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Design and Performance of Resonant Spacing Linear Patch Array with Mitered Bend Feed Network for Wireless Applications

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Abstract

Objective: This research paper focuses on the simulated design and its analysis of 2 element microstrip patch antenna arrays with Quarter wave transformer feed and mitered bend feed network that is widely used in ISM frequency bands in the field of wireless communications. **Methods:** Various types of microstrip array antennas using Quarter wave transformer feed and with miter bend feeds are designed using HFSS 13.0 and fabricated by photolithography technique using FR-4 substrate, which is tested using VNA E5071C. **Findings:** The optimum performance of the feeding system is based on various antenna parameters. Here 1X2 array antennas are designed. Miter bends are used for better impedance matching. Usage of miter bends declines the reflection coefficient. There is improvement in gain by using miter bend feed network. **Applications:** Good impedance matching, optimum reflection coefficient and high gain are achieved by metered bends. The obtained results show that the designed antenna is an apt tool for communications.

Keywords: Corporate Feed, HFSS, Microstrip Antenna, Mitered-Bend Feed, Quarter-Wave Feed Transformer, Reflection Coefficient, WLAN

1. Introduction

The key advantage of printed circuit technology used in microstrip antenna is that it can be developed as a thin protrusion from its surface. Microstrip antenna possesses medical application, satellite, radar communication etc. The limitations of microstrip antenna are narrow strip frequency band and disability to operate at high power levels of wave guide, coaxial line or the least considered strip line. The great challenge involved in the design of any microstrip antenna is to increase the bandwidth and gain[1–5].

Different configuration of microstrip antenna arrays produces improved efficiency and gain. The better the impedance matching across the corporate and series feeding array configuration, the better is the efficiency of microstrip antenna. Power distribution among the antenna elements can be remodelled by corporate feed network, which in turn can control the direction of beam by recommending phase[6–10].

2. Design of Feed Network for an Array

In long distance communications, antenna arrays are used to have high gain. In constructing an array, feed network design is crucial as it regulates the amplitude and phase of

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the radiating elements in order to control the beam scanning properties[11–14].

2.1 Parallel Feed

The practical solution to the array feed problem is to use parallel or corporate feed. Here, one coaxial line is used to feed a network of micro strip transmission lines. A series of power dividers discharge power to and from the antenna elements. To maintain phase among the elements, the micro strip transmission line is used to provide equal path length to all elements. A simple one-dimensional parallel feed system for a linear array, consisting of a branching network of two-way power dividers is as shown in Figure 1.

Figure 1. Parallel feed system

2.2 T–Split Power Divider

For subdividing the power among the array elements, two-way power splitters are used by the parallel feed network.

The simplest method to distribute power equally is with the T-junction which is shown in Figure 2. It is a three-port network that splits the signal from port 1 into two equal halves, where one half (3 dB) of the power is sent to one arm and the other half is sent to the other arm. It also combines the signals from ports 2 and 3 from a transmit point of view.

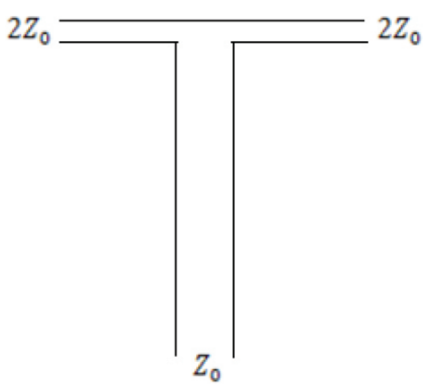

Figure 2. T split power divider.

2.3 Quarter Wave Transformer

In general, micro strips, strip lines and coaxial cables are used as elements for feed networks. To have maximum power transfer through the feed network, Impedance matching is extremely important. The optimum method to have impedance matching is through a quarter wave transformer shown in Figure 3. Maximum power is transmitted by reducing the reflection coefficient between two impedances Z1 and Z_3. By placing a quarter wave transformers of length λ/4 and impedance Z_2 between the two transmission lines, the reflection coefficient is eliminated if the following relation holds good.

$$Z_2 = \sqrt{Z_1 Z_3}$$

A typical corporate-fed micro strip uniform array is a tree-like structure, which appropriately combines/distributes the signals from/to the elements as shown in Figure 4.

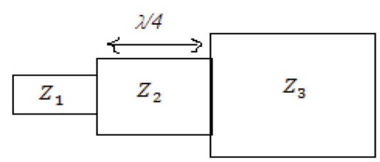

Figure 3. Quarter-wave transformer.

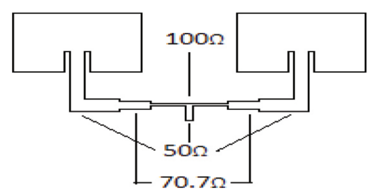

Figure 4. 2-element corporate-fed microstrip array with quarter wave transformer.

2.4 Miter Bends

To guide the signals to/from the elements, many bends exist in the transmission lines of the feed networks. A large portion of the signal reflects back the way the signal travelled down the line, but a part of it gets bounced around the corner. To have minimal reflections, the arc radius of the bend must be at least three times the strip width. A 90° bend as shown Figure 5 behaves as a shunt capacitance between the ground plane and the bend. In order to create a better match, the bend is mitered to reduce the area of metallization and remove the excess capacitance as shown in Figure 6. Design requires T junction and miter bending (MBEND) modification to generate low insertion loss at the input port. Mitered T-junction and micro strip bends were applied in order to have low reflection and insertion losses. The mitered T- junction of 3 dB power divider is shown in Figure 7.

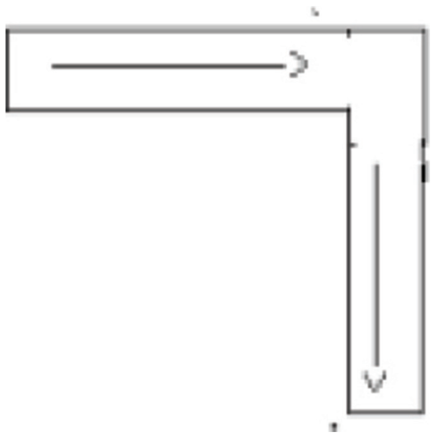

Figure 5. 90° bend.

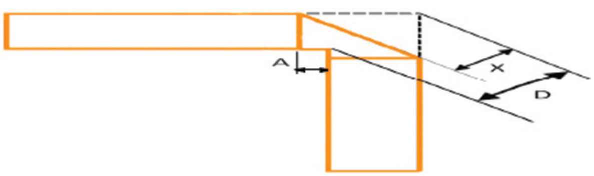

Figure 6. 45° miter bend.

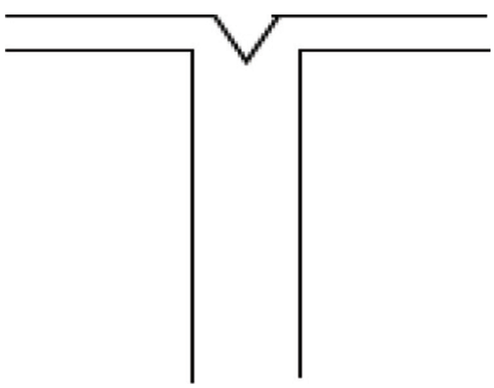

Figure 7. Mitered 'T' bend.

3. Design Consideration

3.1 Rectangular Patch Antenna

The purpose of this work is to show how the rectangular patch antenna has been patterned using FR-4 substrate with the following specifications: Operating frequency =2.4 GHz, ε_{γ}= 4.4 input impedance of 50 Ω, lose tangent δ = 0.02, thickness t=1.6 mm and height h=1.6 mm. The parameters of patch antenna at reference resonant frequency are calculated from the following standard antenna design equations[15–18].

Step 1: Specifications:

Table 1. Design Specifications of an Antenna

Input Parameters	Specifications
Frequency operation	2.4GHz
Input impedance	50Ω
VSWR	< 2
Reflection coefficient	<=-10dB
Gain	4-6 dB

Step 2: Substrate selection:
To provide mechanical support of antenna metallization, substrate is principally needed for the patch antenna. The characteristics of substrates i.e., dielectric constant (ε_{γ}), loss tangent (δ), resistance to chemicals, tensile and structural strengths, flexibility and their variation with temperature and frequency are to be considered for the selection of substrate. The characteristics of various substrates are provided in Table 2. In this work, FR-4 was chosen as the substrate material as it has the advantages of low cost and easy fabrication.

Table 2. Characteristics of different substrates

Name	Relative premitivity(ε_r)	Dielectric tangent loss (δ)
Duriod	2.2	0.0009
Teflon	2.09	0.001
Flame Retardant-4 (FR-4)	4.4	0.02
Gold	1	0
Plexi glass	3.4	0.001

Step 3: Width of the patch (*W*):

Antenna patch width is determined by using

$$W = \frac{c}{2f_0\sqrt{\left(\varepsilon_r + \frac{1}{2}\right)}} \tag{1}$$

Where $C = 3 * \frac{10^8 m}{s}$

Step 4: Actual Length of the patch (L):

The antenna patch actual length is determined from resonant frequency (f_0), given by

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{2a}$$

Where $\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$ (2b)

Effective length and actual length of a patch antenna can be correlated as

$$L = L_{eff} - 2\Delta L \tag{3}$$

Where ΔL is a function of effective dielectric constant ε_{reff} and the width to height ratio $\left(\frac{W}{h}\right)$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{4}$$

Step 5: Inset feed Depth (y_0):

The inset feed depth y_0 expressed as

$$\gamma o = 10^{-4}\{0.016922\varepsilon_\gamma^{\ 7} + 0.13761\varepsilon_\gamma^{\ 6} - 6.1783\varepsilon_\gamma^{\ 6} + 93.187\varepsilon_\gamma^{\ 4} - 682.69\varepsilon_\gamma^{\ 3} + 2.561.9\varepsilon_\gamma^{\ 2} - 4043\varepsilon_\gamma + 6697\}\frac{L}{2} \tag{5}$$

Step 6: Feed width (W_f):

The required feed width to height ratio $\left(\frac{W_f}{h}\right)$ is obtained as

$$\frac{W_f}{h} = \begin{cases} \frac{8e^A}{e^{2A} - 2} & \frac{W}{h} \le 2 \\ \frac{2}{\pi}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\} & \frac{W}{h} \ge 2 \end{cases} \tag{6a}$$

Where $A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r + 1}{\varepsilon_r - 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$ (6b)

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \tag{6c}$$

Step 7: Notch gap (g):

Resonant frequency of patch antenna depends on notch gap (g) and are related as follows:

$$g = \frac{v_0}{\sqrt{2 * \varepsilon_{reff}}}\frac{4.65 * 10^{-12}}{f_0(in\ GHz)} \tag{7}$$

Step 8: Miter Bend designed equation:

$$D = W\sqrt{2}$$
$$X = W\sqrt{2} * (0.52 + 0.65 * e^{\uparrow}((-1.35 * W/h)) \tag{8}$$
$$A = X\sqrt{2} - W$$

The parameters needed in an antenna design can be found using the above mentioned steps. The dimension of single patch is calculated and is included in Table 3.

Table 3. Dimensions of 2 element antenna array with element spacing $\frac{\lambda}{2}$

Description	Value (mm)
Width of the Patch(W)	38.036
Length of Patch(L)	29.1
Height (or thickness) of FR4 Substrate(h)	1.6
Width of Microstrip feed(W_f)	3.059
Notch gap (g)	0.6
Distance of inset fed(d)	9.044
Width of substrate(W_S)	129.6
Length of substrate(L_S)	73.6
Length of 50Ω line	15.46
Width of 50Ω line	3.059
Length of 100Ω line	30.92
Width of 100Ω line	0.709

4. Results and Discussion

4.1 Two Element Antenna Array with Quarter Wave Feed Network

The geometry of the proposed and fabricated antennas is shown in Figure 8 and Figure 9. Figure 10 represents the experimental set up for measuring the antenna characteristics parameters like reflection coefficient and VSWR of two elements of patch antenna array using quarter wave and mitered bend feed network. The simulated and measured plots of reflection coefficients of this antenna are shown in Figure 11 and Figure 12. The antenna is resonated at 2.39 GHz. At resonant frequency the observed reflection coefficient (S_{11}) is -12.23 dB. The simulated and measured plots of VSWR of this antenna are shown in Figure 13 and Figure 14. At resonant frequency the observed VSWR is 1.64. The 3D radiation pattern describes the behaviour of antenna direction and gain as shown in Figure 15 and Figure 16. At resonant frequency the observed gain is 5.33 dB. Summary of obtained results in this sections are presented in the Table 4.

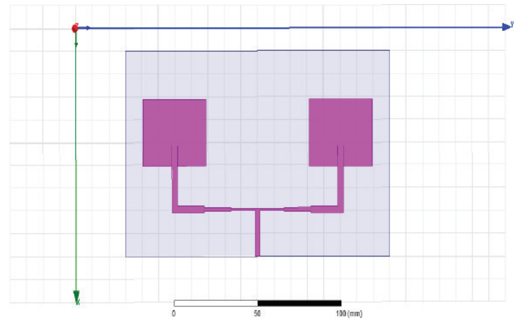

Figure 8. Geometry of two element antenna array with quarter wave feed network.

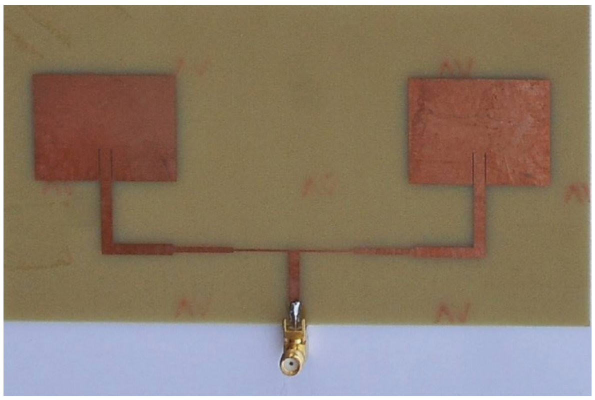

Figure 9. Fabricated two element antenna array with quarter wave feed network.

Figure 10. Experimental set up for measuring the characteristics parameters of microstrip patch antenna array.

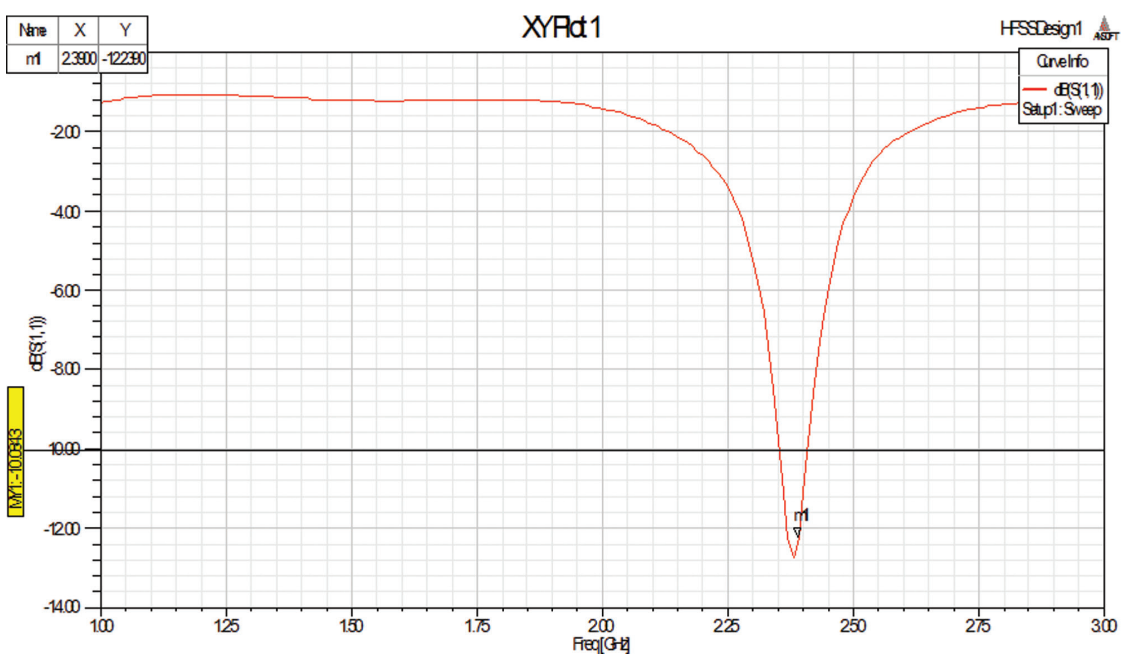

Figure 11. Simulated reflection coefficient of two element antenna array with quarter wave feed network.

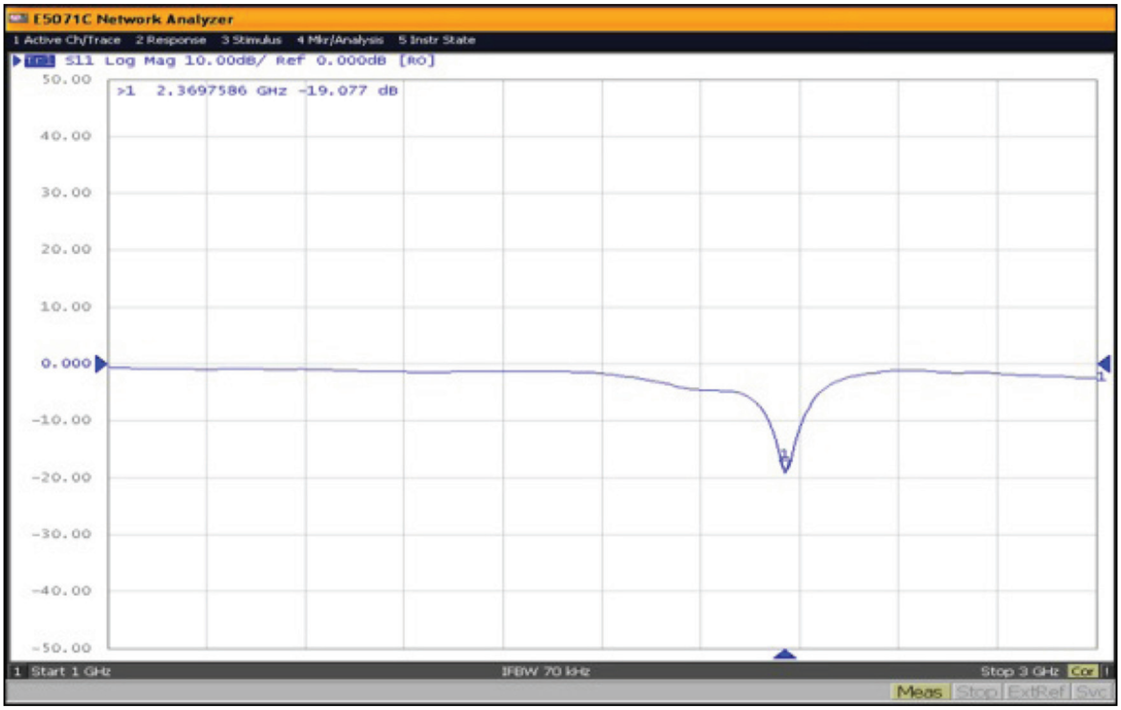

Figure 12. Measured reflection coefficient of two element antenna array with quarter wave feed network.

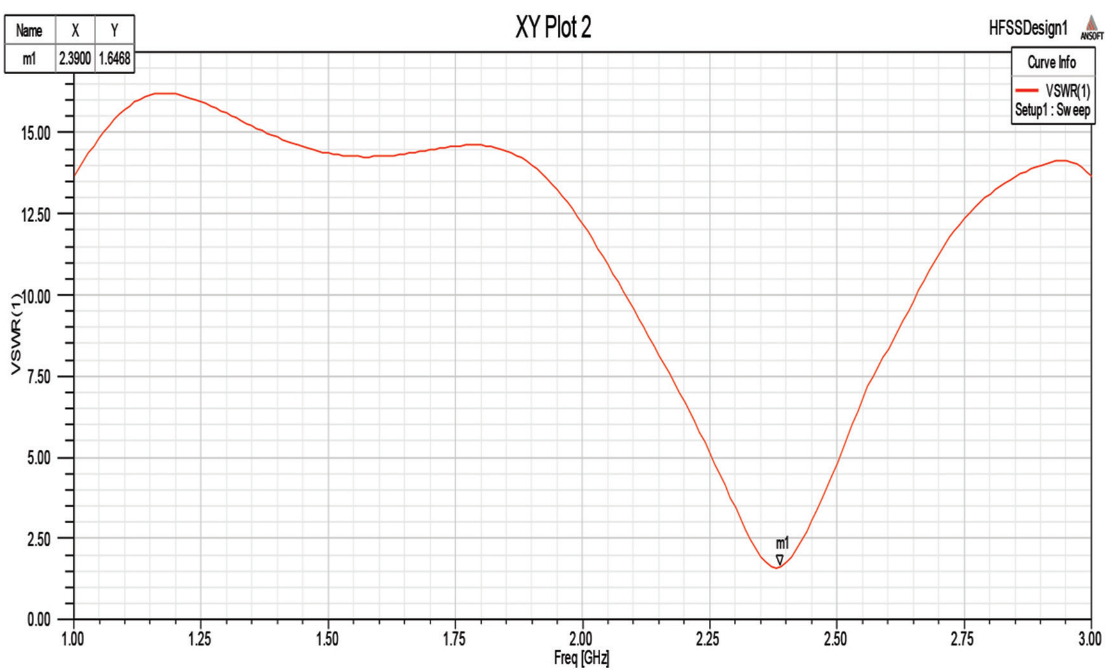

Figure 13. Simulated VSWR of two element antenna array with quarter wave feed network.

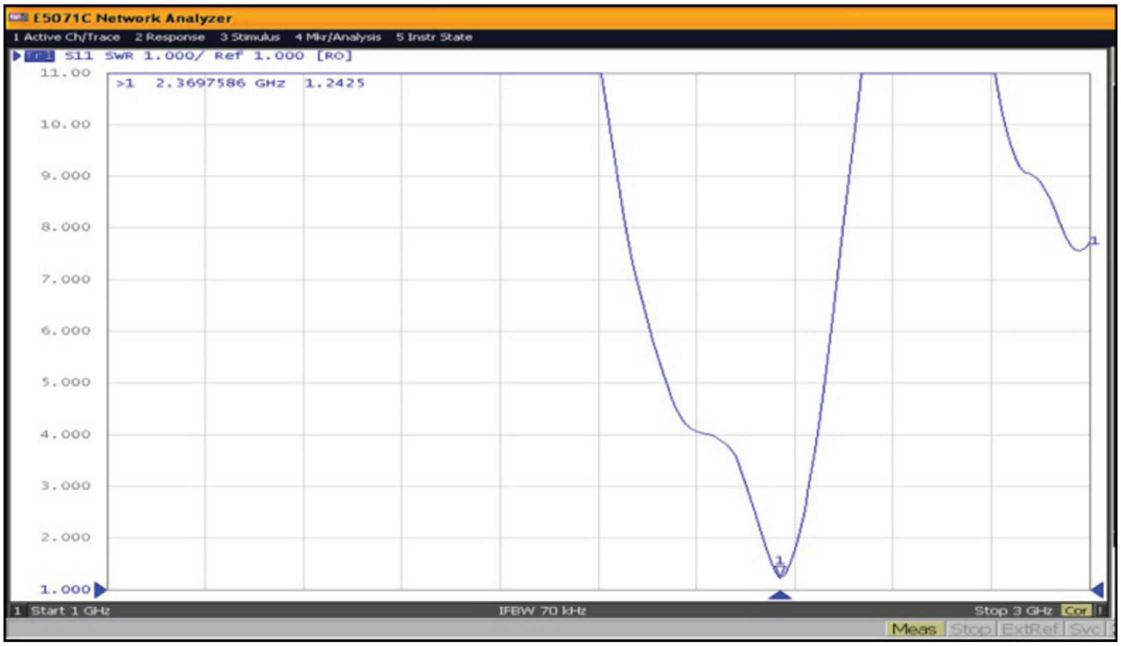

Figure 14. Measured VSWR of two element antenna array with quarter wave feed network.

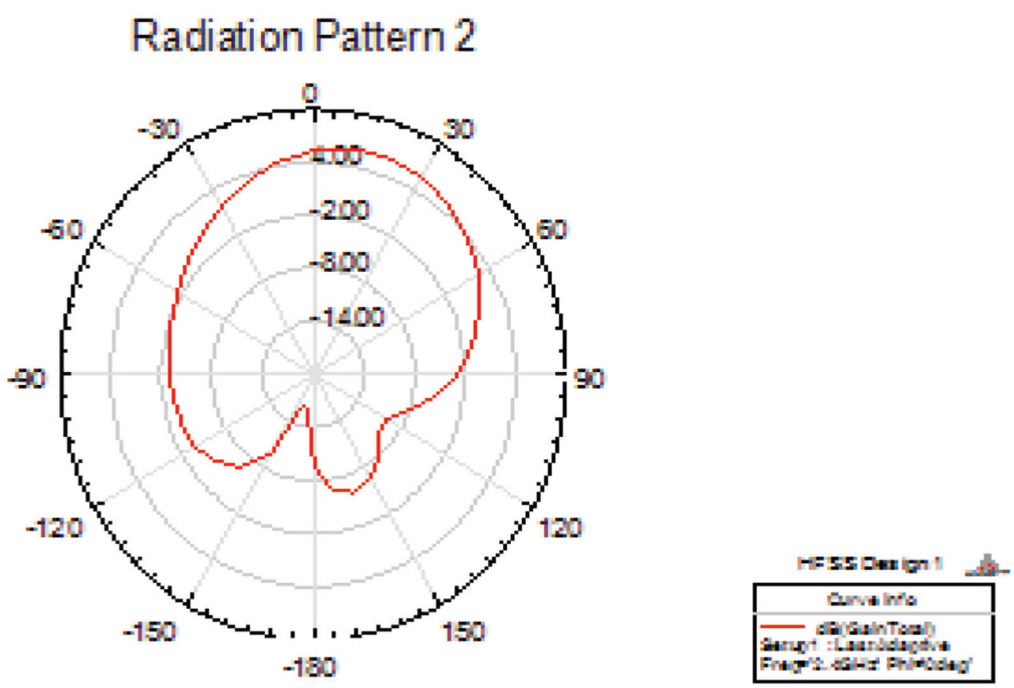

Figure 15. Radiation pattern of two element antenna array with quarter wave feed network.

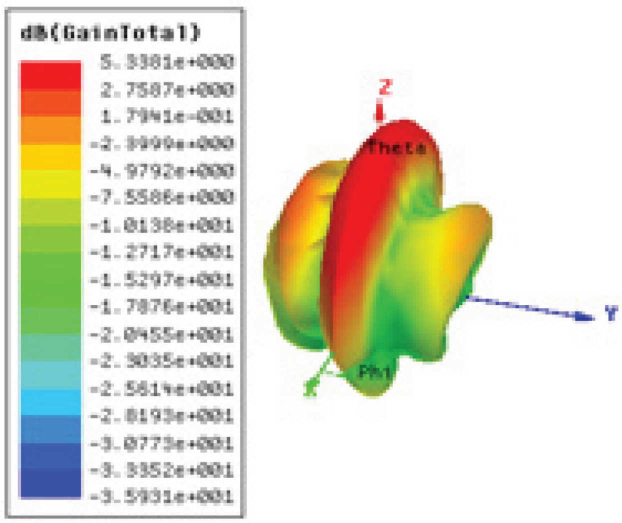

Figure 16. Gain of two element antenna array with quarter wave feed network.

4.2 Two Element Antenna Array with Mitered Bend Feed Network

The geometry of the proposed antenna and fabricated antennas are shown in Figure 17 and Figure 18. The simulated and measured plots of reflection coefficients of this antenna are shown in Figure 19 and Figure 20. The antenna is resonated at 2.39 GHz. At resonant frequency the observed reflection coefficient (S_{11}) is -12.239 dB. The simulated and measured plots of VSWR of this antenna are shown in Figure 21 and Figure 22. At resonant frequency the observed VSWR is 1.88. The 3D radiation pattern describes the behaviour of antenna direction and gain as shown in Figure 23 and Figure 24. At resonant frequency the observed gain is 6.04 dB. Summary of obtained results in this sections are presented in the Table 5.

Table 4. Results of two element antenna array with quarter wave feed network

Resonant frequency in GHz		*Reflection coefficient(s_{11}) in dB*		*VSWR*		*Gain in dB*
Simulated	*Measured*	*Simulated*	*Measured*	*Simulated*	*Measured*	*Simulated*
2.39	2.37	-12.239	-19.077	1.64	1.24	5.338

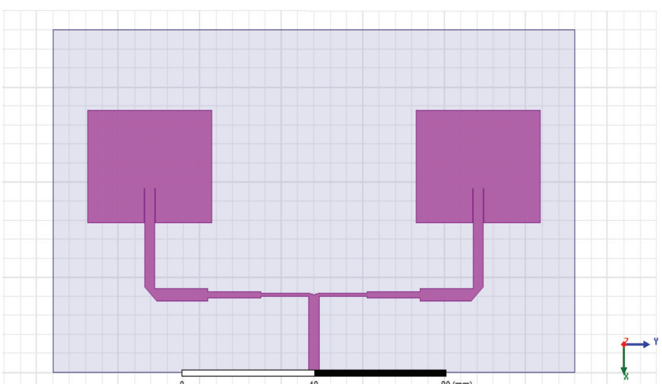

Figure 17. Geometry of two element antenna array with mitered bend feed network.

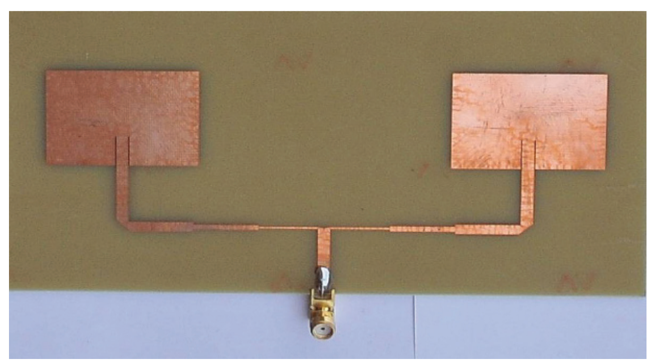

Figure 18. Fabricated two element antenna array with mitered bend feed network.

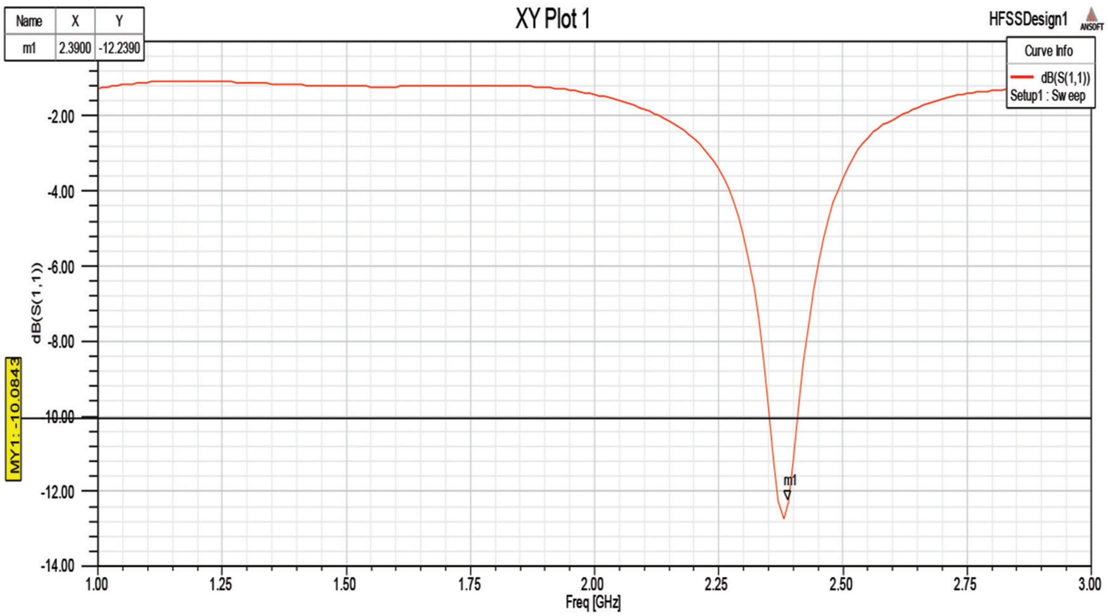

Figure 19. Simulated reflection coefficient of two element antenna array with mitered bend feed network.

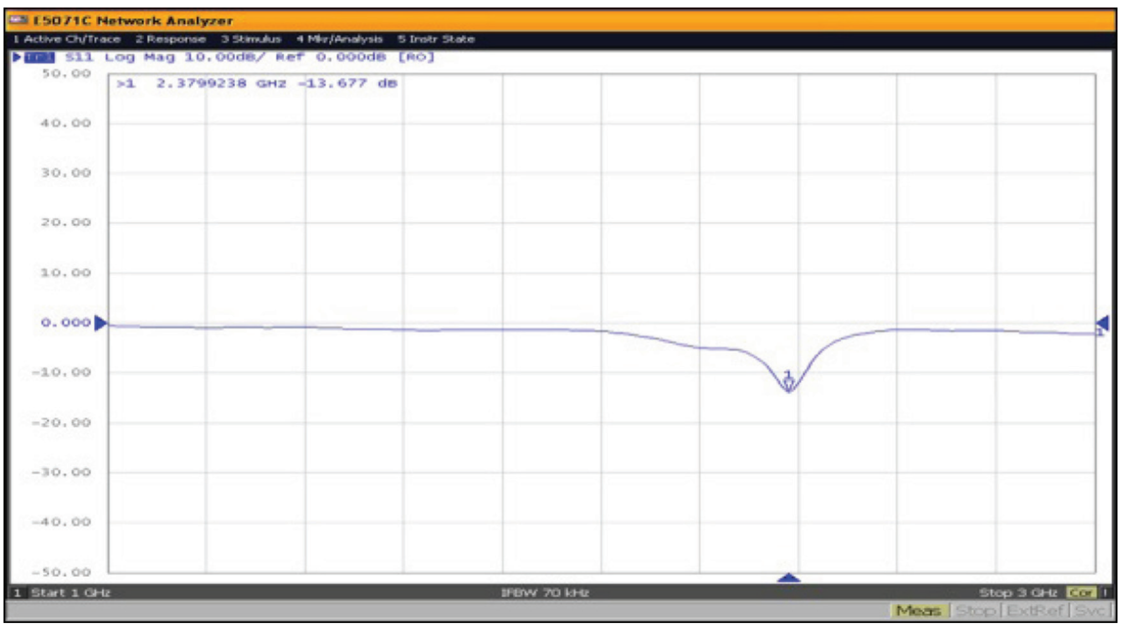

Figure 20. Measured reflection coefficient of two element antenna array with mitered bend feed network.

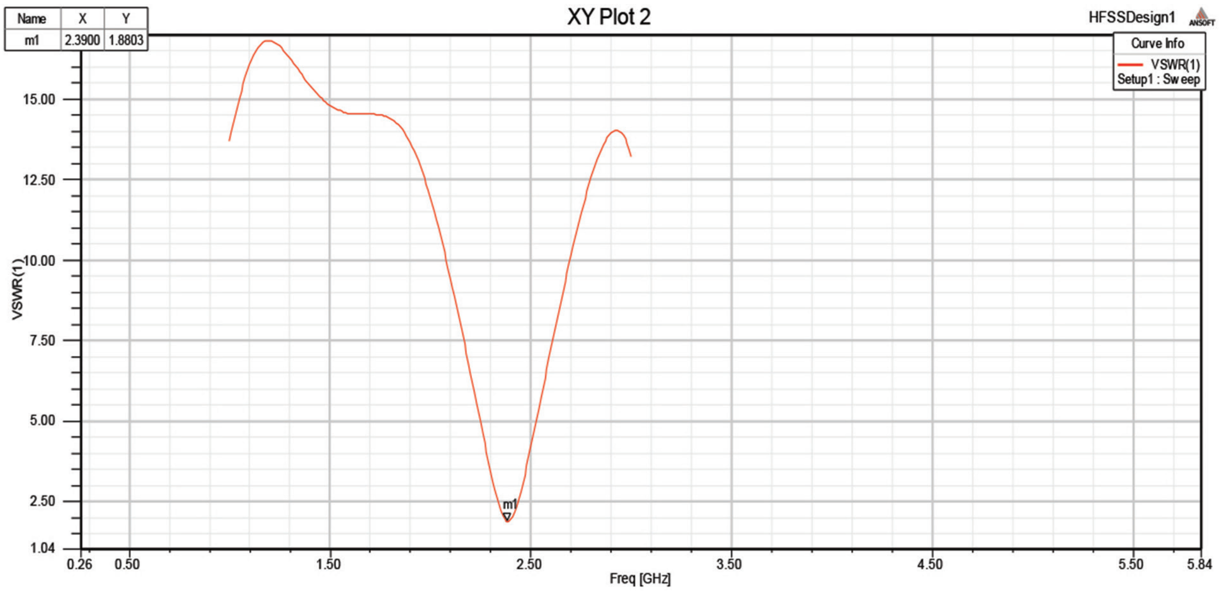

Figure 21. Simulated VSWR of fabricated of two element antenna array with mitered bend feed network.

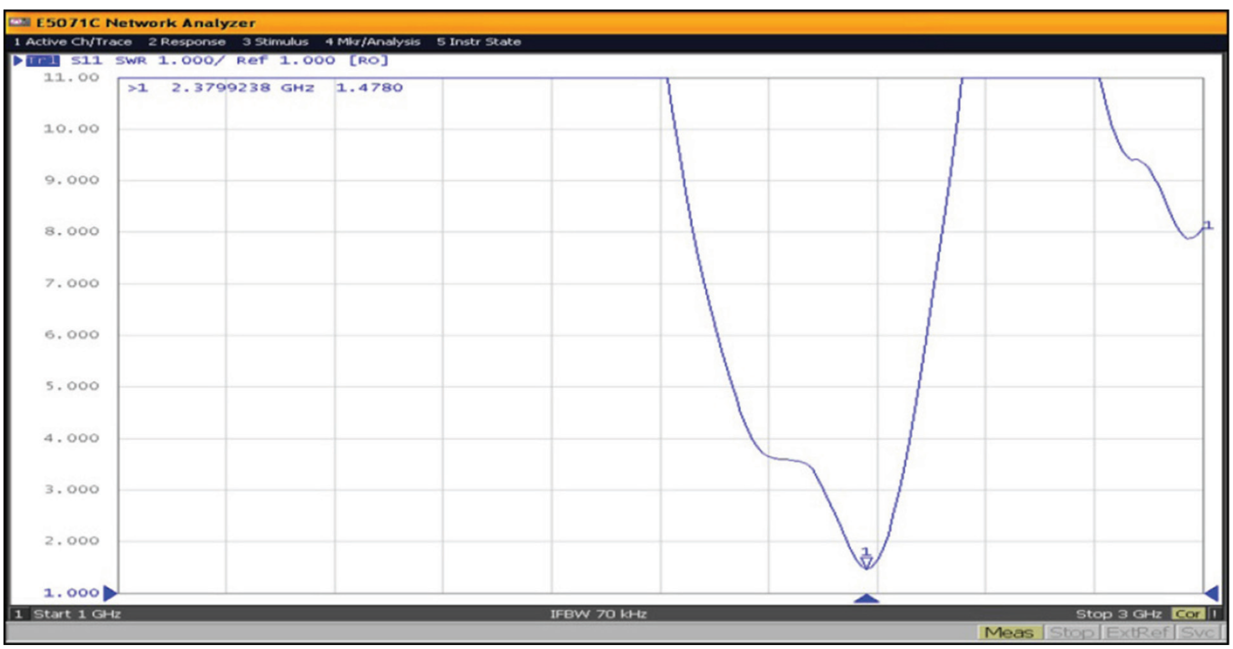

Figure 22. Measured VSWR of fabricated of two element antenna array with mitered bend feed network.

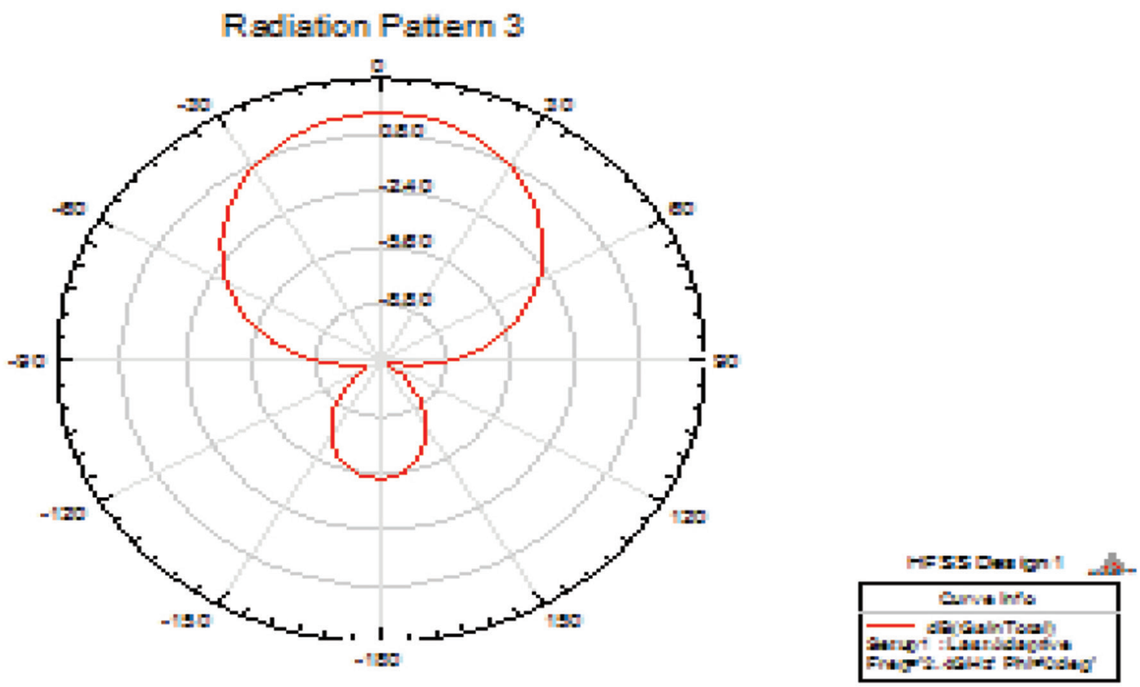

Figure 23. Radiation pattern of two element antenna array with mitered bend feed network.

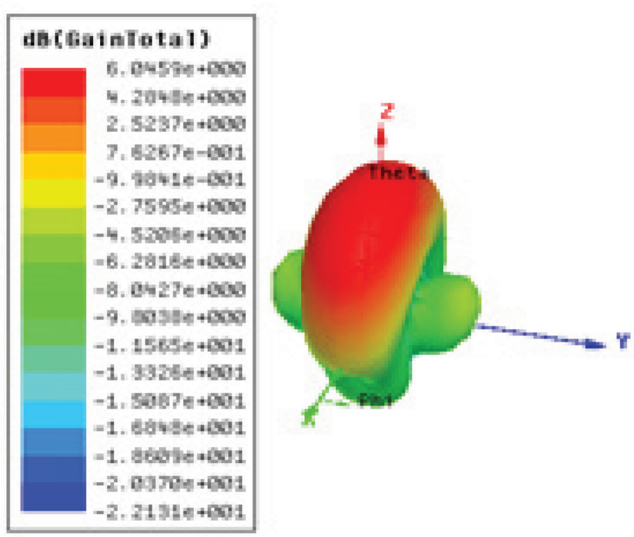

Figure 24. Gain of two element antenna array with mitered bend feed network.

5. Conclusion

To have better gain, the number of elements in the array has to be increased. By using miter bend feed network, better impedance matching is observed and moreover, the gain is raised from 3.0524 dB (single element) to 6.04 dB (2 elements).By using these, the reflection coefficient also decreases. It can be noticed from the results that with the help of miters the gain of an antenna array can also be definitely increased.

Table 5. Two element antenna array with mitered bend feed network

Resonant frequency in GHz		*Reflection coefficient(s_{11}) in dB*		*VSWR*		*Gain in dB*
Simulated	*Measured*	*Simulated*	*Measured*	*Simulated*	*Measured*	*Simulated*
2.39	2.37	-12.239	-13.677	1.88	1.47	6.04

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