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Research Article

Backup Hydrogen Maser Steering Syster Precise Timing Facility

Qinghua Wang, Pascal Rochat, and Xavier Stehlin

SpectraTime, Vauseyon 29, Neuchâtel 2000, Switzerland

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Abstract

Two hydrogen masers (HMs) are used in the Precise Timing Fa System Time, insuring the extremely high short-term stability req a smooth switch over between backup and primary HMs, the “b acquires the phase difference measured between two HMs, co steering correction to the backup HM via a PicoStepper with a (based on outlier removal and a proportional-integral filtering contr performance, the overall backup HM steering system is simula simulated anomalies (phase/frequency spikes, jumps, and drift).

1. Introduction

The Precise Timing Facility (PTF) is one of the key facilities of the accurate, stable, and precise Galileo System Time Master Clock (Processing Facility and to the other Galileo Control Center facilities

Two PTFs are currently under development by two separate team this paper refers to the Italian development [1], coordinated by th

the partnership and support of SpectraTime (former Temex Tir
Astrogeodynamic Observatory, Poland.

Two active hydrogen masers (a primary HM1 and a backup HM
provide the physical realization of GST(MC), insuring the extr
navigation functions, in particular, to perform a reliable satellite cl

The “backup HM steering algorithm” is implemented in order t
primary HM in case of failure of the latter, without producing any
or short-term frequency stability. The algorithm acquires the ph
multichannel phase comparator (MCPC), and generates a steerin
PicoStepper with a 0.1-picosecond resolution.

2. Architecture

Figure 1 shows the architecture of the backup HM steering syste
HM), and the algorithm.

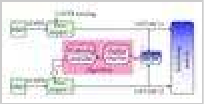

Figure 1: Architecture of the backup HM steer

In the nominal situation, PicoStepper1 applies the steering corre
HM1 with “GST running” (GSTR) obtaining the GST(MC1). Th
compared by MCPC, whose output is used by the “backup HM st
to PicoStepper2 whose input is the backup HM2. Thus, the steered

In case of the HM1 failure, the hot backup HM2 becomes the prim
phase offset “HM2(steered)-HM1” provides the seamless switch
by the GSTR correction for GST(MC).

3. Picostepper

A high-resolution PTF PicoStepper (i.e., microphase stepper), bas
is being developed to provide frequency correction of HMs signals (

Figure 2: PTF PicoStepper.

The unit is being designed to meet the following two PTF requirem

(i) increase of the resolution by a factor of 100 to obtain a m
(ii) reduction of output jitter to get negligible degradation of

The design is based on a double heterodyne architecture where a
adjustment and the second structure for negative adjustment.

As shown in the high-level block diagram (Figure 3), each positi

oscillator (VCXO), a phase detector, a frequency mixer, a frequen
divider and a loop filter. A microcontroller is in charge to manage
the capability to execute a self-test of the unit.

Figure 3: Block diagram of PTF PicoStepper (i.

The 0.1-picosecond resolution of the system is obtained by using tl
and divider ratio. Taking $N = 10$ and $M = 10^5$, the frequency r
corresponds in terms of phase of 0.1 picosecond.

The frequency beats (F1, F2, F3, and F4) in both loops while not s
frequencies of the phase detectors. Thus, the nominal frequency
$N = 9.999900$ MHz.

In order not to degrade the HM performances, a phase noise fi
comparison between the HM specification and the best performanc
noise close to the carrier gives the required cutoff frequency to b
frequency should be around 4 Hz. Since the frequency beats us
implement the desired 4 Hz cutoff frequency.

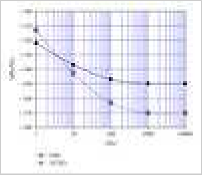

Figure 4: Phase noise figure.

4. Steering Approach

The backup HM steering algorithm together with the MCPC and I
which locks the phase of the backup HM to the primary one. Fig
steering model.

Figure 5: Block diagram of the backup HM ste

The algorithm design is based on a digital proportional integral (PI
periodical generation of the steering commands accepted by the Pi

To eliminate the impact of anomalies of the primary HM output sig
the algorithm first removes the phase outliers of the dynamic l
routine is sensitive only to the difference between the two HMs
rejecting phase outliers from both the primary and the backup
remain in the steered output.

4.1. Phase-Locked Loop and PI Filter

Figure 6 illustrates the PLL control system block diagram in the cor

Figure 6: Block diagram of the phase-locked l

The s-transfer function of second-order closed loop is

$$C(s) = \frac{2\xi\tau s + 1}{\tau^2 s^2 + 2\xi\tau s}$$

where τ is the loop time constant (in seconds), 1000 seconds, whi the frequency stability [2]; ξ is the damping factor, 1; K_c is MCPC 10^{-13}/step.

In discrete domain, basic digital filtering functions can be used. T filter is

$$D(z) = K_p + K_i \frac{z}{z -}$$

where K_i and K_p are coefficients of the discrete integrator and prop

4.2. Dynamic Least-Square Linear Fitting and Outlier Remov

Figure 7 illustrates the block diagram of the Outlier Remover. The the previous 100-second data in sliding windows. If the absolute the outlier criterion C (30 picoseconds), the data are removed a phase outliers of the primary HM are filtered before the steering.

Figure 7: Block diagram of the outlier remove

5. Backup HM Steering System Simulation and Perf

The technical requirement on the backup HM steering system imp exceed 30 picoseconds in the value of the GST(MC) to switch the p

A simulation model [3] is created to analyze and verify the ste various test cases including the nominal and degraded condit (phase/frequency spikes, jumps and drift) occurred in both HMs.

Figures 8, 9, 10, and 11 demonstrate the simulation results or properly to the primary HM1 under all test cases.

(i) With phase spikes at the primary HM1, the algorithm pro the phase offset “HM2(steered)-HM1(outliers removed)” is difference, and the standard deviation is 1.03 picoseconds afte
(ii) In the presence of the phase step of 30 picoseconds (GS HM1 or the backup HM2, the maximum impacted phase offset
(iii) When the HM signal is applied by GST(MC) maximum phase offset “HM2(steered)-HM1” is 6.3 picoseconds.
(iv) Even if the HM frequency drift is seriously degraded, tl specifications with the loop settling time, and the peak offset a the frequency drift of 1e-13 / d(10 times worse of the specifica

e-15 / d). The maximum phase offset as 12.5 picoseconds c
accompanying frequency jump of 2.5e-14 in the HM output sig

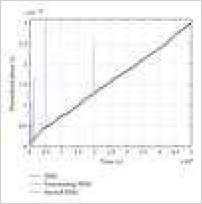

Figure 8: Simulation on phase/frequency spik

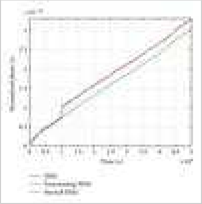

Figure 9: Simulation on phase jump of 30 picc

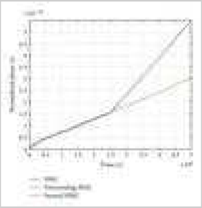

Figure 10: Simulation on frequency jump of 1

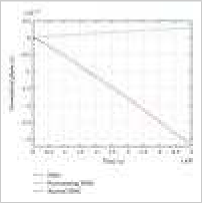

Figure 11: Simulation on frequency drift of 1e

Table 1 summarizes the overall performance budget, taking into a
the input of the MCPC and the input of the switching matrix, the M
total performance is within the PTF requirement on the switch over

Table 1: Overall performance budget.

Besides above phase offset analysis, the frequency offset of “HN
test cases, and it meets the PTF requirement that the frequency ju
of 100 minutes in the value of the GST(MC).

In addition, the worst cases are analysed.

(i) The PLL will be beyond the PicoStepper maximum cont
bigger than 5 nanoseconds, or the frequency jump is bigger th
(ii) For above latter case, the phase offset “HM2steered-HI
To meet this specificaion, the frequency jump is allowed to be

6. Conclusion

We conclude that our steering system is capable of meeting the Ga
to the primary in phase and frequency. Currently the algorithm
prototype phase subject to Galileo Software Standards. It will be
into the PTF operational software.

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