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Planar Monopole Stair Case Antenna for Ultra-wide Band

***Abstract**. Planar monopole antennas are extensively used in many wireless communication applications due to their compact size, low weight and ease of integration with active devices. Many antennas with different band characteristics have been designed such as dual, multi, wide and ultra wide band. In this paper simple monopole antenna is proposed for Ultra wide band applications. The antenna is analysed for bandwidth increment with addition of linear multiple steps, mathematical model is also proposed. Simulation results show that the proposed design can be used for UWB applications with reasonable accuracy. Prototype of proposed design with measured results are also presented. Reasonable agreement is found between the simulated and measured results. Details of the proposed antenna design, simulated and measured results are presented and discussed.*

Słowa kluczowe.** W artykule opisano prostą antenę mono-polarną w zastosowaniu do ultra-szerokich pasm przepustowych. Przedstawiono model matematyczny i analizę wzrostu przepustowości pod wpływem liniowych stopni mnożących. Wyniki badań symulacyjnych zostały zweryfikowane poprzez porównanie z pomiarami rzeczywistymi. **(Płaska, mono-polarna antena schodowa do pasm ultra-wysokich).

Keywords: Monopole Antenna,Ultra-wide Band, Stair case, Mathematical formulation.
Słowa kluczowe: antena mono-polarna, pasma utra-wysokie, schody, formuła matematyczna.

Introduction

Planar monopole antennas are finding numerous applications in mobile and wireless communication due to their compact size, low weight and ease of fabrication and integration with active devices. However, inherent narrow band characteristics of monopole antennas have forced the researchers to explore and investigate the ways and means to enhance the bandwidth of UWB antennas while keeping the sizes as low as possible.

Quite a few techniques as reported in [1,2] have been explored and applied to design and develop antennas for UWB applications. The research work presented in this paper is believed to provide further insight into design and development of UWB antennas.

UWB technology creates enormous interest in itself due its flexibility in multi-path interference, low transmission power, simple transceiver circuitry and precise ranging ability [3, 4, 5, 6]. In *2002*, the FCC allowed intentional UWB emissions in the frequency range from *3.1GHz* to *10.6GHz*, subject to certain limitations for the emission power spectrum [7].

Research and development of the UWB antennas to enable power efficient, high data transmission rates and simple hardware configuration in communication applications is escalating day by day [8, 9,10,11,12,13,14,15]. Techniques to design and experimental Analysis of high performance microstrip antennas are discussed in [16]. Multi-band resonance generation by feed manipulation in microstrip antenna is explored in [17]. Dual band characteristics that can lead to UWB by appropriate selection of placement and dimensions of slots are systematically studied in [18]. Tree type antennas have been employed to achieve lower UWB with reason able accuracy [19]. UWB antenna with dual notched band characteristics is also achieved in [20]. In this paper the geometry of tree type antenna is extended with the addition of symmetrical steps at both the radiating edges of the antenna to achieve UWB, generalization of mathematical modeling is also derived for stair case geometry of antenna.

The rest of the paper is organized as follows; next section describes the geometrical structure and simulation results of proposed design, subsequent section contains analysis of patch size and last section concludes the paper.

Discussion on geometrical structure and simulation results

In order to achieve desired UWB characteristics, the antenna is designed and simulated in successive stages using HFSS. The material used is *FR-4* with thickness of *1.6mm*, ε_r *=4.7* and $\tan\ \delta$ *=0.02*.

Geometrical structure parameters are listed in table 1. Brief description of each stage is as follows.

Table 1. The parameters of designed antenna

Parameter	Lp	Lg	Lf	Wf	Wg	Wg1
Size (mm)	15	30	13	3	35	12.5

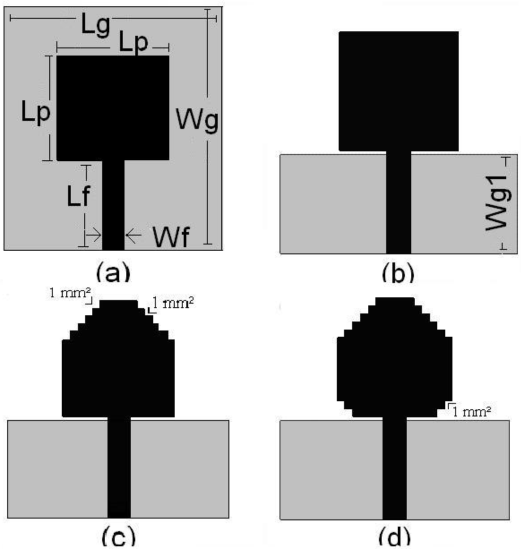


Fig. 1. Geometrical structure of a)First Stage, b)Second Stage, c)Third Stage d)Fourth Stage.

First Stage

In the first stage, the substrate of dimensions 30x35mm^2 is fully grounded. The geometrical structure of first stage of proposed antenna is depicted in Fig 1a. Simulation results depicted in Fig. 2 shows that the antenna resonates at frequency of *8.74GHz* having bandwidth of about *500MHz*

Second Stage

It is reported in the literature that bandwidth is improved using partial ground plane. Therefore, the ground plane is reduced in successive steps and optimized to obtain *30x 12.5mm^2* which gives comparatively better results. Fig. 1b shows geometrical structure of the second stage whereas simulation results depicted in Fig. 2 show significant improvement over the bandwidth as compared with the previous stage. The maximum bandwidth achieved by second stage is *1.6GHz*.

Third Stage

Truncation is another technique employed by many researchers to improve the bandwidth of antennas. Following the same technique, upper edge of the patch is truncated as show in figure 1c. Step size of *1x13mm²* is found to be optimal after series of experimentation.

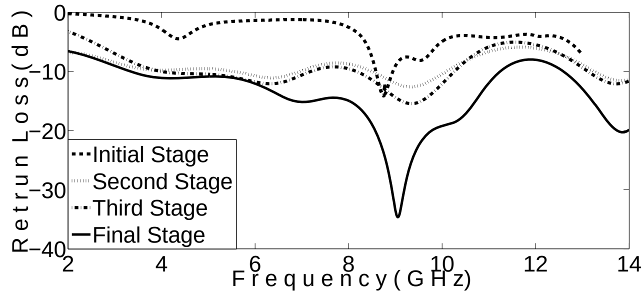


Fig. 2. Effect of stages on Return Loss.

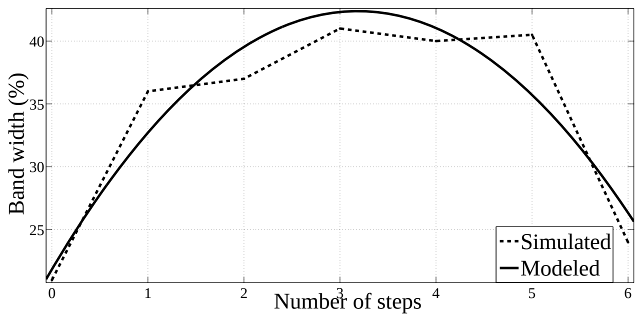


Fig. 3. Effect on Band-width with increasing number of steps.

In order to introduce further steps, Step1 is translated in the lower side of the patch, towards transmission line. The step size of dimension *1x11mm²* is found appropriate for subsequent truncations. Up to and including step-5 in the upper side of the patch, opposite to the transmission line which is entitled as upper stair stage, we obtain the optimize result w.r.t return loss and radiation pattern. The geometrical structure of the upper stair stage with five steps is shown in Fig 1c. Further improvement as compared to previous stage, in bandwidth is observed as shown in Fig. 2, however slight drift in frequency along with multi-band behavior of the antenna is also noticed. The drift in the frequency towards higher side is because of reduction in the patch area by entrenching the steps in the patch. Total area reduction in comparison of the square patch is *23%*.

It has been observed that with the addition of further steps (more than 5) the bandwidth starts decreasing as evident from Fig. 3. Therefore it is concluded that for this particular antenna design the optimal number of steps is five. The approximate relation between the number of steps and Bandwidth is formulated from method of Least Square Errors (LSE), compared with the simulated result and given by:

(1) $$B.W(\%) = -2.119n^2 + 13.4858n + 21.3906$$

Where *B.W%* is percentage bandwidth, *n* is number of steps added in the patch. The maximum achievable bandwidth after implementing third stage is *4.21GHz*.

Fourth Stage

Experimental results from previous subsection indicate that introducing steps more than five in upper edge reduces the bandwidth. Therefore an attempt is made to introduce certain number of steps by truncating lower edge, attached to transmission line. A significant improvement is observed as shown in Fig. 2, with introduction of only two steps in the lower edge of the patch as shown in Fig. 1d. Bandwidth started decreasing with further increase in steps at lower edge.

The antenna is fabricated and return loss is measured using PNA-X Network Analyzer N5242A. The measured and simulated result are shown in Fig. 4 that indicates slight deviation from simulated result, which is probably due to fabrication process, measurement environment and simulation granularity. However, good agreement exists between measured and simulated results. The measured radiation pattern relevant to the fourth stage at frequencies 3.5GHz, 5GHz and 7.1GHz are shown in Fig. 5(a-c)

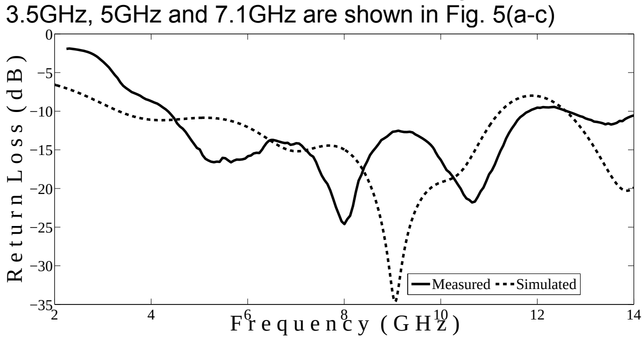


Fig. 4. Simulated and measured results of final stage

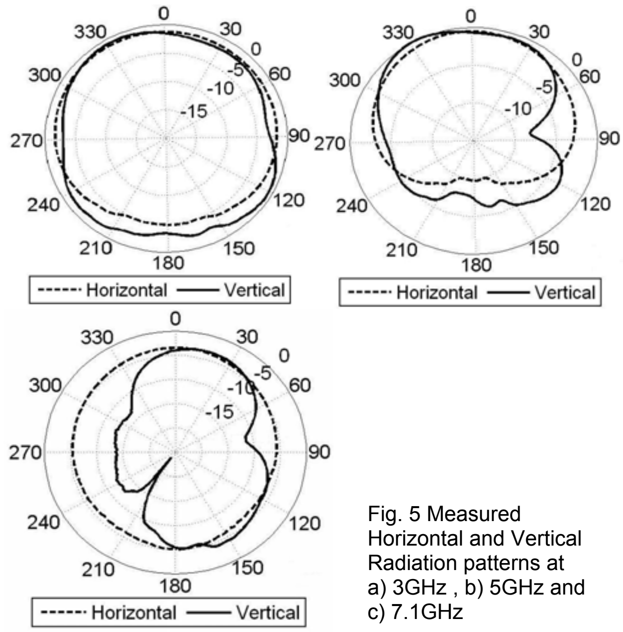


Fig. 5 Measured Horizontal and Vertical Radiation patterns at a) 3GHz , b) 5GHz and c) 7.1GHz

Analysis of patch size

In this section, an attempt is made to extend validity range of proposed techniques by experimentally verifying the relationship among different antenna parameters, number of upper and lower steps are optimized by extensive simulations while using same material for all patch sizes. The resonant frequency with respect to patch size, upper and lower steps and dimensions of ground plane is tabulated in Table 2. The resonating frequency is found and confirm to reasonable agreement among antenna parameters. It is observed that the bandwidth remains almost constant for all the patch sizes as shown in figure 6. It is also observed that the resonating frequency is reducing linearly with the increase in the patch size as described as

(2) $$F_{resonant} = 12.8 - \frac{L}{4}$$

where $F_{resonant}$ is resonating frequency in *GHz* and *L* is length of the patch in *mm*. There are slight variations observed in the simulated result from modelled result.

From the above analysis of the patch size it can be concluded that all of the designs listed in the Table 2 resulted into UWB. The relation of patch size to the substrate size, ground plane, upper and lower steps are shown in the following relations. These relations could be extended to any size of the patch.

(3) $$[L_{substrate}, W_{substrate}] = [2L, 2L + 5]$$

(4) $$[L_{ground}, W_{ground}] = [2L, L/2 + 5]$$

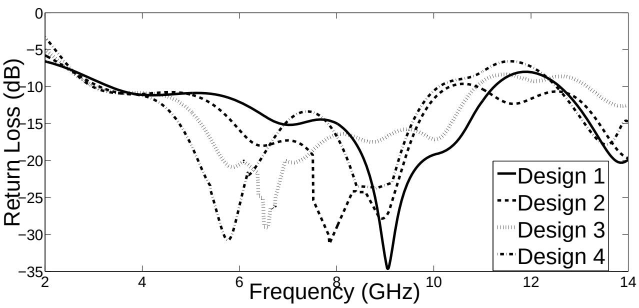
Fig. 6. Effect patch size, ground plane, upper and lower steps.

(5) $$[Step_{upper}, Step_{Lower}] = [L/2 - 2.5, L/4 + 1.75]$$

where L is the length of the patch, $L_{substrate}, W_{substrate}$ are length and width of substrate, L_{ground}, W_{ground} are length and width of ground plane, $Step_{upper}, Step_{Lower}$ are number of upper and lower steps.

Table 2. Relation of Patch size and number of upper and lower steps

Design of Antenna	Resonant Frequency (GHZ)	Patch Size (mm^2)	Substrate size (mm^2)	Ground Plane (mm^2)	Upper, Lower steps
1	8.5	15x15	30x35	30x12.5	5, 2
2	7.46	19x19	38x43	38x14.5	7, 3
3	6.48	23x23	46x51	46x16.5	9, 4
4	5.54	27x27	54x59	54x18.5	11,5



Conclusion

The antenna is designed and simulated using HFSS for UWB applications. The method of partial ground plane and the technique of truncation of upper and lower edges of the patch are applied to achieve the desired results. Both the techniques are employed in successive stages and during each stage certain improvement in bandwidth is observed. However, at this particular frequency maximum bandwidth could be achieved up to and including five steps in upper edge of the patch while steps in lower edge were limited to two beyond which bandwidth started decreasing. Furthermore, in order to extend the validity range of this technique and figure out relationship between antenna parameters and number of steps different experiments were conducted on various patch sizes, ground plane, upper and lower steps keeping the material constant. It has been observed that a linear relationship exist between size of the patch and resonating frequency of the patch antenna. The radiation pattern at *3.5, 5* and *7.1GHz* are measured in anechoic chamber and also tested on Network Analyzer. Simulation and measured results shows reasonable agreement.

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