Microstrip array antenna with inset-fed for WLAN application

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ABSTRACT
This paper proposed three designs of microstrip array patch antennas, to resonate at 2.4 GHz. The purpose of the study is to achieve size reduction with acceptable performance for wireless communication system applications. Based on the array concept, the array antennas are arranged using corporate network technique. It is found that the simulated 4x3 patch array antenna achieved the compact size with dimension reduced up to 26% compared to 4x1 and 4x2 array patch antennas. In terms of return loss, the antenna attenuated more than 19 dB. The 4x3 patch array antenna is fabricated and measured using RO4350 microstrip substrate to validate the concept. The responses are found in good agreement between simulation and measurement.

Keywords: Array antenna,Inset-Fed,Microstrip, Patch antenna

1. INTRODUCTION
An efficient and high performance antenna is very important in Wireless Communication Systems. This is due to the fact that the antenna performance is directly impact on the quality of wireless communications [1-6]. For the application of emerging technology, it requires compact in size components with low in power usage and robustness. Research on various antenna topologies were reported. These topologies were experimented on different type of technology available today [7-12]. However, a low cost and efficient antenna with ease in manufacturing process is the main interest among the industry players. Microstrip technology is well known for its low cost, easy to materialize with acceptable antenna performance [13-16]. Based on these facts, microstrip substrate is chosen because of its low cost, compact in size with an acceptable performance level that is required by the wireless communication system [17-20]. However, there are limitations in microstrip technology such as narrow in bandwidth, low gain and normally contain spurious effect especially when dealing at frequency above 5 GHz [1, 21-23].

Numerous improvement in terms of the antenna design using microstrip technology have been proposed. Amongst these, arrays concept is one of the popular technique. The base cell is used to construct the antenna design, arranged in an array manner; using different feeding techniques available today. The findings were reported that microstrip arrays antenna is possible to achieve high gain, acceptable desired radiation pattern with appropriate beamwidth [17, 23-25].

Based on this concept, three microstrip arrays patch antenna designs are proposed in this work. With arrangement of 4x1, 4x2 and 4x3 array patch antennas are proposed. The antennas are designed at 2.4 GHz for WLAN applications. The performances of the antennas are investigated in terms of gain, return loss and compactness. To validate the concept, results are compared between simulations and measurements and are found agreeable.
2. RESEARCH METHOD

The antennas proposed in this work are based on rectangular patch as shown in Figure 1, designed at 2.4 GHz for WLAN application. The specification of the antenna is as tabulated in Table 1. Quarter wavelength transformer is used to match the feeding line of the antennas.

| Centre frequency, $f_0$ | 2.4 GHz |
|------------------------|---------|
| Return Loss            | $>10$ dB |
| VSWR                   | 1       |
| Substrate specifications| Substrate Thickness=075mm, dielectric constant 3.3, loss tangent=0.004 |

### 2.1. Single Microstrip Patch Antenna Design

Figure 1 illustrates the general view of single patch antenna with microstrip feedline. The design of the patch antenna consists of patch, quarter-wave transformer and feedline [16]. In (1-4) are applied to determine the dimensions of the single patch antenna in terms of width, W and length, L as follow [1]:

- **Width of patch, $w_p$** is defined as follow:
  
  \[ w_p = \frac{c}{2f_0} \sqrt{\frac{2}{\varepsilon_r+1}} \]  
  
  (1)

- The effective dielectric constant is calculated by the formula below:

  \[ \varepsilon_{eff} = \left( \frac{\varepsilon_r+1}{2} \right) + \left( \frac{\varepsilon_r-1}{2} \right) \left[ 1 + 12 \frac{h}{w} \right]^{\frac{1}{2}} \]  
  
  (2)

- The genuine length of patch, $l_p$ is computed utilizing the accompanying formula:

  \[ \frac{\Delta L}{\ell_s} = 0.412 \frac{(\varepsilon_{eff}+3)(\varepsilon_{eff}+0.264)}{(\varepsilon_{eff}-0.258)(\varepsilon_{eff}+0.8)} \]  
  
  (3)

  \[ l_p = \frac{c}{2f_0\varepsilon_{eff}} - 2\Delta L \]  
  
  (4)

As stated in theory, the distance between the edge of patch and substrate must be more than $\frac{\lambda}{4}$ in order to avoid the signal to radiate more to ground. Thus, the length, $l_s$ and the width of substrate, $w_s$ are computed using these formulas:

- **Width of substrate, $w_s$**:

  \[ w_s = w_p + 2\left(\frac{\lambda}{4}\right) \]  
  
  (5)

- **Length of substrate, $l_s$**:

  \[ l_s = l_p + 2\left(\frac{\lambda}{4}\right) \]  
  
  (6)
While the width of the quarter-wave line is obtained by [2, 10]:

\[ Z_T = \frac{60}{\sqrt{\varepsilon_r}} \ln \left( \frac{8d}{w_T} + \frac{w_T}{4d} \right) \]  

(7)

Where \( Z_T \) is calculated as [8, 12]:

\[ Z_T = \sqrt{50 + Z_0} \]  

(8)

The length of quarter line is calculated by:

\[ L_T = \frac{\lambda}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \]  

(9)

And the width of the 50 \( \Omega \) microstrip feed is found using the well-known equation below:

\[ Z_o = \frac{120\pi}{\sqrt{\varepsilon_{eff}}} \left( \frac{\varepsilon_{eff} + \varepsilon_r}{\varepsilon_r - \varepsilon_{eff}} \right) \left( \frac{w_T}{\varepsilon_r + 2} \right)^{1/2} \]  

(10)

Using microstrip feeding technique, a simple rectangular microstrip patch antenna is designed with the layout as shown in Figure 2. This patch is used as base cell to construct the arrays.

![Figure 2. Single patch array design](image)

### 2.2. Microstrip Patch Array Antenna Design

In designing array antenna, the base cells are arranged and feed using inset-fed technique as shown in Figure 3 while Table 2 tabulates all the calculated dimensions of the feedlines.

![Figure 3. Patch array antenna with inset fed](image)

| Impedance | Width (mm) | Length (mm) |
|-----------|------------|-------------|
| 50Ω       | 9          | 3.3         |
| 70Ω       | 2          | 13          |
| 100Ω      | 1          | 13          |

Table 2. Dimension (Width and Length) of 100Ω, 70Ω and 50Ω
Figures 4, 5, and 6 illustrate the topologies of the 4x1 array, 4x2 array and 4x3 array patch antennas respectively, designed at 2.4 GHz. The antennas are simulated and the return losses, S11 of the antennas are shown in Figure 7. It can be seen that the performance of the 4x3 patch array antenna achieved the highest level of return loss which is 19.73 dB.

![Figure 4. 4x1 patch array antenna design](image1)

![Figure 5. 4x2 patch array antenna design](image2)

![Figure 6. 4x3 patch array antenna design](image3)

![Figure 7. Comparison of return loss, S11](image4)

| Table 3. Comparison of Simulation Results for All the Four Antenna Designs |
|--------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
|                          | Single patch | 4x1 patch array | 4x2 patch array | 4x3 patch array |
| Size of design (cm²)      | 45 x 40 = 18 | 157 x 65 = 102.05 | 170 x 130 = 221 | 275 x 145 = 253.75 |
| Return loss, S11 (dB)     | 12.89          | 7.95             | 11.87           | 19.73           |
| VSWR                     | 1.59           | 25.38            | 1.33            | 1.23            |
| Gain (dB)                | 4.25           | 7.31             | 8.49            | 11.41           |
| Directivity (dBi)        | 5.63           | 9.58             | 9.69            | 12.06           |

Table 3 summarized the simulated the return loss and gain for all the designs obtained from CST simulation tool. It has shown that the 4x3 patch array antenna achieved highest gain compared to the other three antenna designs. Therefore, the 4x3 patch array transmits the highest power in the direction to that of an isotropic source. Based on these results, the 4x3 patch array antenna is chosen and the design is fabricated, analysed and compared with simulation results to validate the work.
3. RESULTS AND ANALYSIS

Figure 8 illustrates the simulation results of Voltage Standing Wave Ratio (VSWR) and radiation pattern for the 4x3 array patch antenna, designed at 2.4 GHz. The VSWR achieved 1.23 and the radiation pattern shows directivity and gain of 10.39 dB and 9.08 dB respectively.

Figures 9 and 10 show the radiation pattern for simulated and measured respectively for the 4x3 patch array antenna. Both the radiation patterns portray the omnidirectional antenna that suit with WLAN applications. The simulation result in Figure 8(b), shows the major lobe directed the signal at 0˚ with beamwidth (HPBW) of 43.3˚. This antenna seems to generate more radiation power in the farfield region.

Figure 11(a) and (b) show the return loss and the prototype of the 4x3 array antenna. It is found that the measured return loss attenuated 19.85 dB at 2.427 GHz, shifted by 0.027 GHz from the simulation. The shifted of measured result as compared to simulation may be due to some flaws during fabrication process and also may due to the effect of parasitic element on the substrate. [1]. Table 4 shows the comparison between the 4x3 patch array antenna with previous designs according to return loss and gain. In terms of return loss, the proposed antenna achieved highest gain compared to the other three designs.

![Figure 8](image1.png)

Figure 8. Simulation results of the 4x3 array patch antenna (a) VSWR, (b) radiation pattern

![Figure 9](image2.png)

Figure 9. The 3-D radiation pattern of 4x3 array antenna

![Figure 10](image3.png)

Figure 10. Measured radiation pattern (in 3-D front view) for 4x3 array patch antenna

![Figure 11](image4.png)

Figure 11. (a) S-Parameter: Return loss, S11 of the 4x3 array antenna, (b) Fabrication antenna
4. CONCLUSION

Microstrip array antenna using microstrip feedline were presented. The antennas were simulated and compared in terms of gain and return loss. It was found that the 4x3 array antenna achieved best return loss and this antenna was fabricated. Results were compared between simulation and measurement and were found agreeable. Besides enriching the antenna bank, this antenna may be used for WLAN application.

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