Communications During Critical Mission Operations: Preparing for InSight’s Landing on Mars

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Radio communications with deep space missions are often taken for granted due to the impressively successful records since, for decades, the technology and infrastructure have been developed for ground and flight systems to optimize telemetry and commanding. During mission-critical events such as the entry, descent, and landing of a spacecraft on the surface of Mars, the signal’s level and frequency dynamics vary significantly and typically exceed the threshold of the budgeted links. The challenge is increased when spacecraft shed antennas with heat shields and other hardware during those risky few minutes. We have in the past successfully received signals on Earth during critical events even ones not intended for ground reception. These included the UHF signal transmitted by Curiosity to Mars-orbiting assets. Since NASA’s Deep Space Network does not operate in the UHF band, large radio telescopes around the world are utilized. The Australian CSIRO Parkes Radio Telescope supported the Curiosity UHF signal reception and DSN receivers, tools, and expertise were used in the process. In preparation for the InSight mission’s landing on Mars in 2016, preparations are underway to support the UHF communications. This paper presents communication scenarios with radio telescopes, and the DSN receiver and tools. It also discusses the usefulness of the real-time information content for better response time by the mission team towards successful mission operations.

I. Introduction

COMMUNICATIONS between robotic spacecraft and ground controllers are particularly critical during risky maneuvers. For landers on the surface of Mars, the short phase of the mission called entry, descent, and landing (EDL) is perilous and special attention is paid to the ability to deliver the information on the fast-paced events to mission controllers. As described in Asmar (2012), communications utilize data modulations onto a microwave signal carrier, but there are conditions where the signal dynamics are too high and/or the received signal-to-noise ratio is below the receiver threshold to acquire and lock onto the signal. NASA’s Deep Space Network (DSN) operates open-loop Radio Science Receivers (RSR) that can capture the raw incoming electromagnetic signals and associated noise for detailed and careful post-event digital analyses. This type of receiver, designed for scientific measurements, provides a high level of configuration flexibility and operability that can be optimized for the particular mission event. The RSR proved to be critical for the support of a few cases where the signal carrier was detected and very important real-time information on the state of the spacecraft from the carrier dynamics became available.

II. The InSight EDL

NASA’s twelfth Discovery Program mission will place a geophysical lander on Mars to study its deep interior using seismic instruments along with rotational and thermal measurements, and will be the first mission to unveil the composition, structure and thermal state of Martian crust, mantle and core (Banerdt, 2012). The InSight mission will be launched in March 2016 and land about six months later. Upon approach to Elysium Planitia (see Figure 1), a sequence of programmed events will be initiated as illustrated in the graphical summary of Figure 2. The events are grouped into an entry preparation, hypersonic, parachute, and terminal descent phases. Each critical event must take place at the planned time for the sequence to succeed.

The arrival geometry at Mars is such that the EDL sequence at the selected landing site is in view of Earth. The mission, however, has not plans to communicate the progress of the EDL events to Earth. This is because this

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would require communications at X-band (~8.4 GHz) which not available on the spacecraft at the time. The spacecraft bus is inherited from the design of the Phoenix mission. X-band will be available during the cruise period and later during the surface operations period for emergency communications and Radio Science. But the cruise-phase X-band antennas will be shed with other exterior components prior to EDL. The mission’s plans are based on communicating in the UHF (~400 MHz) proximity link band to one or more orbiters around Mars equipped to receive the UHF link and later relay the information at X-band to DSN stations. The primary spacecraft designated for this function is the Mars Reconnaissance Orbiter (MRO) whose relay is expected to take several hours.

Since the information will not be available to mission controllers in real-time (plus one-way light time from Mars), another method is explored, which can also function as a back-up capability. Our team is planning to receive the UHF link transmitted from InSight to MRO direct to Earth (DTE) in real-time, even though the link was not designed for transmission to Earth and the signal to noise ratio is very low. Initial analysis show that this is possible. Though marginal. This concept was inspired by the fact that the same method was applied to the Mars Curiosity rover landing in 2012 and was successful. In addition, Asmar (2012) describes several other critical events that utilized the same technique for the Spirit and Opportunity rovers, the Huygens landing on Titan and the Cassini Saturn Orbit Insertion. The possibility of returning high value information makes it necessary to attempt such reception for the critical InSight EDL.

![Figure 1. The InSight planned landing location on Mars and sites of previous missions](image-url)

**Figure 1.** The InSight planned landing location on Mars and sites of previous missions (Fernando Abilleira, Mission Design and Navigation).
When the expected signal level is exceedingly low, very large collecting surfaces of radio telescopes, or communication stations, are preferable and there are only a handful of them worldwide. For the InSight EDL UHF DTE, the time of arrival dictated which telescopes should be explored. Although the Parkes radio telescope in Australia was utilized for Curiosity EDL, a modification in the InSight arrival date excluded Parkes and made the view period overlap between parts of Europe and India. Recently, two large European telescopes have initiated the process of preparing to support the historical InSight landing event: the Effelsberg 100-meter radio Telescope in Germany and the Jodrell Bank 76-meter radio telescope in the United Kingdom (see Figure 3). These two telescopes already have front-end instrumentation for reception at the UHF band. Both telescopes were designed for radio astronomy, the reception of natural radiation, and have rarely participated in receiving signals from robotic spacecraft in deep space. As a result, additional procedures have to be implemented along with detailed testing especially for radio-frequency interference (RFI) from terrestrial transmitters and possibly from within equipment at the telescope. Terrestrial sources include Earth-orbiting satellites as well as local use in the surrounding communities especially by emergency response systems that operate near the band of interest. DSN RSR instrumentation and personnel will participate in the activity at one or both telescopes.

Currently, work is under-way to predict the received carrier power (Pc/No) at each telescope taking into account the surface area, elevation angles and system noise temperatures. Initial estimates show the carrier to be higher than 3 dB. This is a small value for traditional communication methods, but thought sufficient from experience in this case to capture the signal carrier. There is no intent to capture the telemetry transmitted from InSight towards MRO. Information obtained from the dynamics of the carrier will inform the project management of the success of the event and survival of the spacecraft. This can include parachute separation, constant velocity start, and actual landing (zero velocity) as each event introduces a detectable and distinct Doppler shift in the signal carrier frequency that can be received one-way light time later and announced to mission controllers.
IV. Lessons Learned from Curiosity EDL

As described in Asmar et al., (2013), the Curiosity EDL operations utilized three methods: X-band DTE, UHF relay to MRO, and UHF DTE. The last option was introduced after all design and development were completed and was considered a secondary back up. Since the first two (primary) methods, succeeded, the last option was successful but not resorted to by mission controllers. However, it proved to be an excellent exercise to prepare for future missions needing to utilize the same technique. The Curiosity UHF DTE was carried out at the historically significant 64-meter CSIRO Parkes Radio Telescope in Australia, an early model for the design of the DSN stations. As planned, a portable DSN RSR was installed at Parkes and configured to receive input at nearly 300 MHz.

CSIRO developed a UHF receiver for the front-end since work in this band had traditionally been abandoned for science purposes mostly due to local RFI. Extensive testing was carried out prior to the event to discover, remove, or isolate sources of RFI from the local community or within the telescope’s machinery. Although considered a back up to a back up with a small chance of achievement, the support succeeded completely and the carrier was visible in real-time, see Figure 4. The resolution was sufficient to discriminate the important events such as parachute deployment and eventual landing. If that had been the only available information, the mission managers would at least know that the complex and risky process of landing the spacecraft on the surface of another planet, which Curiosity dubbed the seven minutes of terror, had taken place successfully.

V. Conclusion

Very important work is in progress in order to prepare for a critical and historical event, the arrival and landing of the InSight spacecraft to the surface of Mars to study the geophysics of the planet with inferences to be applied to all rocky planets. The planned primary communications method during EDL will have a time delay of several hours. Exploring receiving on Earth the very weak UHF signal intended form transmission to MRO and not to Earth is worthwhile as the high value of the returned information will be valuable to the mission. Large radio telescopes in Europe are interested in participating in this attempt to detect the carrier signal and infer information on the health and status of the landed spacecraft. Experience with similar scenarios on previous missions will be applied, proven ground instrumentation will be utilized, and extensive testing will take place, all to increase the reliability of detection. More information will become available as we get closer to the event and testing commences.
Figure 4. The UHF signal received on Earth, with minimum processing, at the Parkes radio telescope during the entry, descent, and landing phase of the Mars Curiosity rover in August 2012. The red circles are estimates of the frequency and show reliable detection to almost landing on the surface.

Appendix A

Acronym List

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<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
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<td>DSN</td>
<td>Deep Space Network</td>
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<td>DTE</td>
<td>Direct To Earth</td>
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<tr>
<td>MRO</td>
<td>Mars Reconnaissance Orbiter</td>
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<tr>
<td>RFI</td>
<td>Radio Frequency Interference</td>
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<tr>
<td>RSR</td>
<td>Radio Science Receiver</td>
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<tr>
<td>UHF</td>
<td>Ultra High Frequency</td>
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References

Sami Asmar, “Communicating by Doppler Detecting Spacecraft Dynamics During Critical Maneuvers,” 12th SpaceOps Conference, Stockholm, Sweden, June 2012
Sami Asmar, Kamal Oudrhiri, Daniel Kahan, Stephan Esterhuizen, John Sarkissian, Suzy Jackson, Brett Preisig, Özgür Karatekin, Hannes Griebel, “Curiosity’s Landing Dynamics as Observed at the CSIRO Parkes Radio Telescope,” IPPW-10 San Jose, CA, June 2013