Paper

High Gain Linear 1×4 X-slotted Microstrip Patch Antenna Array for 5G Mobile Technology

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Abstract— A linear 1×4 antenna array built on the Rogers RT/Duroid 5880 substrate is proposed in this paper to acquire high gain for 5G applications. The proposed design resonates at 38 GHz, i.e. in the Ka-band region, and has small patch dimensions of 5.5×2 mm. The design is simulated using CST studio. The main element consists of X-slot that provides a gain of 6.98 dB with the return loss of –24.25 dB whereas a linear array of 4 elements is made which is fed by the 50Ω m-line using the corporate feeding network which yields a gain of 13.84 dB, as well as the return loss is –15.72 dB. The centre-to-centre spacing (d) of elements in the antenna array is 0.8λ.

Keywords—microstrip patch antenna, millimeter-wave, tapered feed line.

1. Introduction

Deployment of wireless mobile technologies of the future is planned as soon as in 2020. The research community focuses on the upper region of the spectrum while developing standards for the upcoming solutions known as the fifth generation (5G).

Millimeter-waves have been chosen for 5G [1], [2] in order to achieve high data connectivity rates, reduced latency levels, etc., Higher gains are required as well in order to overcome the problem of atmospheric wave absorption. Higher gain may be achieved by introducing specific antenna array designs [3], [4], [5].

The International Telecommunication Union has assigned 28, 38, and 60 GHz frequencies (millimeter-wave band) for the purpose of 5G networks. Hence the need for a new aerial design to be used in the industry [6].

In order to be suitable for mobile applications, the antenna must be as compact as possible. A 5G antenna needs to be designed that not only offers high gain, but also guarantees proper bandwidth, low side lobe levels, high efficiency, high data transfer rates. With all that considered, it needs to be small as well [7].

Microstrip patch antennas (MPA) are very impressive and have proven to be very effective as they are simply to fabricate and easy to install. The are a low-cost solution that is suitable for all types of applications [8].

2. Related Works

Many researchers have worked on arrays for 5G applications. In [9], an antenna was built for 5G communication which uses a phase array operating in the millimeter-wave band. In [10], a design of a 60 GHz antenna with a gain of 5.48 dB, using the two E- and H-shaped slots and offering a return loss is of -40.99 dB was presented. Paper [11] discusses the design of a dual band microstrip antenna which resonates at 28 GHz and 38 GHz, providing a bandwidth of 5.95 GHz and 4.95 GHz at the two center frequencies and using proximity-coupled feed.

In this work, and antenna is proposed which operates at 38 GHz (center frequency), i.e. in the Ka-band region. The design is based on an X-slot which is etched from the patch to improve impedance matching. A microstrip feed line is used due to its simple design and easy impedance matching [12]. The microstrip patch antenna array of 4 elements is made using the corporate feeding method.

3. Antenna Design

The main aerial component is based on the Rogers RT/-Duroid 5880 laminate with a height of 0.254 mm. The overall dimensions of the microstrip antenna are $6\times6.2\times0.254$ mm. The copper ground plane of the antenna is 0.017 mm thick. A microstrip feed line is used to feed the antenna in order to obtain considerable results. Two slots are etched in the center of the patch to obtain optimum results. The dimensions of the patch and substrate/ground are calculated by:

Width of the patch:

$$W=\frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}}\ . \tag{1}$$

Effective dielectric constant:

$$\varepsilon_{reff}=\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}}\ . \tag{2}$$

Effective length of the patch:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \,. \tag{3}$$

Extended length:

$$\Delta L = 0.412\,h \frac{(\varepsilon_{reff}+0.33)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \,. \tag{4}$$

Length of the patch:

$$L = L_{eff} - 2\Delta L \,. \tag{5}$$

Length of the substrate:

$$L_s = 6h + L \,. \tag{6}$$

Width of the substrate:

$$W_s = 6h + W \,. \tag{7}$$

Table 1 shows the calculated parameters.

Table 1
Encoding formats for variable resolution scenarios

Parameter	Description	Values [mm]
Substrate		
L_s	Length	6
W_s	Width	6.25
t_s	Thickness	0.254
Patch		
L_p	Length	5.5
W_p	Width	2
t_p	Thickness	0.017
Feed line		
L_f	Length	2.13
W_f	Width	0.18
Slot		
S_L	Length	1.5
S_W	Width	0.2

The patch is shown in Figs. 1–2, where front and tilted views of the antenna are presented.

The linear 1 × 4 array is made using the corporate feeding methodology. Center-to-center spacing d between the patches of the array is 6.31 mm (0.8λ, where $\lambda = c/f$). The array is fed by a 50 Ω microstrip feed line. Impedance is matched between the 100 Ω and 50 Ω feed lines using a quarter-wave transition line (Fig. 2). The design of the feeding network for the 1 × 4 linear array relies on the following formulas:

Load of the patch:

$$Z_L = \frac{90\varepsilon_r^2}{\varepsilon_r - 1}\left(\frac{L}{W}\right)^2 \,. \tag{8}$$

Impedance of the quarter-wave transition line:

$$Z_T = \sqrt{(Z_0 \times Z_L)} \,. \tag{9}$$

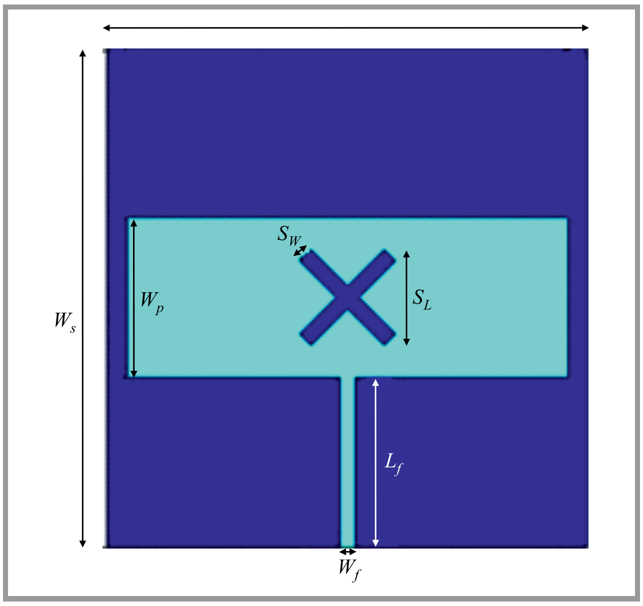

Fig. 1. X-slot microstrip patch antenna (front view).

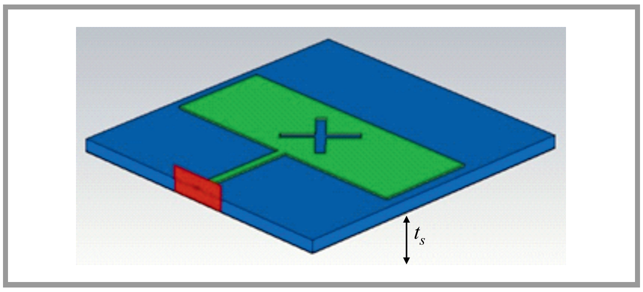

Fig. 2. X-slot microstrip patch antenna (tilted view).

Width of the quarter-wave transition line:

$$Z_T = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{8h}{W_T} + \frac{W_T}{4h}\right) \,. \tag{10}$$

Length of quarter-wave:

$$L_T = \frac{\lambda}{4} = \frac{c}{4f_r\sqrt{\varepsilon_{reff}}} \,. \tag{11}$$

Width of the 50 Ω feed line:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{reff}}\left[1.393 + \frac{W}{h} + \frac{2}{3}\ln\left(\frac{W}{h} + 1.444\right)\right]} \,. \tag{12}$$

Table 2 shows the parameters calculated based on Eqs. (8)–(12), whereas Fig. 3 shows the array design.

4. Antenna Results and Analysis

The return loss or S_{11} parameter defines the relationship between the power values at the ports of the antenna. If S_{11} is zero, this means that nothing is radiated from the antenna and all the power is reflected from the antenna.

Table 2
Parameters of the 1×4 linear antenna array

Parameter	Description	Values [mm]
d	Center-to-center spacing	6.31
L_T	Length of transition line	0.85
W_T	Width of transition line	0.2
W_{100}	Width of 100 Ω feed line	0.2
L_{100}	Length of 100 Ω feed line	6.08
L_{50}	Length of 50 Ω feed line	0.82
W_{50}	Width of 50 Ω feed line	1.3

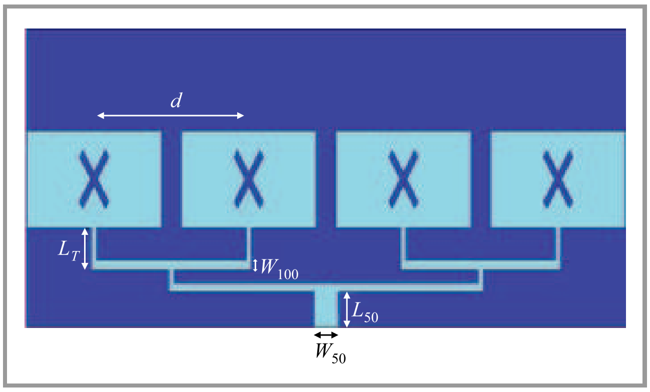

Fig. 3. 1×4 linear microstrip patch antenna array design.

Table 3
Rotation angle of two slots

Rotation angle		Resonating frequency [GHz]	Return loss [dB]	Gain [dB]	Side lobe level [dB]
0°	90°	38.6	−21.82	6.89	−16
15°	75°	–	–	6	–
30°	60°	39.1	−17.33	6.4	−18.8
45°	45°	38	−24.25	6.98	−16.6

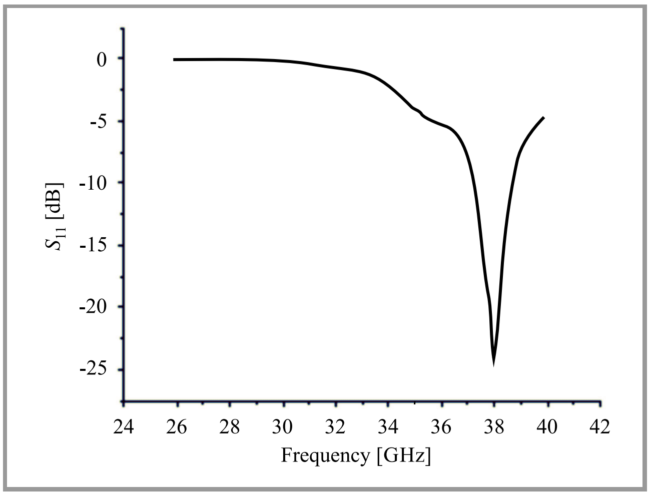

Fig. 4. Return loss is −24.25 dB at 38 GHz for single radiation.

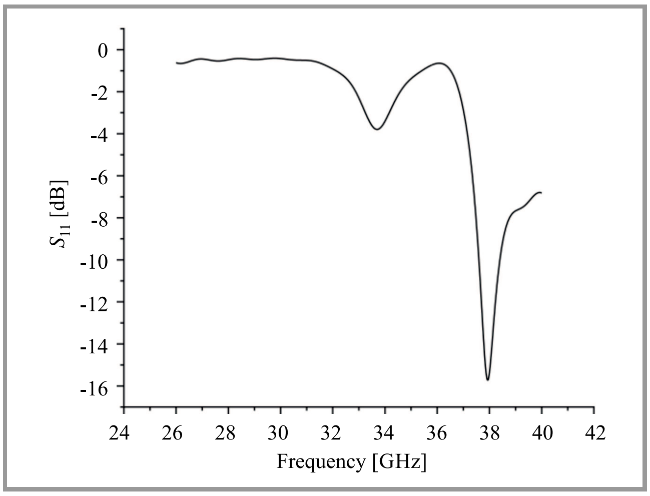

Fig. 5. Return loss is −15.72 dB at 37.92 GHz for 1×4 array.

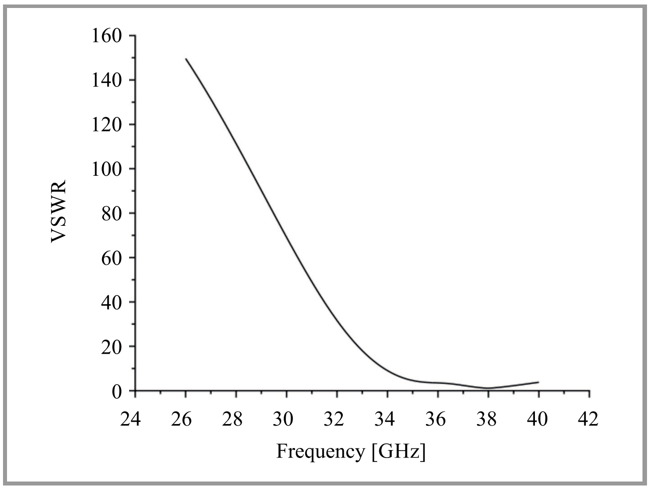

Fig. 6. VSWR is 1.13 at 38 GHz for single radiation.

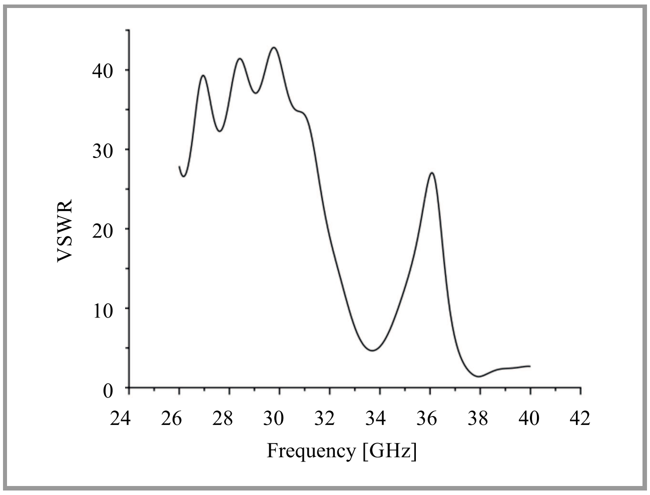

Fig. 7. VSWR is 1.39 at 37.92 GHz for 1×4 array.

It is also known as the reflection coefficient. To improve impedance matching, two slots are made and are rotated at different angles. Finally, it was observed that when both slots were at positioned at 45°, such parameters such as gain, bandwidth, return loss and side lobe level improved. Table 3 shows the results of an analysis that focused rotating the two slots at different angles.

The single element has a return loss of −24.25 dB, whereas the 1 × 4 linear array has a return loss of −15.72 dB at 38 GHz. Figures 4–5 shows a graphical representation of S_{11} for both single and array antennas.

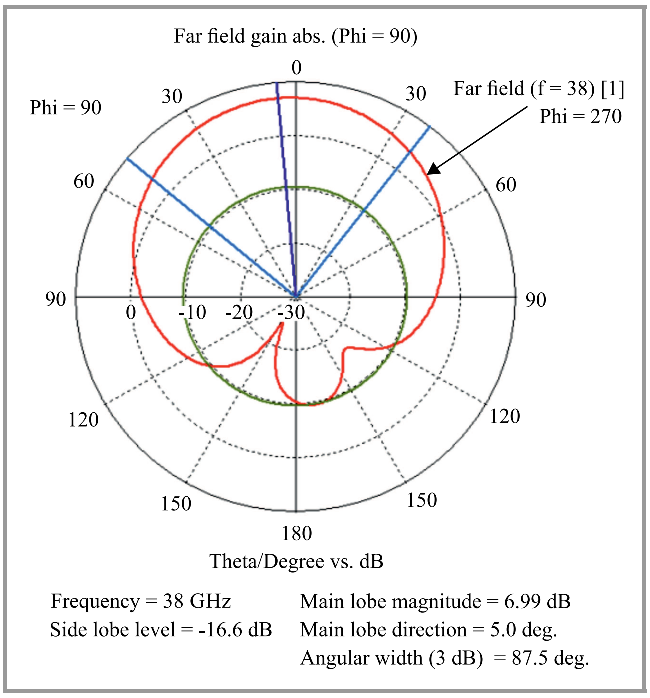

Fig. 8. Side lobe level is −16.6 dB at 38 GHz for the single element. (For color pictures, visit www.nit.eu/publications/journal-jtit)

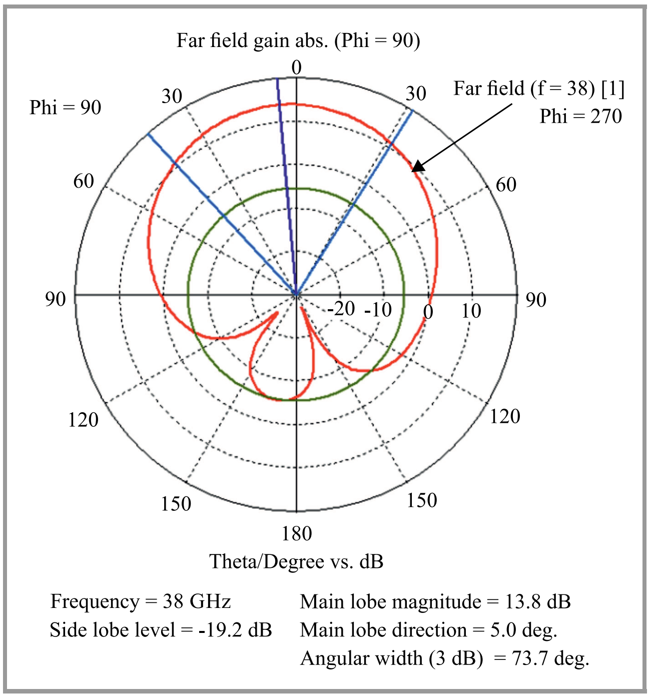

Fig. 9. Side lobe level is −19.2 dB at 37.92 GHz for the 1×4 array.

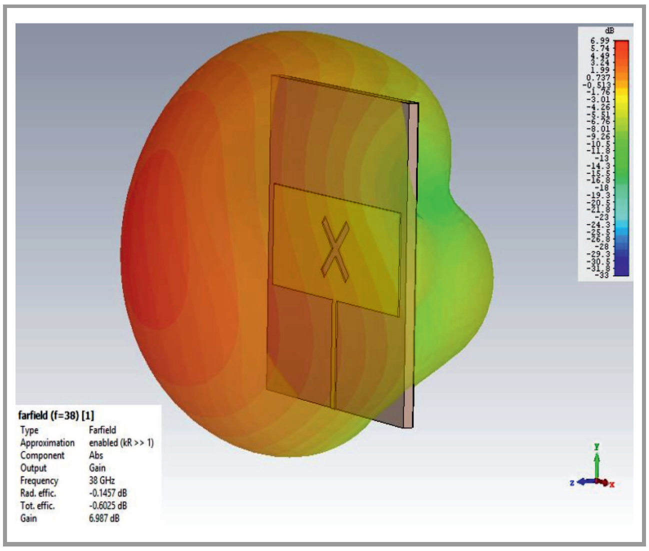

Fig. 10. Gain is 6.98 dB at 38 GHz (single element).

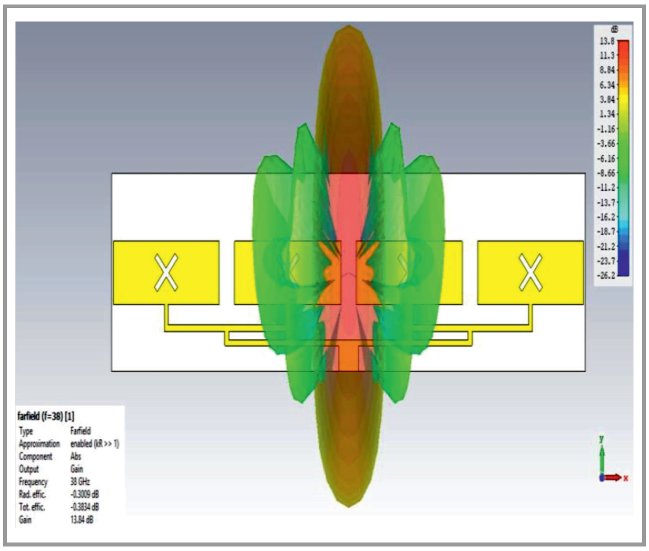

Fig. 11. Gain is 13.84 dB at 37.92 GHz (1×4 array).

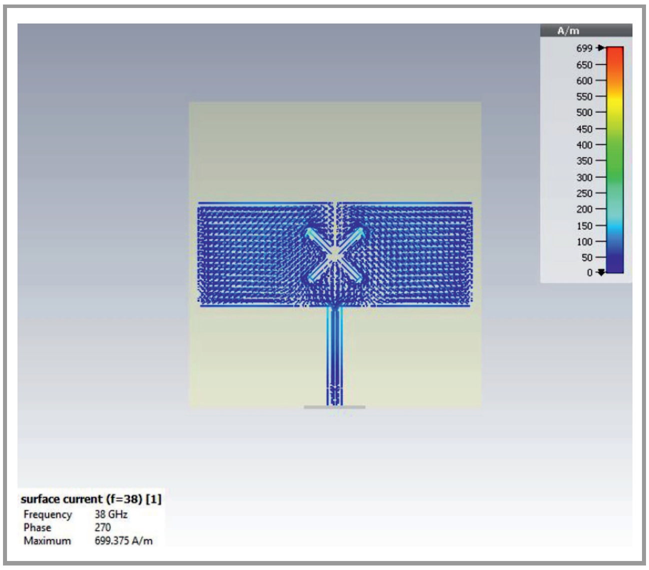

Fig. 12. Surface current distribution of the single radiating element.

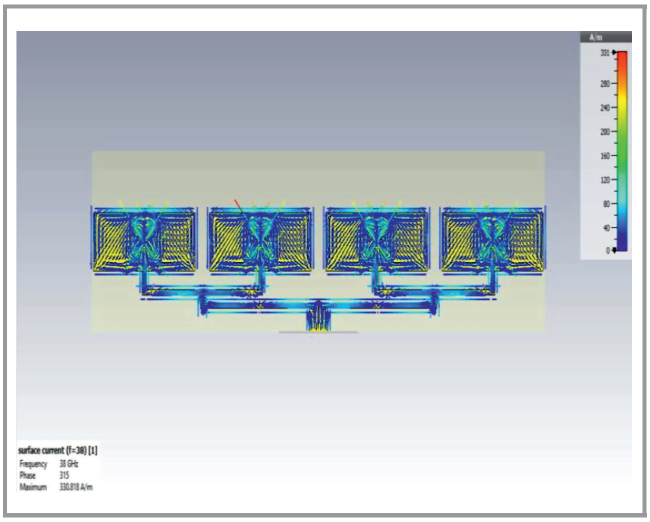

Fig. 13. Surface current distribution of the 1×4 linear array.

The proposed antenna gives the VSWR of 1.13 for the single element and of 1.39 for the antenna array, respectively (Figs. 6–7).

The side lobe level of the single element is shown, equaling −16.6 dB, whereas the side lobe level for the 1×4 linear array equals −19.2 dB (Figs. 8–9).

The main element provides a gain of 6.98 dB, with the corresponding result equaling 13.84 dB for the antenna array. 3D plots of both designs are shown in Figs. 10–11.

Figures 12 and 13 depict the distribution of current in both versions.

Table 4
Proposed antenna characteristics

Antenna model	Resonating frequency [GHz]	S_{11} [dB]	Bandwidth	Gain [dB]
Main element	38	−24.25	1.48 GHz	6.98
1×4 linear array	37.92	−15.72	800 MHz	13.84

Table 5
Comparison with other designs

Reference	Resonating frequency [GHz]	Gain [dB]	Bandwidth [GHz]
[13]	28	9	1.38 GHz
[14]	34	11.2	920 MHz
Proposed	37.92	13.84	800 MHz

Table 4 sums up the best parameters of both versions, while Table 5 presents a comparative study with related works.

5. Conclusion

The antenna design simulations conducted with the use of CST Studio software show that antenna specifications are satisfactory for 5G and, hence, the design is acceptable for 5G applications.

The main element has a return loss of –24.25 dB while the gain is of 6.98 dB with 1.48 GHz of bandwidth. Slotting is done on the patch to achieve the required results; two line slots are made and further rotated at different angles, at last both intersect at same angle which forms an X shape slot. The total dimension of the patch is $5.5 \times 2 \times 0.035$ mm^3 with 0.254 mm as substrate thickness. By utilizing the traditional methodology to enhance the gain that is designing an array, a linear array of 4 elements is made by deploying the quarter wave transition line in corporate feeding. Array provides the gain of 13.84 dB with 800 MHz of bandwidth and return loss of –19.2 dB.

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