RF Characterization of The Mars Exploration Rover Radar Altimeter Antennas-Airbag Interaction[1,2]

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Abstract—This paper presents the experimental results of the Mars Exploration Rover-03 (MER) radar altimeter antennas-airbag interaction. The objective of this work is to determine the impact of the MER airbag on the radiation properties of the radar altimeter antennas, and how transparent the airbag is to the RF signal, in order to ultimately assess any impacts or risks to the radar altimeter system performance. Because the radar altimeter antennas are close (near-field region) to the airbag when it is inflated, we have considered several configurations to characterize the antennas' performance. These characterizations should allow us to determine the proper link budget for the radar altimeter in terms of signal lock during MER descent to the Martian surface.

It is shown that the mutual coupling between radar altimeter' antennas may be affected when the airbag is on top or in the close proximity to the antennas, 0 to 15.24 cm, and the radar may not function properly for certain orientations and positions within this region. It is demonstrated that as the airbag is withdrawn away from the antennas (toward the far-field region of the antennas), the antenna's performance will be decoupled from the airbag. In addition, it is shown that the airbag in the close proximity of the antennas, 0 to 6.35 cm, may degrade the antenna radiation patterns. This degradation appears as a ripple in the amplitude patterns.

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1. INTRODUCTION

The Mars Exploration Rover airbag, when inflated during descent to the Martian surface, may assume different configurations in the proximity of the radar altimeter antennas. With respect to these configurations, the airbag is in the near-field region of the antennas. Hence, the antenna does not uniformly illuminate the airbag (see Figure 1).

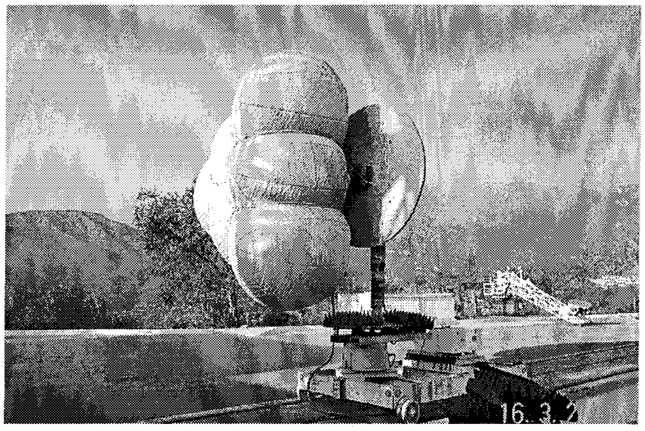

Figure 1. MER airbag (partially covering the radar altimeter antennas) mounted in position for far-field antenna pattern measurement at JPL Mesa antenna range. (The airbag is used to protect the Mars lander, enclosing the rover, during impact and bounce on Martian surface).

That is, the amplitude and phase of the radiated signal are not the same at every point on the airbag side of the antenna. A small displacement of the airbag from the antenna can result in different amplitude and phase illumination of the airbag. Consequently, a signal radiated through the airbag undergoes multiple reflections and may be degraded, depending on how the signals add up in or out of phase for a given airbag material type. This degradation appears as a ripple in the amplitude radiation patterns.

The airbag in close proximity to the antenna (near-field region) appears as load impedance to the antenna. For a given airbag type, the antenna input impedance (including real and imaginary parts) varies depending on the distance between it and the airbag. In other words, the airbag presents an impedance mismatch to the antenna at its design frequency, and the total power reflected back toward the antenna depends on the level of this mismatch. Similarly, the mutual coupling, or total power coupled between the radar altimeter antennas, depends on the load impedance and may vary accordingly. This effect may be quantified by

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considering the antenna radiates in an equivalent medium with dielectric constant greater than the free space value. As a consequence, the antenna resonant frequency is shifted downwards. As the airbag is withdrawn away from the antenna, the dielectric constant moves towards the free space value, and the antenna input impedance is decoupled from the airbag.

Each MER radar altimeter uses two linearly polarized microstrip antennas. One antenna is used to transmit and the other is used to receive signals. The antennas are located about 26 cm apart on a finite size ground plane as shown in Figure 2. The 26 cm separation between the antennas is the flight configuration. The finite size ground plane has an effect on the antenna radiation patterns. This effect depends on the size of the ground plane, the location of the antenna with respect to the edges of the ground plane, and the antenna's polarization orientation with respect to the ground plane [1]. The latter factor has a specific impact on the diffracted fields from the edges of the ground plane [2], known as hard and soft diffraction effects. The amount of power coupled between transmit and receive antennas is through the power radiated from the transmit antenna. The total field radiated from the antenna is due to both the direct radiated field and the diffracted field from the edges of the antennas. For a given antenna configuration on a ground plane, the presence of a given airbag type in the proximity of the antennas may alter the diffracted fields among the other aforementioned factors. Hence the amount of energy coupled between transmit and receive antennas may be further affected. This level of this energy is critical to the proper operation of the radar.

For these reasons, our immediate consideration has been to devise measurement procedures to assess the impact of the airbag at different distances from the radar altimeter antennas, and to verify these assessments through theoretical modeling.

It should be noted here that two considerations were taken into account at the time the test plan was generated [3]: a) There was a possibility that the position of the airbags on the lander would be moved and, b) the possibility (still exists) that the number of abrasion layers on the airbag may change. Therefore, in order to assess the radar altimeter antennas-airbag interactions and provide data that could be used to assess potential changes from the Mars Path Finder, MPF, configuration, we have considered the followings in our measurements:

- Best- and worst case orientation of the inflated airbag with respect to the radar antenna location including:

    a) Lateral distance of the bag from the antenna, and
    b) Altitude of the airbag above the antenna

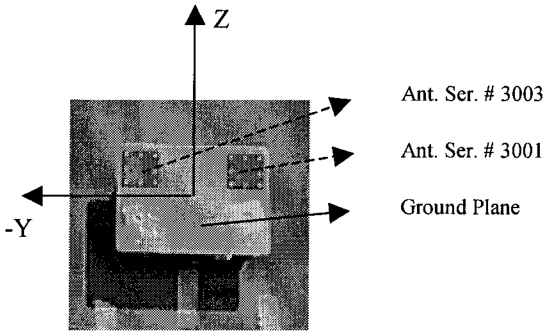

Figure 2. MER radar altimeter antennas (serial Nos. # 3001 and 3003) mounted on a flight like finite size ground plane (36.7 cm x 26.8 cm). The antenna is 1.5 cm away from the edge of the ground plane in the Z-direction, and 1.1 cm in the in the y-direction. The antenna polarization is along the Z-direction.

- Number of abrasion layers in the airbag; the baseline airbag has 4-layer. We also tested an airbag with 2-layer and compared its performance with 4-layer airbag.

The airbags used in the testing were as close to flight condition as possible, including nickel-coated lines for grounding, pyro lines, and carbon residue on the interior of the airbag from the inflation event. The major departures from flight conditions were:

- Inflation pressure, which slightly affects the shape of the airbags but not the results
- An air inside the bag instead of the inflation gas, we believe that this difference may not have an effect on the results.
- Lack of water/ice on the airbag due to inflation byproducts- a test of wet bags could be attempted, with proper safety procedures, if there was a reason to believe this would have a large effect on the results.

This paper is organized into two parts. The first details the impact of the airbag on the antennas' mutual coupling and return loss. The second details the impact of the airbags on the antenna radiation patterns and absolute gain.

2. *Mutual Coupling and Return Loss*

The test configuration utilizing the Network Analyzer to determine the mutual coupling and the input reflection coefficients of the radar altimeter antennas with and without the airbag is shown in Figure 3a and b respectively. The antennas (one transmit and one receive) are mounted on a ground plane as shown in Figure 1. Prior to testing with the airbag, the Network Analyzer is calibrated over the frequency band 4.2 to 4.4 GHz in order to establish a baseline.

A. *MER Airbag on Top of Radar Altimeter Antenna*

The polarization orientation of the radar altimeter antennas with respect to the ground plane was chosen to obtain optimum performance in terms of mutual coupling between the antennas and return loss [2]-[3]. Figures 4 and 5 show the antennas' return loss measurements (S11 and S22), without the airbag, over the frequency band 4.2 to 4.4 GHz. The mutual coupling between transmit and receive antennas, S21, and vice versa, S12, taken on 2/20/01 were measured without the presence of the airbag, and the results are depicted in Figures 6 and 7. The return loss for both antennas was found to be below –20 dB at the antenna design frequency of 4.3 GHz (the resonant frequency), and the mutual coupling between the antennas was found to be below –70 dB over the frequency band 4.2 to 4.4 GHz. Both values meet MER requirements for the radar altimeter subsystem, RAS. *These requirements are –70 dB or lower for the antennas mutual coupling, and –11 dB or lower for the antennas return loss.*

The airbag was inflated and placed on top of the antennas (touching the antennas) as shown in Figure 3b. Both the mutual coupling and the return loss were measured and compared to the results without the airbag as depicted in Figures 4, 5, 6, and 7.

The return loss results show a shift of approximately 40 MHz in the antenna design frequency. The mutual coupling between the antennas was found to be below -70 dB over ±20 MHz from the design frequency, and gradually increased to about –58 dB at ±60 MHz from the design frequency. The latter doesn't meet the MER requirement.

B. *Measurement Repeatability*

The Network Analyzer was recalibrated on 2/21/01, after which the above experiment was repeated. The return loss data without the airbag taken on 2/21/01 *agree very well* with the data taken on 2/20/01. Similar observations can be made on the antennas' mutual coupling data taken without the airbag present. These data are given in [1] (see Figures 8, 9, 10 and 11 in [1]).

Measurement repeatability of the data taken with the airbag on top of the antennas is also given in [1]. The airbag was repositioned and inflated for each test, and slight changes in the bag position with respect to the antenna were apparent in the data. These data shows how sensitive the antennas' return loss and mutual coupling to the orientation and location of the airbag with respect to the antenna.

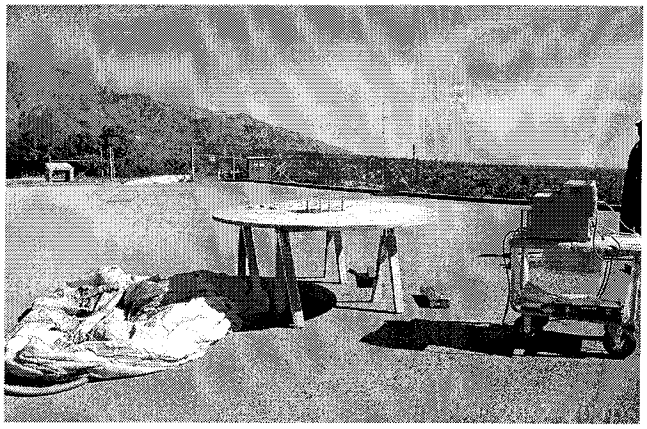

Figure 3a. MER radar altimeter antenna test configuration without the airbag, using the Network Analyzer to determine the antenna-(s) return loss and mutual coupling between the antennas.

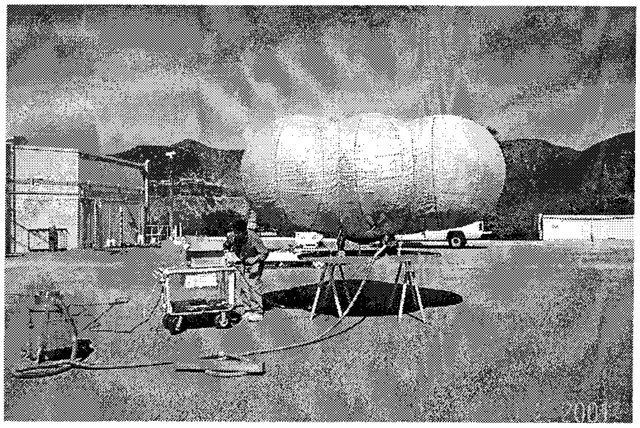

Figure 3b. Test configuration with airbag mounted on top of radar altimeter antennas to determine antennas' return loss and mutual coupling between them.

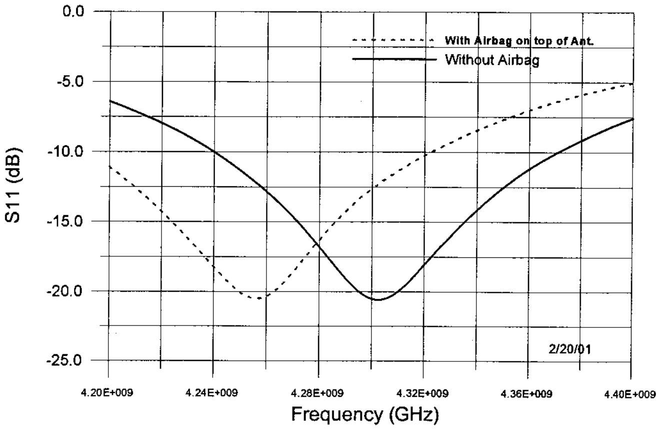

Figure 4. Transmit antenna return loss vs. frequency with and without the airbag on top of the antennas.

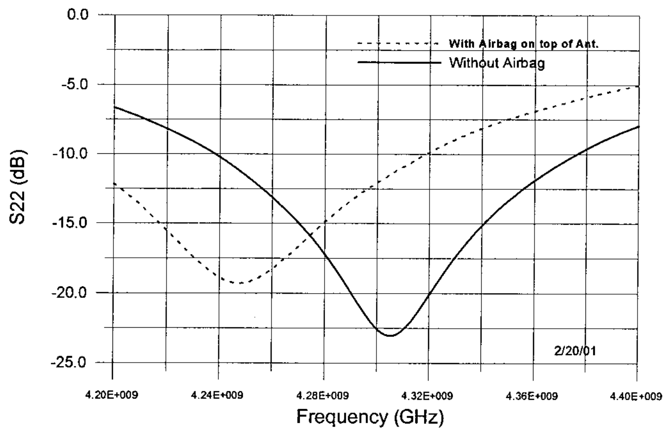

Figure 5. Receive antenna return loss vs. frequency with and without the airbag on top of the antennas.

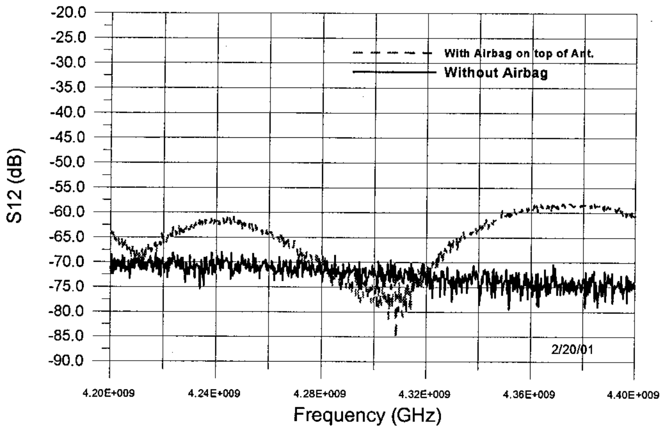

Figure 6. Mutual coupling between antennas (3003 to 3001) with and without the airbag on top of the antennas.

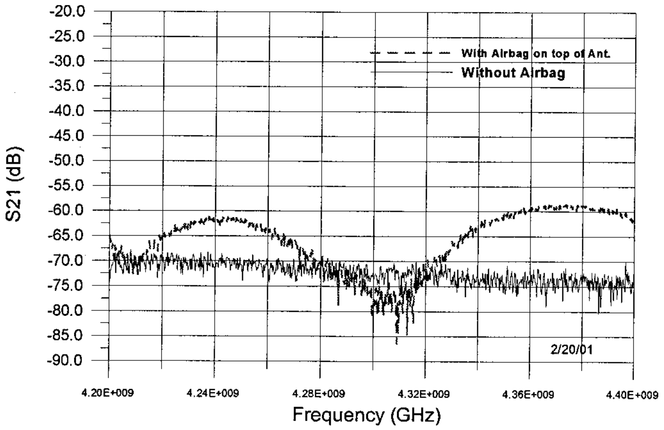

Figure 7. Mutual coupling between antennas (3001 to 3003) with and without the airbag on top of the antennas.

C. *MER Airbag at 0.89 cm from Radar Altimeter Antenna*

An experiment was conducted on 2/21/01 to assess the impact of the airbag located at 0.89 cm (0.35 in.), or 0.13λ, above the antennas. The impact on the antennas' return loss and mutual coupling when tested in that configuration is depicted in Figures 8, 9, 10, and 11. It is interesting to note that more power is coupled (–55 dB) between the antenna elements (transmit and receive) than in the case without the airbag present (–70 dB).

D. *MER Airbag at 11.43 cm from Radar Altimeter Antenna*

Another experiment was conducted with the airbag positioned at 11.43 cm (4.5 in.), or 1.63λ, above the antenna. We observed that the impact on the antenna return loss is minimized, as shown in Figures 16 and 17. However, the mutual coupling between the antennas, shown in Figures 18 and 19, is about –50 dB in the region near the design frequency. This impact violates the MER requirement for RAS of –70 dB.

We expect that, as the airbag is withdrawn toward the far-field region of the antennas, the antennas' performance will be decoupled from the airbag. These observations are verified in the following experiment conducted with the airbag partially covering the antennas.

E. *MER Airbag Partially Covering Radar Altimeter Antennas*

The airbag was positioned at an inclined angle, 40 degrees, with respect to the radar altimeter antennas. In this configuration, the transmit antenna is approximately 15.2 cm (6 in.) away from the airbag, while the receive antenna is approximately 30.5 cm (12 in.) away from the airbag. For this partially covered antenna-airbag configuration, the antennas' return loss performance data shown in Figures 8 and 9 agree well with the data taken without the airbag. As expected, the mutual coupling between the antenna elements is minimized and is closer to the case without the airbag as shown in Figures 10 and 11. However, this impact still violates the MER requirement for RAS.

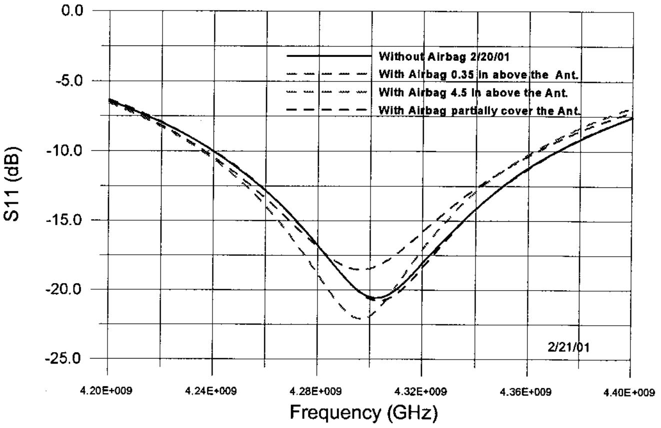

Figure 8. Comparison between the transmit antenna return loss data, S11, taken without the airbag and with the airbag located at 4.5 and 0.35 in. and partially cover the antenna.

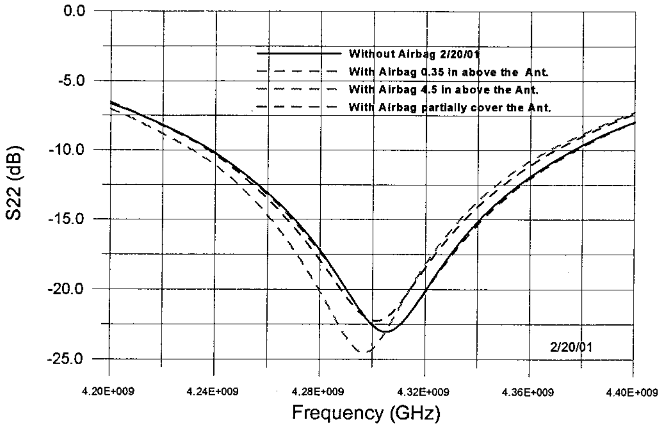

Figure 9. Comparison between the receive antenna return loss data, S22, taken without the airbag and with the airbag located at 4.5 and 0.35 in. and partially cover the antenna.

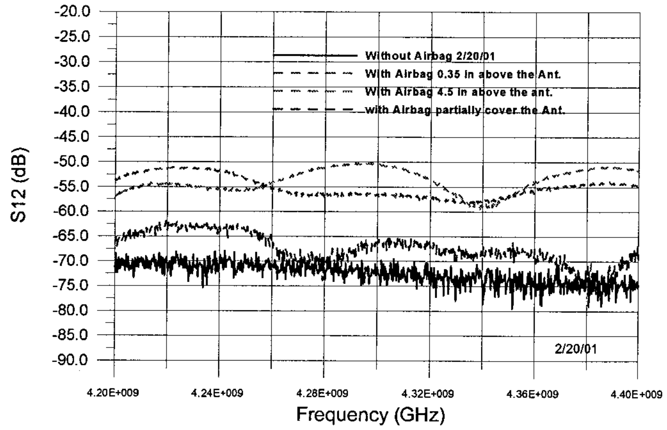

Figure 10. Comparison between the antennas'mutual coupling data, S12, taken without the airbag, with the airbag located at 4.5 and 0.35 in., and partially covering the antenna.

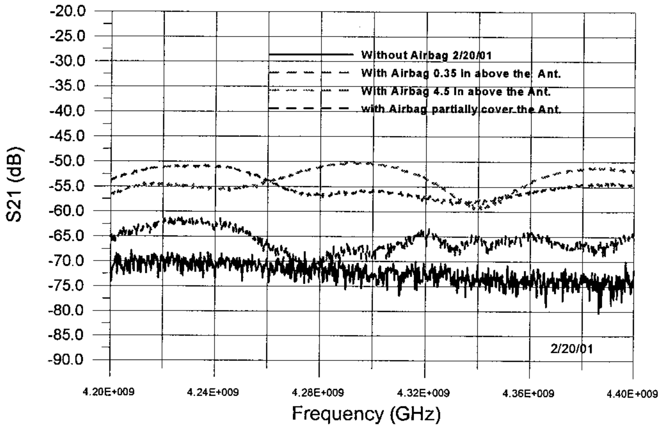

Figure 11. Comparison between the antennas' mutual coupling data, S21, taken without the airbag, with the airbag located at 4.5 and 0.35 in., and partially covering the antenna.

3. *Radar Altimeter Antennas Gain and Radiation Properties*

The purpose of this experiment is to determine the impact of the airbag on the antenna radiation patterns and gain. The experiment was performed at the JPL Mesa antenna far-field range. Prior to testing with the airbags, the antenna range was calibrated using a standard-gain horn. The principal radiation patterns and gains of the radar altimeter antennas, shown in Figure 2, were then measured in order to establish a baseline.

Figures 12, and 13 show the principal radiation patterns of both antenna elements (transmit and receive). The impact of the finite size ground plane on the antenna radiation performance can be seen clearly in Figure 12. Referring to Figure 12, the transmit antenna amplitude pattern drops slowly in the region of 60 to 90 degrees, since the antenna is closer to the edge of the ground plane in that angular region, while its amplitude pattern drops rapidly in the region of 300 to 270 degrees. Similar but opposite observations can be made on the receive antenna.

The radar antenna gains were measured and are shown in Table 1. The MER requirement for RAS on the antenna gain is 9 dB*i*.

Table 1. Antenna Gain Measurements With No Airbag Present

Antenna	Requirement	Ser. # 3001	Ser. # 3003	Uncertainty
Gain (3/14/01)	9.0 dB	11.24 dB	11.04 dB	± 0.1 dB
Gain (3/13/01)	9.0 dB	11.14 dB	10.94 dB	± 0.1 dB

A. *MER Airbag on Top of Altimeter Antennas*

The radar altimeter antenna was mounted on a wooden board as shown in Figure 1. The wooden board is used to support the airbag in front of the antenna. The antenna principal plane pattern cuts were first measured with the wooden board in place. These data are shown in [1] (Figures 32 and 33 in [1]). It is observed that multiple reflections from the surrounding buildings cause a very small ripple (less than ± 0.1 dB) in the amplitude patterns.

The airbag was then placed in front of the antennas (touching the antennas). Both principal plane cuts were measured and compared to the data taken without the presence of the airbag, as shown in Figures 14, and 15. It can be seen that the presence of the airbag in front of the antenna (touching the antenna) causes amplitude ripples in the antenna radiation patterns. These ripples are in part due to multiple-reflections that the radiated signal undergoes as it propagates through the airbag. A preliminary theoretical analysis supported these observations (see Figures 45, and 46 in [1]).

The antenna gain loss due to the presence of the airbag in front of the antennas is given in Table 2. The worst case is based on a slight movement of the airbag that causes a null (minimum peak of the ripple amplitude) to appear along the main beam axis.

Table 2. Antenna Gain Loss

Antenna Ser. # 3001	Without Airbag	With Airbag
Nominal	0 dB	0.98 dB
Worst Case	0 dB	2.12 dB

B. *MER Airbag at 6.35 cm (2.5 in.) from Radar Altimeter Antennas*

An experiment was conducted on 3/16/01 to assess the impact of the airbag located at 6.35 cm (2.5 in.), or 0.9λ, away from the antennas. The impact on the antenna radiation patterns when tested in this configuration is depicted in Figures 14, and 15. It is interesting to note that the depth of the ripple in the amplitude patterns is much smaller than in the case with the airbag touching the antennas.

C. *MER Airbag Partially Covering The Antennas*

The airbag was positioned at an incline angle partially covering the radar altimeter antennas as shown in Figure 1. In this configuration, the transmit radar antenna is approximately 20 cm away from the airbag. As expected, we observe that the impact of the airbag on the antenna patterns is less than the case of the airbag touching the antenna [1].

D. *Antenna Patterns Measurement Repeatability*

The measurement repeatability of the data taken with the airbag in front of the antennas (touching the antennas) on 3/16/01, is compared with those taken on 3/15/0. The data are fairly repeatable, particularly, in the angular region ± 30° from the peak of the beam [1]. This portion of the beam is expected to be used by MER radar altimeter.

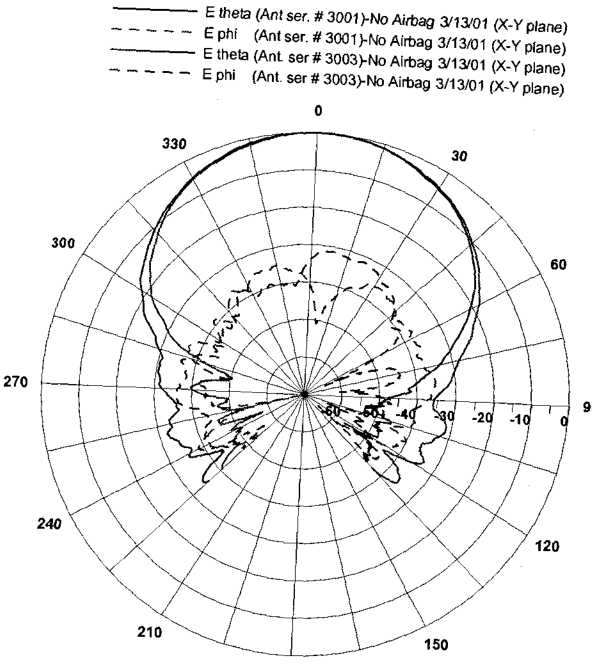

Figure 12. Transmit and receive antennas co-polarized, E theta, and cross-polarized, E phi, radiation patterns in X-Y plane.

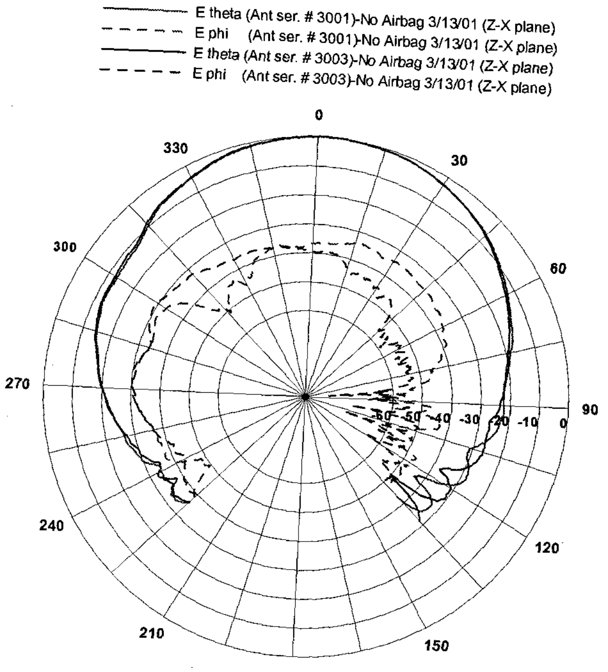

Figure 13. Transmit and receive antennas co-polarized, E theta, and cross-polarized, E phi, radiation patterns in Z-X plane.

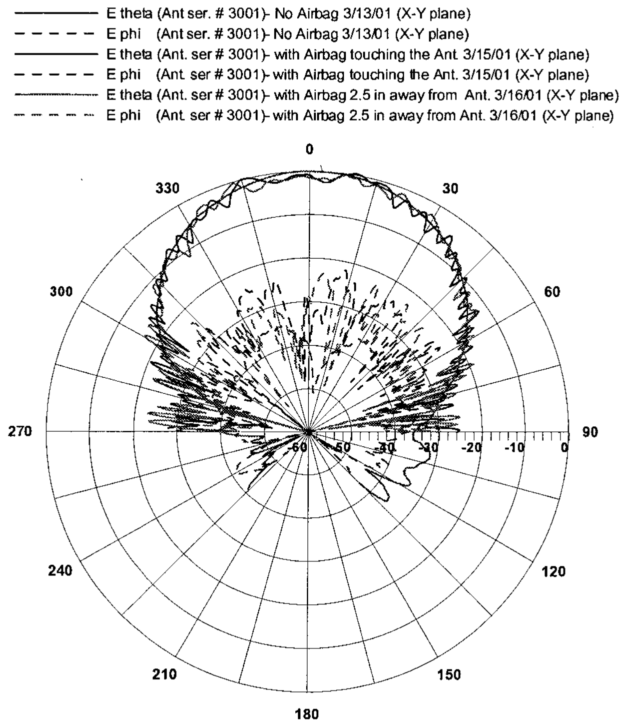

Figure 14. Comparison of transmit antenna co- polarized, E theta, and cross-polarized, E phi, radiation patterns data in X-Y plane without the airbag, with the airbag on top of the antenna, and with airbag at 2.5 in. away from the antenna.

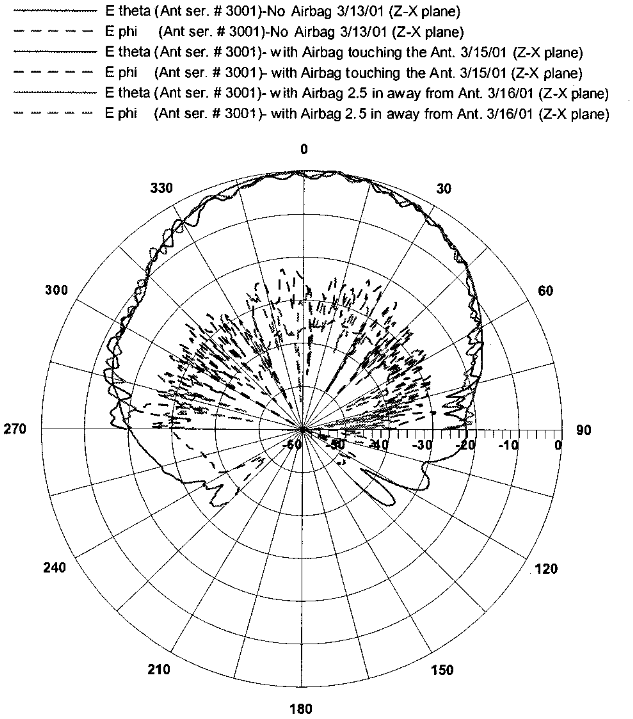

Figure 15. Comparison of transmit antenna co- polarized, E theta, and cross-polarized, E phi, radiation patterns data in Z-X plane without the airbag, with the airbag on top of the antenna, and with airbag at 2.5 in. away from the antenna.

G. *Four-Layer and Two-Layer Airbags*

The data presented so far are based on the use of a MER airbag made of four-layer Vectran material. This material has a dielectric constant of 3.3. We also tested a thinner, two-layer airbag, to determine its impact on the antenna radiation performance. We conducted an experiment on 3/19/01 with the airbag inflated and touching the antenna. The principal radiation patterns of this airbag when tested in this configuration are given in [1], and compared to those of the four-layer airbag. The two-layer material airbag appears to have less impact on the antenna pattern than the 4-layer material.

4. *Conclusion*

The impact of the Mars Exploration Rover airbag on the radiation properties of the radar altimeter antennas is presented. It is demonstrated that the radar antenna gain margin above the MER requirements for the RAS may compensate for the airbag's effect on the antenna patterns. It is shown that the mutual coupling between transmit and receive antennas may exceed the requirement of the MER, for the radar altimeter subsystem, RAS, when the airbag is in the close proximity of the antennas. However, and simply put that inflating the airbag earlier with respect to the Mars Pathfinder mission timeline for airbag inflate maybe a risk to the radar altimeter system performance. This is because the radar when it is switched to receive mode may lock on the coupled signal from the transmitter antenna due to the airbag rather than the reflected signal from Martian surface.

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