Microstrip Antenna Array Design for Generalized Spatial Modulation—Multiple Input Multiple Output (GSM-MIMO) Applications

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Abstract An array of patch antenna aims at improving the gain of the antenna as well as improves the radiation in different directions. By selecting two antennas out of four in 4 * 1 array, the power can be increased to a great extent, and by this switching technique of the antenna in the array, the transmission of bits is done in an efficient way. In this, the 4 * 1 array of rectangular microstrip antenna along with single RMSA is designed and simulated to get proper gain and radiation pattern at around 2.54 GHz frequency.

Keywords Switching · Patch antenna · RMSA · Array · 4 * 1 array
Ansys HFSS · Improved gain and bandwidth

1 Introduction

Spatial modulation is a technique in which selection of single antenna is done from a group of transmitting antennas in order to transmit the information bits. This increases the system efficiency but has error probability issues. To overcome this issue, Generalized Spatial Modulation (GSM) came into existence. In GSM, a combination of two or more antennas is selected at a time to transmit the data. This concept helps to minimize the error probability, and the system efficiency is also increased. Let us consider that the number of transmitting antennas is N_t and the number of active antenna chosen to transmit the data at any instant of time is N_p. Therefore, the available number of combinations to select N_p antennas out of N_t will be given by $C_{N_p}^{N_t}$, where C is the symbol used for combination.

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But the combination used will be in the power of two, so the permitted combination will be $N = 2^{\left\lfloor \log_2 C_{N_p}^{N_t} \right\rfloor}$. The information bits through first part of the system model is given as $l_1 = \left\lfloor \log_2 C_{N_p}^{N_t} \right\rfloor$, while the second part is $l_2 = N_p \log_2 M$, where M is the set of constellation points. Hence, the transmitted part will be addition of both the parts $L = l_1 + l_2 = \left\lfloor \log_2 C_{N_p}^{N_t} \right\rfloor + N_p \log_2 M$. For example, if $N_t = 4$ and $N_p = 2$, then the total number of combinations will be 6, but the acceptable combinations will be only 4. The length of information bits will be $l_1 = 2$ bits and $l_2 = 4$ bits for $M = 4$ which makes $L = 6$ bits [1]. But in this paper, all possible six antenna combinations have been simulated.

In this paper, the design of an array with the design of each possible combination of selecting two antennas out of four in 4 * 1 array along with the simulation and obtained results is shown. The array is designed by selecting proper parameters of the patch antenna. The design and analysis are done using Ansys HFSS software. The design is based on the selection of proper dimensions of the substrate, ground plane, patch, cut-out, feed line and the source required for feeding the antenna.

2 Methodology and Software Used

Ansys HFSS software provides best way to model the patch antenna and helps to analyse the radiation pattern, *S*-Parameters, polar plot, etc., very efficiently. The steps followed for the design of the antenna are to first model the design based on the parameters listed below [2]. For designing of the patch antenna, we must know about the dielectric constant ε_r, operating frequency f_0 and height of the substrate h. After selecting the above parameters as per the requirement for the desired application, the other necessary parameters for the design of patch antenna can be selected using the equations stated as under [3].

A. Width of the patch [4]:

$$\mathrm{W} = \frac{C_0}{f_0}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

C_0 = speed of the light; f_0 = operating frequency; ε_r = effective dielectric constant of substrate.

B. Length of the patch [5]:

$$L_e = L + 2\Delta L = \frac{\lambda_0}{2\sqrt{\varepsilon_0}} \tag{2}$$

$\Delta L = h/\sqrt{\varepsilon_e}$; λ_0 = wavelength; ε_0 = dielectric constant.

C. Effective dielectric constant of the patch [4]:

$$\varepsilon_e = \left(\frac{\varepsilon_r + 1}{2}\right)\left(\frac{\varepsilon_r - 1}{2}\right)\left(\frac{1 + 10h}{W}\right)^{-1/2} \tag{3}$$

h = height of substrate.

D. Length of the ground plane [5]:

$$L_g = 6h + L \tag{4}$$

E. Width of the ground plane [5]:

$$W_g = 6h + W \tag{5}$$

F. Length of the feed = decided on the basis of length to be elongated from the patch to the edge of the substrate [6]
G. Width of the feed selected on the basis of characteristic imp of transmission line (50Ω).

These basic equations stated above helps in deciding all the basic dimensions of the single patch antenna. The design and analysis of single patch antenna help in the implementation of the patch antenna array with all the known and calculated dimensions. The antenna parameters are thus studied obtaining the simulated results. The design is done using Ansys HFSS 2015.

2.1 Design Considerations

Knowing all the above parameters and doing calculations, the required design of patch antenna at 2.5-GHz frequency is made and it is simulated to obtain the results. This design is then used to further move towards the design of 4 * 1 patch antenna array. Table 1 shows all the dimensions calculated and used in the design of the single patch antenna and patch antenna array in the design (shown in the simulated results section). The required operating frequency is f_o = 2.54 GHz, but these results after simulation using this operating frequency are obtained at less than 2.54 GHz.

The above calculations are used to implement single patch antenna and 4 * 1 patch antenna array. The array needs to have proper dimensions and results, so that the switching circuit can be implemented in that array to have the ultimate aim accomplished.

Table 1 Dimensions for single patch and patch antenna array

Calculated patch dimensions	Single patch	4 * 1 array
Dielectric substrate	Rogers RT/duroid 5880 (2.2)	FR4 Epoxy (4.4)
Length of substrate (L_s) (mm)	53.63	82.11
Width of substrate (W_s) (mm)	61.89	657.68
Height of substrate (h) (mm)	2.54	2.54
Length of patch (L_P) (mm)	38.39	27.57
Width of patch (W_p) (mm)	46.65	55.91
Length of ground plane (mm)	55.65	82.11
Width of ground plane (mm)	61.89	657.68
Length of feed (L_f)	7.62 mm	As per required elongations to reach till the edge
Width of feed (W_f) (mm)	1.885	1.885
Length of source (L) (mm)	1.885	1.885
Width of source (h) (mm)	2.54	2.54
Length of the air-box (L_b) (mm)	70	100
Length of the air-box (W_b) (mm)	85	460
Height of the air-box (H_t) (mm)	15	15
Gap between the antennas in the array (G)		59.5 mm ($\lambda/2$ between each antenna)

3 Simulated Design Details with the Results

Ansys HFSS software is used to design the array of 4 * 1 patch antenna array, and the design is simulated to obtain the results. The array is then implemented by selecting two antennas out of four at a time. Thus, it will have six possible combinations of selection of two antennas out of four in the array. Each possible combination is simulated. The results are studied in order to have the implementation of switching circuit in the array as the results of each combination are known well.

3.1 Single Patch Antenna Design with Results

The single patch antenna is designed using the parameters mentioned in Table 1. The effect of dimensions of the patch by changing is observed carefully on the simulated results. This is the first step towards to design the array and getting the proper knowledge about the parameters of the patch antenna to be analysed.

The above result in Fig. 1 shows that the S-Parameter plot is at −25 dB at 2.5 GHz, and bandwidth is shown using the marker points $m1$ and $m2$ which is around 900 MHz. The 3D-polar plot in Fig. 2 shows maximum gain of about 5 dB (Fig. 3).

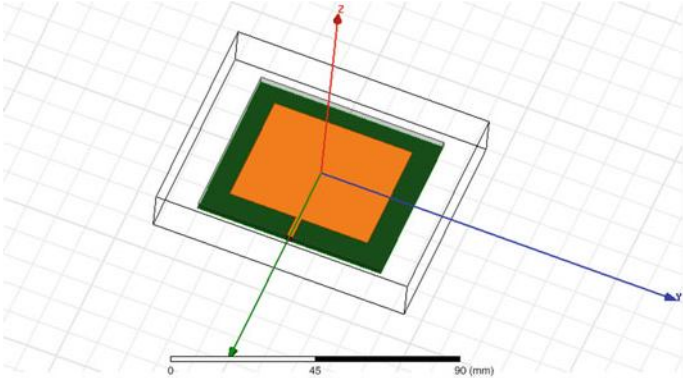

Fig. 1 Single patch antenna design

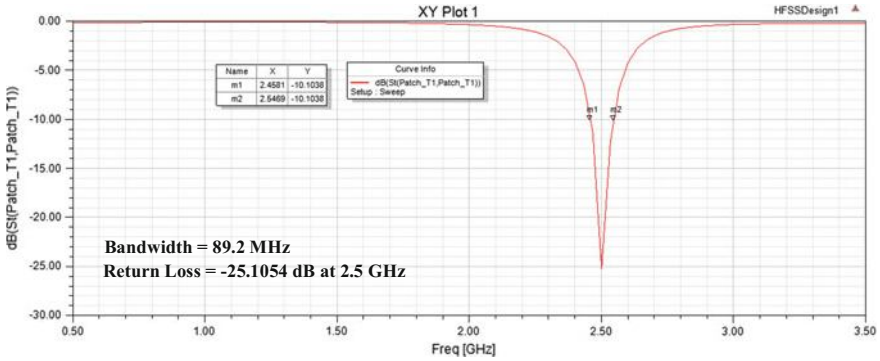

Fig. 2 Single patch antenna *S*-Parameter plot

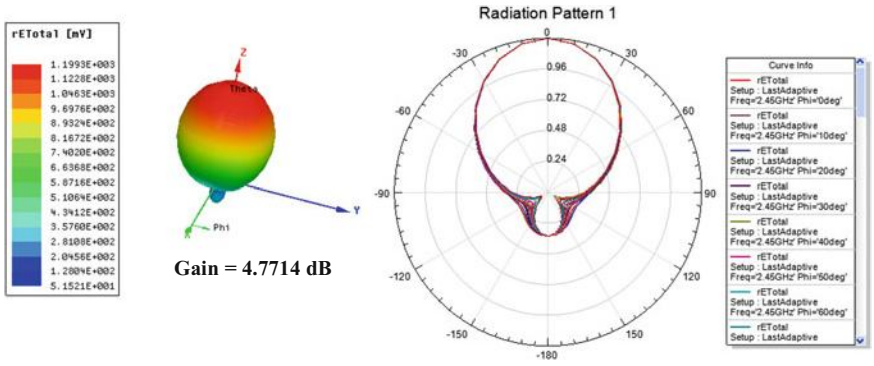

Fig. 3 Single patch antenna 3D-polar plot and radiation pattern plot

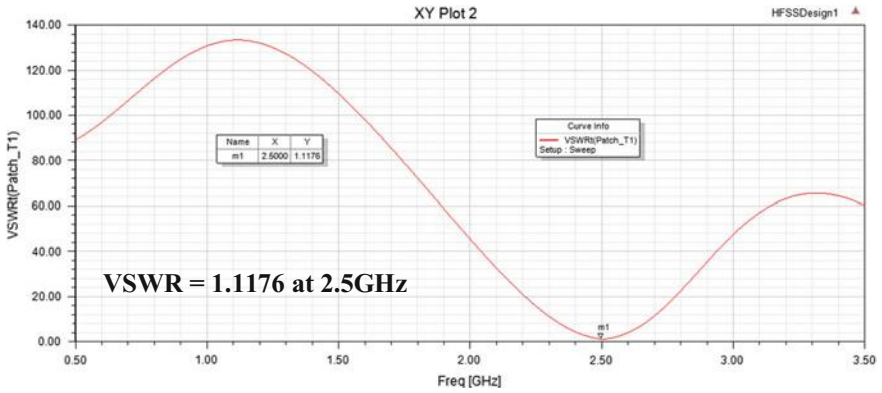

Fig. 4 Single patch antenna VSWR plot

The VSWR plot shown in Fig. 4 shows that the VSWR of the simulated antenna is 1.1176.

*3.2 4 * 1 Array Patch Antenna Design with Results*

The 4 * 1 array is implemented on the basis of single patch antenna designed, and dimensions are calculated as shown in Table 1. The array is basically designed to get improved antenna parameters. The array results are simulated and analysed so that it can be proceeded further for implementation of the switching circuit. The design of 4 * 1 patch antenna array simulated results is shown below.

The above result in Fig. 5 shows that the *S*-Parameter plot is at −46.39 dB and the bandwidth is shown using the marker *m*1 and *m*2 which is around 950 MHz.

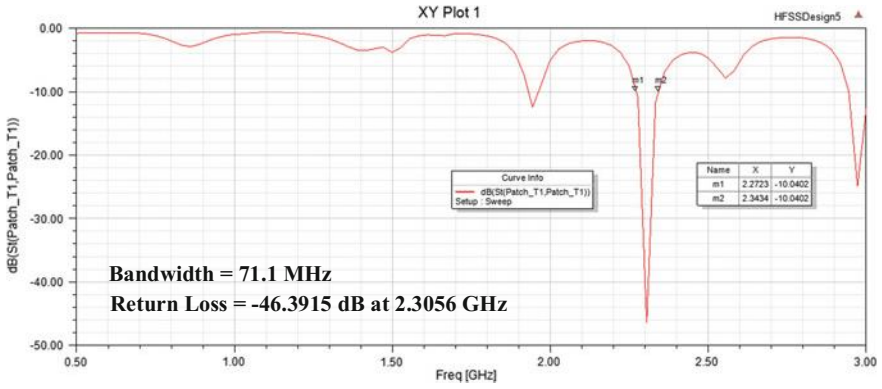

Fig. 5 4 * 1 array patch antenna *S*-Parameter plot

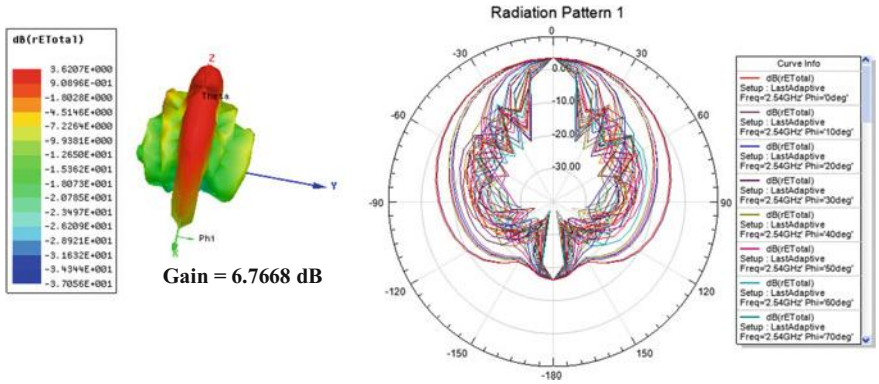

Fig. 6 4 * 1 array patch antenna 3D-polar plot and radiation pattern plot

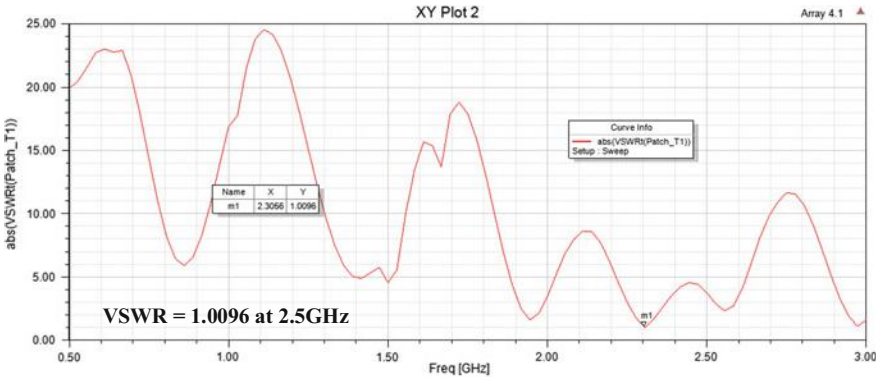

Fig. 7 4 * 1 array patch antenna VSWR plot

The 3D-polar plot in Fig. 6 shows maximum gain of about 9 dB. The VSWR plot in Fig. 7 shows that the VSWR of the deigned antenna is 1.0096.

4 Combination of Antenna Selection Simulated Results

The 4 * 1 array patch antenna is then used for the selecting of two antennas at a time out of four with all the possible combinations, viz. (1,2), (1,3), (1,4), (2,3), (2,4) and (3,4) antennas out of all four antennas in the array. The implemented designs of each combination are simulated, and simulated results are shown in Figs. 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 and 19.

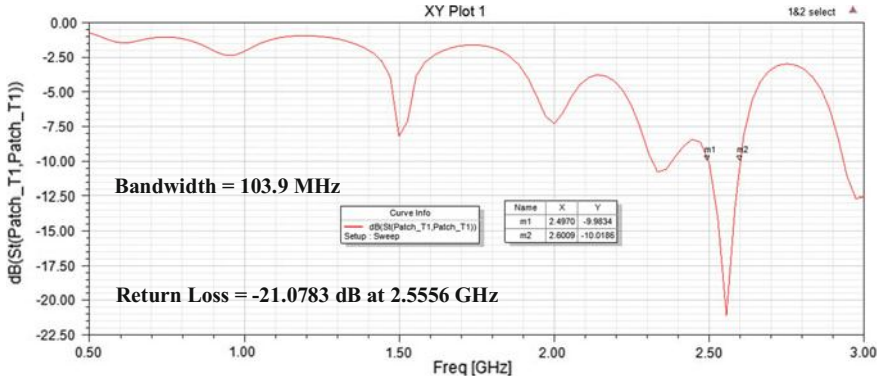

Fig. 8 1&2 antennas selected in 4 * 1 array patch antenna *S*-Parameter plot

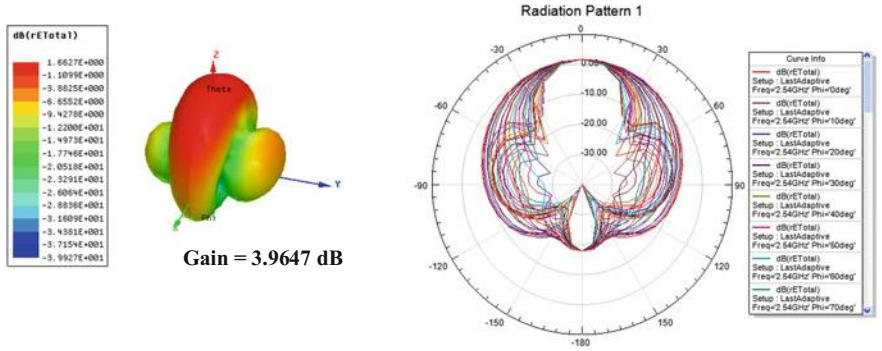

Fig. 9 1&2 antennas selected in 4 * 1 array patch antenna 3D-polar plot & radiation pattern plot

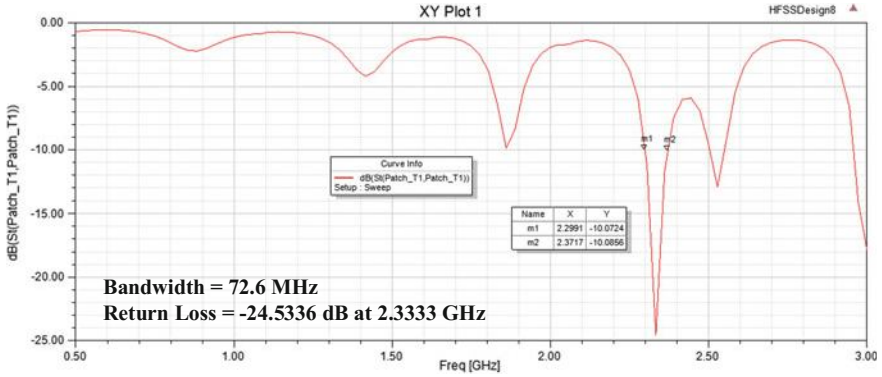

Fig. 10 1&3 antennas selected in 4 * 1 array patch antenna *S*-Parameter plot

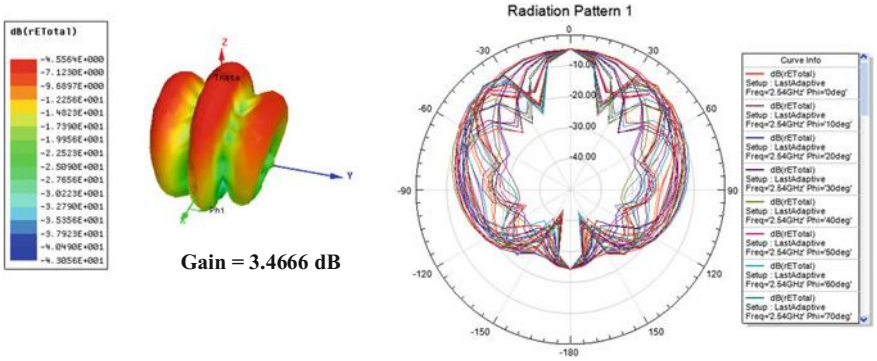

Fig. 11 1&3 antennas selected in 4 * 1 array patch antenna 3D-polar plot and radiation pattern plot

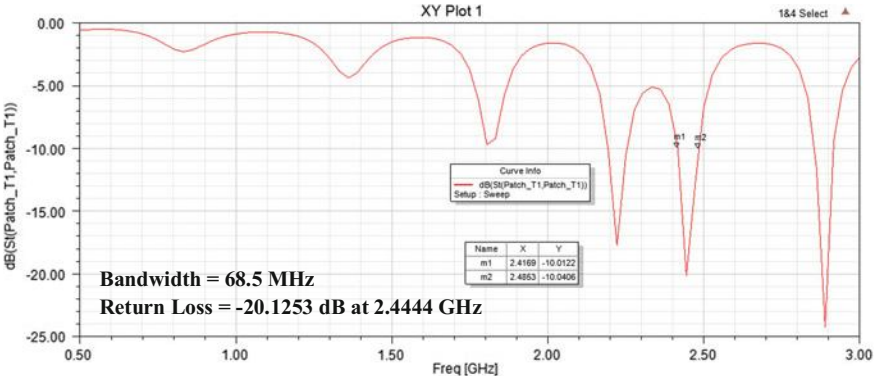

Fig. 12 1&4 antennas selected in 4 * 1 array patch antenna *S*-Parameter plot

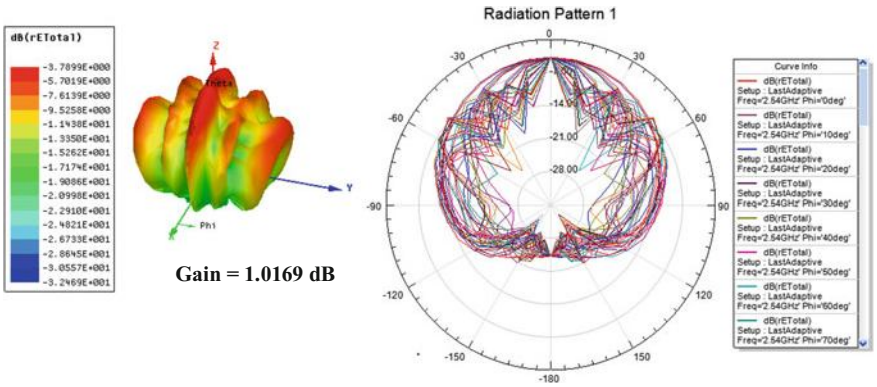

Fig. 13 1&4 antennas selected in 4 * 1 array patch antenna 3D-polar plot and radiation pattern plot

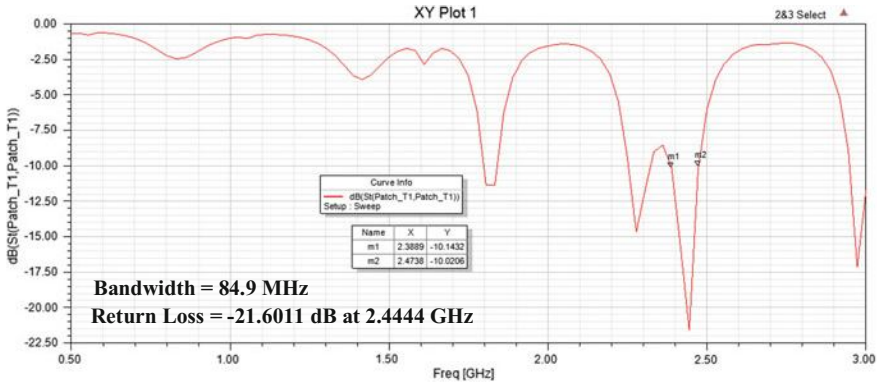

Fig. 14 2&3 antennas selected in 4 * 1 array patch antenna *S*-Parameter plot

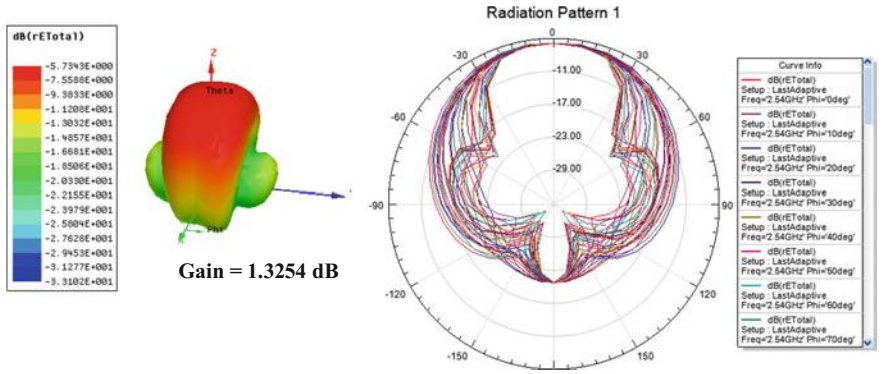

Fig. 15 2&3 antennas selected in 4 * 1 array patch antenna 3D-polar plot and radiation pattern plot

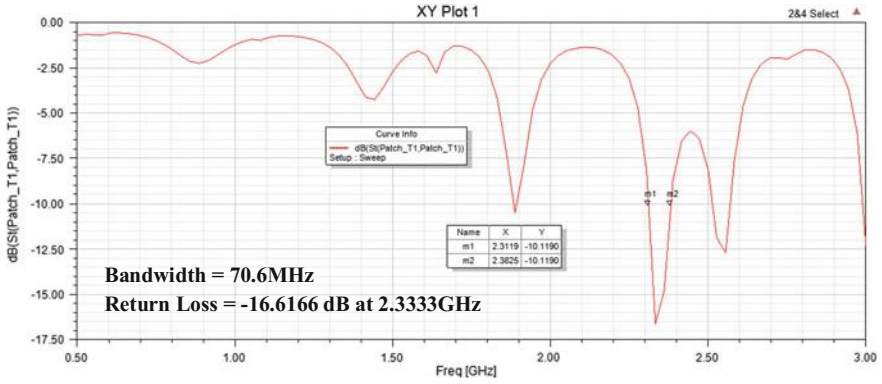

Fig. 16 2&4 antennas selected in 4 * 1 array patch antenna *S*-Parameter plot

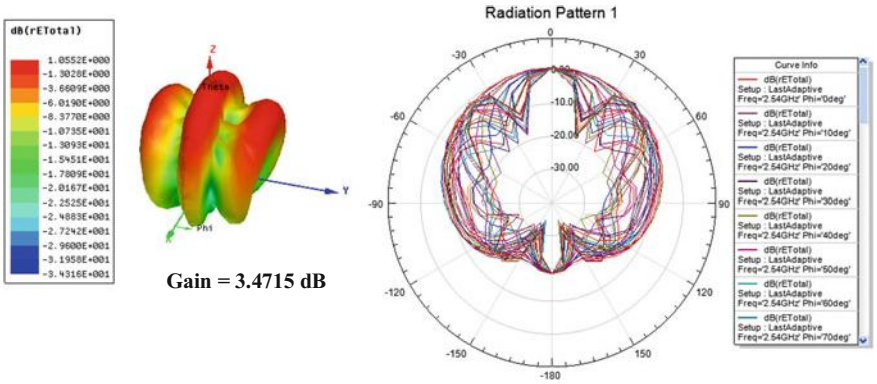

Fig. 17 2&4 antennas selected in 4 * 1 array patch antenna 3D-polar plot and radiation pattern plot

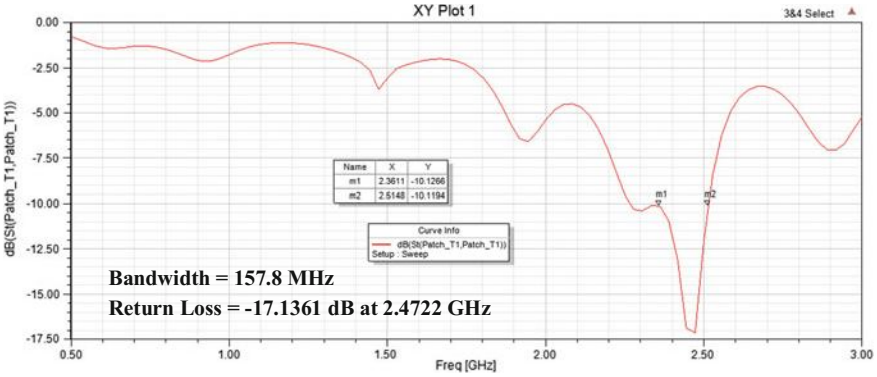

Fig. 18 3&4 antennas selected in 4 * 1 array patch antenna *S*-Parameter plot

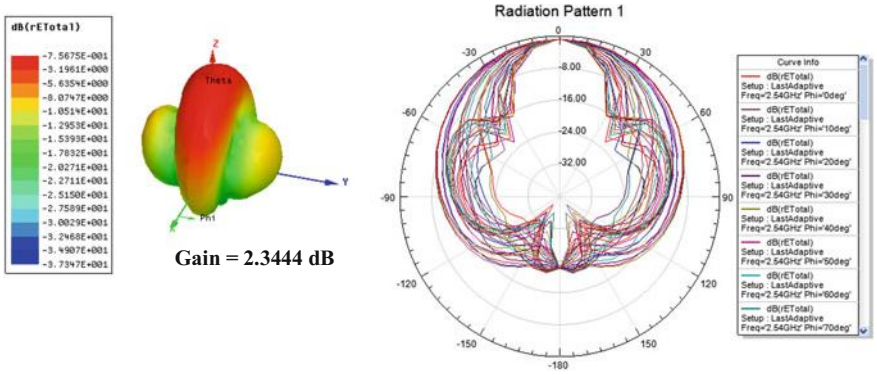

Fig. 19 3&4 antennas selected in 4 * 1 array patch antenna 3D-polar plot and radiation pattern plot

All the above implemented design gives good results in gain, bandwidth and efficiency as per the theoretical standard results [7]. The switch can now be implemented in the array in order to select two antennas out of four in the array. The above design for the 4 * 1 patch antenna array as shown in Fig. 5 is chosen in this way so as to have equal length for the division of power from the source even when two antennas out of four are selected randomly at a time.

The design of two antennas selection out of four in the 4 * 1 patch antenna array is done in order to study the changes on antenna parameters when two antennas out of four will be selected with the help of the implemented switch.

5 Conclusion

The switching technique to be implemented in the array will give the efficient transfer of bits, and thus the selection of two antennas out of four in the array is simulated. The simulated results are studied to implement the switching circuit in the 4 * 1 patch antenna array. When the switching of antenna occurs, two antennas are selected randomly out of four; however, the design is for four antennas working simultaneously in 4 * 1 patch antenna array. For two antennas to be selected, the proper switching circuit network needs to be implemented in the array. The switching circuit must be implemented such that the design gives required results of *S*-Parameter, radiation pattern and VSWR even if two antennas are selected randomly at a time.

References

1. Mesleh, R.Y., Ahn, C.W.: Spatial modulation. IEEE Trans. Veh. Technol. **57** (2008)
2. Ansoft HFSS 2015 version 16 Manual
3. Balanis, C.A.: Antenna Theory Analysis and Design. Wiley India (p.) Ltd. (2005)
4. Chosh, C.K., Bhattacherjee, A.K., Roy, B.C.: Design and performance analysis of microstrip patch array antennas with different configurations. Int. J. Future Gener. Commun. Netw. **9**, 97–110 (2016)
5. Wahab, N.Ab., Maslan, Z.B., Muhamad, W.N.W., Hamzah, N.: Microstrip rectangular 4x1 patch array antenna at 2.5 GHz for WiMax application. In: Second International Conference on Computational Intelligence, Communication Systems and Networks (2010)
6. Garg, R., Bhartia, I., Bahl, P., Ittipiboon, A.: Microstrip Antenna Design Handbook. Artech House, INC Publications (2001)
7. Ray, K.P., Kumar, G.: Broadband Microstrip Antennas. Artech House, INC Publications (2003)