Ground station to spacecraft link: Contributions and perspectives

Contribution	Typical ADEV (X-band)	Perspective
H-Maser	1E-13 @ 1s	Optical clock 1E-14 @ 1s Sapphire oscillator 3E-15 @ 1s
Carrier Tracking Loop	1E-14 @ 1s	Ka-band 3E-15 @ 1s
Up-and Down-Converter	3E-14 @ 1s	Reference clock at 10GHz
Low Noise Amplifier	1E-15 @ 1s	
Distribution System 100MHz	1E-14 @ 1s	Distribution at 10GHz
Klystron Power Amplifier	3E-14 @ 1s	
Antenna	6E-14 @ 1s	Removal of mechanical noise using a small reference antenna in the post processing for time scales > 100s (Iess2006)
Troposhere	1E-14 @ 100s	Better calibration models and radiometric data, high-altitude antenna location, complementary optical link
Ionosphere	1E-14 @ 1s	
Plasma	4E-14 @ 1s	Removal of plasma scinitillations with multi-link configurations (Iess2005)
On-board equipment	9E-14 @ 1s	ACES

Comparison of link performances

τ[s]	1	10	100	1000	10000	1 d
ESA SPEC Optical Clock: 1E-14/sqrt (τ)	1.0E-14	3.2E-15	1.0E-15	3.2E-16	1E-16	3.4E-17
Maser based station	1.8E-13	4.3E-14	1.4E-14	4.7E-15	1.6E-15	8.0E-16
Opt Clock based station	1.1E-13	3.9E-14	1.3E-14	4.4E-15	1.4E-15	5.5E-16
Opt Clock based station with recommended improvements	1.1E-14	4.2E-15	1.5E-15	4.9E-16	1.6E-16	7.1E-17

Table 9 Ka-Band one-way link, ADEV

τ[s]	1	10	100	1000	10000	1 d
ESA SPEC Optical Clock: 1E-14/sqrt (τ)	1.0E-14	3.2E-15	1.0E-15	3.2E-16	1E-16	3.4E-17
Maser based station	1.8E-13	4.4E-14	1.9E-14	6.2E-15	2.6E-15	1.4E-15
Opt Clock based station	1.1E-13	3.9E-14	1.8E-14	6.0E-15	2.5E-15	1.3E-15
Opt Clock based station with recommended improvements	1.7E-14	4.4E-15	2.0E-15	6.3E-16	2.6E-16	1.4E-16

Table 10 X-Band one-way link, ADEV

Questionnaire Evaluation: Radio Science Experiments

Parameter	Requirements
Important parameters	Ranging, „Doppler“, Orbital parameters, detection of plasma
Complementary measurements	Troposheric, ionospheric corrections, geo-information, tides, gravity potential, G/S location, solar activity, quasar observation
Duration data recording	1 to 8 hours
ADEV	<1E-14 for integration times of 0.1s to 2 hours
Clock Stability	Planetary studies LT of 6 hours stability must be a factor 36 better than for studies at 1AU (LT < 10min)
Ranging stability	1mm
Ranging accuracy	200mm
Range rate stability	0.01mm/s
Range rate accuracy	0. 001 mm/s @1 week integration time
Datation stability wrt UTC	300ns
Stability and accuracy wrt to definition of second	1E-15
Calibration uncertainties	10% of the previous values
Uncertainties of on-board clock frequency and time	ADEV of on-board clock 1E-13, accuracy 10%, time accuracy 0.1s
Post processing time	0.5 years

Applications

- Wide-band ranging systems either based on tones, high chip-rate PN modulation or combinations will enhance ranging precision and stability to make optimum use of advanced clocks in particular at long round-trip light times.
- Optical clocks will enhance synchronization in between ground stations and help to maintain synchronization over extended time periods, once performed by external means.
- For missions requiring T&F transfer between space and ground using a bi-directional 2-way link, several error contributions are common to up- and down-link and will cancel subsequently. The full performance of the ground-based optical clock will be available in this case.
- Availability of ground optical clocks becomes crucial in support of missions, where the clocks themselves are the sensor, like
    - SAGAS Search for Anomalous Gravitation using Atomic Sensors
    - EGE Einstein Gravity Explorer
        - ADEV@1000s 1E-16 (Perigee 2500 km)
        - ADEV@10000s 1E-17 (Apogee 50000 km)