BI-STATIC DEEP ELECTROMAGNETIC SOUNDINGS FOR MARTIAN SUBSURFACE CHARACTERIZATION : EXPERIMENTAL VALIDATION IN THE EGYPTIAN WESTERN DESERT.
V. Ciarletti[1,], A. Le Gall[1], J.J. Berthelier[1], Ch. Corbel[1], F. Dolon[1], R.Ney[1], A. Reineix[2], Ch. Guiffaud[2], S. Clifford[3], E. Heggy[3], [1]CETP/IPSL, 10-12, Ave. de l'Europe, 78140 Velizy France; e-mail: valerie.ciarletti@cetp.ipsl.fr, [2]XLIM, 123 Ave. Albert Thomas, 87060 Limoges, France, [3] LPI, 3600 Bay Area Blvd., Houston, TX 77058, USA

Introduction: Getting observations of the morphology and structure of the Martian underground at kilometric depths appears to be of prime interest in several scientific fields of research. Access to the geological features which are present in the subsurface will allow us to improve our understanding of the processes which have been active during the formation and evolution of the planet. The search for recent or past water on Mars is one of the key questions addressed by almost all current and upcoming missions to the planet. Although very large data bases of observations of the Martian surface in the visible and infra-red domain have been acquired by instruments flown onboard Martian probes or installed onboard the recent NASA rovers, the analysis of returned data have shown that there is a clear need for investigations to explore and understand the subsurface. Electromagnetic sounding with Ground Penetrating Radars (GPR) appear to be a powerful mean to get information on the structures buried in the subsurface. Given the large permittivity and conductivity values of liquid water compared to those of soil and rock, GPRs are particularly well adapted to the detection and the localization of water table.

The pioneering investigations from orbit by both MARSIS and SHARAD radars have already provided information at large scale for the whole planet, while the upcoming ExoMars ESA mission will focus on the detailed description of the structure of the Martian surface and subsurface in area that will be explored by the ExoMars rover.

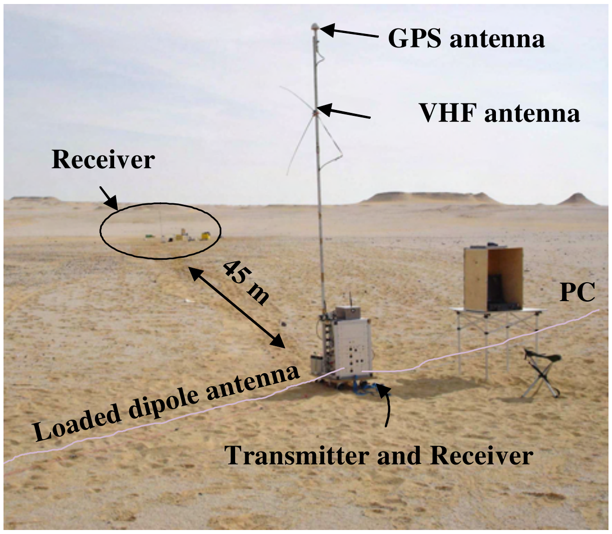
Deep soundings from the surface with TAPIR: On Earth, conventional GPRs usually aim at very shallow soundings and operate in the UHF frequencies band from the surface. Their operation implies a series of measurements made at a number of locations on the surface to achieve the proper determination of the individual reflectors location and/or of the buried interfaces position. However, performing deep soundings requires the use of lower frequencies electromagnetic waves (in the range of a few MHz) which encounter less attenuation as they propagate into the soil. Unfortunately the subsequent size of the electrical antennas (several tens of meters) precludes any motion of the radar on the surface.

The TAPIR (Terrestrial And Planetary Investigation by Radar) in an impulse GPR developed at CETP for the now canceled NETLANDER mission. It was designed to be operated at central frequencies ranging from 2 to 4 MHz from a fixed position at the surface of Mars. This advanced radar allows to determine, from a single position, not only the distance of the reflectors, from the propagation delay of the echoes, but also their direction by determining the direction of propagation of the reflected waves from the 2 measured horizontal electrical components and the 3 magnetic components of the wave [1],[2],[3].

An upgraded version of the TAPIR instrument that allows to perform bi-static measurements has been developed. A 70 m loaded dipoles antenna laid on the surface is used for transmission (Tx). At the receiver (Rx), a single small magnetic antenna, which can be successively positioned along 3 mutually orthogonal directions, provides 3 independent orthogonal magnetic components and two orthogonal 70 m loaded dipoles antennas provide the two horizontal components of the electric field. Rotating the transmitting electric antenna by 90° allows to vary the polarization of the transmitted signal, which provides additional information on the reflectors. This bi-static configuration considerably reduces the interferences due to the coupling between the transmitting and receiving antennas and also reduces (by increasing the propagation delay) the radar blind zone which prevents from detecting shallow targets in a mono-static configuration.

Experimental validation: The principle of the bi-static operating mode has been technically tested and validated on the Pyla dune (South of France) [4] for distances between transmitter and receiver up to 300 meters. The particularly accurate synchronization of the transmitter and receiver allowed to perform up to 2^{31} coherent additions of the received signals in order to improve the signal to noise ratio.

In November 2005, research teams from the Lunar and Planetary Institute (LPI), Southwest Research Institute (SwRI), and Centre d'étude des Environnements Terrestre et Planétaires (CETP), conducted electromagnetic sounding investigations in the West Egyptian Desert on the Abou Saied plateau [5],[6]. According to the available data, this limestone plateau is horizontally stratified with the local water table of the Nubian Aquifer lying more than 250-280 m beneath the surface. This field survey allowed to collect data on a site presenting potential deep reflecting structures. Bi-static soundings were made with TAPIR for two distances between transmitter and receiver (45m and 100m) and for two different polarizations at the transmitter. The pulse duration was set to 500ns in order to ensure a satisfying spatial resolution. Up to 2^{26} coherent additions of the received signals were performed in order to detect even very weak echoes. Signals were clearly observed on both electric and magnetic antennas. The first echoe corresponds to the direct wave propagating horizontally from the Tx to the Rx and the following ones are due to reflections either on the surface relief or the subsurface structures.



Deployment of TAPIR on the Abou Saied Plateau

Retrieval of the direction of the received signals:

The work presented focuses on the retrieval of the direction of arrival of the detected echoes. This information is essential not only to localize properly the sub-surface reflecting structures but also to discriminate between the echoes coming from the subsurface and those due to the surface clutter.

In order to validate the different methods proposed to retrieve the direction of arrival, they have been thoroughly applied at first on simulated data. An accurate FDTD code (developed at XLIM) able to model the whole bi-static configuration including both the antennas and a layered subsurface (with possibly rough interfaces, gradients, inhomogenities,..) has been used. The retrieved directions are compared to the known theoretical values; which gives an estimation of the accuracy and limitations of the proposed methods. So far, the estimation relies on the fact that, at a sufficient distance from the transmitter, the propagating electromagnetic wave can be considered as locally plane and the orthogonality of the electric, magnetic and propagation vectors is used to retrieve the propagation vector direction. The study performed on simulated data demonstrates the validity of this assumption for rather deep reflectors located at depths larger than 100m (for a permittivity value of 9). As far as shallow reflectors are concerned, the bi-static mode cleary makes the detection possible (whereas mono-static sounding would fail because of the inherent radar blind zone) but the direction of arrival estimation remains critical. The exact extension of validity domain depends on the electromagnetic properties of the sub-surface materials.

Taking advantage of the results obtained on simulated data, the estimation of the direction of arrival is made on the available sets of measured signals. The combination of these GPR results, the laboratory characterization of collected field samples and the FDTD modeling (XLIM) constrain the location, orientation, and nature of the detected reflecting structures and an coherent interpretation of the subsurface structure is proposed.

Conclusion: The concept of bi-static deep sounding has been validated in the Egyptian Western Desert with the TAPIR HF GPR; this operating mode considerably reduces the blind zone of the radar and offers the opportunity of getting complementary information by increasing the distance between Tx and Rx.

The EISS (Electromagnetic Investigation of the Sub Surface) experiment proposed for the EXOMARS mission is based on the bi-static capacity of TAPIR. The original idea of the EISS experiment is to take benefit of the unique opportunity offered by the simultaneous presence on the surface of Mars of a fixed Lander (Geophysical Environmental Package) and of the EXOMARS rover. EISS will allow to perform bi-static soundings of the subsurface: The long loaded dipole antennas will transmit the electromagnetic waves from the immobile GEP and a much smaller magnetic antenna located on the rover will be used as the receiver. The displacement of the rover over distances of 1 to 2 kilometers allows to perform successive soundings that can be subsequently analyzed to get a 2D description of the subsurface structure along the path of the rover even if only magnetic measurements is performed at the receiver.

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References:

[1] Berthelier J.J et al. (2003), *J. Geophys. Res.*, *108*, E4 10.1029/2002JE001866 [2] Ciarletti V.et al (2003), *J. Geophys. Res.*, *108*, E4 10.1029/2002JE001867 [3] Berthelier J.J et al. (2005), *Geophys. Res. Let.*, 32, L22305, 10.1029/2005GL024203 [4] Le Gall A. (2005) Workshop on Radar Investigations of Planetary and Terrestrial Environnement, February 7-10, Houston [5] Clifford S.et al. (2006), *LPSC XXXVII,* #2442. [6] Dinwiddie C. et al. (2006), *LPSC XXXVII* #2335