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Surman Journal for Science and Technology
ISSN: Online (2790-5721) - Print (2790-5713)
مجلة صرمان للعلوم والتقنية
Vol4, No.2, Dec. 2022
Pages: 018 ~ 027

Design and Optimization of a 4x4 Directional Microstrip Patch Antenna

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الملخص

فى هده الورقة صمم هوائي الشرايحة 4*4 لاستخدامها فى الصناعة والعلوم ومواد التردد .وصمم الهوائي عند تردد 9.3جيجا هيرتز فى حزمة ترددات الاكس ومادة مقاومة للحرارة من الزجاج المنسوج وبسمك 1.6 ملم وثابت عزل 4.4 .والهدف الاساس هو الحصول على اقصى اتجاهية مع افضل كسب واقل فقد.واستخدمنا برنامج محاكاة الترددات العالية واداة التحسين لمحاكاة الموجات الكهرومغناطيسيات وللحصول على افضل اداة .

فى البداية صممت2*2 سلسلة هوائي الشرايح الصغيرة مع استخدام اداة التحسين باقل فقد -12.6 ديسيبل وكسب 9 دسيبل بينما نتائج هوائي الشرايح الصغيرة 4*4 كانت بفقد -13.9 ديسيبل وكسب 6 دسيبل. صنع هوائي 2*2 للشرايح الصغيرة و اختبر اداءه فى المعمل.

Abstract

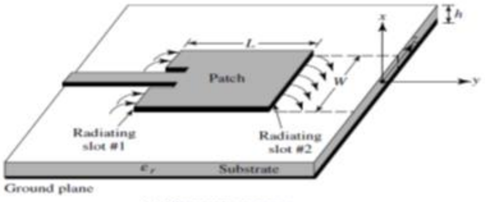
In this paper, the proposed 4×4 microstrip patch is designed for the industrial, scientific, and material(ISM) frequency X - band. The antenna is designed at 9.3 GHz in X - band and FR4 material that have thichness1.6 mm and dielectric constant 4.4. Our aim is to obtain a high directivity with better gain and reduced losses. We used in this project (HFSS) commercial software to obtain EM simulation. We did an optimization tool to obtain our goal. We started by designing a 2×2 array of microstrip antenna after that we extended it to 4×4 a rectangular microstrip patch antenna. The simulation result after the optimization for 2×2 is S_{11}= -12.6 dB the gain is 9 dB and for 4×4 microstrip array is S_{11}= - 13.9 dB and the gain is 6 dB. The design of a 2x2 microstrip array has been manufactured and tested in the laboratory. Further, we will extend it to16×16 array of microstrip antenna

***Keywords**: Microstrip antenna, array antenna, probe feeding, X-band frequency*

1. Introduction

The antenna is a device, which used to convert electrical power to radio waves or vice – versa, and antennas are the key components of any wireless system [1]. The low profile microstrip antenna may be required in high–performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints. These antennas are low- profile, conformable to the planar and nonplanar surface, simple and inexpensive to manufacture using modern printed – circuit technology. The major disadvantages of microstrip antennas are their low efficiency, low power, poor polarization purity, poor scan performance, and very narrow frequency bandwidth. In some application narrow bandwidth are desirable. In this project, we started to design a 2×2 microstrip patch Antenna that has FR4 material substrate which its dielectric constant of $\varepsilon r = 4.4$ and thickness of 1.6 mm. After the optimization result of 2×2 has been obtained S11 = -13.16 dB and gain 9 dB.future working, we will manufacture this array antenna and we will extend it to a 16×16 microstrip antenna.

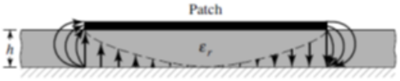
This project is arranged as follows, section (1) describes the model of the transmission line to analyze the microstrip patch antenna. section (2) the design procedure of microstrip patch antenna .the analysis of the antenna system is described in section (3). The simulation and manufactured result of a 2×2 and a 4×4 microstrip patch antenna are given in section (4). Finally. , the project is concluded in section (5).



(a) Microstrip antenna

Fig .1 Microstrip antenna

(a) Top view

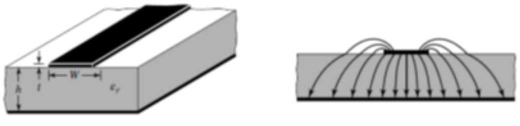


(b) Side view

Fig .2 Physical and effective lengths of rectangular Microstrip patch.

2. Method of Analysis

There are many methods of analysis for microstrip antennas. So we used in this project the transmission line model which one of the simplest methods to analyze the microstrip patch antenna. The geometry of the microstrip line is shown in fig (2). The microstrip antenna consists of a nonhomogeneous line of two dielectrics (air and substrate), a major portion of electric field lines resides in the substrate and the other part resides in the air. The phase velocity of the wave is not the same in the air and the substrate (dielectric) so the pure transverse – electric – magnetic (TEM) mode of transmission cannot be sustained in the transmission. As the result, in the transmission line, the dominant mode of propagation is quasi TEM mode [2, 3].



(a) Microstrip line (b) Electric field lines

Fig .3 Microstrip line and its electric field lines

For low frequencies, the effective dielectric constant is essentially constant. At intermediate frequencies, its values begin to monotonically increase and eventually approach the values of the dielectric constant of the substrate [2, 3].
The effective dielectric [2, 3] constant is given by:

$$\epsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1+12\frac{h}{w}]^{-1/2} \quad (1)$$

Because of the fringing effects, electrically the patch of microstrip antenna looks greater than its physical dimension. The extended (ΔL) of the patch is given by[2,3,4]

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)} \quad (2)$$

Since the length of the patch has been extended by (ΔL) on each side, the effective length of the patch is now (L = λ / 2) for dominant TM mode with on fringing) [2,3,4]:

$$L_{eff} = L + 2\Delta L \quad (3)$$

For the dominant TM mode, the resonant frequency [2, 3, 4] of the microstrip antenna is a function of its length. Usually, it is given by:

$$f_r = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = \frac{\vartheta_0}{2L\sqrt{\varepsilon_r}} \quad (4)$$

Where v0 is the speed of light in free space [2, 3].
The width of the patch is given by [2, 3] :

$$w = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{\vartheta_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (5)$$

The actual length of the patch is given by:

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \quad (6)$$

We used in this project the microstrip transmission line which characteristic impedance ZO =50Ω by this value
We calculated the width of the transmission line [1].

$$Z_0 = \begin{cases} \dfrac{60}{\sqrt{\varepsilon_r}} \ln\left(\dfrac{8d}{w} + \dfrac{w}{4d}\right) & for\ w/d \leq 1 \\ \dfrac{120\pi}{\sqrt{\varepsilon_e}\ [\frac{w}{d} + 1.393 + 0.667 \ln(\frac{w}{d} + 1.444)]} & for\ w/d \geq 1 \end{cases} \qquad (7)$$

$$\frac{w}{d} = \begin{cases} \dfrac{8e^A}{e^{2A} - 2} & for\ w/d < 2 \\ \dfrac{2}{\pi}[B - 1 - \ln(2B - 1) + \dfrac{\varepsilon_r - 1}{2\varepsilon_r}\{\ln(B - 1) + 0.39 - \dfrac{0.61}{\varepsilon_r}\}] & for\ w/d > 2 \end{cases}$$

3-DESIGN PROCEDURE

In this section, we describe the steps of my design. As my goal to design a 4×4 microstrip antenna at the frequency (9.3 GHz). The substrate material is FR4 which its dielectric (constant = 4.4, substrate height =(1.6) . It is chosen because of its low cost, low loss, and its availability [2]. A transmission line model, as discussed in the previous section, which characteristic impedance Z0=50 Ω is used to calculate the physical
parameters of the microstrip patch antenna. These physical parameters are :
- Calculation of width (W): The width of the antenna is obtained from (5) by setting:
V0 = 3 × 108 m/s and f0=9.3 GHz. Hence W = 9.81 mm

- Calculation of effective dielectric constant (εreff): The effective dielectric constant is obtained from (1) by setting εr =4.4, h=1.6 mm, and W=9.81mm. Hence :
εreff= 3.3 .

- Calculation of effective length (Leff): The effective length of the antenna is obtained from (3). Hence :
Leff =8.14 mm.

- Calculation of length extension (ΔL): The length extension is obtained from (2). Hence :
ΔL =0.58 mm.

- Calculation of actual length of the patch (L): The actual length of the patch is obtained from (6). Hence:
L =6.98 mm.

-calculation of the width of transmission line characteristic impedance Zo=50Ω the width is obtained (8).Hence:
W=3.1mm.

3- ANTENNA SYSTEM ANALYSIS

We used in this project coaxial line feeds, where the inner conductor of the coax is attached to the radiation patch while the outer conductor is connected to the ground plans, are also widely used the coaxial probe feed is also easy to fabricate and match[3]. And it has low spurious radiation, However, it also has a narrow bandwidth and it is more difficult to model, especially for thick substrates (h > 0.02 λ0) [3]. As shown in fig (4) following:

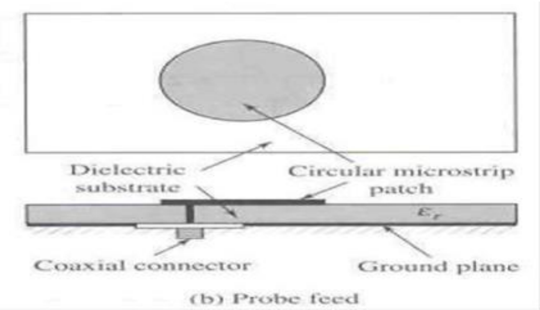


Fig .4 the probe feed.

4-EM SIMULATION

The design of the 2×2 microstrip patch antenna is illustrated in fig (5) which consists of 4 patches and impedance-matched feed lines.

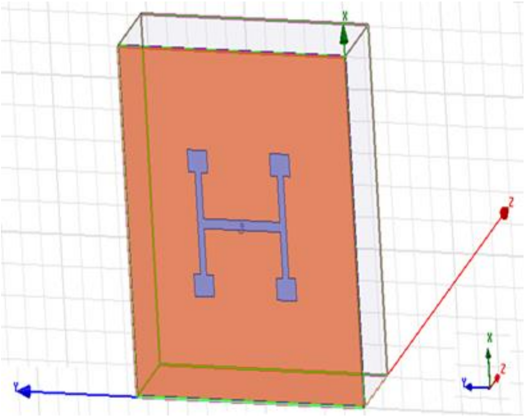


Fig (5) proposed 2×2 inset – fed microstrip patch antenna

The simulation result before the optimization provides S11= - 12.6 dB as shown in fig (6) and the gain of 7.8 dB as shown in fig (7).

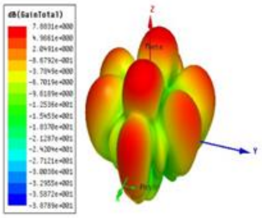


Fig .6 Gain of the 2×2 microstrip patch antenna

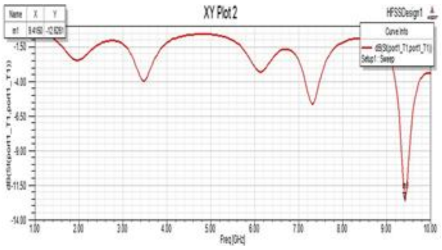


Fig .7 S11 of the 2×2 microstrip patch antenna

l After that we did optimization and we set our goal to be S11 ≤ 10dB then we obtained the best length and width of the single patch and the best width of transmission line which are 7.37 mm, 9.37 mm, and 1.5 mm, respectively the optimization result comes out to be S11 = -12.9 dB and the gain 9 dB shown that in fig (8) and fig (9):

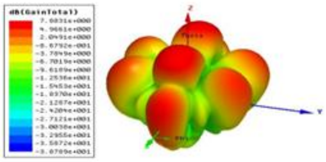


Fig .8 Gain of the 2×2 microstrip patch antenna after optimization

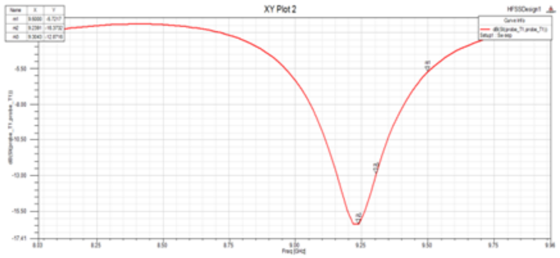


Fig .9 S11 of the 2×2 microstrip patch antenna.

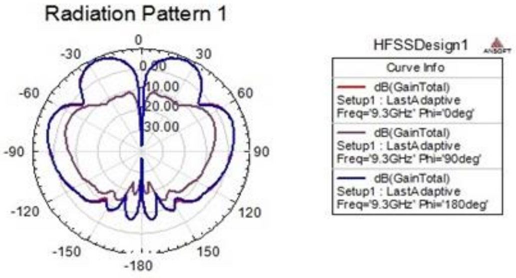


Fig.10 the Radiation pattern of 2x2 microstrip patch array antenna.

After that, we extended it to a 4×4 microstrip patch antenna as shown in fig (10). The proposed antenna contains 16 patches and an impedance-matched feed line.

We used the HFSS software to obtain the EM simulation and we calculated the dimension of the microstrip patch antenna using the transmission line model as discussed in the previous section. Then, we connected the patch using a microstrip transmission line as shown in fig (10). The dimensions of a single microstrip patch before the optimization is the width and the length are 9.81 mm and 6.98 mm, respectively the total size of the antenna array comes out to be 109.96 mm ×115.62 mm, and the spacing between patches equal to $\lambda = 32$ mm .

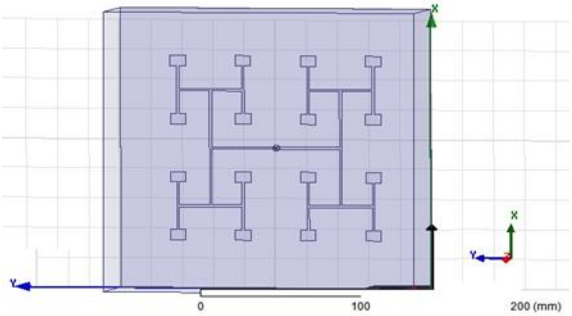


Fig .11 proposed a 4×4 inset – fed microstrip patch antenna.

The simulation result after the optimization goal provided S11 = -13.9 dB at the resonant frequency, the gain 6dB, and bandwidth of 0.2GHz in fig (11) and fig (12).

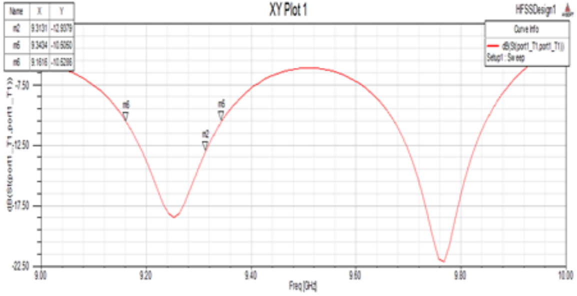


Fig .12 S11 of the 4×4 microstrip patch antenna

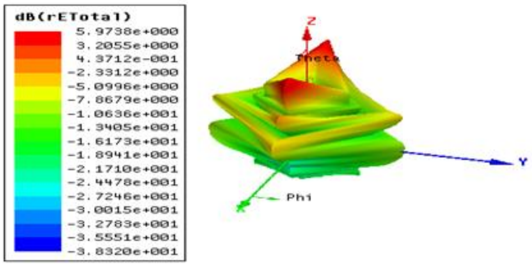


Fig .13 Gain of 4×4 microstrip patch antenna.

4. Manufacture Process

The 2x2 microstrip patch antenna has been manufactured as illustrated in fig(13) and tested as illustrated in fig(14).

Fig.14the manufacture of 2x2 microstrip array antenna.

The measurement of S11 after manufactured is about -9dB at 9.3GH and -31dB at 9.6GH as shown in fig (14).

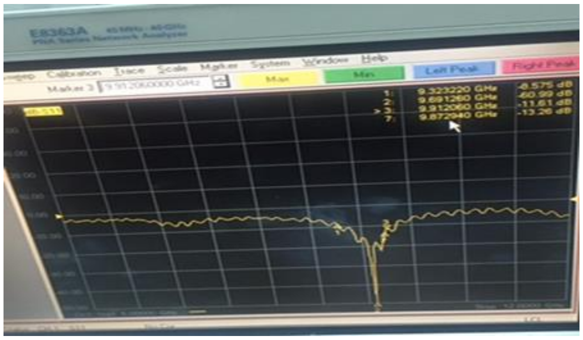


Fig.15 the result of testing 2x2 microstrip array.

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5. Conclusion

In the beginning, the basic of designing a microstrip patch antenna was learned on HFSS. After that, we designed a 2×2 microstrip antenna and then we did an optimization tool on HFSS to achieve the best return losses and the gain and the 2x2 microstrip array antenna has been manufactured**.**

Finally, we extended it to a 4×4 microstrip array antenna and we achieved S11 = -13.9 dB at the resonant frequency (9.3GHz) , the gain is 6dB and bandwidth of 0.2GHz .Future works we will fabricate this array antenna and we will extended it to 16×16 array of microstrip antenna.

6. References

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