

DS1 Technology Validation Report for Small Deep Space Transponder (SDST)

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EXTENDED ABSTRACT

The Small Deep Space Transponder (SDST) is a Level-1 technology validation objective of the New Millennium Deep Space 1 mission. The SDST was developed as a replacement for the Cassini Deep Space Transponders (DST) and supports the radio frequency transmit, receive, and radiometric functions as were previous transponders. Additionally, the SDST provides a significantly greater functional integration by combining the command detection unit (CDU) and telemetry modulation unit (TMU) in one assembly. The integral design allows for smaller size, mass, and power consumption of the telecom subsystem compared to previous generation of hardware. Furthermore, the SDST is the first Ka-band capable deep space transponder. Previous Ka-band capable missions such as Mars Observer (MO), Mars Global Surveyor (MGS) and Cassini, rely on either an external frequency translator or frequency multiplier to provide the Ka-band downlink. The SDST provides full support of Ka-band downlink functions, including telemetry modulation, and radio-metrics (coherent Doppler, ranging, and DOR).

The development of the SDST was performed by Motorola Inc., Scottsdale, AZ, under funding from a JPL Multi-Mission Consortium. Developed over a 3 year span at a cost of \$10.4 Million Dollars (including non-recurring engineering and flight unit cost), the SDST development process is a model for the better-faster-cheaper development. Key technologies enabling the SDST design include: Radio Frequency Integrated Circuit (RFIC), advanced high frequency MultiChip Modules (MCMs) and a 70,000 gate CMOS Application Specific Integrated Circuits (ASICs) which implements bulk of the receiver and telemetry modulation functions. Some of the design (down-conversion frequency scheme, DRO's) were derived directly from the Cassini DST, while others, such as the MCM and ASICs were new developments. The mixture of inherited technology and new development shortens design cycle and lower the development cost.

A high firmware content was implemented in SDST's digital signal processing module, which was designed to work in X-band deep-space, S-band STDN and S-band SGLS transponders. The high firmware content enables many optional capabilities to be provided with only firmware changes and allow specific tailoring for each mission. Particular attention was paid during development to ensure that the SDST provides flexible control in software. This feature was important for the multi-mission consortium where different spacecraft design may dictate slightly different control interface. Transponder modes such as the telemetry and ranging modulation indices, telemetry subcarrier frequency, and convolutional coding type are user controllable during mission operation. Other functions such as the carrier tracking loop bandwidth, and automatic uplink acquisition are firmware options. Furthermore, the SDST design accommodates interface to the spacecraft avionics via either MIL-STD-1553, MIL-STD-1773 or RS422 serial bus using the 1553 protocol. This design allows future flight users maximum flexibility in selecting the system architecture.

This report summarizes the results of DS1's in-flight technology validation activities related to the SDST. These activities were designed to show that the intended functions of the transponder can be achieved under the operating environment in space. Specific in-flight checkout activities were designed to exercise the transponder through different operating modes and relevant performance data was collected both onboard by the flight system and on the ground by monitoring DSN station performance data. Additional validation data was obtained through routine operation of the spacecraft by thoroughly monitoring the telecom link performance and relevant SDST performance data. All SDST functions for uplink, downlink, and radio-metric measurements were successfully validated, including the optional Ka-Band Downlink. In some cases, such as frequency stability measurements, the inflight checkout activity also provided measurements of SDST performance in the

actual operating environment not achievable with ground based testing. Specifically, the inflight technology validation activities focused on the following performance validations:

- Uplink: Uplink carrier receiver acquisition
Command data rate and command threshold
Carrier tracking and uplink power measurements
- Downlink: Verification of telemetry encoding and carrier modulation
Verification of transition between two-way coherent and one-way modes
Validation of the phase modulator performance model
Validation of the Ka-band exciter technology and its associated performance characteristics
Validation of beacon tone generation
- Radiometrics: Measurement of frequency stability of the DS1 auxiliary oscillator under inflight temperature condition.
Verification of coherent carrier tracking performance
Verification of the X/Ka-band relative carrier tracking performance
Verification of the X/Ka-band ranging functions

Although strictly not a SDST validation objective, the availability of a stable Ka-band downlink signal from DS1 permitted a direct verification of Deep Space Network's (DSN) operational readiness at Ka-band. The DS1 Ka-band downlink was used to:

- Demonstrated dual-band (X/Ka) end-to-end telemetry flow from spacecraft to DS1-MSA
- Demonstrated capability to generate necessary station predicts for Ka-band tracking
- Demonstrated station capability to perform radio metric tracking on Ka-band downlink (Doppler and ranging)
- Verified X/Ka band Radio metrics performance
- Demonstrated DSS-25 capability to accurately point the 34 m antenna using blind pointing
- Measured Ka-band system noise temperature which compares favorably with model

The inflight checkout activities and ongoing flight validation of the SDST provided confidence on the transponder design. With successful flight validation and experience gained through mission operations, the risk of using the transponder design for future mission has been substantially reduced.

Subsequent to a successful DS1 flight validation, the design of SDST has been enhanced to remove some of the operational idiosyncrasies due to nonlinearity of the phase modulator and the changes in receiver best lock frequency. The current generation of SDST, scheduled to be flown on Mars 01 and SIRTf missions has incorporated these changes. Furthermore, unlike the DS1 SDST which functioned only with a single string C&DH, the Mars 01 SDST supports dual-string cross strapping with the C&DH. These performance improvement and added functionality, together with DS1's inflight validation, makes the use of SDST truly low risk for future flight projects.