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Up-Link Frequency Control Using Closed-Loop Mode

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Abstract

We describe the possibility of frequency stabilization on the HALCA satellite by applying a closed-loop up-link frequency control. The closed-loop mode is able to remove systematic variations of the residual delay rate and the frequency stability is greatly improved.

1 Introduction

The HALCA Satellite is not equipped with a hydrogen maser oscillator, and so the clock and phase are up-linked from ground tracking stations equipped with their own hydrogen maser oscillator. The received phase is Doppler shifted by the effect of the orbital motion of the satellite and fluctuated by the atmosphere. So the transferred phase must be controlled at the ground station in order to keep the received phase on the satellite constant, effectively equipping the satellite with a hydrogen maser frequency oscillator.

There are two up-link frequency control methods. One is the open-loop frequency control based on the calculation of the up-link frequency from the orbit prediction. The other is the closed-loop frequency control based on the measurement and control of the frequency offset on the satellite. At present for HALCA the open-loop control is used, although the accuracy of the orbit prediction is not so good.

In this report, we describe the possibility of high frequency stabilization on the satellite by applying a closed-loop up-link frequency control.

2 Merits of the Closed-Loop Mode

- An accurate orbit prediction is not necessary
- The time correction for correlation processing becomes easy.

- The possibility of real-time correlation processing becomes available.

3 Frequency Control Algorithm (PI Control)

1. Control is started with open-loop frequency control mode
2. Closed loop frequency control mode switched ON ($t = t_0$)
3. Estimation of true Doppler frequency

$$f_{true-dopp}(t) = \frac{\hat{f}_{up-cont}(t) - \frac{f_{down-measure}(t+T_{up+down})}{r}}{2} \quad (1)$$

4. Estimation of deviation (frequency offset on the satellite)

$$\Delta f(t) = f_{up-cont} - f_{true-dopp} \quad (2)$$

5. Calculation of manipulated variable

$$\begin{aligned} f_{up-cont}(t+5T_S) &= f_{up-cont}(t+4T_S) \\ &+K_P \cdot \Delta f(t) + K_I \cdot \sum_{t=t_0}^{t} \Delta f(t) \\ &+f_{true-dopp}(t) - f_{true-dopp}(t-T_s) \end{aligned} \quad (3)$$

6. Decision of up-link frequency

$$f_{up}(t+5T_s) = F_{u0} - f_{up-cont}(t+5T_s) \quad (4)$$

7. Iteration of steps 3–6

T_s : sampling time(1 second)
$T_{up+down}$: propagation time
$f_{true-dopp}$: true Doppler frequency
$f_{up-cont}$: manipulated variable of up-link frequency
$f_{down-measure}$: measurement variable of down-link frequency
Δf : frequency offset
r : transponding ratio (14.2[GHz]/15.3[GHz])
K_P : coefficient of proportionality
K_I : coefficient of integration
f_{up} : up-link frequency
F_{u0} : nominal up-link frequency (15.3 GHz)

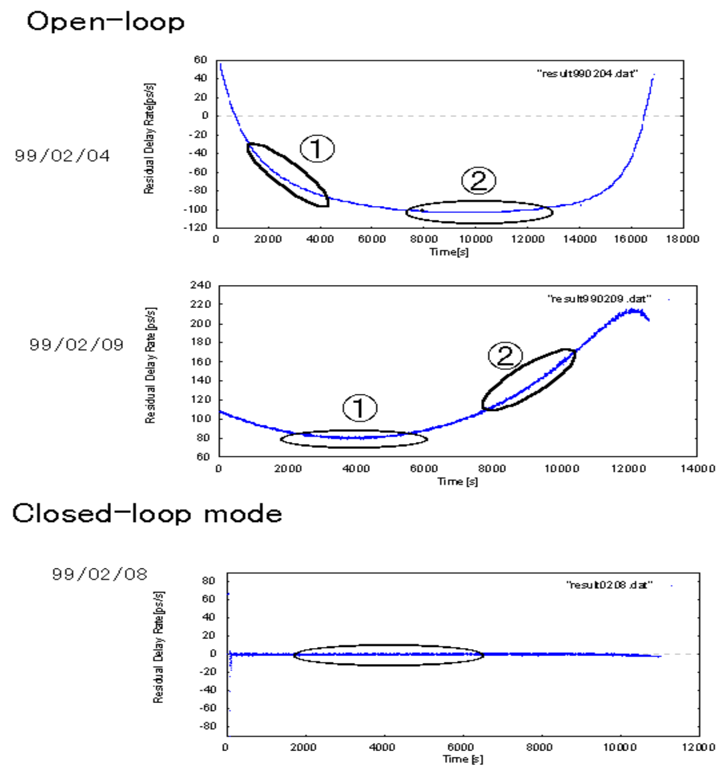

Figure 1: Result of open-loop mode and closed-loop mode.

4 Result

The results of the frequency control experiment are shown in Figure 1 and Figure 2. In Figure 1 the vertical axis is the residual delay rate and the horizontal axis is observation time. In Figure 2 the vertical axis is Allan standard deviation and the horizontal axis is the averaging time.

5 Conclusion

The closed-loop mode is able to remove the systematic variation of residual delay rate and the frequency stability is greatly improved. Therefore, it is clear that the closed-loop control is possible and offers significant improvements.

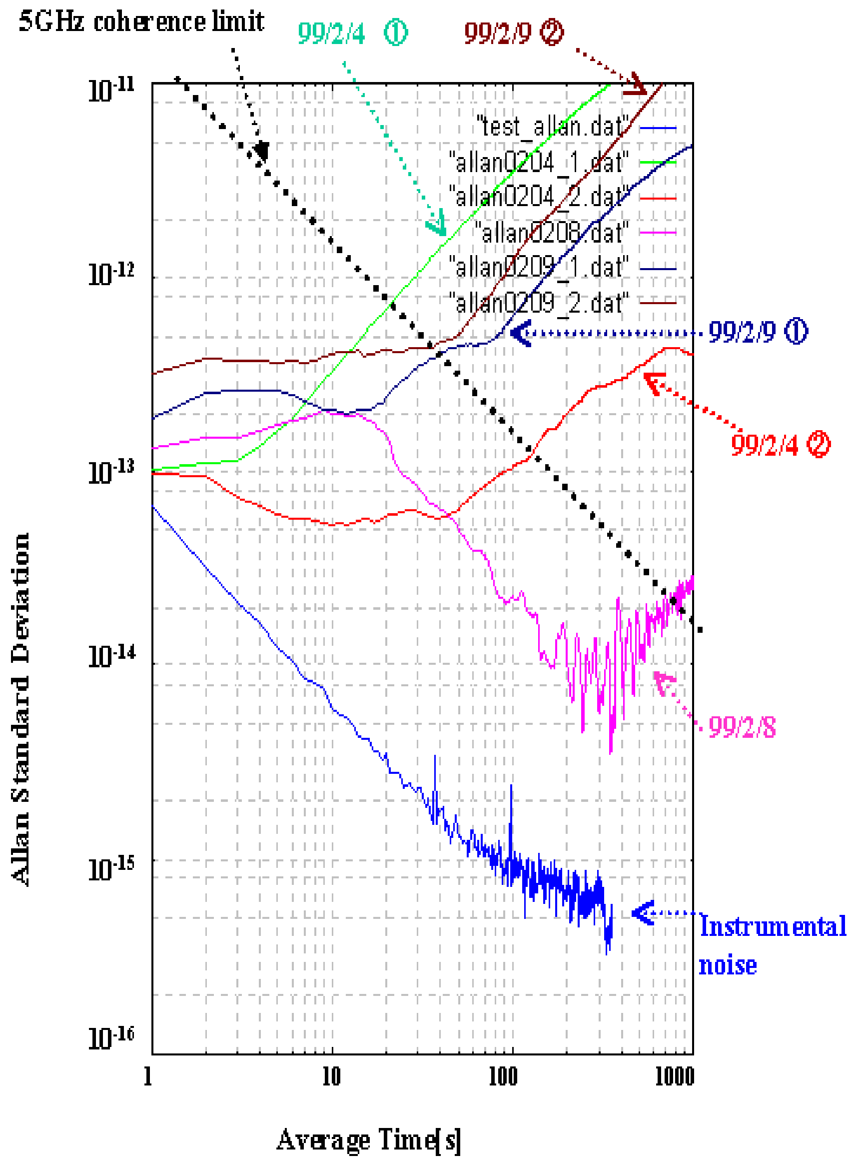

Figure 2: Frequency stability.