DEEP SPACE AND SECURE TRANSPONDERS

- Dehop Rehop Transponder (DRT)
- Ka Band Transponder for Radio Science
- S/S Deep Space Transponder (S/S DST)
- Spread Spectrum Transponder
- X/X Deep Space Transponder (X^2 PND)
- X/X/Ka Deep Space Transponder (X/X/Ka DST)

Dehop Rehop Transponder (DRT)

Applications

- Military Telecommunication satellite FH Spread-Spectrum transponder payloads.

Main design features

- >100 MHz input and output X band channel
- Two operative hopping transponders with frequency orthogonality
- Flexible frequency steps
- Two IF SAW filtering (Bo, 2xBo)
- Up link and Downlink frequency hopping diversity
- Forbidden bands setting
- Two different on board Pseudo Noise generators (counter mode) selectable by TC.
- Two separate Time of Day generators
- Up to 256 128 bits security keys, on flight updatable
- Synchronized configuration update availability

Background

- Koreasat 5 satellite

Production

- Delivery schedule: 10 – 15 months
- Capacity: 6/year

Technical Description

The Dehop Rehop Transponder (DRT) unit is composed of two identical sections, operating in Spread Spectrum - Frequency Hopping (SSFH), using a 100 MHz class frequency Band transponder.

In the nominal configuration the two transponders are simultaneously operating providing two separate transparent path of [Bo]MHz bandwidth. In case of failure, one section is able to recover the whole traffic capacity using the [2xBo]MHz IF filtering.

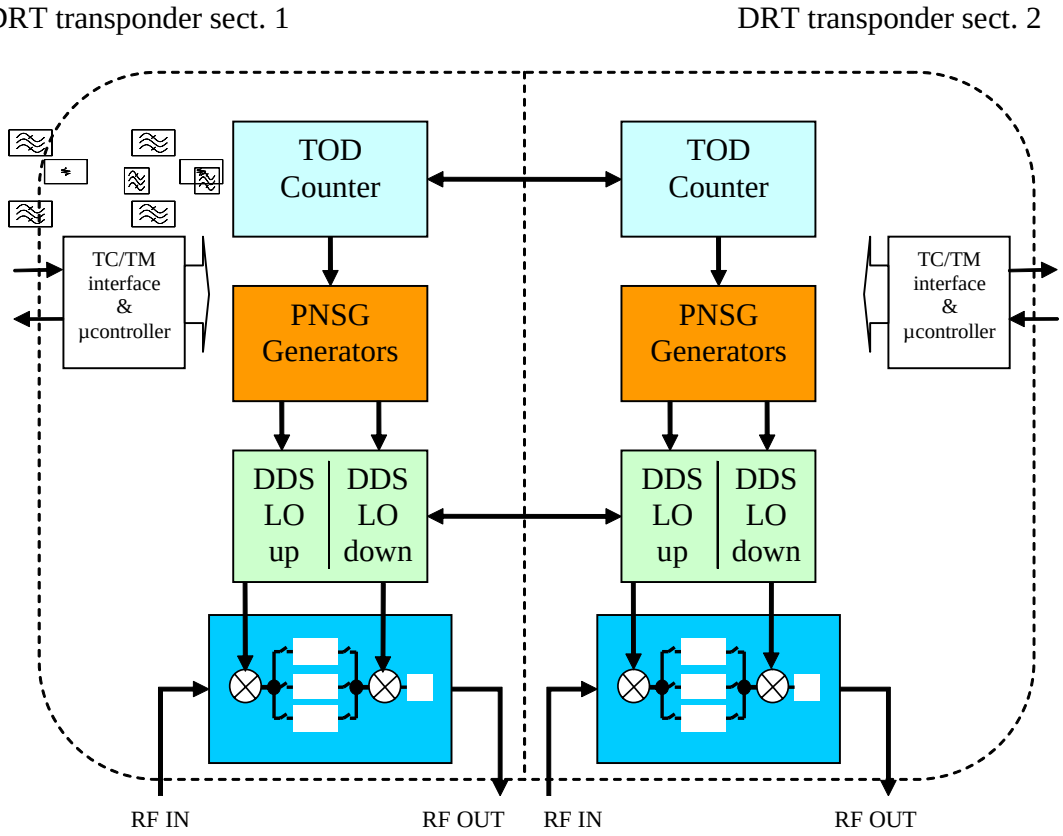
The frequency overlapping is managed by the Orthogonality algorithm, separately operating for UP and Down-link.

The hopping sequence is generated by two selectable PNSG based on Time Of Day; 256 Keys can be selected (by TC) to initialize the PNSG, 240 of witch, on flight updatable.

The LO frequency generation is obtained by separate Digital Direct Synthesizer (DDS) generators fed by different frequency code for Up and Down-link, to guarantee high switching speed and phase continuity of the useful signal between hops. Uplink ad downlink can have also the same pseudo noise frequency sequence.

The Two TOD counter (one for each section, internally synchronized and updatable on flight by TC) are linked to the on board USO precision, the TOD information is also externally available on several connectors.

Block Diagram



Technical Typical performances

Frequency range	: X Band	Power consumption	: < 45 W
Frequency setting accuracy	: <3Hz	Power supply voltage	: 100V
Gain	: 10 dB	TC/TM interface	: ML/DS16
Limited Output carrier level	: -2dBm max	Mass	: < 10.5Kg
Hopping frequency	: ≤ 100KHz	Dimension	: 310x254x160 mm
Hopping Bandwidth	: >100MHz	Qualification temperature range	: -20/+65°C
IP3	: +24 dBm	Design life	: 15 years
Noise Figure	: 15 dB(typ.)		

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Updated : June 2012

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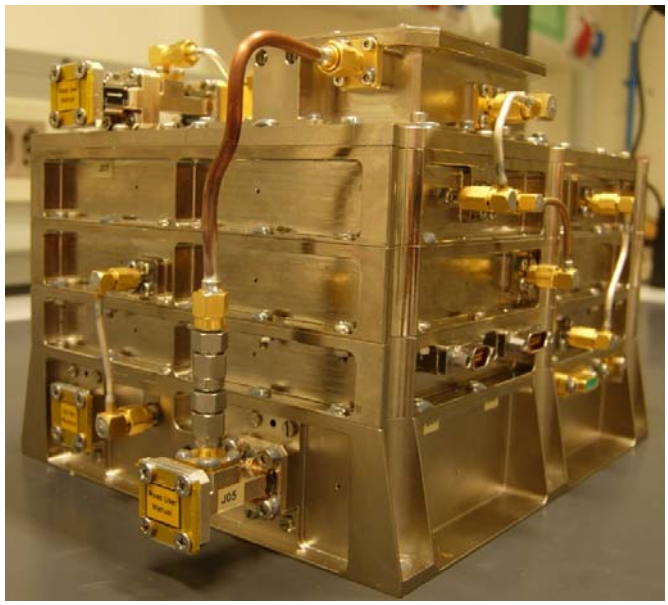
Ka Band Transponder for Radio-Science



KaT Engineering Model for MORE Experiment

Applications

High accuracy range and range-rate measurements for Radio-Science experiments.

Main features

The main features of the Ka-Band Transponder (KaT) for Radio-Science are summarized hereafter:

- Wide-band Regenerative PN Ranging up to 25 Mcps (MegaChipsPerSecond)
- On-board self-calibration function for precise Group Delay measurement
- Excellent frequency stability performances
- Additional Ranging modes capabilities:
- ESA/NASA Transparent Ranging capabilities
- Mixed Ranging (transparent channel plus Regenerated Tone up to 12.5 MHz)
- Flexible architecture and frequency plan
- Low power consumption
- Low weight and compact dimensions.
- Excellent performance stability over temperature and lifetime

Production

- Delivery schedule for EM: 14 months
- Delivery schedule for recurring FM: 18 months

Background

- Cassini: fully analogue KaT
- Juno: 1 EM + 1 FM currently in flight toward Jupiter
- MORE for BepiColombo: 1 EM + 1 EQM + 1 FM (under production)

Technical Description

The KaT is the first equipment for Radio-Science able to support an innovative Wide-Band Pseudo-Noise (PN) Ranging modulation scheme. This technique allows estimating the Earth-to-Spacecraft distance and the relative Spacecraft radial velocity with an accuracy never reached before.
The KaT is conceived around an extreme flexible Digital Core based on the KaT ASIC which implements all the algorithms relevant to the modulation and demodulation processes. The KaT ASIC also includes the Leon2FT Microprocessor that is devoted to digital receiver configuration, transponder management and data handling functions.

The chosen hardware/software partitioning allows a great flexibility in terms of functions, algorithms and design parameters. In order to support the required chip rate, the ASIC is built using the 0.18µm space-qualified technology provided by ATMEL.

An on-board calibration function has been included in the KaT in order to allow PN ranging group delay measurements. This approach is overcoming potential aging effects on the KaT group delay that could degrade the ranging measurement accuracy. The KaT group delay stability is better than 0.1 ns pk-pk over a time of 36 hours.

The KaT shows excellent performances in terms of frequency stability, a crucial specification for such kind pf Radio-Science Instrument, granting an Allan Deviation figure lower than 10^{-15}.

Technical Typical Performance

General Features

Mass: ..... 3 Kg
Power consumption: ..... < 40 W (for 32 dBm output power)
Dimension (L x W x H): ..... 215x140x175 mm
Power Bus Interface: ..... ≤100 V
TM/TC Interface: ..... ML/DS16, 1553, CAN, LSSB
Qualification Status: ..... Under qualification
Qualification temperature range: ..... -20/+65°C (operative)
Design life: ..... >15 Years

Performances

Acquisition threshold : ..... -131 dBm @ 4 kHz/s
Tracking threshold: ..... -135 dBm @ 1.2kHz/s (-138 dBm @ 400 Hz/s)
Turn-around ratio: 3360/3599
Output power: ..... Up to 35 dBm @ 32GHz
Allan Deviation: ..... $\leq 4 \times 10^{-16}$ @ 1000 sec
Doppler shift: ..... ±6 MHz
Noise figure: ..... <4 dB
PN Ranging Chip rate: ..... up to 25 Mcps
PN Ranging tracking jitter ..... <6 ns-rms @ P_r/N_0=30dBHz
Transparent Ranging BW: ..... 27 MHz
Mixed Ranging low-frequency BW: ..... 4 MHz
KaT Group-delay stability: ..... <0.1ns pk-pk

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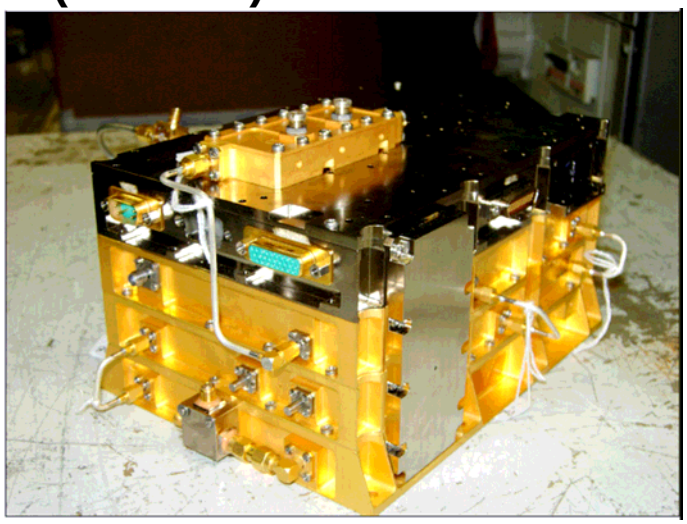
S/S Deep Space Transponder (S/S DST)



Applications

DEEP **S**PACE **S**-**B**AND **T**T&C (**O**N **B**OARD **T**RANSPONDER **U**NIT).

Main features

- Acquisition and tracking of the up-link PM carrier
- Tracking and demodulation of data both from a 16 kHz subcarrier in BPSK/NRZ format and directly from the carrier in PM/SP-L format.
- Command data decisions and recovering of the bit timing for the On-Board Computer.
- Ranging demodulation and automatic gain control.
- Data modulation according to the specified signalling schemes (i.e. modulation on subcarrier for low-rate telemetry, direct modulation on carrier for medium-rate telemetry.
- Down-link carrier PM modulation with ranging and/or modulated telemetry
- Non-coherent capability whereby the down-link frequency is derived within the transponder unit to provide a fixed transmit frequency
- Coherent capability whereby the down-link frequency is related to the received frequency through the 240/221 turn-around ratio..

Background

TAS-I has acquired over the last decade a vast experience in the design and development of integrated transponders for Deep Space missions.

JWST (James Webb Space Telescope)

- EM unit manufactured and delivered in 2011. Currently undergoing pre-compatibility tests with the Ground Station
- EQM unit delivery by end of 2012
- FM's units delivery by 2013/2014
- FM units production cycle: 14 months

Technical Description

The compactness of the equipment (mass: 3.1 kg, including the Diplexer) is achieved by combining advanced flight-proven architectural solutions (i.e. frequency plan based on under-sampling, all-digital demodulation and modulation techniques both for spread-spectrum and standard signalling) with a high degree of technological integration both in the analog domain (use of hybrid for Front-End implementation, LO synthesis based on RF CMOS chip) and the in digital domain (the MSDRx ASIC integrates in a MG2RT technology-based device the demodulation, baseband and modulation functions)..

The transponder unit core based on a digital architecture leads to the following advantages with respect to a fully analog solution:

- Optimization of demodulation performance;
- Inclusion of data demodulation capability;
- Data rate flexibility with easy matched filtering implementation;
- Design flexibility with receiver tuning based on programmable constants;
- All-digital modulation capabilities based on Direct Digital frequency Synthesis.

Main Characteristics

General Features	
Overall Frequency Stability	± 1 ppm (both for the receiver and transmitters sides)
Telemetry and Telecommand Interface	1553, MLC/DS16
Receiver Side	
Nominal up-link carrier frequency	Selectable in the S-Band TT&C range 2025-2120 MHz. In flight selection of the up-link frequency by digital serial command.
Modulation format	PM/BPSK/NRZ, PM/SP-L, BPSK
Receiver noise Figure	< 2 dB
Signal Dynamic Range	From -60 dBm to -142 dBm
Carrier Loop Bandwidth	Tunable by firmware
Tracking Range	±250 kHz at minimum carrier level
Command Data rates	PM/BPSK/NRZ: – Selectable by command in range 7.8125 bps ÷ 4000 bps PM/SP-L: – Selectable by command in the range 16 kbps ÷ 256 kbps BPSK – Selectable by command up to 1 Mbps
Implementation loss	< 2 dB
Transmitter Side	
Nominal down-link carrier frequency	Selectable in the S-Band TT&C range 2200-2300 MHz. In flight selection of the up-link frequency by digital serial command.
Modulation format	Residual Carrier: PM/BPSK/NRZ, PM/NRZ, PM/SP-L (up to 512 kbps) Suppressed Carrier: GMSK (up to 10 Mbps)
Modulation Indices	Selectable by command, both for Telemetry and Ranging
Transmitted Power	Up to 6 W
Spurious and Output harmonics	Better than 50 dBc
Coherent & Non-Coherent mode	Selectable by command. In coherent mode the Rx/Tx turn-around ratio is 221/240
Integrated Phase Noise (10 Hz – 100 kHz)	≤ 2 deg-rms,
Allan deviation at tracking threshold	Integration Time = 100 s: $<5\times10^{-14}$

Power, Environment, Mass and Dimensions

Power	Input Voltage: 22 Volt - 35 Volt	Consumption: – Receiver: <13 W – Transmitter (6 W output): 30 W
Temperature	Operating:-25°C to +60°C	Non-Operating:-40°C to + 70°C
Mass Budget	< 3 kg (including diplexer)	
Dimensions	253 x 175 x 130 mm (LxWxH) overall	

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Spread-Spectrum Transponder

Applications

SPREAD **S**PECTRUM **T**ransponder :

- Military and Civilian applications in X/C//Ku/Ka band for secure **T**elemetry **T**racking & **C**ommand systems

Main features

- Design Modularity: Implementation of Receiver Front-End and transmitter Back- End in C/X/Ku/ka band
- Multi-standard Modulations: Direct Sequence Spread Spectrum (DS-SS), PM,FM
- Full Support of ESA/NASA Spreading Codes
- Support of Non Linear Spreading Codes with arbitrary length (support of AES in Counter Mode non linear Codes)
- Support of infinitely long PN Codes (Code period up to 50 years)
- Support of Advanced Aided Acquisition System for very Long PN Codes.
- Dual Mode DS-SS: ESA-NASA/AES Codes
- Up Link UQPSK demodulation capabilities
- Support of On-Board Viterbi decoding
- Command data rate flexibility (both on I and Q channels)
- Different PN codes on I and Q transmitter channels
- Full programmability of Up Link and Down Link frequencies.
- Special Anti-jamming DSP: High Anti-Jamming performance.
- Down Link I:Q power ratio flexibility
- Compact implementation

Background

- **Koreasat 5:** Equipment manufactured and qualified. Currently on-orbit.
- **Sicral 1b:** Equipment manufactured and qualified. Currently on-orbit.
- **Yahsat 1A and 1B:** Equipment manufactured and qualified. Currently on-orbit.
- **Sicral2 :** Equipment manufacturing on-going.

Figure 1 : SST Flight Equipment

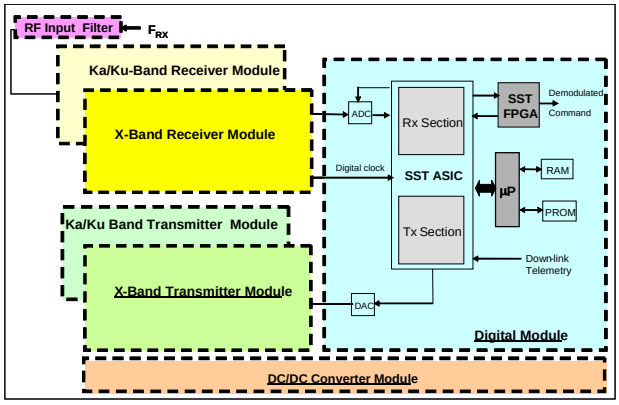

Figure 2 : Top level Secure TTC Transponder Architecture

Technical Description

The On Board SST Architecture adopts a very flexible design based on a Common Platform jointly with Custom blocks. The Common Platform includes the Digital Section (ASIC, µP, FPGA, DAC, ADC), the Transmitter RF/IF section and the Receiver RF/IF section. The Custom Parts include: the DC/DC Converter, the Programmable Read-Only Memory (PROM) Interface, the RF Front-End and Back-End sections, and the Interface Card, as depicted in Fig.2 The SST exploits a Multi-standard platform which allows adopting different modulation techniques, DS-SS, PM, FM. Regarding the DS-SS modulation, different PN codes (several hundreds) of arbitrary length can be selected by TC. The SST supports the **A**dvanced **E**ncryption **S**tandard (192 bits Keys) in Counter mode PN Code generator jointly with external Keys upload capability, ensuring to the customer, the maximum PN codes secrecy. Advanced anti-jamming DSP algorithms ensure error free communications also in presence of a jammer over Signal power ratio J/S up to 50dB.

GENERAL FEATURES AND PERFORMANCES

General Features	
SST Platform: General Features	
Mass	4 kg
Power Consumption	44W (in case of 28dBm output Power in K band)
Power Bus Interface	User defined 28/100 Volts
Telemetry and Telecommand Interface	User defined (1553 is supported).
Temperature	Operating:-25°C to +60°C ,Non-Operating-40°C to + 70°C
Dimensions (XxYxZ)	150 x 282 x 195 mm
SST Platform: Receiver Features	
Nominal up-link Carrier Frequency	S/C/X/Ku/Ka
Modulation format	UQPSK
Data Format	NRZ
Up-link I/Q Power Ratio	Selectable in the range from +10 dB to –10 dB
Receiver noise figure	< 2.5 dB (if the LNA is integrated in the equipment)
PN Code Rate	Programmable up to 4 Mchip/s.
PN Code length (chips)	Arbitrary length
PN code family	User Defined, ESA, NASA and non-linear codes are supported including AES (key length: 192 bits)
Data rate	Selectable by MLC in the range: 7.8125 ÷ 128000 bps
Implementation loss	< 1 dB both for I- and Q-channel
SST Platform: Transmitter Features	
Down-link carrier Frequency	S/C/X/Ku/Ka
Modulation format	UQPSK
Down-link I/Q Power Ratio	Programmable with 0.1 dB step
Transmitted Power	S-band: up to 5 W, X-band: up to 4 W, K-band: up to 1 W
PN Code Rate	Programmable up to 4 Mchip/s.
PN code length (chips)	Programmable by MLC
PN code family	User Defined (non-linear codes are supported)
TLM data Format	NRZ
General Performances	
SST Acquisition Performance Nominal Mode (No Jammer)	
Signal Acquisition Threshold S/N_0	40dBHz
Maximum Up-Link Doppler Range	±4000Hz (with extension to ±20 kHz using on-board local sweeping)
Maximum Up-Link Doppler Rate	±300Hz/s
Maximum Code Acquisition Time	<10sec (Code period ~ 40 years), <3sec (TRANSEC Standard Code)
SST Acquisition Performance Stressed Mode (with Jammer)	
Maximum J/S	55 dB (Jammer-Over-Signal power ratio)
Maximum Up-Link Doppler Range	±2500Hz
Maximum Up-Link Doppler Rate	±70Hz/s
Maximum Code Acquisition Time	<25sec (Code period ~ 40 years)
SST Tracking Performance	
Signal tracking Threshold	36 dBHz (S/N_0, S/J_0)
Maximum Up-Link Doppler Range	± 250 kHz

Updated : June 2012

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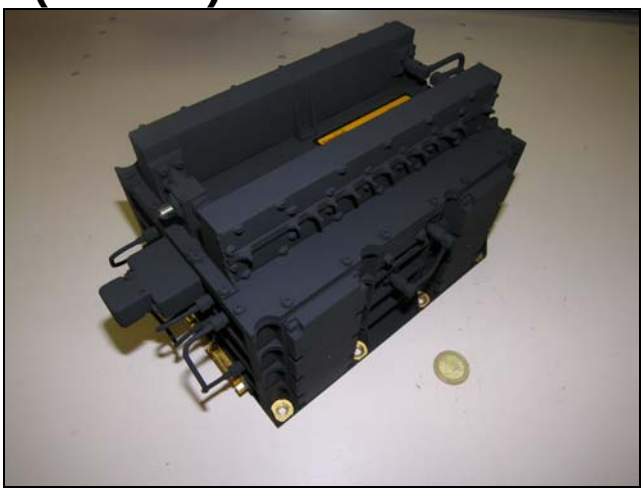
X/X Deep Space Transponder (X^2 PND)



Applications

DEEP **S**PACE **X**-**B**AND **T**T&C (**O**N **B**OARD **T**RANSPONDER **U**NIT).

Main features

- Acquisition and tracking of the up-link PM carrier
- Tracking and demodulation of data both from a 16 kHz subcarrier in BPSK/NRZ format and directly from the carrier in PM/SP-L format.
- Command data decisions and recovering of the bit timing for the On-Board Computer.
- Ranging demodulation and automatic gain control.
- Data modulation according to the specified signaling schemes (i.e. BPSK for low-rate telemetry, SP-L for medium-rate telemetry, and GMSK up to 10 Ms/s rate telemetry).
- Down-link carrier PM modulation with ranging and/or modulated telemetry
- Non-coherent capability whereby the down-link frequency is derived within the X^2PND to provide a fixed transmit frequency
- Coherent capability whereby the down-link frequency is related to the received frequency through the 880/749 turn-around ratio.

Background

- TAS-I has acquired over the last decade a vast experience in the design and development of integrated transponders for Near Earth missions.
- **LISA PATHFINDER X^2PND** FM's units manufactured and delivered on 2010. Currently tested at satellite level.
- **GAIA X^2PND** FM's units manufactured and delivered on 2011. Currently tested at satellite level.
- **X^2PND** FM units production cycle: 14 months

Technical Description

The compactness of the X^2PND equipment (mass: 3.1 kg, including the Diplexer) is achieved by combining advanced flight-proven architectural solutions (i.e. frequency plan based on under-sampling, all-digital demodulation and modulation techniques both for spread-spectrum and standard signaling) with a high degree of technological integration both on the analogue (use of hybrid for Front-End implementation, LO synthesis based on RF CMOS chip and the digital domain (the MSDRx ASIC integrates in a MG2RT technology-based device the demodulation, baseband and modulation functions).

The X^2PND core based on a digital architecture leads to the following advantages with respect to a fully analogue solution:

- Optimization of demodulation performance;
- Inclusion of data demodulation capability;
- Data rate flexibility with easy matched filtering implementation;
- Design flexibility with receiver tuning based on programmable constants;
- All-digital modulation capabilities based on Direct Digital frequency Synthesis.

Main Characteristics

General Features	
Overall Frequency Stability	± 1 ppm (both for the receiver and transmitters sides)
Telemetry and Telecommand Interface	1553, MLC/DS16
Receiver Side	
Nominal up-link carrier frequency	Selectable in the X-Band TT&C range 7145-7235 MHz
Modulation format	PM/BPSK/NRZ, PM/SP-L, BPSK
Receiver noise Figure	< 2 dB
Signal Dynamic Range	From -60 dBm to -142 dBm
Carrier Loop Bandwidth	Tunable by firmware
Tracking Range	>±500 kHz at minimum carrier level
Command Data rates	PM/BPSK/NRZ: – Selectable by command in range 7.8125 bps ÷ 4000 bps PM/SP-L: – Selectable by command in the range 16 kbps ÷ 256 kbps BPSK – Selectable by command up to 1 Mbps
Implementation loss	< 2 dB
Transmitter Side	
Nominal down-link carrier frequency	Selectable in the X-Band TT&C range 8400-8500 MHz
Modulation format	Residual Carrier: PM/BPSK/NRZ, PM/SP-L (up to 512 kbps) Suppressed Carrier: GMSK (up to 10 Mbps)
Modulation Indices	Selectable by command, both for Telemetry and Ranging
Transmitted Power	Up to 6 W (low power output also available)
Spurious and Output harmonics	Better than 50 dBc
Coherent & Non-Coherent mode	Selectable by command. In coherent mode the R/Tx turn-around ratio is 749/880
Integrated Phase Noise (10 Hz – 100 kHz)	≤ 5 deg-rms,
Allan deviation at tracking threshold	Integration Time = 100 s: $<5\times10^{-14}$

Power, Environment, Mass and Dimensions

Power	Input Voltage: 22 Volt - 35 Volt	Consumption: – Receiver: <14W – Transmitter (5 W output): 38 W
Temperature	Operating:-20°C to +60°C	Non-Operating:-40°C to + 70°C
Mass Budget	< 3.3 kg, including Diplexer	
Dimensions	258 x 148 x 195 mm (LxWxH) overall	

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X/X/Ka Deep Space Transponder

(X/X/Ka DST)

Applications

- Deep Space TT&C

Main features

The X/X/Ka DST handles simultaneously the three following functions :

- Demodulation of telecommands received in X-Band and transmission of the demodulated signal to the on-board Data Management System;
- Modulation and transmission to the on-ground station of the Telemetry stream coming from the Data Management System either in X or Ka-Band or both simultaneously;
- Transponding of the ranging signal in X and Ka-Band.

The X/X/Ka DST is capable to interface with the ESA ground segment and the NASA Deep Space Network.

Production

- BepiColombo Transponder FM (delivery date July 2012)

Background

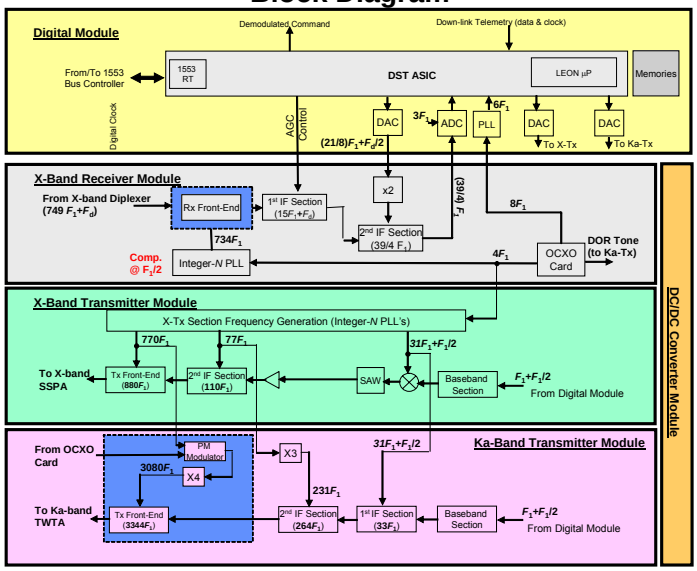
- TAS-I has acquired over the last decade a vast experience in the design and development of integrated transponders for deep space missions.

Technical Description

The X/X/Ka DST is derived from TAS-I digital transponder platform and it includes some fundamental improvements with respect to the previous design:

- Frequency agility.
- Digital-loop receiver architecture based on sub-sampling allowing to:
  - Reduce of the hardware complexity and power consumption.
  - Autonomous acquisition by local sweeping with programmable sweep rates.
  - Select 2nd order or 3rd order digital phase-locked loop on the basis of signal-to-noise ratio and signal dynamic (i.e. Doppler and Doppler rate).
  - Dynamically adjustment of the loop tracking bandwidth according to the received signal level.
- Regenerative and transparent ranging channels.
- Telecommand echo suppression filter.
- Support of DOR both in X- and Ka-Band according to CCSDS recommendation.
- All-digital modulation capabilities both in X and Ka-Band (residual & suppressed carrier)
- Possibility to synchronize the transponder either with the internal reference (TCXO/OCXO) or with an external USO (separately for Rx & Tx side).
- Remote command and TM interface based on MIL-STD-1553.
- Turn-around ratios flexibility. The X/Ka turn-around ratio is customizable according to mission requirement and CCSDS recommendation (low ratio: **3328/749**, medium ratio: **3344/749**, high ratio: **3360/749**).

Block Diagram



Technical Performance and Budgets

X/X/Ka DST: General Features	
Mass	3.7 kg
Dimensions	250 mm x 130 mm x 175 mm
Power Consumption	Rx Only: 16 W Overall: 32 W (depending by the Tx configuration and modulations scheme)
Power Bus Interface	User defined
Overall Frequency Stability	± 1 ppm (both for the receiver and transmitters sides)
Telemetry and Telecommand Interface	1553
X/X/Ka DST: Receiver Side	
Nominal up-link carrier frequency	X
Modulation format	PM/BPSK/NRZ, PM/SP-L
Receiver noise Figure	< 2 dB
Signal Dynamic Range	-60 ÷ -151 dBm
Carrier Loop Bandwidth	Tunable by firmware
Tracking Range	> 1.2 MHz at minimum carrier level
Command Data rates	PM/BPSK/NRZ: 7.8125 bps ÷ 4000 bps PM/SP-L: 4 kbps ÷ 1 Mbps BPSK: 4 kbps ÷ 4 Mbps All bit rates are selectable on-board by serial command.
Implementation loss	< 2 dB
X/X/Ka DST: Transmitter Side	
Nominal down-link carrier frequency	X/Ka
Modulation format	Residual Carrier: PM/BPSK/NRZ, PM/SP-L (X/Ka band) Suppressed Carrier (up to 10 Mbps in X-Band, up to 50 Mbps in Ka-Band)
Modulation Indices	Selectable by command, both for Telemetry and Ranging
Transmitted Power	Up to 12 dBm (additional SSPA module available for X and Ka)
Spurious and Output harmonics	Better than 50 dBc
Integrated Phase Noise (1 Hz – 100 kHz)	X-band: ≤2 deg-rms, Ka-band: ≤6 deg-rms
Allan deviation at tracking threshold	Integration Time = 1000 s: $<6x10^{-16}$

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