BROADBAND GROUND PENETRATING RADAR WITH CONFORMAL ANTENNAS FOR SUBSURFACE IMAGE FROM A ROVER. D. E. Stillman[1], C. Oden[2], R. E. Grimm[1], and B. Pyke[2], [1]Dept. of Space Studies, Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80302 (dstillman@boulder.swri.edu), [2]Earth Science Systems, Wheat Ridge, CO.

Introduction: Ground-Penetrating Radar (GPR) provides geologic context via subsurface imaging and will be flown on the next two Mars rovers (WISDOM [1] on ExoMars and RIMFAX [2] on Mars 2020). The ExoMars antennas cannot be easily attached to an MSL class rover because the front of the rover is used for the arm and the rear is used for the RTG. RIMFAX had to change the location of its antenna post selection because their proposed location was not approved by the rover engineers. In fact, these engineers suggested moving the antenna to the belly of the rover, but RIMFAX decided against this. The motivation of this research is to design a broadband radar antenna that conforms to the rover belly, while maximizing the scientific capabilities of the GPR. Therefore, we have designed our antennas to be as thin as possible so that rover mobility is not compromised. Furthermore, we aim to design a GPR with: (1) high bandwidth – which controls the resolution and allows certain mineralogies and rock units to be discriminated based on their frequency-dependent EM or scattering properties, (2) high antenna efficiency at low frequency – which controls the depth of penetration, and (3) high dynamic range – which also controls the depth of penetration and allows the detection of interfaces with small changes.

Antenna Design / Polarization: We have designed and field-tested a prototype GPR that utilizes bistatic circularly polarized spiral antennas (**Fig. 1**). This antenna type was chosen because they have an inherent broadband response and provide a better low frequency response compared with similarly sized linearly polarized antennas. The resulting spiral antennas provide high gain (0 to 8 dBi) from 200 to 1000 MHz (**Fig. 2**).

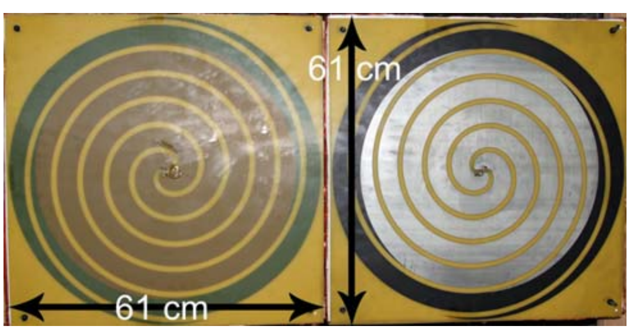

Figure 1. Spiral antennas sized to be mounted to the underbelly of a MSL-class rover and efficiently radiate energy down to 200 MHz.

Thickness: Antennas output energy both upward and downward. Upward energy reflects via the rover belly back downwards, thus interferes with subsurface reflected energy. To minimize this we use 1) an antenna with a high metallization ratio so less energy can transmit through the antenna and into the subsurface, and 2) space qualified attenuative foam to attenuate energy above the antenna.

Our antenna testing shows that a backplane decreases antenna gain at low frequency and slightly raises gain at high frequency. As the thickness of attenuative foam increases low frequency gain was recovered. Overall, we found a 4.6 cm total antenna and foam thickness produced reasonable results of antenna gain.

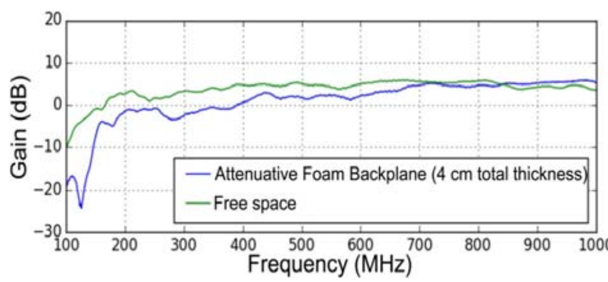

Figure 2. 4 cm of attenuative foam produces good bandwidth from 200 – 1000 MHz.

Field Test: The antennas are mounted on the platform shown below to simulate emplacement on an MSL-class rover (**Fig. 3**). The field test was performed to test the antennas, thus we used commercial impulse GPR electronics with a center frequency of 500 MHz and a dynamic range of ~150 dB. Field location is at Earth Science Systems GPR test pit near Bennett, CO where multiple pipes are buried in sand. Radargram from the field test shows the capability of detecting three metal pipes and the sand-clay interface at 3 to 3.7 m deep (**Fig. 4**).

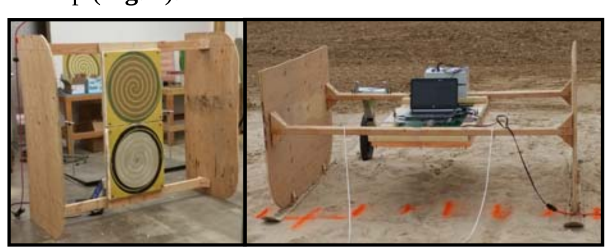

Figure 3. Field test of antennas.

Dynamic Range: There are three different techniques to operate a GPR: (1) Impulse – where a broadband pulse is quickly transmitted and then the reflected energy is measured as a function of time, (2) Continuous Wave (CW) – where the transmitter sweeps through a number of frequencies and both the transmitter and receiver are always on, and (3) Gated CW – where the transmitter emits a single frequency or chirp and then turns off, and the receiver is always turned on. For the single frequency mode, the process is repeated with a different frequency until the entire bandwidth has been swept through.

We evaluated which GPR operational mode was able to obtain the highest dynamic range (DR: the ratio between the largest and smallest values of energy the GPR can measure). We also assumed that range gain (where received energy is amplified with time before being digitized) was used when the transmitter was off. DR is important because it allows us to image smaller reflection caused by changes in electrical or magnetic properties and it allows deeper penetration as signals are attenuated as they propagate.

We chose to use a Gated CW operational mode because it produces the largest DR (**Table 1**). This occurs because Gated CW is able to emit for energy into the ground longer than the impulse operation and receives energy at depth when the transmitter being off, thus allowing range gain. A broadband gated CW radar has many of operational benefits. As the high frequencies will get absorbed faster than low frequencies, therefore the radar could be programmed to measure at high frequencies for a longer period to increase resolution. Similarly, the radar can measure at lower frequencies for a longer period to increase depth of penetration. Thus, we are building in flexibility to perform high resolution shallow imaging and deep imaging.

Summary: We are building a GPR that maximizes depth of penetration and resolution with conformal antennas that efficiently radiate energy from 200 – 1000 MHz with a system high dynamic range (~180 dB). We have built and field-tested our bistatic circularly polarized spiral antennas that could be mounted to the underbelly of a MSL-class rover. We are currently testing the electronics so that we can operate the radar in a gated CW mode to maximized dynamic range.

Table 1. Comparison of the dynamic range (DR) of three operational modes. Note an increase in the T_{trace} by a factor of 10 also increases the DR by 10.

Radar type	Power	Duty Cycle	DR (T_{trace} = 0.1 s)
Impulse + range gain	1 W*	0.1%	158 dB
CW	4 mW**	100%	164 dB
Gated CW + range gain	1 W	10%	178 dB

* Higher power can be obtained but requires bigger pulse repetition rate, which lowers T_{trace} and causes a decrease in transmitted energy and DR.

** No value in increasing power because transmitter and receiver are always on.

This broadband radar system will allow for maximum versatility; thus allowing high resolution shallow mapping and deep mapping. Furthermore, the frequency range can be changed to increase the dynamic range at low frequency (i.e. to see deeper) or at high frequency (i.e. to increase resolution). Broadband surveys allow certain mineralogies and rock units to be discriminated based on their frequency-dependent EM or scattering properties. Overall, we estimate that this radar should provide penetration to tens of meters in martian regolith or hundreds of meters in ice-rich regolith.

References: [1] Ciarletti et al. (2011) *Proc. IEEE*, *99*, 824-836. [2] Hamran et al., (2014) *2nd Intern. Workshop on Instrum. for Planet. Missions*, 1034.

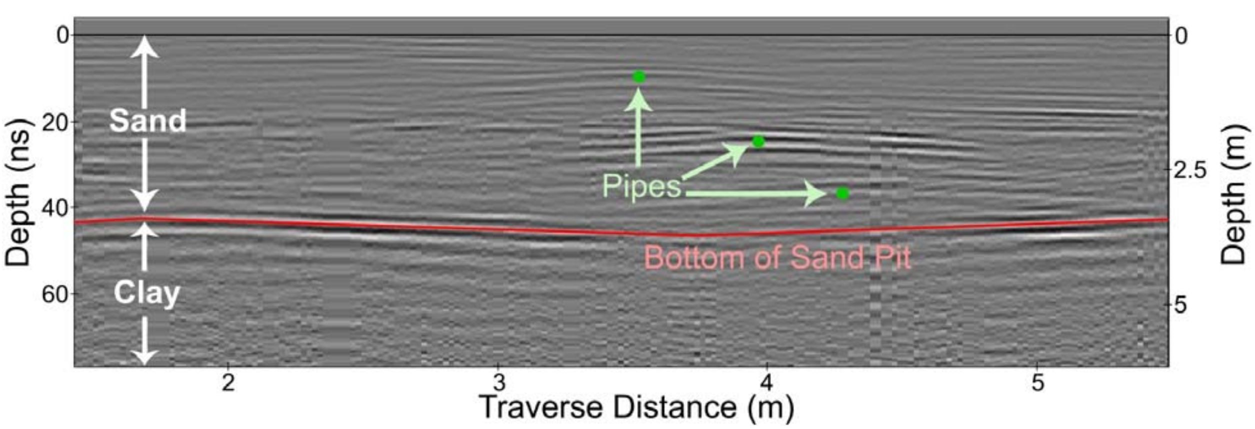

Figure 4. Radargram showing detectability of three pipes and the bottom of the sand pit.