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Microstrip Patch Antenna System Design for In-Cabin Wireless Communications and Internet Services

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Abstract: Due to the increasing communication requirements, using the internet when air traveling is no longer luxury but it is a necessity. In this paper, a microstrip patch antenna system has been designed which can be used as an access point and provide internet connections at the 5GHz band in the Airbus A321 type of aircraft. The electromagnetic field radiation simulation and positioning of the designed antennas in the aircraft cabin have been performed also. The microstrip antennas have been designed within IEEE 802.11 ac/ax standard. 5GHz WiFi internet service is providing at 5300 MHz (CH 60) center frequency with 4 antennas which FR-4 dielectric material was used. The designed antennas are used as access points and they are connected with a fiber connection. The electromagnetic field radiation of the antennas placed in the cabin was simulated with the HFSS simulation program. As a result of the simulations, these antennas have been observed to be useful.

Keywords: Microstrip patch antenna, 5G, WIFI/WLAN, In-flight connectivity (IFE), Airbus A321

Introduction

Today, as in all transportation vehicles, the internet usage needs is inevitable for passengers in the air transportation as well. For this reason, it has become a necessity for airline companies to both supply with the wireless internet using and in-flight entertainment (IFE) service. Thus, passengers is have beatifically time during the flight.(Akl et al., 2011).

Leading airline companies in the world use many different aircrafts which have different brands and models in accordance with the purpose of the travel. This article is based on the Airbus A321 type aircraft model.These planes have a cabin length of 34.4 m, a cabin height of 2.18 m, and a cabin width of 3.7 m and frequently included in their squadrons of the airline companies.(Airbus, 2005). Wireless access points (APs) have been placed in the aircraft cabin in order to meet the wireless internet access at a sufficient level for each user. These access points are designed with microstrip patch antennas due to today's technology and easy applicability.

Microstrip patch antennas have become more popular in recent years and have begun to be used in more areas, thanks to their lightness, easy adaptation to the surface on which they are applied, ease of production and low cost (Dündar, Gültekin & Uzer, 2019). In this article, the design details and simulation values of microstrip antennas to be used as access points in aircraft are mentioned.

Table 1. Table of the regions using the CH60 frequency band

Channel	Center Frequency (MHz)	Frequency Range (MHz)	Bandwith (MHz)	United States FCC U-NII Band(s)	United States / Canada / Singapore / Mainland China / Korea / New Zealand / Vietnam	Europe / Japan / Israel / Turkey / Australia / South Africa / Bahrain	Russia	India / Brazil / Indonesia	Taiwan
60	5300	5290 - 5310	160	U-NII-2A	DFS/TPC	Indoors/DFS/TPC	Indoors/TPC	Indoors	DFS

Currently, the 5 GHz frequency band is quite popular for WiFi WLAN. Table 1 shows the list of countries using the CH60 frequency band. Microstrip antenna design has been carried out to cover the WLAN CH60 frequency band 5290-5310 MHz in order to cover both domestic and international travels and to be valid and usable in all continents as much as possible. In addition to being compatible with the IEEE802.11 a/h/j/n/ac/ax standards, the CH60 band is in a range that will not interfere with other in-flight wireless communication systems (Chilakala, 2008). Avionic communication frequency bands are shown in Table 2 (Gutton & Baissinot, 1995).

Table 2. Avionic communication frequency bands

Frequency Range	System
190 – 1750 kHz	Automatic Direction Finder (ADF)
2-30 MHz	High Frequency (HF) Radio
75 MHz	Marker Beacon
108 – 112 MHz	Localizer (LOC)
108 – 118 MHz	VHF Omnidirectional Range (VOR)
118 – 137 MHz	Very High Frequency (VHF) Radio
329 – 335 MHz	Glide Slope
962 – 1213 MHz	Distance Measuring Equipment
1030, 1090 MHz	Traffic Alert and Collision Avoidance (TCAS)
1030, 1090 MHz	Air Traffic Control (ATC)
1530 – 1660 MHz	Satellite Communication (SATCOM)
1575.42 MHz	Global Position Satellite (GPS)
4235 – 4365 MHz	Radio Altimeter
5031 – 5091 MHz	Microwave Landing System (MLS)
5440, 9350 MHz	Weather Radar

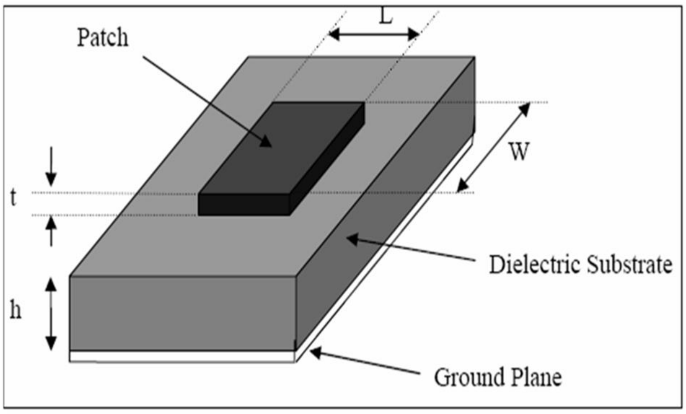

Figure 1. Standard microstrip patch antenna structure

Figure 1 shows the microstrip antenna structure. At the bottom is the ground layer. The material used in the ground layer is conductive and enables the antenna to radiate in one direction (Kütük & Taşneli, 2013). On top of the ground layer, there is a dielectric layer consisting of dielectric material. For ideally situation the dielectric constant should be less than 2.5 (Balanis, 1982). The thickness of the dielectric layer generally ranges from 0.05 mm to 6.35 mm. At the top is the patch layer, which is positioned to radiate. The patch layer is conductive. The patch layer can be used with conductors such as gold and silver, usually copper. Patch design can be made in different ways. The thickness of the patch layer varies between 0.035 mm and 0.070 mm (Bazan, 2010). Variables such as the shape of the patch and the feeding technique differences directly affect the parameters of the antenna (Sainati, 1996).

Method

Microstrip Patch Antenna Design

The designed antenna is required to operate at 5300 Mhz center frequency. Based on this, FR-4 with relative dielectric constant $\mathcal{E}_r$ = 4.9, loss tangent tanδ = 0.02 was chosen as the substrate material, and the dielectric material thickness was determined as 0.7 mm. The next step in the design is to calculate the patch dimensions using the material's dielectric constant, thickness. The patch width W is calculated using equation 1 as follows.

$$W = \frac{c_0}{2f_c\sqrt{\frac{2}{\mathcal{E}_r + 1}}} \quad (1)$$

In the formula c_0 is the speed of the light and f_c is the center frequency. For f_c = 5.3 GHz center frequency, W = 16.316595971 mm. If $\frac{W}{h} \geq 1$, the effective dielectric constant ($\mathcal{E}_{reff}$) is calculated by equation 2 [1];

$$\mathcal{E}_{reff} = \frac{\mathcal{E}_r + 1}{2} + \frac{\mathcal{E}_r - 1}{2}[1 + 12\frac{h}{W}]^{-\frac{1}{2}} \quad (2)$$

For $\mathcal{E}_r$= 4.9, h=0.7 mm and W = 16.316 mm values, $\mathcal{E}_{reff}$=4.534 is obtained.

$$L_{eff} = \frac{c_0}{2f_c\sqrt{\mathcal{E}_{reff}}} \quad (3)$$

The effective length L_{eff} given by equation 3 is calculated as 13.281 mm by using c_0=3x10^8 m/s,

$\mathcal{E}_{reff}$=4.534 ve f_c = 5.3 GHz.

$$\Delta L = dL = 0.412\frac{(\mathcal{E}_{reff} + 0.3)(\frac{W}{h} + 0.264)h}{(\mathcal{E}_{reff} - 0.258)(\frac{W}{h} + 0.8)} \quad (4)$$

$$L = \frac{c_0}{2f_c\sqrt{\mathcal{E}_{reff}}} - 2\Delta L \quad (5)$$

Length extension (ΔL) and patch length (L) is calculated via equation 4 and equation 5 with use the values W = 16.316 mm, c_0=3x10^8 m/s, $\mathcal{E}_{reff}$=4.534, ve f_c = 5.3 GHz, L_{eff} = 13.281 mm, h=0.7 mm. ΔL=0.318mm and L=12.494 mm has been found. As a result of the calculations, our patch sizes were found to be W = 16.316 mm and L=12.494 mm.

Table 3. Antenna Parameters

Parameters	Value
Dielectric Material	FR-4
W	16.316 mm
L	12.494 mm
$\mathcal{E}_r$	4.9
$\mathcal{E}_{reff}$	4.534
L_{eff}	13.281 mm
f_c	5.3 GHz
ΔL	0.318 mm
c_0	3x10^8 m/s

The parameters of the designed antenna are given in Table 3 with the calculated values.

Access Point Placement and Calculations

Access points has placed in the middle of the ceiling of the aircraft and spaced evenly in the aircraft cabin. Pleaced 4 access points have provide sufficient level of wireless internet access for all passengers.

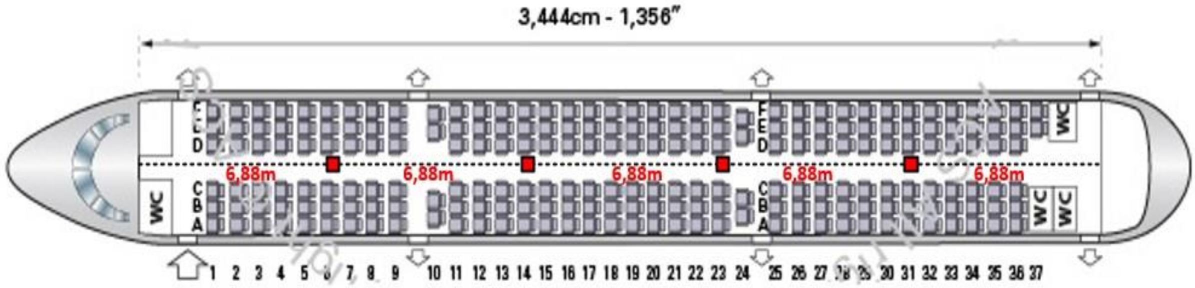

Figure 2. Access points places in the aircraft cabin

As can be seen in Figure 2, when the access points are evenly spaced, there is a distance of 6.88m between them. Each access point is required to radiated signal up to 3.44m. The free space path loss for access points is calculated as follows (Chilakala, 2008);

$$FSPL = 20\log_{10} d + 20\log_{10}\left(\frac{4\pi}{c}\right) - G_t - G_r \tag{6}$$

Considering that a passenger at 3.44m from the access point uses a mobile phone with a 2 dB receive gain, the free space path loss value is calculated as 52.74 dB. The signal strength received by the passenger mobile phone was calculated from the equation 7.

$$P_{out} = P_t + G_t - L_t - L_{fs} - L_m + G_r - L_r \tag{7}$$

When the required values are put in equations, it is expect that a passenger using a mobile phone at a distance of 3.44m from the access point will receive a signal with a strength of -49.82 dBm.

Connections Between Access Points

In order for the data transmission between the APs to not cause any electromagnetic interference (EMI) to the avionic system and flight safety within the aircraft, they are connected to each other as a fiber connection with RF Over Fiber (RFoF) technology as in Figure 2. With the RFoF system, due to the low emission power of the antennas and the fiber links that do not contain electromagnetic radiation, it can effectively reduce the EMI threats from wireless access during flight (Zhang et al., 2013). Compared to the standard system, it is thought that a 4-8 dB reduction in electric field strength can be achieved by using RFoF based access in the cabinet. At the same time, a higher energy efficiency is achieved as well.

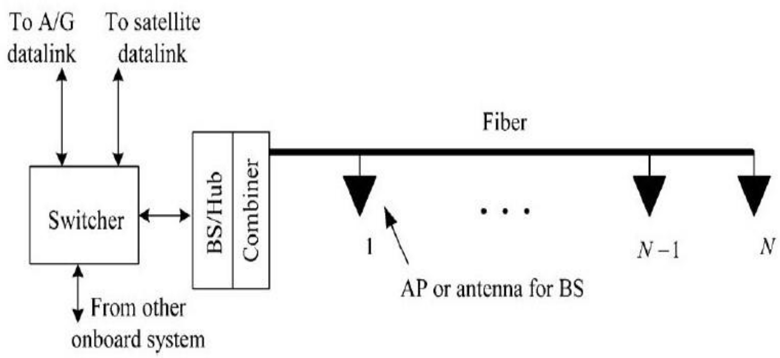

Figure 3. RFoF system connection diagram

Results and Discussion

In this study, the antenna design was simulated in the HFSS simulation program as in Figure 3 and the design values were obtained. Looking at the graph of the designed microstrip antenna in S_{11} parameter Figure 4, the Center Frequency was obtained as -18.72 dBm at 5300 MHz.

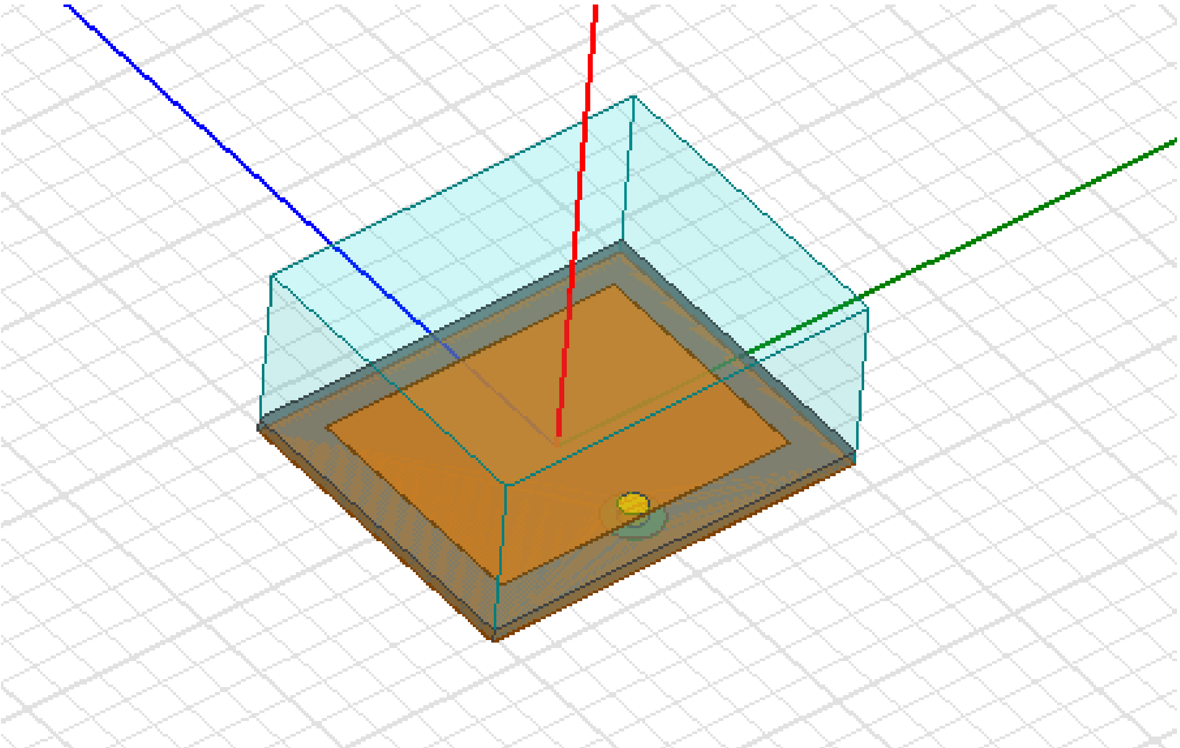

Figure 4. Designed microstrip patch antenna view

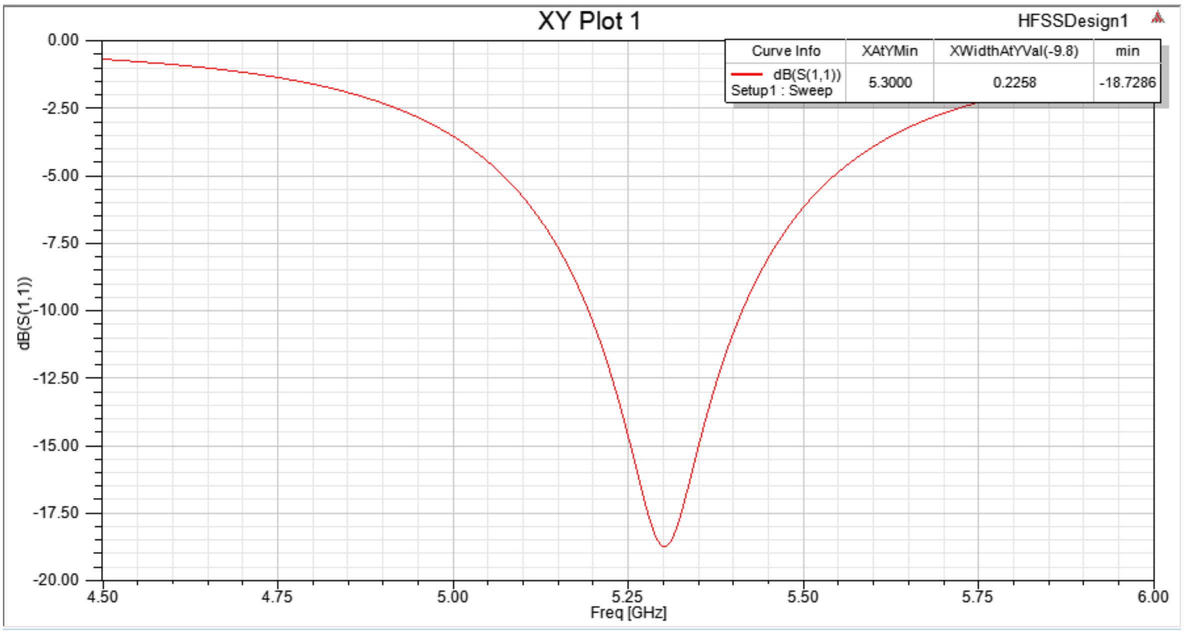

Figure 5. Microstrip patch antenna S11 parameter graph

When we look at the area below the -10dB reference value, it is seen that an antenna with a bandwidth of 225MHz has been designed. When these values are considered, the compatibility of the antenna with the CH60 WLAN class is seen.

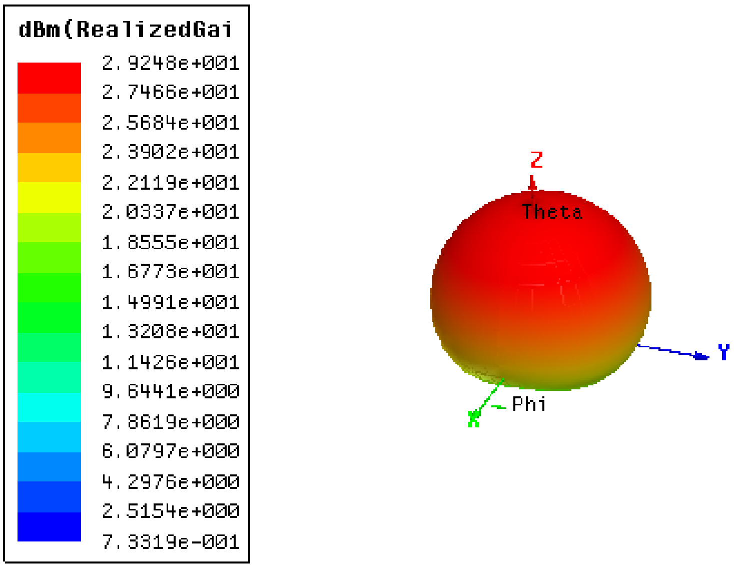

Figure 6. Gain plot of microstrip patch antenna

When the gain graph of the designed microstrip antenna in Figure 5 is examined, it is seen that the gain value is sufficient to be used for WiFi AP with both the radiation pattern and 2.92 dBm gain.

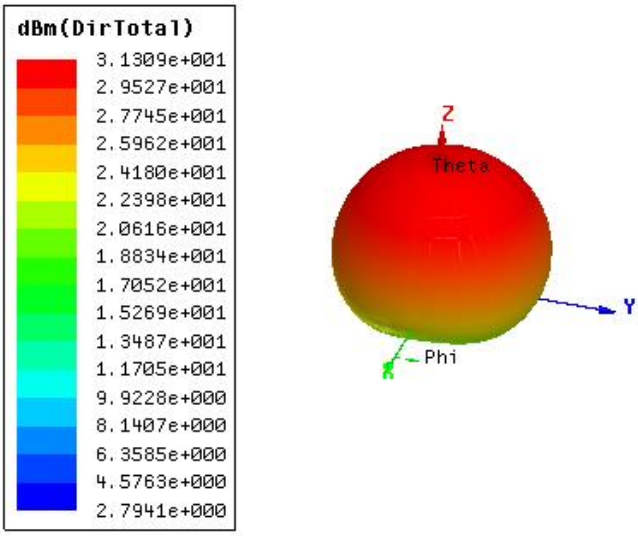

Figure 7. Directivity plot of microstrip patch antenna

Similarly, when the 3D directivity graph of the antenna in Figure 6 is examined, it is seen that the directivity is at a sufficient level.

Conclusion

As a result of the design, calculations and simulations, it has been seen that the antenna design with -18.72 dBm and 225 MHz bandwidth is suitable for APs that will operate at 5300 MHz center frequency. With a gain of 2.92 dBi, it has been calculated that the radiated in the cabin is at a sufficient level. When 4 of the microstrip patch antennas designed as AP are used and placed inside the aircraft at 6.88m intervals, a distribution with a signal reception power of at least -49.82 dBm is provided on the user's side. Via connecting the designed APs to each other with RF over Fiber technology, it has both minimized electromagnetic interference (EMI) on the avionic system and made it safer for aircraft systems. It has been determined that the antenna designed for Airbus A321 type aircraft cabin wireless internet distribution can be used for internet distribution and In-Flight Entertainment (IFE) applications.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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