Nano Atomic Clock
NAC1
User Manual

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<table>
<thead>
<tr>
<th>Rev.</th>
<th>Description</th>
<th>Date</th>
<th>ECO No</th>
<th>Approved</th>
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<td>A</td>
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<td>10-09-15</td>
<td>-</td>
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<td>A6</td>
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<td>11-09-16</td>
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<td>B2</td>
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<td>29-04-18</td>
<td>-</td>
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<td>B3</td>
<td>Specification updated</td>
<td>02-08-18</td>
<td>-</td>
<td>C.L</td>
</tr>
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</table>
Warnings

- Do not operate the unit before reading this manual.
- To avoid electrostatic discharge (ESD) damage, proper ESD handling procedures must be observed in unpacking, assembling, and testing the NAC1.

Warranty

- The Rubidium Frequency Standard purchased under your order is warranted for one year against defects in material or workmanship.
- This warranty does not cover cases of inappropriate operation.
- Do not attempt to open the unit!

Before Cleaning

- Disconnect the product from the power before cleaning or maintenance.

General Notes

1. To avoid electric shock or fire hazard:
   - Apply voltage to the connectors as specified in the product Electrical ICD specifications.
   - Do not connect the unit to power supply with reverse polarity.
   - Operate this unit under dry conditions.
   - Operate this unit in un-explosive atmosphere.
2. Use output load impedance of 1MΩ.
3. Use frequency corrections instruction with caution.
   Uncontrolled corrections can cause the frequency accuracy to get out of calibration or even cause the clock to be unlocked!
4. **Solder**: Hand solder using 63/37 Tin/Lead solder with maximum soldering tip temperature of 330°C (626°F).

The information and specifications included in this manual are subject to change without prior notice.
The information contained within this manual is the proprietary of AccuBeat Ltd.
# Table of Contents

1. General description .............................................................................................................................................. 6  
   1.1. Introduction ................................................................................................................................................. 6  
   1.2. Key features ............................................................................................................................................... 7  
      1.2.1. The NAC1’s main features ................................................................................................................ 7  
      1.2.2. Special features .................................................................................................................................... 7  
2. NAC1 Overview .................................................................................................................................................... 8  
   2.1. Precautions ................................................................................................................................................. 8  
   2.2. Packaging ................................................................................................................................................. 8  
   2.3. Absolute Maximum Ratings ................................................................................................................... 8  
   2.4. Mechanical Interface and Mounting ...................................................................................................... 9  
   2.5. Recommended Operating Characteristics .......................................................................................... 10  
3. Evaluation Kit ....................................................................................................................................................... 11  
   3.1. Installing the NAC1 on the evaluation board ....................................................................................... 11  
   3.2. Installing the NAC1 GUI software ....................................................................................................... 12  
   3.3. Cabling ..................................................................................................................................................... 14  
   3.4. Evaluation Board Overview ............................................................................................................... 14  
   3.5. Initial Start Up ......................................................................................................................................... 16  
      3.5.1. Initial Power-On ................................................................................................................................. 16  
      3.5.2. Establishing Communication with NAC1 ................................................................................... 16  
      3.5.3. Basic NAC1 GUI Features ............................................................................................................. 17  
      3.5.4. Frequency Tuning ........................................................................................................................... 18  
4. Functional Description ......................................................................................................................................... 19  
   4.1. Principle of Operation ............................................................................................................................... 19  
   4.2. Built-In Test (BIT) ..................................................................................................................................... 20  
      4.2.1. S/W indication .................................................................................................................................... 20  
      4.2.2. H/W indication ................................................................................................................................... 20  
   4.3. 10 MHz Output Characteristics ........................................................................................................... 21  
   4.4. Frequency Adjustments ......................................................................................................................... 22  
   4.5. 1PPS Output .............................................................................................................................................. 22  
   4.6. Rubidium free run .................................................................................................................................... 23  
   4.7. Rubidium disciplined to 1PPS ............................................................................................................. 23  
   4.8. 1PPS Input ................................................................................................................................................ 23  
5. Disciplining Mode ................................................................................................................................................. 24  
6. Appendices ........................................................................................................................................................... 26  
   Appendix A: Mechanical ICD ....................................................................................................................... 26  
   Appendix B: Electrical ICD .......................................................................................................................... 27  
   Appendix C: Software ICD (CLI) ................................................................................................................ 28  
   Appendix D: Specifications ......................................................................................................................... 35
List of Figures

Figure 1 : NAC1 Mechanical drawing and Pinout .................................................................9
Figure 2 : Protective sheet for Evaluation Board .....................................................................11
Figure 3 : NAC1 on Evaluation board ....................................................................................12
Figure 4 : LabVIEW85RuntimeEngineFull installation ..........................................................13
Figure 5 : visa441runtime installation ..................................................................................13
Figure 6 : Evaluation Board Connections ............................................................................14
Figure 7 : NAC1 GUI Software .............................................................................................16
Figure 8 : NAC1 Block Diagram ............................................................................................20
Figure 9 : BIT LED indication ...............................................................................................21
Figure 10 : NAC1 10MHz Output Driver ...............................................................................21
Figure 11 : Evaluation Board 10MHz Output Driver ..............................................................22
Figure 12 : Mechanical ICD ....................................................................................................26

List of Tables

Table 1: Absolute Maximum Ratings ...................................................................................8
Table 2 : Recommended Operating Characteristics ..............................................................10
Table 3 : Electrical ICD ..........................................................................................................27

Abbreviations

1PPS – 1 Pulse Per Second
BIT - Built In Test
CLI – Command Line Interface
DAC – Digital to Analog Converter
H/W - Hardware
TCXO – Temperature Compensated Crystal Oscillator
P/N – Part Number
S/N – Serial Number
S/W – Software
I/O – Inputs/Outputs
Rb – Rubidium
1. General description
   1.1. Introduction

AccuBeat's 1st generation Nano-Atomic-Clock (NAC1) is an ultra-small, ultra-low power Rubidium Atomic Clock. NAC1 utilizes a modulated miniature diode laser to optically pump a miniature Rubidium glass cell. The modulation frequency is derived from a local crystal oscillator which is then locked to the Rubidium atomic line, thereby delivering the high stability of the atomic quantum transition to NAC1 outputs at 10MHz and 1PPS.

The small size and low power consumption of the NAC1, enables atomic timing accuracy in various applications such as: GPS receivers, UAV's, Autonomous sensors and Backpack secure communication radios.

This manual provides technical guidance to facilitate mechanical, electrical, and functional integration of the NAC1.

This manual also describes the NAC1 Evaluation Kit (AccuBeat P/N: AA50766), which includes an evaluation board, cabling, and the NAC1 Graphic User Interface (GUI) software.

Installation and use of the NAC1 Evaluation Kit is presented in Section 3 of this User Manual. The description of NAC1 functionality in Section 4 includes examples from the Evaluation Kit.
1.2. **Key features**

1.2.1. **The NAC1’s main features are as follows:**

Input: 1PPS (for disciplining).

Outputs:

- Main frequency output (10MHz).
- 1PPS

Medium term stability: 2E-11 @ 100s.
Phase noise: <148 dBC/Hz @ 100 KHz (relative to the main 10MHz output).

Size: 32cc (41.1mm X 35.3mm X 22 mm)

Weight: \( \leq \) 75 grams.

Communication: UART (CMOS 3.3V, 1MΩ).

Power supply: 3.3VDC

1.2.2. **Special features:**

- **Disciplined to 1PPS:** The NAC1 is disciplined to a 1PPS signal, which improves the long-term-stability as well as the accuracy.
2. NAC1 Overview

2.1. Precautions

- Do not operate the unit before reading this manual.
- To avoid electrostatic discharge (ESD) damage, proper ESD handling procedures must be observed in unpacking, assembling, and testing the NAC1.

2.2. Packaging

Please retain the original NAC1 ESD-safe packaging material in the event that the device needs to be returned to AccuBeat for service.

2.3. Absolute Maximum Ratings

Table 1 indicates the absolute maximum ratings to which the NAC1 can be subjected without permanent unrecoverable damage. Note that the NAC1 cannot be expected to operate normally when operated outside of the Recommended Operating Conditions (Table 2) and no performance is guaranteed under absolute maximum ratings.

All ratings apply at 25°C, unless otherwise noted.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage (Vcc)</td>
<td>4.1 V</td>
</tr>
<tr>
<td>Maximum current draw</td>
<td>1PPS in, Tx, Rx, BIT: +/- 2 mA</td>
</tr>
<tr>
<td></td>
<td>1PPS out, 10 MHz out: +/- 20 mA</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>-40°C to +90°C</td>
</tr>
</tbody>
</table>

Table 1: Absolute Maximum Ratings
2.4. Mechanical Interface and Mounting

The physical dimensions of the NAC1 are 1.62” x 1.41” x 0.87” H.

Detailed dimensions and NAC1 Pinout are shown in Figure 1.

Pin #3 is not present in the NAC1.

For initial testing and evaluation it is recommended that the pins should not be modified or soldered to a PCB. The recommended socket for connecting the PCB is SAMTEC P/N: SC-2P7-TT or SC-2P7-GG.

When soldering the NAC1 to a PCB, please notice that the bottom surface of the NAC1 will be parallel to the PCB in order to prevent electrical shortages.
2.5. Recommended Operating Characteristics

The NAC1 pinout is shown above in Figure 1. The electrical function of each pin is defined in this section. Refer to the Reference Section for a detailed functionality description of each pin.

<table>
<thead>
<tr>
<th>PIN #</th>
<th>NAME</th>
<th>FUNCTION</th>
<th>VOLTAGE LEVELS</th>
<th>NOTES</th>
<th>REFERENCE SECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N/C</td>
<td>Not Connected</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>GND</td>
<td>Ground</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>N/A</td>
<td>Not Applicable</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>BIT</td>
<td>Built-In Test</td>
<td>2.5 V &lt; Logic H &lt; Vcc 0 V &lt; Logic L &lt; 0.5 V</td>
<td>1,5</td>
<td>4.2</td>
</tr>
<tr>
<td>5</td>
<td>Tx</td>
<td>Comm. Transmit</td>
<td>2.5 V &lt; Logic H &lt; Vcc 0 V &lt; Logic L &lt; 0.5 V</td>
<td>5</td>
<td>Appendix C: Software ICD (CLI)</td>
</tr>
<tr>
<td>6</td>
<td>Rx</td>
<td>Comm. Receive</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Vcc</td>
<td>Input Voltage</td>
<td>3.3 VDC +/- 0.1 VDC</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>GND</td>
<td>Ground</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>1PPS IN</td>
<td>1 Pulse Per Second Input</td>
<td>2.5 V &lt; Logic H &lt; Vcc 0 V &lt; Logic L &lt; 0.5 V</td>
<td>2,6</td>
<td>4.8</td>
</tr>
<tr>
<td>10</td>
<td>1PPS OUT</td>
<td>1 Pulse Per Second Output</td>
<td>2.5 V &lt; Logic H &lt; 2.85 V 0 V &lt; Logic L &lt; 0.5 V</td>
<td>2,3,5</td>
<td>4.5</td>
</tr>
<tr>
<td>11</td>
<td>Fact. Use</td>
<td>Factory Use</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>10MHz OUT</td>
<td>10MHz Output</td>
<td>2.5 V &lt; Logic H &lt; Vcc 0 V &lt; Logic L &lt; 0.5 V</td>
<td>5</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Table 2: Recommended Operating Characteristics

Notes:

1. Built-in Test (BIT) output:
   0: Normal Operation
   1: Unlocked

2. Timing reference is the rising edge of an input pulse.

3. Output 1PPS is 20μs in duration.
   Timing reference is the rising-edge of Pin # 10. Rise time < 10 ns.

4. Regulated 3.3V DC.
   Recommended regulator: MICREL P/N: MIC39100-3.3WS

5. Load Impedance = 1MΩ.

6. Input Impedance = 1MΩ.
3. Evaluation Kit

The Evaluation Kit enables the developer to easily evaluate and test the NAC1. It includes all of the necessary hardware, software, and cabling to facilitate validation of performance and software interface development.

The Evaluation Kit (AccuBeat P/N: AA50766) contains the following items:

4. USB to Serial Cable (AccuBeat P/N: ZE00314).

3.1. Installing the NAC1 on the evaluation board

In an ESD-safe environment carefully remove the NAC1 and the evaluation board from their ESD protective bags. Note that the NAC1 pinout is “keyed” (see Figure 1) so the NAC1 can only be inserted in the proper orientation.

Gently insert the NAC1 into the socket on the evaluation board as shown in Figure 3 below.

**Note:** In order to prevent a short circuit between NAC1 signals, please verify that the protective sheet provided with the NAC1 Evaluation Kit is located between the NAC1 pins and the Evaluation board sockets (see Figure 2).

![Figure 2 : Protective sheet for Evaluation Board](image-url)
3.2. Installing the NAC1 GUI software

The AccuBeat NAC1 GUI software (P/N: SW50051) provides a convenient graphical user interface (GUI) for monitoring and controlling the NAC1. After quick installation of the drivers, it will run on any PC running Microsoft Windows® XP or Windows® 7 and having at least one available RS232 (COM) or USB port. Note that multiple NACs can be monitored from a single PC, provided additional COM ports are available.

To install the NAC1 GUI software, insert the provided CD-ROM into the CD drive of the PC. *The installation will not start automatically.* Please browse to the CD-ROM drive in Windows Explorer. In the **GUI Drivers** directory you may find two `.exe` files.

For both files please perform the following procedure:

- Double-click on `visa441runtime.exe` / `LabVIEW85RuntimeEngineFull.exe`.
- The following message will open:

![NI-VISA Runtime 4.4.1](image)

This self-extracting archive will create an installation image on your hard drive and launch the installation. After installation completes, you may delete the installation image to recover disk space. You should not delete the installation image if you wish to be able to modify or repair the installation in the future.

- Click on 'OK'.
- The following Unzip message will open:
- Click on 'Unzip'.
- The directories will be unzipped and the following installation messages will open:

**Figure 4 : LabVIEW85RuntimeEngineFull installation**

**Figure 5 : visa441runtime installation**

- Finish both installations by clicking three times the "Next >>" button.
- Restart your PC.
- Browse to the CD-ROM drive in Windows Explorer. Open the **SW50051- Graphical User Interface (GUI) for NAC1 customer** directory and double-click on **NAC1 Customer GUI.exe** to open the NAC1 GUI.

3.3. Cabling

Connect the provided RS-232 cable between the evaluation board and the COM port on the PC. On laptops without an available COM port, a USB-to-RS232 adapter might work. We recommend using the USB to Serial adapter (Support RS232 Serial communication) that was supplied with the NAC1 Evaluation Kit.

Connect *banana to banana cables* (Red & Black) between J36 and J52 power input connectors and a 7V DC power supply VCC and Ground respectively.

NAC1 signal outputs and inputs are available from the evaluation board on connectors J97 (10 MHz Output), J38 (1PPS Output) and J37 (1PPS Input). Connect either (or both) of these to your test equipment (1PPS Input reference, frequency counter, spectrum analyzer, etc.).

3.4. Evaluation Board Overview

Detailed schematics of the evaluation board are provided in **Figure 6** below that shows the connections to the evaluation board.

![Figure 6: Evaluation Board Connections](image)
10 MHz Output (SMA) – The NAC1 output is a 10MHz, CMOS 0-3.3VDC waveform.

7V DC Power Input – Input power to the evaluation board is provided from an external power supply through twisted pair banana cables. The use of a current limiter to 2A is recommended.

RS232 Connection (D9) – The evaluation board provides a level shifter (U1), which converts the NAC1 0-3.3 VDC serial interface to the RS232 standard +/- 12 V for direct interface with a PC COM port. Connect the test fixture (J22) to a PC with a standard (non-Null) DB9F-DB9F RS232 cable. To avoid problems, please use the proper cable which is provided by AccuBeat with the Evaluation Kit.

BIT Lock Indicator LED – Indicates normal operation following initial acquisition of the clock signal. Note that this is the logical complement of the BIT output (NAC1 Pin # 4).

Power LED – Indicates the state of the external power supply.

1PPS Input (BNC) – The 1PPS input connection to the evaluation board accepts a 1PPS reference of arbitrary amplitude (logic high: 2.5V < Vin < 5V) and passes it directly to the NAC1.

1PPS Output (BNC) – The 1PPS output can be buffered by a CMOS 0-3.3 V logic gate on the evaluation board. For this option please transfer J99 Jumper to J98 Head.

Note: Do not change the configuration of the other JUMPERs connectors.
3.5. Initial Start Up

3.5.1. Initial Power-On

Make sure NAC1 is placed on its socket on the Evaluation board with the protective sheet.
Connect the Evaluation board voltage input to the Power Supply.
Connect power and RS232 to the Evaluation Board as described in Section 3.3.
Make sure the simulated COM port number is known to you.
Run the NAC1 GUI software:

![NAC1 GUI Software](image)

**Figure 7: NAC1 GUI Software**

The GUI enables simple communication to the NAC1. The GUI provides visual presentation of the NAC1 parameters such as BIT, serial number and other internal parameters.

3.5.2. Establishing Communication with NAC1

Choose the relevant COM port number from the ‘COM. Selection’ and click the ‘Open Terminal’ button.
You can use the ‘Close Terminal’ button to close communication with the device and ‘Exit’ button to close the application.
3.5.3. Basic NAC1 GUI Features

The ‘Read Parameters’ button triggers the read of the NAC1 status and setup. The ‘Rx Reading’ indicator will be lit during the process of data acquiring.

The ‘Received Data’ window is basically used for the visual confirmation of the last issued command. When the reading of parameters is completed, the updated data will be displayed on the GUI screen.

**Note:** After power up, start-up scripts will operate for another 5 minutes from the moment the BIT is valid (warm-up time). You cannot communicate with NAC1 until the start-up scripts will end.

‘BIT’ (Built-In Test) indicates the overall status of the NAC1 control loops and readiness to function. 

See also ‘UMR’ command description (Appendix C: Software ICD (CLI)) and Section 4.2 for more information.

The ‘SW Reset’ button performs NAC1 Soft Reset, which is equivalent to a power cycle.

See also the ‘RST’ command description (Appendix C: Software ICD (CLI)).

The ‘Disciplining’ dialog allows controlling the disciplining process. The default setting is ‘Enable’. Selecting ‘Disable’ will disable the disciplining, effectively switching NAC1 to Holdover state, regardless to the 1PPS input status.

See the ‘SDM’ command description (Appendix C: Software ICD (CLI)) and Section 5 for more information.

The ‘Output Delay’ dialog allows deferring the ‘1PPS Output’ phase by the specified number of nano-seconds. This is a pure administrative function and doesn’t affect the disciplining algorithm.

See also the ‘SPD’ command description (Appendix C: Software ICD (CLI)) for more information.

The ‘Ext. 1PPS Input Delay’ dialog allows deferring the ‘1PPS Input’ phase by the specified number of nano-seconds.

See also the ‘SED’ command description (Appendix C: Software ICD (CLI)) for more information.

The VER CLI instruction can be used to remotely identify the unit.

The instruction returns the unit part number (for example: NAC1), S/W and F/W versions, and the unit’s serial number.

See also the ‘VER’ command description (Appendix C: Software ICD (CLI)) for more information.
3.5.4. Frequency Tuning

The ‘Frequency Tuning’ dialog allows tuning the NAC1 microwave synthesizer by applying corrections or setting an explicit frequency value. Corrections are sent in steps of 7.6E-13, 1.96E-10 or 4.98E-8 and can be positive or negative with an arbitrary number of steps. Moreover, corrections can be applied for the current session only (until power down) or forever. In the latter case the correction value affects the base frequency, stored in a non-volatile memory. Every new correction is added to the base frequency.

See also the ‘RFC’ command description (Appendix C: Software ICD (CLI)) and Section 4.4 for more information.
4. Functional Description

This chapter provides an overview of the operation principles of a Rubidium Frequency Standard and describes the main features in the NAC1 unit.

4.1. Principles of Operation

Atomic Clocks, the most accurate man-built machines, have been commercially available for over 40 years. Recent developments in atomic clocks technology have enabled a substantial reduction of size and power consumption of these clocks, using the phenomenon of Coherent Population Trapping (CPT), with alkali atoms such as Rubidium and Cesium. The CPT utilizes the transparency of an atomic vapor cell, which is created when illuminated by two laser beams that differ in their frequency (wavelength) by an amount that equals the hyperfine transition frequency of a Rubidium (@ ~6.8GHz ) or Cesium (at@ ~9.2GHz ). Instead of using 2 lasers one uses a single laser, which is modulated by half the hyperfine frequency synthesized from a local crystal oscillator, thereby creating two sidebands. When the separation between the sidebands exactly equals the hyperfine frequency, the vapor becomes transparent. One uses this transparency to lock the local crystal oscillator (that provides the clock output) to the atomic line. With this technique one gets rid of the conventional lamp and resonance microwave cavity which are being used in the traditional Rubidium Frequency Standard technology, thereby saving substantial size and power.

AccuBeat’s NAC1 utilizes a novel and unique scheme where numerous servo-loops are operating simultaneously to stabilize all the key parameters of the clock, and where the sensors of the loops origin from the atomic vapor. This results in an improved stability of the clock’s output and low sensitivity to disturbances. In addition, the vapor cell in NAC1 is based on a proven traditional glass technology which has been used in Rubidium Clocks for dozens of years. This assures very high reliability and confidence in the design. For the same reason AccuBeat selected to use Rubidium rather than Cesium due to the long Rubidium heritage in vapor cell atomic clocks (Cesium is normally used in atomic beam clocks which deploy a totally different approach).

A detailed block diagram of the NAC1 is provided in Figure 8 below:
The NAC1 provides outputs of 10MHz and 1PPS.
The NAC1 is comprised of a unique DFLL (Digital Frequency Locked Loop), where a TCXO is locked to the Rubidium atomic line using an embedded processor. The algorithm improves temperature stability and enables very fine digital frequency control.

4.2. Built-In Test (BIT)

Successful BIT result indicates that the internal TCXO is locked on the Physics Package.

You can expect the ‘BIT’ to turn ‘OK’ (Green) in 3 minutes after the NAC1 power-up at a room temperature (25 ºC) or up to 10 minutes at -20 ºC.

The NAC1 has two options for BIT status indication: S/W indication and H/W indication.

4.2.1. S/W indication:
The CLI of the NAC1 contains the BIT indication. The unit BIT can be remotely monitored by using the CLI. See also the ‘UMR’ command description (Appendix C: Software ICD (CLI)) for more information

4.2.2. H/W indication:
The H/W BIT indication uses a high-impedance CMOS Compatible logic output in Pin 4 (BIT) of the NAC1.

Frequency lock is indicated both by FLL status = 0 in the FLL status field of 'UMR' CLI command and by the low (logic 0) electrical state of the BIT output pin, which is high (logic 1) upon initial power-on and whenever FLL status = 1.

A visual indication of the BIT status can be created by connecting a LED in series to the power supply and an appropriate resistor. Please see the following Figure 9.
4.3. 10 MHz Output Characteristics

The buffered CMOS clock output at 10 MHz is provided on Pin #12 of the NAC1. The output series impedance is $200 \, \Omega$. For reference, the output driver circuit of the NAC1 is shown below in Figure 10.

![Figure 10: NAC1 10MHz Output Driver](image)

The NAC1 is designed for embedded low-power applications, i.e. it is expected to drive a high impedance input, not a $50 \, \Omega$ measurement instrument or transmission line. If a high-level (high-power) output driver is required, an external driver circuit should be implemented, such as the one implemented on the Evaluation Board. See Figure 11 below.
The 10MHz output appears on Pin # 12 as soon as the NAC1 is powered on and is always present until Power-down. When the NAC1 is out of lock (BIT = 1, FLL status = 1), the output frequency is provided by the free-running TCXO, which has frequency accuracy specification of ≈ ±5 ppm and temperature sensitivity of 0.1 ppm/°C. Therefore, the unlocked frequency accuracy during acquisition is significantly worse than the frequency accuracy when the NAC1 is locked.

4.4. Frequency Adjustments

*** Please read this subsection before performing any frequency adjustments ***

*** Use frequency adjustments with caution!!! ***

*** Uncontrolled frequency adjustments can result in a large frequency offset***

The internal frequency calibration of the NAC1 is set prior to shipment. It is often desirable (and likely) that the calibration will need to be updated from time to time to remove cumulative frequency aging offsets.

The frequency adjustments can be performed with steps of 7.6E-13 and over > 2E-8 range.

When using frequency correction, the correction will influence the main 10MHz output.

For digital frequency adjustments, use the RFC CLI instruction (for more details see Appendix C: Software ICD (CLI) and Section 3.5.4).

4.5. 1PPS Output

A CMOS Compatible 1 pulse-per-second (1PPS) output is available on Pin # 10 immediately upon power up. The output series impedance is 100 Ω. Nominal levels are 0 - 2.85V DC. For the synchronization purposes, the “on-time” point is the Rising edge of Pin # 10.
The 1PPS output is derived by digital division of the 10MHz reference frequency by a factor of 1E7. The frequency stability and accuracy of the 1PPS output therefore reflects that of the 10MHz. Consequently, when unlocked (BIT=1, FLL status = 1) the 1PPS Output stability reflects the free-running TCXO.

4.6. Rubidium free run
In the Rubidium free run mode, the output frequency accuracy is determined by the Rubidium accuracy. In this case, only the FLL is activated.

4.7. Rubidium disciplined to 1PPS
In order to improve the frequency accuracy, the NAC1 is disciplined to an external 1PPS. In this mode, both the FLL and the DPLL are activated. When no 1PPS input is available, the unit operates in the Hold-Over mode.

To operate the disciplining mode, connect a 1PPS source (Section 4.8) to NAC1 Pin # 9 and verify that the mode parameter of the 'SDM' CLI command is ‘1’ (for more details see Appendix C: Software ICD (CLI)).

4.8. 1PPS Input
A Rubidium clock (locked or unlocked to GPS), Cesium clock or GPS receiver can be used as a 1PPS source for the NAC1.
It is most important to use an accurate 1PPS source, since the NAC1 disciplines to the external 1PPS source. If the 1PPS input is accurate, then the NAC1 is accurate as well.

AccuBeat has a variety of GPS-disciplined Rubidium clock products, which can function as highly accurate 1PPS source. For additional information, please contact AccuBeat sales department or visit us online at www.accubeat.com.

Note: The 1PPS input must be positive, meaning that the 1PPS input signal looks as follows:

```
    |
    |
```

And not like this:

```
    |
```

Note: The 1PPS input must be positive, meaning that the 1PPS input signal looks as follows:
5. Disciplining Mode

This chapter provides a general overview on the disciplining algorithm implemented in the NAC1 clock.

The 1PPS disciplining uses a DPLL (Digital Phase Locked Loop) algorithm to discipline the Rb frequency to an external 1PPS. A phase meter is implemented within the NAC1 for improved synchronization (< 100 ns) as well as for frequency calibration of the NAC1. The phase meter measures the time difference between the internal NAC1 1PPS (Pin #10) and the externally applied reference 1PPS (Pin #9). The phase meter measures the relative phase between the NAC1 and the reference once per second with a resolution of 5 ns. Based on the measurements of the phase meter, internal steering algorithms adjust the frequency of the NAC1’s microwave synthesizer so as to simultaneously steer both the phase and frequency to that of the external reference.

The DPLL algorithm has 4 states:

<table>
<thead>
<tr>
<th>DPLL State</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1PPS input is applied and disciplining mode is activated (‘SDM 1’)</td>
</tr>
<tr>
<td>1</td>
<td>1PPS input is applied and disciplining mode is activated (‘SDM 1’)</td>
</tr>
<tr>
<td>2</td>
<td>1PPS input is applied and disciplining mode is activated (‘SDM 1’)</td>
</tr>
<tr>
<td>3</td>
<td>1PPS input is not applied or disciplining mode is not activated (‘SDM 0’)</td>
</tr>
</tbody>
</table>

**State 0:**
The Rb 1PPS will be synchronized to the external 1PPS. During this phase, the Rb 1PPS will abruptly synchronize to the external 1PPS. No frequency correction is sent to the clock by the DPLL algorithm. In a standard unit the time for this state is about 15 minutes (under normal conditions such as continuous 1PPS input etc.).

**State 1:**
This state applies corrections to the clock frequency using the DPLL algorithm calculations. During this phase, the DPLL uses unique parameters set applicable to state 1. In a standard unit, the time for this state is about 60 minutes from power up (under normal conditions like continuous 1PPS input etc.).

**State 2:**
This state applies corrections to the clock frequency using the DPLL algorithm calculations. At this time the DPLL uses unique parameters set relevant to state 2. In a standard unit the clocks get to state 2 after completion of state 1 (under normal conditions like continually 1PPS input existence etc).

**State 3:**
The clock is in Hold Over mode. No frequency corrections are sent to the clock.
Passing from state 0 / 1 / 2 to state 3 is done by disconnecting the 1PPS input or by setting the disciplining mode to 'Off' (‘SDM 0’).

Exit from state 3 (Hold Over) to active disciplining is done by connecting a 1PPS input and setting the disciplining mode to 'On' (‘SDM 1’).

Indication of the DPLL state appears in the UMR instruction field number 6 (‘DPLL STATE’).

Hold Over declaration is made as follows:

- In case of 1PPS disconnection – the HW waits for two sequential cycles and verifies that no 1PPS input exists. After two cycles the HW produces the SW indication that no 1PPS input is detected. The SW waits for another two sequential cycles to determine that no 1PPS input exists, and the NAC1 mode is set to Hold Over (state 3).
- In case the user sends a ‘SDM 0’ instruction, the NAC1 will immediately be set to Hold Over (state 3).

**Note:** When using the disciplining mode, the NAC1 frequency accuracy is derived from the accuracy of the 1PPS input source. Therefore, use only 1PPS input that is generated from accurate and stable sources.

In case that during the operation the 1PPS source becomes invalid (for example: no satellites receiving in the GPS receiver), disconnect the 1PPS input or send SDM = 0 instruction to the NAC1.

Please note that when resetting the unit (CLI instruction ‘RST Y’) the DPLL algorithm is also restarted.
6. Appendices

Appendix A: Mechanical ICD

Figure 12: Mechanical ICD (NAC1004)
## Appendix B: Electrical ICD

<table>
<thead>
<tr>
<th>PIN #</th>
<th>Function</th>
<th>Electrical Characteristics</th>
<th>Block Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>10MHz Output</td>
<td>CMOS, 3.3V@1MΩ</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1PPS Output</td>
<td>CMOS compatible, 3.3V@1MΩ Rise / Fall time: &lt;10 ns, Pulse width: 20 µs</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1PPS Input</td>
<td>CMOS, 3.3V@1MΩ</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Built in test (BIT)</td>
<td>CMOS compatible, 3.3V@1MΩ '0' = Normal operation, '1' = Alarm</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Power input</td>
<td>3.3±0.1 VDC</td>
<td></td>
</tr>
<tr>
<td>5,6</td>
<td>Serial Comm.</td>
<td>Control and monitor interface</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>UART, format CMOS compatible, 3.3V@1MΩ, 115200BPS</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Electrical ICD (NAC1004)
Appendix C: Software ICD (CLI)

C.1. General Comments on the CLI Commands

The CLI is based on ASCII characters.
Default protocol configuration:
- Baud Rate: 115,200
- Parity: None
- Start Bit: 1
- Data Bits: 8
- Stop Bit: 1
- Flow Control: None

Each setup command is used to:
1. Set the appropriate parameters according to the full syntax.
2. View the current system parameters (in this case only the command name is entered).

For example:

**SEO Y<cr>**  - Will set the echo ON when used with a terminal application to configure the system mode.

**SEO<cr>**  - Will cause the system to reply "SEO Y" to indicate that the echo mode is used in the system.
General notes:

1. The setup commands can be sent in one of the following formats:
   - Command<space><data><CR>
   - Command<space><data><LF>
   - Command<space><data><CR><LF>
   - Command<space><data><LF><CR>
     Note: The command parsing will start right after the <CR> or <LF>.  
     In the 3rd and 4th forms above the <LF> and <CR> will be ignored.
2. In case of CLI commands with several parameters, each parameter is separated from each other with the comma sign (',').
3. Parameters can be skipped by typing the ',' only without any value following them. In the case where there is no intention to change the trailing parameters, they can be simply omitted.
4. All values should be in ASCII format.
5. If the communication is with a PC, the recommendation is to work with SEO N.
6. If the communication is interactive with a user (for example communication using a Hyper Terminal) the recommendation is to work with SEO Y.
7. a. When SEO N is applied, the output (response from the unit) to all CLI commands will be in the following form:
       Command<space><data><CR><LF>
       b. When SEO Y is applied, the output (response from the unit) to all CLI commands will be in the following form:
       Command<CR><CR><LF> Command<20><data><CR><LF><3E><20>
       Note: The first Command<CR> is the ECHO of the received command.
8. Error messages:
   a. If the operator enters characters that do not match one of the specific CLI commands the following error message will be reported: "Unknown command".
   b. If the operator enters characters that do not match one of the parameters in a CLI command the following error message will be reported: "Invalid command"
9. Case sensitivity: Both commands and their parameters can be entered in uppercase or lowercase letters.
## C.2. CLI Commands Summary

<table>
<thead>
<tr>
<th>#</th>
<th>Command Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>VER</strong> - Report Version</td>
</tr>
<tr>
<td>2</td>
<td><strong>SEO</strong> - Set Echo ON/OFF</td>
</tr>
<tr>
<td>3</td>
<td><strong>RST</strong> - Reset Unit</td>
</tr>
<tr>
<td>4</td>
<td><strong>RFC</strong> - Rubidium Frequency Correct</td>
</tr>
<tr>
<td>5</td>
<td><strong>SDM</strong> - Set Disciplining Mode</td>
</tr>
<tr>
<td>6</td>
<td><strong>SED</strong> - Set External 1PPS input Propagation Delay</td>
</tr>
<tr>
<td>7</td>
<td><strong>SPD</strong> - Set Output Propagation Delay</td>
</tr>
<tr>
<td>8</td>
<td><strong>UMR</strong> - User Monitor Report</td>
</tr>
</tbody>
</table>
C.3. General Commands

VER – Report Version

VER

This command generates a version report in the following form:

VER Model,PN,Mver,Sn,SW_Ver,FW_Ver

- **Model** - Unit model (Up to 4 characters. Example - "NAC1")
- **PN** - Part number (Up to 7 characters. Example - "NAC1-00")
- **Mver** - Model revision (Up to 2 characters. Example - "A1")
- **Sn** - Serial number (Up to 6 characters. Example - "000000")
- **SW_Ver** - Software Version (Up to 5 characters. Example - "01.00")
- **FW_Ver** - Firmware Version (Up to 5 characters. Example - "01.00")

SEO – Set Echo ON/OFF

SEO mode

mode = Y set Echo ON
     N set Echo OFF (Default)

This command is mainly used to set echo ON when used with a terminal to configure the system. The Local Echo mode is not stored in the system FRAM and restores to its defaults upon reset or power cycle.

RST – Reset Unit

RST Y

Y = Y, the SW will be reset. The unit locking process will be restarted.
C.4. Clock Frequency Setting

RFC – Rubidium Frequency Correct

Use this CLI command to set the frequency correction.

RFC cmd,x

<table>
<thead>
<tr>
<th>cmd</th>
<th>Rubidium frequency correction step value</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Steps of 7.6E-13 (will also be saved in a non-volatile memory).</td>
</tr>
<tr>
<td>I</td>
<td>Steps of 1.94E-10 (will also be saved in a non-volatile memory).</td>
</tr>
<tr>
<td>G</td>
<td>Steps of 7.6E-13 (will be saved in a volatile memory).</td>
</tr>
<tr>
<td>J</td>
<td>Steps of 1.94E-10 (will be saved in a volatile memory).</td>
</tr>
</tbody>
</table>

x - Number of frequency change steps, as a signed value (-127 ÷ 127).

Note: Use frequency corrections with caution!
Uncontrolled correction can cause an offset to the clock frequency.
C.5. 1PPS Disciplining

SDM – Set Disciplining Mode
Use this CLI command to set disciplining mode.

**SDM mode**

```
  mode = 0 , DPLL OFF (Not disciplined, Open loop).
  1 , DPLL ON (Disciplined, Default).
```

When SDM set to 0 ('SDM 0') the clock will ignore the 1PPS input and will be in 'Hold Over' mode.

SED – Set External 1PPS input Propagation Delay
Use this CLI command to set external 1PPS input propagation delay.

**SED x**

```
  x = Delay in ns units (Range: -25,000 ÷ 25,000ns, Default: 0ns).
```

The parameter will be saved in a non-volatile memory.

SPD – Set Output Propagation Delay
Use this CLI command to set external 1PPS output propagation delay.

**SPD x**

```
  x = Delay, in ns units. (Range: -500,000,000 ÷ 500,000,000 ns, Default: 0ns).
```

The parameter will be saved in a non-volatile memory.
C.6. Monitor Commands

UMR - User Monitor Report

UMR BIT, N/A, DPLL_Mode, N/A, FLL_mode, DPLL_State, EXT_PPS

BIT - BIT status (indicates the FLL status: 0 = BIT OK, 1 = BIT Failed)
N/A - Not Applicable
DPLL_Mode - DPLL Loop (1=On, 0=Off)
  1 - Disciplining mode is enabled ('SDM 1').
  0 - Disciplining mode is disabled ('SDM 0').

N/A - Not Applicable
FLL_mode - FACTORY USE (FLL Loop mode: 1 = On, 0 = Off)
DPLL_State - DPLL state
  The DPLL state value can be one of the following:
  0, 1, 2 – 1PPS input exists and disciplining mode is enabled ('SDM 1').
  3 – 1PPS input does not exist or disciplining mode is disabled ('SDM 0').

EXT_PPS - External 1PPS status (1 = Exists, 0 = Does not exist).
Appendix D: Specifications

Rubidium Frequency Standard

NAC1 - Nano Atomic Clock

SPECIFICATIONS

Key Features

❖ Phase noise (floor): -150dBc / Hz
❖ Power Consumption: < 1.2W
❖ Size: 32cc (41.1mm X 35.8mm X 22 mm)
❖ Aging: <3E-10/month
❖ Temp Stability: ±1E-9 / -20°C to 65°C
❖ Outputs: 10 MHz, 1PPS
❖ Supply voltage: 3.3 VDC
❖ UART interface for monitoring and control
❖ ROHS Compliant

Description

The NAC1 is the newest and smallest addition to AccuBeat’s line of Rubidium Frequency Standards. Incorporating proven traditional glass technology and based on Coherent Population Trapping (CPT), the NAC1 is an extremely small and compact atomic clock that has been designed as a board mounted component. NAC1 provides 10 MHz and 1PPS outputs and short term stability (Allan Deviation) of 2E-11 @ 100 seconds with aging of 3E-10/month at 25°C. The NAC1 has a UART interface for monitoring and control, a Built in Test (BIT) output and a warm-up time of typically 180 seconds. Measuring just 41.1mm X 35.8mm X 22mm and weighing only 75 grams and with a power consumption of less than 1.2 Watts, the new NAC1 is a Rubidium atomic clock especially suitable and designed for a wide range of portable applications.

Applications:

The NAC1 is specifically designed for low power applications such as:

❖ GPS receivers
❖ UAV’s
❖ Autonomous sensors
❖ Backpack secure communication radios.
## Inputs & Outputs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>10MHz Output</strong></td>
<td>CMOS compatible, 3.3V@1MΩ</td>
</tr>
</tbody>
</table>
| **1PPS Output**          | CMOS compatible, 3.3V@1MΩ  
Rise / Fall time: <10 ns, Pulse width: 20 µs |
| **1PPS Input**           | CMOS, 3.3V@1MΩ                                                              |
| **Built in test (BIT)**  | CMOS compatible, 3.3V@1MΩ  
'0' = Normal operation, '1' = Alarm                                   |
| **Power input**          | 3.3±0.1 VDC                                                                |
| **Serial Comm.**         | Control and monitor interface  
UART format, CMOS compatible, 3.3V@1MΩ, 115200BPS                         |

![NAC1 Diagram](image)

## Physical Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td>41.1mm X 35.8mm X 22mm</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>&lt;75g</td>
</tr>
</tbody>
</table>
# STANDARD PRODUCT SPECIFICATIONS

<table>
<thead>
<tr>
<th>Performance</th>
<th>Stability (Allan Deviation)</th>
<th>Phase Noise</th>
<th>Aging*</th>
<th>Maximum frequency change over operating temperature range</th>
<th>Digital Tuning (Through Serial communication)</th>
<th>Initial offset at shipment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 2E-10 @ TAU = 1sec</td>
<td>&lt; -86 dBc/Hz @ 10Hz</td>
<td>&lt; 3E-10 / month</td>
<td>±1E-9 (-20°C to 65°C)</td>
<td>Range: ±2E-8 Resolution: 7.6E-13</td>
<td>±5E-11</td>
</tr>
<tr>
<td></td>
<td>&lt; 8E-11 @ TAU = 10sec</td>
<td>&lt; -120 dBc/Hz @ 100Hz</td>
<td>&lt; 1E-9 / year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; 2E-11 @ TAU = 100sec</td>
<td>&lt; -138 dBc/Hz @ 1kHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; -143 dBc/Hz @ 10kHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; -148 dBc/Hz @ 100kHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; -150 dBc/Hz @ Floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Frequency**

- Phase Noise:
  - < -86 dBc/Hz @ 10Hz
  - < -120 dBc/Hz @ 100Hz
  - < -138 dBc/Hz @ 1kHz
  - < -143 dBc/Hz @ 10kHz
  - < -148 dBc/Hz @ 100kHz
  - < -150 dBc/Hz @ Floor

- Aging*:
  - < 3E-10 / month
  - < 1E-9 / year

- Maximum frequency change over operating temperature range:
  - ±1E-9 (-20°C to 65°C)

- Digital Tuning (Through Serial communication):
  - Range: ±2E-8
  - Resolution: 7.6E-13

- Initial offset at shipment:
  - ±5E-11

**Time Accuracy**

- 1PPS Sync.:
  - ±100nsec

**Warm-up**

- Warm-up Time (Time to BIT):
  - 180s (Typ)

**Power Consumption**

- Operation:
  - < 1.2W

- Warm-up:
  - < 2.4W

**Storage Temperature**

- -40°C to +90°C

**No damage operating temperature**

- -40°C to 85°C but the clock is locked at -20°C to 65°C only

*After 30 days of continuous operation

All specifications at 25°C, Vcc = 3.3VDC unless otherwise specified
### How to Order

<table>
<thead>
<tr>
<th>AccuBeat P/N</th>
<th>Output Frequency</th>
<th>Wave Form</th>
<th>Special Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAC1004</td>
<td>10MHz</td>
<td>Square</td>
<td>Standard</td>
</tr>
<tr>
<td>NAC1C04</td>
<td>10MHz</td>
<td>Square</td>
<td>Without pin 11</td>
</tr>
</tbody>
</table>

### Evaluation Kit

<table>
<thead>
<tr>
<th>AccuBeat P/N</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA50766</td>
<td>NAC1 Evaluation Kit</td>
</tr>
</tbody>
</table>