Ka Band at ESTRACK: expanding Deep Space communication capabilities
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TTC Communications

- Present Baseline X/X.
- Unbalanced (little TC, larger TM)
- Use for tracking -> Coherency, stability
- Need of guaranteed availability -> Only link with the spacecraft, last resource
  - Ka Band links sensitive to cloud and rain attenuation
- Need of robust link
  - Use of well proven modulations and coding
  - Some modulations schemes are not efficient but reliable
  - Introduction of new functionalities take time
- Interoperability -> Need of standardisation -> CCSDS
Why Ka Band?

- TTC communications are very conservative (last resource, safety first!)
- Ka Band comms less reliable (atmospheric attenuation)

**Why to go to Ka-band?**

- Lower link losses with equal antenna surfaces and $P_{TX}$
  (lower antenna and transmitter efficiency reduces the gain)
- Larger Bandwidth available
  Up to 1500 MHz @26 GHz and 500 MHz @32/34 GHz per 12 MHz @X Band
- Better accuracy for navigation and radio science
  Some missions include X-X, X-Ka and Ka-Ka links to cancel solar plasma effect
Some milestones at ESTRACK:

**SMART**
- Launch in 2003. Moon Orbit
- X Band for TTC. Ka Downlink demonstrator

**Bepi-Colombo**
- Launch in 2018. Mercury Orbit
- X/Ka band for TTC. Ka Uplink and Downlink for Radioscience

**JUICE**
- Launch in 2022. Jupiter Orbit
- X/Ka band for TTC. Ka Uplink and Downlink for Radioscience

**VIL4**
- 2002-2015. X/Ka experimental antenna

**CEB (Ka RX), MLG (Ka RX/TX)**
- 35 m operational antennas
- 2014. Operational demonstration with JUNO

**METOP-SG**
- Launch in 2021. SSO 817 km
- K-band for PL data downlink

**EUCLID**
- Launch in 2020. L2 Halo Orbit
- X-band for TTC. K-band for PL data downlink

**PLATO**
- Launch in 2024. L2 Lissajous Orbit
- X-band for TTC. K-band for PL data downlink

**SNOWBEAR**
- 2017. S/K LEO 6.4 m antenna

**CEB (K RX)**
- 2017. X/K 35 m operational antenna

**MLG (K RX)**
- 2018. X/K 35 m operational antenna
Ka-band communications in DS

Challenges

• Atmospheric effects reduce the geometrical link advantage vs. lower band
• Larger losses, lower efficiencies, more demanding pointing (vs. X-band)
• Reduced transmit power

How to tackle the challenges

• Detailed site atmospheric characterisation (monthly/seasonal stats of effects)
• Novel operations concepts (short term weather forecast based planning)
• Optimise on board distribution of RF system, enhanced AOCS, characterisation of in-flight thermal deformation
• Ground Pointing enhancement / Beam squint compensation

Ka shall be used if it provides better performances
Data return improvement by use of weather forecast

- **Ka-band**: significant atmospheric attenuation and uncertainty, i.e. large dependence upon weather effects
- **Deep Space**: Large round Trip Delay. “Now-Cast” not possible
- Revision of the Ka-band link operation concept: *maximisation data return*, using long term yearly/monthly atmospheric statistics -> Enhance the predictability of Ka-band downlink operations
- Downlink budgets based on *daily atmospheric statistics*, determined by weather forecast analysis
Data return improvement by use of weather forecast

- **Global and mesoscale meteorological models**
  - ECMWF global scale forecast available at lead + time lead time series
  - MM5 mesoscale downscaled forecast available at lead time series

- **Radiative transfer model**
  - Calculation of 3D atmospheric parameters (temperature, pressure, humidity, liquid and ice water, hydrometeor microphysics)

- **Optimization of received and lost frames for the target satellite pass**

- **Link budget model**
  - Calculation of atmospheric attenuation and sky-noise temperature at Ka-band at several elevation angles for the receiving ground station
  - Calculation of downlink parameters (signal-to-noise ratio, frame error rate, received and lost frames)
Data return improvement by use of weather forecast

**Operational**

- **received frames per pass**
- **perc. lost frames per pass [%]**

**JPL - Maximization approach**

- **ideal case**
- **use of daily weather forecast**
- **current Ka-Band Operations baseline**

* Use of seasonal/Monthly forecast
Ka-band for Radio-science and Tracking

Ka-band allows to implement a triple link (X/X, X/Ka, Ka/Ka) or a dual link (X/X, X/Ka) to completely cancel plasma contributions from radiometric tracking observables. The configuration was originally used on JPL S/C Cassini. Now it is embarked on JPL S/C JUNO (in the X/X, Ka/Ka version). Planned in Bepi-Colombo and JUICE.

On DOY 197-2014, the first ESA Ka/Ka link was established with the JUNO S/C

Tests have demonstrated the superior data quality of the 2-way Ka-band Doppler (factor 4 over X-band):

- MLG (Ka/Ka): 0.029 mm/s
- DSS-15 (X/X): 0.129 mm/s
- DSS-25 (X/X): 0.103 mm/s
Ka-band for improved S/C Tracking

- Ka-band 2-way links less sensitive to solar plasma effects -> improved S/C tracking.
- All tracking observables (Doppler, RNG and DDOR) are positively affected

- 2-way Ka-band also used in Radio-science experiments on board Bepi-Colombo and JUICE

- Ka-band wide BW allows the use of wideband PN ranging at 24Mcps, with on-board signal regeneration -> much better jitter performance compared to standard ranging systems
Ka-band Quasar catalogue for DDOR

ESA is collaborating with NASA/JPL in building a quasar catalogue in Ka-band for DDOR use. Collaboration is on going since 2012.

Before ESA/NASA collaboration

After 3 years of ESA/NASA collaboration
DEPLOYMENT IN STATIONS
26 GHz EO Terminals: SNOWBEAR

Operational validation of technologies development in the field of Earth Observation High Rate Data Reception in the band 25.5 – 27 GHz. First use METOP-SG (EUMETSAT)

- 6.4m antenna (MT Mechatronics):
  - 3 axes full motion (no key-holes)
  - K-band reception and autotrack
  - S-band autotrack (acquisition aid)

- Radome (FDS)
  - Multilayer design optimised for K-band and S-band, suitable for X-band operation

- K-band LNAs (Callisto Space)
  - Fully redundant Cryogenic and room temperature configuration for both data and tracking channels

- K-band converter (Antwerp Space):
  - 3 channels
  - Simultaneous 1.2 GHz (Data) and 70MHz (tracking) output IF

- High Data Rate receiver (Kongsberg Spacetec)
X/K/Ka 35m antennas

ESA 35 m stations can be used for L2 missions (X and K bands) and Deep Space Missions (X and Ka bands). A movable mirror selects the receiving chain of feeds, dichroids and mirrors:

**X/K feed for L2 Missions**

**Set of dichroids and X/X feed**

- Ka-RX feed
- Ka-TX feed

**for DS Missions**
Ka Cryo feeds and LNAs

\[ R_{bU} = K \cdot \left( \frac{G}{T_{sys}} \right) \]

- To enhance \( \frac{G}{T_{sys}} \) -> Larger area (very expensive!!) or lower \( T_{sys} \)
- Only front end noise impacts on terminal performances (if properly designed)
- Atmospheric attenuation fixes a limit!

1 dB improvement in \( T_{sys} \) allows a datarate increase of 26 %
0.5 dB improvement in \( T_{sys} \) allows a datarate increase of 12 %
Ka Cryo feeds and LNAs

- Special semiconductors for low noise -> InP, future InAs
- Working at low temperature (~15°K). Post LNA at higher temperature
- Not only LNA, also cryo cooling of passive front end
# Ka Cryo feeds and LNAs

<table>
<thead>
<tr>
<th></th>
<th>X band</th>
<th>Ka band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insertion loss at 300K</td>
<td>0.1 dB</td>
<td>0.3 dB</td>
</tr>
<tr>
<td>Feed NT at 300 K</td>
<td>7 K</td>
<td>20 K</td>
</tr>
<tr>
<td>Insertion loss at 10K</td>
<td>0.04 dB</td>
<td>0.1 dB</td>
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<tr>
<td>Feed NT at 10 K</td>
<td>1 K</td>
<td>7 K</td>
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<tr>
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<tbody>
<tr>
<td>Tsys (K)</td>
<td>75</td>
<td>60.0</td>
<td>36.0</td>
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<tr>
<td>G/T improvement (dB)</td>
<td>-</td>
<td>1.0</td>
<td>3.2</td>
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<tr>
<td>User Datarate improvement (%)</td>
<td>-</td>
<td>25.0%</td>
<td>108.3%</td>
</tr>
<tr>
<td>Equivalent antenna diameter increase (m)</td>
<td>35</td>
<td>39.1</td>
<td>50.5</td>
</tr>
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Frequency converters

- Frequency converters shall translate the incoming signal without degradation
  - Reject interferences and noise
  - Low Phase noise
  - Very low IL and GD variation over large bands
- Ka-band operates with larger BW (higher IF)
Wide Band EO Modems

Improved performances:

- New communication standards (SCCC or DBV-S2) **Variable CM (VCM)** or **Adaptive CM (ACM)**, adapting VCM in real-time to propagation conditions during contact). Data throughput 50% higher or more by using link margins in low elevation angles and efficient ModCods (more bits per symbol) in high elevation angles.
- Multiple RF channels per polarization (two channels for the available 1.5 GHz bandwidth)
- Two simultaneous polarizations (requiring cross polarization cancellation techniques).

Some key parameters

- larger bandwidths (675 MHz BW, 500 Msps, Up to 2.7 Gbps)
- VCM/ACM and SCCC-based ModCods (CCSDS-131.2-B-1)
- 27 SCCC-based ModCods for ACM
- Supported Mods: BPSK, QPSK, 8PSK, 16APSK, 32APSK, 64APSK
- No Preventive Maintenance, No Tuning, Adaptive filters, Pilot detection,...
Wide Band Lagrange/DS Modems

TTCP improved performances

- CCSDS compatible AR4JA LDPC (for DS applications). Up to 20 Mbps Rates 1/2, 2/3, 4/5. Block lengths 1024, 4096 and 16384 bits.
- Optimised 75 Mbps High Speed LDPC version (rate 1/2, 4096-bit. EUCLID)
- Flexible IF from 52 – 1850 MHz. BW up to 500MHz (entire Ka-Band DS).
- Higher TM rates (up to 300 Mbps RS, 132 Mbps RS+CC)
- Wideband RG codes and high chip rates (24 Mcps) for improved RG
- Input signal: -105 dBm to -5 dBm
- Low in-band spurii: -83 dBc in selected bands.
- ±5 MHz carrier frequency uncertainty.
- Up to 68 kHz/s carrier frequency rate uncertainty at Ka band
- Two parallel independent complete RX chains to process 2 simultaneous bands (E.g. X-band and Ka-band, dual frequency RG)
- Increased Open Loop sampling and accuracy
Ka HPAs (KPA and SSPA)

Ka-band UL (34 GHz) to implement RS experiments (Bepi Colombo, JUICE)
Critical: ADEV ($10^{-16}$@1000 sec) and stability
Two developments: 500 W KPA and 100 W SSPA
Pointing calibration System

- Large Diameter (35m) High frequency (34 GHz) ->
  Minimum HPBW ~ ± 0.008 deg
- 8 mdeg Pointing error -> 3 dB Losses
- Error compensation for all AZ and EL.
- For a dish of 600 moving tonnes
- Many sources of error: Random, Systematic, RF refraction, wind, temperature,
Pointing calibration System

- Pointing errors Calibration with radiostars
- Final max. error
  - <4 mdeg (no wind)
  - <6 mdeg (60 km/h wind)
Ka-TX Squint correction

- Spacecraft in movement generates an offset between RX and the TX beams (RX-TX squint)
- Worst case Rx-Tx offset for future ESA mission ~40 mdeg.
- 17 mdeg offset @X Band only 0.7 dB losses, but ....
  - @ Ka-band 12 dB losses!
- TX and RX beams shall be offset
Ka-TX Squint correction

- Two movable mirrors in the Ka-Tx path
- Ka-Tx feed is fix. Do not moves! -> fixed WG TX
- Feed kept in phase center -> reduced losses compared with moving table solution
Radiometers

Ka-band TM DL optimisation needs to characterise the atmospheric effects at each Deep-Space antenna site.

This characterisation is done by using passive microwave radiometers (profilers) produced by RpG.
Radiometers for precise tropospheric delay calibration

- Main contributors to Doppler and DDOR tracking observables: plasma and tropospheric wet delay
- Radio-science eliminates the plasma effects via the triple link (X/X, X/Ka, Ka/Ka).
- Tropospheric delay must be calibrated by other means -> dedicated water vapour radiometer with profiling capabilities. ESA has a prototype under development
Conclusions

• Ka-band already an operational asset at ESTRACK
• Future exploration missions will demand new bands (22/26 and 37/40 GHz)
• Ka-band can provide advantages in both power limited or BW limited scenarios
• Ka-band soon will be an standard feature (Bepi-Colombo, EUCLID, Metop-SG, JUICE, PLATO, …)

But...

• Requires optimised system design
• All aspects of the system shall be considered
• Need of an overall view: from the operational concept to the subsystem design