Ultra-High Resolution FemtoStepper

100fs Resolution Phase Stepper

Easy-to-Use RF Device & Compact light weight

Calibration | Time Transfer | Doppler Shift Compensation | Instrument

Applications

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1   FemtoStepper System Description

The FemtoStepper provides a highly stable 10MHz, available on four outputs, that is adjustable in phase and frequency with an extremely high resolution. In addition to the 10MHz outputs, the micro-stepper provides a one pulse per second (1PPS) available on four outputs generated from the 10MHz output.

The FemtoStepperprovides a 10MHz signal that is derived from a high performance, ultra low phase noise crystal oscillator which is phase locked to an external 10MHz reference input. It allows to adjust the outputs in phase and frequency without disturbing the reference signal source and precautions are taken in order to minimize the added noise.

The design is based on a double heterodyne architecture where a first structure is used for positive phase / frequency adjustment and the second structure for negative adjustment.

The device is controlled remotely through an RS-232 serial link. which provides a prompt with a defined list of commands. All commands are parsed for correct syntax and operational range prior to execution. Commands that contain errors are rejected.
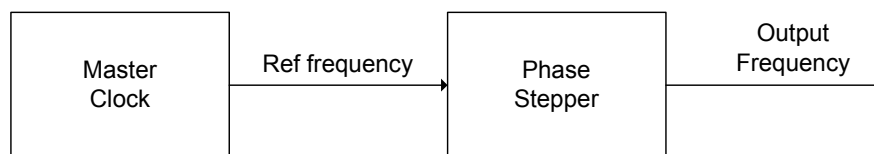
Figure 1- Application Diagram

Figure 2- Block Diagram

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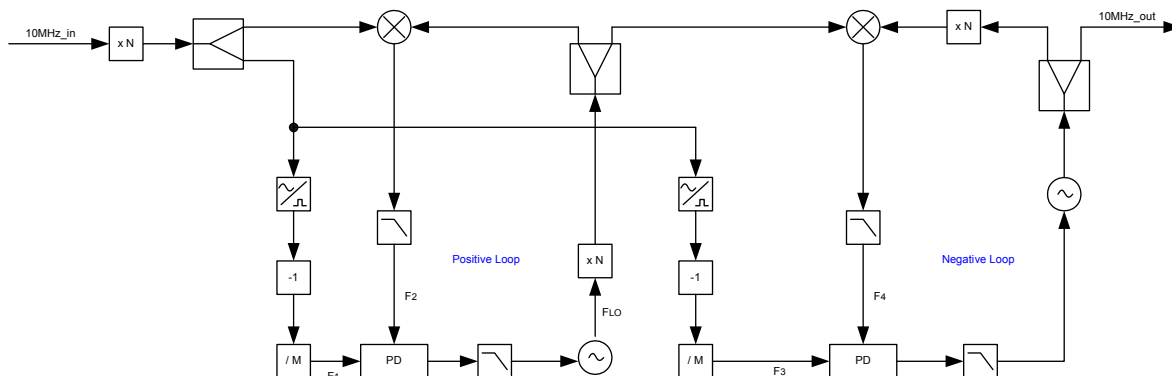
1.1   Frequency Adjustment

The frequency offset is applied to the output 10MHz OCXO through the double heterodyne structure in order to increase the resolution.

$$F_{out} = F_{in} + \frac{\Delta f}{G}$$

Where :

   G :   Heterodyne Gain of 10^6.

Δf is managed by the microprocessor.

The relationship between the output frequency and the input frequency is the following :

$$F_{out} = \frac{F_{in}}{1 - \dfrac{N}{10^{17}}}$$

Where :

   N :   Frequency offset by 10^{-17} steps.

The frequency offset is always the absolute value from the 10MHz input.

The output range is limited nearly $\pm 10^{-9}$. ($\pm 9.9999999 \times 10^{-10}$)

1.2   Phase Adjustment

The output phase is adjustable with 0.1 picosecond resolution over a maximum range of ±50ns in order to cover an entire period of the 10MHz output signal. The phase adjustment is performed under microprocessor control.

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1.3   Microprocessor control and PPS (pulse per second) facility
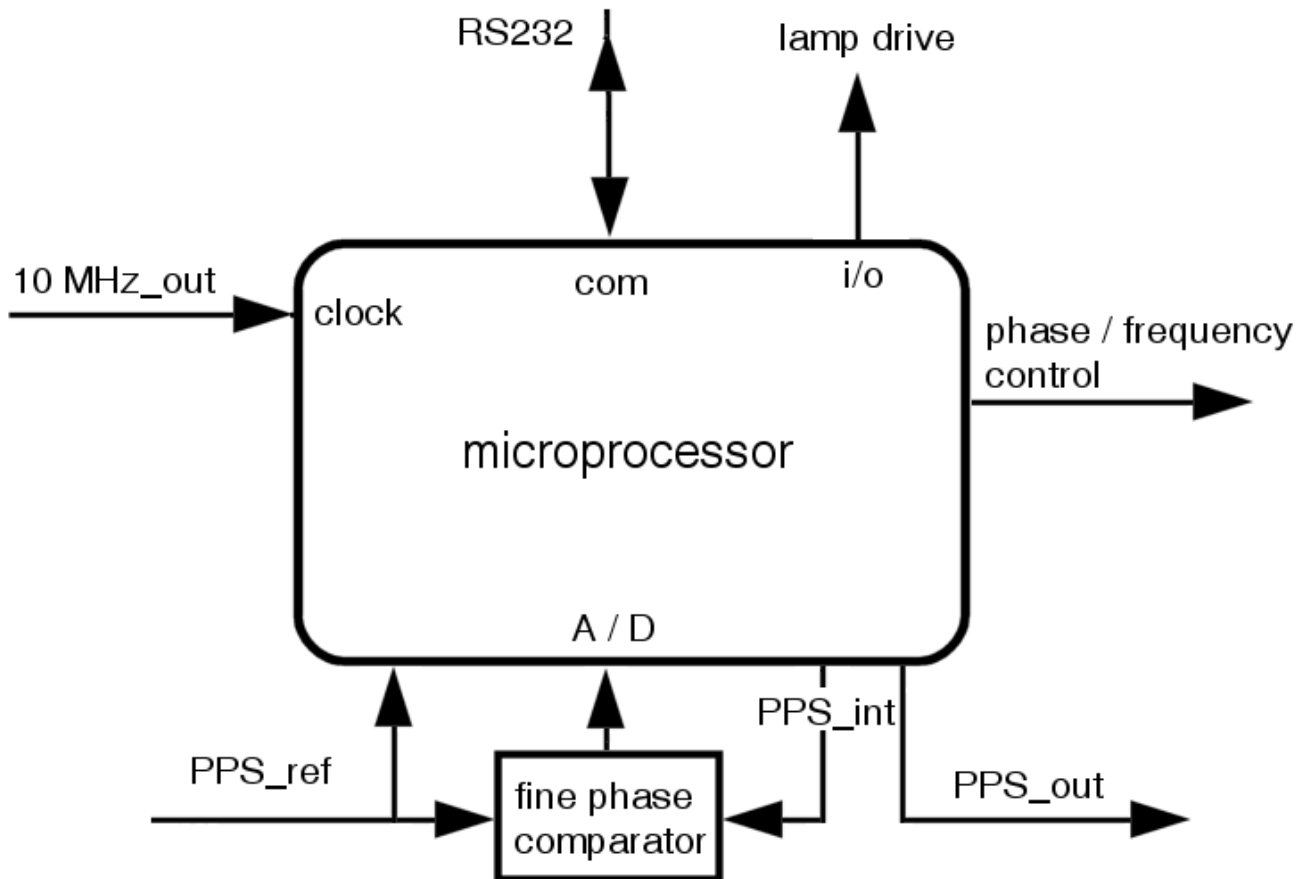
Figure 3 – The microprocessor and its surrounding

The microprocessor is controlling the functions. It is clocked by the 10 MHz_out. A division by 1e+7 is made, providing the PPS_out. The PPS_out can be aligned to a reference PPS_ref within +/- 200 ns when the command AL1 is issued. .
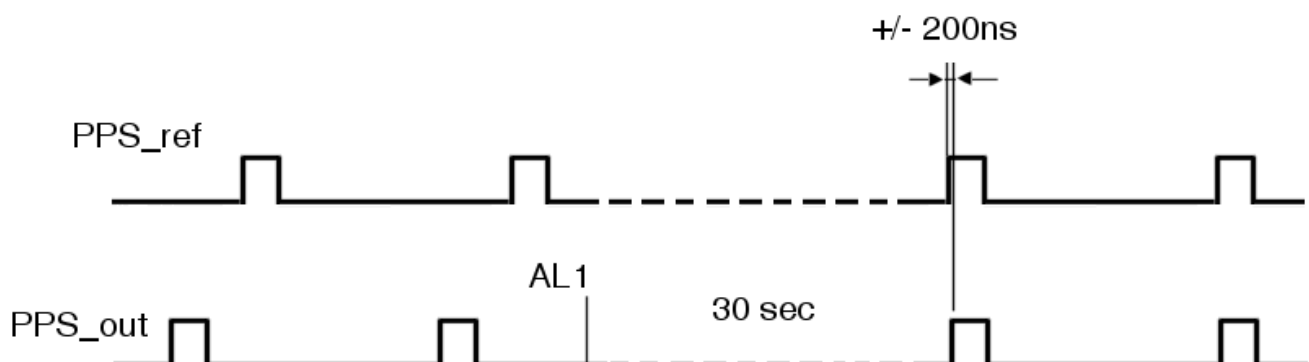
Figure 4 – The PPS_out can be aligned to the PPS_ref.

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2   FemtoStepper Installation

2.1   Safety

<div style="border:1px solid black; padding:10px;">

⚠️   **- Use proper ESD precautions**

                          - Ensure that all cables are properly connected

</div>

2.2   Unpacking

Unpack and carefully inspect the unit. Check for physical damage. If physical damage is observed, then immediately contact SpectraTime SA.

Unit Supply:

1 FemtoStepper Rack 19"/2U
1 Cable SUB-D 9 pins male/female
1 Euro power cable
2 Brackets for rack mount (only with standard version)
1 Connector for Backup DL power supply

2.3   Electrical & Indicator Interfaces

Fig. 3   Interfaces

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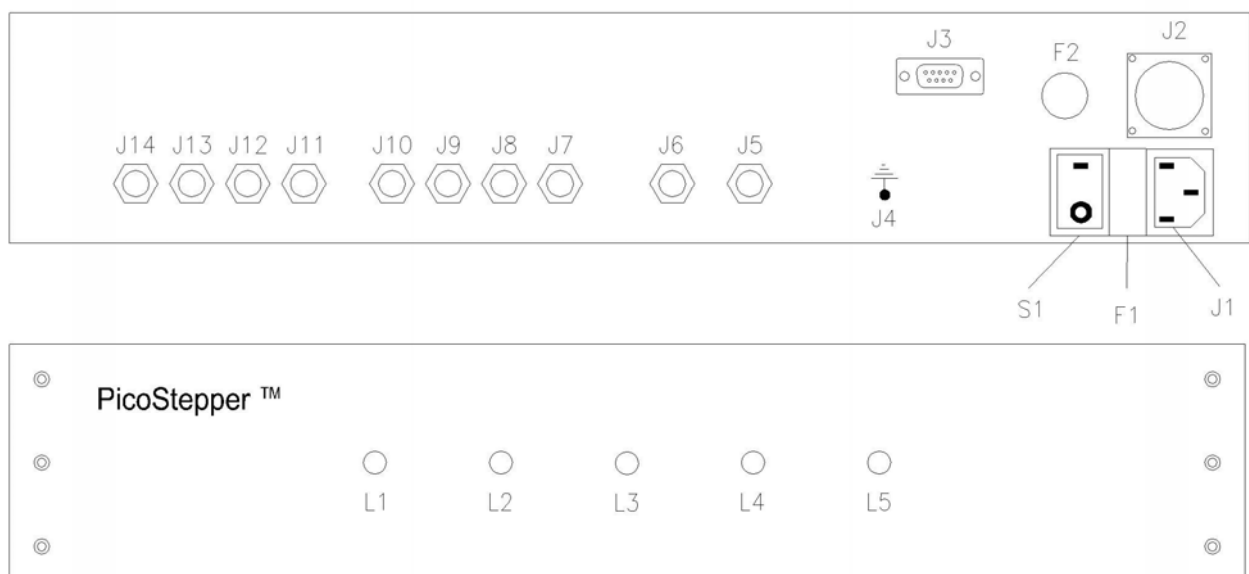
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| N°	In/Out	Designation
J1	In	230VAC primary power
J2	In	+24VDC backup power
J3	In/Out	COM Interface
J4	-	Ground connection
J5	In	10 MHz reference signal
J6	In	PPS reference signal
J7-J10	Out	4x PPS output
J11-J14	Out	4x 10MHz output
S1	-	On/Off switch
F1	-	Primary power supply fuse - T 1,6A
F2	-	Backup power supply fuse - T 3,15A
L1	-	Primary power indicator
L2	-	Backup power indicator
L3	-	Alarm indicator
L4	-	Running indicator
L5	-	Initialization indicator

Table 1: Interfaces

	Pin	Designation
J2	1	GND VDC backup power
J2	2	+24 VDC backup power
J2	3	+24 VDC backup power
J2	4	GND VDC backup power

Table 2: Backup Power Connector

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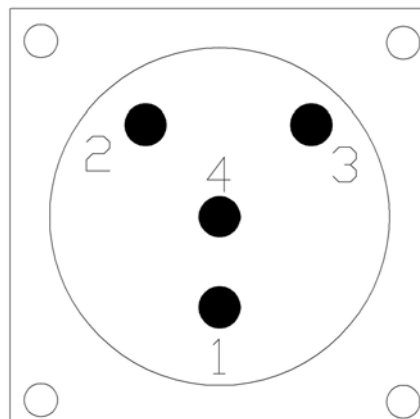
2.4   Connections

- Connect the **10MHz** input reference to the FemtoStepper unit (J5).

- Connect, if PPS functionality is desired, the PPSref signal (J6).

- Connect the male SUB-D-9 to the unit (J3) and female SUB-D-9 to the computer.

- Connect the primary power cable (230VAC) to the unit (J1).

- Connect the backup power cable (+24VDC) to the unit (J2).

- Optionally, connect the device to ground (J4).

- Switch on the unit (S1).

2.5   Recommendations

- Warm-up FemtoStepper **several hours** before to start any applications.

- To reduce warm-up time, keep FemtoStepper powered-up at all times even when an input reference signal is not available.

- To ensure a continuous operation, connect a uninterruptable backup 24V power source.

- Avoid locations of the unit with variable air flow and temperature changes.

- Avoid to place FemtoStepper close to vibration environment and high magnetic fields changes.

2.6   System Power-Up

- Switch on the unit (S1).

- If the primary power is connected, L1 indicator is green.

- If the backup power is connected, L2 indicator is green.

- The alarm indicator (L3) is red while warming-up.

- During the first five seconds, the microprocessor is performing an initialization. At the end of the initialization sequence, L5 switches off.

- After approximately fifteen minutes, the alarm (L3) indicator have to switch off. If still red, check if an input reference is connected (J5).

- When ready to operate the running indicator (L4) becomes green.

- When a frequency offset is applied, the running indicator (L4) is blinking.

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3 System Control

The device is controlled remotely through an RS-232 serial link. which provides a prompt with a defined list of commands. All commands are parsed for correct syntax and operational range prior to execution. Commands that contain errors are rejected.

The RS232 protocol is :

> 9600 bits/s
> 8 data bits
> No parity
> 1 stop bit
> No handshake

FemtoStepper accepts the following basic ASCII commands: Data is in decimal ASCII code.

Command name	Syntax command	Data field (if any)	Response syntax	Response data (if any)
Identification	**ID**<CR><LF>	-	TNTMPS-aaa/rr/s.ss<CR><LF>	aaa: 001 rr: revision number s.ss: software version
Serial number	**SN**<CR><LF>	-	xxxxxx<CR><LF>	xxxxxx : 6 digits serial nbr
Status	**ST**<CR><LF>	-	yyxx<CR><LF>	yy : always 00 (for future use) xx : HEX ASCII Bit signification : Bit 7 :- Bit 6 :backup power active Bit 5 :primary power active Bit 4 :- Bit 3 :frequency offset not 0 Bit 2 : stepping activity Bit 1 : OOL - Bit 0 : OOL +
Single Phase Step	**PS**s<CR><LF>	s= + : Positive Step s= - : Negative Step	s<CR><LF>	s: signe s= + : Positive Step s= - : Negative Step
Packet Phase Step	**PS**sddddddd<CR><LF>	s=+ : Positive Packet Step s=- : Negative Packet Step dddddd: number	sddddddd<CR><LF>	s:signe s=+ : Positive Packet Step s=- : Negative Packet Step dddddd: value
Actual phase offset	**PH**<CR><LF>	-	sddddddd<CR><LF>	s:signe s=+ : Positive Packet Step s=- : Negative Packet Step dddddd: value From 000000 To 500000
Frequency offset	**FA**sdddddddd<CR><LF>	s= + : Positive offset s= - : Negative offset dddddddd: number	sdddddddd<CR><LF>	s= + : Positive offset s= - : Negative offset dddddddd: value
Actual frequency offset	**FR**<CR><LF>	-	sdddddddd<CR><LF>	s= + : Positive offset s= - : Negative offset dddddddd: value
Align PPSOUT to PPSREF	**AL**d<CR><LF>	d= 1 : align d= ? : alignment status	d<CR><LF>	d= 0: ready for alignment d= 1: alignment in progress d= 2 : no PPSREF
Set PPSOUT delay (rounded to 200ns)	**DE**ddddddddd<CR><LF>	ddddddddd=delay in ns. Max 999999800 ????????? :interrogation	ddddddddd<CR><LF>	ddddddddd=delay in ns. Min 000000000 Max 999999800
Send information every second	**BT**x<CR><LF>	x= 0 : Stop to send x= 3 : PPSRef position x= 5 : Status	x= 3 : aaaaaaaa sbbb<CR><LF> x= 5 : yyxx<CR><LF>	aaaaaaaa= PPSOUT vs PPSREF delay in ns. sbbb= fine phase comparator value in approx. ns yyxx= see ST command

Table 2 :   Serial commands summary

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4   RS232 Commands

4.1   Identification

ID<CR>[<LF>] :   Identification

Answer :   **TNTMPS-aaa/rr/s.ss<CR><LF>**
                    aaa :   001
                    rr :   revision number
                    s.ss :   software version

Example :   **ID<CR>** answers **TNTMPS-001/01/1.00<CR><LF>**

4.2   Serial number

SN<CR>[<LF>] :   Serial number

Answer :   **xxxxxx<CR><LF>**
                    xxxxxx :   6 digits serial number

Example :   **SN<CR>** answers **000015<CR><LF>**

4.3   Status

ST<CR>[<LF>] :   Status

Answer :   **yyxx<CR><LF>**
                    yy : always **00** (reserved for future use)
                    xx : HEX ASCII status :
                          bit 7 :--
                          bit 6 :backup power active
                          bit 5 :primary power active
                          bit 4 :--
                          bit 3 :frequency offset not 0
                          bit 2 : stepping activity
                          bit 1 : OOL negative loop
                          bit 0 : OOL positive loop

Example :   **ST<CR>** answers **0068<CR><LF>**
                    (backup and primary power active, frequency offset applied, system locked)

Note :   BT5<CR> send status once per second in the same format.

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4.4   Single Phase Step

PSs<CR>[<LF>] :   Single phase step

s = **+**:   1 positive phase step of 10^{-13} second
     - :   1 negative phase step of 10^{-13} second

Answer :   **s<CR><LF>**
s :   sign of the single phase step

Example :   **PS+<CR>** answers **+<CR><LF>**

Note :   Phase adjustment are not absolute value.

4.5   Packet phase step

PSsdddddd<CR>[<LF>] :   Packet phase step

s = **+**:   positive phase adjustment
     - :   negative phase adjustment

dddddd : phase adjustment in 10^{-13} second
            000000 to 500000
            000001 : minimum phase adjustment ($\pm 1 \times 10^{-13}$ s)
            500000 : maximum phase adjustment ($\pm 5 \times 10^{-9}$ s)
            000000 : no phase adjustment

Answer :   **sdddddd<CR><LF>**
sdddddd : phase adjustment value

Example :   **PS+000100<CR>** answers **+000100<CR><LF>**
(a positive phase adjustment of 10^{-11} second is asked)

Note :   Phase adjustment are instantaneous phase changes and are cumulative with previous phase changes.

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4.6   Actual Phase Adjustment

PH<CR>[<LF>] :   Actual phase adjustment

Answer :   **sdddddd<CR><LF>**

                    s = **+**:   positive phase adjustment
                        - :   Negative phase adjustment

                    dddddd : phase adjustment value in 10^{-13} second step

Example :   **PH<CR>** answers **-000020<CR><LF>**
                    (an total actual negative phase adjustment of $2x10^{-12}$ second has been applied)

Note :   The actual phase is the accumulated phase changes from the starting of the system. A frequency offset different from 0 reset the phase adjustment to 0.

                    <u>Example :</u>
                    At T_0 the command PS+000002<CR> has been sent,
                    At T_1 the command PS-000007<CR> has been sent,
                    At T_2 the command PS+000009<CR> has been sent,
                    At T_3 the command PH<CR> answers +000004 which corresponds to the total accumulated phase adjustment applied until T_3 ($2-7+9=4x10^{-13}$ second).

4.7   Frequency Offset

FAsdddddddd<CR>[<LF>] :   Frequency offset

                    s = **+**:   positive frequency offset
                        - :   Negative frequency offset

                    dddddddd :   frequency offset in 10^{-17} step
                                     00000000 to 10000000
                                     00000001 : minimum frequency offset ($\pm 1x10^{-17}$)
                                     99999999 : maximum frequency offset ($\pm 9.9999999x10^{-10}$)
                                     00000000 : no frequency offset

Answer :   **sdddddddd<CR><LF>**
                    sdddddddd :   frequency offset value

Example :   **FA+00010000<CR>** answers **+00010000<CR><LF>**
                    (a positive frequency offset of 10^{-13} relative to input reference frequency is asked)

Note :   Frequency offset are absolute value from input reference frequency. A new frequency offset overwrite the previous one.

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4.8   Actual Frequency Offset

FR<CR>[<LF>] :   Actual frequency offset

Answer :   **sdddddddd<CR><LF>**

                       s = **+** :   positive frequency offset
                           - :   negative frequency offset

                       dddddddd :   frequency offset in 10^{-17} step

Example :   **FR<CR>** answers **-00100000<CR><LF>**
                       (a negative frequency offset of 10^{-12} relative to input reference frequency is applied)

Note :   Frequency offset are absolute value from input reference frequency. A new frequency offset overwrite the previous one.

                       <u>Example :</u>
                       At T_o the command FA+00600000<CR> has been sent,
                       At T_1 the command FA-00020000<CR> has been sent,
                       At T_2 the command FR<CR> answers -00020000 which is the actual frequency offset (it corresponds to the last frequency offset command applied before T_2.)

4.9   Pulse Per Second Alignment

ALd<CR>[<LF>] :   PPSOUT alignment to PPSREF

                       d = 1 : align
                           ? : interrogation

Answer :   **d<CR><LF>**
                       0: ready for alignment
                       1: alignment in progress
                       2: no PPSREF

Example :   **AL1<CR>** answers **1<CR><LF>**

Notes: -   While the command is in progress, an internal PPSLOCAL is aligned to PPSREF. This can take up to 30 seconds.
                -   The alignment is done within +/- 200 ns.
                -   After an alignment DE????????? answers 000000000<CR><LF>
                -   This command has no influence on the 10 MHz output.

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4.10 PPSOUT Delay

DEddddddddd<CR>[<LF>] :   Set a PPSOUT delay

dddddddd :	delay in ns
	000000000 to 999999800
	000000000 : no delay
	000000200 : minimum delay
	999999800 : maximum delay
	????????? : interrogation

Answer :   **dddddddd<CR><LF>**
                   dddddddd :   just asked delay

Example :   **DE?????????<CR>** answers **000000000<CR><LF>**

Notes :
- After power on / Reset, the PPSOUT position is random.
- After the command AL1, the PPSOUT is aligned to PPSREF and the delay is settled to 0.
- This command has no influence on the 10 MHz output.

4.11 Information Every Second

BTx<CR>[<LF>] :   send information once per second on the serial port

                   x = 0 :   stop to send

Answer :   none

                   x = 3 :   PPSOUT vs PPSREF position

Answer :   **aaaaaaaaa sbbb<CR><LF>** once per second

aaaaaaaaa :	raw PPSOUT vs PPSREF position in ns, rounded to 200 ns steps
000000000 :	PPSOUT aligned to PPSREF
000000200 :	minimum value
999999800 :	maximum value
????????? :	no PPSREF

sbbb :	s : sign +/- ; bbb : analog fine PPS comparator value in approximately ns. PPSLOCAL vs PPSREF.
+000 :	PPSLOCAL and PPSREF are perfectly aligned.
-500 :	lowest value
+500 :	highest value

Remark : the command AL1<CR><LF> must be sent first to bring the PPSLOCAL in the PPS phase comparator working range.

                   x = 5 :   Status

Answer :   **yyxx<CR><LF>** once per second
                   See Status command for details

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