DEVELOPMENT OF TWSTFT CARRIER PHASE TECHNIQUE IN LNE-SYRTE

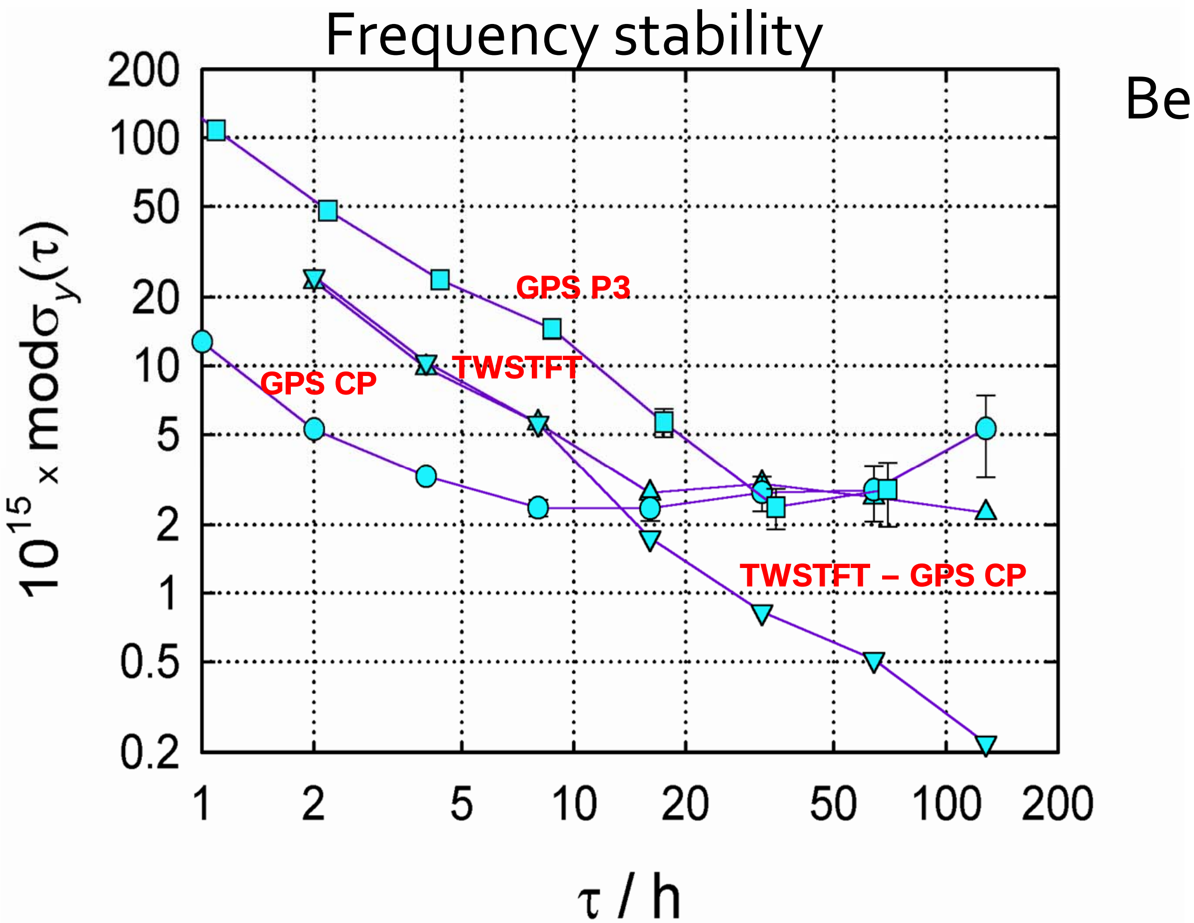
Amale Kanj, Joseph Achkar and Daniele Rovera

LNE-SYRTE, Observatoire de Paris/LNE/CNRS/UPMC, Paris
amale.kanj@obspm.fr

Outline

- Introduction and motivation
- Principle of TWSTFT carrier phase technique
- TWSTFT equation system
- Experimental validation of the system set-up
- Understanding the satellite LO frequency distortion
- Characterization of the TWCP link (stability)
- Conclusion and outlooks

Introduction and motivation



Results obtained with 2.5 Mchips/s, OP-NPL link (Bauch et al., Metrologia **43** (2006) 109-120).

Best results:

- 8x10^{-16} @ 1 day in 2009 with 2.5 Mchips/s
- Same performance can be reached today at 1 Mchips/s.

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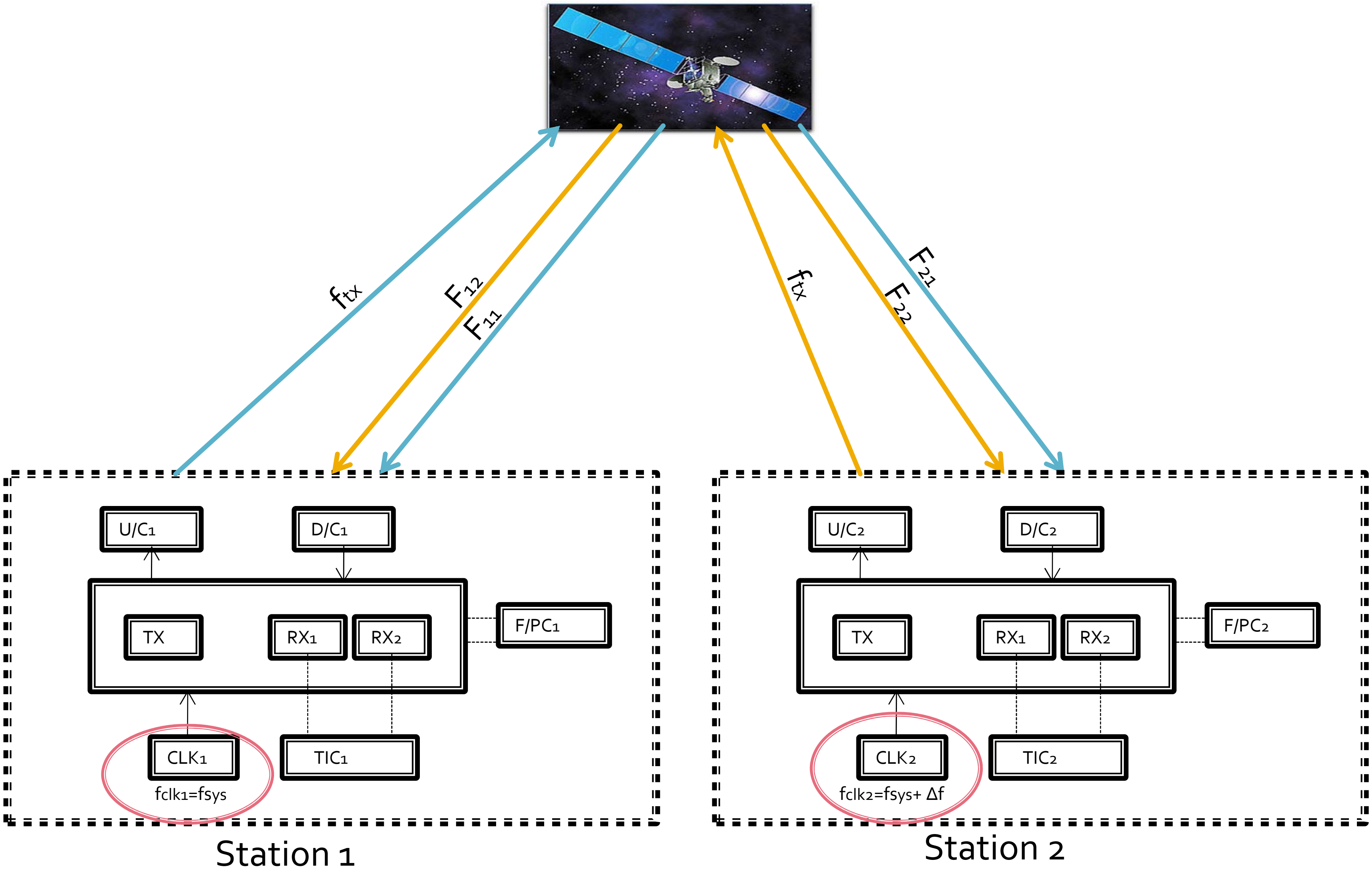
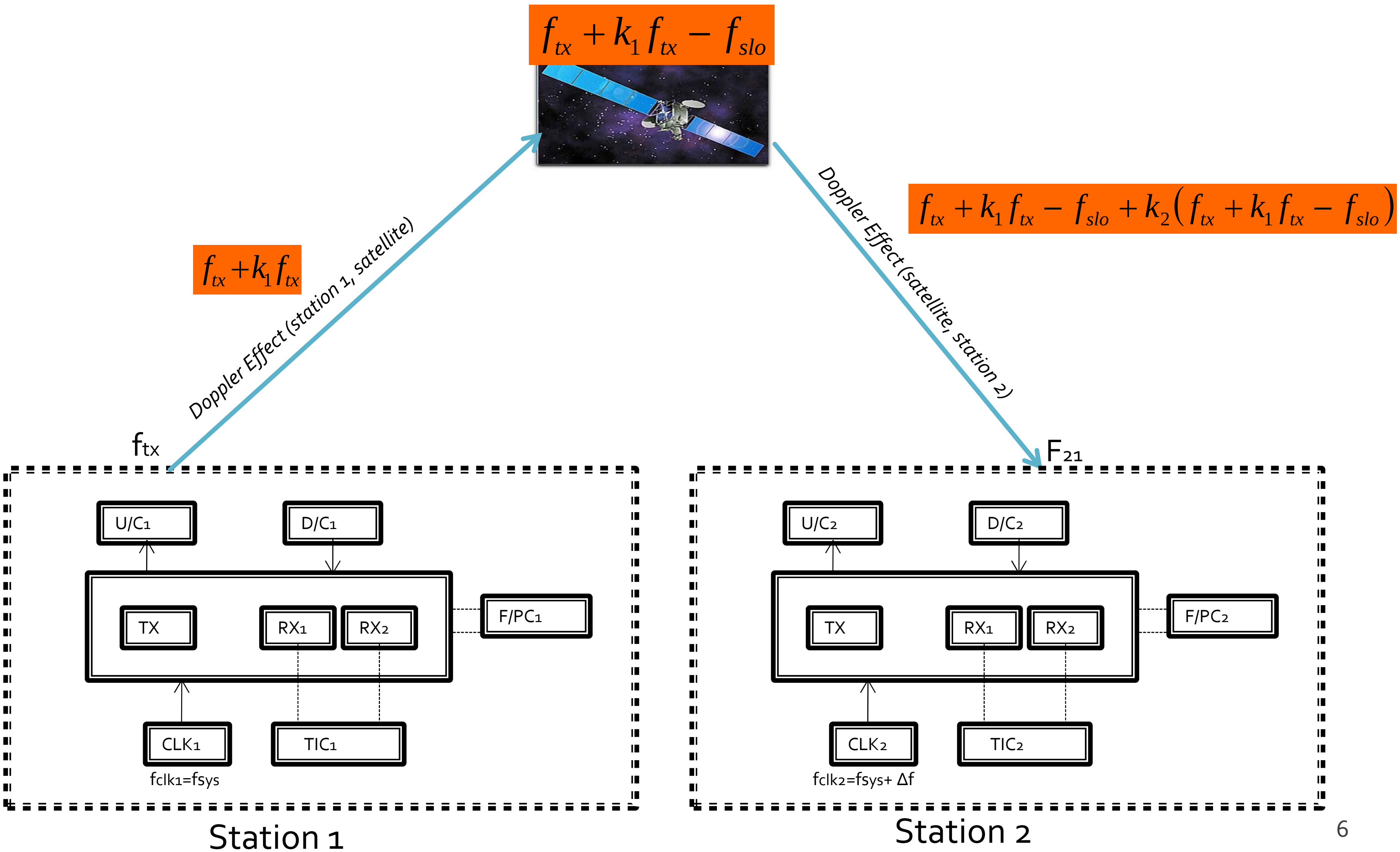
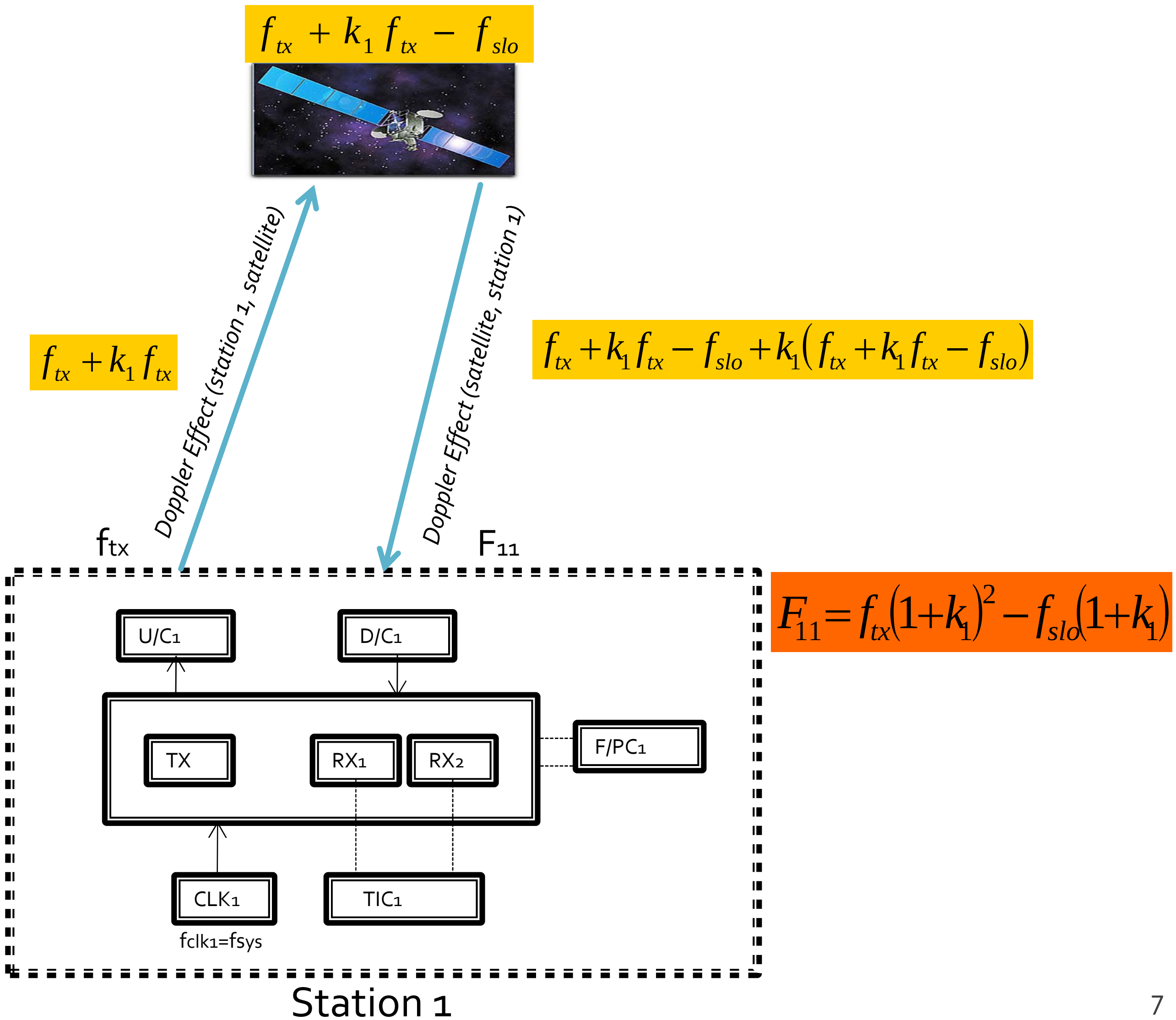
TWSTFT carrier phase principle



Transfer from station 1 to station 2



Ranging Signal



Doppler effect

- The Doppler coefficients are calculated using the following equation :

$$k_n(t) = \frac{v_n(t)}{c}$$

- v_n (t): projection of the satellite velocity in the direction of station n at the instant t.
- c : speed of light

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TWSTFT carrier phase equation system

$$
\begin{cases}
F_{11} = f_{tx}(1+k_1)^2 - f_{slo}(1+k_1) \\
F_{12} = f_{tx}\left(\dfrac{f_{sys}+\Delta \mathrm{f}}{f_{sys}}\right)(1+k_1)(1+k_2) - f_{slo}(1+k_1) \\
F_{21} = f_{tx}\left(\dfrac{f_{sys}}{f_{sys}+\Delta \mathrm{f}}\right)(1+k_1)(1+k_2) - f_{slo}\left(\dfrac{f_{sys}}{f_{sys}+\Delta \mathrm{f}}\right)(1+k_2) \\
F_{22} = f_{tx}(1+k_2)^2 - f_{slo}\left(\dfrac{f_{sys}}{f_{sys}+\Delta \mathrm{f}}\right)(1+k_2)
\end{cases}
$$

System's unknowns

The unknowns of the system are :

- Δf : frequency shift between clocks in comparison
- k_1 : Doppler coefficient according to station 1
- k_2 : Doppler coefficient according to station 2
- f_{slo} : on-board satellite LO frequency

Solving the equation system

- Linearization of the equations of the TWSTFT carrier phase system by applying Taylor development and neglecting the terms from the second order

$$\frac{\Delta f}{f_{sys}} = -\left[\frac{F_{11} - F_{22} - F_{12} + F_{21}}{2} - \frac{f_{tx}(F_{12} - F_{22})}{f_{tx} - f_{slo}}\right]\frac{1}{2 f_{tx}}$$

F_{11}, F_{22}, F_{12}, F_{21} are measured.

f_{slo}, k_1 and k_2 must be known by other means.

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System set-up

Equipment used :

- 2 TWSTFT stations
- 2 SATRE modems
- 1 Maser clock
- Satellite simulator

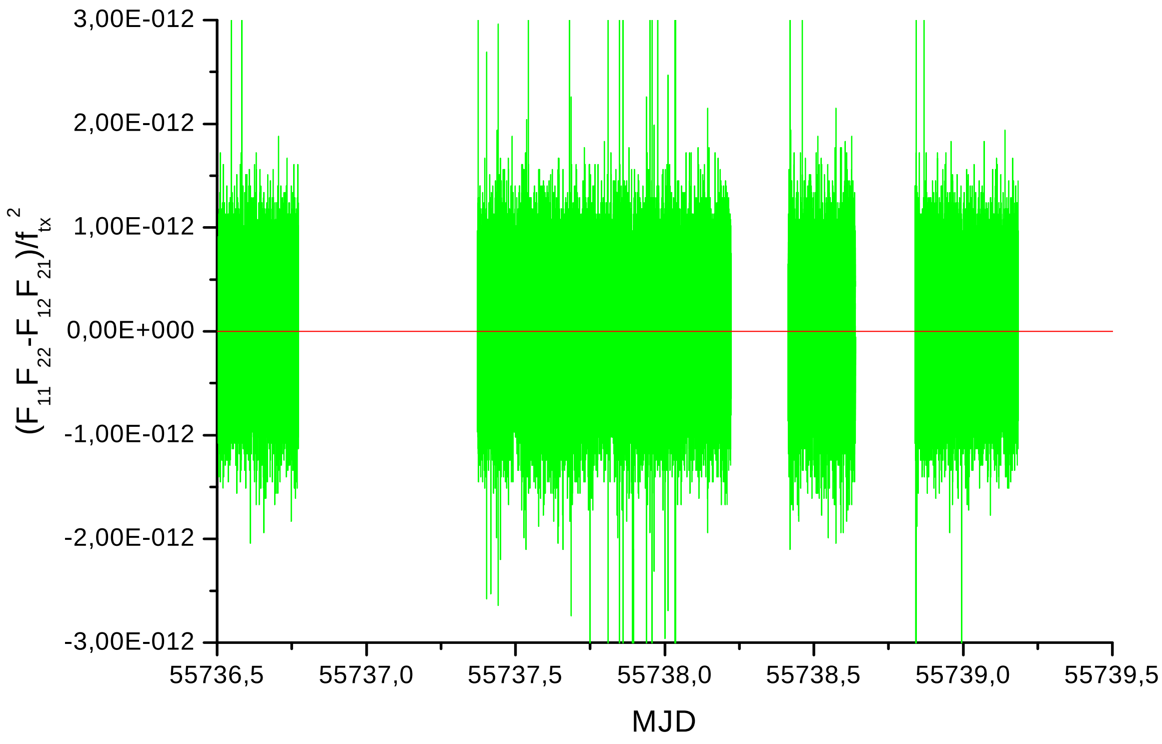
Experimental data recorded every second:

- 1 Mchip/s code delay
- Carrier frequency

- Satellite: Telstar 11 N in the Ku band
- 50 min of measurements during odd hours over one month
- 3 days of continuous 1 s measurements

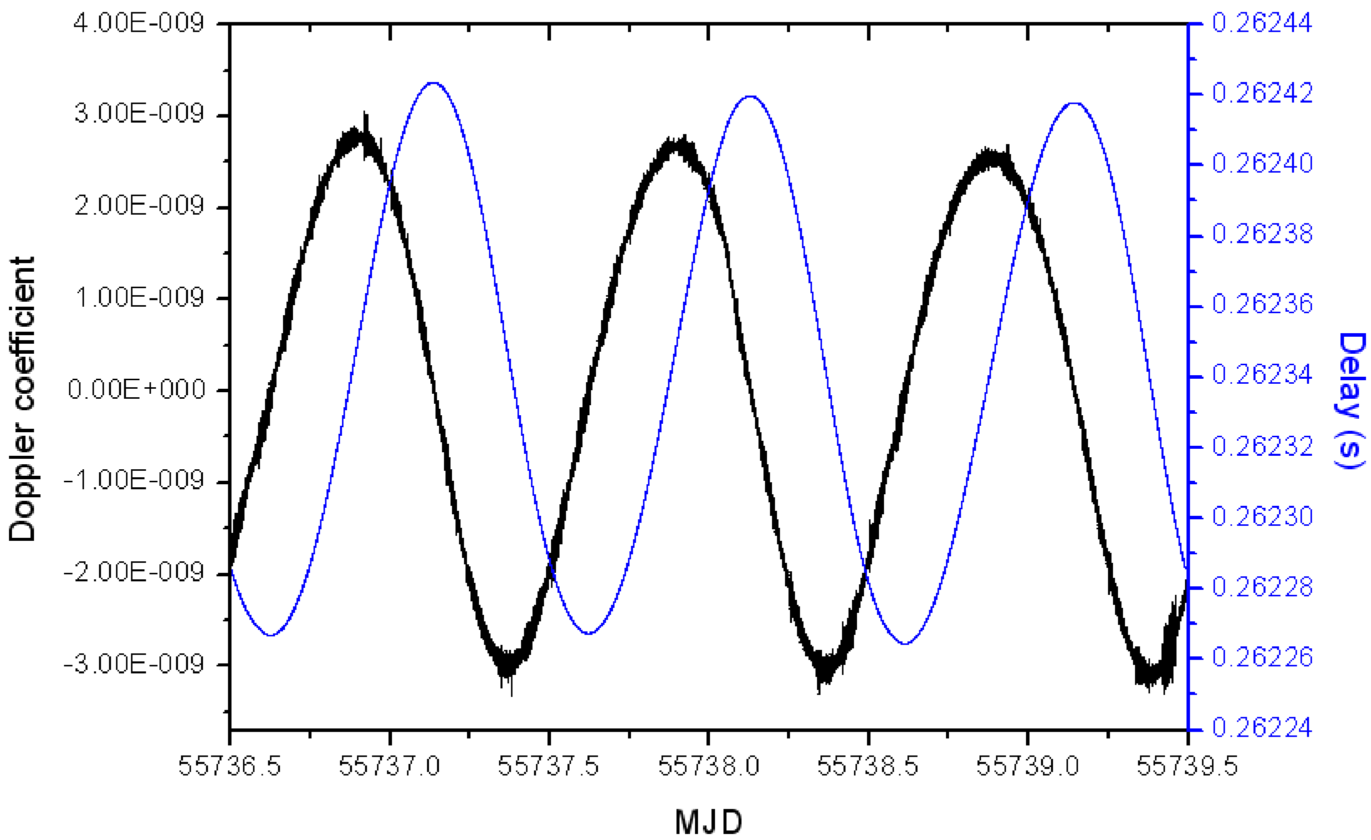
Results: Experimental validation of the different carrier frequencies

$$F_{11}F_{22} - F_{12}F_{21} = 0$$



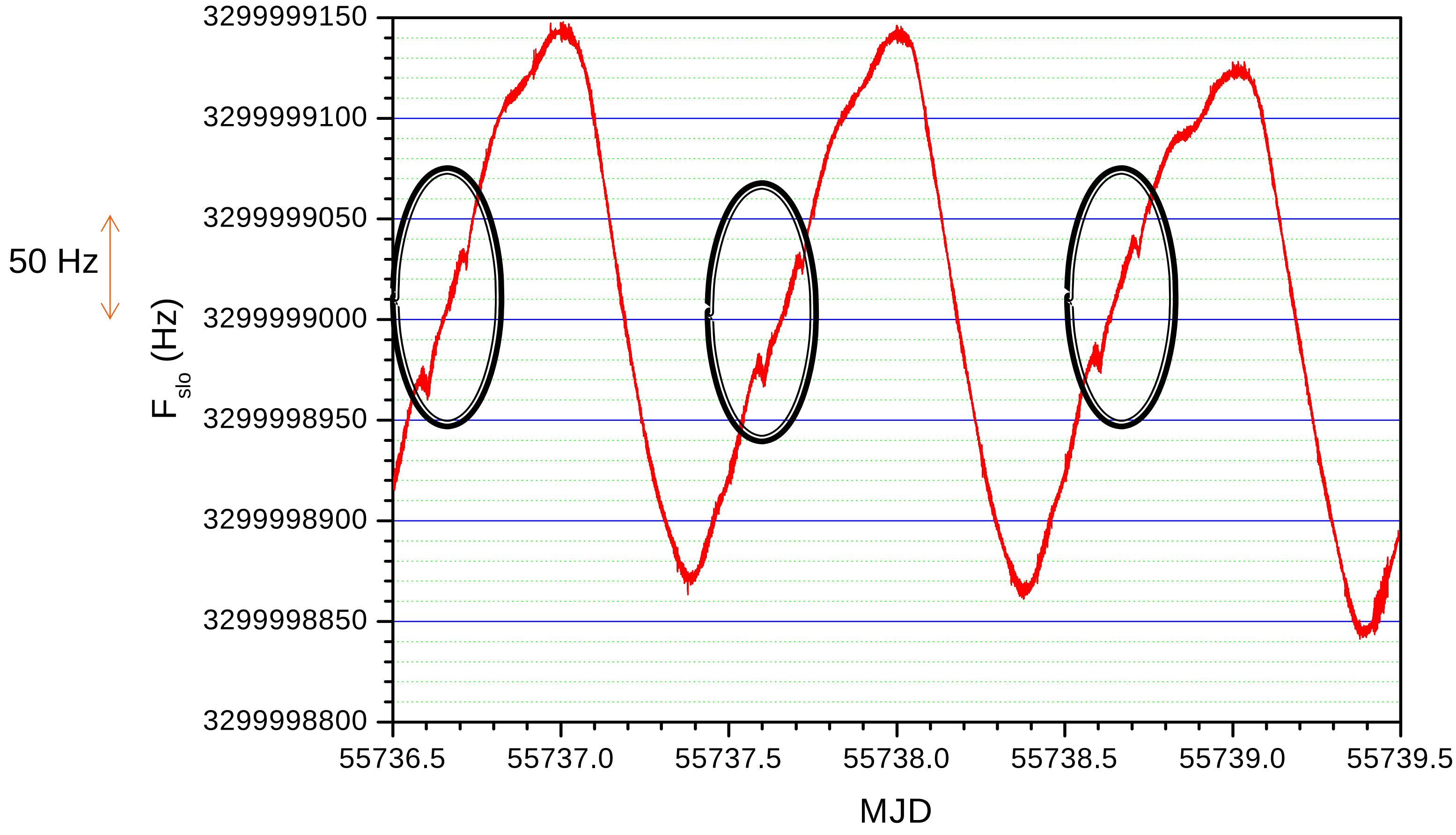
No drift nor offset observed

Results: Determination of ranging delay and Doppler coefficients



Results: Satellite LO frequency

$$f_{slo} = -[\frac{F_{11}}{(1+k_1)} - (1+k_1)\, f_{tx}]$$



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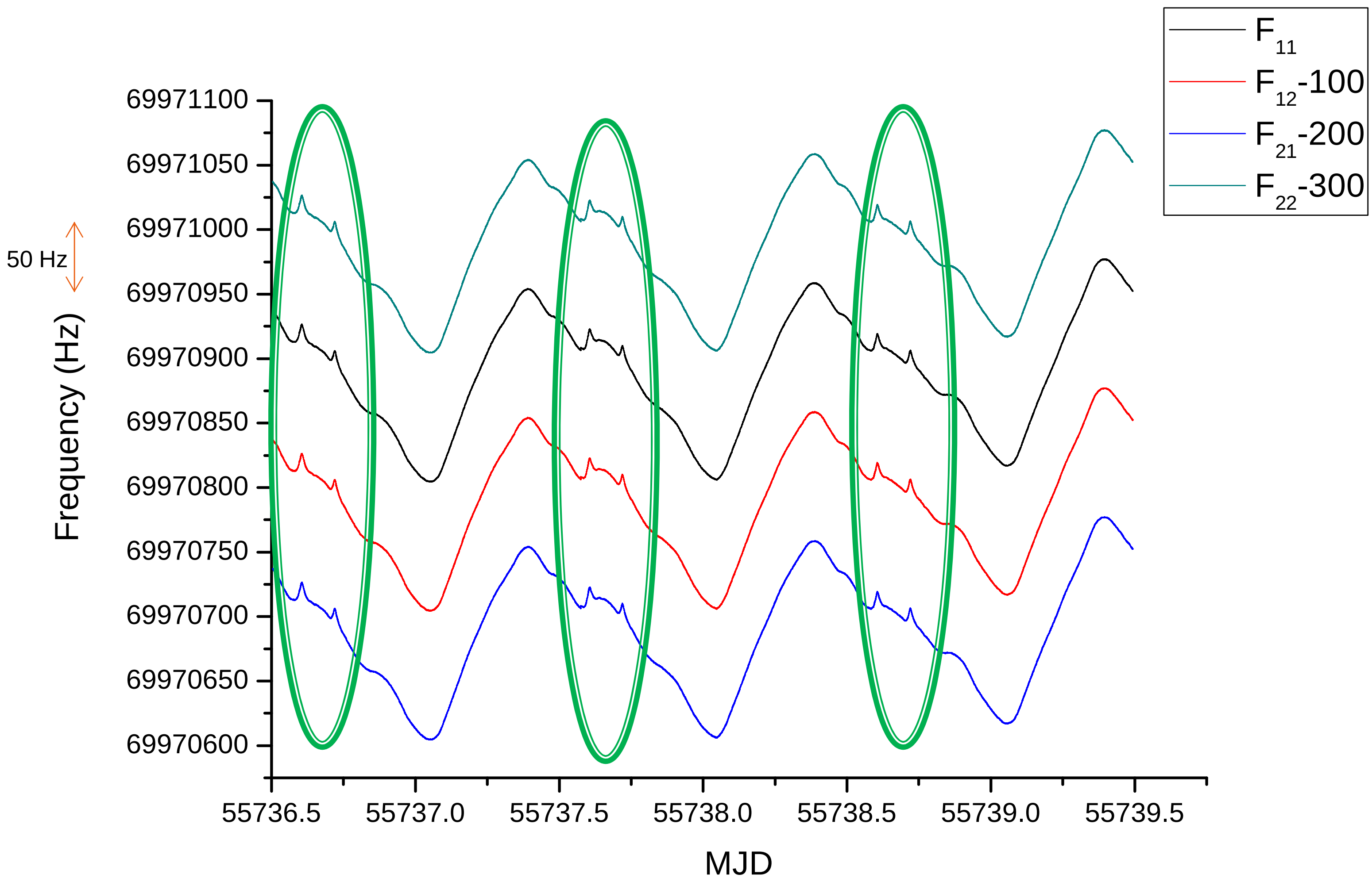
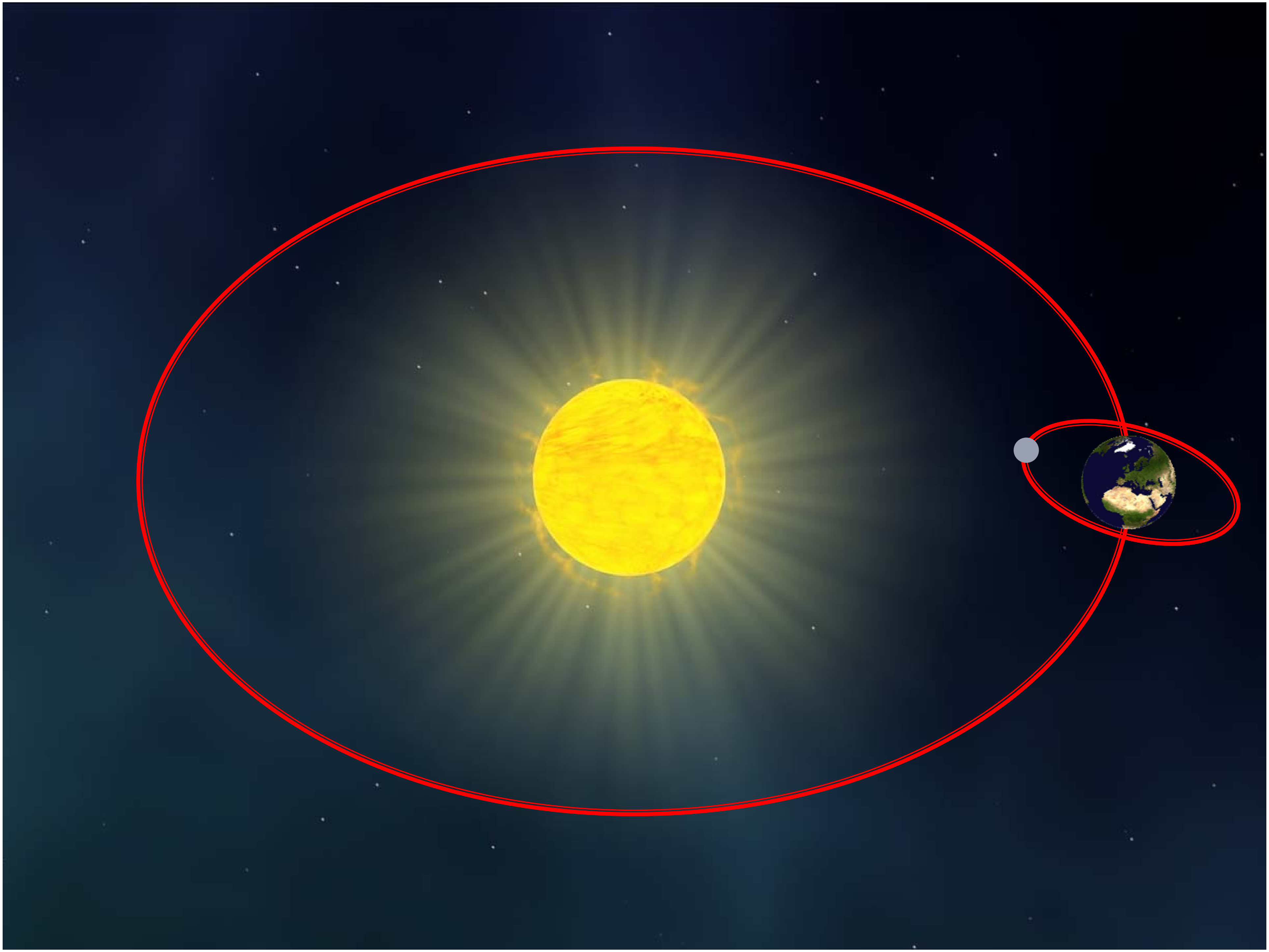
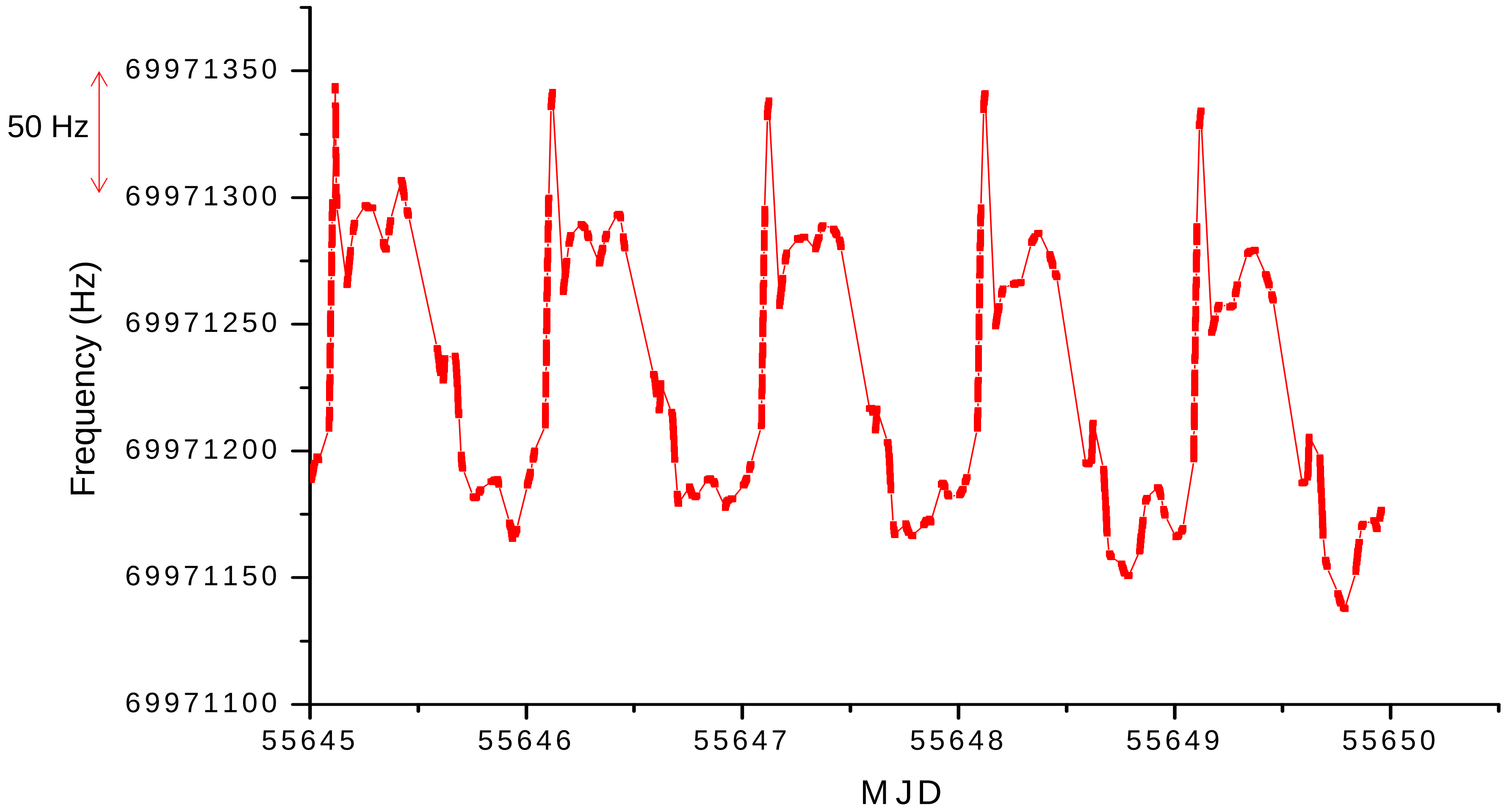
Results: Carrier frequency measurements





Understanding the signal distortion



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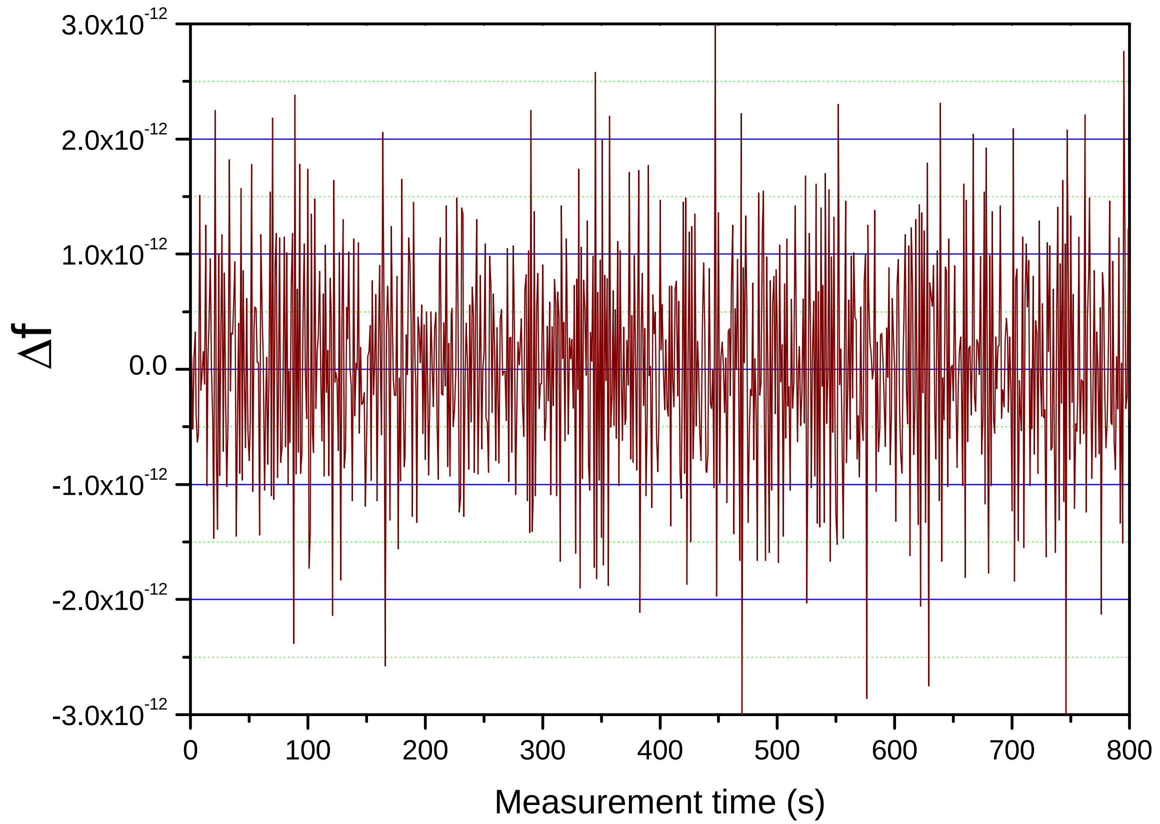
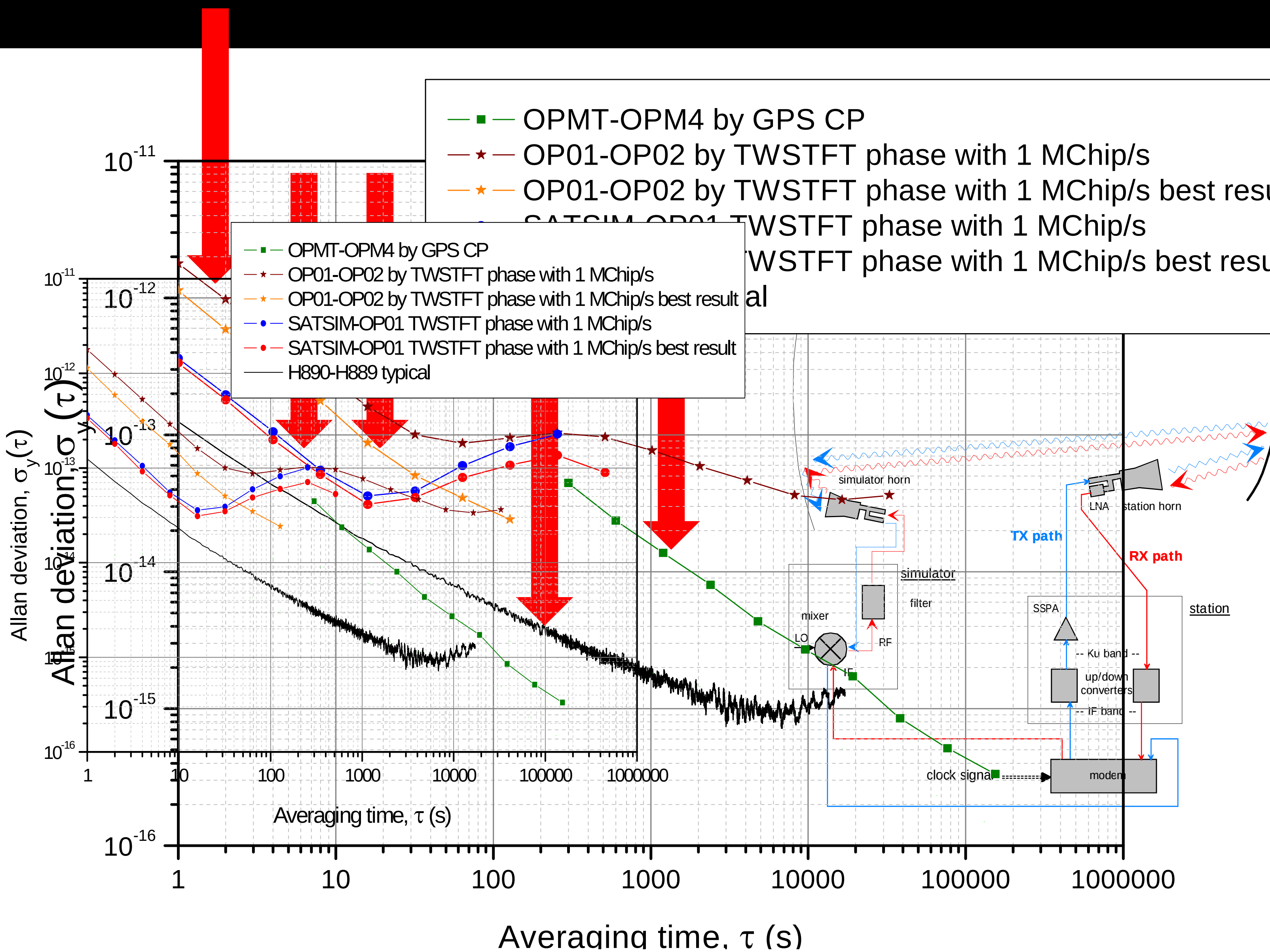
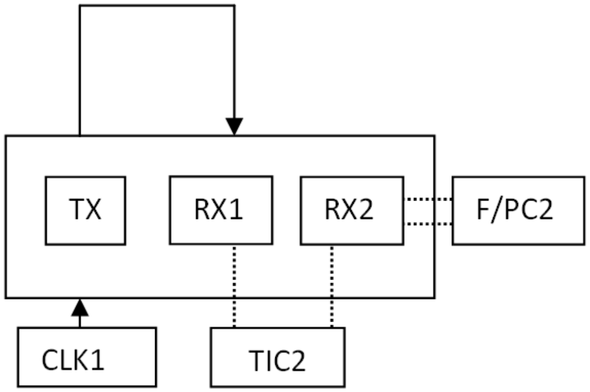
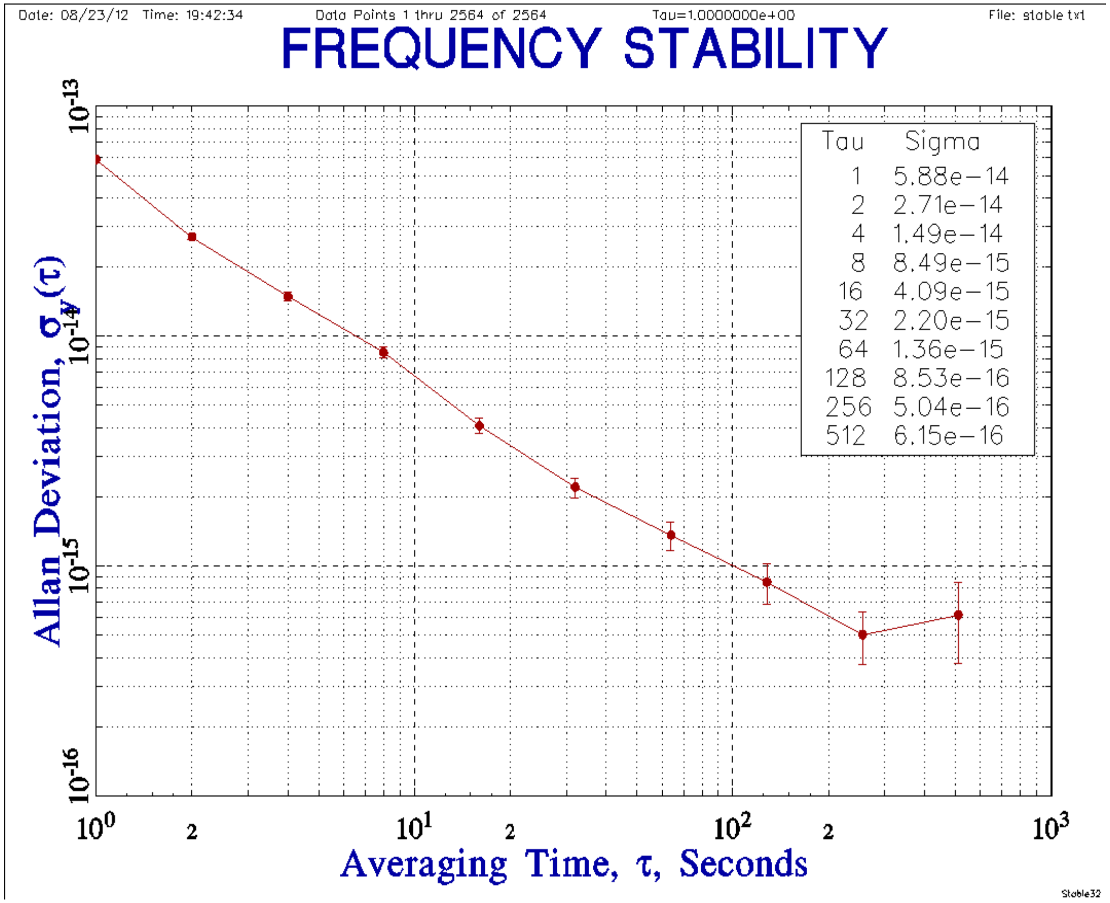
Results: Determination of clocks offset (common clock in this case)




OPMT-OPM4 by GPS CP
OP01-OP02 by TWSTFT phase with 1 MChip/s
OP01-OP02 by TWSTFT phase with 1 MChip/s best result
SATSIM-OP01 TWSTFT phase with 1 MChip/s
SATSIM-OP01 TWSTFT phase with 1 MChip/s best result
H890-H889 typical
Allan deviation, σy(τ)
Averaging time, τ (s)
10-11
10-12
10-13
10-14
10-15
10-16
1
10
100
1000
10000
100000
1000000
simulator horn
station horn
LNA
TX path
RX path
simulator
filter
mixer
LO
RF
IF
station
SSPA
-- Ku band --
up/down converters
-- IF band --
clock signal
modem

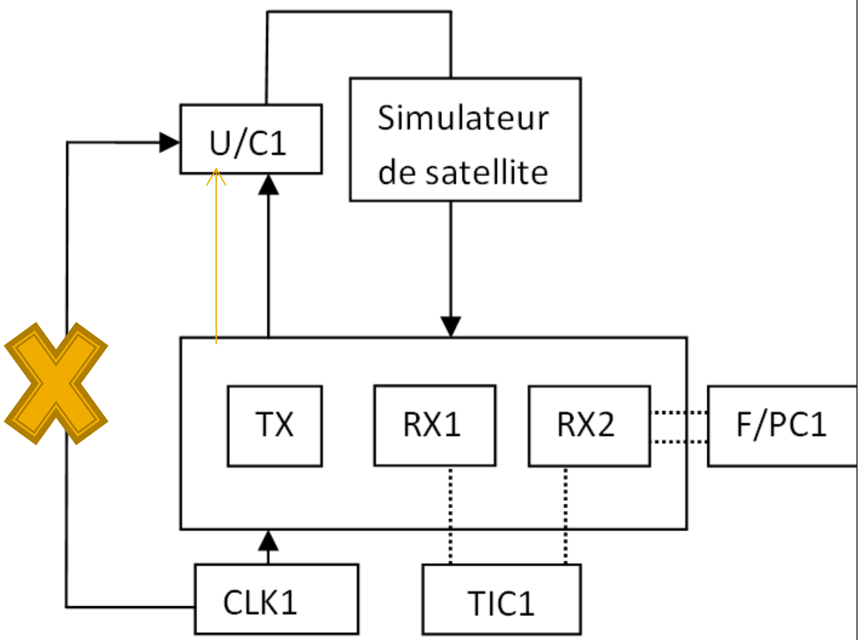
Additional tests (1)

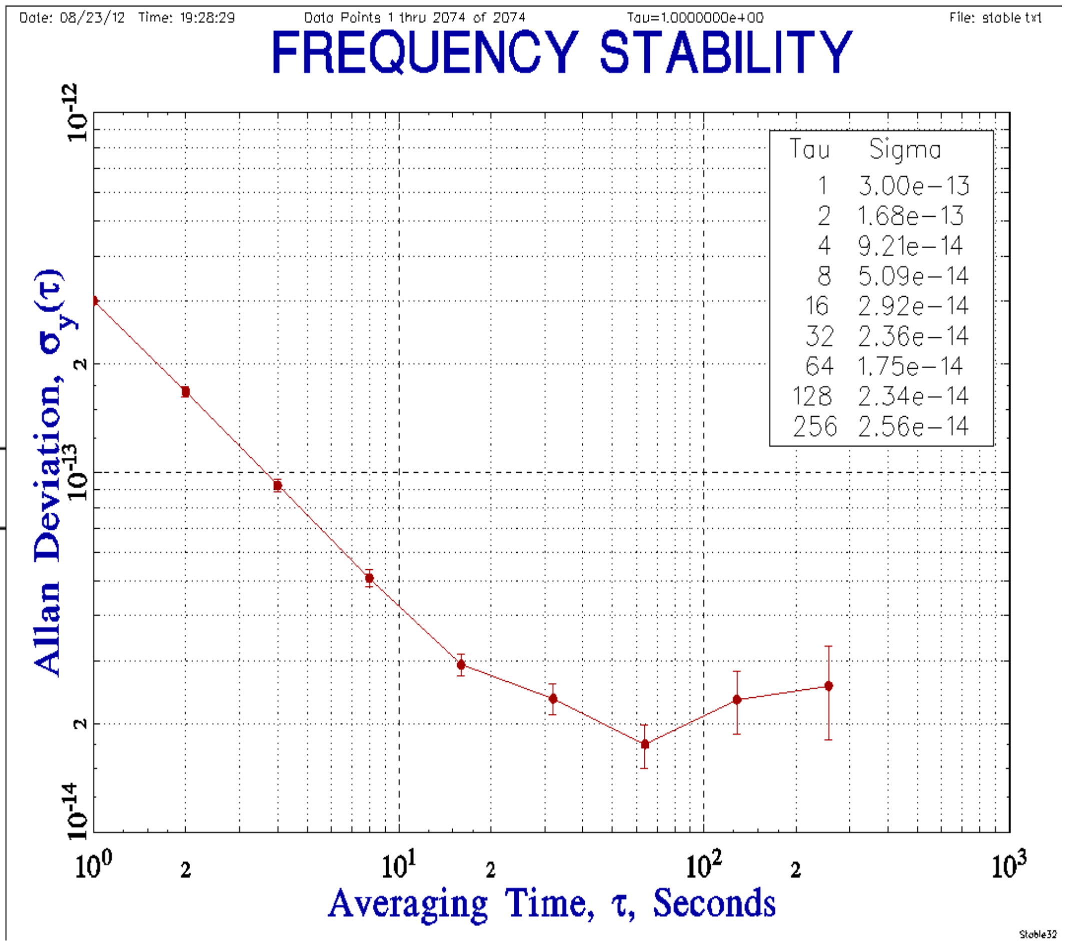




- Satellite
- Atmospheric propagation
- Up and down converters

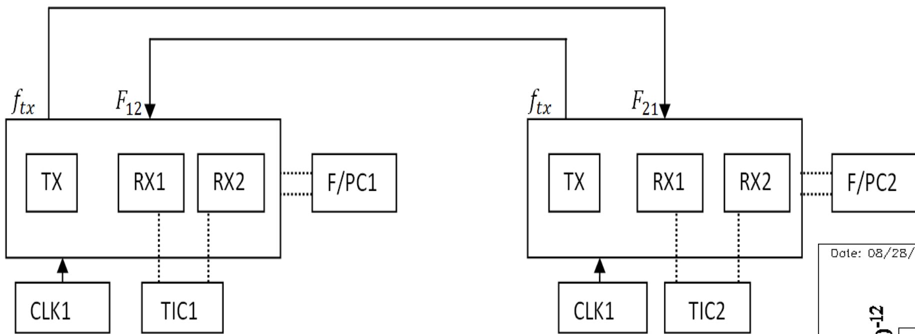
Additional tests (2)

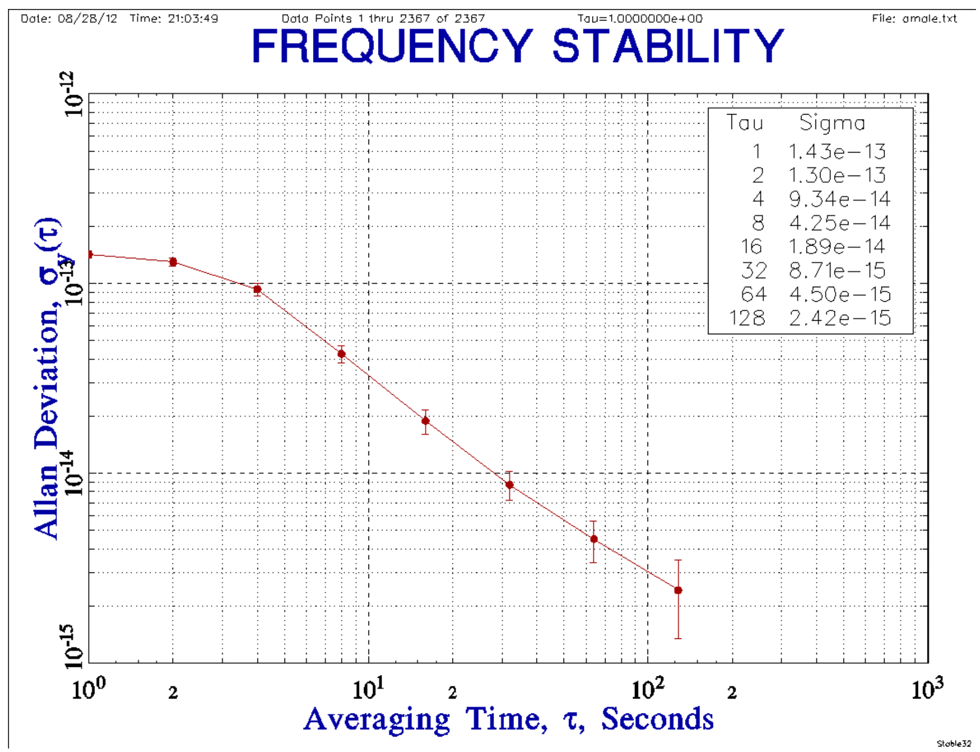




- **Satellite**
- **Atmospheric propagation**

Additional tests (3)





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Conclusion and outlooks

- We have presented the first results of application of TWSTFT carrier phase method in colocation at LNE SYRTE and we have reported the following performances:
- ✓ $1\text{x}10^{-12}$ at 1 s.
- ✓ $3\text{x}10^{-14}$ at 100 s.
- X Stability degradation at 300 s seems coming from the used equipments.
- The use of phase data instead of frequency data to overcome the need for doing continuous measurements as in the present case.
- Study of atmospheric effects impact on TWSTFT carrier phase.


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