Evaluation of the Performance of a Multi-band Antenna for On-board Applications

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1. Introduction

Modern life depends so much on wireless technologies that one can no longer afford to be offline for long, even during flights. Although not yet proliferated, the aircraft industry has already begun efforts to introduce in-flight wireless connectivity [1, 2]. The antenna requirements for these access points within the cabin are not as stringent as antennas placed outside the aircraft. Yet planning of wireless access points in this scenario, even for mobile phone access, is complicated by the fact that the aircraft, particularly long-haul ones, are expected to conform to wireless standards currently existing in different parts of the world. It is therefore challenging to integrate access points for wireless technologies such as AWS, GSM and various WiMax and WLAN bands operating at 1710-1755 MHz, 1805-1880 MHz, 1900-1990 MHz, 2110-2170 MHz, 2.4-2.5 GHz, 5.15-5.35 GHz, and 5.45-5.85GHz.

This group has recently proposed a multifunctional microstrip antenna with two U-shaped slots to achieve the dual wideband operation to meet the above requirements [3, 4]. The dimensions and locations of the U-slots were designed for locating its operational bands. A thick substrate used there, which in fact uses existing aircraft panel material and helps broaden the individual bandwidths. We have found that the experimental result for this antenna meets all current requirements for in-cabin wireless communication needs.

However the cabin of an aircraft cabin is usually a metallic structure, with a number of other metallic objects such as seat supports in close vicinity. Hence the performance of such an antenna will have to be validated in a cabin-like environment and preferably in a real cabin. The field intensity variation in an aircraft differs from many other structures and hence on-site measurements are required to analyze the performance of the antenna inside the cabin [1]. In this paper we report experiments towards such a validation. Very few in cabin measurements are done for GSM and CDMA wireless networks but in this paper we report measurements over a larger range of frequencies (1.8GHz to 5.4GHz), using a portable network analyzer. The field distribution is measured using a small field probe antenna placed at different locations in an x-y plane and corresponding readings are noted using a portable network analyzer. The test antenna (U-slot antenna) acts as the transmitter and a specially designed UWB monopole antenna acts as the field probe receiver.

2. Multi-band Antenna Design and Results

The proposed antenna consists of a rectangular patch with two U slots as shown in Figure 1, supported by a customized substrate. The substrate used here has a three layer internal structure. The outer skin layers have a dielectric constant ε_r=3.5 and thickness of 0.6mm. The sandwiched honeycomb layer in the middle is 8.5mm thick. Two U slots are provided on the patch to facilitate dual band operation. The dimensions of the patch correspond to resonance in the lower range of frequencies, with the larger U-slot helping to achieve the broad bandwidth required. The location of the feed and the dimensions of the inner (smaller) U-slot are fine-tuned based on numerical simulations for good radiation performance in the upper band. Key dimensions of this antenna are listed in Table-I [3].

The photograph of a fabricated antenna is shown in Figure 1. The measured and simulated S11 of this antenna is shown in Figure 2. At the first resonance of 1.9 GHz, it can be seen that the current distribution is that of TM01 mode strongly perturbed by the presence of two U slots. The surface currents originate behind the outer U slot and are strong towards the outer edges of the outer slot and slightly towards the vertical edges of the patch. The presence of two U slots forces the surface currents of the TM01 mode to travel around the U slots. The current paths are symmetric around the slots and on the patch. It has also been observed that there is not much difference between the antenna behaviour at 1.9 GHz and at 2.3 GHz. Hence the operational mode remains TM01 through the lower band. This also explains the symmetrical radiation patterns seen through this band. However, the surface current distribution at the resonant frequency of 5.4 GHz is different from these. At this frequency the inner slot plays a significant role and creates variations in surface currents. The surface currents emanate from multiple points on the patch. They are very strong around the inner slot perimeter. Based on these TM11 mode of operation can be concluded. The radiation pattern at 5.4 GHz therefore has a null at a point near to the boresight, which can be attributed to the asymmetric paths of the currents w.r.t the x-axis. The null is not seen in the H plane as the currents travel in symmetry w.r.t the y-axis. These characteristics are evident from the radiation pattern of this antenna measured in an anechoic chamber, shown in Figure 3.

Table-I Geometrical parameters of the antenna

[All dimensions in mm]

Parameter	Dimension
Patch length	71
Patch Width	52
Outer slot length	40
Outer slot Base	18
Outerslot Width	4
Inner slot length	13
Inner slot Base	5
Inner slot Width	1
Feed offset	9

Figure 1 Fabricated antenna

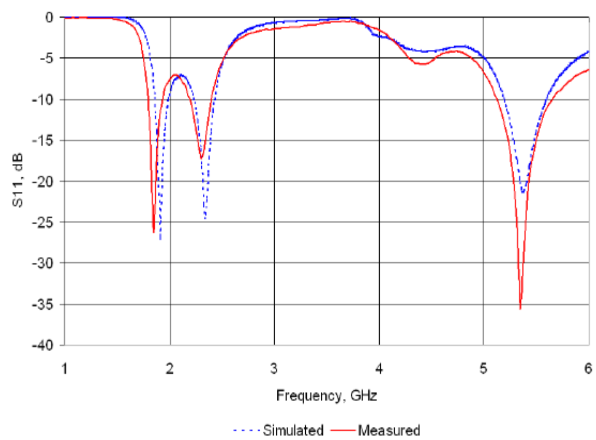
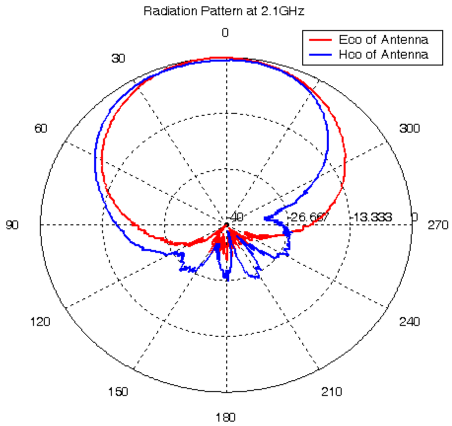


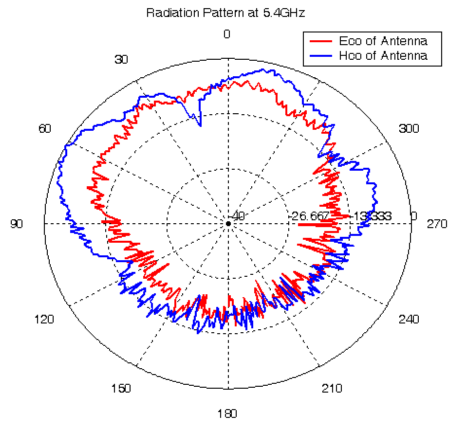
Figure 2 Comparison of simulated and measured S11.

3. Design of Wideband Field Probe Antenna:

Field pattern over such large volume can be measured using a small wideband probe antenna. An ideal field probe is an antenna which is isotropic in nature. This can also be achieved by choosing a miniature UWB ultra-wideband antenna which has almost a flat frequency response for large range of frequency. Some of the antenna design can be used as field probe such as a biconical printed antenna or a planar inverted cone antenna [5]. This paper uses a UWB monopole planar antenna based on that reported in [6] modified for a wideband response from 1.6GHz to 7.4GHz. This has a small printed patch on one side of FR-4 substrate. The cable head acts as the ground plane and a separate metal match is not present on the substrate. This antenna is fabricated and its photographs are shown in Figure 4. The measured S11 characteristics of this antenna (Figure 5) indicate its wideband performance.



(a) At 2.1 GHz



(b) At 5.4 GHz

Figure 3 Measured E-plane and H-plane radiation patterns of the antenna shown in Figure 1, at the middle of two operational bands.

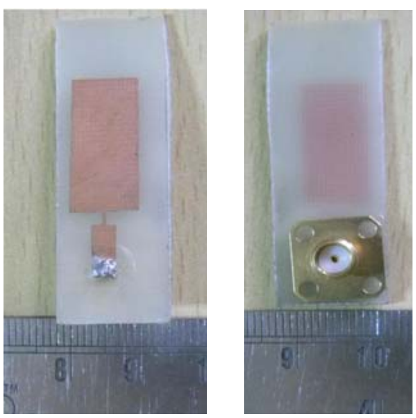


Figure 4 Front and Back side view of the wideband probe antenna.

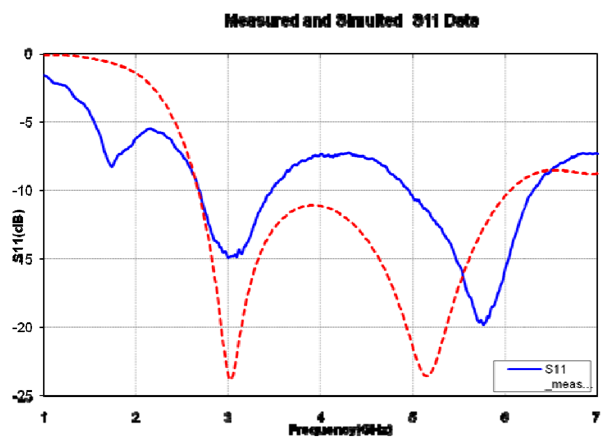


Figure 5 Measured and Simulated S11 of the Wideband probe antenna shown in Figure 4.

4. Experimental Setup

In order to evaluate the antenna described in Section 2 in an indoor environment, setup shown in Figure 6 is used. A portable network analyzer (Agilent RF Fieldfox N9912A) is used for this measurement. The probe is moved on an x-y grid at various heights to record the field distribution. . S21 at various locations are recorded using the RF field fox analyzer and simultaneously the data is downloaded in a laptop interfaced with it. The data is post-processed using matlab. Samples of these measurements show the field distribution at different frequencies shown in Figure 7 at 2.1GHz and 5.4GHz. It may be observed that these agree fairly well with the radiation patterns of the candidate antenna shown in Figure 3. However, multiple nulls and peaks are observed in the measured surface plot due to reflection from various surfaces nearby.

5. Conclusions

The performance of a multi-band antenna consisting of a microstrip patch with two U-slots is designed and tested for use in aircraft cabin wireless access points. The objective of this paper is to evaluate this antenna that covers most of the current wireless bands from 1.7GHz to 5.85GHz. These include GSM, CDMA, WiMAX, UMTS located from 1.7GHz to 2.2GHz and WLAN bands at 2.4GHz and 5.15-5.85GHz. A specially designed wideband probe antenna is used for characterization of field radiated from this antenna. This measurement setup gives room for future development like human presence in the cabin, the fading effects, and the path loss between transmitter and receiver.

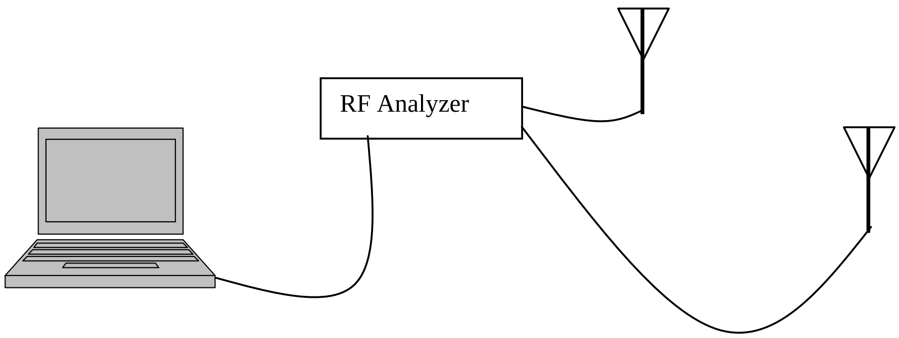


Figure 6 Schematic of the measurement setup using RF Analyzer

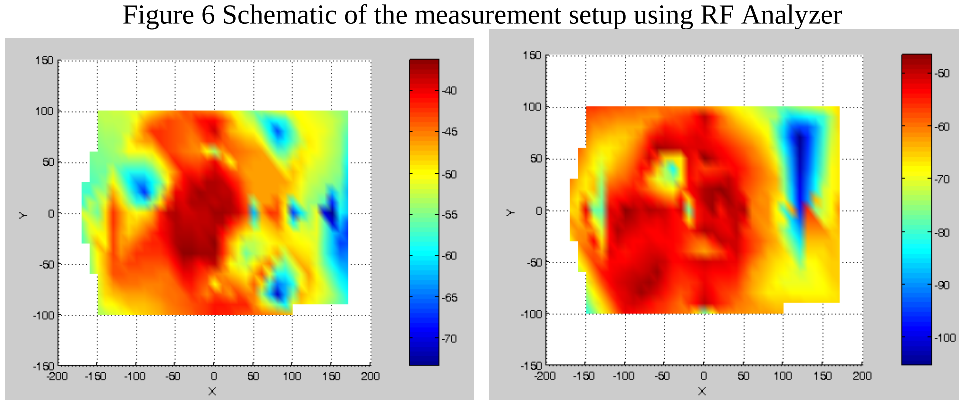


Figure 7 Surface plots of field distribution at a distance of 1m from the antenna 2.1GHz and 5.4GHz

Acknowledgments

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