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Design, Simulation, Realization and measurement of a 3.5 GHzlinear patch antenna network

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ABSTRACT

This paper presents the development of a uniform linear patch antenna array on FR4 substrate and operating at the frequency of 3.5GHz for satellite reception. The rectangular patch antenna array (7x1) with coaxial cable feed was designed and simulated using CST (Computer Simulation Technology) Microwave Studio software. The performance of the designed antenna was compared to that of the rectangle single patch antenna in terms of voltage standing wave ratio (VSWR), bandwidth, directivity, radiation pattern and gain. The array antenna was then fabricated on an FR4 substrate with a dielectric constant of 4.3 and a thickness of 1.6 mm, respectively. Thearray antenna was measured in the laboratory using a network analyzer (VNA) and the results show good agreement with the simulated performance of the array antenna.

***Keywords* -** antenna array, CST Microwave, VNA network analyzer, FR-4 substrate

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I. INTRODUCTION

The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper. In the literature, patch antennas have been the subject of several studies [1-4]. These studies show that they can take many forms; rectangular, square, circular or simply a dipole. These shapes are the most common because they are very easy to analyze and manufacture, but also have a very interesting radiation pattern. Although having multiple advantages, it also has several disadvantages such as low gain, narrow bandwidth and low efficiency. These drawbacks can be overcome by building an antenna network.

In this article, we present the design of a rectangular (7x1) patch antenna array with coaxial cable as a feed method. The 7x1 patch array antenna was then fabricated on the FR-4 substrate with a dielectricconstant of 4.3 and a thickness of 1.6 mm. Thisantenna offers a reflection coefficient of -19.18 dB and a VSWR of 1.35 and a coupling between antennas on average -24.23 dB. More significantly, according to the rigorous simulation study using CST Microwave software, the 7x1 antenna array outperforms the single patch antenna in terms ofradiation gain, directivity and bandwidth. This work is organized as follows. Section II describes the design, synthesis and measurements of the antenna. Section III presents the results and finally, sectionIV concludes the work.

II. ANTENNA DESIGN

In designing a patch antenna, many substrates can beused to achieve good response and their dielectric constants are generally in the range of $2,2 \leq \varepsilon_r \leq 12$. The most desirable substrate for good antenna performance is normally a thick substrate where the dielectric constant is at the lower end. This is due to the fact that this range offers better performance compared to the thin substrate. RT Duroid 5870 was originally chosen as the substrate because it has a low loss tangent which does not reduce antenna efficiency and has a relatively low dielectric constant. But, it was replaced by FR4 because the cost of using RT Duroid 5870 is too high. Comparatively, FR4 has a higher dielectric constant which results in a smaller patch size, high tangent loss, and lower gain. The performance evaluation of the array antenna is therefore carried out once the patch antenna has been established. The specifications of the rectangular antenna are listed intable1.

TABLE1: Specific characteristics of the rectangular patch antenna

Working frequency f_o	3,5 GHz
Substrate	FR4
Dielectric permittivity of thesubstrate	4,3
Height of dielectric substrate	1.6mm
Tangential losses of the substrate	0 ,018
Ground plane thickness	0.035 mm

A- Conception of patch antenna:

The objective of this part is to design a single micro- ribbon patch antenna composed of a patch and a coaxial cable for the power supply. To determine the dimensions of a rectangular patch antenna, the operating frequency, dielectric constants and substrate thickness must be known. The method of analysis used for the determination of physical dimensions is that of transmission line theory and is presented in several steps as follows [5]. The coaxial cable feed or probe feed is a technique widely usedto feed micro ribbon antennas (fig.1). In this case theinner conductor of the coaxial connector passes through the dielectric and is soldered to the patch, while the The main advantage of this type of feed is that it can be applied to any chosen location inside the patch, with ease of manufacture.

However, this method has drawbacks in terms of the radiation pattern and losses appear with the drilling of the ground plane, the dielectric as well as the plated element [1,6].

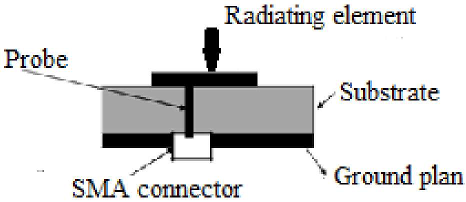

Figure 1: Micro ribbon antenna fed by probeB- Patch antenna network

The antenna array to be studied is linear and uniform (distance between antennas identical) and consists of seven printed antennas (rectangular patch antennas) regularly spaced on an axis with a distance d (the pitch of the array) of forty millimeters [7-10].

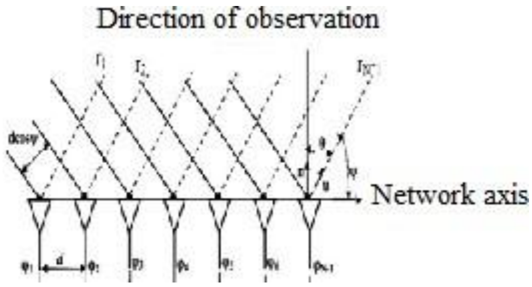

Figure 2: Geometry of the linear network.

Each source has a radiation pattern f(φ) and is supplied with phase according to an illumination lawdefined by:

$$F(\varphi) = \sum_{N} A_N \cos\left[(2N-1)\varphi\right] \quad (1)$$

Where A_N is the network factor which depends to the pitch of the network and its law of illumination. For regular linear networks made up of identical radiating elements, the field radiated by the networkin one direction $F(\varphi)$.

D- Simulations under CST Microwave

Table3 shows measured and simulation values obtained to have the best design. Since the desired design is the network configuration, simulations for a single antenna are not very extensive. The unique patch antenna design is required for performance comparison with the patch array antenna. Theantenna was simulated using CST Microwave software. However, only the patch array antenna wasmanufactured as in fig.3. The size of the manufactured antenna is 280x52mm. We got the dimensions below the antenna using the equations from (1) to (6).

TABLE2: Specific values of model

Type d'antenne		Longueur du patch (mm)	Largeur du patch (mm)	S11(dB)	VSWR	Directivité (dB)	Gain (dB)	Largeur de Bande (MHz)
Antenne unique	Calcul	35.9	31.7	--	--	--	--	--
	Après simulation	52	38,8	-33.81	1,041	7.080	6,68	86
7x1	Simulation	280	52	-21.08	1,35	13.020	12.8	76
	Mesures	280	52	-19,18	--	--	13,02	79

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The network obtained is presented in figure 3:

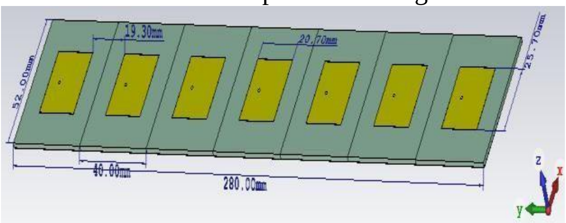

Figure3: Structure of the antenna array of seven elements.

E-Network realization

Taking into account the design steps, we made our prototype of the antenna array as shown in Fig.4, using as a substrate type FR4 having a permittivity relative $\varepsilon_{r=}$4,3 and thickness h=1.6 mm with two layers of 0,035mm.

Figure4: Manufacture of the rectangularpatch antenna array with 7 elements.

III. PRESENTATION DES RESULTATS ET DISCURSSIONS

A- Simulation results

- Network gain in 2D

Fig.5 is the simulated radiation pattern of a single plate antenna with a directivity of 6.680dB and a gain of **6.60dB**. Fig.6 is the simulated network radiation pattern with directivity and gain of **13.020dB and 12.8dB** respectively. As the two radiation patterns have been compared, it can be concluded that the array design antenna generates more intensity or focus at the center of the radiation.

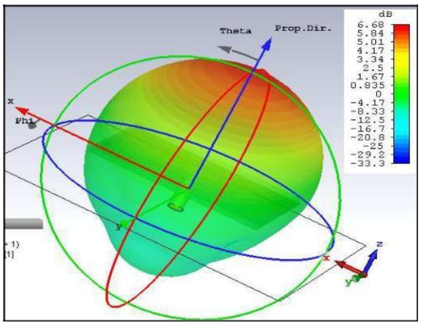

Figure5: 2D gain of a patch antenna.

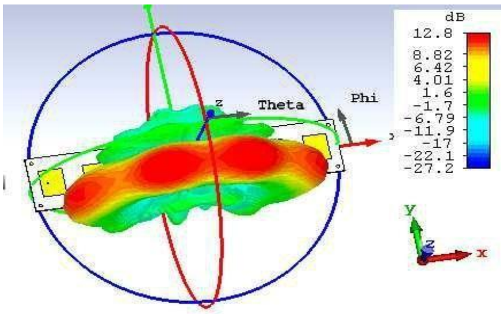

Figure6: Gain in 2D of the linear network for N = 7.

- Network radiation pattern:

In principle we expected a fully rounded radiation pattern on the E plane, but Fig; 7b shows a radiation pattern with maximum amplitude ripples of around -1.975dB.

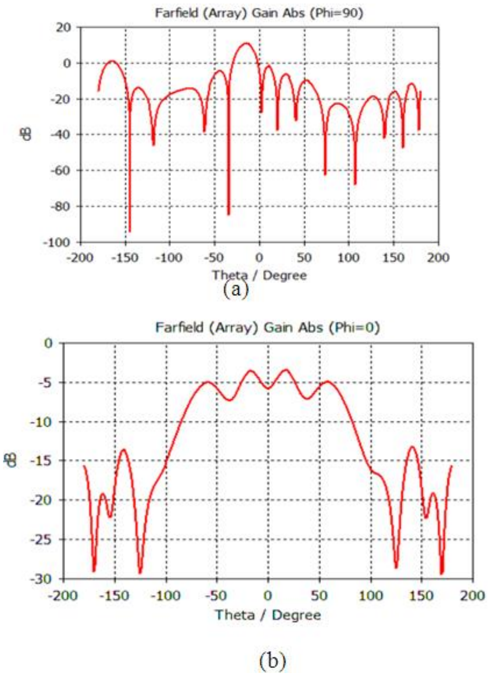

Figure6: Cartesian gain of the linear network for N = 7: a) plane H, b) plane E.

- Reflection coefficient and coupling coefficient between antennas

Fig.7a shows the reflection coefficient obtained on each element of the network, the second antenna along the OX axis of the network is the one with the highest reflection coefficient, -17.26dB. The averagereflection coefficient across the network is - 21.08dB. On the other hand, fig.7b represents the transmission coefficient which exists between our different antennas, the average coupling between antennas obtained and rated at -20.74dB. Thebandwidth it is 76 MHz.

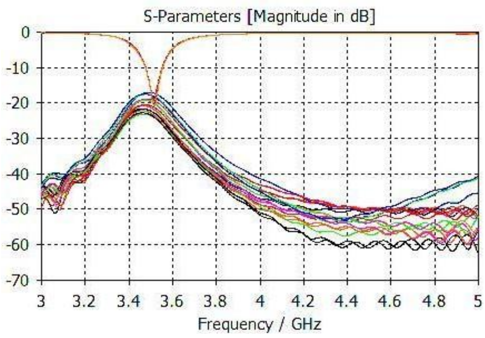

Figure 7: a) Reflection coefficient, b) Transmission coefficient for N = 7.

We find that the network has low radiation at the ends of the network and strong towards the center, this may be due to coupling effects. The edge elements see an edge and do not undergo the same coupling. All antennas would radiate the same if only the edge effects observed at the ends were negligible.

- Standing wave report

Fig.8 and Fig.9 show the standing wave ratio (VSWR) for the single antenna and the array antenna. At the center frequency of 3.5 GHz, the VSWR value is 1.041.

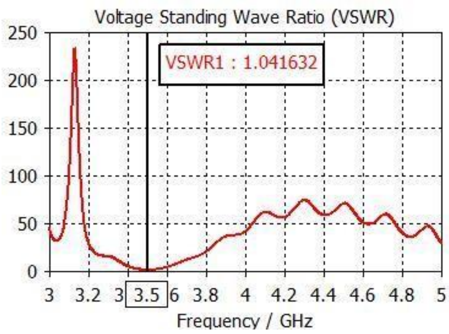

Figure 8: Single antenna standing wave ratio.

Figure 9 on the other hand is the VSWR value foran array antenna. The VSWR is 1.35 at the center frequency of 3.5GHz.

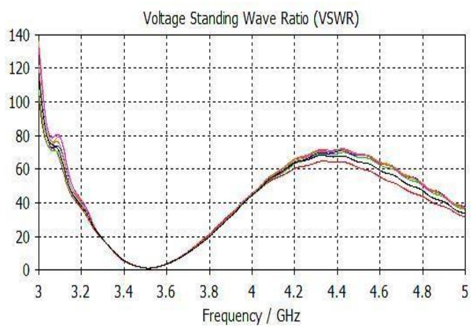

Figure9: Rapport d'onde stationnairedu réseau linéaire

B- Comparative study of theoretical and practical results

-Reflection Coefficient

Fig.10 shows the reflection coefficient of an array of microstrip patch antennas for both simulation and measurement. The result of the simulation gives a reflection coefficient of -21.08 dB at theoperating frequency 3.5 GHz while the result of

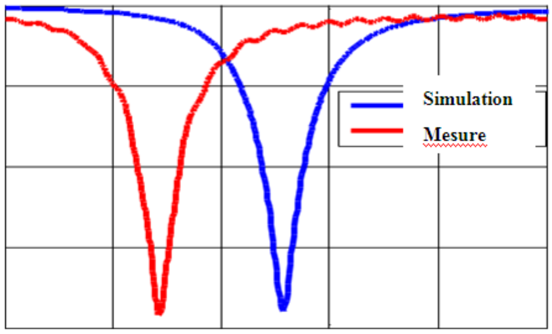

Figure10: Reflection coefficient of 7rectangular patch antennas

Fig.11 show the transmission coefficient obtained during the simulation (S21=-20.74dB) and measurements (S21=-24.23dB) of the antenna network.

After measurements, we observe a significant drop in the transmission coefficient between antennas at the working frequency, what should be noted is that this practical result is better because we have made the measurement on the central element of the network. We observed a much higher coupling at theantennas located at the ends of the array, this is reflected in the decrease in the radiated power and in the distortion of the radiation pattern as we observed in the simulation.

This result can also be justified by the fact that on the ox axis of our network we observe at the ends a high concentration of the electric field generally called edge effects which prevents or decreases the radiation of the antennas located in this periphery.

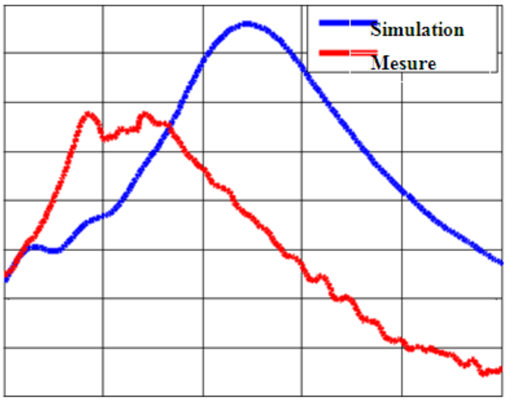

Figure11: Transmission or couplingcoefficient.

IV. CONCLUSION

A rectangular micro-ribbon array antenna fed by coaxial cable was designed, simulated and compared to the single rectangle antenna. The performance has been measured and shows that the array antenna exceeds the single antenna in terms of directivity, bandwidth and gain. The design of the final array antenna was manufactured, and the performance was compared to that of the simulated array antenna. Overall, the performance of the array antenna meets the desired requirements in terms of reflection coefficient and coupling between antenna. The reflection coefficient obtained during the simulation is equal to -21.08 dB and VSWR is 1.35 at the center frequency of 3.5 GHz. However, the center frequency was shifted by approximately 6.8% from the simulated value. It should be noted that the permittivity of FR4 can vary from 4.3 to 4.9 depending on the batch. The bandwidth measured at S11 <-10 dB is 79 MHz compared to 76MHz obtained during the simulations, the coupling parameters went from - 20.74dB obtained during the simulation and improved during the measurements because it decreased to be at -24.23dB. We noticed that the elements of the network with equivalent characteristics did not radiate in the same way, we conclude that this was due to edge effects. All the results obtained by simulations and by measurements have been organized in a table so that it is easily usable.

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