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Research Article

Ultra Wideband Planar Microstrip Array Antennas for C-Band Aircraft Weather Radar Applications

Abdellatif Slimani,[1,2] Saad Dosse Bennani,[2,3] Ali El Alami,[1,2] and Jaouad Terhzaz[4,5]

[1]*Faculty of Sciences and Technics, University Sidi Mohamed Ben Abdellah, Fes, Morocco*
[2]*Laboratory of Renewable Energy and Intelligent Systems, University Sidi Mohamed Ben Abdellah, Fes, Morocco*
[3]*National School of Applied Sciences, University Sidi Mohamed Ben Abdellah, Fes, Morocco*
[4]*CRMEF, Casablanca-Settat, Casablanca, Morocco*
[5]*Mohammadia School of Engineers, University Mohammed V, Rabat, Morocco*

Correspondence should be addressed to Abdellatif Slimani; abdellatif.slimani@usmba.ac.ma

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A miniaturized ultra wideband (UWB) planar array antennas for C-band aircraft weather RADAR applications is presented. Firstly, the effect of the ground plane is studied. Later, the realization and experimental validation of the geometry that has an UWB characteristic are discussed. This array antennas is composed of a twenty-four radiating element that is etched onto FR-4 substrate with an overall size of $162 \times 100 \times 1.58$ mm^3 and a dielectric constant of $\varepsilon_r = 4.4$. The results show that this miniaturized array antennas gives us a bandwidth which is about 115% and a gain greater than 13 dB which are required in aircraft weather radar applications.

1. Introduction

Weather system radar, also called weather surveillance radar (WSR), is a type of system that is used to locate precipitation and estimate its type (snow, rain, etc.). Nowadays, various frequency bands are assigned in this system, for example, S, C, X, and K bands. The band covered in this paper is C which included in the UWB range frequency allocated by the FCC (Federal Communications Commission) [1].

Aircraft weather measurement radars specifically use antennas which have a high characteristic radiation that treat the atmosphere by transmitting and receiving radio waves, for discovering the weather condition (Figure 1) [2–4]. They are very complex electromagnetic systems, which are generally composed of many different components which are as follows: power source, transmitter, antenna, duplexer, receiver, and screen.

The optimum transmission of radio waves by the radar requires antennas that have good radiation performance. In this paper, our target is dedicated to optimize the radiation performance and the beam steering of antenna component [5–7]. For that, microstrip array antennas are selected [8–12].

In this paper, we tried to work on UWB (ultra wideband) patch antennas. The term UWB commonly refers to systems that either have a large relative bandwidth [1]; this technology is known by a lot of advantages, especially in term capacity of channels and data transfer rate. The FCC is informed that any antenna has a bandwidth equal or greater than 500 MHz, and this bandwidth is included in the frequency range of 3.1 GHz to 10.6 GHz which is valid for UWB communication systems, which based on narrow pulses to transmit data at extremely low power [2, 13, 14].

Firstly, our objective in this manuscript is the conception and realization of an array antennas with a high radiation performance and UWB characteristic, which is a continuation of another work [15]. The design of this array antennas is down using a methodology well detailed in the paper [16] and based on the two electromagnetic simulators HFSS and CST. Finally, we made a comparison between simulation

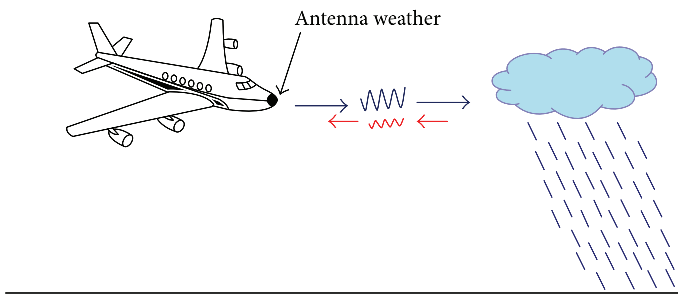


Figure 1: The aircraft weather radar.

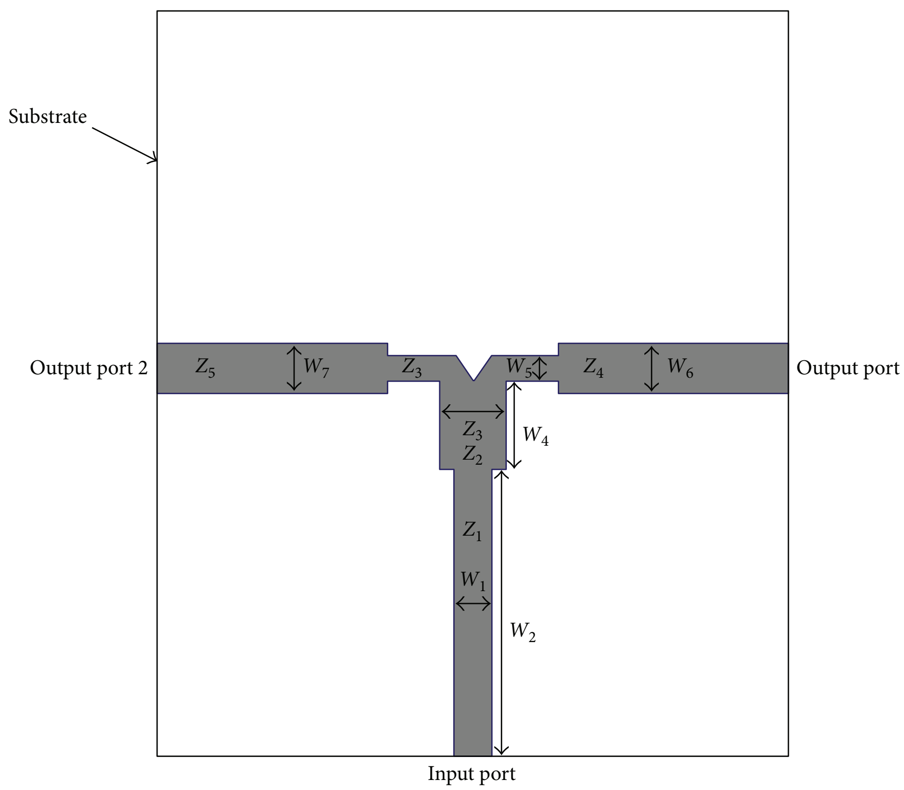


Figure 2: T-junction power divider.

and experimental result in terms of bandwidth and adaptation performances.

This paper is divided into four principal parts, such as in section 2, the proposed array antennas geometry and technique design are presented. In section 3, we presented a discussion and comparison between simulation results. Finally, in section 4, a discussion and comparison between simulation results and experimental results were presented.

2. Methods and Materials

In this paper, a standard T-junction power divider (Figure 2) is used to divide power equally to two principal parts of array antennas (left and right parts (Figure 3)) [17, 18].

$$Z_3 = \sqrt{\frac{Z_1 \cdot Z_4}{2}}. \quad (1)$$

In the designing of the feed array, we have to consider the reflection levels and electrical lengths of the bends. Removing a part of the area of metallization in the bend's corner can reduce the reflection level of the bend. The percentage mitre is the cut-away fraction of the diagonal between the inner and outer corners of the unmitred bend (Figure 4).

The optimum percentage mitre is given by [19].

$$M = \left(\frac{100^x}{e}\right)\% = \left(52 + 65\exp^{(-1.35\,W_i/h)}\right)\%, \quad (2)$$

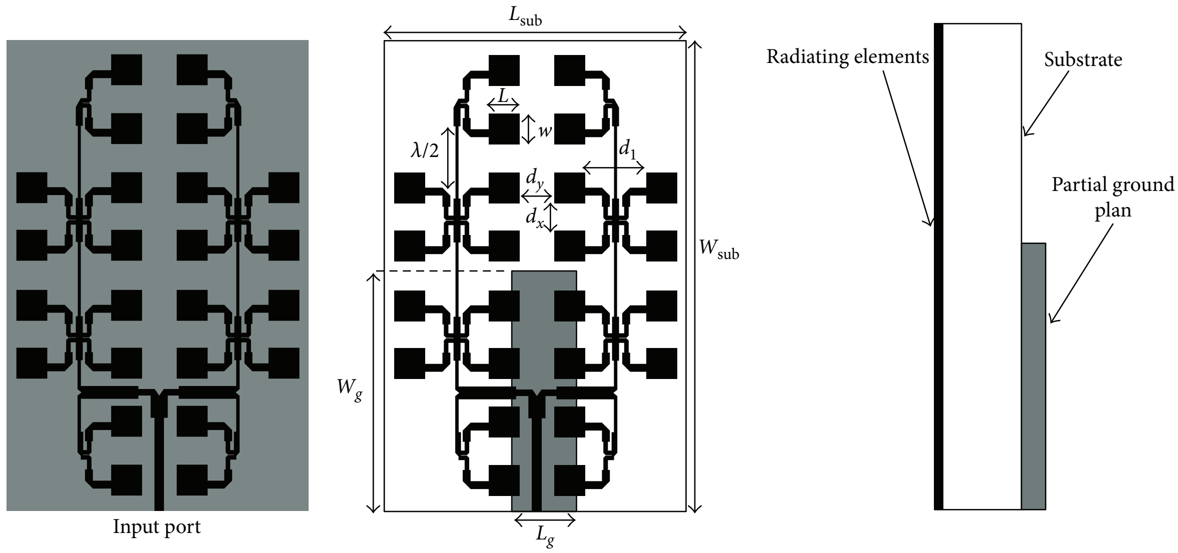


Figure 3: Geometry of the proposed UWB array antennas. (a) Array antennas with total ground plan, (b) array antennas with partial ground plan, and (c) the side view of the array antennas.

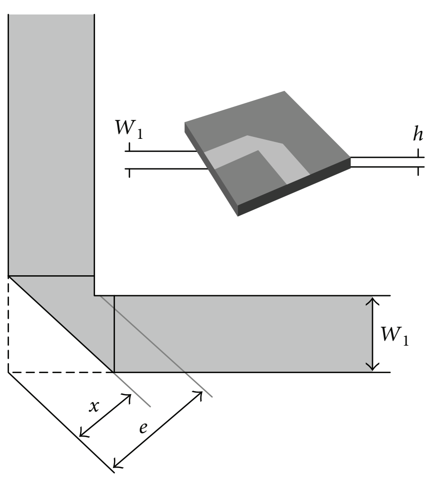


Figure 4: Microstrip mitred bend.

where h is the thickness substrate, $W_i/h \geq 0.25$, and dielectric constant $\varepsilon_r \leq 25$.

For our array antennas design (Figure 5), we give e for each corner and we calculate the value of x by applying (2). Table 1 shows the results obtained.

The characteristic impedances of microstrip lines which are used for feeding array antennas elements are given in Table 2.

The geometry of the proposed UWB array antennas is depicted in Figure 3. Figure 3(a) represents array antennas with total ground plane, while Figure 3(b) represents array antennas with partial ground plane. The antennas are located on the x-y plane, and the normal direction is parallel to z-axis. There are prints on FR-4 epoxy substrate with a dielectric $\varepsilon_r = 4.4$, thickness $h = 1.58$ mm, and a loss tangent $\delta = 0.02$. These array antennas are excited by a 50 Ω source power.

Table 3 shows the geometric parameters of our array antennas that have been calculated by the use of the relation cited in the paper [12].

3. Simulated Results and Discussion

In this part, we made a comparison between the simulation results found by HFSS and CST, before moving to experimental validation of the geometry that gives us the desired results.

3.1. T-Junction Power Divider. Figure 6 shows the input impedance of the power divider as a function of the frequency, such that the black curve (continuous) represents its imaginary part, while the red curve (dotted) represents its real part. We can observe that the real part is equal to 50 Ω, and the imaginary part is equal to zero. So the input impedance of our divider is well modeled with the source impedance.

3.2. Effect of Ground Plane in the Performance of Array Antennas

3.2.1. Return Loss. Figures 7 and 8 show the comparison return loss simulation between the patch array antennas with partial and total ground plane. If we observe the evolution of the returns loss, we can see that for the partial ground plane case, we have an adaptation over the entire desired band, with a S_{11} less than −10 dB (Figure 8), which justifies that this array antennas is an UWB.

In other hand, for the total ground plane case (Figure 7), we can observe that the return loss is not adapted over the whole band C. So, this array antennas is not an UWB on all C-band. This distortion of the return loss amounts to the mutual coupling result between the radiating elements and ground plane, such as the waves radiated by the radiating

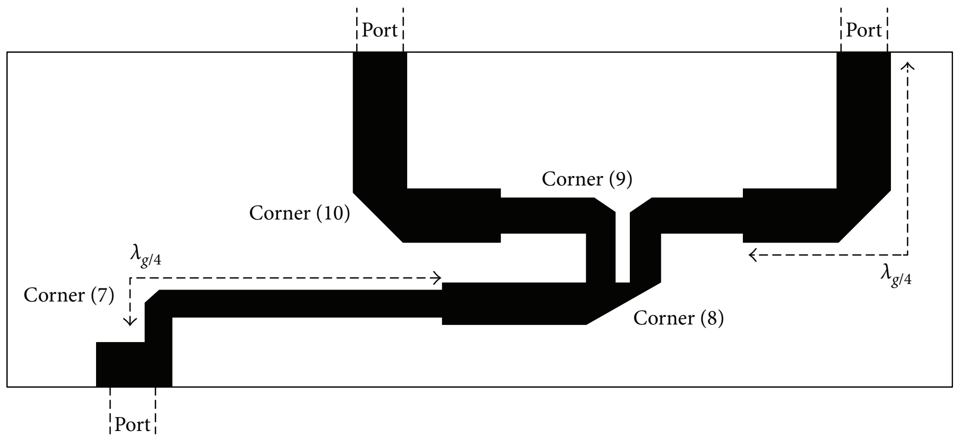


FIGURE 5: Power divider with mitred bend.

TABLE 1: Parameter corners of the proposed array antennas.

Corner	e_i(mm)	x_i(mm)
7	0.67	0.4
8	3	1.7
9	1.1	0.6
10	2.9	1.65

TABLE 2: Microstrip line impedances.

Impedance	Value (Ω)	Impedance	Value (Ω)
Z_1	44	Z_7	87.1
Z_2	33.9	Z_8	72
Z_3	54	Z_9	80.6
$Z_4 = Z_5$	40.4	Z_{10}	60

TABLE 3: Parameters of the proposed array antennas.

Parameter	Value (mm)	Parameter	Value (mm)
W_1	3.5	W_{13}	2.2
W_2	28.7	W	10.5
W_3	5.2	L	10
W_4	$\frac{\lambda_g}{4}$	W_{sub}	162
W_5	2.5	L_{sub}	100
$W_6 = W_7$	4	W_g	82.6
W_{10}	1	L_g	21.2
W_{12}	1.2	d_x	9.5
W_{11}	1.5	d_1	12

elements and guided by the substrate, towards the total ground plane, its return totally towards the radiating elements, which produces a mutual coupling between radiating elements, and makes a disruption and mismatch of the array

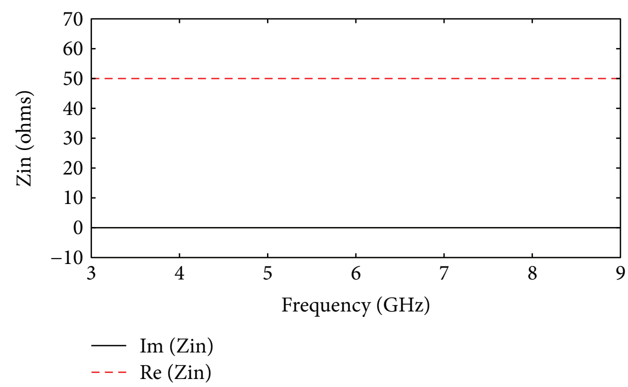


FIGURE 6: Input impedance of T-junction power divider.

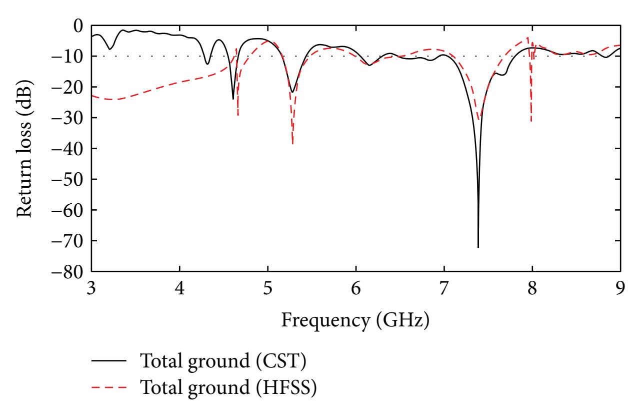


FIGURE 7: Return loss comparison between HFSS and CST for the array antennas with total ground plane.

antennas. For that, in UWB applications, we do not use array antennas with total ground plane.

From the result shown in Figure 8, we observed that the array antenna with partial ground plane has a bandwidth with UWB characteristic. The S_{11} is lower than −10 dB from 3.4 GHz to 9 GHz, which is about (115%), and it covers the standard of IEEE 802.15a (3.1–10.6 GHz) fixed by the FCC.

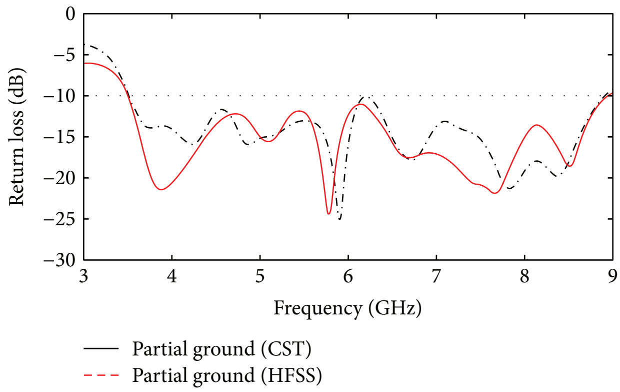


Figure 8: Return loss comparison between HFSS and CST for the array antennas with partial ground plane.

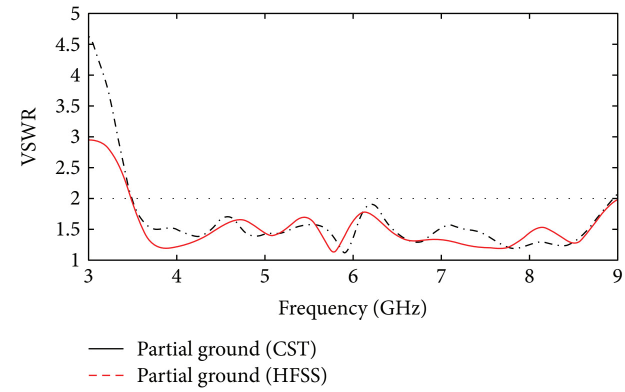


Figure 10: VSWR comparison between HFSS and CST for the array antennas with partial ground plane.

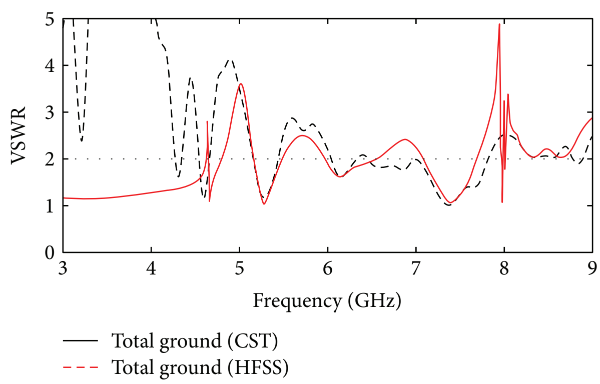


Figure 9: VSWR comparison between HFSS and CST for the array antennas with total ground plane.

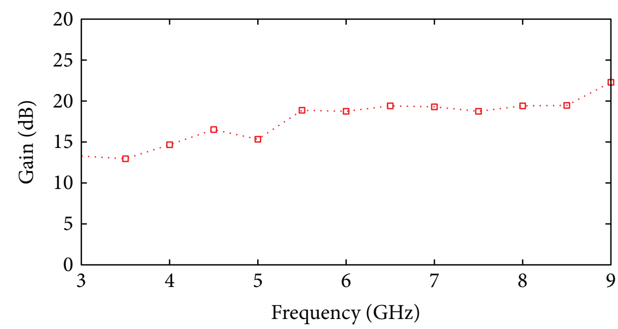


Figure 11: Gain versus frequency.

For CST simulation, we can observe that this array antennas has three resonant frequencies which are $f_{r1} = 6$ GHz, $f_{r2} = 6.8$ GHz, and $f_{r3} = 7.8$ GHz, and four resonant frequencies for HFSS are $f_{r1} = 3.8$ GHz,$f_{r2} = 5.2$ GHz,$f_{r3} = 5.8$ GHz, and $f_{r4} = 7.7$ GHz.

3.2.2. Voltage Standing Wave Ratio (VSWR). Figures 9 and 10 show the simulated VSWR for both patch array antennas. The result simulations indicate that the VSWR of the array antennas with partial ground plane is less than 2, over the bandwidth range of 3.4 GHz to 9 GHz, which includes all C-band. However, the VSWR of the array antennas with total ground plane is greater than 2 in a lot of frequency of the desired band, which do not respect our objective, consisting of the UWB characteristic in all C-band.

Since our objective is to have an UWB array antennas which covers all C-band, the simulation results show that the array antennas with partial ground plane is suitable for our application.

3.3. Gain Versus Frequency. Figure 11 shows the gain of our array antennas with partial ground plane in the UWB frequency range. In most of the frequencies between 3 GHz and 9 GHz, the gain increase is between 13 dB and 23 dB. Therefore, we can notice that our array antennas has a high gain in all of the band C.

3.4. Far-Field Radiation Pattern. Figure 12 shows the polar radiations of microstrip array antennas with partial ground plane in 2D, between HFSS and CST at the resonance frequency 6 GHz. Figure 12(a) shows the polar gain radiation pattern in E-plane (x–z), and Figure 12(b) shows the polar gain radiation pattern in H-plane (y–z).

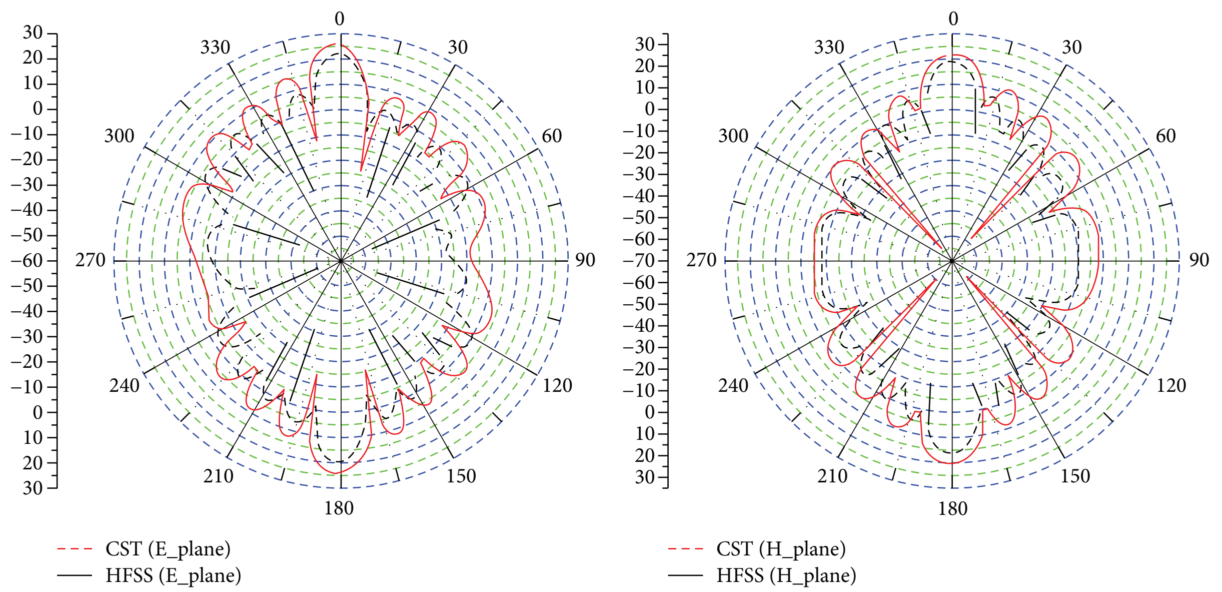
According to Figure 12, we can observe that our array antennas has a bidirectional radiation pattern directed towards the desired directions (End-Fire).

In the E-plane, we can see that it has six secondary lobes. It is the same for the H-plane, where there are six side lobes with a main lobe directed to the desired angle. The level of the main lobe gain can reach 23.

Finally, the results of the UWB array antennas present the best performance in terms of adaptation, bandwidth, and gain. These performances are summarized in Table 4.

4. Fabrication and Experimental Results

According to the simulation results, the array antennas with partial ground plane has good characteristics in terms of bandwidth (including all C-band) and radiation pattern. These results lead us directly to its experimental validation, where the prototype is connected to SMA-female connector.



(a) (b)

Figure 12: Comparison of 2D gain radiation pattern of the proposed array antennas. (a) E_plane in CST and HFSS and (b): H_plane in CST and HFSS.

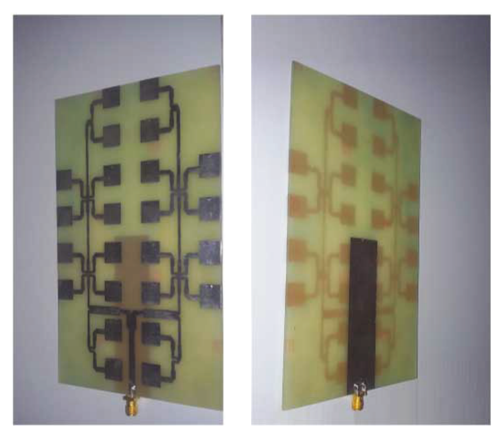
Table 4: Compared result between HFSS and CST.

Array antennas	Bandwidth (%)		Gain (dB)	
	HFSS	CST	HFSS	CST
[9]	72	71	4–6.61	4–5.87
[10]	71	73	7–13.46	7–13.14
[15]	115	115.1	13–20.7	11–21.2
[16]	115	115.1	13–20.7	11–21.2
This work	115.1	115.2	13–23	12.5–22

It is tested using VNA-network analyzer in collaboration between our laboratory of renewable energy and intelligent systems and the laboratory of electronic and communication. Its photos are shown in top and bottom view in Figure 13 while Figure 14 represents its dimensions.

4.1. Return Loss. Figure 15 shows the comparison between the simulated and measured results of the return loss. From the results, we can conclude that this array antennas is satisfactory, because we need an UWB array antennas which contains all C-band in our radar application. So from these results, we can observe that this array meets this requirement, such as $S11 \leq -10$ dB from 3.4 GHz to 8.7 GHz with a bandwidth of 5.6 GHz with several resonance frequencies close to 3.7 GHz, 7 GHz, and 8.2 GHz. So the important thing in the impedance bandwidths of experimental result is able to cover the desired frequency band 4–8 GHz.

4.2. VSWR. Figure 16 represents a comparison between simulated and experimental VSWR results. We can note that the three results are clear and that their values are less than 2 on all band of 3.4 GHz to 9 GHz.



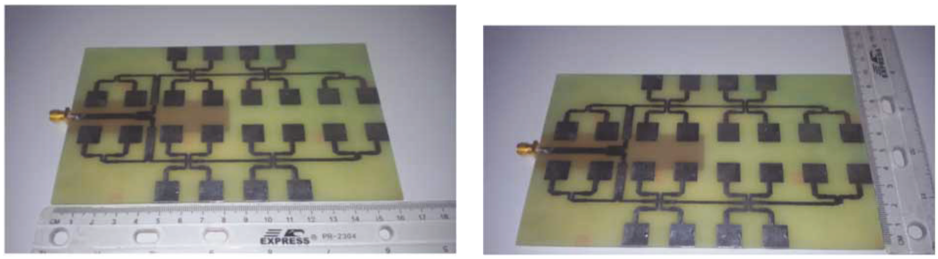
(a) (b)

Figure 13: Geometry of realized UWB array antennas. (a) Rectangular radiating elements in the top view of array antennas. (b) Partial ground plane in the bottom view of array antennas.

Finally, the proposed UWB array antennas has a good characteristic in terms of several parameters. Table 5 gives us a conclusion and comparison between simulated and experimental results obtained.

5. Conclusion

In this paper, the ultra wideband planar array antennas for C-band aircraft weather radar applications has been presented, which composed of a twenty-four radiating element.



(a) (b)

Figure 14: Dimensions presentation of the realized UWB array antennas. (a) Length of array antennas. (b) Width of array antennas.

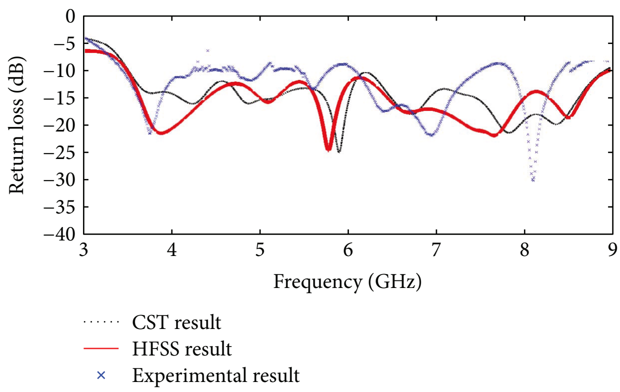


Figure 15: Comparison between simulated and experimental return loss result of our array antennas.

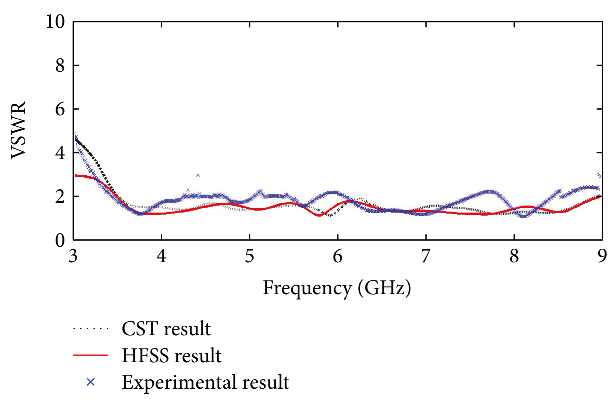


Figure 16: Comparison between simulated and experimental VSWR result of our array antennas.

The simulation results show that the array antennas with partial ground plane has a best performance than the array antennas with total ground plane in terms of matching and bandwidth which allowed us frankly to validate it experimentally.

The proportionality between the simulation and the measurement results with the high radiation performance over an ultra wide frequency range from about 4 GHz to higher than 8 GHz benefits this array antennas to be good candidates in C-band aircraft weather radar application.

Our perspective is to draw up and plot the measurement radiation pattern, because in our country, there is no an anechoic chamber to make these measurements of the field.

Table 5: Comparison between measured and simulated results.

		Bandwidth (%) at −6 dB	Bandwidth (%) at −10 dB	Resonant frequency	Level S11 (dB)
Simulation result	HFSS	119	115	3.8 GHz	−22
				5.2 GHz	−16
				5.8 GHz	−25
				7.7 GHz	−22
	CST	119	115	6 GHz	−26
				6.8 GHz	−16
				7.8 GHz	−21
Experimental result		117	110	3.7 GHz	−22
				7 GHz	−22
				8.2 GHz	−30

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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