Microstrip Patch Antennas at 5.8GHz for Wireless Power Transfer System to a MAV

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ABSTRACT

Wireless power transfer has become an attractive energy solution to increase the autonomy and supply power to the Micro Aerial Vehicles (MAV) without wired connection. This paper proposes microstrip antennas at 5.8 GHz for microwave wireless power transmission system to a MAV.A single patch antenna is designed for transmitter array with a gain of 5.2dB while a circular polarized patch antenna is designed for rectenna array with a directivity of 6.1dB and an axial ratio of 0.314dB.These antennas are designed, optimized and simulated by using FEKO EM simulation software.

KEYWORDS

Microwave wireless power transfer, MAV, microstrip patch antennas, smart array antennas, circular polarization, FEKO.

1 INTRODUCTION

Recently, Micro Aerial Vehicles (MAV) or micro drones (the length, height and width are 15 cm according to Defense Advanced Research Projects Agency) have proliferated in the market due to their low cost. These devices demonstrate an enormous potential especially in the field of internet of thing, and they are massively used in order to gather information and charge the nodes of Wireless Sensor Network.

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However, most commercial MAVs currently available suffer from a major drawback: their flight autonomy is limited due to their dependence on batteries to function. Commonly marketed MAVs typically present flight duration which falls between 5min and 20 min. In order to solve this limitation, we propose to use dedicated wireless power transmission (WPT) system enable MAV to maintain the flight without need for batteries.

In fact, WPT is an old concept over 100 years ago that was investigated and demonstrated intensely by notorious scientists such as Nikola Tesla or William C. Brown, and can be defined as the technology that enables a power source to transmit electromagnetic energy to an electrical load across an air gap, throughout a given distance without resorting to wires or cables [1].

WPT can be achieved by several methods such as near-field inductive coupling, magnetic resonant coupling and microwave power transmission (MPT) [2]. We have opted especially for the method of microwaves to charge the MAV. On one hand, the wireless charging via microwaves seems the most suitable method for long distance WPT applications .On the other hand, a microwave frequency band is presently adequate for WPT system because of the following reasons: the operating frequencies are set and fixed in the GHz range, which make obtain antennas with smaller size than those operating at lower frequencies. Moreover, the main merit of this method is the possibility of wireless power transmission to moving targets as in our case to mobile MAV.

In particular, a typical MPT system consists of two main sections: the power transmitter and the receiver. In the transmitter, a microwave generator converts Direct Current (DC) power to microwaves power. Then, the transmitting antenna radiates this power uniformly through the free space to receiver. In the reception, a rectenna captures and converts microwaves energy back to useful direct power DC .A block scheme of the basic architecture of a MPT system is illustrated in Fig. 1.

Microwaves are produced by vacuum tubes such as klystron and magnetron. Several researchers propose to use magnetrons because they are cheaper and more efficient for phased array antennas [3].The microwave source often uses the 2.45 GHz or 5.8 GHz frequencies of the ISM band [4].The transmit antenna, as described in [5], should present an extremely directive radiation pattern and have a high gain. Rectenna is the key component which consists of a receiving antenna and a rectifying circuit. The receiving antenna captures the radiated RF signals from the environment , subsequently the rectifier circuit extracts the power of those signals and converts them into DC voltage.

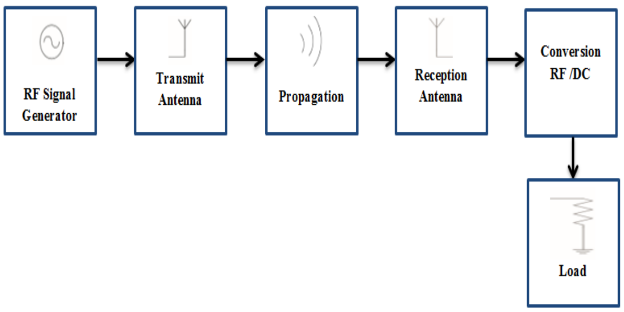

Fig. 1: A block scheme of the basic architecture of a MPT system

The core components of a rectifying circuit are presented in Fig. 2.

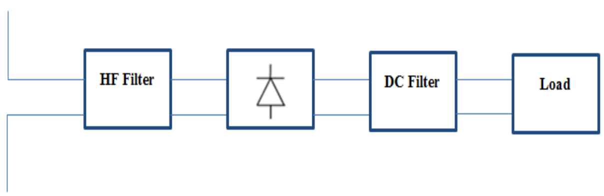

Fig. 2: The core components of a rectifying circuit

The HF filter helps to ensure that the antenna is correctly matched to the rectifying circuit and to preserve the antenna from re-irradiating the high order harmonics generated by the rectifier in order to maximize the power transfer [6]. The diode is a converter that rectifies the alternating current AC of the microwaves, and transforms it into a DC current. We mention that the diode is the most crucial component in a rectifier circuit. It mainly determines the RF-DC conversion efficiency. Semiconductor Schottky diodes are usually used for high frequency rectifiers because of their lower junction capacitance and voltage threshold in comparison to the common PN diodes [6].The DC filter (low-pass filter) blocks the high order harmonic frequencies generated by the output of the diode to protect the load and achieve high energy conversion efficiency.

Recently, the development of efficient MPT system to power MAVs has become a vital research topic. In this paper, microstrip patch antennas at 5.8GHz will be proposed, designed and fabricated for MPT system to a MAV.

2 RELATED WORK

The MPT system to a MAV has been studied in the Department of Aeronautics and Astronautics, at the University of Tokyo, as a part of the Japanese twenty first century Center of Excellent projects "Innovative Aerial Robot Project"[7][8][9]. Fig.3 illustrates the overall MPT system developed in this project. This system is divided into three subsystems: a tracking, a power-transmission, and a power-receiving subsystem.

Supposing a surveillance MAV works in a devastated area. For example, when its battery becomes low, it returns to the ground station. Thus, its battery is charged wirelessly and automatically by receiving the microwave beam transmitted from the transmitter while it is circling above the ground station without landing and take-off.

The concept of this MPT system is as follows: first, a pilot signal of 2.45GHz is sent from an antenna attached to a MAV to tracking antennas, each of which is provided for the x and y directions. The tracking subsystem receives the pilot signal transmitted, then it detects the current position of MAV via a software retro-directive mechanism and sends the information to the transmitter subsystem. Secondly, this last one uses this information in order to form and steer the microwave beam at 5.8 GHz to the MAV. Finally, in the receiving subsystem, a rectenna attached to the MAV receives the microwave beam and converts it into DC current to charge the MAV.

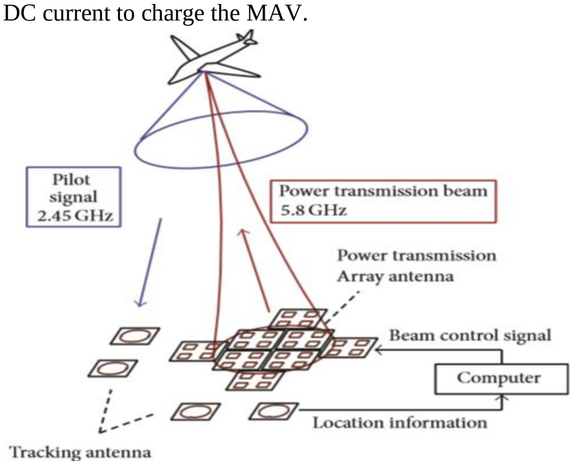

Fig. 3: Overview of Wireless Power transmission to a MAV [7]

In the literature, many kinds of MPT subsystems have been proposed. The next sections present a brief review of each subsystem.

2.1 Transmitter Subsystem

In [10,11], a 4x4 antenna array consisting of patch antennas operating at 5.8 GHz is developed. The single patch antenna presented a return loss (S11) of -22.5 dB at 5.7 GHz. The full 16 antennas array provides a gain of 16.8 dB and a S11 of -18.19 dB at 5.8 GHz. The authors in [7] proposed a microwave active phased array at 5.8 GHz having eight sequential rotated antennas (SRA). The phases of the antennas are shifted by six-bit phase shifters. Each element radiates a power of 0.7 W and the total transmit power is about 5.6W. In [9, 12], a phased array of five horn antennas operating at 5.8GHz was developed. Each horn antenna transmits 0.7 W of power which corresponds to a total power of 3.5 W. Each phase of microwaves was controlled by the six-bit digital phase shifters connected to a PC. Moreover, in [13], a phased array of five horn antennas have been also proposed but with a circular polarization by using a circularizer. In this case, it achieved a total power of 5 W.

2.2 Tracking Subsystem

A 2D tracking subsystem (x-y plane) can be developed to receive a microwave pilot signal at 2.45GHz emitted from the moving MAV to analyze its current position via a software retro-directive mechanism. In [12], the authors used two patch antennas placed in the rectangular coordinates to follow the MAV. The angles of incidence αx and αy of the pilot signal are computed and analyzed by a LabVIEW program. In [9], three patch antennas are used as tracking antennas so that each pair of antennas is capable of detecting the angles of incidence αx and αy of the pilot signal. In [13], four patch antennas placed in the (x-y) plane are used as tracking antennas so that in each direction there are two antennas. The angle of incidence of the pilot signal is calculated by a LabVIEW program.

2.3 Receiver Subsystem

In [10,11],the authors proposed a single circularly polarized square patch antenna at 5.8GHz for the rectenna system with a S11 of -13 dB and an axial ratio of 0.35dB. Furthermore, a single shunt RF-DC rectifier was designed, obtaining an efficiency of 70 % for an input power 20 dBm. In [12], an array of eight circularly polarized patch antennas connected in parallel is adopted as a receiving antenna for a rectenna system at 5.8GHz. In [13], a light-weight flexible rectenna was developed with a single circular polarized patch antenna by using a commercial felt pad as an antenna substrate and a copper tape as a microstrip antenna . The efficiency was maximum 45.3% when the input power was 63mW.In [9], a rectenna consisting of a circular polarized patch on a felt pad substrate was developed. The efficiency was 56%.

2.4 Synthesis

In our study, we will focus on the development of the transmitter and receiver subsystems. Based on the review gained in the previous section, we will propose our system. In order to obtain antennas with a small size, the frequency chosen is 5.8GHz .It has a smaller antenna aperture area, smaller components size and greater transmission ranges than 2.45 GHz [14].We have chosen microstrip patch antennas for both, the transmitter and receiver subsystems. These antennas are lightweight, conformable to planar structure, simple to replicate and manufactured with a low profile and compatible with modern printed-circuit technology.

Our proposed transmitter subsystem will consist of phased-array smart antennas .In fact, we propose to use smart antennas as emission antennas because they are reconfigurable and seem to be a promising way to form, control and direct the microwave beam towards the moving target (MAV). Thus, they can improve significantly the efficiency of MPT system as they concentrate the energy only in the desired direction (position of the MAV).

In the receiving subsystem, we propose to use a circular polarized CP square patch antenna array to complete the proposed system in [11], which consists of a single CP square patch antenna .Particularly, we will use the antenna array in order to increase the gain and the efficiency, and reduce the conversion loss of rectenna system. Indeed, the design of the square antenna array at reception was chosen because of its relevance in terms of power, size and directivity [15].Furthermore, as the MAV is circling, its yaw angle changes constantly [7].Then, in order to ensure a stable and constant power transmission regardless of MAV's yaw angle, a circular polarization is chosen for this antenna array. For a rectenna, circular polarization allows a nearly constant DC output even if the transmitting or receiving antennas change their directions in the space[14][15].

A wide number of techniques to generate circular polarized microstrip patch antenna CPMA are available in literature. The single-feed and dual-feed techniques are commonly used [16].The dual-feed technique provides a wider bandwidth for CPMA compared to the single-feed technique. Nevertheless, it requires a larger size for feeding network [17].Consequently, CPMAs with single-feed technique are currently receiving much attention. Several methods such as truncated corners, stubs ,slots and notches integrated onto the patch antenna have been reported to generate a circular polarization with this technique[18].The truncated corners method in which a symmetrically pair of a square patch corners are truncated, is widely used[18].We choose this method to reduce the array size [19] because the antenna array is intended to be implemented in a MAV. Further, it aims to avoid the degradation of the antenna array performances.

3 DESIGN, SIMULATION AND RESULTS

3.1 Proposed Transmitting Antenna

As a first step in designing the antenna array, we have started with a single antenna element which is a rectangular patch printed on a FR4 substrate (relative permittivity $\varepsilon r = 4.4$ and a thickness h=1.6mm) and feeding by a microstrip line having a characteristic impedance of 50 Ω.Using the design procedure presented in [20], we have calculated the dimensions of the patch at 5.8GHz.The antenna was designed, optimized and simulated by FEKO. We mention that the parameters of the antenna are studied by varying one of them and fixing the others .In effect, several optimization processes were applied by using FEKO until we get the desired frequency with the best performances of the antenna .Table 1 below shows the various optimized parameters, Fig.4 illustrates the geometry of the proposed antenna and Fig.5 presents the simulated return loss of our antenna.

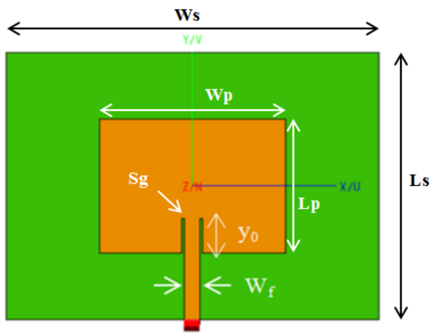

Fig. 4: Geometry of the proposed transmitting antenna

Table 1: Optimized Parameters of Proposed Antenna

Parameter	Value(mm)
Lp	11.6
Wp	15.5
Ls	23.2
Ws	31
Wf	3.08
Sg	0.15
Y0	3.43

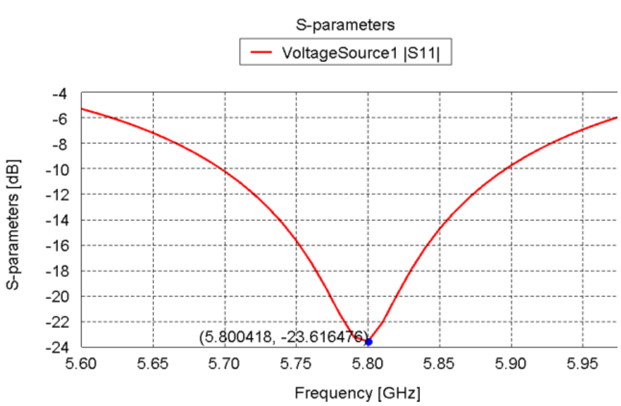

Fig. 5: Simulated S11 versus frequency

It can be observed clearly that the antenna resonates exactly at 5.8 GHz. The S11 parameter is equal to -23.61 dB (<-10dB) at the operating frequency 5.8GHz, which means good input impedance matching (the antenna is well matched to the impedance of 50 Ω).The simulated bandwidth at -10dB is 200 MHz which is from 5.69 to 5.89GHz.

Fig. 6 shows the 3D gain pattern of our antenna. We observe that the maximum gain is 5.2dB .It is perpendicular to the radiating element. This antenna radiates mainly in the broadside direction.

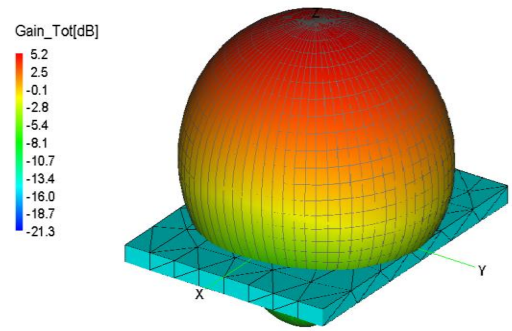

Fig. 6: 3D gain pattern of the transmitting antenna at 5.8 GHz

To obtain a good impedance matching, the feeding point must be placed at a specific position denoted by Y0. For that, a parametric study is done. Fig. 7 and Table 2 show respectively the effect of Y0 on the antenna's return loss and resonance frequency.

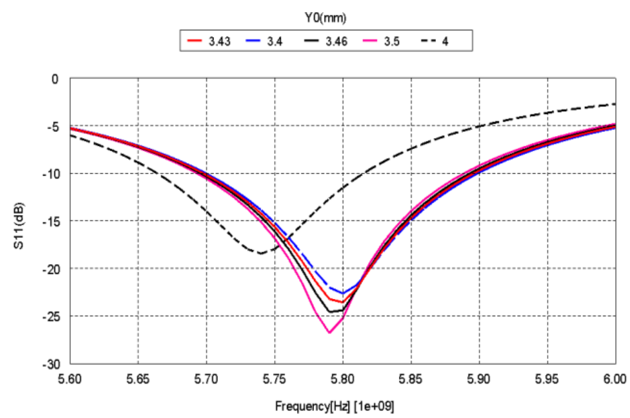

Fig. 7: Parametric study of S11 versus Y0

Table 2: Effect of Y0 on S11 and fr

Y0(mm)	frGHz)	S11(dB)
3.4	5.8	-22.7
3.43	5.8	-23.6
3.46	5.79	-24.6
3.5	5.79	-26.8
4	5.73	-18.5

It can be noticed that the S11 parameter and resonance frequency are affected by the positionY0.The optimal position is obtained for Y0=3.43mm which can provides a good impedance matching with a good S11 of -23.6 dB at 5.8 GHz.

We have manufactured the proposed antenna according to the aforementioned dimensions. Commercial FR4 substrate was used because it resists to heat and has excellent chemical and mechanical properties. The reflection coefficient S11 was measured using Vector Network Analyzer ANRITSU MS2026C. The photograph of the fabricated antenna is shown in Fig. 8.

Fig. 8: Photograph of the fabricated antenna

The measured and simulated values for the reflection coefficient are shown in Fig. 9. Table 3 presents the comparison between simulation and measurement results of the proposed antenna.

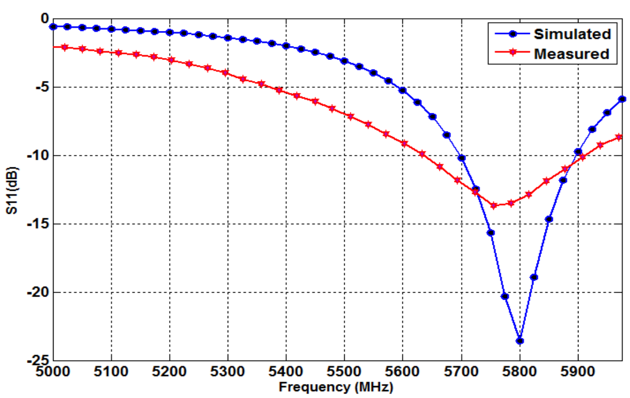

Fig. 9: Simulated and measured S11 versus frequency of the proposed antenna

Table 3: Comparison between Measurement and Simulation Results

Parameter	Simulation	Measurement
fr(GHz)	5.8	5.75
S11(dB) at 5.8 GHz	-23.6	-13
Bandwidth (MHz)	200	280

We have noticed that the curves are not exactly the same. The fabricated antenna resonates at the frequency 5.75 GHz instead of 5.8GHz obtained by simulation. This lag can be due particularly to the manufacturing errors (millimetric shifts in terms of dimensions of the antenna or the position of the feed), the measurement environment and the unknown loss of substrate used. The simulated S11 corresponding for the resonant frequency is low (-23.6dB) compared to the measured one (-13dB).Moreover, the measured bandwidth (280 MHz) is slightly larger than the simulated one (200 MHz). Despite these small shifts, we can consider that there is a good agreement between simulated and measured results.

Table 4 presents a comparison between the performances of the proposed antenna and developed antenna in [10] [11] .

Table 4: Comparison of Previous Antenna with the Proposed Antenna at 5.8GHz

Ref	S11 (dB)	Bandwidth(MHz)
Our work	-23.6	200(5.69 -5.89)
[10][11]	-21	130(5.72 -5.85)

The global results of our proposed antenna are satisfactory.

3.2 Proposed Receiving Antenna

We have started by the design of the single square patch element of the receiver array. The antenna was mounted on a FR4 substrate and fed by a coaxial cable (50Ω). Two symmetrical corners of the square patch were truncated with length T in order to achieve CP properties. The antenna geometry performed by FEKO is presented in Fig.10, while the corresponding optimized parameters are in Table 5.

The main performances of the proposed CP square patch antenna, such as the S11 parameter, axial ratio, and directivity are evaluated by simulations and presented respectively in Fig. 11, Fig. 12 and Fig. 13.

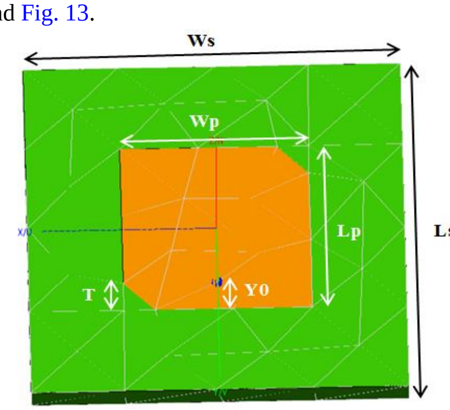

Fig.10: Geometry of the CP square patch antenna

Table 5: Optimized Parameters of CP Antenna

Parameter	Value(mm)
Lp	11.1
Wp	11.1
Ls	22.2
Ws	22.2
T	2.22
Y0	3.4

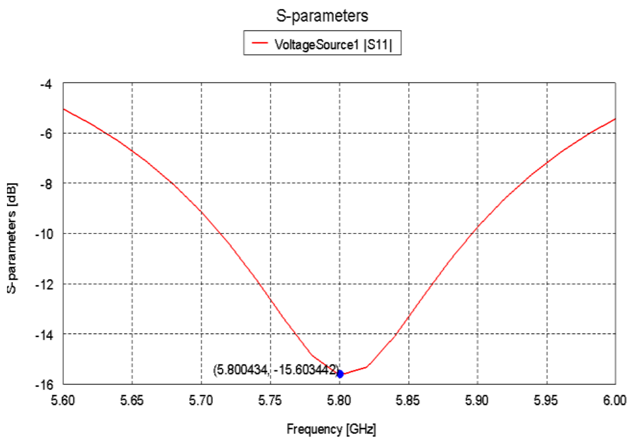

Fig. 11: Simulated S11 versus frequency of the receiving antenna

In order to achieve the desired CP operation, the Axial Ratio must be kept below 3dB .It is clear from the graphs that the proposed CP antenna provides eventually a good axial ratio of 0.314 dB and satisfies the return loss requirement (S11 = -15.6dB below -10 dB) at the operating frequency 5.8 GHz. The bandwidth is 183MHz which is from 5.713 to 5.896 GHz. The maximum directivity of 6.1 dB is achieved.

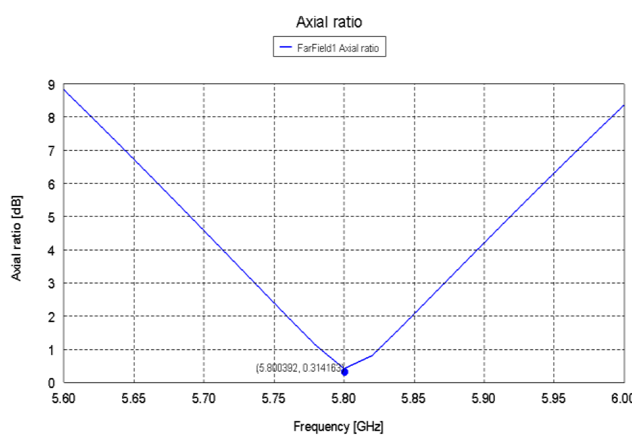

Fig. 12: Simulated axial ratio versus frequency of the receiving antenna

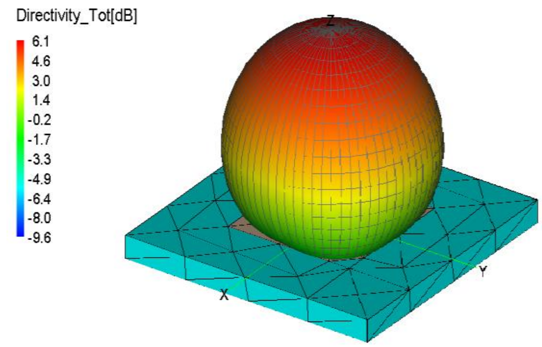

Fig. 13: 3D directivity pattern of the CP square patch antenna at 5.8 GHz

Fig. 14 and Fig. 15 present respectively the parametric study of S11 versus truncation's length T and parametric study of axial ratio versus T. Several optimization processes were applied by using FEKO to find the optimal value of T which gives the best axial ratio and minimum S11 at 5.8 GHz.In fact, we have tested for several values but we have chosen only the optimal value T = 2.2mm and two others close to this value T = 2 and T = 2.4 to show the influence of T on the resonance frequency, the S11 parameter and the Axial Ratio.

It can be seen that the performances (S11, resonance frequency, Axial Ratio) of CP antenna are affected by the truncation's length. The optimal value is T= 2.2mm which can provides a return loss of -15.6dB and an axial ratio of 0.314 dB at the operating frequency 5.8GHz.

Fig. 16 and Fig. 17 show respectively the comparison of S11 and Axial Ratio obtained by FEKO (MoM) and HFSS(FEM). The comparison of S11 and axial ratio between FEKO and HFSS is summarized in Table 6.

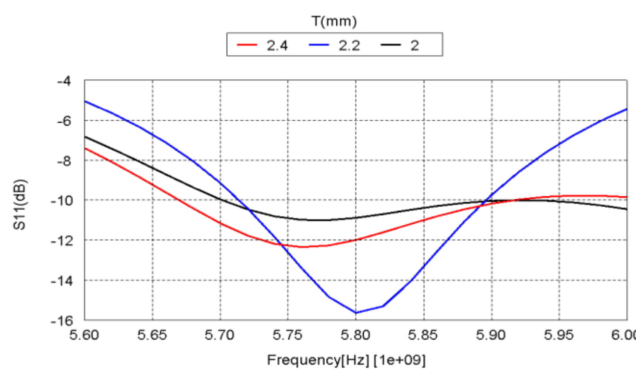

Fig. 14: Parametric study of S11 versus T

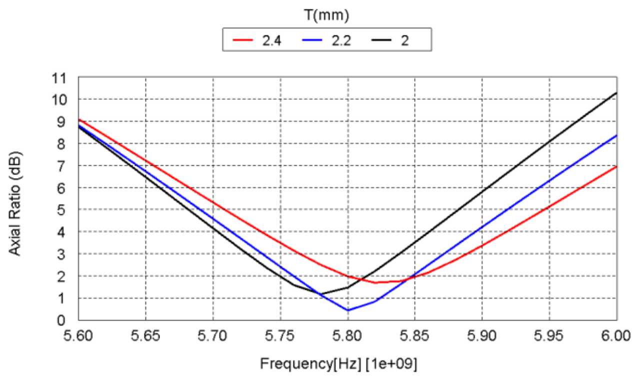

Fig.15: Parametric study of Axial Ratio versus T

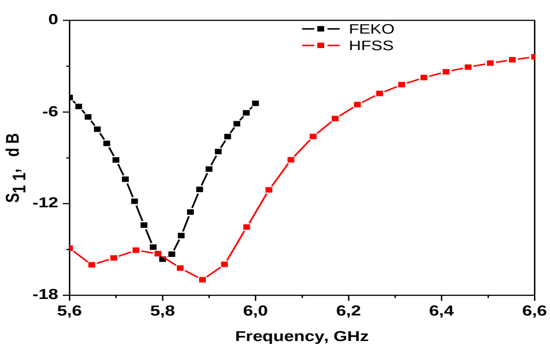

Fig.16: Comparison of S11 between FEKO and HFSS

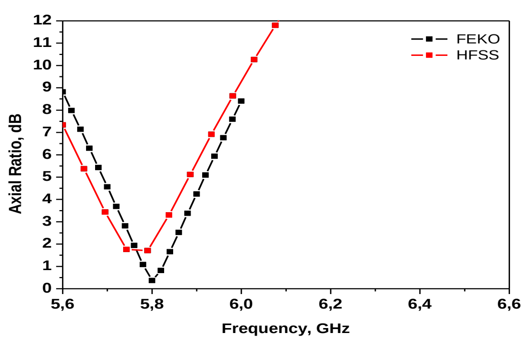

Fig.17: Comparison of Axial Ratio between FEKO and HFSS

Table 6: Comparison of S11 and Axial Ration between FEKO and HFSS

Simulator	Resonance frequency (GHz)	S11at 5.8GHz (dB)	Axial Ratio at 5.8GHz (dB)
FEKO	5.8	-15.6	0.341
HFSS	5.84	-15.5	1.5

There exist some differences in terms of resonance frequencies and Axial Ratio. For the Method of Moments (FEKO),the antenna resonates at 5.8 GHz while for the Finite Element Method(HFSS), this antenna resonates at 5.84 GHz .The Axial Ratio obtained by FEKO (0.341 dB) is better than that obtained by HFSS (1.5dB)at 5.8 GHz . We note that the S11 parameter at 5.8 GHz for the two methods is quite the same. By simulating the same antenna with different simulation platforms, we find that the results are not exactly the same because each one is based on a different method of calculation .In fact ,we have chosen FEKO because it is based on the method of moments (MoM) which remains the most accurate and fastest method among the numerical methods for the design of patch antennas with the best performances [21][20].

Table 7 presents a comparison between the performances of the proposed CP antenna and developed antenna in [10][11] .

Table 7: Comparison of Previous CP Antenna with the Proposed Antenna at 5.8GHz

Ref Ref	S11 (dB)	Directivity(dB)	Axial Ratio(dB)
Our Our work	-15.6	6.1	0.314
[10 [10] [11]	-13	5.7	0.35

It is clear that the performances of our antenna are improved compared to the proposed antenna in **[**10**][** 11**]** .

4 CONCLUSION

In this study, microstrip patch antennas at 5.8 GHz for wireless power transmission system to a MAV have been successfully designed, optimized and simulated using FEKO. The single patch antenna proposed for transmitter subsystem demonstrated a gain of 5.2 dB, a simulated return loss of -23.61 dB and a measured S11 of -13 dB at 5.8 GHz while the CP square patch antenna designed for receiver array presented a directivity of 6.1 dB , a return loss of -15.6dB and an axial ratio of 0.314 dB. Thereby, it is clear from these results that the proposed antennas are suitable for MPT system. Hence, the research can be extended further for designing, simulation, and manufacturing full transmitter and receiver arrays as future work.

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