Design and Analysis of Directive Microstrip Patch Array Antennas with Series, Corporate and Series-Corporate Feed Network

H. Errifi, A. Baghdad, A. Badri, and A. Sahel
EEA and TI Laboratory, FST, Mohammedia, Morocco
Email: errifi.hayat@live.fr

***Abstract*—In the recent years the development in communication systems requires the development of low cost, minimal weight and low profile antenna that is capable of maintaining high performance over a wide spectrum of frequencies. This technological trend has focused much effort into the design of a microstrip patch antenna. The aim of this paper is to design and simulate a rectangular microstrip patch array antenna using HFSS software "Ansoft-High Frequency Structure Simulator" and compare the performance of 2 elements, 4 elements, 8 elements, and 16 elements patch arrays with that of a single patch for the same operating frequency. Also comparisons are made between the performance of series, corporate and series-corporate feed network in terms of return loss, gain, directivity and radiation pattern. Details of simulated results are presented and discussed. Enhancement in gain, directivity and better return loss performance can be obtained by the use of RT-DURROID substrate because Low dielectric constant substrates are generally preferred for maximum radiation. Quarter wave transformer and power divider are used to feed the elements. These arrays are designed to operate at a frequency of 10 GHz. Our goal is to obtain a high directivity with better gain and reduced losses, to be especially used for X band applications such as satellite communication, radar, medical applications, and other wireless systems.**

***Index Terms*—microstrip patch antenna, array antenna, corporate-series feed array, corporate feed array, series feed array, microstrip line feed, return Los, directivity**

I. INTRODUCTION

The importance of wireless communication and multimedia services is increasing the efforts of design and implementation of novel microstrip patch structures from miniaturized electronic circuits to the antenna arrays.

Microstrip patch antennas have found extensive application in wireless communication system due to their advantages such as low profile, conformability, low-cost fabrication and ease of integration with feed network. Microstrip antenna in its simplest form consists of a radiating patch (of different shapes) which is made up of a conducting material like Copper or Gold on one side of a dielectric substrate and a ground plane on the other side, Fig. 1. It is used in communication systems due to simplicity in structure, conformability, low manufacturing cost, and very versatile in terms of resonant frequency, polarization, pattern and impedance at the particular patch shape and model [1], it can be used for high frequency and high speed for data transfer.

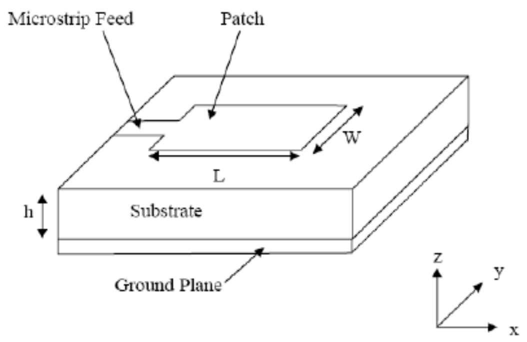

Figure 1. Microstrip patch antenna geometry

In various communications and radar systems, microstrip array antennas are greatly desired. They are used, to synthesize a required pattern that cannot be achieved with a single element. In addition, they are used to scan the beam of an antenna system, increase the directivity, and perform various other functions which would be difficult with any one single element. The elements can be fed by a single line or by multiple lines in a feed network arrangement. The first is referred to as a series-feed network while the second is referred to as a corporate-feed network [1]. This paper presents the characteristic of microstrip array antennas, series-feed, corporate feed and their combination. The performance comparison is also given for better understanding.

II. MICROSTRIP PATCH ANTENNA DESIGN

For a rectangular patch, length L is usually $0.3333\lambda_0<L<\lambda_0$, where λ_0 is the free-space wavelength. Patch is usually very thin such that patch thickness t is very less than λ_0. The dielectric constant of the substrate ε_r ranges from 2.2 to 12. The thickness h of the dielectric substrate is usually in the range $0.003\lambda_0 \le h \le 0.05\lambda_0$ [2].

The Performance of the microstrip antenna depends on its dimension. Depending on the dimension the operating

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frequency, radiation efficiency, directivity, return loss and other related parameters are also influenced. For an efficient radiation, the practical width of the patch can be written as:

$$W = \frac{c}{2fr\sqrt{\frac{2}{\varepsilon r+1}}} \tag{1}$$

The length of the antenna becomes

$$L = L_{eff} - 2\Delta L \tag{2}$$

where

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon eff+0.3)\left(\frac{W}{h}+0.264\right)^{1}}{(\varepsilon eff-0.258)\left(\frac{W}{h}+0.8\right)^{1}} \tag{3}$$

and

$$\varepsilon eff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(1+\frac{12h}{W}\right)^{-1/2} \tag{4}$$

Inset length of the patch for inserting microstrip feed line [3]:

$Y_0 = 10^{-4}$ [0.001699 εr^7 + 0.13761 εr^6 – 6.1783 εr^5 + 93.187 εr^4 - 682.69 εr^3 + 2561.9 εr^2 - 4043 εr^1 + 6697] $\frac{L}{2}$ this expression is valid for $2 \le \varepsilon r \le 10$.

where λ is the wave length, *fr* is the resonant frequency; *L* and *W* are the length and width of the patch element respectively. In the following Fig. 1-1 shows a single patch antenna that has been designed to cover operating frequency of 10 GHz with input impedance of 50 Ω, using RT-DURROID (εr=2.2) and height (h=0.79mm).

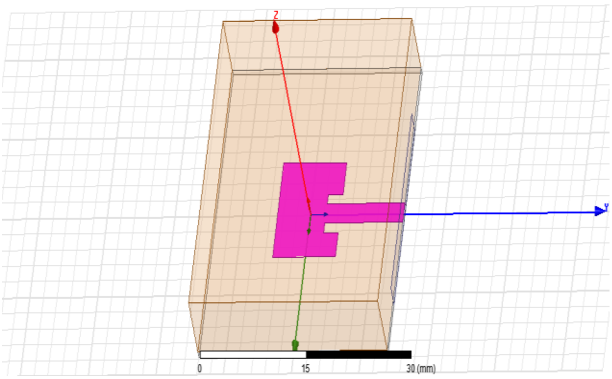

Figure 1-1. Single element rectangular patch antenna

The dimension of the patch is 9.31mm×11.86mm with inset feed at 2.5mm. The width of the transmission line is 2.408mm [4].

III. MICROSTRIP PATCH ARRAY ANTENNAS DESIGN

Microstrip antennas are used not only as single element but also very popular in arrays. Main limitation of microstrip is that it radiate efficiently only over a narrow band of frequencies and they can't operate at the high power levels of waveguide, coaxial line, or even stripline [5]. This can be minimized with the help of various array configurations, feeding methods, dielectric materials and ground planes. Antenna arrays are used to scan the beam of an antenna system, to increase the directivity, gain and enhance various other functions which would be difficult with single element antenna.

A. Software Tools

The software used to model and simulate the microstrip patch array antennas is HFSS. HFSS is a high-performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. Ansoft HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. Ansoft HFSS can be used to calculate parameters such as S-Parameters, Resonant Frequency, and Fields [6].

B. Feed Network

In the microstrip array, elements can be fed by a single line or multiple lines in a feed network arrangement [1], [5]. Feeding methods are classified as:

- Series feed network
- Corporate feed network
- Corporate-series feed network.

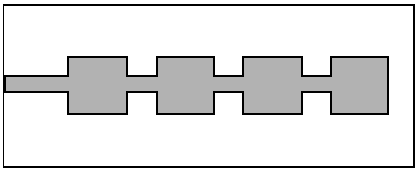

Figure 2a. Series feed

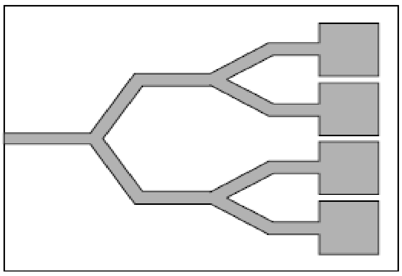

Figure 2b. Corporate feed

The series feed (Fig. 2a) usually consists of a continuous transmission line from which small proportion of energy are progressively coupled into the individual element disposed along the line. The series feed constitutes a traveling wave array if the feed line is terminated in a matched load. Here the difference between the series feed and corporate feed. A corporate feed (Fig. 2b) is most widely used parallel feed configuration. For a uniform aperture distribution, the power is equally split at each junction. However different power divider ratios can be chosen to generate a tapered distribution across the array. The disadvantages of this type of feed is that it requires long transmission lines between radiating elements and the input port hence the insertion loss of the feed network can be prohibitively large thereby reducing the overall efficiency of the array. The series-corporate feed is the combination of series feed and corporate feed; it is frequently used for array antennas [7] to get benefits of both feeding networks. In this paper the series, corporate and series corporate-feed with inset feed is being discussed for the antenna array design. When feeding is bed, the total efficiency could be reduced to a low level which makes the whole system to be rejected.

The effects of the feed network are important in high gain microstrip antenna array with large number of radiating elements and complicated feed network [8].

C. Microstrip 2×1 Patch Array Antenna Design

Using the same dimensions and a spacing of λ/2 between the patch elements, an array of 2 rectangular patches is designed. We opted for two feeding methods, once is series feed using a quarter wavelength transformer and the other is corporate feed through a network of microstrip line in the form of T-junction (power divider) excited by source 50Ω. Fig. 3 and Fig. 4 show the proposed antennas.

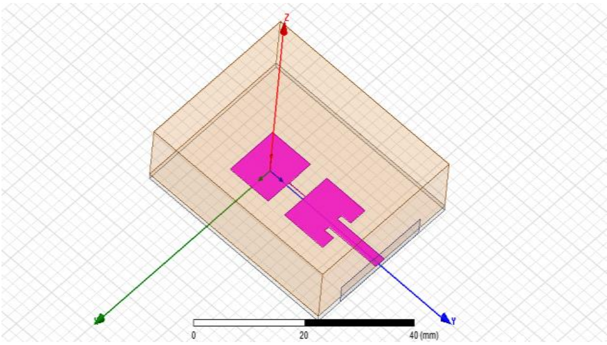

Figure 3. Rectangular 2×1 patch array antenna with series feed

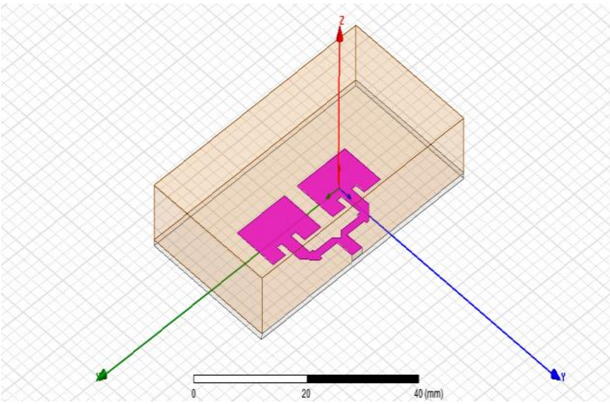

Figure 4. Rectangular 2×1 patch array antenna with corporate feed

D. Microstrip 4×1 Patch Array Antenna Design

To design a 4×1 rectangular patch array antenna, series feed, corporate feed and series-corporate feed networks are used as shown in Fig. 5, Fig. 6, and Fig. 7 respectively. Here 4 elements are used and each element has the same dimensions as mentioned above in order to increase the antenna performance. In this design, the patch elements are connected using quarter wavelength microstrip line in series feed and T- junction power divider is used in corporate feed. The structure of the power divider is symmetric. The spacing between the patch elements is λ/2.

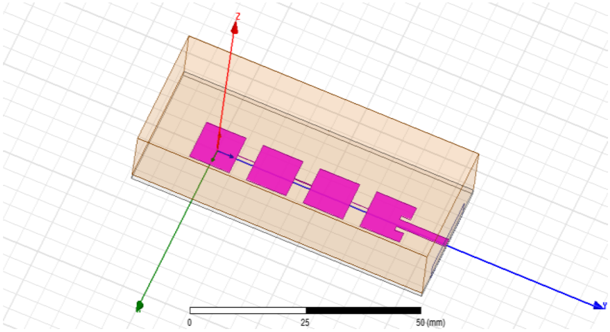

Figure 5. Rectangular 4×1 patch array antenna with series feed

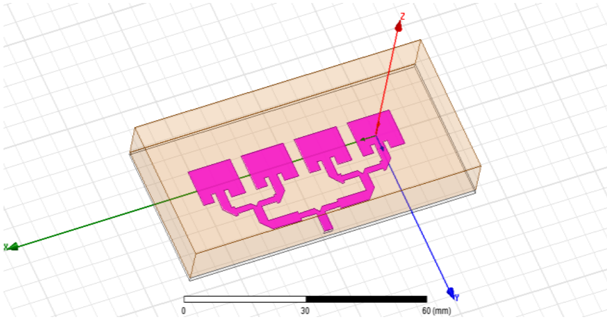

Figure 6. Rectangular 4×1 patch array antenna with corporate feed

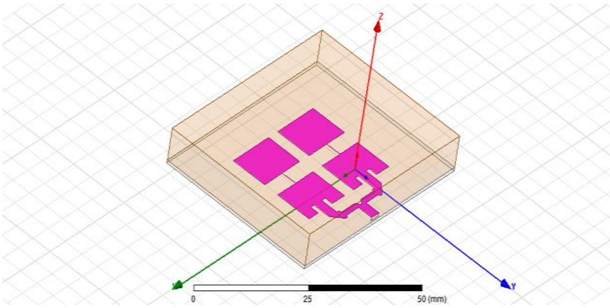

Figure 7. Rectangular 2×2 patch array antenna with series-corporate feed

E. Microstrip 8×1 Patch Array Antenna Design

Using the same dimensions mentioned above and a spacing of λ/2 between the patch elements, an array of 8 rectangular patches is designed. Series feed, corporate feed and series-corporate feed networks are used respectively as shown in Fig. 8, Fig. 9, and Fig. 10. The patch elements are connected using a quarter wavelength microstrip lines in series feed and T- junction power dividers are used in corporate feed and both for series-corporate feed. The structure of the power divider is symmetric.

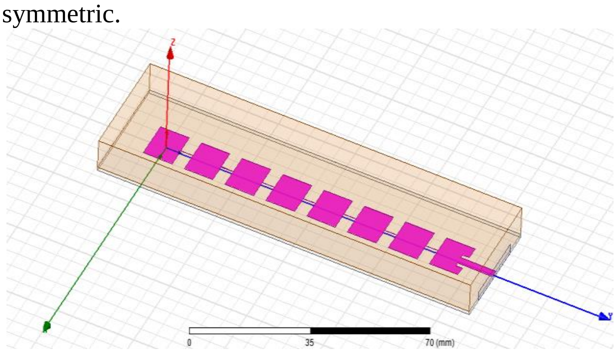

Figure 8. Rectangular 8×1 patch array antenna with series feed

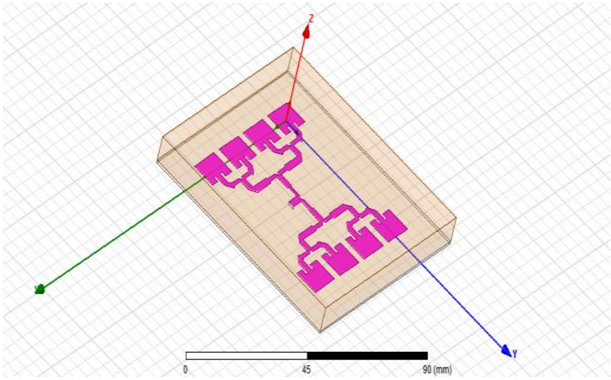

Figure 9. Rectangular 8×1 patch array antenna with corporate feed

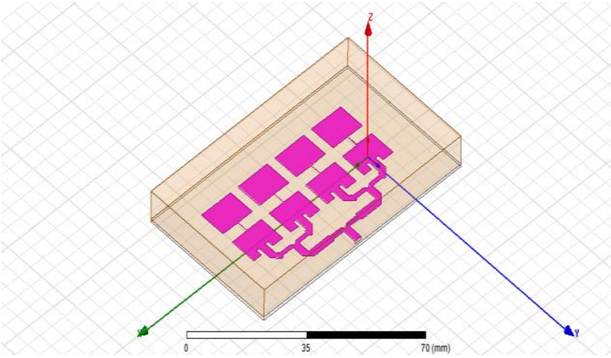

Figure 10. Rectangular 2×4 patch array antenna with series-corporate feed

F. *Microstrip 16×1 Patch Array Antenna Design*

Using the same dimensions mentioned above and a spacing of λ/2 between the patch elements, an array of 16 rectangular patches is designed. Series-corporate feed network is used as shown in Fig. 11. The patch elements are connected using a quarter wavelength microstrip lines and T- junction power dividers. The structure of the power divider is symmetric.

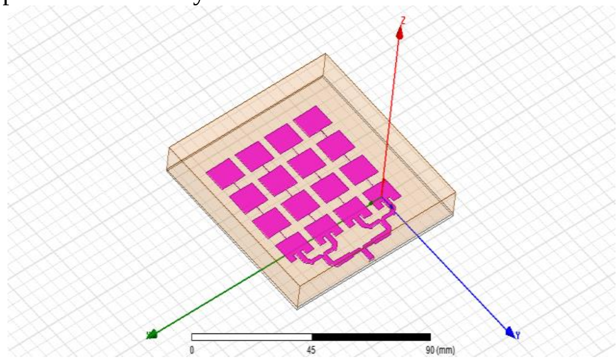

Figure 11. Rectangular 4×4 patch array antenna with series-corporate feed

IV. SIMULATION RESULT AND DISCUSSION

Now-a-days, it is a common practice to evaluate the system performances through computer simulation before the real time implementation. HFSS simulator [6] also helps to reduce the fabrication cost because only the antenna with the best performance would be fabricated.

A. *Microstrip Patch Antenna*

1) *Return loss*

Fig. 12 shows the return loss simulated for microstrip single patch antenna. This antenna resonates at frequency of: 10.6GHz, with return loss -14.33dB.

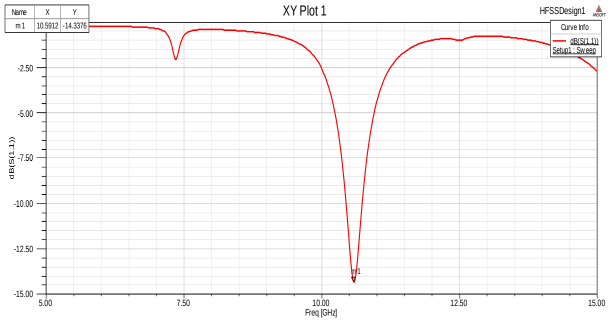

Figure 12. Return loss of single patch antenna

2) *Gain and directivity*

The simulated gain and directivity of the antenna, according to Fig. 13, are 8.53dB and 8.89dB respectively at φ = 0_ for the operating frequency. The beamwidth is about 65.

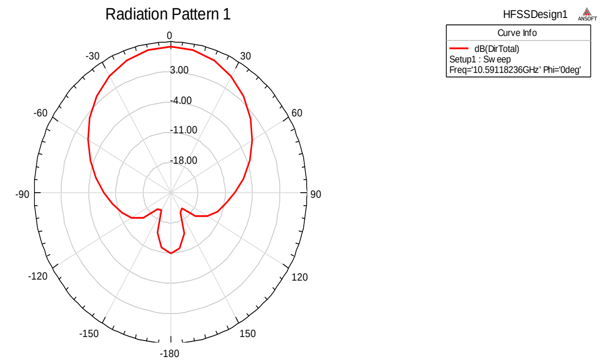

Figure 13. Radiation pattern of single patch antenna

From these results we can say that proposed antenna don't exploit well the X-band.

B. *Microstrip 2×1 Patch Array Antenna*

1) *Return loss*

S parameter calculation has been performed for microstrip 2×1 patch array antenna with series and corporate feed network. The center frequency is selected as the one at which the return loss is minimum. Fig. 14 shows that the return loss for patch array antenna with series feed is -22.67dB at frequency 10.7GHZ and for corporate feeding the return loss is about -38.91dB at frequency 10.45GHZ (Fig. 15).

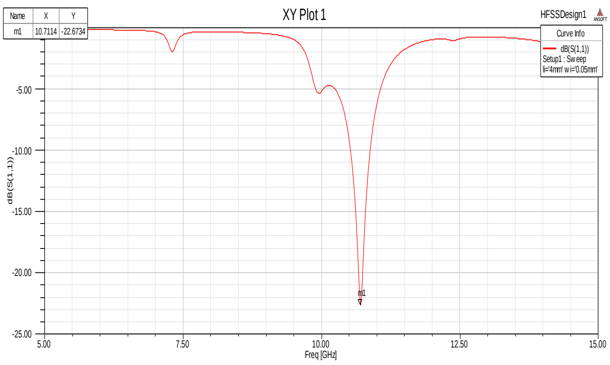

Figure 14. Return loss of the 2-elements series feed antenna array

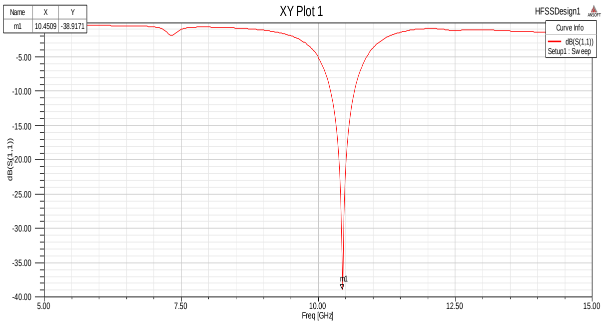

Figure 15. Return loss of the 2-elements corporate feed antenna array

The return loss is lower in corporate feed; therefore antenna efficiency is higher at this method of feeding.

2) Antenna parameters

Some of antenna parameters, such as the gain, directivity and 3dB beam width for 2×1 patch array antenna series/corporate feed are tabulated below. From the Table I, it is clear that gain and directivity of 2×1 phased array antenna with corporate feed are better than those of series feed.

TABLE I. PARAMETERS OF 2×1 PATCH ARRAY ANTENNA SERIES/CORPORATE FEED

Antenna parameters	Microstrip 2×1 patch array antenna	
	Series feed	Corporate feed
Gain	9.61dB	9.93dB
Directivity	10dB	10.19 dB
Beam width	60 °	43 °

3) Radiation pattern of designed antenna

The radiation pattern of an antenna is important in determining most of the characteristics which include beam width, beam shape, directivity and radiated power.

The representation of radiation pattern of 2×1 patch array antenna excited by series and corporate feeding is shown in Fig. 16.

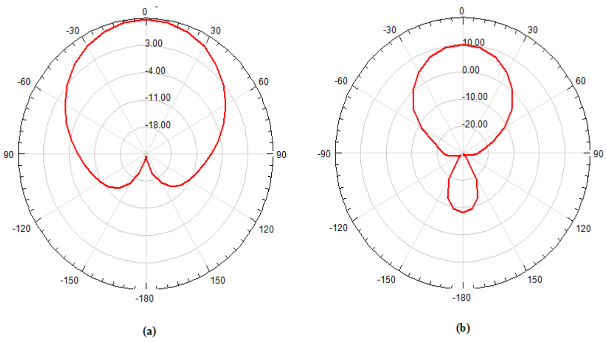

Figure 16. Radiation pattern of the 2-elements antenna array: (a) series feed, (b) corporate feed

It can be observed clearly that the beamwidth of corporate feed array antenna is narrowed more than that of series feed.

C. Microstrip 4×1 Patch Array Antenna

1) Return loss

S parameter calculation has been performed for microstrip 4×1 patch array antenna with series, corporate and series-corporate feed network. The center frequency is selected as the one at which the return loss is minimum.

Fig. 17 shows that the return loss for patch array antenna with series feed are -28.54dB at frequency 10.7GHZ. For corporate feeding the return loss is about -33.69dB at frequency 10.45GHZ (Fig. 18), and -17.89dB at frequency 10.59GHZ for series-corporate feed (Fig. 19).

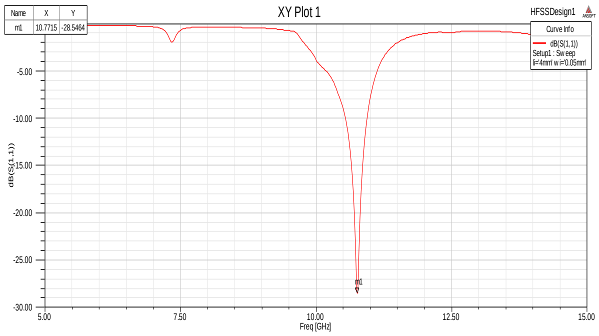

Figure 17. Return loss of the 4-elements series feed antenna array

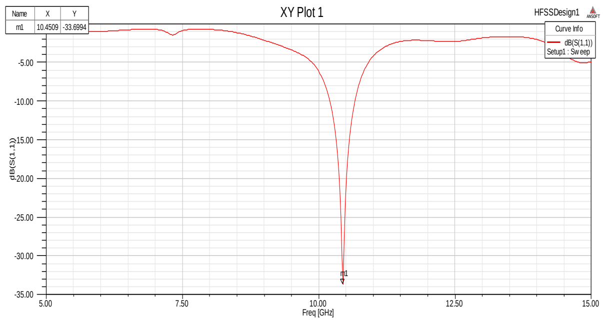

Figure 18. Return loss of the 4-elements corporate feed antenna array

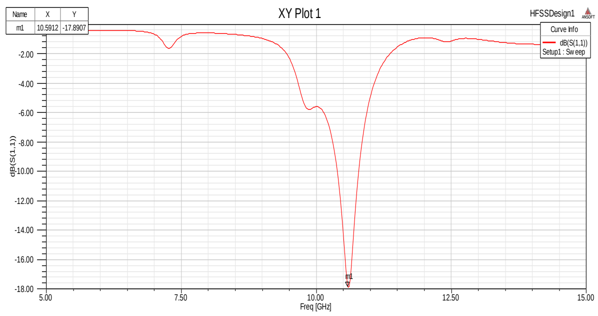

Figure 19. Return loss of the 4-elements series-corporate feed antenna array

According to the figures above, it was observed that with the variation of feed network, the resonant frequency does not shift much, but the return loss show a considerable change; it reaches a minimum value for corporate feed network.

2) Antenna parameters

TABLE II. PARAMETERS OF 4×1 PATCH ARRAY ANTENNA SERIES, CORPORATE AND SERIES-CORPORATE FEED NETWORK

Antenna parameters	Microstrip 4×1 patch array antenna		
	Series feed	Corporate feed	Series-corporate feed
Gain	10.48dB	12.85dB	11.27dB
Directivity	10.86dB	13.18dB	11.6dB
Beam width	52 °	22 °	40 °

Some of antenna parameters, such as the gain, directivity and 3dB beam width for 4×1 patch array antenna series, corporate and series-corporate feed are tabulated below. From the Table II, it is clear that gain and directivity of 4×1 phased array antenna with corporate feed are better than those of series and series-corporate feed.

3) Radiation pattern of designed antenna

The representation of radiation pattern of 4×1 patch array antenna excited by series, corporate and series-corporate feeding is shown in Fig. 20.

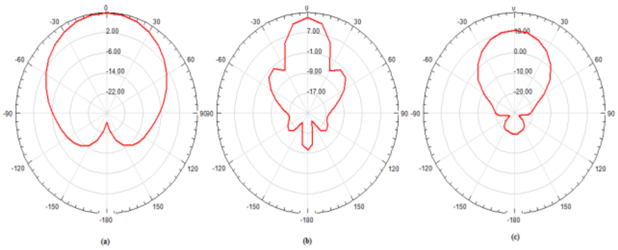

Figure 20. Radiation pattern of the 4-elements antenna array: (a) series feed, (b) corporate feed, (c) series-corporate feed

It can be observed clearly that array antenna with corporate feed has a narrow beam width comparing with other methods of feeding networks. We also noted the absence of secondary lobes.

D. *Microstrip 8×1 Patch Array Antenna*

1) Return loss

In this part S parameter calculation has been performed for microstrip 8×1 patch array antenna with series, corporate and series-corporate feed network. Fig. 21 shows that the return loss for patch array antenna with series feed are -30.62dB at frequency 10.75GHZ. For corporate feeding the return loss is about -22.12dB at frequency 10.43GHZ (Fig. 22), and -16.57dB at frequency 10.59GHZ for series-corporate feed network (Fig. 23).

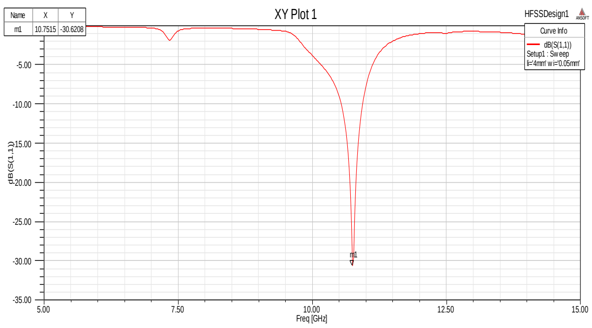

Figure 21. Return loss of the 8-elements series feed array antenna

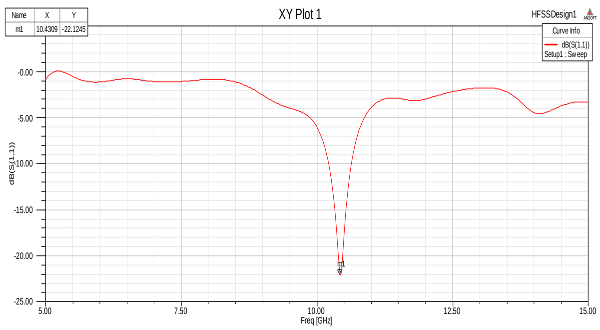

Figure 22. Return loss of the 8-elements corporate feed array antenna

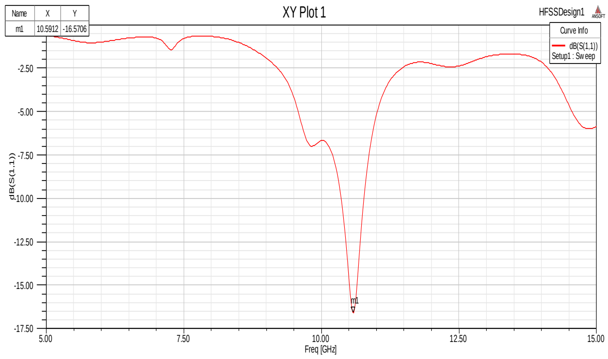

Figure 23. Return loss of the 8-elements series-corporate feed array antenna

We note that return loss increased for corporate feed compared to series feed and this is due to the feeding network that contains more microstrip lines causing more losses.

2) Antenna parameters

Some of antenna parameters, such as the gain, directivity and 3dB beam width for 8×1 patch array antenna series, corporate and series-corporate feed are tabulated below. From the Table III, it is clear that gain and directivity of 8×1 phased array antenna with series-corporate feed are better than those of series and corporate feed.

TABLE III. PARAMETERS OF 8×1 PATCH ARRAY ANTENNA SERIES, CORPORATE AND SERIES-CORPORATE FEED NETWORK

Antenna parameters	Microstrip 8×1 patch array antenna		
	Series feed	Corporate feed	Series-corporate feed
Gain	10.73dB	13.69dB	14.13dB
Directivity	11.13dB	14dB	14.51dB
Beam width	46 °	-	21 °

When the patch number increases, the feeding network becomes more complicated and radiation efficiency decreases that is why it is better to make a combination between a series and corporate feed to facilitate the design and improve the radiation efficiency by reducing the number of microstrip lines.

3) Radiation pattern of designed antenna

The representation of radiation pattern of 8×1 patch array antenna excited by series, corporate and series-corporate feeding is shown in Fig. 24.

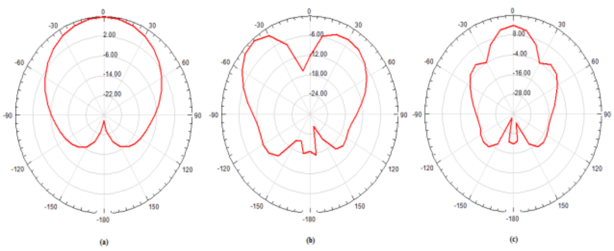

Figure 24. Radiation pattern of the 8-elements antenna array: (a) series feed, (b) corporate feed, (c) series-corporate feed

It can be observed clearly that array antenna with series-corporate feed represents an improvement in radiation pattern; it has a narrow beam width comparing with other methods of feeding networks.

E. Microstrip 16×1 Patch Array Antenna

1) Return loss and radiation pattern

In this section 4×4 patch array antenna has been designed with series-corporate feed network.

The representation of return loss and radiation pattern is shown in Fig. 25 and Fig. 26 respectively.

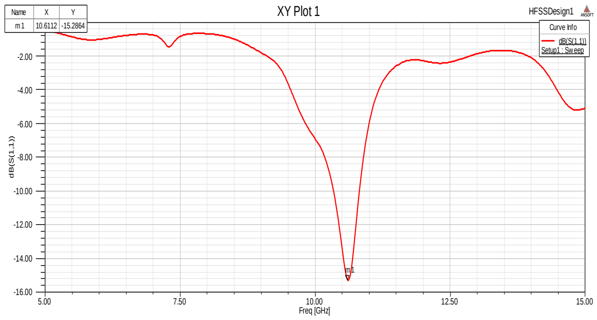

Figure 25. Return loss of the 16-elements series-corporate feed array antenna

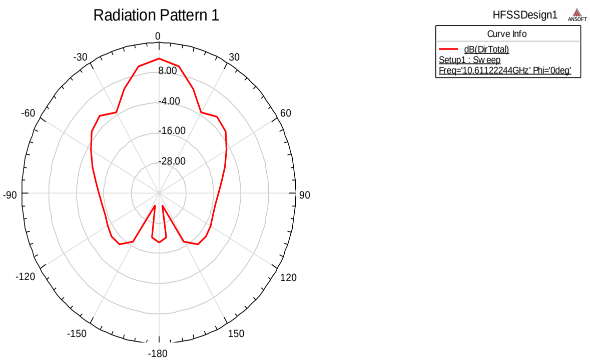

Figure 26. Radiation pattern of the 16-elements antenna array series-corporate feed

2) Antenna parameters

Simulation results obtained for single patch antenna and 16 elements array antenna are presented in this Table IV:

TABLE IV. COMPARISON BETWEEN SINGLE PATCH ANTENNA AND 16×1 PATCH ARRAY ANTENNA SERIES-CORPORATE FEED NETWORK

	Single patch antenna	16x1 patch array antenna series-corporate feed
Resonance frequency	10.6 GHz	10.6 GHz
Return loss	-14.3 dB	-15.28 dB
Gain	8.53 dB	14.91 dB
Directivity	8.89 dB	15.3 dB
Beam width	65 °	11 °

We can see from table above much improved result is achieved with 16×1 patch array antenna series-corporate feed network as compared to other arrays. Regarding to return loss we got almost the same curve of single element, the radiation pattern is more directive it has the beam width 11 at $\phi=0$.

V. CONCLUSION

The unique feature of this microstrip antenna is its simplicity to get higher performance. In many applications basically in radar and satellite communication, it is necessary to design antennas with very high directive characteristics to meet the demand of long distance communication and the most common configuration to satisfy this demand is the array form of the microstrip antenna.

For an array antenna with a large number of patches, the gain and directivity increase whatever the feeding method (series, corporate or series-corporate) however observing the performance analysis of the three of these array antennas, it is convenient to say that 16×1 patch array antenna with series-corporate feed network provides better performance than the other arrays, -15.28 dB return loss and 15.3dB directivity is achieved at 10.6GHz.

The microstrip 16×1 patch array antenna with series-corporate feed has the higher directive gain as well as the narrow beam width (11° at $\varphi = 0$) which seem to be suitable criteria to design a directive patch antenna for radar system.

Here designed array antennas covers 10GHz operating frequency and it would also be possible to design the bands, operating any other system such as in WLAN, WIMAX, WBAN or other wireless systems, by changing the dimension of the patch element.

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Hayat Errifi is a PhD student in Telecommunication and information engineering at the EEA & TI Laboratory (Electronics, Electrotechnics, Automatic and information Processing), Hassan II University Casablanca, Faculty of Sciences and Technology of Mohammedia in Morocco. she received the B.Sc. degree in Electronics and informatics, from Hassan II University Casablanca, Faculty of Sciences and Technology of Mohammedia, Morocco, in 2009, and M.Sc. degree in Electronic and automatic systems engineering (Telecommunication and Information Technologies specialty) from Hassan II University Casablanca, Faculty of Sciences and Technology of Mohammedia, Morocco, in 2011. She's currently working on antenna theory, design and optimization of patch antenna and patch array antenna under the supervision of Pr. A. Baghdad. Her main research interest is improving patch antenna directivity and reducing return loss.

Abdennaceur Baghdad is a holder of a doctorate in Electronics in 1992 at the University of Lille, France. He is University Professor Habilité (Professeur habilité) at the University Hassan II Mohammedia-Casablanca - Morocco (FSTM) where he teaches the electronics, Hyperfrequencies, antenna and telecommunication. He is a member of the laboratory EEA & TI (Electonics, Electrotechnics, Automatic and information Processing). The research works of A. Baghdad concerns the communication and Information Technology (Electronics Systems and Telecommunication). He supervises doctoral theses and he is a co-author of several national and international publications. He was a member of steering committees of three international congresses in the same domain of research.

Abdelmajid Badri is a holder of a doctorate in Electronics and Image Processing in 1992 at the University of Poitiers, France. In 1996, he obtained the diploma of the authorization to Manage Researches (Habilitation à Diriger des Recherches: HDR) to the University of Poitiers –France, on the image processing. He is University Professor (PES-C) at the University Hassan II Mohammedia-Casablanca - Morocco (FSTM) where he teaches the electronics, the signal processing, image processing and telecommunication. He is a member of the laboratory EEA & TI (Electonics, Electrotechnics, Automatic and information Processing) which he managed since 1996.The research works of A. Badri concerns the communication and Information Technology (Electronics Systems, Signal/Image Processing and Telecommunication). He is qualified by CNU-France in 61th section: informatics engineering, automatic and signal processing. He managed several doctoral theses. He is a co-author of several national and international publications. He is responsible for several research projects financed by the ministry or by the industrialists. He was member of several committees of programs of international conferences and president of three international congresses in the same domain. He is a member and co-responsible in several scientific associations in touch with his domain of research.

Aïcha Sahel is a holder of a doctorate in Electronics and Image Processing in 1996 at the University of Poitiers, France. She is university Professor at the University Hassan II Mohammedia - Casablanca - Morocco (FSTM) where she teaches the electronics, the signal processing, the image processing and Telecommunication. She is a member of the laboratory EEA & TI (Electronics, Electrotechnics, Automatic and Information processing). The research works of A. Sahel concern the Communication and Information Technology (Electronics Systems, Signal/Image Processing and Telecommunication). She co-supervises doctoral theses and she is a co-author of several national and international publications. She is a member in financed research projects. She was a member of steering committees of three international congresses in the same domain of research.