Design Guidelines for Designing High Gain Patch Antenna in the Ku-band

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Abstract— In this paper, a general method is proposed to design patch antenna with high gain in the Ku band. The design method is illustrated with the help of two examples. It is shown that high gain antennas can be designed with satisfactory performance in the desired band. The designed antennas can be used in the applications relating to the Ku-band such as satellite communication, radar, point to point communication etc.

Keywords- ***Antenna radiation patterns; patch antenna; high gain antenna.***

I. INTRODUCTION

The patch antennas have been studied rigorously and widely since last three decades. This class of antenna offers various advantages as low cost, light weight, easy fabrication and conformability etc but on the other hand these antennas have narrow bandwidth and low gain [1]. Various approaches have been used to overcome the problems of narrow bandwidth and low gain [2]. Recently the authors have proposed use of partial Koch to improve the gain of triangular patch antenna [3]. Similarly star shaped patch antenna has been designed to overcome the problem of low gain at higher order modes in the Ku band [4][5]. The design of star shaped antenna in [4][5] has been generalized in this paper and guidelines have been provided for the design procedure at any frequency in the Ku-band. Furthermore slots usage to improve antenna performance is also discussed by the authors in [6]. This paper generalizes the design procedure of [4]-[6] to design a single layer patch to achieve high gain at higher order modes without having to resort to air gaps, parasitic patches, superstrates, staked patches or arrays etc. The design guidelines have been verified by designing two antennas in band of 16GHz-16.3GHz [4]-[6] and 24GHz-24.25GHz. These two frequency bands have been selected for their usage in practical applications like point to point communication, radar, amateur radio, radiolocation services etc and the growing trend towards the usage of higher microwave frequencies. The paper is organized as follow: In Section 2 existing literature on the high gain antennas is presented. Section 3 presents the proposed method guidelines, Section 4 presents design example based on the proposed method. The discussion on the design is presented in Section 5 while conclusion is drawn in Section 6.

II. STATE OF THE ART

The low gain problem is tackled by different techniques. These techniques can be broadly classified into five categories. 1) Use of Substrates-Superstrates 2) Use of Stacked/Parasitic patches 3) Lossless feeding Techniques 4) and Higher order mode Excitation. Among these categories 2 and 3 were initially used to tackle bandwidth problem but later these were also used for gain enhancement. Nicolaos et al. [7][8] presented the resonance conditions for a substrate-superstrate printed antenna geometry for high gain. K.F.Lee et al. [9] have used same size parasitic elements to achieve high gain apart from bandwidth. Parasitic elements obtain energies from fed by near field coupling and function as radiating element in an array. Along with the parasitic elements concept the stacked elements concept [10] is used to achieve high gain. L-probe feed [11] has been shown to increase the bandwidth and gain of the fed patch. The L-probe acts as a series resonant element with resonant frequency close to the dominant mode thereby increasing the gain of the patch. The higher order modes in case of patch antennas however are discussed very little to increase gain. This is due to the difficultly and challenge associated with the excitation of higher order modes in given dimensions of the patch. Furthermore high side lobe levels, undesirable radiation patterns and narrow impedance bandwidth are associated with higher order modes [1]. The star shape antenna thus designed alleviates this problem and hence facilitates the antenna design without having to resort to complex and thick designs.

III. PROPOSED METHOD GUIDELINES

The equation relating the resonant frequency and the patch dimensions at particular mode [1] is given below.

$$f_{mn} = \frac{k_{mn} c}{2\pi\sqrt{\varepsilon_r}} \qquad (1)$$

where ε_r is relative dielectric constant, c the speed of light and k_{mn} is the wave number at mn^{th} mode given as:

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$$k_{mn} = \sqrt{\left(\frac{m\pi}{L}\right)^2 + \left(\frac{n\pi}{L}\right)^2}$$

where L is the length of square patch. Using equ (1) one can simply finds out the dimension L by plugging in the mode numbers m n, frequency desired (this is f_{70}) and relative dielectric constant and then by using calculated dimension L the dominant mode frequency can be found easily for the initial design. This is explained by two examples: Example 1: (Frequency = 16GHz, dielectric constant = 2.33 and m=7, n=0) the dimension L comes out to be 42.12mm. Putting L = 42.12mm and the dominant mode m = 1, n = 0, the frequency is found to be 2.4GHz for dielectric constant of 2.33. Similarly for Example 2: (Frequency = 24GHz, dielectric constant = 2.33 and m=7, n=0) L is found to be 28.6mm and frequency at dominant mode is 3.4 GHz. These calculations are summarized in Table 1.

TABLE 1 FREQUENCIES AND DIMENSIONS CALCULATION SUMMARY

Freq f_{70}	**€$_r$**	**Length L**	**Freq f_{10}**
16GHz	2.33	42.12mm	2.4GHz
24GHz	2.33	28.6mm	3.4GHz

The dominant mode frequencies calculated are to be used for initial design of square patch [1] which when undergoes the surface modification [4]-[6] resonates at f_{70} frequency. The initial antenna design [4], its improvement [6] have been reported by the authors however the design procedure was not generalized in [4]-[6]. Here we present the general design guide lines of the design. Following are the designs guidelines

1. Using above listed method calculate the dominant frequency from the desired frequency $f_{70.}$
2. Design square patch at the dominant frequency with side length L [1].
3. Cut squares of side L/4 from four edges of the designed square patch in 2 resulting in the cross shaped antenna [4].
4. Cut L/2 equilateral triangles from center of cross shaped antenna to result in star shaped antenna [4].

These guidelines have been shown in fig.1 (left).

IV. Examples to Illustrate Design Procedure and Simulation Results

Example 1 can be seen in [4][5] where the simulated and measured results are discussed. Here as an Example 2 the square patch is designed at 3.4GHz with substrate RT DURIOD 5870 having relative permittivity of 2.33 and height h = 1.5mm as calculated in Table 1. The antenna is fed with coaxial probe. The design of 24GHz star antenna follows the guidelines listed above. The final design is shown in Fig. 1(right) **along with** its S_{11} parameter and radiation patterns at 24GHz in Fig 2(left) and Fig. 2(right) respectively. The simulated gain at 24GHz is found to be 12.9dBi. The other resonant modes in fig.2 (left) can be suppressed by use of suitable slots [6] which will eventually enhance the antenna performance.

V. Discussion and Explanation of High Gain

For the same size antenna, increasing the frequency will decrease the wavelength hence the gain of the antenna will increase. This can be verified through equ. (2) [1]

$$G = \frac{4\pi A_{eff}}{\lambda^2} \quad (2)$$

where A_{eff} is the effective aperture area.

A basic square patch can be viewed as a two element array, consisting of two radiating edges of length $\lambda/2$ and separated by a distance $\lambda/2$ [6]. In case of square shaped antenna resonated at f_{70} frequency, the distance between the radiating edges become greater then $\lambda/2$, however when the surface modification is done leading to star shaped antenna the distance decreases hence surface current densities become favorably in phase leading to high gain [6]. The Microstrip patch antennas have been studied extensively in last three decades to alleviate the problems of low gain and narrow bandwidth. However, the higher order modes of the patch antennas are not discussed significantly due to difficulty in their excitation and deteriorated performance associated with them. This approach of surface modification leading to star shape patch antenna provides the method to excite the higher order modes properly. Furthermore, the performance of antenna is highly improved in terms of gain, radiation patterns and bandwidth. Thus the design procedure facilitates the design of high gain patch antenna at higher frequencies by utilizing higher order modes without resorting to complex designs and techniques already reported in the literature.

VI. Conclusion

The paper presents a generalized method to design a high gain patch antenna suitable for the applications relating to the Ku-band. The method is verified through two design examples. The performance of the designed antennas can be further improved by use of suitable slots. The proposed method alleviates the problems ass**o**ciated with higher order modes such unstable radiation patterns, high SLLs etc. The method provides the procedure through surface modification of the patch to excite higher order modes in the patch and hence achieve high gain without complex designs.

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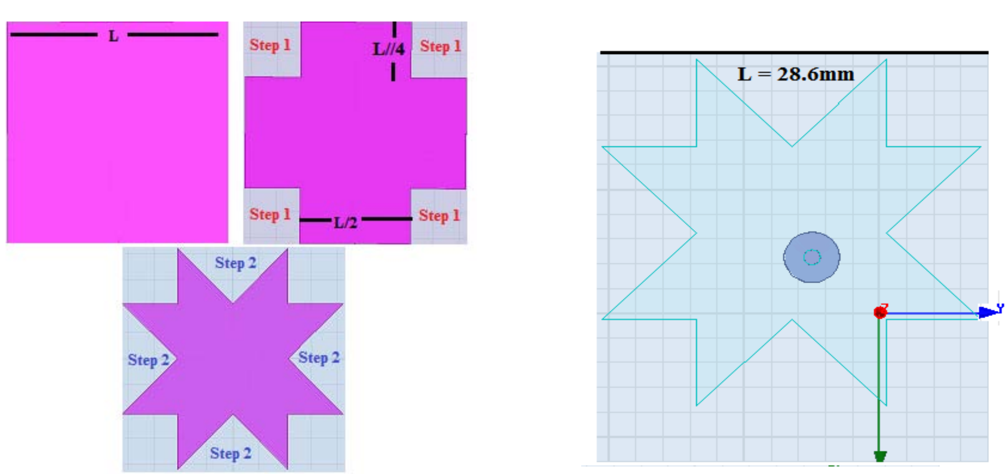

Figure 1. (left) Design Procedure Illustration, (right) Designed of Star Shaped at 24GHz

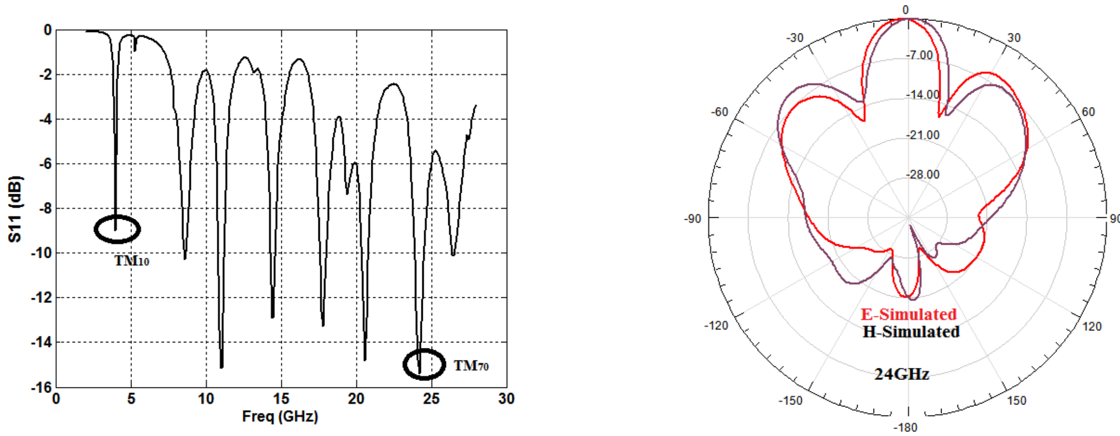

Figure 2. (left) Simulated S_{11} of Star Shape 24GHz, (right) Radiation Patterns of Star Patch at 24GHz