

DESIGN, SIMULATION AND ANALYSIS OF SQUARE PATCH ANTENNA OPERATING AT 5.8GHZ WITHOUT SLOT AND WITH K-SLOT

G. N. Onoh,¹V.E Idigo,²T. L. Alumona,²C.O Azubogu,²E .N. Ifeagwu,³U .I. Obinna

¹*Department of Electrical/Electronic Engineering,
Enugu State University of Science and Technology, Enugu.*

²*Department of Electronic and Computer Engineering,
Nnamdi Azikiwe University, Awka.*

³*Faculty of Electrical Engineering,
University Teknologi, Malaysia.*

Abstract

This paper presents the radiation performance of a square patch antenna with K-shape slot at the center of the square patch. The design method consists of incorporating a narrow slot at the center of square patch, producing a K-shape over the square patch and placing a feed along the diagonal of square patch. The design of the square patch without slotted and the design with slotted (K-shape) are simulated using Microwave Office Version 7.03. The result of the two designs is compared and the analysis of the design includes Return Loss, Bandwidth, Radiation Pattern, HPBW, Gain, Co and Cross Polar Isolation. A coaxial feed was used as a feeding technique and the simulation results are in good agreement with the numerical results.

Keywords: Square patch antenna, return loss, bandwidth, HPBW and coaxial feed.

1.0 Introduction

Microstrip patch antennas have attracted much attention because their geometries are suitable for monolithic integration with microwave and millimeter wave devices. It can provide polarization diversity (linear, right hand circular polarization and left hand circular polarization etc) that can be utilized in wireless local area networks (WLAN), satellite communication systems and modern military platforms. Various design techniques for circular and rectangular patch antennas have been reported in the literature [1], [2]. Dual feed method has been reported by some researchers [3] to get circular polarization.

The design, a K-shaped slot is incorporated at different locations in the square patch. The feed point and patch dimensions are related with gain, bandwidth, radiated field and resistance at the patch edge. Single feed point is located along the diagonal of the square patch. The return loss depends on the location of the feed point.

Experiments are performed at 5.8 GHz using FR-4 substrate ($\epsilon_r = 4.7$) with substrate thickness of 1.6 mm.

Here below in section 2, basic structure and design of patch antennas are described. Section 3 deals with the experimental results and various design considerations are discussed in section 4. Finally the paper is concluded in section 5.

2.0 Basic Structure and Design

2.1 Basic Structure

The basic structure of the square patch antenna is shown in Fig. 1. The patch with a side length L is printed on FR-4 substrate with a thickness of 1.6 mm (h) and substrate dielectric constant of 4.7 (ϵ_r). The loss tangent of the substrate material is 0.019 ($\tan \delta$). A narrow K-shaped slot was incorporated on the square patch in different locations. The feed method is a direct connection to coaxial feeder of 50 Ω impedance.

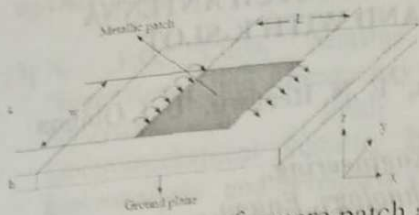


Figure 1. Structure of square patch antenna

2.2 Design Considerations

were considered based on the application.

- Selection of substrate material
- Feed technique and its location
- Dimensions of patch and slot (K-shape).

Selection of substrate material

The dielectric properties of the substrate have large effect on the patch antenna performance. For the selection of substrate, the major electrical properties to be considered are relative dielectric constant (ϵ_r) and loss tangent ($\tan \delta$). A higher dielectric constant (ϵ_r) results in a smaller patch but it reduces the operational bandwidth. A higher loss tangent reduces efficiency and increases feed losses. Generally, it is preferred to select a substrate with lowest possible dielectric constant. Substrate thickness should be chosen as large as possible to maximize bandwidth and efficiency but not so large as to excite surface waves. The excitation of surface waves not only contaminates the radiation pattern and reduces the efficiency of the antenna, but also can cause unwanted coupling between the active devices within the module [4].

The substrate material for the patch antenna was selected as FR-4 substrate. Its electrical and physical properties are shown below.

- I) Dielectric Constant ($\epsilon_r = 4$)
- II) Loss tangent ($\tan \delta = 0.019$)
- III) Copper peel strength ($l = 0.03556\text{mm}$)
- IV) Height of the substrate ($h = 0.16\text{mm}$)

Feed Method and Location

The microstrip antenna can be fed by using microstrip line, coaxial line or by an aperture

in the ground plane. In coaxial line feed, the inner conductor of the coaxial line is attached to the radiating patch while outer conductor is connected to the ground plane. It is easy to fabricate and match.

The input impedance can be matched to 50 Ohm using several techniques. The simplest feed method is a direct connection to a 50 Ohm coaxial feeder. For the feed point at the radiating edge, input impedance is maximum and for a feed point at the centre of the patch, input impedance is zero. Input impedance can be controlled by adjusting the position of feed point along the diagonal of the patch. A match to 50 Ohm may be achieved by suitably locating the feed point.

Due to ease of fabrication and matching, coaxial feed was used. The feed point was located along the diagonal of the square patch where the return loss is below -10dB. It was found that to get return loss below -10dB, the feed point should be located on the diagonal at a distance of ($dx = 5.4\text{mm}$ and $dy = 3.9\text{mm}$) as shown in figure 4. Thus by changing the feed point along the diagonal, the return loss can be below or above -10dB.

Design procedures

The essential parameters for the design are:

- $f = 5.8\text{GHz}$
- $\epsilon_r = 4.7$
- $h = 1.6\text{mm}$

The transmission line model will be used to design the antenna.

Step 1: Calculation of the Width (W): The width of the Microstrip patch antenna is given by Equation (1) as:

$$W = \frac{c}{2f\sqrt{\epsilon_r}} \quad (1)$$

Substituting $c = 3e8\text{ m/s}$, $\epsilon_r = 4.7$ and $f = 5.8\text{ GHz}$, we get:

$$W = 0.0119\text{ m} = 11.9\text{ mm}$$

Step 2: Calculation of Effective dielectric constant ($\epsilon_{r_{eff}}$): Equation (2) gives the effective dielectric constant as:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{W}\right)^{-\frac{1}{2}} \quad \dots(2)$$

Substituting $\epsilon_r = 4.7$, $W = 11.9$ mm and $h = 1.6$ mm we get:

$$\epsilon_{reff} = 3.995$$

Step 3: Calculation of the Effective length (L_{eff}): For efficient radiations, the length of the patch should be half wavelength in the dielectric ($\lambda/2$) but it is taken smaller due to fringing effect. Equation (3) gives the effective length as:

$$L_{eff} = \frac{c}{2f \sqrt{\epsilon_{reff}}} \quad (3)$$

Substituting $\epsilon_{reff} = 3.995$, $c = 3e8$ m/s and $f = 5.8$ GHz we get:

$$L_{eff} = 0.0129 \text{ m} = 12.9 \text{ mm}$$

Step 4: Calculation of the length extension (ΔL): Here ΔL is the extension in length due to fringing effect and it is a function of the ratio of length L to height h of the substrate (L/h) and effective dielectric constant (ϵ_{reff}) of the substrate. Equation (4) gives the length extension as:

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

Substituting $\epsilon_{reff} = 3.995$, $W = 11.9$ mm and $h = 1.6$ mm we get:

$$\Delta L = 0.71 \text{ mm}$$

Step 5: Calculation of actual length of patch (L) The actual length is obtained by equation (5) as:

$$L = L_{eff} - 2\Delta L \quad \dots(5)$$

Substituting $L_{eff} = 12.9$ mm and $\Delta L = 0.71$ mm we get:

$$L = 0.0115 \text{ m} = 11.5 \text{ mm}$$

Step 6: Calculation of the ground plane dimensions (L_g and W_g): The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by [5] that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for this design, the ground plane dimensions would be given as:

$$L_g = 6h + L = 6 \times 1.6 + 11.5 = 21.1 \text{ mm}$$

$$W_g = 6h + W = 6 \times 1.6 + 11.9 = 21.5 \text{ mm}$$

3.0 Results and analysis

The software used to model and simulate the square patch antenna was Microwave Office software. The antenna was designed using FR-4 substrate material with the parameters given in section 2.2. The patch length L calculated for frequency of 5.8 GHz was approximately 11.5mm, but some optimization was done in order to get a better return loss there by reducing the length of the patch to 11.2mm. The ground plane length was greater than the patch length and it was taken approximately as 21mm from the calculation. The location of feed point was found at 6.58 mm from the corner along the diagonal of the square patch. The square patch antennas without slot and with K-slot in different locations are shown figure 2 and 3 respectively.

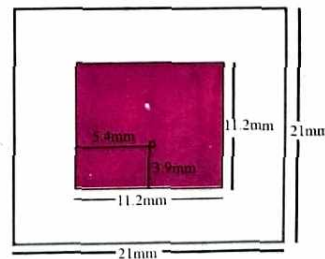


Figure 2. The proposed square patch antenna without slot

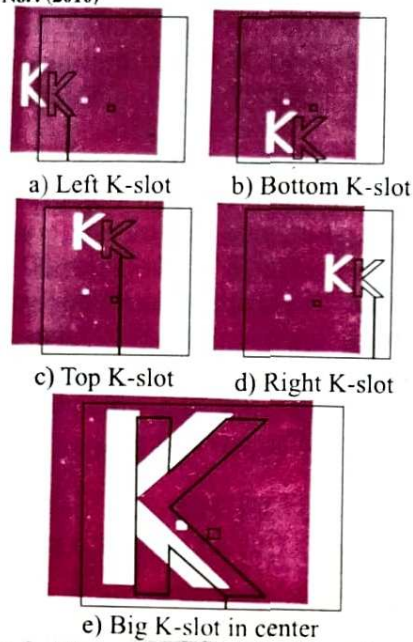


Figure 3. The proposed square patch antenna with K-slot in different locations.

The antennas above with different locations of K-slot were simulated and analyzed. The coaxial probe feed used is designed to have a radius of 0.5mm. A frequency range of 4-10 GHz is selected. All the parameters of the antennas were fixed, the only changes made was the position of the K-slot at the top, bottom, left and right sides of the square patch and also Big K-slot at the center of the square patch. The simulated graph of scattering parameter (S_{11}) was illustrated in the figure 4.

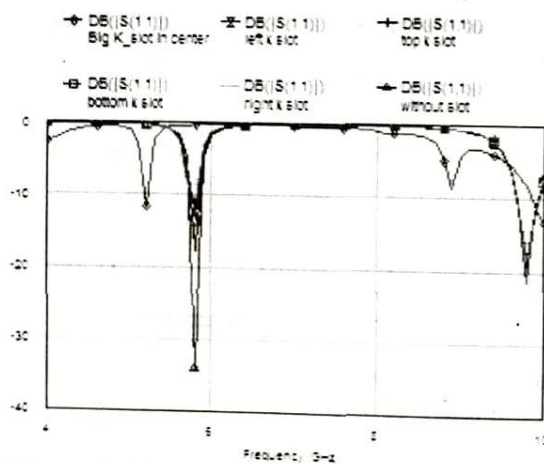


Figure 4. The simulated return loss for the proposed antennas with and without slot.

The measured results from the S_{11} are recorded in table 1.

Table 1. The measured results of the square patch antenna without slot and with slot in different locations.

Square patches	Resonant Frequency (GHz)		Return loss (dB)		Bandwidth (MHz)	
	1 st Freq	2 nd Freq	1 st RL	2 nd RL	1 st BW	2 nd BW
Without slot	5.8	9.8	-34.13	-17.96	30.0	25.47
Top K-slot	5.8	9.8	-17.31	-19.06	20.0	25.47
Bottom K-slot	5.8	9.8	-13.57	-18.32	14.0	25.45
Left K-slot	5.8	9.8	-11.80	-21.30	10.0	27.51
Right K-slot	5.8	9.8	-10.64	-20.06	7.00	28.54
Big K-slot	5.2	8.9	-11.63	-8.52	6.73	-

From the results shown in table 1, it can be observed that the square patch antenna without slot has two resonating frequency (5.8GHz & 9.8GHz) and minimum return loss (-34.13dB & -17.96dB) respectively. The resonating frequency of the square patch antenna is the same compared with the other slotted patch antenna except that of the Big K-slot at the center patch which has different resonating frequency (5.2GHz & 8.9GHz) and return loss (-11.63dB & -8.52dB). The bandwidth of the square patch without slot is wider (30.0MHz) at 5.8MHz frequency compared to that of when K-slot is in cooperated in the patch but at the frequency of 9.8GHz the Right K-slot have a better bandwidth than the square patch without slot. It can be seen from the table 1 that the slot in the square patch antenna makes the return loss to increase and thereby reducing the bandwidth of some of the slotted antenna.

This antenna has a very narrow bandwidth. The far field radiation patterns of the E and H planes is correspond to scan angles of $\phi=0^\circ$ and $\phi=90^\circ$, respectively. Figure 5a and 5b shows the E-plane and H-plane of the square patch antenna without slot at 5.8 GHz and 9.8GHz.

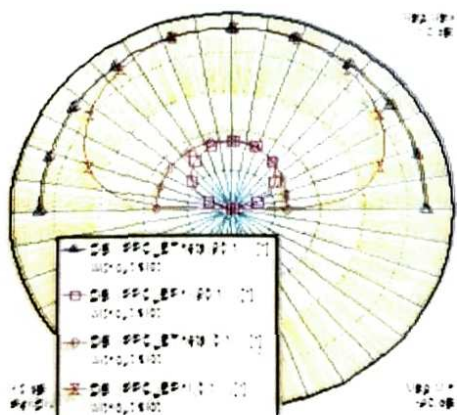


Figure 5a. Polar plot for square patch antenna without slot for frequency of 5.8 GHz

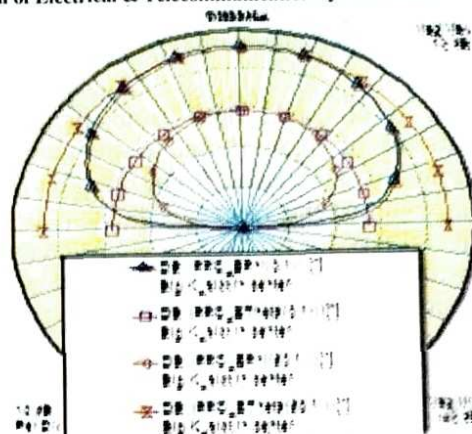


Figure 6a. Polar plot for square patch antenna with Big K-slot at the center for 5.2 GHz frequency

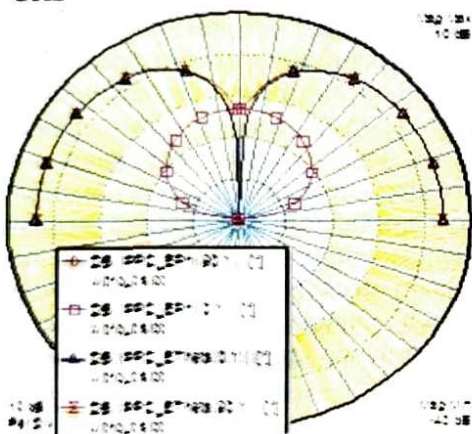


Figure 5b. Polar plot for square patch antenna without slot for frequency of 9.8 GHz.

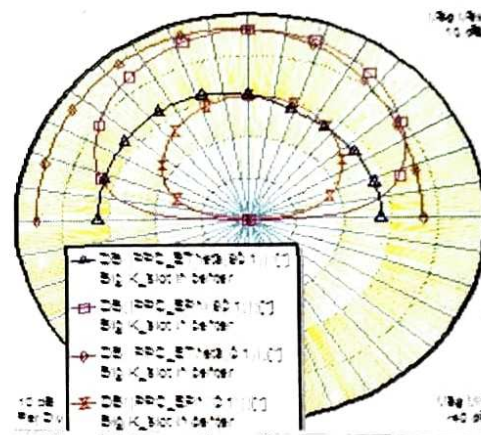


Figure 6b. Polar plot for square patch antenna with Big K-slot at the center for 8.9 GHz frequency

Table 2. The results measured from the radiation patterns for frequency of 5.8GHz & 5.2GHz.

Square patches	Frequency (MHz)	Gain (dB)	HPBW (°) -3dB	Co & cross polar Isolation (dB)
Without slot	5.8	5.95	81.5	28.77
Big K-slot in center	5.2	5.61	83.18	14.79

Figure 6a and 6b shows the polar plot of the square patch antenna with Big K-slot at the center of the patch for 5.2 GHz and 8.9GHz frequency. The radiation pattern of the patch with Big K-slot at the center was chosen for comparison in this design because it has different resonating frequency compare to other K-slotted patch antennas simulated in this design.

Table 3: The results measured from the radiation patterns for frequency of 9.8GHz & 8.9Ghz

Square patches	Frequency (MHz)	Gain (dB)	HPBW (°) -3dB	Co & cross polar Isolation (dB)
Without slot	9.8	-13.5	69.56	28.87
Big K-slot in center	8.9	6.59	60.14	16.26

The results measured from the radiation patterns in figure 5 and 6 are tabulated in table 2 and 3 above. From the table 2 it can be seen that the values of the gain as well as the HPBW for the two square patch antennas (with K-slot on top and without slot) are approximately close to each other because the center frequency is also close. But the co and cross polar isolation is different. The co and cross polar isolation for the patch without slot is 28.77dB (5.8GHz) while that of square patch with Big K-slot at the center of the patch is 14.79dB (5.2GHz).

In table 3, the gain of the square patch antenna without slot for 9.8GHz frequency is -13.5dB, it is very small compare to that of Big K-slot for 8.9GHz frequency, but the co and cross polar isolation of square patch without slot is better compare to Big K-slotted patch.

4.0 Discussions

The square patch antennas provide polarization diversity as left hand circularly polarized or right hand circularly polarized wave can be obtained by changing the feed point along the diagonal of the patch.

The major limitation of the microstrip antennas is their narrow bandwidth. The bandwidth may be increased by increasing the size of the antenna. The length of the patch is determined by the resonant frequency and dielectric constant. Since the frequency is predetermined, using a substrate of lower dielectric constant is a way to increase the length and consequently the bandwidth. When designing a microstrip patch, the width is required to be as large as possible, the thickness should be as thick as possible, and the dielectric constant and loss tangent should be as low as possible.

However, low dielectric constant has one disadvantage that it increases the size of antenna. Again bandwidth is inversely proportional to the quality factor Q . Lowering the Q increases losses that results in degradation of antenna efficiency. However, radiation losses may be increased by increasing the substrate thickness

(without exciting higher order modes) [5]. The height of the patch above the conducting plane should be approximately two percent of the width of the patch. Moreover, it should be minimum 0.01 wavelengths above the conducting plane. Lower heights result in higher Q and high currents resulting in higher losses.

5.0 Conclusion

The aim of this paper was to design, simulate and compare the results obtain from a square patch antenna without slot and with K-slot in different locations on the patch. It can be observed from the results that the bandwidth of the square patch antenna without slot decreases when a K-slot was in cooperated in the patch and the return loss also increases, it shows that the slot affects current distributions in the patch. The gain and HPBW of the antenna with and without K-slot almost have a close values but the co and cross polar isolation is different. From the results obtain it can be concluded that the square patch antenna without slot have a better performance compared to the ones with K-slot.

References

- [1] Kin Lu Wong, Jian-Yi Wu, "Single-feed small circularly polarized square microstrip antenna", *Electronics Letters*, Vol.33, No.22, pp.1833, Oct 1997.
- [2] Wen-Shyang Chen, Chun-Kun Wu, Kin-Lu Wong, "Novel Compact Circularly Polarized Square Microstrip Antenna". *IEEE Trans. On Antennas and Propagation*, Vol.49, No.3, March 2001.
- [3] Abboud F., Damiano J., and Papiemik A. "Simple model for the input impedance of coax-fed rectangular patch antenna for CAD," *IEE Proc. PanH*, 135, pp.323-326, 1988.
- [4] Pues H and Van de Capelle, "Accurate transmission line model for the rectangular MSA," *Proc. IEE. Pt. H (Microwaves, optics, acoustics)* Vol.131, No.6, 1984.
- [5] Kumar, G. and Ray, K.P., *Broadband Microstrip Antennas*, Artech House, Inc 2003.