

Optimization of Micro strip antenna using 2x2 slot array for wireless application

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Abstract: A bandwidth-enhanced Micro strip slotted array antenna is fabricated on an electrically-thin substrate to provide an economical solution for communication applications. To improve the impedance bandwidth of a rectangular micro strip patch without having any impact on its radiation characteristics, we perform etching of straight slot which is parallel and near to top side of the patch. For demonstrating the usefulness of the suggested technique, a planar array of dimension 2x2 with a side-lobe of 25 dB in both the E and H-planes are studied and fabricated on the FR4 substrate with 0.787 mm thickness. Simulation studies will be carried out on Method of Moments based EM Tool and analysis of the model is done by changing different operational parameters like the width of the slot, array element spacing, and array pattern. The antenna output parameters will be studied by changing substrate materials, ϵ_r ranging from 2 to 4.4 and complete analysis is presented in a detailed manner.

1. Introduction

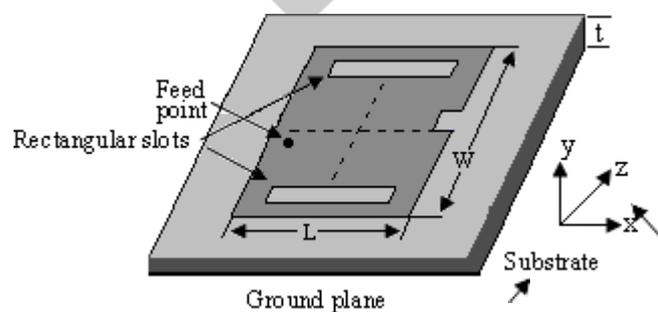
Over the last two decades the wireless communication system has experienced a significant growth from first generation (1G) analog voice signal to forthcoming fourth generation (4G) mobile technology. The motto of 4G communication system is to provide Wi-Fi (Wireless Fidelity) communication network and high quality audio and video services. Today's technology requires high data rate and longer range to provide quality services to the users. For current mobile communication, the diversity scheme has already been implemented to mitigate the fading effects of multipath scenario [1], [2]. In a multipath rich wireless channel, deploying multiple antennas at both the transmitter and receiver achieves high data rate without increasing the total transmission power [3]. In this study, an antenna array has been designed to improve the gain, antenna beam, bandwidth and reliability of the communication system. This is achieved as a result of the use of multiple antenna elements, excited through single feed point via the transmission line networks.

The array antenna structure is very interesting study and it is widely applicable to increase the range and reliability [4]-[6] of Wi-Fi LAN, Bluetooth, PDA (Personal Digital Assistants) CS (Digital Communication System) and mostly in the field mobile communication. This article describes the design, analysis and simulation of single element and multi elements patch antenna array for recent wireless communication system which operates at 5.25 GHz band. The antenna is designed, optimized and analyzed with commercially available IE3D electromagnetic simulator. In this investigation, a simple rectangular patch with rectangular slots in three different positions has been taken to achieve good performances. We focused on the antenna aspect of array system where four element microstrip patch configuration is proposed. Some good review articles are [7], [8], [9] and [10] where they did not optimize the distance between the antenna elements for reducing the effect of mutual coupling between the elements. But despite that they still give good introduction to the advantages and disadvantages of the system.

2. Design Principles

Initially the dimension of the single patch has been designed with three slots in three different positions with characteristic parameters of length (L), width (W) and thickness (t) as shown in Figure 1.

Figure 1. Geometry of a single element of the microstrip patch array.



To meet the actual design requirements i.e. operating frequency 5.25GHz, beam pattern, band width and the radiation efficiency, some approximations have been taken. The calculations are based on transmission line model. The width and length of the microstrip patch have been calculated by the following formula [11]

$$W = \frac{c}{2f \sqrt{\frac{\epsilon_r + 1}{2}}} \tag{2}$$

Where the required frequency $f_0=5.25$ GHz, $c= 3e10$ cm/s and $\epsilon_r= 2.2$. Substituting above values, the width of the patch (W) becomes 22.58 mm. The effective length of the patch can be calculated with the help of equations (3) and (4).

$$L_{eff} = \frac{c}{4f_0 \sqrt{\epsilon_{reFF}}} \tag{3}$$

$$\epsilon_{reFF} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{1}{\sqrt{1 + 12t/w}} \right) \tag{4}$$

In this design, RT/duroid substrate has been used with substrate parameters are $\tan\delta=0.001$, thickness of the substrate, $t=1.588$ mm. Substituting $W=22.58$ mm, $\epsilon_r= 2.2$ in equation (4) we get $\epsilon_{reFF} = 1.925$. Hence $L_{eff} = 20.60$ mm. The length extension is to be calculated by (5)

$$\Delta L = 0.412t \frac{(\epsilon_{reFF} + 0.3) \left(\frac{W}{t} + 0.264 \right)}{(\epsilon_{reFF} - 0.258) \left(\frac{W}{t} + 0.8 \right)} \tag{5}$$

Substituting $\epsilon_{reFF} = 1.925$ and the values of W and t, we get $\Delta L= 0.823$ mm. Now the actual length (L) of the patch is given by $L= L_{eff} - 2\Delta L = 20.60$ mm- 1.686 mm = 18.91 mm. Apart from this approximate calculation, the dimension has been slightly adjusted in order to achieve the desired frequency. Table 1 shows the detail dimensions of the patch, the slotted portions and the exact location of the feed point.

Table 1.

Parameters of the patch	Calculated value	Actual value
Width(W)	22.58 mm	24.4 mm
Length(L)	18.91 mm	18.8 mm
Horizontal slot dimension	-	(9x2)sq.mm
Vertical slot dimension	-	(2x3.5)sq..mm
Feed point	-	(-7,-2)

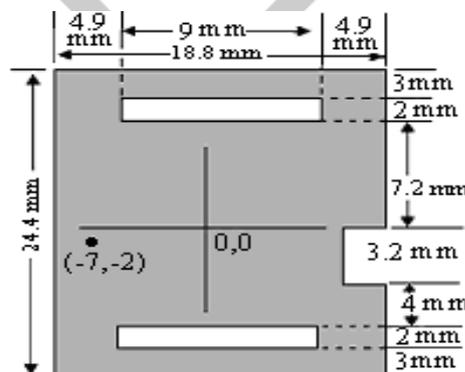


Figure 2. Design of single element of the array at 5.25 GHz

A number of feed points have been studied in this letter but the minimum RL and maximum radiation efficiency has been achieved at the feed location of $(-7, -2)$ and $(-7,-2)$.The characteristics of the array are slightly differ for the other three image points i.e $(7,2)$, $(7,-2)$ and $-7,2$.

For the fundamental TM_{10} mode, the patch length should be slightly less than $\lambda/2$, where λ is the wavelength in the dielectric medium. Here, λ is equal to $\lambda_0/\sqrt{\epsilon_0}$, where λ_0 is the free- space wavelength and ϵ_0 is the effective dielectric constant of the patch. The designed antenna is a microstrip patch array with circularly polarization. When signal feed, a standing wave occurs but some

of the fields will “leak out” around the edges of the patch. This is called fringing field. In the Figure 3, E-field on one side outside the patch is going into the patch and on the other side leaving the patch [12].

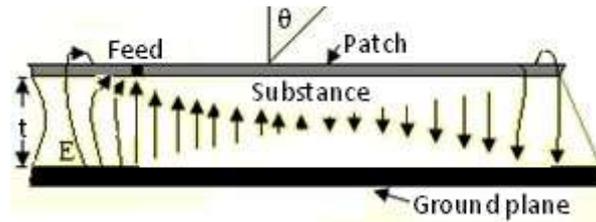


Figure 3. Side view of microstrip patch antenna showing E-fields.

3. Design of Single Element

Figure 4 shows the single element and double element of the array. The characteristics of the single element both simulated and measured are shown in the Figure 5, Figure 6, and Figure 7.

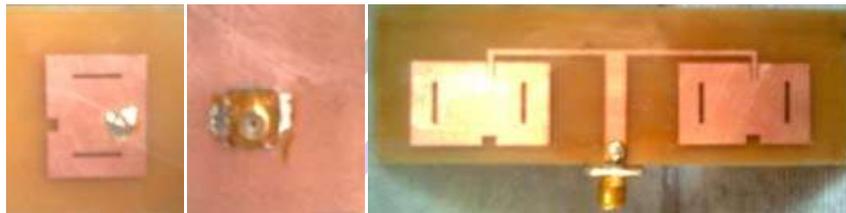


Figure 4. Fabrication of single element and two elements of the array

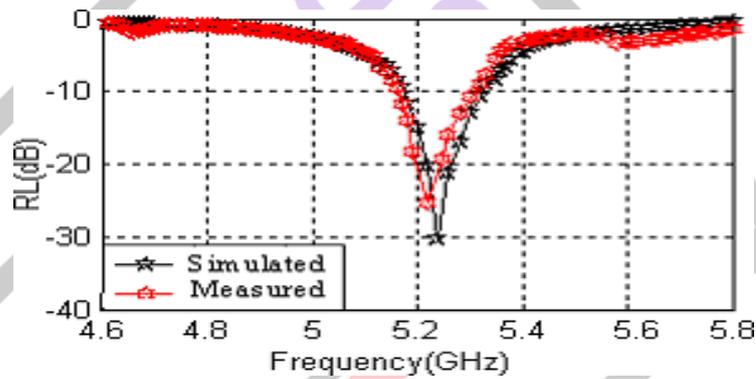


Figure 5. RL for single element of the array

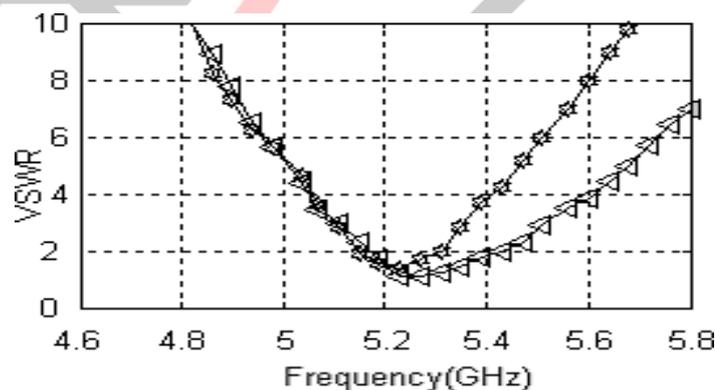


Figure 6. VSWR for single element of the array

4. Array Design

The most vital design of an antenna array is the feed network. This is constructed by first connecting two adjacent elements together with a transmission line and this can be calculated from (5). Now two separate groups, each containing two elements, need to be connected together. This is done with a transmission line drawn between the centers of the 0.54 mm wide transmission line.

$$Z_0 = \frac{\eta_0}{2\sqrt{\epsilon_{re}}} \ln \left(\frac{8t}{W_e} + 0.25 \frac{W_e}{t} \right), \text{ for } \frac{W}{t} \leq 1 \tag{6}$$

and for $\frac{W}{t} \geq 1$, $Z_0 =$

$$\frac{\eta_0}{\sqrt{\epsilon_{re}}} \left[\frac{W_e}{t} + 1.393 + 0.667 \ln \left(\frac{W_e}{t} + 1.444 \right) \right] \tag{7}$$

Where

$$\frac{W_e}{t} = \frac{W}{t} + \frac{1.25}{\epsilon} \frac{h}{t} \left[1 + \ln \left(\frac{4\epsilon W}{h} \right) \right], \text{ for } \frac{W}{t} \leq \frac{1}{2\epsilon} \tag{8}$$

$$\frac{W_e}{t} = \frac{W}{t} + \frac{1.25}{\epsilon} \frac{h}{t} \left[1 + \ln \left(\frac{2t}{h} \right) \right], \text{ for } \frac{W}{t} \geq \frac{1}{2\epsilon} \tag{9}$$

and

$$\epsilon_{re\text{eff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} F \left(\frac{W}{t} \right) - C \tag{10}$$

and

$$F \left(\frac{W}{t} \right) = \left(1 + 12 \frac{t}{W} \right)^{-1} + 0.04 \left(1 - \frac{t}{W} \right)^{-1}, \text{ for } \frac{W}{t} \leq 1 \tag{11}$$

$$F \left(\frac{W}{t} \right) = \left(1 + 12 \frac{t}{W} \right)^{-1/2}, \text{ for } \frac{W}{t} \geq 1 \tag{12}$$

$$C = \frac{\epsilon_r - 1}{4.6} \frac{h}{t} \frac{1}{\sqrt{W/t}} \tag{13}$$

W_e is the effective width of the patch, t is the thickness of the dielectric substance, Z_0 is the impedance of the transmission line and η_0 is the free space intrinsic impedance. The transmission line is split by using T-junction with equal power split. So both branches will receive input power which is as follows

$$P_{in} = \frac{1}{2} \frac{V_0^2}{Z_0} \tag{14}$$

If P_1 and P_2 be the output power, then

$$\frac{P_1}{1} = \frac{P_2}{2} = \frac{1}{2} \frac{V_0^2}{2Z_{out}} = \frac{1}{2} P_{in} \tag{15}$$

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As equal power split is required, the out put impedance Z_{out} of the transmission line using (14) and (15) is obtained as $Z_{out} = 2Z_0$ (16)

Typical impedance of a rectangular patch antenna varies from 100 to 400Ω. From simulation results the impedance of each element is 192 ohms and from (16) the impedance of transmission should be 192/2=96 ohms. Equation (6) gives that the width of the thick line should be 3.1 mm. The array is fed by a probe of diameter 1.2mm in the middle of the thicker transmission line by using SMA of impedance 50 ohms. From (16) we get that the probe ideally should have an impedance of 96/2=48 ohms.

The distance between the antenna elements has been optimized and fixed at $x_1 = 3\text{cm}$. The isolation test has been carried out by placing the antenna elements at three different positions such as 2.2 cm, 2.5 cm and 3.0 cm respectively. From simulation results it is observed that to achieve better isolation the adjacent elements should be separated by the distance of at least $\lambda/2$. In this design $\lambda/2 = 2.857\text{ cm}$ and the element distance (x_1) has been fixed at 3.0 cm. Figure 8 and Figure 9 show the geometry and the prototype of the proposed array.

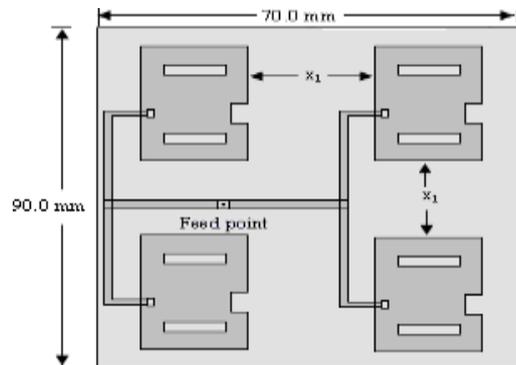


Figure 8. Geometry of (2x2) circularly polarized planar antenna array.



Figure 9. The prototype of the proposed array.

5. Results of The Array
A. Radiation pattern

The microstrip patch antenna radiates normal to its patch surface. So the elevation pattern for $\phi = 0$ and $\phi = 90$ degrees are important for the measurement. The simulated E-plane and H- plane pattern, 3D pattern view and the impedance characteristics of the array are illustrated in the Figure 10 and Figure 11. The measured and simulated values of VSWR are shown in the Figure 12. The simulated results for isolation between ports of the antenna elements with $x_1 = 3.0\text{cm}$ are shown in the Figure 14.

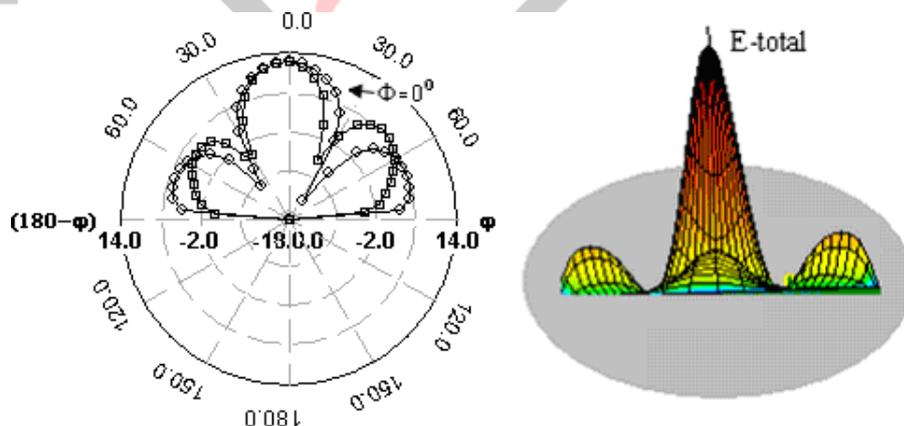


Figure 10. Simulated E-plane & H-plane pattern and 3D view of the array at 5.25 GHz.

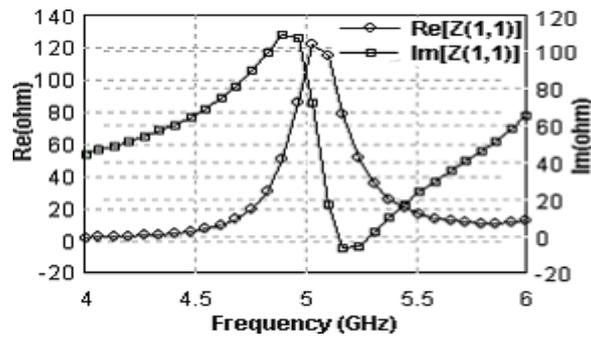


Figure 11. Impedance Characteristics of the array

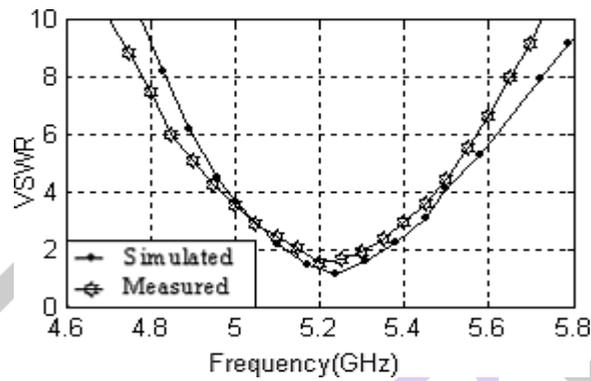


Figure 12. VSWR simulated and measured

B. Return Loss and other Characteristics.

The return loss (shown in Figure 13) of the antenna is -26 dB at 5.25 GHz and from RL curve, the bandwidth obtained for $RL > -9.5$ dB is 180 MHz. The measured value of VSWR, obtained from the curve is 1.5.

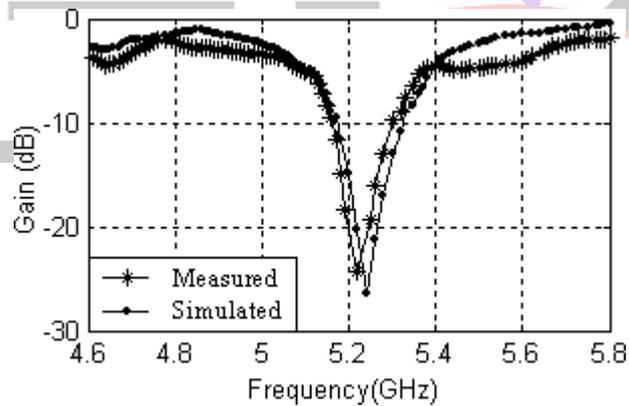


Figure 13. Return Loss curve at 5.25 GHz.

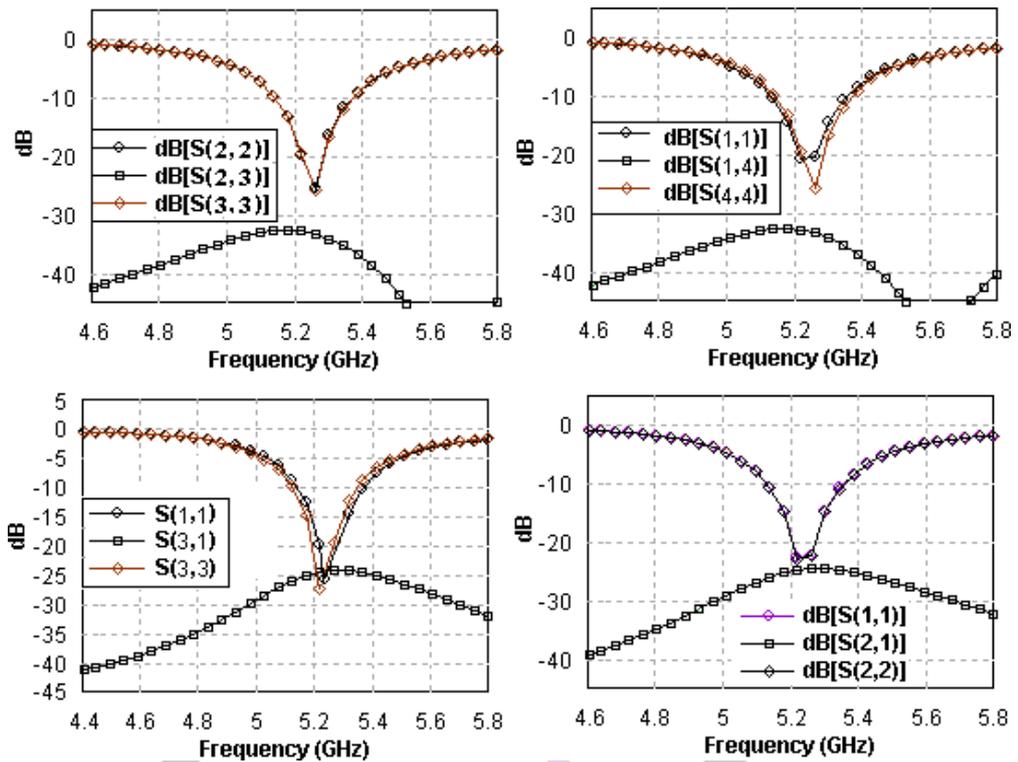


Figure 14. Simulated results of S-parameter keeping the distance between the elements of 3.0 cm.

Figure 15 shows the isolation between two antenna elements obtained from the simulations and the measured results of isolation between each pair of antenna elements at x_1 of 3.0cm (0.526λ) are illustrated in the Figure 16. In this investigation, isolation of more than 23 dB for each pair of elements has been achieved that causes very low mutual coupling. Isolation of more than 20 dB for each pair of antenna elements needs to maintain for low mutual coupling and this can be achieved when the separation between the antenna elements is at least 0.5λ [13, 14]. In case of S_{12} parameters three different distances between the antenna elements of 3.0cm (0.526λ), 2.5 cm (0.44λ) and 2.0 cm (0.35λ) respectively have been considered to optimize x_1 . In this design, the optimized value of x_1 is 3.0 cm (0.526λ).

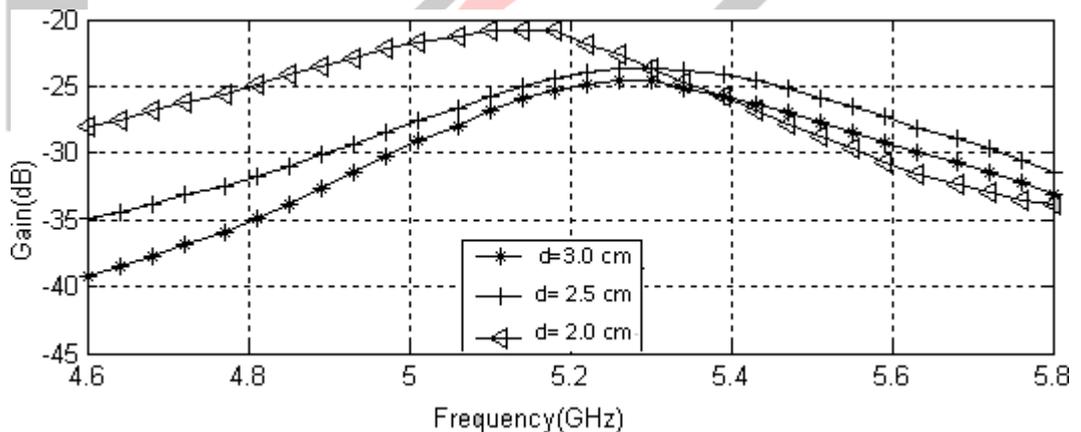


Figure 15. Simulated results of S_{12} between two adjacent antenna elements for three different x_1 value.

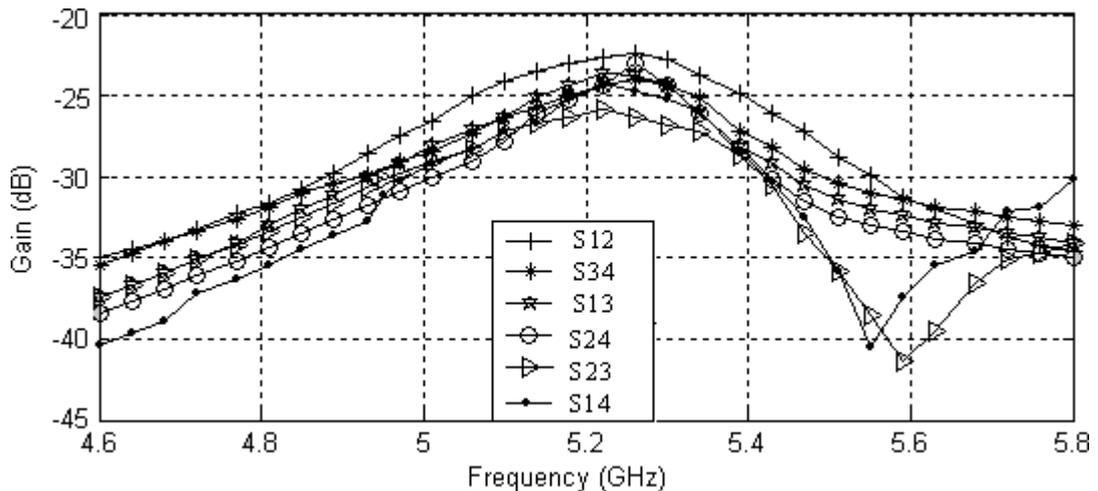


Figure 16. Measured results of S-parameters for $x_1=0.526\lambda$

Conclusion

The proposed slotted microstrip antenna array is electrically small and suitable to handle easily. From the results it is observed that the maximum gain obtained in the broadside direction and the peak gain at design frequency for the array is 13.88 dBi for both $\phi=0^\circ$ and $\phi=90^\circ$. The measured value of RL (< -25 dB) and VSWR (< 1.5) fairly tallied with the simulated result. If the dielectric constant is high, the electrical length of the antenna will be reduced but the bandwidth would be narrow.

In this investigation, the B.W of 180 MHz and isolation between the antenna elements of less than -25 dB has been achieved. It is clearly observed that the impedance bandwidth, radiation efficiency improved significantly by employing proposed (2×2) array antenna. In case of single element it has been observed that the antenna gain is quite low. But while employing the array, gain increases significantly. This is one of the most advantages of the array structure. All S-parameters have been studied by inserting the feed point to each element separately.

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