with the z command, the X72 will revert to the previously saved configuration upon restart. The X72 will respond with the following output (See Note 9):

```
r>z
Saving Tdata 2, serial number xx
1PPS Coefs saved
```

The "y" Coefficients – Factory Default

If the factory default values of Damping Factor = 1 and Tau = 400 are acceptable for your application, no modifications to the y coefficients are required. The X72 1PPS disciplining is enabled at the factory allowing the unit to work right out of the box. If the user wishes to return the y coefficients to the factory defaults, enter the value 0 for both the Damping Factor and Tau in the process described above. This will cause the X72 to operate at the factory default Damping Factor of 1 and Tau of 400.

The "j" Command

The j key can be pressed at any time to return the current value in hex format from the Delta Register (See Note 1) as well as the 1PPS state (See Note 2 and the following table). The output format will appear similar to the following:

```
r>j
Delta Reg: 39386F5  1ppsState:6
```

1PPS States Returned with the j Command.

Description	Expected Values	Action Being Performed
INITIALIZE0STATE	0	Start up initialization
INITIALIZE1STATE	1	Start up initialization
INITIALIZE2STATE	2	Start up initialization
HOLDOVERSTATE	3	Seeking useable 1PPS
JAMSYNC1STATE	4	Synch X72 output 1PPS to input
JAMSYNC2STATE	5	Synch X72 output 1PPS to input
DISCIPLINESTATE	6	Keep X72 output 1PPS aligned to input by controlling X72 frequency
PIDCALCSTATE	7	Calculations for disciplining algorithm
PDATEDDSSTATE	8	Update X72 DDS based on PIDCALCSTATE output.
ALCSLOPESTATE	9	Calculate slope of incoming 1PPS vs. X72 1PPS during holdover.

See *X72 1PPS Algorithm Theory of Operation* beginning on page 12 for additional information on 1PPS states.

The “g” Command

With the “g” command the user can change the X72 to operate in any of three modes which affect the output of the Lock Pin (pin 21). Note that this 1PPS mode can be changed by the user but cannot be saved. If power is cycled to the unit, it will revert to the factory default. The modes are:

0 = 1PPS Disciplining Disabled – Normal Rb Lock Pin functionality. Only the Rb loop needs to be locked to indicate a locked condition on pin 21.
1 = 1PPS Disciplining Enabled - Normal Lock Pin functionality. Only the Rb loop needs to be locked to indicate a locked condition on pin 21.
2 = 1PPS Disciplining Enabled – Requires both Rb loop to be locked AND 1PPS synchronization lock to indicate a locked condition on pin 21.

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Note that there are two types of 1PPS Customer firmware. The *1PPS Standard* firmware provides an Rb or Rb/1PPS lock indicator at pin 21 and a Service indicator on pin 8 of the X72 I/O connector. The *1PPS LED* firmware uses the same functions for pin 21, but pin 8 is reserved for 1PPS lock indication only. There is no Service pin on the *1PPS LED* versions. The factory default mode set by the g command for each firmware version is:

1PPS Standard Firmware – Mode 2. Rb lock and 1PPS lock indicated on pin 21.
1PPS LED Firmware – Mode 1. Rb lock only indicated on pin 21 and 1PPS lock indicated on pin 8.

The key sequence to change the output/lock indicator mode with the g command is as follows:

- At the “r>” prompt, press the g key and then press either the 0, 1, or 2 keys depending upon the output mode you wish to set. Then press Enter.

NOTES

1. These numbers are in HEX format.
2. 1ppsStates: 0-2 - Initialize; 3, 9 - Holdover; 6-8 - Disciplining
3. When connecting to a GPS receiver, the factory default mode is recommended. Start with y1=1 (DF) and Y2=400 TC in seconds). These values work well for most GPS receivers.
4. Use “z” command to save your settings.
5. X72 Rubidium system will lock approx. 5 minutes after startup.
6. X72 initial frequency must be less than +/- 3PPB for 1PPS to lock.
7. Initial 1PPS lock will occur between 3-5 minutes after both lock and valid 1PPS are present
8. Confirm the firmware version by issuing the “i” command.
9. *xx* is a value returned which is the hex equivalent of the number of times the table has been written to. TData can be either 1 or 2.

1PPS Firmware Versions

Customer Standard	Customer LED
5.02	5.04

Flywheeling Recovery – Normal

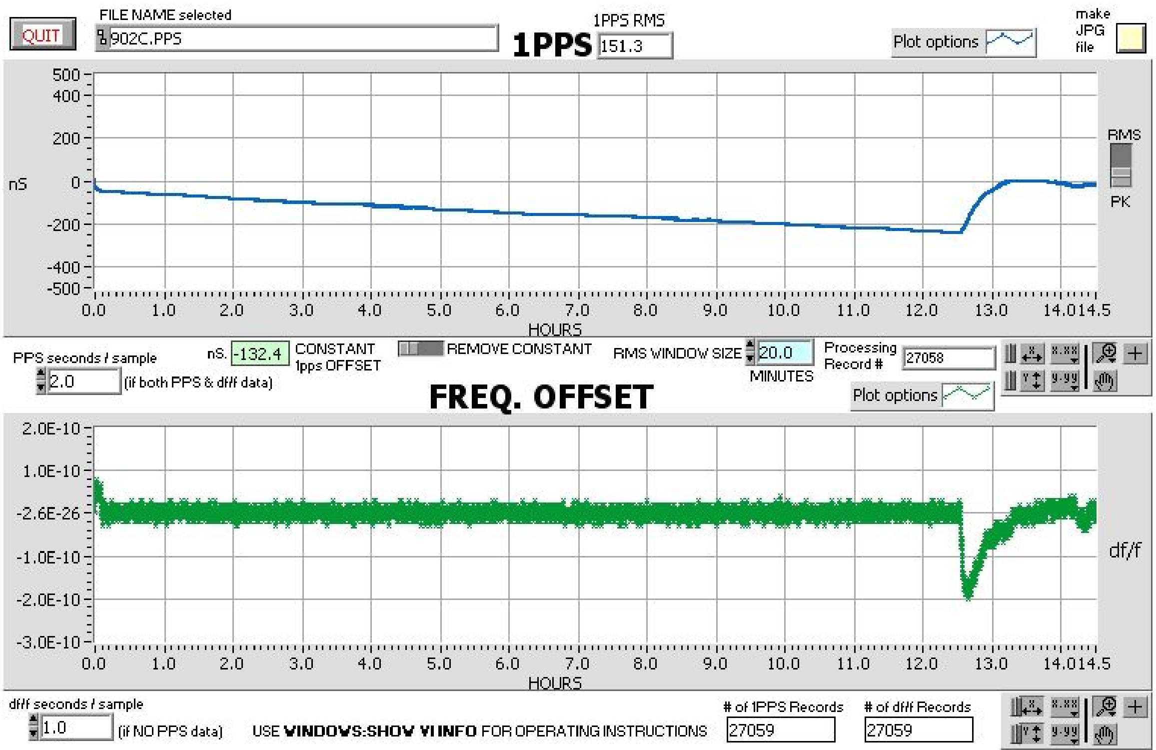

Figure 3 – Flywheeling Recover with 1PPS offset < 1usec

In this test the X72 was synchronized to 1PPS before this data set. Antenna is removed at hour 0 and reapplied at approximately hour 12.5. The X72 1PPS output signal had reached an offset of 220 nsec.

The subsequent frequency change is what returns the 1PPS offset to 0 nsec.

Recovery with Jam Synch

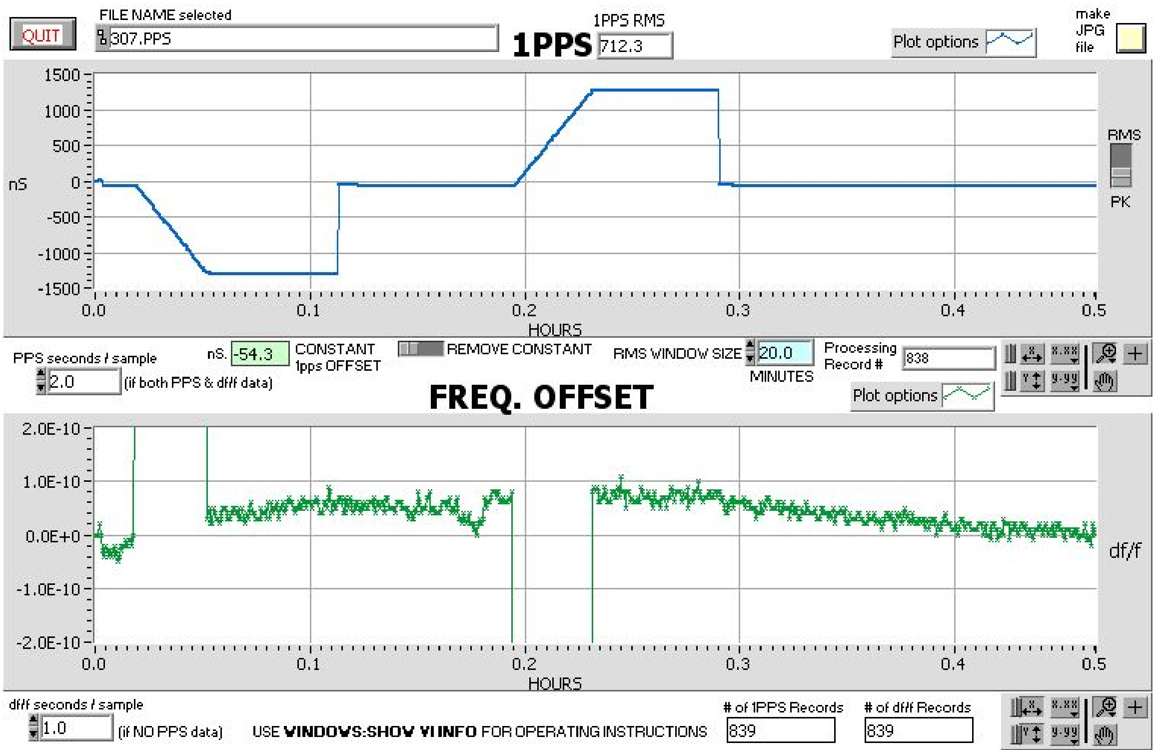

Figure 4 – Flywheeling Recover with 1PPS offset > 1usec

In this test, the antenna to the GPS receiver is removed. The X72 is purposely put off frequency long enough to induce a 1PPS error over 1usec. When the antenna is reapplied, the X72 1PPS recovers by resetting to 1PPS 0 nsec (JamSynch). This procedure was repeated to cause both a leading and lagging 1PPS.

NOTE: *This test was performed on a unit started "cold "which is what causes the general curve in the frequency data (excluding the intentional offsets).*

X72 1PPS Algorithm Theory of Operation

X72 qualifies 1 pulse per second inputs by analyzing the time difference between the X72's 1PPS output and the external 1PPS input. This is referred to as the HoldOver state. The X72 determines whether the 1PPS input is useable by calculating the rate of change in timing measurements that are taken once per second.

Once a 1PPS input is qualified, the X72 1PPS algorithm determines whether it's necessary to adjust the counter that produces the 1PPS output (JamSynch state). The algorithm then begins to adjust the output frequency of the X72 to keep the 1PPS output aligned with the 1PPs input. This is called the disciplining state and the control method is a Proportional Integral Derivatives (PID) scheme.

The amount of frequency change and the length of time required to reach 1PPS accuracy can be adjusted by setting y1 (damping factor) and y2 (time constant) parameters. During this disciplining state, the timing of each 1PPS input is compared to the expected value. If the offset exceeds 333 nsec, the algorithm changes to the HoldOver state and the process begins again.

Figures 6-10 provide additional details.

X72 1PPS Algorithm High Level Flow Chart

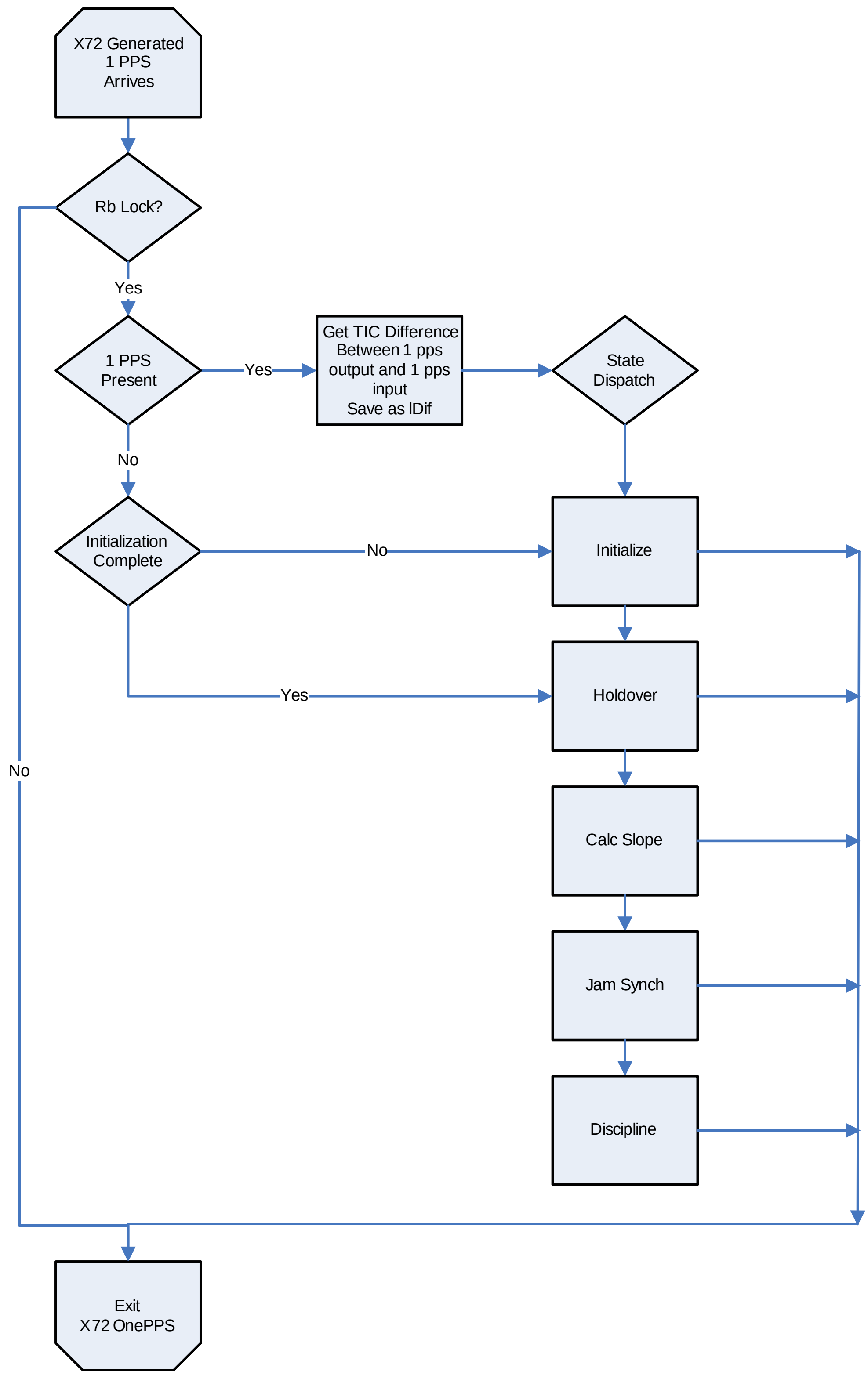

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Figure 5 – X72 1PPS Algorithm States

INITIALIZATION

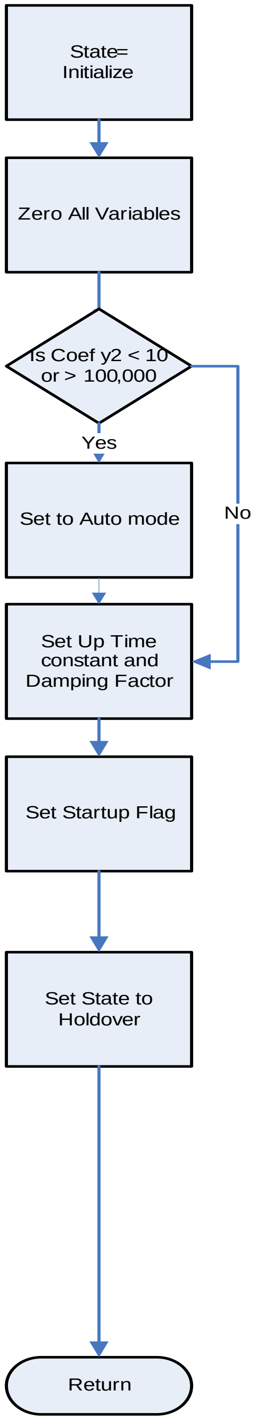


Figure 6

- During initialization, the algorithm sets up variables based on the time constant (TC) and damping factor (DF).
- X72 checks for 1PPS input once per second. If present it enters the holdover state
- Automatic mode is used when the time constant is set to 0.
- X72 1PPS will be in the initialization state when there is no 1PPS applied.
- The “j” command will show the 1PPS count.

HOLDOVER

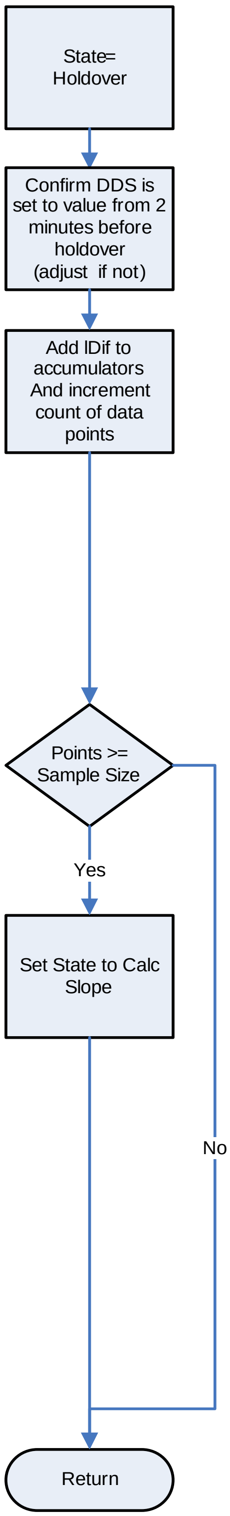
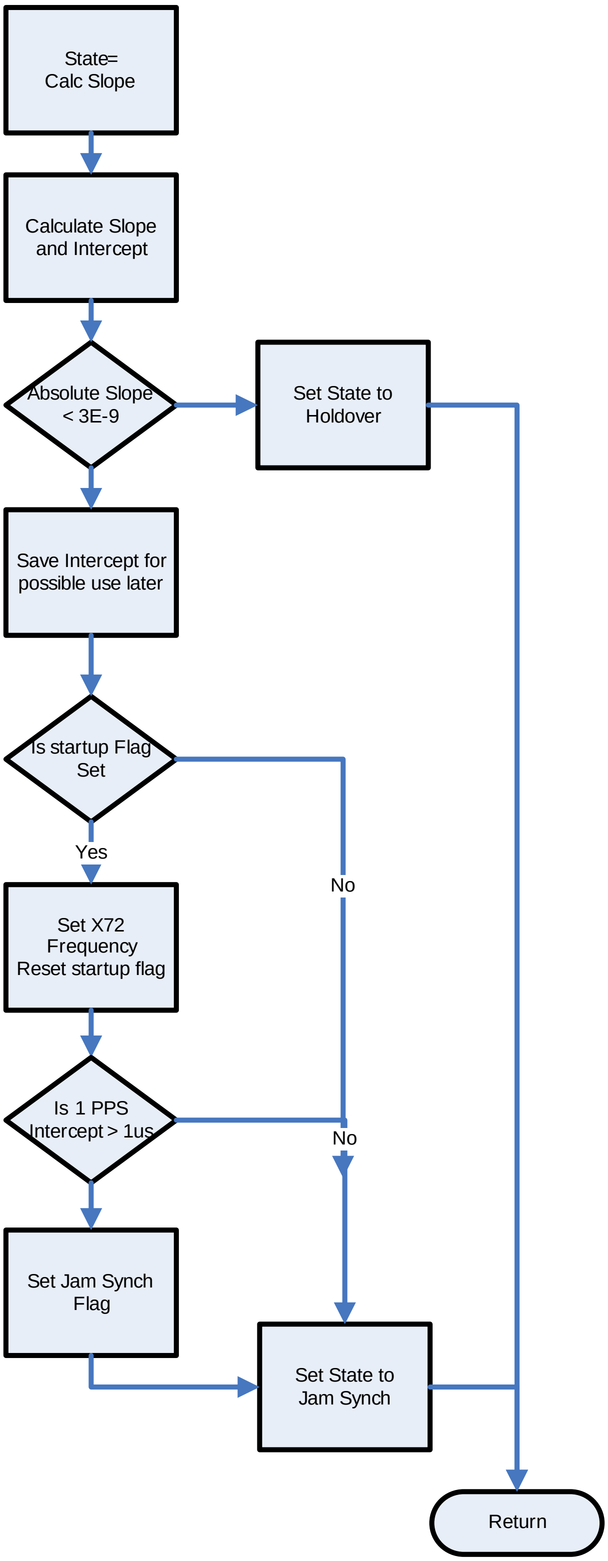


Figure 7

- During holdover, 1PPS input statistics are accumulated and periodically results are calculated (CalcSlopeState).
- The sample size is set to 120 data points (120 seconds).

CALCSLOPE



- The frequency difference between X72 and the 1PPS source is calculated. If the difference is < +/- 3E-9 then the state is changed from holdover to JamSynch.
- This state executes every 120 seconds during holdover.

Figure 8

JAMSYNCH

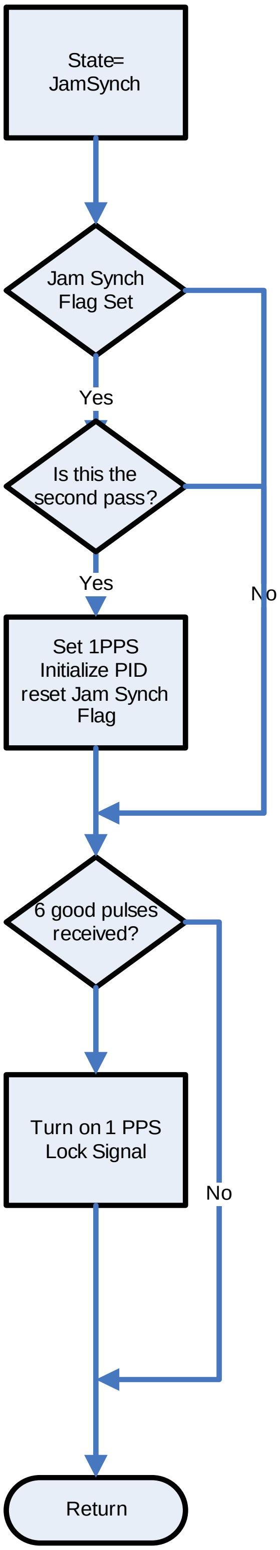


Figure 9

- The X72 1PPS output is compared to the X72 1PPS Input.
- If the difference is >=1 usec, then the state is returned to holdover to collect a second data set. When two consecutive slopes are in range, X72's 1PPS output is synchronized to it's 1PPS input.
- If the difference is < 1 usec. The algorithm waits 6 more pulses and then advances to DISCIPLINE state.

DISCIPLINE

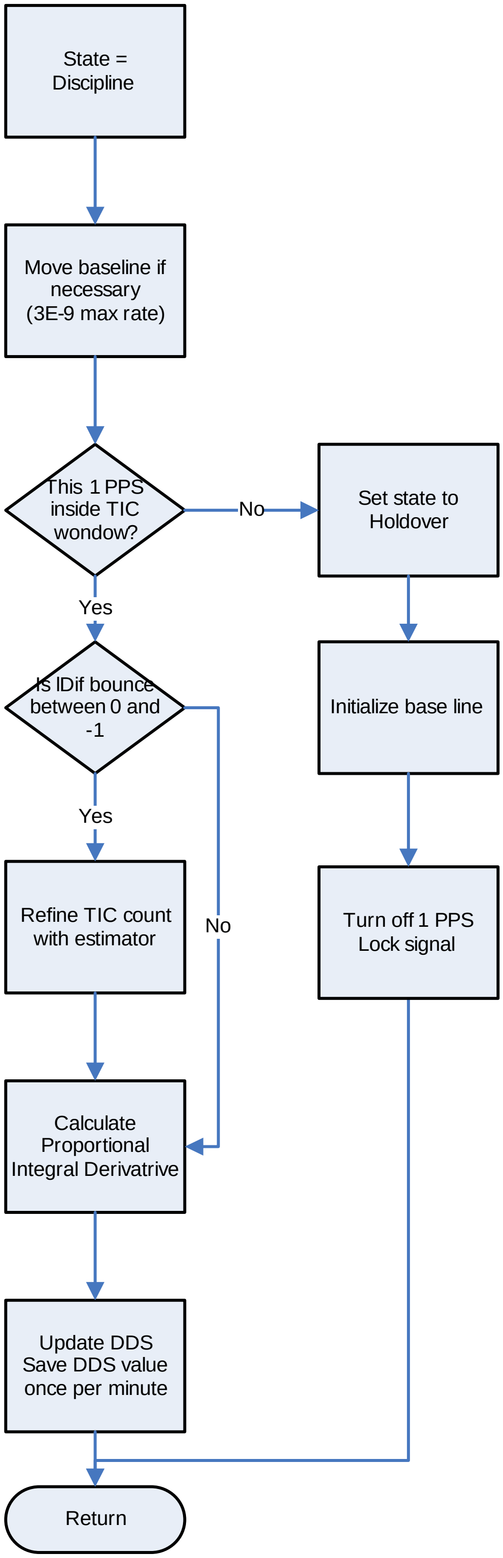


Figure 10

- In DISCIPLINESTATE the X72 uses a PID (proportional-integral- derivative) method to steer the 1PPS output of X72. This method means the X72 average frequency offset will be close to zero. You can expect to see some frequency change when recovering from holdover.
- If at any time a 1PPS input signal is more than 330 ns from its expected value then the 1PPS algorithm will return to holdover state.
- If the input source is very stable, the X72 will further refine the input estimate to provide a smoother frequency output.
- Every minute the X72 saves the DDS setting in case holdover occurs. Since some receivers take a long time to produce 330 ns of error after signal loss, the X72 reverts to the DDS value from 2 periods before the 1PPS becomes invalid.