NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mars Exploration Program

Electra Mars Proximity-Link Communications and Navigation Payload Description

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Jet Propulsion Laboratory
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Introduction

The Mars Exploration Program (MEP) has identified the need for establishing a robust Mars relay infrastructure to provide mission-enabling and enhancing telecommunications and navigation services to future MEP elements. To this end, the MEP has funded development of a standardized proximity-link communications and navigation payload, known as the Electra UHF Transceiver (EUT), for flight on each science orbiter. The EUT, shown in Figure 1, was flown for the first time on the 2005 Mars Reconnaissance Orbiter (MRO) mission, and is also planned for flight on the 2013 Mars Atmosphere and Volatile Evolution Mission (MAVEN).

As a continuation of this strategy, the 2009 Discovery Announcement of Opportunity requires orbiter missions with mission lifetimes of one Mars year or more to carry the Electra UHF relay communications payload for feed-forward provision of in-situ telecommunications and navigation services to other MEP missions. The cost of the payload and ground support will be funded by MEP, and these costs are not counted against the overall project cost. In addition, the actual cost of any extended mission operations to support relay services would also be provided by MEP and would not be counted against the overall project cost. However, the proposing project is responsible for any and all costs associated with integrating the payload into the overall flight system, and for implementing the functional capability within the project mission operation system/ground data system required to operate the payload.

This document provides a high-level description of the Electra payload interfaces to assist proposers in incorporating this payload into their orbiter design. Applicable Discovery Mars

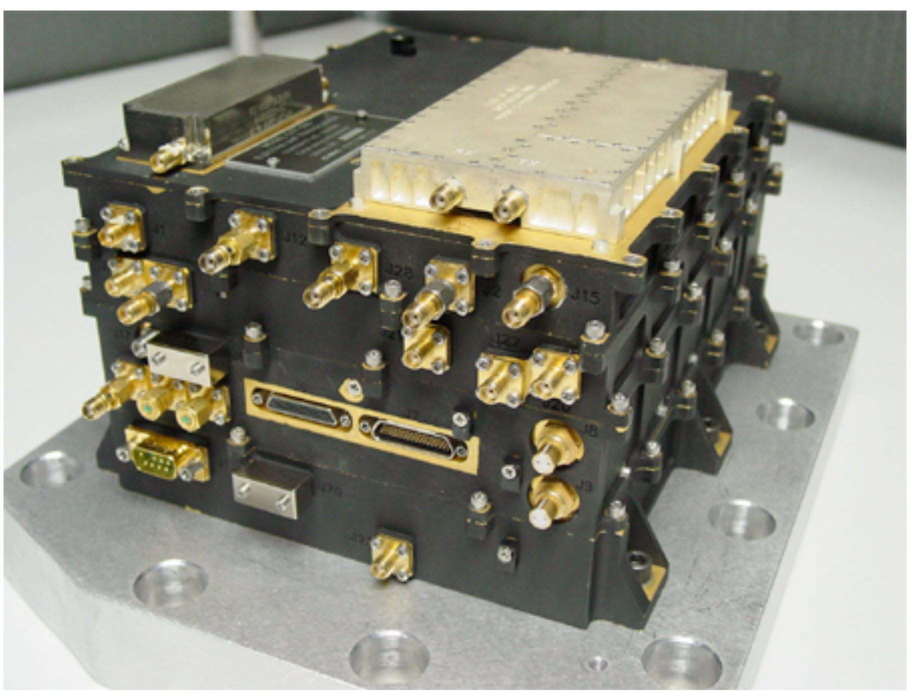

Figure 1: Electra UHF Transceiver

orbiter proposals shall include the Electra payload in the overall spacecraft block diagram, include appropriate Electra mass and power allocations in the overall spacecraft design, and incorporate requisite functionality into the overall mission operations system.

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Electra Payload Description

The Electra Payload consists of the Electra UHF Transceiver, with an integrated internal Temperature Controlled Crystal Oscillator (TCXO) frequency reference, a low gain UHF quadrifilar helix antenna and ancillary cabling and mounting hardware. Table 1 lists the payload elements and masses. The total estimated mass for the single-string payload is 6.5 kg (not to exceed). Accommodation of the payload on the spacecraft requires placement of the UHF low gain antenna such that it can be pointed in the nadir direction, with a clear field-of-view over a cone angle of ±60 deg relative to the antenna boresight.

The heart of the Electra Payload is the Electra UHF Transceiver (EUT), which is a fully-reconfigurable, frequency-agile transceiver operating in the 390-450 MHz band. The EUT incorporates a modular design with functional elements residing in four stacked modules: a Filtering and Switching Unit (FSU) slice, a Receiver/Modulator (RXA/MOD) slice, a Baseband Processor Module (BPM) slice, and a Power Amplifier-Power Supply Module (P/A-PSM) slice. The EUT is shown in Figure 1. Key EUT specifications are provided in Table 2.

The Electra payload has a number of interfaces with elements of the spacecraft bus, including the spacecraft command and data handling subsystem and the spacecraft power subsystem. These interfaces are summarized in Table 3. The worst case, End-Of-Life (EOL) power consumption estimate for the payload is summarized in Table 4 (over temperature, age, radiation).

Figure 2 depicts a simplified block diagram of the Electra Payload, highlighting the primary payload elements and payload interfaces with the spacecraft bus.

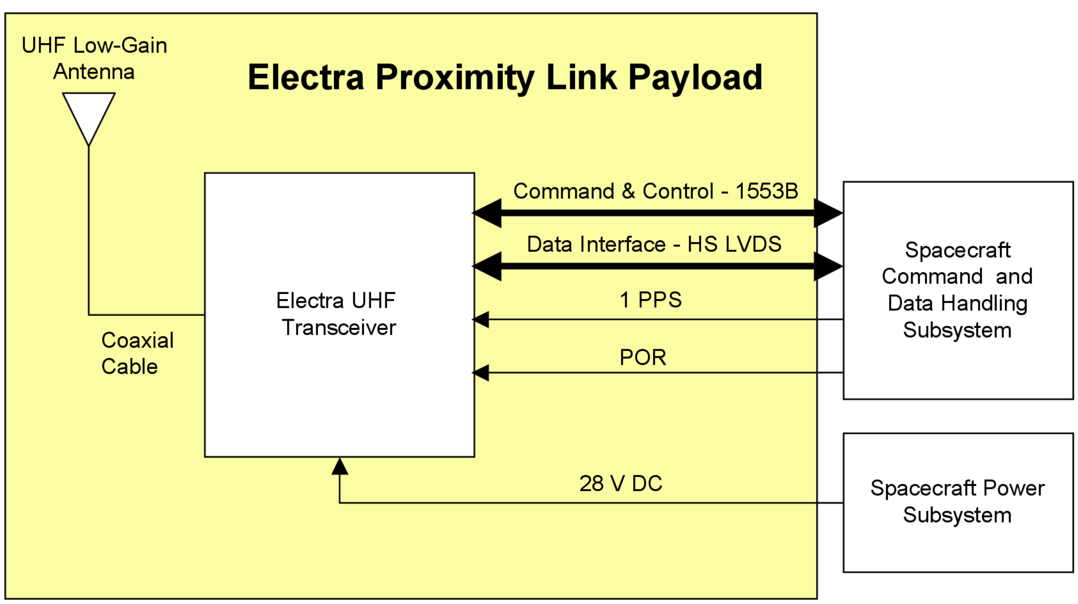

Figure 2: Electra Proximity Link payload block diagram

Electra Payload Element	Mass (kg)	Dimensions (cm)
Electra UHF transceiver (EUT)	5.2	21.7 l x 20.1 w x 12.2 h
UHF Low Gain Antenna (including coaxial cable to transceiver)	1.0	26.1 dia x 30.5 h
Cabling for payload-spacecraft interfaces	0.3	TBD
TOTAL (Not to Exceed)	**6.5**	**-**

Table 1: Electra Payload Elements and Mass/Volume Estimates

Parameter	Electra UHF Transceiver
Duplex modes	Full Duplex (FD), Half Duplex (HD)
Transmit (TX) Frequency	FD: 435 – 450 MHz HD: 390 – 450 MHz
Receive (RX) Frequency	FD: 390 - 405 MHz HD: 390 – 450 MHz
Operational Modes	Sleep, Standby, RX, TX, RX/TX
TX/RX Rate	1,2,4,8,…,2048 ksps
Modulation	Manchester, NRZ-L, BPSK, QPSK Mod Index 60 or 90 deg
Coding	K=1, R=1/2 Convolutional Encode/Decode
Spectrum Record	Open Loop Signal Sampling <100 ksps, 1-8 bits/sample
RX Noise Figure	FD: 4.9 dB; HD: 3.9 dB
RF TX Power	FD: 5.0 W, HD: 7.0 W
Communications Protocol	CCSDS Proximity-1 Space Link Protocol
Reconfigurability	Yes
Radio Metric Tracking	Carrier Phase/Doppler, Amplitude; Coherent or Non-Coherent modes
Mass	5.2 kg (w/ internal TCXO)
Dimensions (l,w,h)	21.7 x 20.1 x 12.2
DC Power	8.5 W – Sleep Mode (WC, EOL) 25.5 W – RX Mode (WC, EOL) 77.8 W – TX/RX Mode (WC, EOL)
Parts Grade	B+
TID	20 krad

Table 2: Key EUT Specifications

Electra Payload Interface	Description
Command and control	Redundant, cross-strapped 1553-B physical interface with 1553 protocol
Proximity link data (Forward and Return)	Redundant, cross-strapped High-Speed Low Voltage Differential Signaling (HS-LVDS)
DC power	28 VDC
1 Pulse-Per-Second (1 PPS) timing	Direct analog line
Power-on-Reset (POR)	Direct analog line

Table 3: Electra Payload – Spacecraft Bus Interfaces

Electra Payload Operating Mode	DC Power (W)
Full-duplex (transmit/receive)	65.0
Receive-only	23.6
Sleep	7.0

Table 4: Electra Payload Power Consumption (Worst case, EOL)

EMI/EMC Considerations

Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC) issues should be carefully considered in accommodation of the Electra relay payload on a Discovery Mars orbiter. Just as spacecraft subsystems and science instrument payloads must be designed and implemented to avoid generation of EMI that would degrade communications on the deep space link to/from Earth, a Discovery Mars orbiter carrying the Electra relay payload must also ensure mitigation of any EMI that would degrade Electra relay communications at UHF frequencies.

As a reference, the Mars Reconnaissance Orbiter carried the EMI specification summarized in Table 5 on the spacecraft flight system, which places a limit on the electric field strength generated by the various spacecraft elements in the Electra UHF band as measured at the Electra antenna: (The latter two rows of the specification provide enhanced EMI suppression at the default relay return link frequency of 401.585626.)

It should be noted that while the MRO avionics system met this specification, several of the MRO science instruments exceeded these EMI levels, leading to degraded relay performance when these instruments are active, and potentially resulting in the need to power off offending instruments during relay support periods. Early attention to EMI/EMC considerations in payload and instrument design, and thorough payload-level and system-level EMI/EMC testing, are key to achieving electromagnetic compatibility.

Frequency Range	Electric Field Level
350-490 MHz	< 10 dBuV/m
390-405 MHz and 435-450 MHz	< 0 dBuV/m
401.585626 +- 2 MHz	< -5 dBuV/m
401.585626 +- 0.1 MHz	< -10 dBuV/m

Table 5: MRO EMI/EMC Specification

Deliverables and Schedule

The Mars Exploration Program will provide specific Government Furnished Equipment (GFE) deliverable items to a selected Discovery Mars orbiter carrying the Electra relay payload, as summarized in Table 6. A phased delivery schedule is anticipated, with early delivery of an Engineering Model transceiver to support interface testing and early flight integration tests, and subsequent delivery of Flight Models for final flight system integration. The Discovery Mars orbiter proposal should specify the need dates for the EM and FM deliveries based on the proposed system integration schedule. The program may optionally choose to deliver flight spares of the EUT and/or UHF antenna, if program resources allow, in order to increase the likelihood of launch readiness of the Electra payload.

In order to ensure successful accommodation of the Electra relay payload, a selected Discovery Mars orbiter mission carrying the payload should establish an Electra Interface Control Document (ICD), in collaboration with the GFE payload provider, as early as possible in the project development lifecycle, and should conduct an early Electra Payload Accommodation Review to ensure a full understanding of spacecraft interfaces and verify compatibility of spacecraft environments with payload capability.

Each item of Electra hardware will be delivered with an End Item Data Package documenting all payload level test results. For the EUT, these include functional, environmental, and Proximity-1 protocol compliance testing. For the UHF antenna, these include functional and environmental testing as well as Voltage Standing Wave Ratio (VSWR) and gain pattern measurements.

Combining the UHF antenna free space gain pattern with simple field of view considerations is

Delivery	Deliverable Item
Engineering Models:	• Electra UHF Transceiver (EUT) Engineering Model (EM) w/ integrated TCXO • EUT EM Ground Support Equipment
Flight Models:	• EUT Flight Model (FM) w/ integrated TCXO • UHF FM Quadrifilar Helix Antenna • EUT FM Ground Support Equipment

Table 6: Electra GFE Deliverables

insufficient for predicting the as-built relay antenna gain pattern. At the UHF wavelength of operation, 67cm to 77cm, other RF conductive spacecraft components will parasitically couple with the UHF antenna forming a "composite" antenna. The net antenna gain pattern can be quite distorted from the free space gain pattern. On past NASA lander and orbiter missions, this has been handled in the design phase via EM modeling and in the implementation and operations phase via pre-launch and post launch antenna gain pattern tests.

The EUT EM and FM Ground Support Equipment provides emulation of orbiter C&DH monitor and control of the EUT payload, and simulation of a relay user spacecraft for support of functional tests of the Discovery Mars orbiter relay capability.

Relay Operations Support

As stated in the introduction, the actual cost of any extended mission operations to support relay services would be provided by MEP and would not be counted against the overall project cost. However, the proposing project is responsible for implementing the functional capability within the project mission operation system/ground data system (MOS/GDS) required to operate the payload.

In support of relay operations, the Discovery Mars MOS/GDS needs the capability to schedule Electra relay services during selected overflights of a user spacecraft. Supported services include delivery of user command files, return or user telemetry, collection of radio metric tracking observables (carrier phase/Doppler and amplitude) on the UHF relay link, provision of time correlation services to establish the clock bias of a user spacecraft, and full spectrum recording of a user's UHF signal. Once a service is negotiated and committed to a user, the Discovery Mars orbiter MOS/GDS will need to sequence the operation of the Electra payload and support interfaces with the user mission's GDS for receipt of user command products and for delivery of user telemetry and other Electra products (e.g., Doppler observables, full spectrum UHF recordings, time correlation measurements). Efficient processing of user's data in the Discovery Mars orbiter's GDS is desired in order to minimize the end-to-end latency of relay services. The Discovery Mars orbiter's MOS/GDS should provide sufficient visibility into the end-to-end relay data flow to support tracking of user mission relay products through the Discovery Mars orbiter flight and ground systems.

As with other spacecraft payloads and subsystems, it is recommended that the Electra health, Electra performance and the relay link protocol performance be monitored both in real time and via post processing telemetry.

In the early phases of relay support planning, the Discovery Mars orbiter mission may be called upon by user missions to support UHF transceiver-level tests of the lander telecom system with the orbiter's Electra Ground Support Equipment (GSE) to verify relay compatibility. In the latter phase of preparing for relay support, the relay spacecraft mission team will be called upon to support relay service system level tests performed in the orbiter project spacecraft test bed. Again, funding for any such testing would be provided outside of the Discovery mission cost cap.

For further insight on relay support planning, it may be instructive to review the "Mars Relay Description for Discovery Proposals", available online in the Discovery 2010 AO Program Library (at http://discovery.larc.nasa.gov/dpl.html) to understand the functional service capabilities and relay interfaces of the current and planned Mars relay orbiters, and which a relay-equipped Discovery Mars orbiter will be expected to support.

Acknowledgment

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