

# EFFICIENT WINDOW MOUNT UHF ANTENNAS

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***Abstract:*** In this paper we present the design, development and testing of a robust, efficient window mount UHF antenna that is low in profile and directs energy towards the window. The antenna is less than 3 inches in height, has a reflection coefficient better than -10 dB over the 400 – 450 MHz frequency band and a gain greater than 7 dBi over this frequency range. The antenna is based on a novel variation of a microstrip patch configuration, which provides both broad bandwidth and good front-to-back ratio. To provide the broad bandwidth without making the height of the antenna unwieldy we incorporate a parasitic proximity coupled feeding technique. To ensure good front-to-back ratio we utilize a cavity-backed solution and also electromagnetic absorbing material. The absorbing material is strategically located in order to minimize its impact on the overall efficiency of the antenna. In this paper we present the design procedure undertaken to develop the antenna, as well as the techniques to make the radiator robust. We also present the theoretical and experimental results for the new window mount antenna.

## 1 Introduction

Combat Identification (CID), the ability to differentiate friend or foe with high confidence, is a serious and challenging problem for military forces [1]. The development of a CID system that can be quickly deployed is of great value by increasing the survivability of soldiers and improving situational awareness of troops. An airborne CID interrogator system that can be deployed without modification of aircraft would allow faster and more cost-effective deployment of CID systems. The development of a window mounted CID antenna would facilitate the quick deployment of CID systems in multiple airframes. Being able to install the antenna behind a window, without hanging an antenna outside of the fuselage, would eliminate the flight testing and safety of flight analysis required for all the variants of aircraft that may deploy this system. Allowing the CID interrogator and antenna to simply be installed on the interior of the aircraft, would allow the identification and position of friendly forces to be easily accomplished given a variety of available aircraft assets.

In this paper we summarize the design procedure for an efficient, low profile UHF antenna that can be mounted to the inside of the window of an aircraft. We also present

the physical design of the antenna and the measured response of the antenna in a ‘realistic’ environment. The paper is organized as follows. Section 2 gives an overview of the concept of the low profile UHF antenna highlighting the design philosophy behind its creation. In Section 3 we give an overview of the physical design of the antenna and how we developed the prototype. In Section 4 we present the measured responses of the antenna including its radiation performance and reflection coefficient response. In Section 5 we investigate how backward directed radiation can be reduced and also the performance of the UHF antenna in a realistic environment. Finally we summarize our findings in Section 6.

## 2 Window Mount Antenna Design

The requirements for the window mounted UHF antenna are summarized in Table I [3]. As can be seen from these specifications, it is important that the majority of the radiation is directed away from the inside of the aircraft for safety reasons.

**Table I** Window Mounted UHF Antenna Requirements [3]

<b>Operating Frequency Band</b>	400 - 450 MHz
<b>Antenna Pattern</b>	Azimuth Beam: 60° (Threshold), 90° (Objective) Elevation Beam: 60° (Threshold), 90° (Objective)
<b>Antenna Gain – Minimum</b>	6 dBi
<b>Polarization</b>	Linear Vertical or Circular
<b>Power Handling - Minimum</b>	100 Watts
<b>Input Impedance</b>	50 Ohms
<b>Installation/Removal Time</b>	< 20 minutes
<b>Safety</b>	99% of energy to be radiated in front of antenna
<b>Environmental</b>	King Air or C23 Aircraft
<b>Altitude</b>	9,000 ft
<b>Size</b>	Fit within window
<b>Weight</b>	As light as possible

In order to establish size constraints for the window mounted UHF antenna we investigated the two possible air platforms; the King Air Twin Turbo Prop and the C23 aircraft [4, 5]. To determine the maximum size that we can make the antenna assembly, we reviewed the overall dimensions of the aircraft [4, 5]. For the King Air Twin Turbo Prop, the windows are 15” in diameter [4]. The antenna will need to be mounted on the inner glass pane (~1.5 inches inward from the outer fuselage surface). The C23 aircraft has square windows with an estimated size of 14 inches by 20 inches [5]. To create a universal antenna, the overall dimensions need to be compliant with both aircraft.

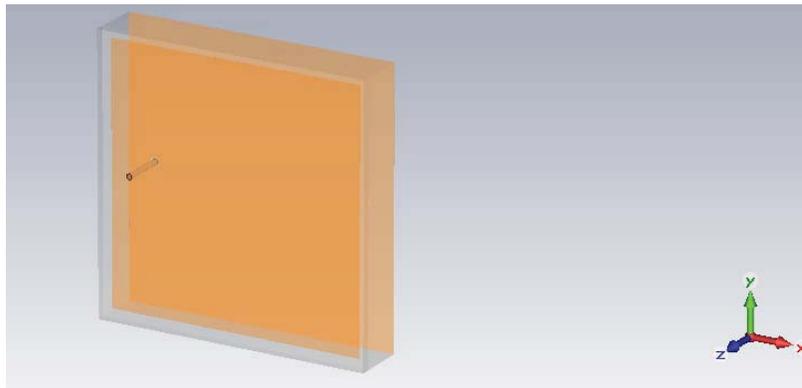
## 2.1 Generic Patch Based Solutions

### 2.1.1 Introduction

A patch-based solution for the window mount UHF radiator has several advantages over a dipole approach. Firstly, due to the ground-plane present in a patch antenna, it will inherently have better front-to-back ratio (FBR) allowing for safer operational environment. Also, it is very simple to control the polarization of a patch-based solution; if dual or circular polarization is subsequently required for future implementations of the system, modifications to the radiator are relatively easy to implement. There are however several drawbacks associated with incorporating a patch-based solution. For the proposed CID system, the antenna needed to operate over 400 – 450 MHz; which corresponds to a relative bandwidth of approximately 11 %. Achieving such a bandwidth with conventional microstrip patch technology requires the use of electrically thick materials and possibly a multi-radiator approach. Also, given that the size of the windows of the aircraft are not electrically large (at UHF frequencies), the ground-plane of the antenna will be relatively small and therefore we would expect the amount of power directed within the cabin to be higher than the requirement (a 20 dB FBR). In the following sub-section we highlight these challenges with a design example.

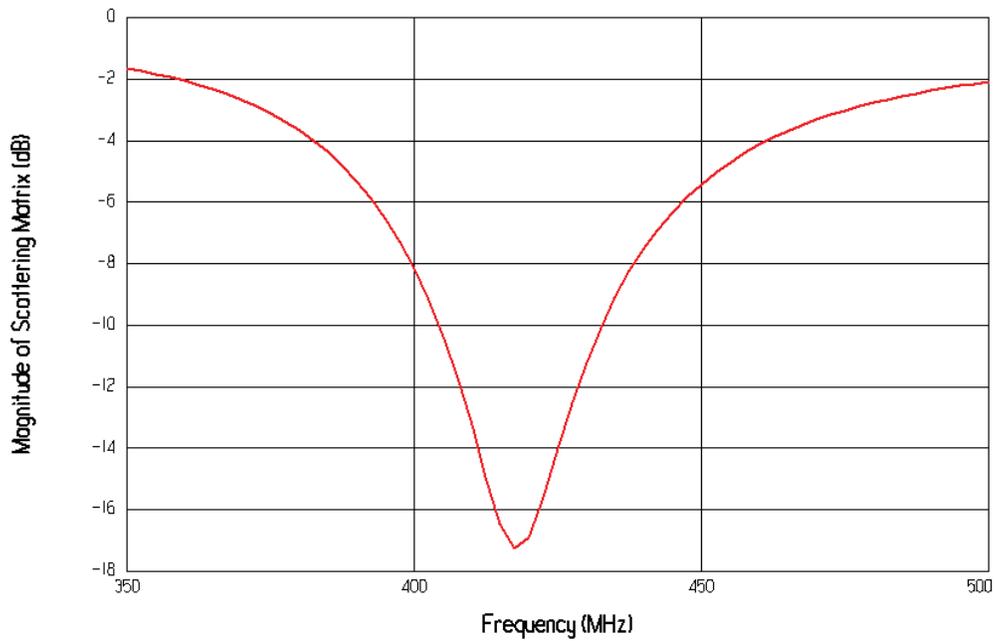
### 2.1.2 Conventional Probe-Fed Patch

Fig. 1 shows a schematic of a conventional probe-fed microstrip patch antenna designed for operation in the UHF band of frequencies with the overall size of the ground-plane constrained to fit approximately within a King Air C90 window. The substrate for the antenna is 2" foam.



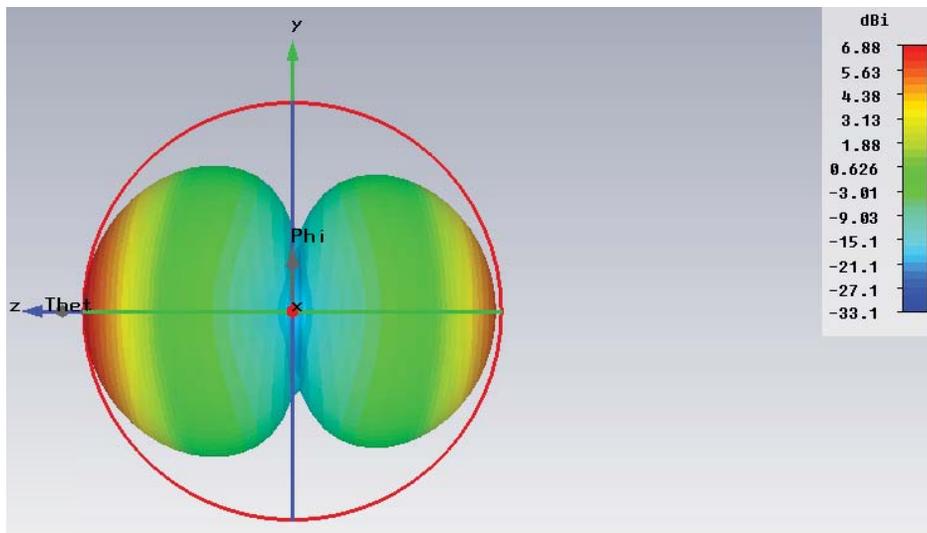
**Fig. 1** Schematic of a UHF conventional probe-fed microstrip patch

Fig. 2 shows the predicted reflection coefficient performance of the conventional probe-fed microstrip patch antenna. Even though it is matched within the 400 – 450 MHz frequency range, the antenna has difficulty meeting the bandwidth requirement. Increasing the thickness (closer to 4") and also using multiple radiators would need to be utilized to meet the bandwidth requirement.



**Fig. 2** Predicted reflection coefficient of the UHF conventional probe-fed microstrip patch

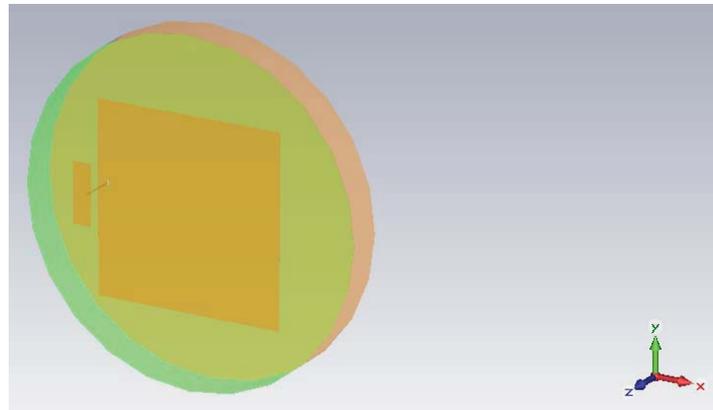
Fig. 3 shows the simulated radiation performance (including gain) of the conventional probe-fed microstrip patch antenna highlighting the FBR of the radiator. In this diagram the forward direction is the positive z axis. As we can see here, the FBR is less than 3 dB and this value is a direct consequence of the size of the ground-plane.



**Fig. 3** Predicted radiation performance of the UHF conventional probe-fed microstrip patch at 425 MHz

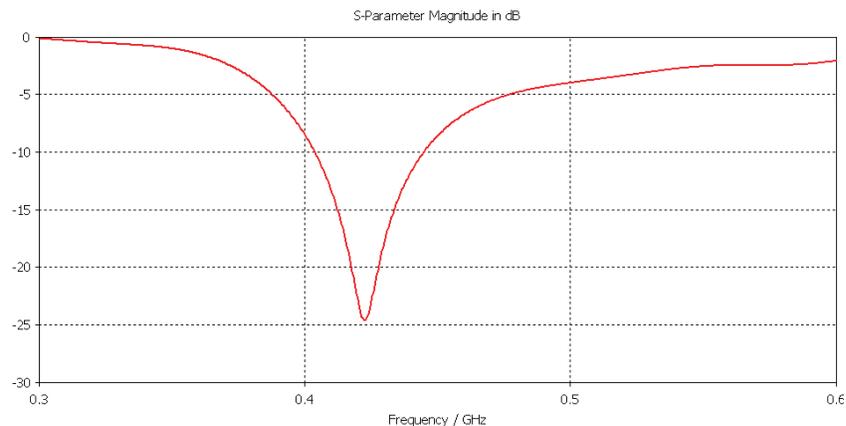
### 2.1.3 Low Profile Version

To overcome the first issue related to a conventional microstrip patch antenna, we investigated a new variation; a proximity coupled coplanar probe-fed patch antenna. Fig. 4 shows the configuration. Here we have moved the probe feed off the patch conductor to a smaller patch etched on the same layer as the large patch. The philosophy behind using this approach is simply to counter the inherent inductance of the probe feed through the introduction of a small capacitive gap close to the feed of the antenna [6].

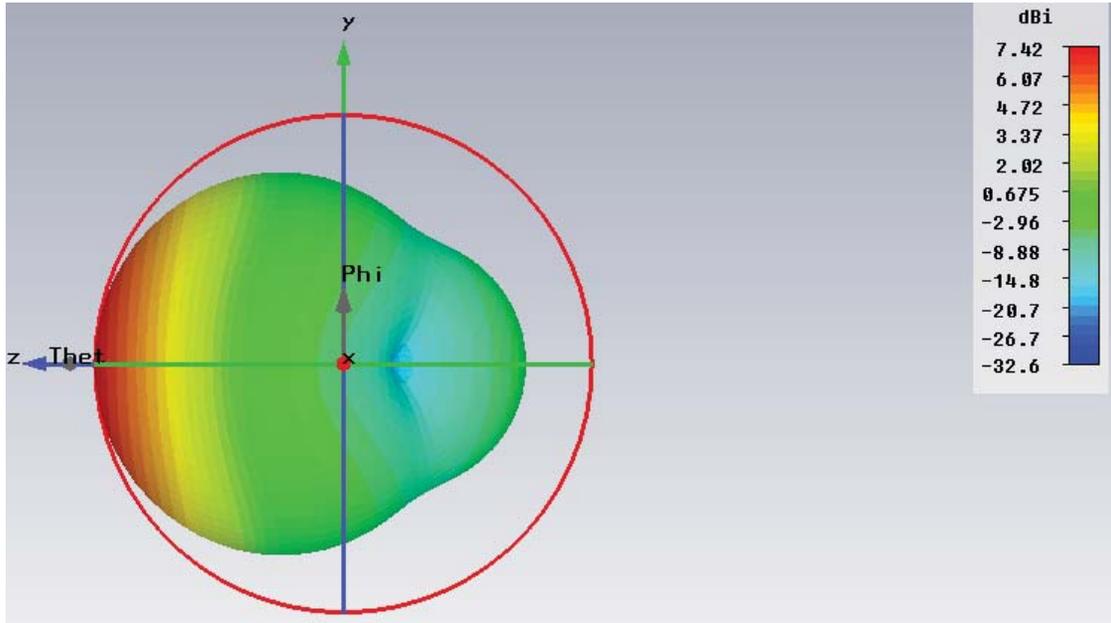


**Fig. 4** Schematic of a proximity coupled coplanar probe-fed microstrip patch for window mounting

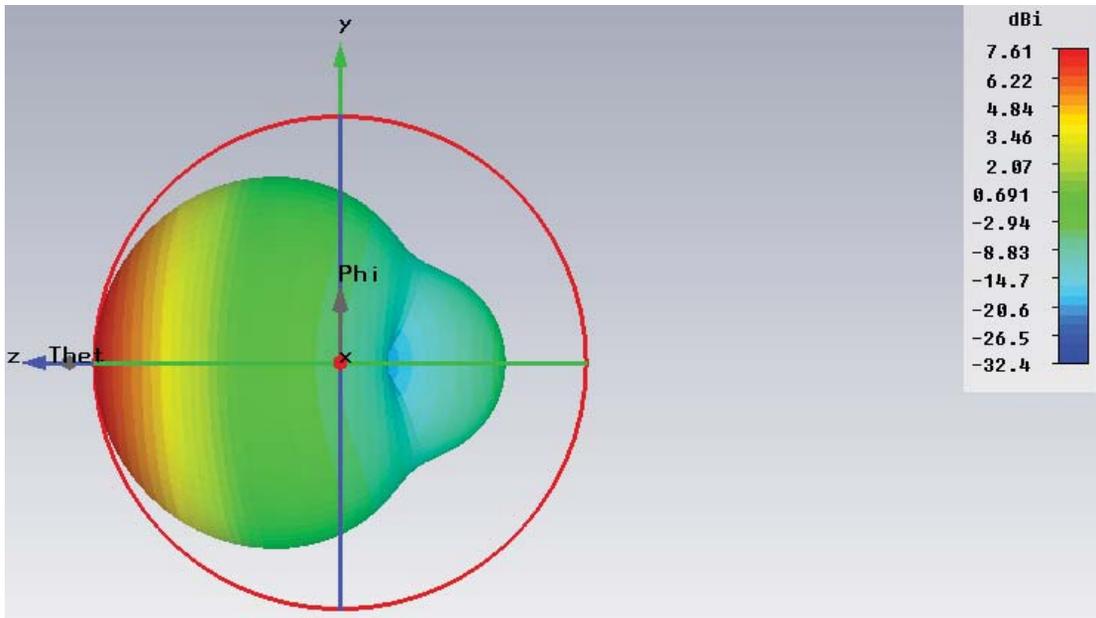
Fig. 5 shows the predicted reflection coefficient of a patch antenna whose overall size is consistent with the window of a King Air C90 aircraft. As can be seen from the plot, the antenna displays a good reflection coefficient over the required bandwidth. The radiation performance of the antenna at 400 MHz and 450 MHz is shown in Figs. 6 and 7. The FBR values at these frequencies are approximately 8 and 10 dB, respectively, which is not as bad as for the conventional UHF probe-fed patch antenna. This is because the actual patch conductor of the new configuration is slightly smaller.



**Fig. 5** Predicted reflection coefficient of a UHF proximity coupled coplanar probe-fed microstrip patch



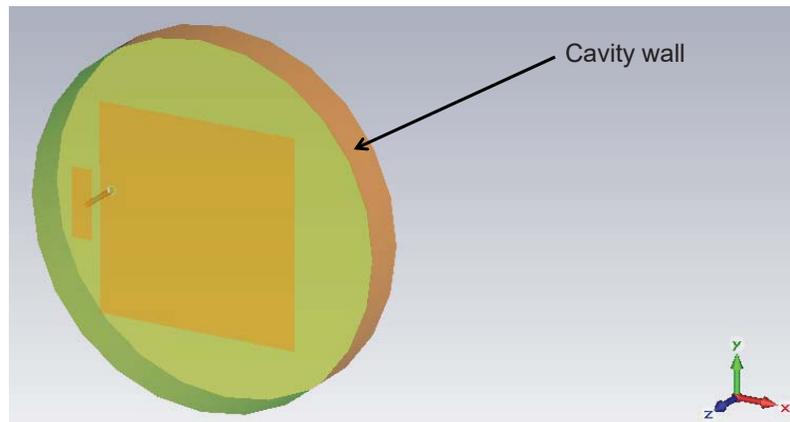
**Fig. 6** Predicted radiation performance of a proximity coupled coplanar probe-fed microstrip patch at 400 MHz



**Fig. 7** Predicted radiation performance of a proximity coupled coplanar probe-fed microstrip patch at 450 MHz

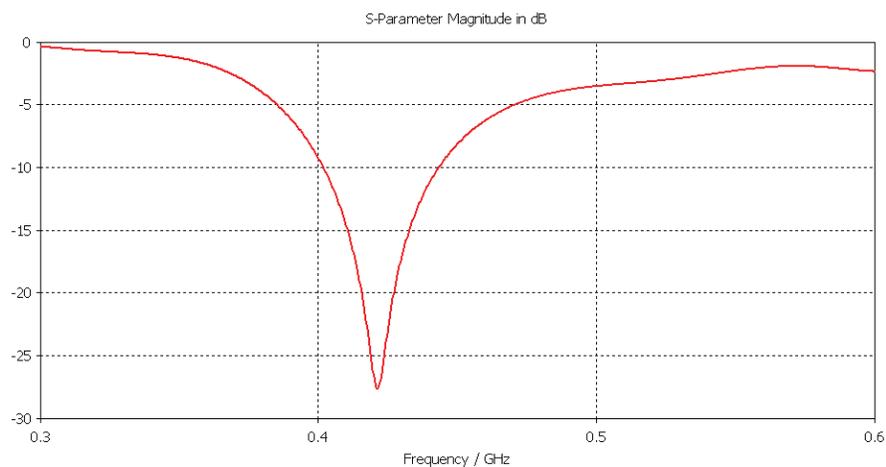
### 2.1.4 Cavity Backed Version

The technique we investigated to improve the FBR was to create a cavity backed solution, as shown in Fig. 8. Here we have incorporated a cylindrical side wall around the radiator. In reality, the environment in which the antenna is to be mounted is more compatible with a cavity backed solution, given the metallic nature of the fuselage of the aircraft.

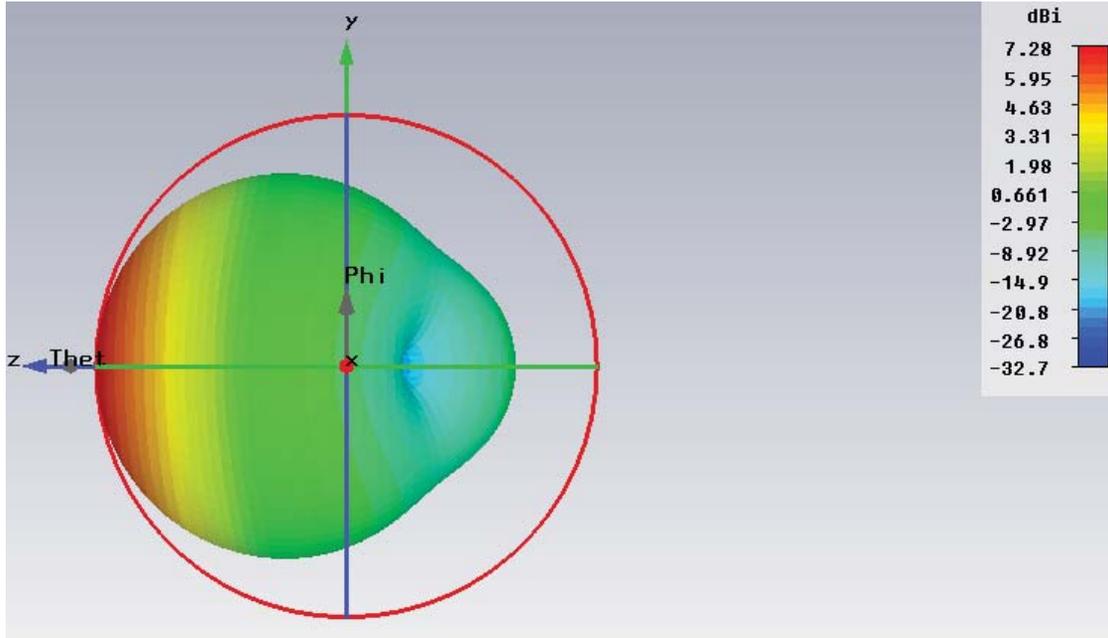


**Fig. 8** Schematic of a cavity backed proximity coupled coplanar probe-fed microstrip patch for window mounting

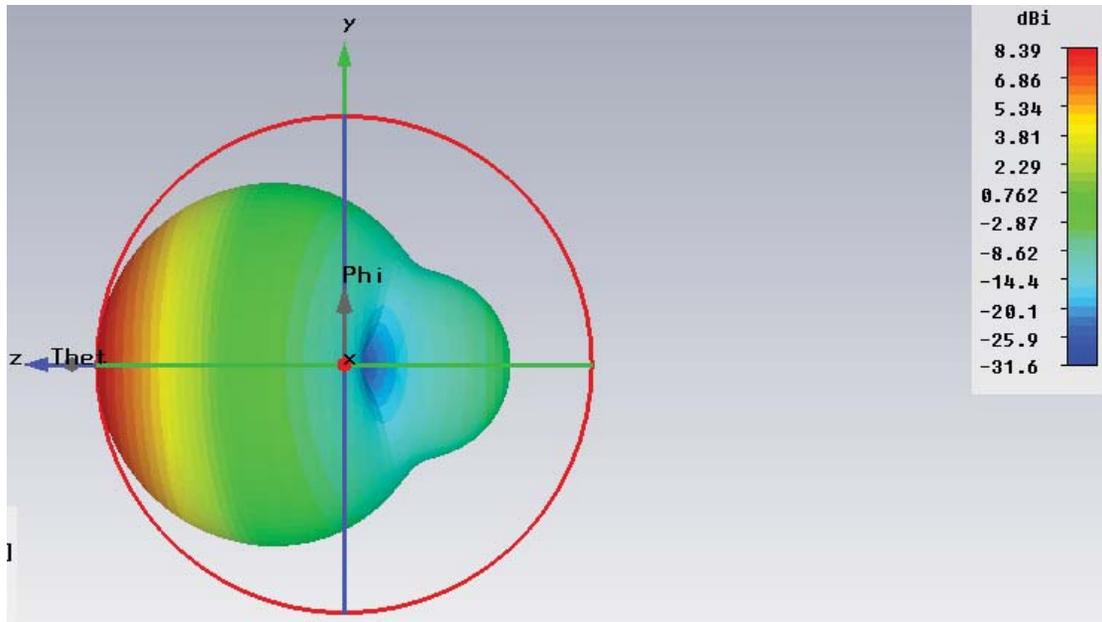
We modified the dimensions of the inherent UHF patch radiator to ensure efficient operation in the UHF band. Fig. 9 shows the predicted reflection coefficient performance of the antenna while the predicted radiation performance of the cavity backed version of the antenna at 400 MHz and 450 MHz is shown in Figs. 10 and 11, respectively. The use of the metallic enclosure has improved the FBR at these frequencies to 11 dB and 13 dB, respectively.



**Fig. 9** Predicted reflection coefficient of the cavity backed proximity coupled coplanar probe-fed microstrip patch



**Fig. 10** Predicted radiation performance of the cavity backed proximity coupled coplanar probe-fed microstrip patch at 400 MHz

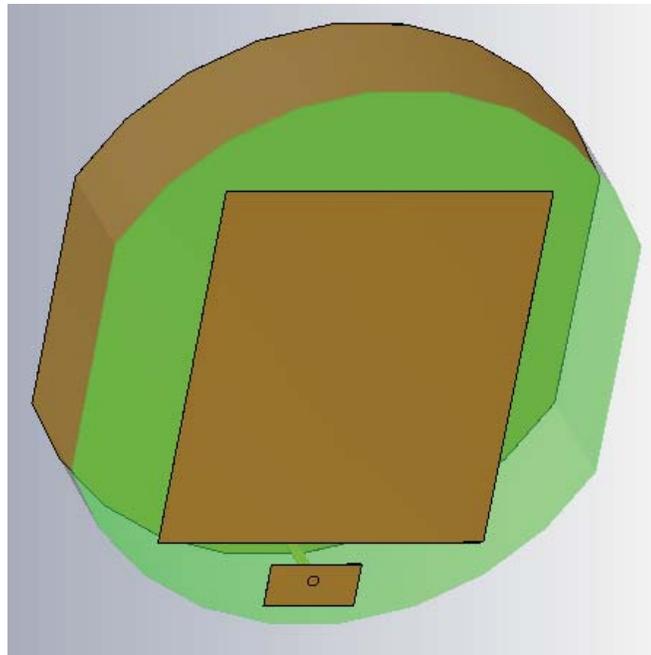


**Fig. 11** Predicted radiation performance of the cavity backed proximity coupled coplanar probe-fed microstrip patch at 450 MHz

## 2.2 Form-Fit Patch Based Solutions

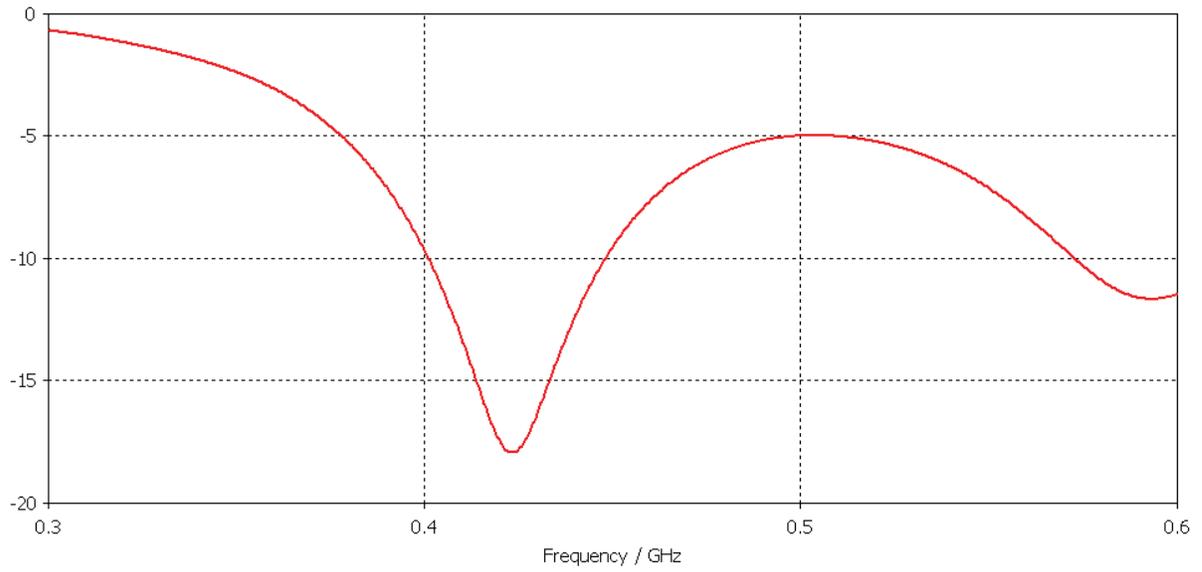
### 2.2.1 Proximity Coupled Coplanar Probe-Fed Patch Solution

Given that we have now constrained the size of the UHF window mount antenna to be compliant with both aircraft, we needed to modify the previous design such that it can fit within the space constraints. Fig. 12 shows a schematic of the new antenna. The radiator is based on our previously outlined approach; a coplanar coupled microstrip patch antenna. As stated before, using this approach enables us to minimize the height of the antenna while ensuring we can meet the bandwidth requirements (400 – 450 MHz). As can be seen from Fig. 12, the ground-plane of the radiator is shaped such that it can fit into either style of window and the patch radiator is rectangular in shape.

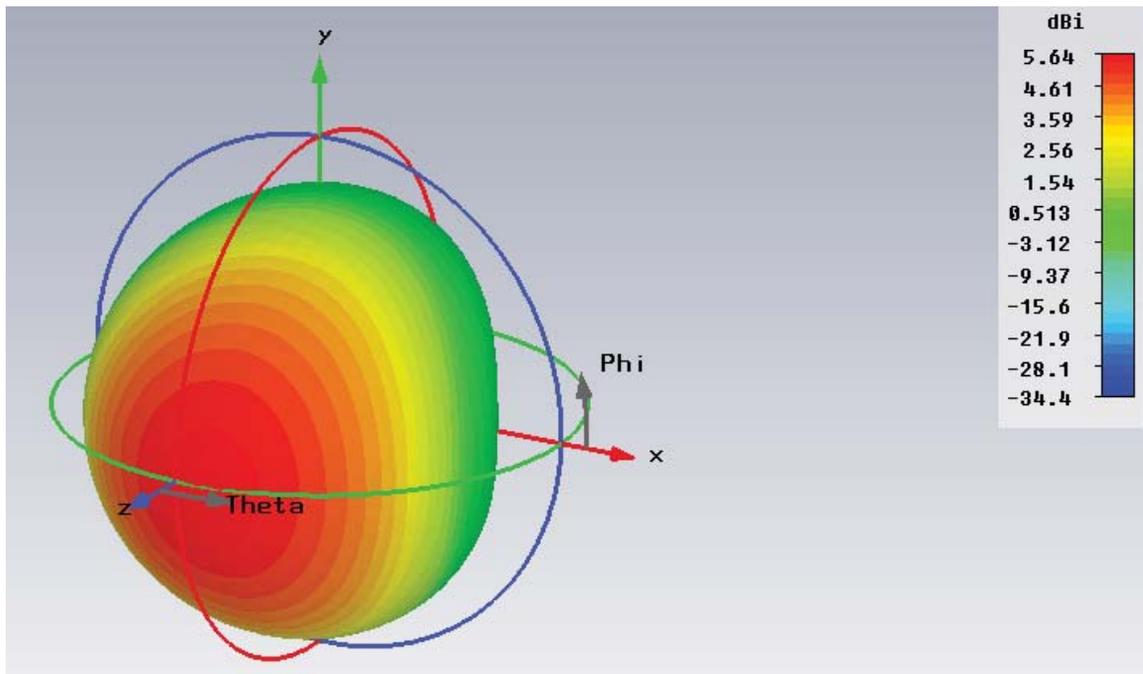


**Fig. 12** Schematic of the form-fit coplanar coupled patch antenna

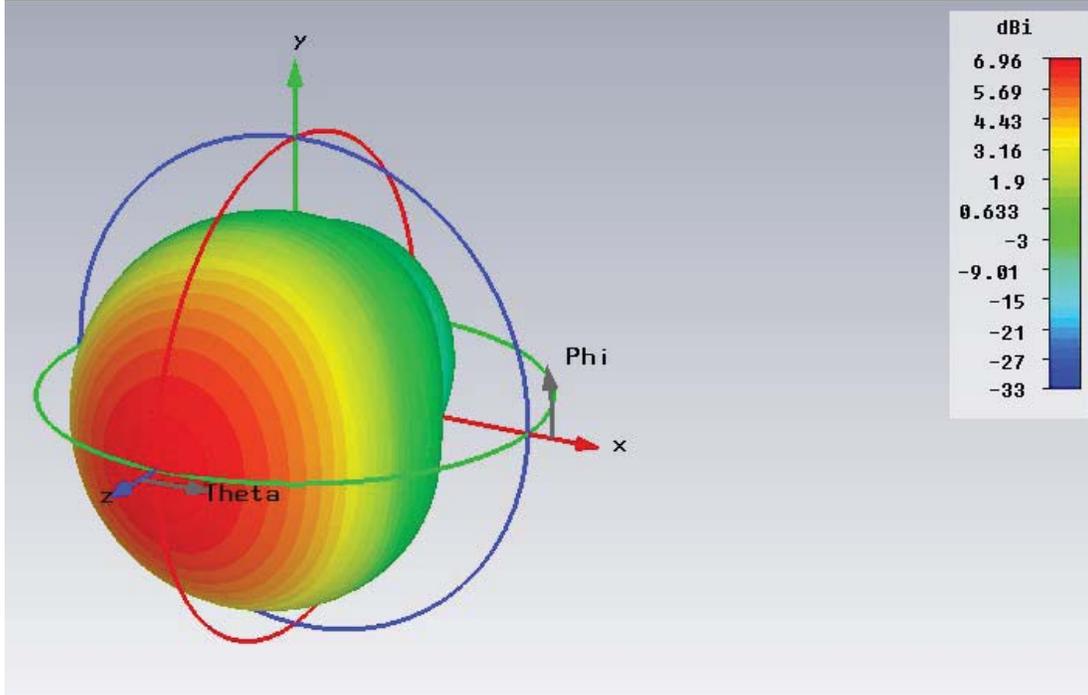
Fig. 13 shows the predicted reflection coefficient performance of the new coplanar coupled patch antenna and as can be seen from the plot, the antenna displays good return loss performance over the 400 – 450 MHz frequency band. It should be noted we have increased the height of the Rohacell™ substrate to approximately 2.6" due to the necessary reduction in cross-sectional area. Figs. 14 and 15 present the predicted radiation performance of the new antenna at 400 MHz and 450 MHz, respectively. As for the previously considered versions of this antenna, the new radiator displays high efficiency.



**Fig. 13** Predicted reflection coefficient of the form-fit coplanar coupled patch antenna



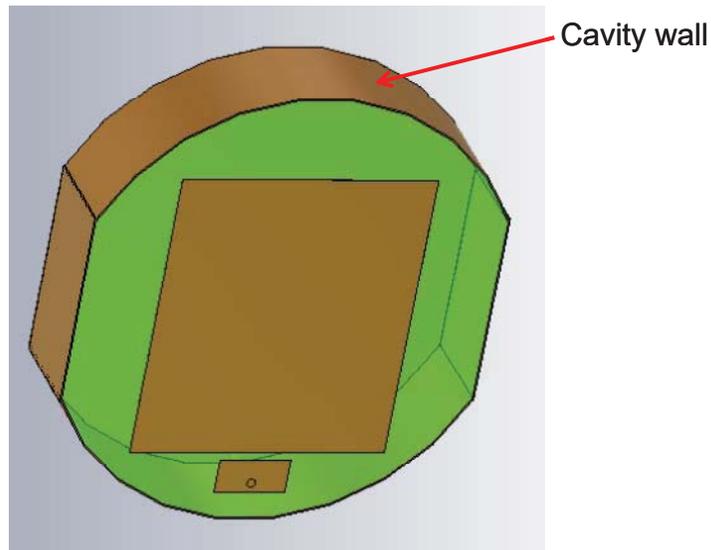
**Fig. 14** Predicted radiation performance of the form-fit coplanar coupled patch antenna at 400 MHz



**Fig. 15** Predicted radiation performance of the form-fit coplanar coupled patch antenna at 450 MHz

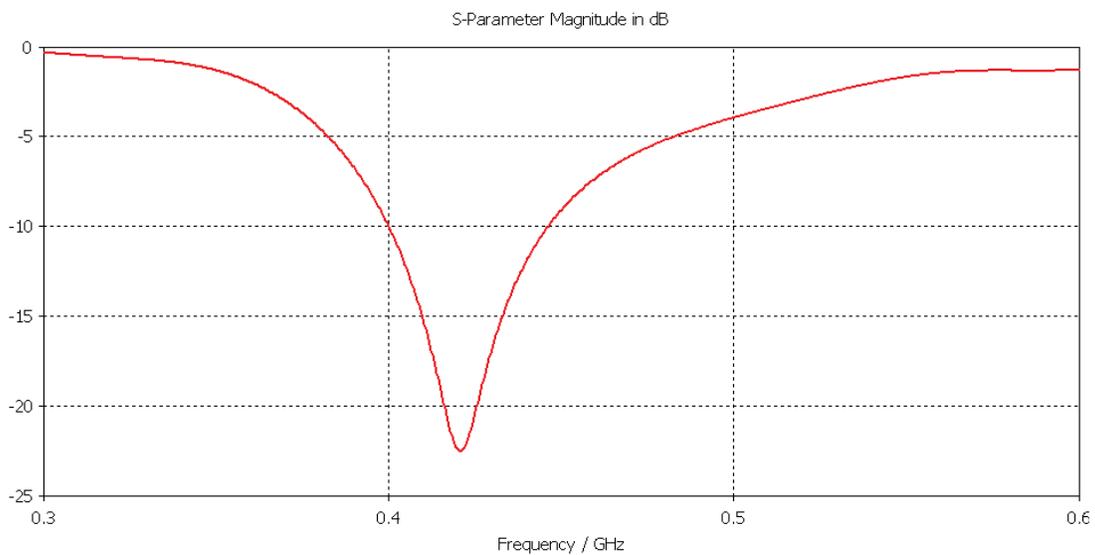
### 2.2.2 Cavity Backed Solution

The next step in the electromagnetic design phase was to make the UHF window mount radiator more independent of its surrounding environment, as well as reduce the backward directed radiation. As was highlighted before, a technique that can work well and features both of these properties is to create a cavity backed version of the antenna. Doing so should help reduce the backward directed radiation as well as enable the antenna to radiate efficiently despite the metal frame of the aircraft. Fig.16 shows a schematic of a cavity backed version of the coplanar coupled patch antenna. Here the metallic cavity walls extend down to the ground-plane of the antenna and are the same elongated cylindrical shape that was described previously.

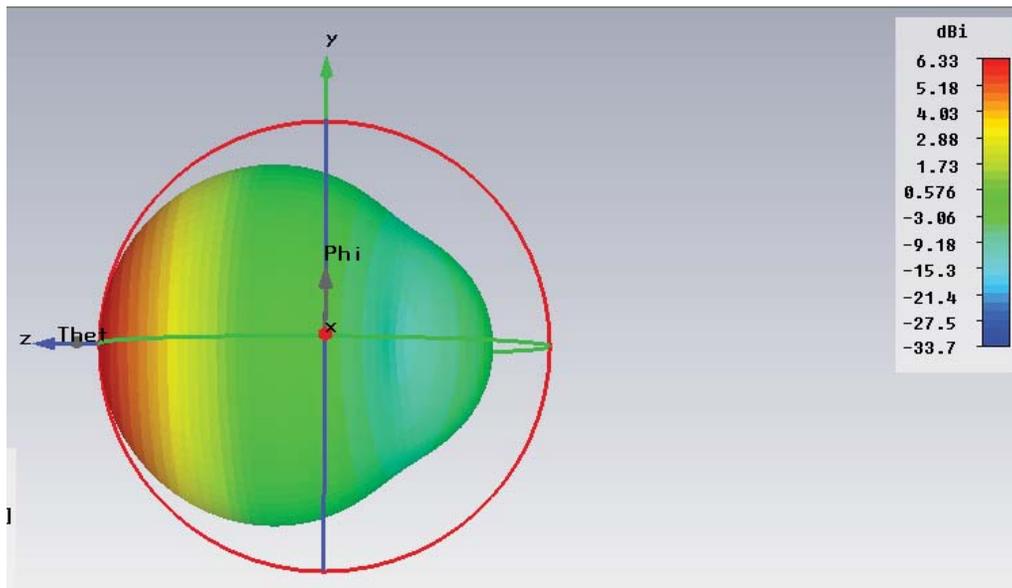


**Fig. 16** Schematic of the cavity backed version of the coplanar coupled patch antenna

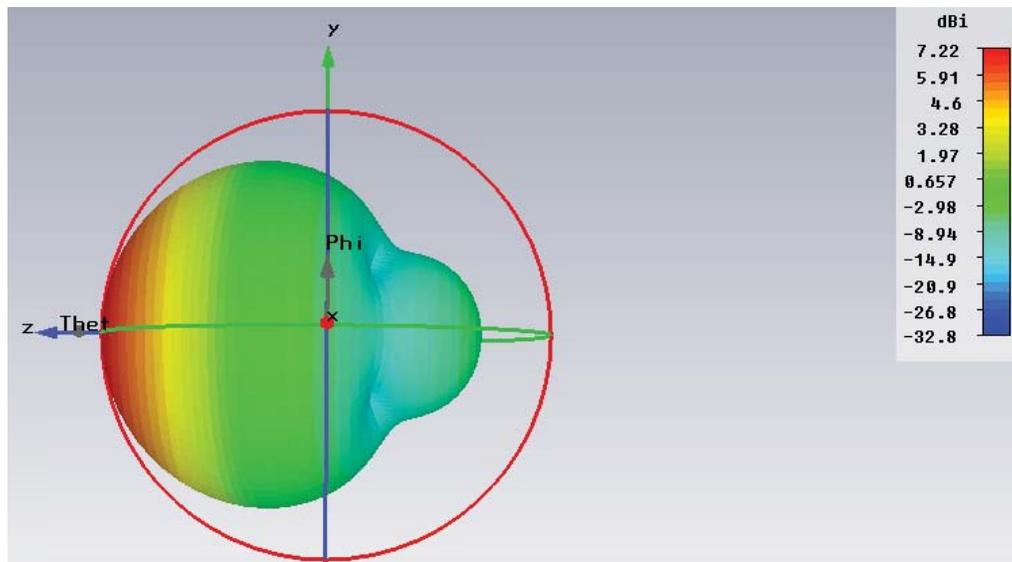
Fig. 17 shows the predicted reflection coefficient performance of a cavity backed version of the coplanar coupled patch antenna designed for the UHF band of frequencies. As can be seen from these results, the cavity backed antenna displayed good return loss over the 400 – 450 MHz frequency range. The predicted radiation performance of the antenna at 400 MHz and 450 MHz is shown in Figs 18 and 19. Here we show a side view of the radiation patterns (including gain) to highlight the front-to-back ratio performance of the antenna. Despite the small size of the antenna, the FBR was better than 10 dB. This radiator appeared to be a good choice for the fundamental radiator for the window mount CID system.



**Fig. 17** Predicted reflection coefficient of the cavity backed coplanar coupled patch antenna



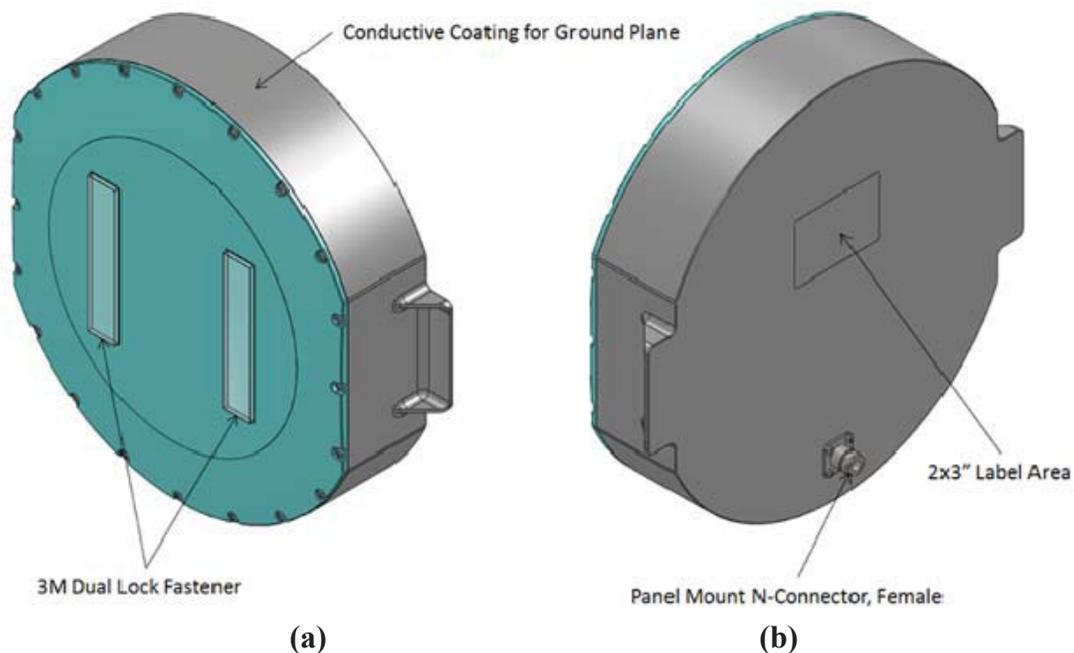
**Fig. 18** Predicted radiation performance of the cavity backed coplanar coupled patch antenna at 400 MHz



**Fig. 19** Predicted radiation performance of the cavity backed coplanar coupled patch antenna at 450 MHz

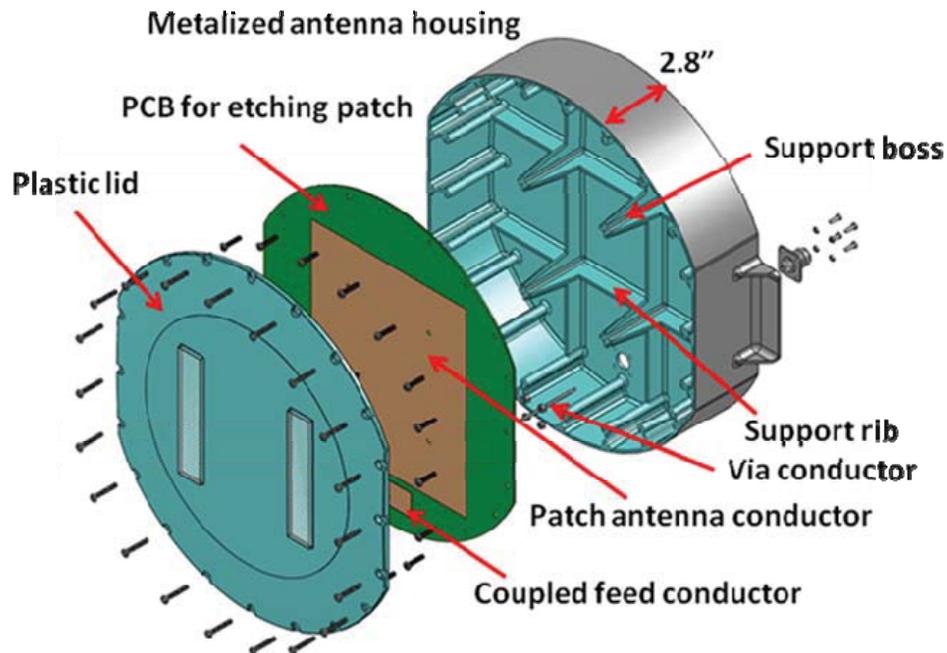
### 3 Structural Design and Development of Common Window Mount Antenna Prototype

A prototype of the window mount antenna was developed. The general shape and exterior features of the prototype antenna can be seen in Fig. 20. Here the antenna is connected to the external RF circuitry with an N-type connector and Velcro® strips are used to adhere the antenna to the window. As can be seen in Fig. 20, handles are used to help install and remove the radiator. As before, this antenna meets the physical size constraints associated with both the BeechCraft King Air C90 and the C23 aircraft windows.



**Fig. 20** Schematic of the prototype window mount antenna including the housing: **(a)** front view; **(b)** back view

The main components of the prototype window mount antenna assembly include a plastic main housing, the printed circuit board (PCB) on which the antenna is etched, a plastic cover, an N-type connector, and a probe feed/via between the antenna conductor and the N-type connector. An exploded view of the prototype window mount antenna is presented in Fig. 21. The main housing separates the antenna conductor from the surface of the ground plane by approximately 2.8" using mounting bosses, as shown in Fig. 21. The housing also included strengthening ribs to increase the rigidity of the assembly. The PCB of antenna was fastened to the housing using 24 #6-32 nylon pan-head screws. These screws, the strengthening ribs and the mounting bosses were expected to have minimal impact on the electromagnetic performance of the antenna.

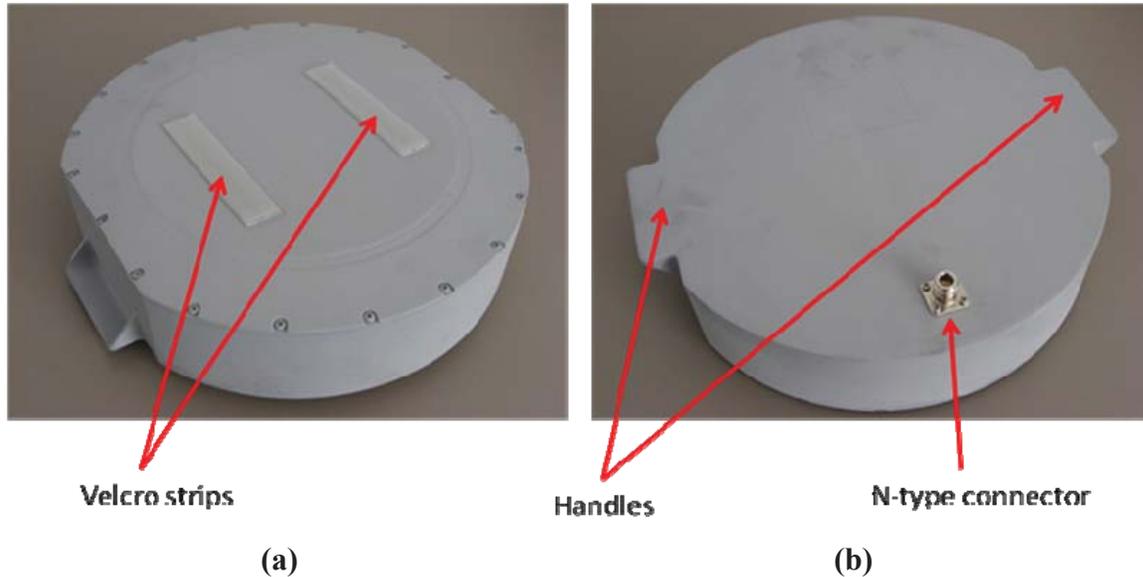


**Fig. 21** Schematic showing an expanded view of the prototype window mount antenna assembly

As discussed before, the window mount antenna is based on a cavity backed patch radiator. To create a ground plane and metallic cavity walls for the antenna, the back and side walls of the exterior of the antenna housing were coated with the Cho-Shield® 2056 conductive coating. Cho-Shield® 2056 is a conductive paint specifically formulated for adhesion to plastics and is a hybrid combination of silver-plated copper and pure silver. The exterior rather than the interior of the housing was chosen because of the raised support ribs and mounting bosses used to support the PCB of the patch conductor. Metalizing these support structures with the conductive paint would have compromised the performance (efficiency and return loss) of the window mount antenna. The exterior surface of the plastic cover included a large curved section that surrounds the flat section. This would facilitate mounting to both flat panel windows, as well as contoured windows. The cover was fastened to the housing using twenty #6-32 steel screws. The connector chosen was a 4-hole panel-mount N-type female connector with a solder cup.

The prototype antenna PCB was milled on an FR4 laminate. The main housing and cover was made of an ABS-like SLA resin, 'Accura' 50 and the housing had a conductive coating applied to its exterior. Fig. 21 shows photographs of the assembled (and painted) prototype window mount antenna assembly. As highlighted in the photographs, the antenna was connected to the external RF circuitry with an N-type connector and Velcro® strips positioned on the front of the antenna allow the structure to be adhered to the aircraft window. As also shown in Fig. 22, handles were located on the sides of the radiator and used to help install and remove the radiator from the window. This

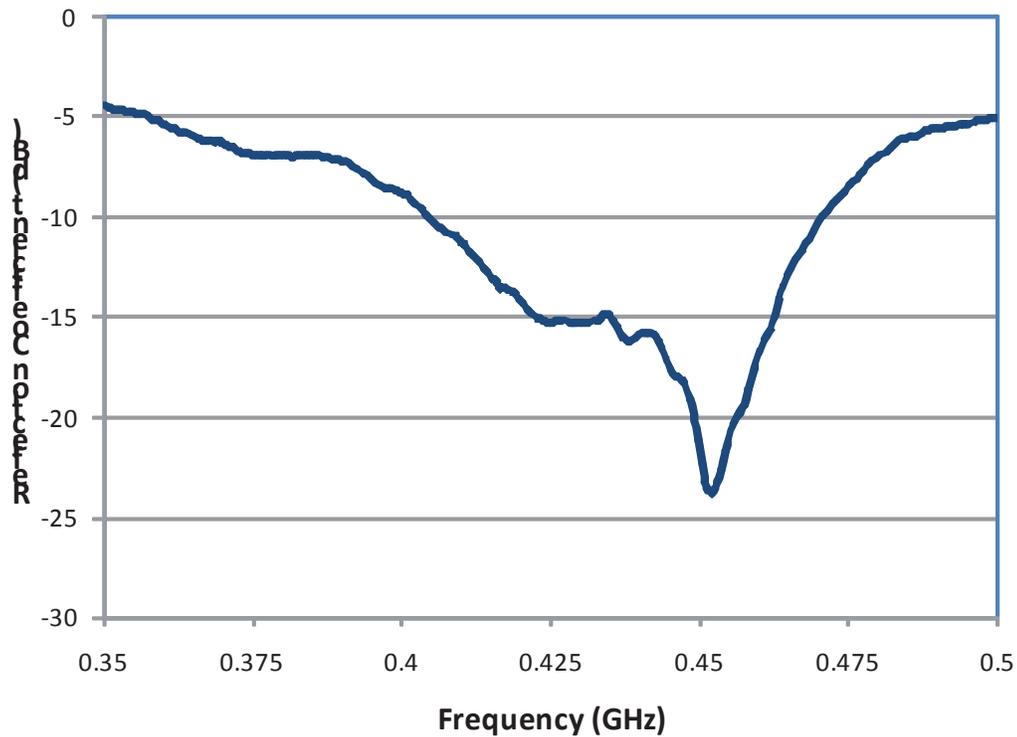
prototype window mount antenna met the physical size constraints associated with both the BeechCraft King Air C90 and the C23 aircraft windows.



**Fig. 22** Photographs of the developed prototype window mount UHF antenna assembly: (a) front view; (b) back view

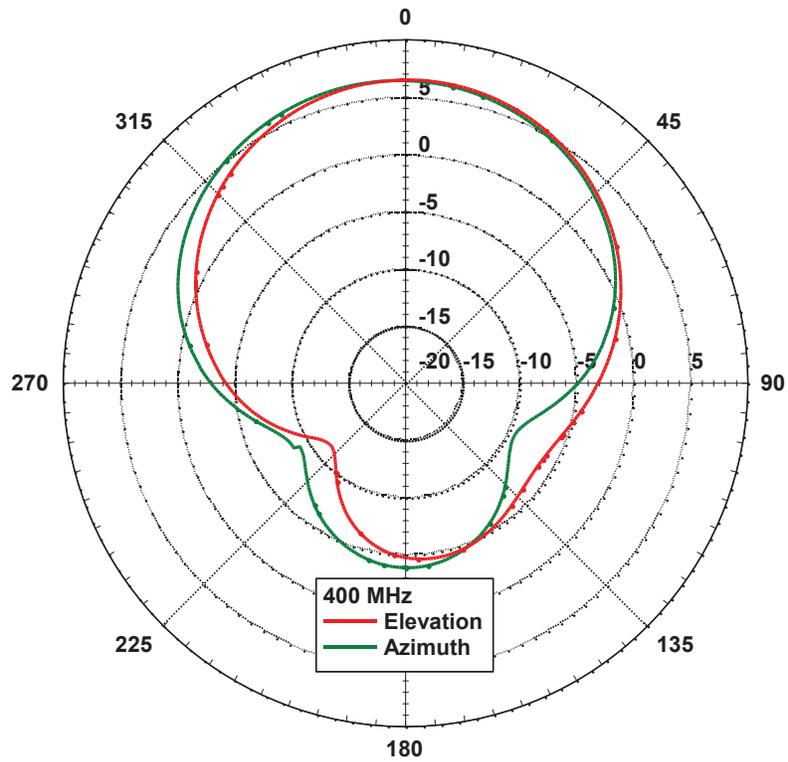
#### 4 Measured Performance of Window Mount Antenna

We measured the electromagnetic performance of the developed proof of concept window mount antenna in ‘free-space’ (not mounted on a window). The reflection coefficient of the antenna was measured using a Vector Network Analyzer (Anritsu 37369E) and the performance is shown in Fig. 23. As can be seen from this plot, the antenna displayed a broadband impedance response, despite its electrically low profile. The measured reflection coefficient of the antenna was better than -10 dB over the desired 400 – 450 MHz frequency range. These results were in good agreement with the predicted return loss response for the window mount antenna presented in Section 2. The results show that by feeding the patch antenna with a co-planar coupling mechanism we were able to achieve a broadband, low profile radiating solution. The results presented in Fig. 23 show that the proposed window mount antenna assembly met the required frequency band of operation (see Table I).

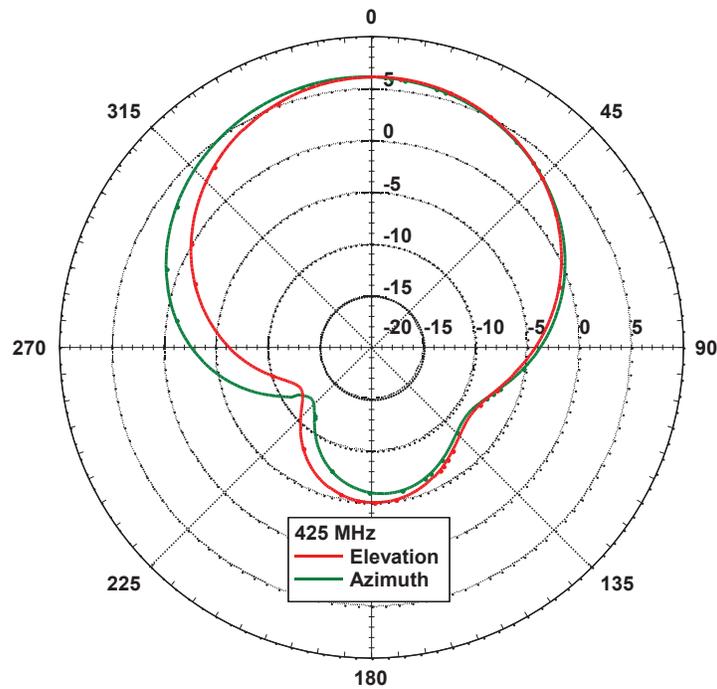


**Fig. 23** Measured reflection coefficient of the developed proof of concept window mount UHF antenna assembly

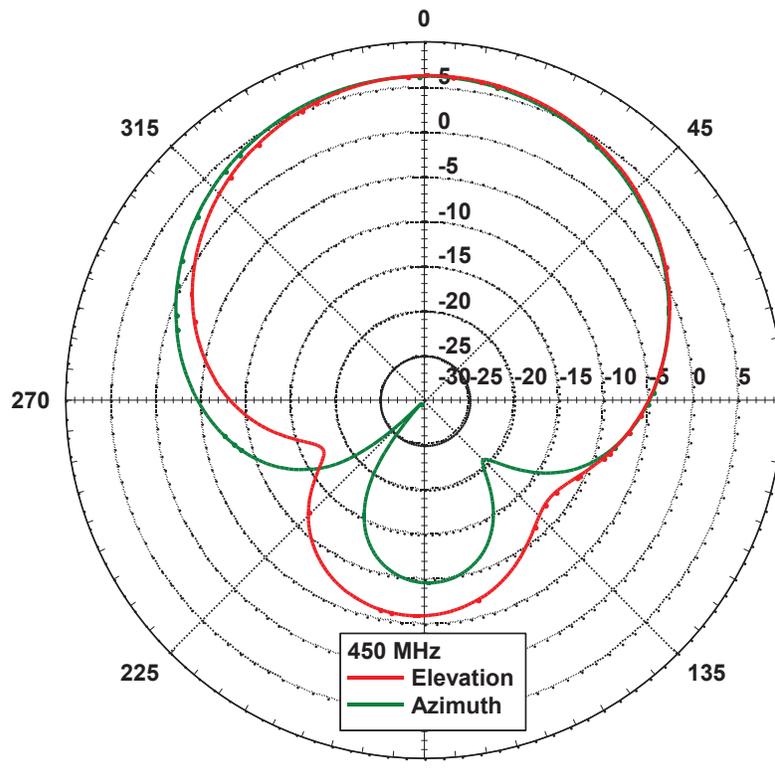
The co-polar radiation patterns and the gain of the new window mount antenna were measured across the UHF band in our anechoic chamber. Figs. 24 – 26 summarize the measured Elevation and Azimuth radiation performance of the prototype antenna across 400 – 450 MHz (normalized to the maximum gain). As can be seen from these plots, the antenna had a broadside gain of greater than 6 dBi and beamwidths in excess of 90° in both planes across this frequency range. The antenna also displayed very smooth patterns, with almost no gain undulation. The significance of the minimal gain undulation is that it indicated that the radiator was relatively platform independent. The front-to-back ratio of the prototype window mount antenna was approximately 10 dB at 400 MHz, and improved as the frequency increased. The measured results presented in Figs. 24 – 26 were consistent with the predicted response of the low profile UHF window mount antenna assembly.



**Fig. 24** Measured radiation performance (including gain) of the prototype window mount UHF antenna at 400 MHz



**Fig. 25** Measured radiation performance (including gain) of the prototype window mount UHF antenna at 425 MHz



**Fig. 26** Measured radiation performance (including gain) of the prototype window mount UHF antenna at 450 MHz

## 5 Reducing Backward Direct Radiation

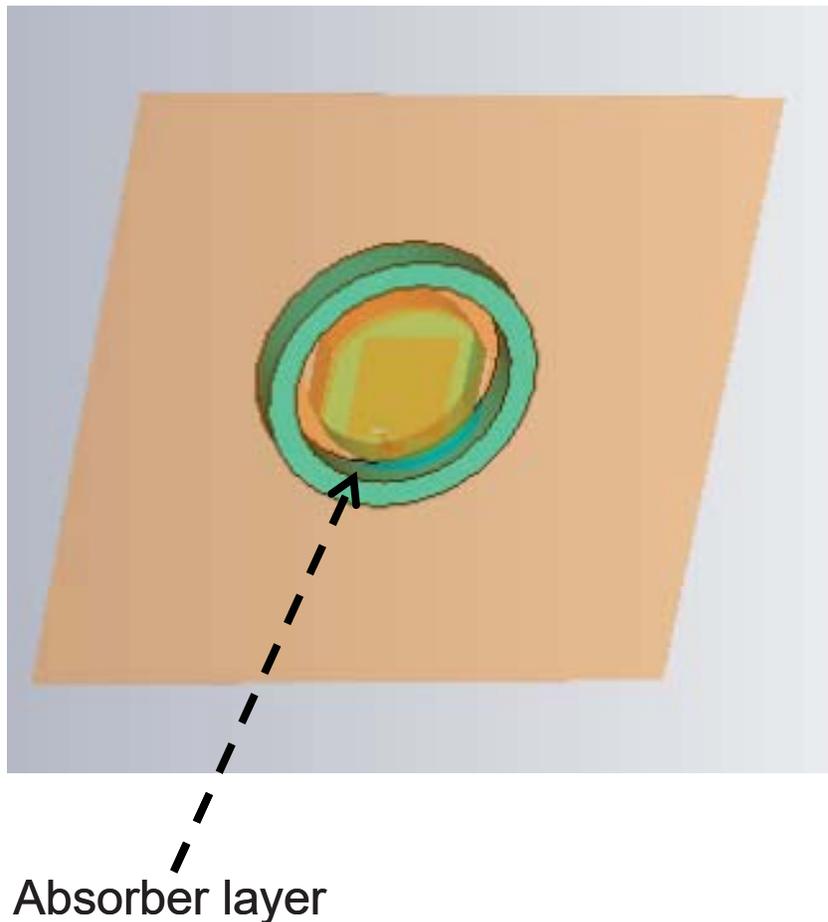
### 5.1 Consideration of Surrounding Environment

In an ideal situation, the cavity surrounding the window mount radiator would be in direct electrical contact with the fuselage of the aircraft; this would significantly reduce the backward directed energy. However, practically this would not be the case and the antenna would not be in direct contact with the aircraft fuselage. We considered cases where there was a gap between the fuselage and the top of the proposed antenna. When there was a 2" gap between the radiator and the 4' x 4' metallic surface (representing the fuselage) the FBR was degraded to approximately 10 dB across the 400 – 450 MHz frequency band.

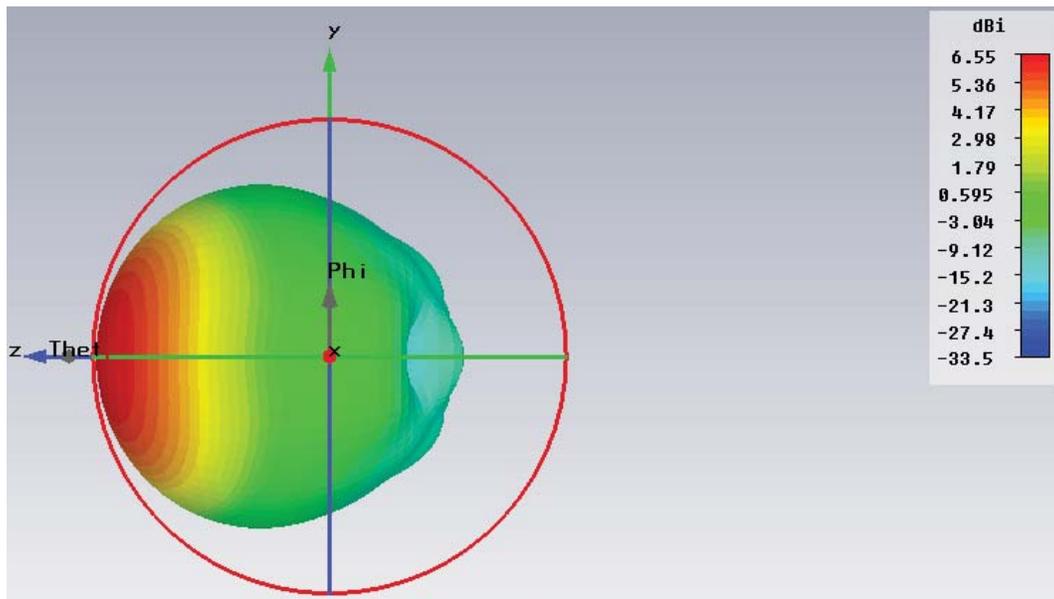
### 5.2 Improving the Front-to-Back Ratio using Absorbers

The approach that we considered to reduce the backward directed energy was relatively straightforward. Here we placed a ring of absorbing material (for example,

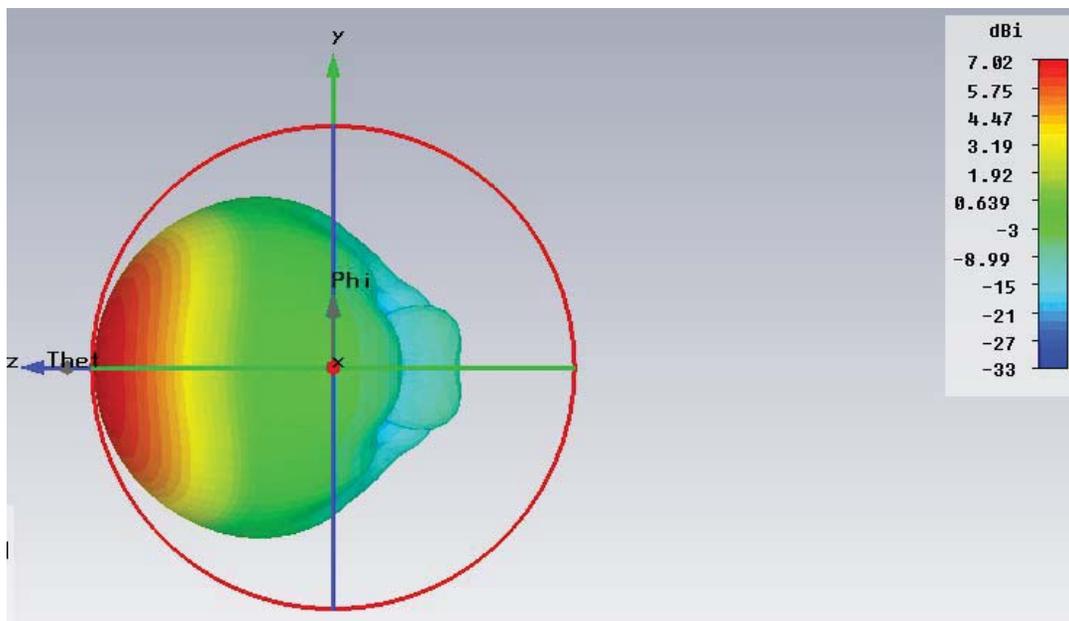
ECCOSORB®) on the extended ground-plane surrounding the antenna. Fig. 27 shows the configuration. The objective of using the absorbing material was to dampen the mode excited on the large ground-plane due to the gap. Figs. 28 and 29 summarize the radiation performance of the new configuration. As can be seen from these plots, the backward directed energy was significantly reduced. The FBR was better than 18 dB across the frequency range and was of a comparable level to when there was direct electrical contact between the radiator and the fuselage/ground-plane. Importantly, it did not appear that we compromised the gain of the antenna despite the presence of the absorbing material; the gain of the antenna was in excess of 6 dBi. For the configuration presented in Fig. 27, the absorbing material was 2" thick and the height was the same as the antenna (2.6"). Note that for the configuration presented in Fig. 27, the absorber and the antenna were not in contact with the metallic surface representing the fuselage.



**Fig. 27** Schematic of the cavity backed version of the coplanar coupled patch antenna with a FBR reduction technique



**Fig. 28** Predicted radiation performance of the cavity backed coplanar coupled patch antenna with a FBR reduction technique at 400 MHz

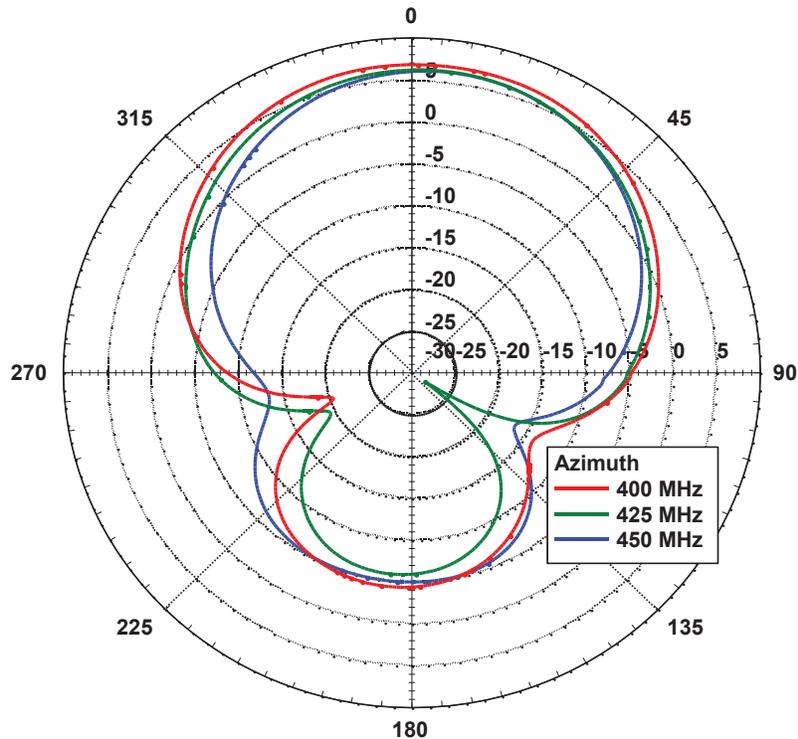


**Fig. 29** Predicted radiation performance of the cavity backed coplanar coupled patch antenna with a FBR reduction technique at 450 MHz

### 5.3 Measured Radiation Performance of Window Mount Antenna in Test-Fixture and FBR Investigation

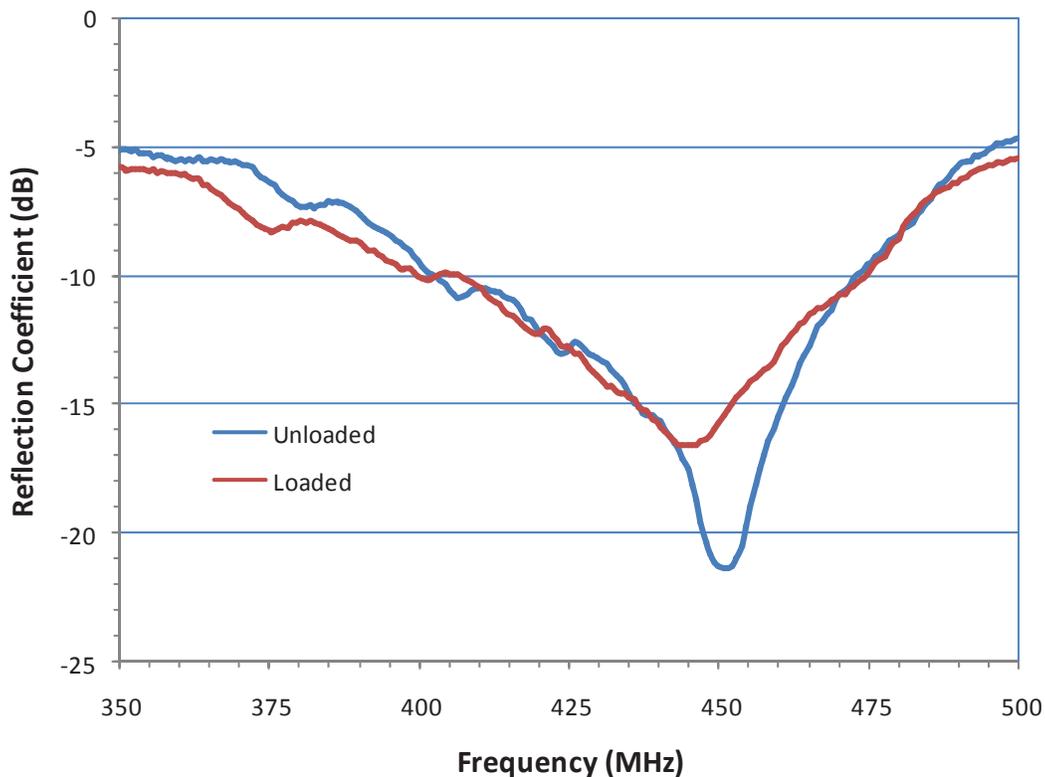
We developed a mock-up test fixture to enable us to measure the radiation performance of the antenna in a window mount environment. The fixture comprised a 3' × 3' metal sheet with a hole in the middle, cut to the appropriate size (consistent with the BeechCraft King Air C90 windows). A sheet of Plexiglass was bolted to the metallic sheet and the window mount antenna was connected to the mock-up test fixture using the Velcro strips.

Fig. 30 shows the measured azimuth radiation patterns of the prototype UHF antenna when mounted on the aircraft window mock-up test fixture (with no surrounding absorber) across the 400 – 450 MHz frequency range. The patterns are normalized with respect to the measured gain. The results highlight the unique feature of incorporating a cavity backed solution; we have been able to create an efficient radiating solution that is relatively independent of the surrounding environment, even when that environment is a large metallic structure. A conventional patch antenna configuration would not have been able to achieve such a result. It is important to note that the FBR of the antenna remained relatively unchanged; approximately 10 dB. This was consistent with the theoretical findings presented earlier and therefore to improve the FBR, we need to utilize the procedures that we theoretically investigated in Section 2.



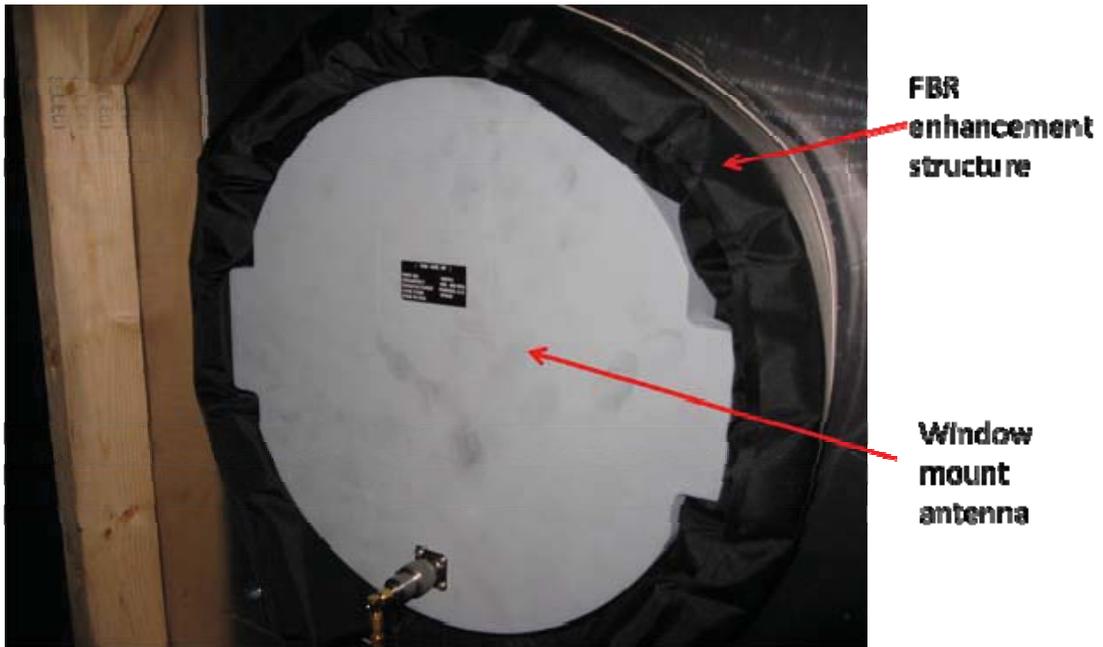
**Fig. 30** Measured azimuth radiation patterns (including gain) of the prototype UHF antenna when mounted on the window mock-up test fixture

To make the electromagnetic absorbing ring for the proposed UHF window mount antenna more robust and easy to install around the radiator, we created a pouch for the material. The pouch was made from urethane backed nylon which is robust and waterproof. Fig. 31 shows the measured reflection coefficient of the window mount antenna, with and without the FBR enhancement structure (ring of absorber). As can be seen from these results, the FBR enhancement structure had minimal impact on the impedance response of the antenna and the combined platform met the bandwidth requirements for CID applications.

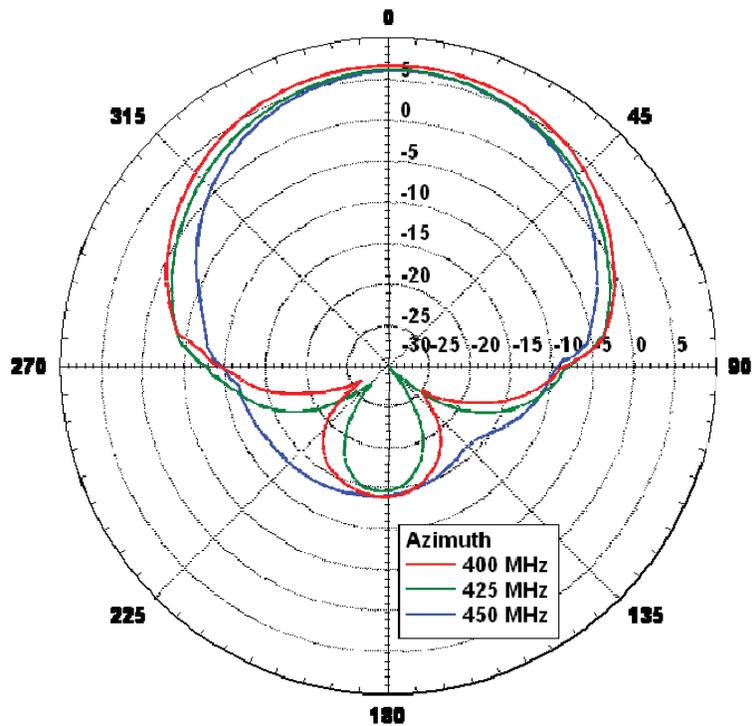


**Fig. 31** Measured reflection coefficient of the window mount UHF antenna with (loaded) and without (unloaded) the FBR enhancement structure

We also measured the radiation performance of the prototype UHF antenna with the FBR enhancement structure in our anechoic chamber using the mock-up test fixture we developed. Fig. 32 shows the prototype window mount antenna on the test fixture and the FBR enhancement structure positioned around its circumference. We measured the azimuth radiation performance of the window mount antenna with the FBR enhancement structure on our test-fixture within the anechoic chamber. The results are summarized in Fig. 33. As can be seen from these results, the FBR was further improved and it is approximately 20 dB.



**Fig. 32** Photograph of the prototype window mount UHF antenna with the FBR enhancement structure on a mock-up test fixture (seen from behind)



**Fig. 33** Measured azimuth radiation performance (including gain) of the window mount UHF antenna with the new FBR enhancement structure on a mock-up test fixture

## 6 Conclusions

In this paper we have presented a highly efficient, low profile window mount UHF antenna based on a cavity backed proximity coupled coplanar probe-fed patch. The antenna operates efficiently over 400 – 450 MHz and can be easily installed on the window of various aircraft. We gave an overview of the basic radiating structure and summarized the design procedure to good bandwidth and enhanced FBR.

In this paper we also highlighted the physical design developed for the window mount UHF antenna assembly. The radiation and reflection coefficient performance of the antenna were experimentally examined and the results were consistent with the predicted responses. In this paper we also examined the performance of the antenna when mounted in a realistic environment and investigated how we can improve the FBR in this scenario. We showed that by incorporating a ring of absorbing material around the circumference of the cavity backed antenna we could achieve an FBR approaching 20 dB across the entire frequency range of operation, without dramatically impacting the overall efficiency of the radiator. The UHF cavity backed proximity coupled coplanar probe-fed patch antenna we have developed is very suited to applications such as CID.

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