

Design and Implementation of Step-Constant Tapered Slot Antennas for UWB Application

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Abstract

This paper presents the analytical design and high performance of step-constant tapered slot antenna (STSA) for ultra-wideband application. The return loss, radiation pattern, antenna gain, and level of cross polarization of this antenna are presented and analyzed. Utilizing Rogers (RO3006) substrate having a relative permittivity of 6.15, the proposed antenna provides the ultra-wideband (UWB) from 3.1 GHz to 10.6 GHz. It is observed that the return loss and gain are increased with increasing the step size. It has been observed from the simulation results incorporating CST microwave studio commercial software version 2015, the optimum return loss, directivity and gain are -43 dB, 10.52 dBi and 10.20 dB, respectively, for 15 step size. Therefore, the newly proposed antenna will be a decent candidate for ultra-wideband application.

Keywords

Antenna Gain, Voltage Standing Wave Ratio (VSWR), Step Constant Tapered Slot Antenna (STSA), Ultra Wideband (UWB), Reflection Coefficient

1. Introduction

Over the last decade, ultra-wideband (UWB) technology is being used widely due to the diverse applications such as wireless communications [1], remote sensing [2] [3], biosensing [4]-[15], microwave imaging [1], position location [11] [12] [13], tracking [1], and radar system [1]. To transmit a huge amount of digital data, ultra-wideband technology is used which has the ability over wide operating bandwidth with very low power emission for a short distance. The Federal Communications Commission (FCC) of USA provides UWB frequency

range of 3.1 GHz to 10.6 GHz [16] [17]. The amount of radio frequency (RF) bandwidth (>500 MHz) that is achieved by the UWB system mainly maximizes its performance [16] [17]. However, a quality full communication system depends on antennas that can efficiently radiate and accept UWB signals.

In recent time, various types of antennas have been manifested in the applications of ultra-wideband. Among them tapered slot antenna (TSA) is an important one [18] [19]. A typical tapered slot antenna provides wide operational bandwidth, improves gain, and identical radiation pattern [20]. TSAs can be divided into three basic profiles of taper namely: 1) linear tapered slot antenna (LTSA), 2) constant width slot antenna (CWSA), and 3) exponential tapered slot antenna or Vivaldi antenna [21] [22]. The bandwidth and gain of TSAs are mostly affected by the taper profile.

TSAs are traveling-wave antenna in nature. Generally, by using single or more travelling waves the distribution of voltage or currents of all antennas can be presented which is known as travelling wave antennas. The properties of the traveling wave are, 1) reasonably high directivity 2) thin beam width and 3) nearly identical E-plane and H-plane radiation patterns over a widespread frequency band. Another important benefit of tapered slot antennas is they display broadband action, small side lobes, planar footsteps and simple in construction. If there is a noble match of TSA between the input side and at the radiation side of an antenna, then TSA has a large bandwidth. Greater than 10 GHz operating frequencies TSAs are also suitable, where a large electrical length and a small geometrical length considerably relate to each other. Through conventional geometries the simple direct polarization is the leading drawback of the TSA [23].

In this paper, a micro strip line (L-shape) fed Step-constant tapered slot antenna (STSA) component has been designed by using Rogers (RO3006) substrate. We investigate the use of Rogers (RO3006) substrate based antenna for ultra-wideband applications focusing on multiple key aspects such as 1) reflection coefficient, 2) directivity and antenna gain, 3) voltage standing wave ratio (VSWR) and 4) radiation pattern. In addition, the performance parameters of the designed Rogers-based Step-constant Tapered Slot Antenna have been compared with the conventional UWB antenna for ensuring the validity. However, the key parameters of the antennas are analyzed using a Computer Simulation Technology (CST) microwave studio software version 2015.

2. Step Constant Tapered Slot Antenna (STSA) Design

The Tapered slot antenna (TSA) is a traveling wave antenna in which the wave propagates through the tapered slot for radiation. Among the types of TSA, this paper represents the design of the step constant tapered slot antenna (STSA). By the modification of some important parameters most favorable antenna design can be achieved. The basic configuration of the proposed step-constant antenna is shown in **Figure 1**. The feeding of the antenna is located on the left side of a

substrate having dielectric constant and thickness of $\epsilon_r = 6.15$ and $h = 1.5$ mm, respectively. A waveguide port is connected between the micro strip-line to the substrate. At one direction, the width of the strip is 0.4 mm and the length is 7 mm long in the creation part. At the other direction, the width of the slot is 0.4 mm and length is 10 mm, respectively. The final optimized parameters of the antenna are listed in **Table 1**. In order to construct the step, the following equations are used in where each step has a specific length and width.

$$\text{Length of the step: } S_L = A(L/2) \quad (1)$$

$$\text{Width of the step: } S_W = -A(W/2), A(W/2) \quad (2)$$

$$\text{Taper Length: } T_L = K^*L/2 \quad (3)$$

$$\text{Taper Width: } T_W = K^*W/2 \quad (4)$$

where, No. of step = K ($=5, 10, 15, 20, 25, 30$), $L = 8$ mm, $W = 3.9$ mm, and $A = 1, 2, 3, 4 \dots$. The back view from **Figure 1(b)** shows that, the L-shape micro strip-line is used for feeding the step constant tapered slot antenna. The width of the beginning part and the second part is the same but the length is different for better reflection coefficient and gain.

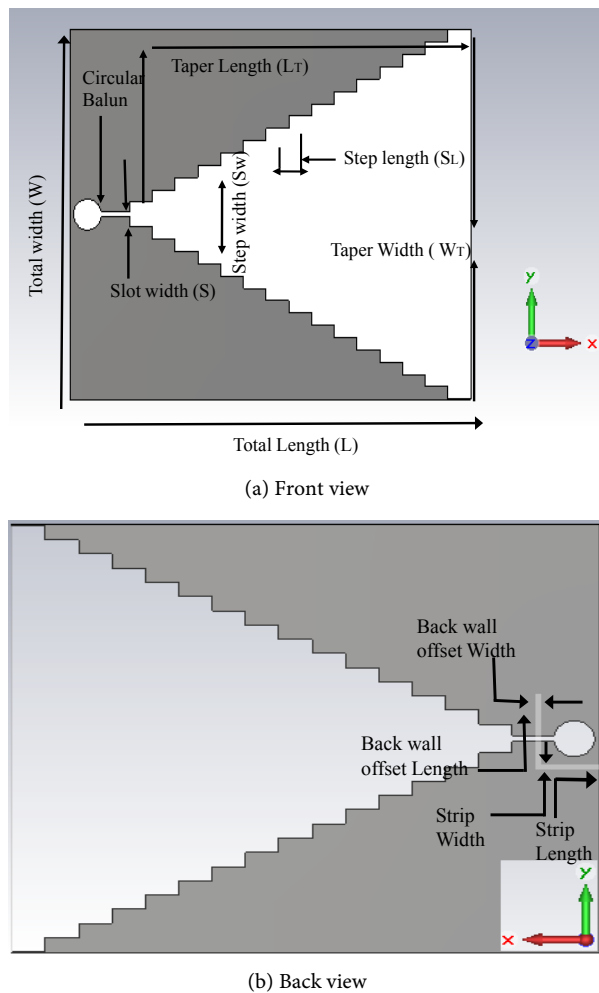


Figure 1. Structural design of the proposed step-constant antenna.

Table 1. Design parameters of step-constant tapered slot antenna (STSA).

Parameters	Dimension (mm)	Parameters	Dimension (mm)
Low frequency (GHz)	3.1	Strip length (S)	7.0
High frequency (GHz)	10.6	Back wall offset length	10
Step length (S_L)	8.0	Back wall offset width	0.4
Step width (S_W)	3.9	Strip width (S_W)	0.4
Total length (L)	70.5	Slot line width (W_S)	0.4113
Total width (W)	58.7	Slot line length (L_S)	5.5
Taper length (L_T)	60.0	Circle radius (r)	2.5
Taper width (W_T)	58.7	Substrate thickness (h)	1.5

3. Simulation Results and Discussion

3.1. Reflection Coefficient

Reflection coefficient signifies the amount of power reflection from the antenna. The most common parameter of antennas is S11. The amount of power reflection from the antenna represents S11, and it is called reflection coefficient [23] [24]. Another well-known name of the reflection coefficient is return loss. The optimum simulation results are shown in **Figures 2-5**. In addition, the acceptable limit of reflection coefficient is less than or equal to -10 dB [25]. **Figure 2** represents the simulated reflection coefficient versus frequency for the different step constant antenna.

From **Figure 2**, it is clear that the reflection coefficient of STSA is increasing to a specific step size ranging 5 steps to 15 steps and after that, if we increase the step size ranging 15 steps to 30 steps, the reflection coefficient of STSA is again decreasing. This is because for ultra wide band application, users need a high gain antenna, which is confirms in-between 15 to 30 step sizes.

3.2. Directivity and Gain

The amount of power transmission in the way of peak radiation defines the antenna gain. Antenna gain relates to the power delivered to the antenna and antenna directivity relates to the power radiated by the antenna. **Figure 3(a)** and **Figure 3(b)** represent the simulated gain and directivity for 15 Step-size of the proposed STSA.

3.3. Voltage Standing Wave Ratio (VSWR)

The function of the reflection coefficient is VSWR. It defines the reflection of power from the antenna. For antennas, the VSWR must be a real and positive number. When the VSWR is low, the antenna is better matched to the transmission line and the large amount of power is supplied to the antenna. The lowest value of VSWR is 1.0. If Γ denotes the reflection coefficient, then the VSWR is defined by the subsequent formula [23] [24]:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{5}$$

Figure 4 shows the VSWR respectively for different step size of the proposed STSAs. Here, minimum VSWR which is equals to 1.00 has been achievable at the operating frequency 5.92 GHz.

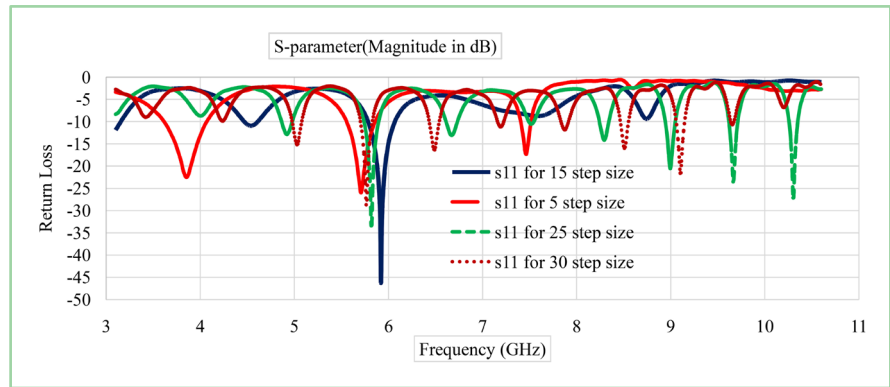


Figure 2. Simulated reflection coefficient for different STSA.

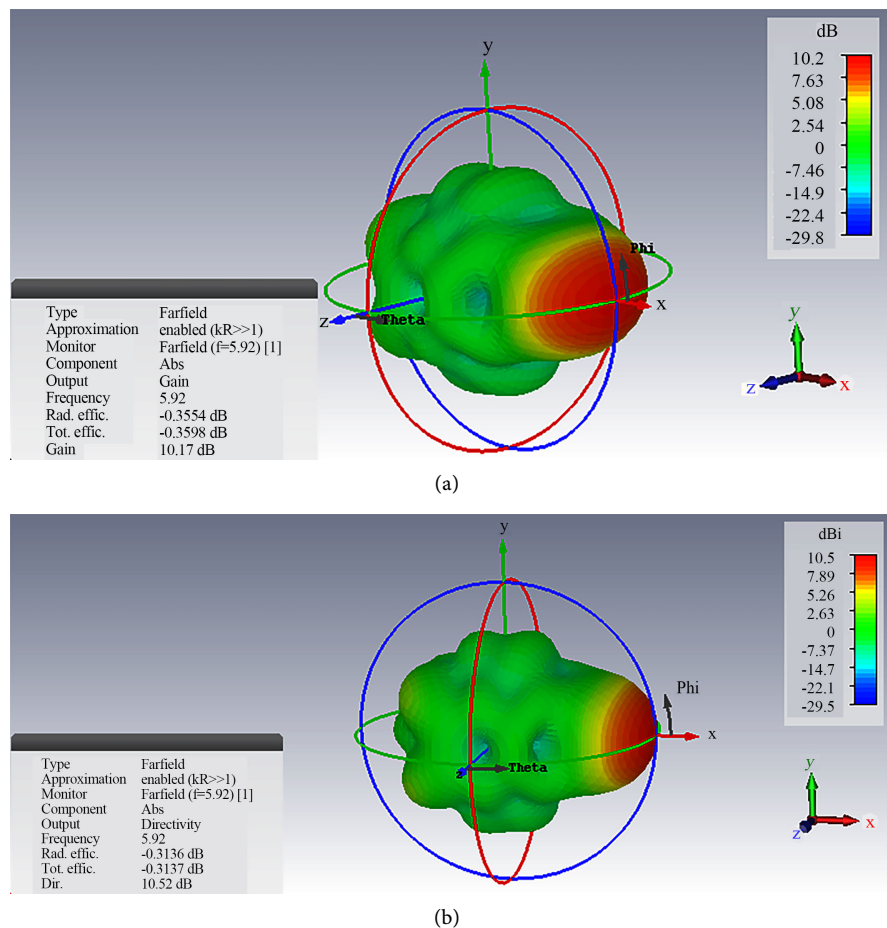


Figure 3. Simulated (a) gain and (b) directivity for 15 step of the proposed constant tapered slot antenna.

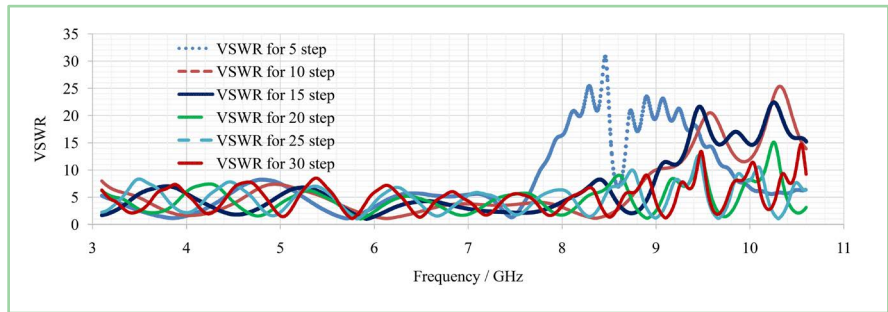
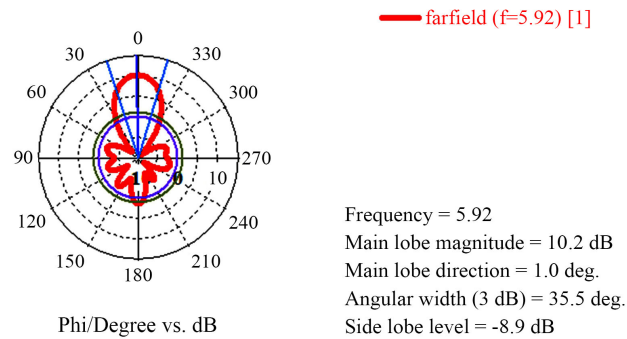


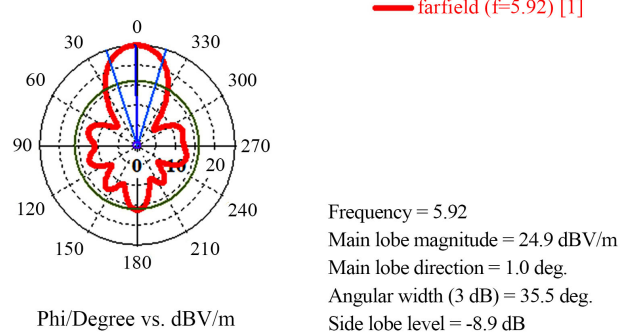
Figure 4. Simulated VSWR for different step-constant tapered slot antenna.

Farfield Gain Abs (Theta=90)



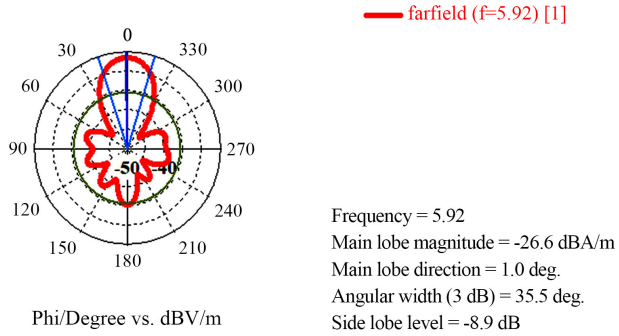
(a) Gain

Farfield E-Field(r=1m) Abs (Theta=90)



(b) E-field

Farfield H-Field(r=1m) Abs (Theta=90)



(c) H-field

Figure 5. Simulated polar plot (a) gain, (b) E-field and (c) H-field of proposed step constant antenna.

After analyzing **Figure 4**, it is established that at 15 step-size STSA provides best reflection coefficient, gain, directivity and VSWR from other ultra wide-band antennas. In Addition, **Table 2** summarizes the simulated results. From **Table 2**, it can be realized that at 15 steps, the STSA has the optimum reflection coefficient, voltage standing wave ratio, gain, and directivity among others.

3.4. Radiation Pattern

The variation of the power radiated by an antenna as a function of the direction away from the antenna defines the radiation pattern. This power variation as a function of the arrival angle is observed in the antennas far field. The region far from the antenna is called far field. In this area, the radiation pattern does not change shape with distance. In addition, this region is dominated by radiated fields, with the E- and H-fields orthogonal to each other and the direction of propagation as with plane waves [23] [24].

Figure 5 represents the simulated polar plot for 15 steps constant antenna at the working frequency of 5.92 GHz. The performance of proposed STSA has been analyzed comparing with the performances of other present UWB antennas and tabulated in **Table 3**. It is being observed from **Table 3** that the STSA designed in this work, has provided the greater outcomes as compared to other UWB antennas reported in the literature [16] [21] [25] [26].

3.5. Substrate Choice

A dielectric substrate is an insulator which is a main constituent of the antenna structure. The simulation results of the proposed antenna depend on the material and thickness of the substrate. Substrate thickness has a key role in antenna performance characteristics [24]. The step-constant tapered slot antenna is considered with the material of the substrate and compared with thickness for improve return loss and gain. The obtained results have been tabulated in **Table 4** for frequency range 3.1 GHz to 10.6 GHz.

From the simulation results in **Table 4**, it is concluded that the material and thickness of the substrate is the most important part, while designing the slot antenna, especially for step-constant tapered slot type antenna. It is observed that, 1.5 mm thick substrate is more directive as compared to 1 mm and 2 mm thick substrate, in terms of return loss, VSWR, antenna gain and directivity.

Table 2. Performance of the designed STSA.

Antenna step size	Reflection coefficient (dB)	VSWR	Directivity (dBi)	Gain (dB)
5 step	-25.92	1.10	8.38	8.1
10 step	-28.66	1.07	8.71	8.47
15 step	-46.22	1.00	10.52	10.21
20 step	-35.82	1.03	10.55	10.2
25 step	-33.34	1.04	10.43	10.03
30 step	-28.67	1.07	10.18	9.78

Table 3. Performance comparison of the designed step-constant tapered slot antenna (STSA) with other UWB antennas.

Performance parameter	Proposed antenna (15 step size)	Conventional antennas		Graphene based antennas	
		Ref. [26]	Ref. [16]	Ref. [21]	Ref. [27]
Return loss (dB)	-46.22	-32.5	-45	-25.23	-39.92
VSWR	1.00	1.06	1.00	NR	NR
Gain (dB)	10.21	5.4	8.6	4.83	NR
Directivity (dBi)	10.52	NR	NR	NR	NR

*NR = Not Reported.

Table 4. Comparison analysis of varying thicknesses and substrate.

Simulation Results	Substrate Thickness (mm)			Substrate		
	1.5	2.0	1.0	Taconic RF-60A	Roger RO3006	FR-4
Return Loss	-46.22	-32	-21	-43	-46.22	-20.46
VSWR	1.00	1.05	1.19	1.01	1.00	1.20
Gain	10.21	8.23	10.2	10.2	10.21	9.95
Directivity	10.52	8.9	10.5	10.52	10.52	11.7

4. Conclusion

In this paper the simulation results show that gain and reflection co-efficient of proposed step-constant TSA for different step size is increasing to a specific step size (5-step to 15-step) and after that if we increase the step size (15-step to 30-step) the gain and reflection co-efficient of STSA is decreasing. An STSA is designed on a Rogers (RO3006) substrate. Back wall offset is the extra metallization fixed at the opening of the slot line. An increase or decrease in the back wall offset parameter results in rapid changes in the return loss characteristics of the antenna. But the above condition is true only for certain values of back wall offset parameter.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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