

## Design and Implementation of Triangular Microstrip Array Antennas

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### Abstract

This paper presents triangular microstrip array antennas for long-distance WLAN links at 2.4GHz. The proposed antennas include single patch, two-element patch array, and four-element patch array. The radiating patches are of triangular shape and the feeding technique is using the microstrip line method. Impedance matching is achieved by using the inset-feed method. The antennas exhibit good resonance and radiation characteristics. The reflection coefficients are below -10 dB. Furthermore, the gains for the single element, two-element, and four-element antennas are 5.8, 7.3, and 12 dB respectively. The two-element patch array was manufactured and measured. The simulation results are in good agreement with the measured ones. The proposed antennas have been modelled and simulated using the FDTD technique in CST simulation tool.

### Introduction

Wireless communication has grown tremendously allowing users to access network services without the need to connect to a cable and infrastructural work. The two wireless systems that have experienced the fastest and most popular development are the standards developed by the IEEE for cabling, denoted under the number IEEE802.11. The point-to-point WLAN application is based on the IEEE802.11b, g and works in industry, science and medicine (ISM) 802.11. WLAN technology is widely used to provide wireless access networks with a maximum reach of 100m. The range of the Wi-Fi network can be expanded using highly directive antennas. This implementation is known as a point-to-point connection. It provides a good alternative for using wires [1]. Point-to-point Wi-Fi links can increase the reach of the WLAN, offer network scalability and other advantages such as high gain and high throughput. Point-to-point WLAN brings a crucial responsibility to antennas because they are meant to provide wireless transmission between these devices. For noise ratio

and noise immunity, antennas in microwave bands will have compact structure and ease of construction. For high performance point-to-point applications where size, weight, cost, efficiency and ease of installation are constraints. Low profile antenna is very needed to meet these requirements, microstrip antenna is preferred. The microstrip antenna is currently one of the fastest growing segments in the telecom industry and promises to become the preferred carrier in telecommunications in the future. Since the early days, there has been tremendous worldwide activity aimed at developing an efficient, high gain, low profile antenna [2]. Conventional microstrip antennas typically have a conductive patch, printed on a dielectric holder connected to the earth, and have attractive features of low profile, lightweight, manufacture and conformability to host set-up [3]. Triangular microstrip patches have been studied, both theoretically and experimentally [4-7]. They have radiation characteristics similar to those of rectangular plates, but with a smaller size. The easiest triangular microstrip antenna is an equilateral conductor, similar to the square piece [8]. For wireless point-to-point needs, the antenna should have a

narrow beam. This configuration cannot be achieved with a single antenna [9]. Consequently, the array antennas are used. Beam width reduction and gain enhancement can be accomplished by building network antennas. Triangular microstrip antennas for 2.4GHz WLAN are presented in this paper. A single patch, 2x1 array, and 4x1 array are designed, simulated, fabricated, and measured. The antennas are implemented using FR4 dielectric substrate with thickness of 1.6mm and dielectric constant of 4.5.

### Antenna Design

The proposed microstrip antenna is shown in Figure 1. It consists of triangular a patch fed by a microstrip line. The patch is printed on FR4 dielectric substrate with thickness ( $h$ ) of 1.6mm and dielectric constant  $\epsilon_r= 4.5$ . The length of the patch ( $a$ ) at the operating frequency of 2.4 GHz as given by [4]:

$$f_0 = 2c / (3a\sqrt{\epsilon_r}) \quad (1)$$

Where  $c= 3 \times 10^8$  is the speed of light,  $f_0 = 2.4$  GHz is the resonant frequency,  $\epsilon_r= 4.5$  is the dielectric constant of the substrate. we get,  $a= 37.5mm$ .

Impedance matching is accomplished using the inset fed. In this method, a small slot is etched in the conductor in order to move the feeding point inside the patch. The feeding point is based on the reflection coefficient result. It is chosen such that the reflection coefficient remains below -10 dB. An extensive parametric study is done to find the best feeding position, which is found to be  $X_0 = 2mm$  and  $Y_0 = 10mm$ .

The two-element microstrip array is shown in Figure 2a. Two triangular patches are connected in parallel using T-junction power divider. The power divider provides an equal power division [10-12]. The input line of the power divider has an impedance of  $50\Omega$  whereas the output lines have impedances of  $100\Omega$ . Thus, their combination in parallel yields a resistance is  $50\Omega$  resulting in a matched condition. Quarter wavelength transformers are used to bring the impedance levels back to  $50\Omega$ .

The impedance of the quarter wavelength transformer is given by

$$Z_T = \sqrt{Z_1 * Z_2} = \sqrt{50 * 100} = 71\Omega \quad (2)$$

where  $Z_T$  is the impedance of the transformer,  $Z_1$ , and  $Z_2$  are the impedances of the two transmission lines. The length of the transformer is 15mm which is quarter wavelength at the operating frequency. The  $100\Omega$  output lines have a width of 0.7mm whereas the  $71\Omega$  lines have a width of 1.6mm.

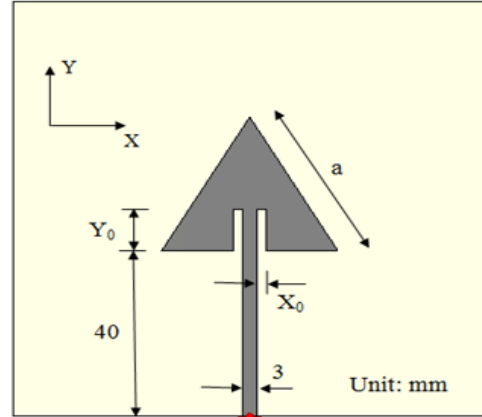
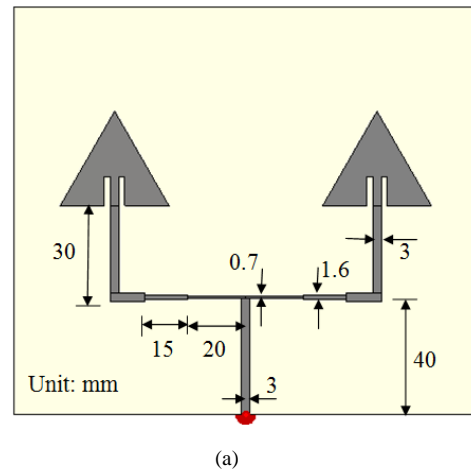
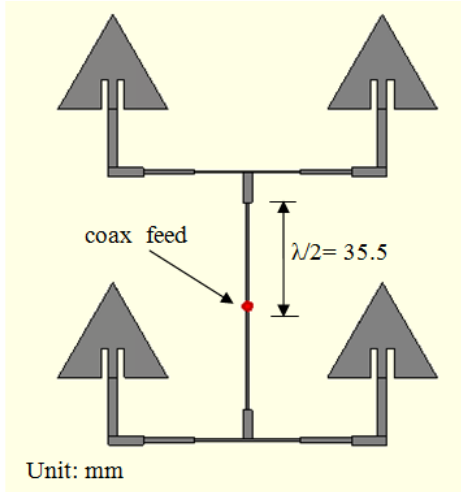


Fig. 1 The inset-fed microstrip patch antenna ( $a=37.5mm$ ,  $X_0=2mm$ ,  $Y_0=10mm$ ).

The four-element microstrip array antenna is shown in Figure 2b. Three T-junction power dividers are combined to form four-way power divider feeding the four patches. The power dividers divide the input power equally in addition to achieving good impedance matchings. The antenna is fed using a coaxial connector. The feeding coaxial cable is soldered to two parallel  $100\Omega$  lines. Hence, impedance mismatch is avoided at the feeding point.  $\lambda/4$  transformers are then used to bring the impedances back to the  $50\Omega$  level as in the two-element array



(a)

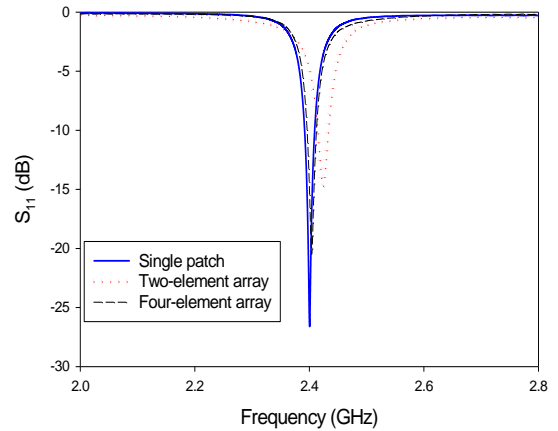


(b)  
**Fig. 2** 2-D view of the microstrip patch array: (a) two-element array; (b) four-element array.

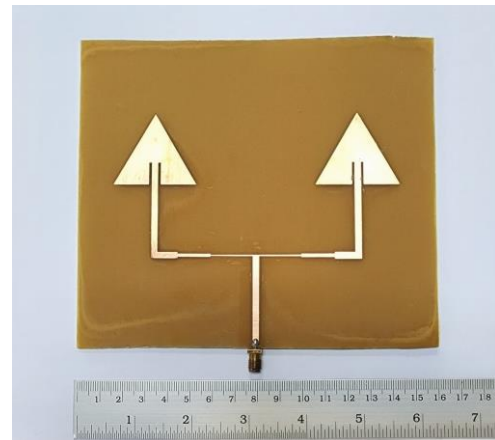
### Simulation and Measurement Results

The 3-D electromagnetic simulation software of CST has been used in the design, modelling, and optimization of the presented designs. The electromagnetic method used in the simulation is the finite-difference-time-domain method (*FDTD*). The simulated return losses are shown in Figure 3. The proposed antennas resonate at 2.4GHz as required. Furthermore, the antennas exhibit good impedance matching with  $S_{11}$  being below -10 dB within the operating bandwidth. The simulated -10 dB bandwidths are about 2%, 1.5%, and 1% for the single patch, two-element array, and four-element array respectively.

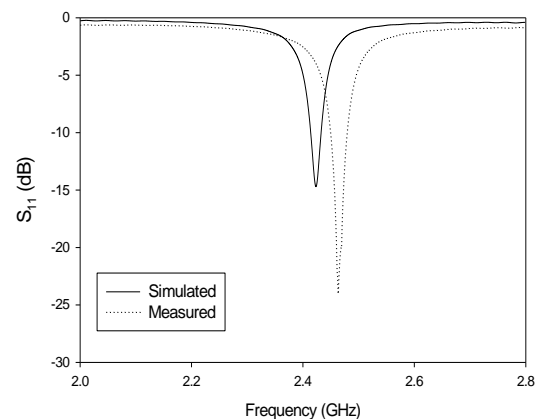
The two-element array has been fabricated and tested as shown in Figure 4a. The return loss of the antennas has been measured using the vector network analyzer. The simulated and measured reflection coefficients are shown in Figure 4b. There is a small shift towards 2.42GHz in the resonance frequency that can be clearly observed in the  $S_{11}$  result. This is attributed to the dielectric constant of the *FR4* material which can take any value between 4.2 and 4.8. In simulations, it was assumed that  $\epsilon_r = 4.5$ .



**Fig. 3** The simulated reflection coefficients.



(a)



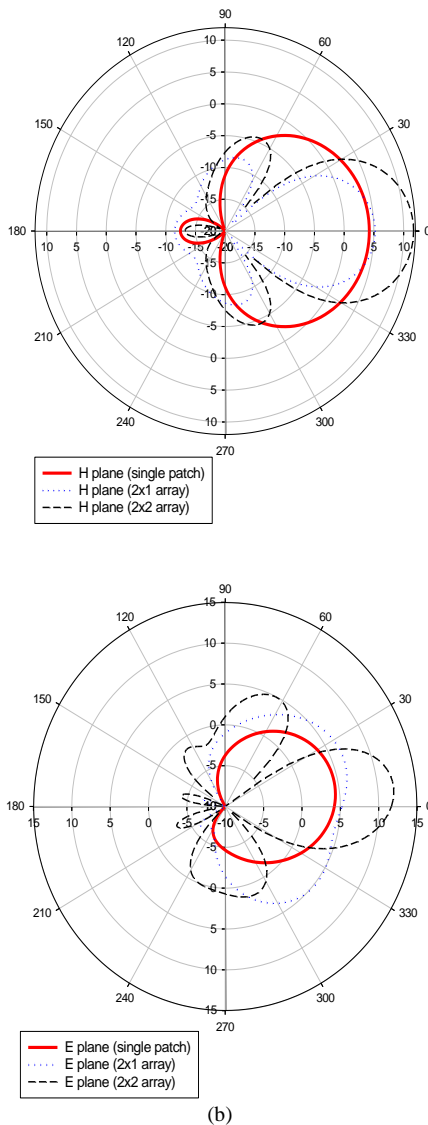
**Fig. 4** (a) The fabricated two-element array; (b) Simulated and measured reflection coefficients

The simulated radiation patterns of the presented antennas are shown in Figure 5. The antennas provide directional radiation patterns with maximum gain being

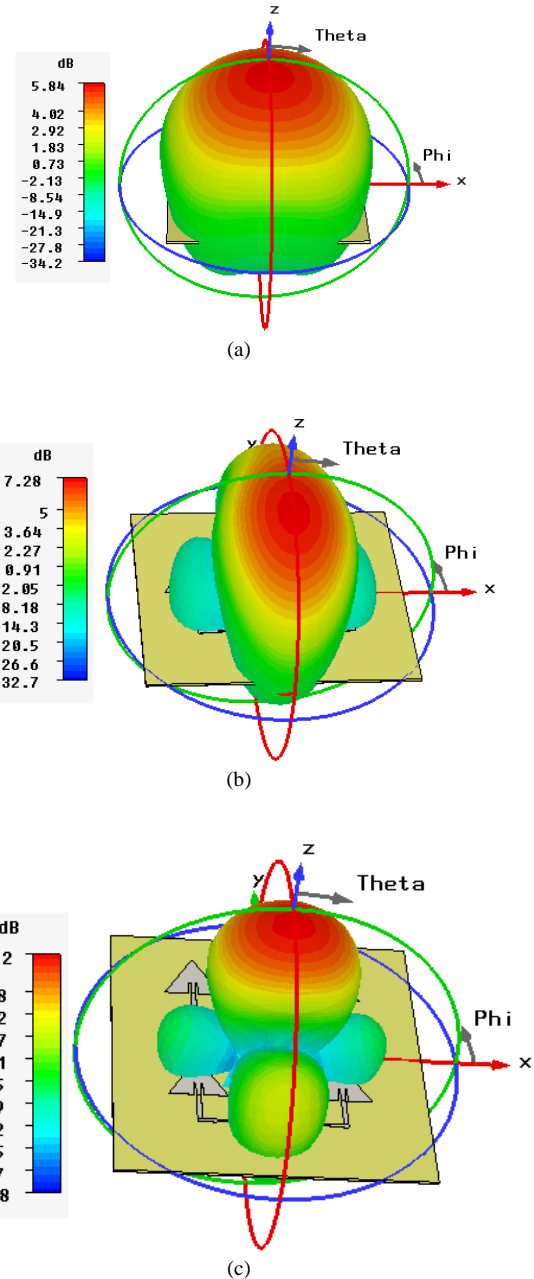
perpendicular to the patch. There is no ripple or nulls or tilting in the radiation patterns. The gain increases with the order of the array antenna. The realized gains are 5.8 dB, 7.3 dB, and 12dB for the single patch, two-element array, and four-element array respectively. The half-power beamwidths in the  $E$  plane are  $82^\circ$ ,  $118^\circ$ , and  $31.3^\circ$  respectively. The half-power beamwidth in the  $H$  plane are  $77.2^\circ$ ,  $39.2^\circ$ , and  $63.1^\circ$  respectively. Thus, the gain increases with the order of the array as expected. Table 1 summarizes the resonance and radiation properties of the proposed antennas. The cross polarization levels are very low and thus can't be observed in the polar plot of the radiation patterns. A few side lobes are observed in the array patterns. These side lobes can be minimized by optimizing the spacing between the radiating patches. The 3-D patterns are shown in Figure 6.

**Table 1: Summary of the antennas responses.**

prototype	Gain (dB)	Return Loss(dB)	HPBW ( $E$ lane)	HPBW ( $H$ plane)
Single patch	4.5	-26	$82^\circ$	$77.2^\circ$
2X1 array	6.5	-14	$118^\circ$	$39.2^\circ$
2X2 array	12	-20	$31.3^\circ$	$63.1^\circ$

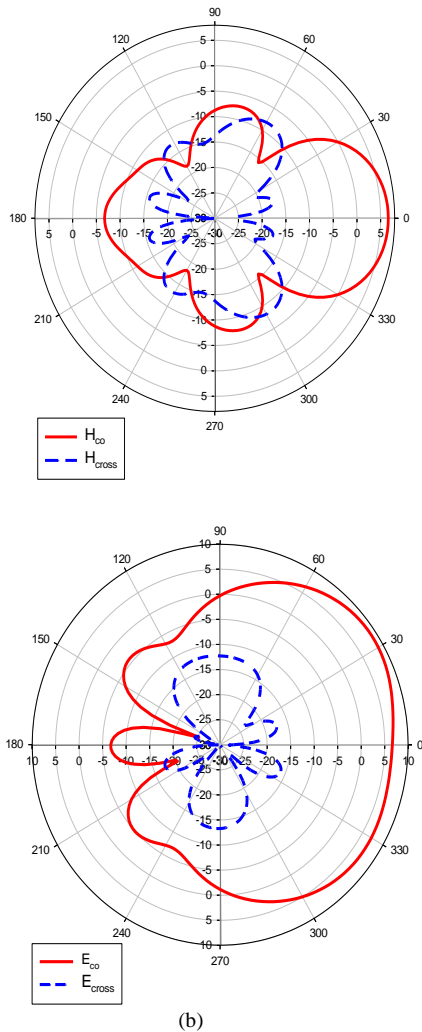


**Fig. 5** The simulated radiation patterns: (a) H plane; (b) E plane.



**Fig. 6** The 3-D radiation patterns of the proposed antennas: (a) single patch; (b) two-element array; (c) four-element array

The radiation pattern for the two-element array has been measured as shown in Figure 7. The measured result is in good agreement with the simulated one. The main beam direction is  $0^\circ$  indicating broadside radiation. The *HPBW* in the H and E planes are  $42^\circ$  and  $116.2^\circ$  respectively. The measured realized gain is about 7 dB. The cross polarization levels are too low and are below -15dB.



**Fig. 7** The measured radiation pattern for the 2x1 array: (a) H plane; (b) E plane.

## Conclusions

Triangular microstrip antennas operating in the 2.4GHz frequency band are presented. A single element, two-element array, and four-element array are presented. The proposed antennas are simulated in the CAD tool of CST®. The antennas exhibit satisfactory performances making them good candidates for WLAN links at 2.4GHz. The return losses are very low confirming little power reflections. Furthermore, the radiation patterns are

directional with good gains. The cross polarization levels are too low.

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