RECTANGULAR SLOT ANTENNA WITH PATCH STUB FOR ULTRA WIDEBAND APPLICATIONS AND PHASED ARRAY SYSTEMS

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Abstract—This paper presents a coplanar waveguide fed rectangular slot antenna tuned by a patch stub. The presented antenna has 98% impedance bandwidth, and 6 dB average gain. The antenna can be used in phased array applications with more than 61% usable bandwidth.

1. INTRODUCTION

In applications where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, low profile antennas like microstrip and printed slot antennas are required. Printed slot antennas fed by a coplanar waveguide (CPW) have several advantages over microstrip patch antennas. Slot antennas exhibit wider bandwidth, lower dispersion and lower radiation loss than microstrip antennas, and when fed by a coplanar waveguide they also provide an easy means of parallel and series connection of active and passive elements that are required for improving the impedance matching and gain [1].

A number of bow-tie slot designs were recently introduced which demonstrate wide bandwidth that ranges from 17% to 73% [2–11]. However, in order to use these antennas in phased array systems, the antenna element size must be smaller than half the wavelength at the highest operating frequency to avoid grating lobes while scanning the main beam. Thus, the separation distance between elements must be small, and such spacing results in high coupling, which causes scan blindness and anomalies within the desired bandwidth and scan volume.

Recently, the authors presented a novel wideband small-sized triangle slot antenna with a tuning stub [12]. This antenna can provide up to 50% bandwidth, and its bent version provides 57% bandwidth in the X-band for a size of only 12 mm. In this paper, a CPW fed rectangular slot antenna with a stub patch that supports ultra wideband characteristics is presented. Parametric studies and radiation characteristics for this antenna are presented. The numerical simulation and analysis for this class of antennas are performed using the Momentum software package of the Advanced Design System (ADS) by Agilent Technologies, which is based on the method of moments. Verifications of the ADS results are further performed by measurements and by using Ansoft HFSS software package, which is based on the finite element method.

2. ANTENNA GEOMETRY AND PARAMETRIC STUDY

The geometry and parameters of the rectangular slot antenna with a patch stub are shown in Fig. 1, where $W1$ and $L1$ are the width and height of the rectangle, $W2$ and $L2$ are the width and height of the patch stub, and $L3$ is the distance between the patch stub and the CPW feed line. The antenna is supported by a dielectric substrate of a height equal to 32 mil and a relative dielectric constant of 3.38. The CPW is designed for a 50 Ω characteristic impedance with slot and feed line widths equal to 0.125 and 2 mm, respectively. In order to provide design criteria for this antenna, the effects of each geometrical parameter are analyzed. The antenna dimensions ($W1$, $L1$, $W2$, $L2$, $and L3$) are chosen to be (11, 7, 6, 1 and 1 mm) and one parameter is changed at a time while the others are kept constant.

Figures 2, 3, 4, 5 and 6 show the effect of changing $W1$, $L1$, $W2$, $L2$ and $L3$, respectively. All the results in these figures show that this antenna has three resonant frequencies: $f1$, $f2$ and $f3$. As shown in Fig. 2, with the increase of $W1$, $f1$ and $f3$ decrease and $f2$ increases. As a result, when $W1$ increases, the return loss level
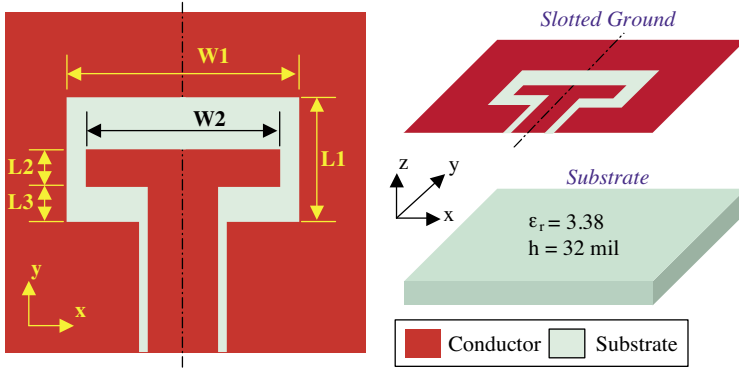
Figure 1. The geometry and parameters of the rectangular slot antenna with patch stub.
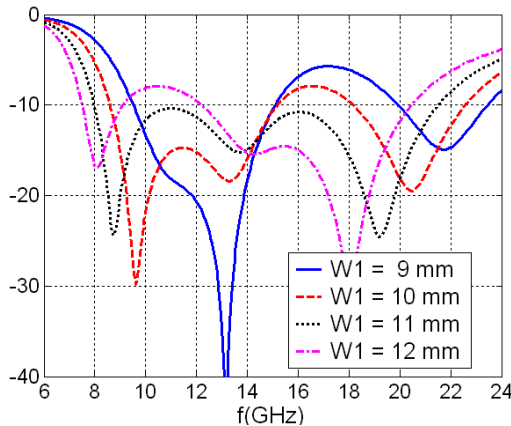

Figure 2. The effect on $S11$ due to the change of $W1$.

between $f2$ and $f3$ improves, while in the region between $f1$ and $f2$, it improves when decreasing $W1$. As shown in Fig. 3, the slot height, $L1$, affects the level of the return loss at $f1$ and $f3$, and as $L1$ decreases, $f2$ and $f3$ increase, resulting in an increase in bandwidth. Figure 4 shows the effect of $W2$. Contrary to the effect of $W1$, the increase of $W2$ decreases $f2$ and slightly increases $f1$ and $f3$, which results in improving the return loss level between $f1$ and $f2$, while the return loss level between $f2$ and $f3$ improves when decreasing $W2$. Finally, the effect of $L2$ and $L3$, as shown in Figs. 5 and 6, is found to be opposite to the aforementioned effect of $L1$.
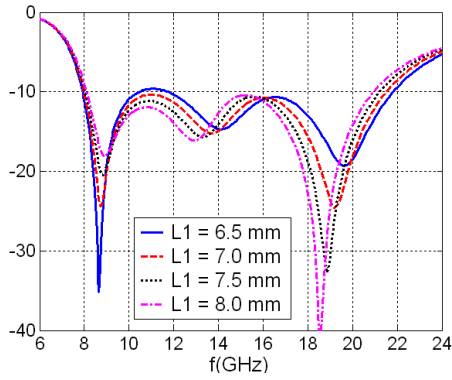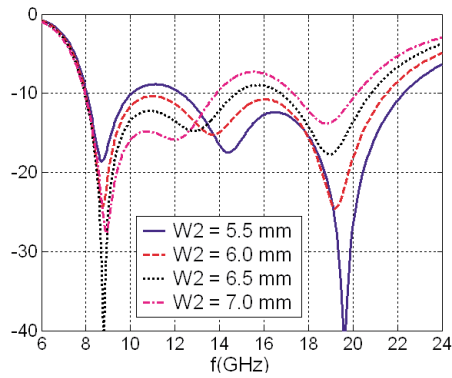
Figure 3. The effect on $S11$ due to the change of $L1$.
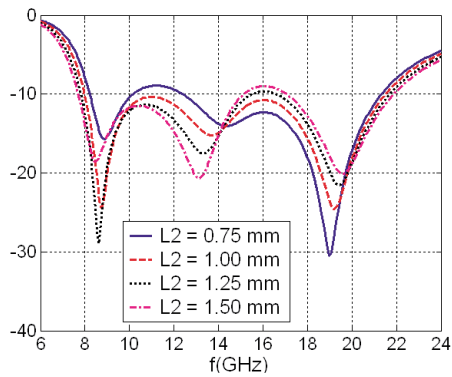

Figure 4. The effect on $S11$ due to the change of $W2$.

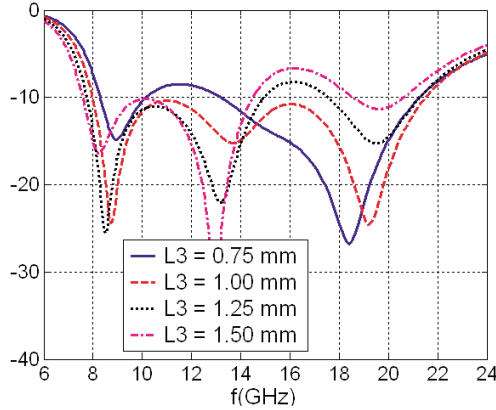**Figure 5.** The effect on $S11$ due to the change of $L2$.

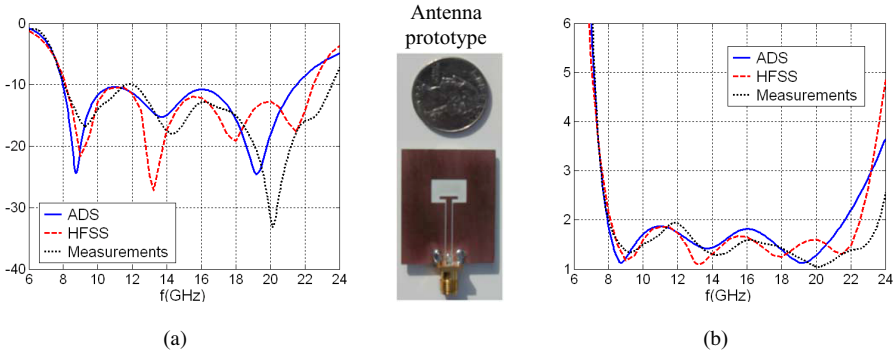**Figure 6.** The effect on $S11$ due to the change of $L3$.

Figure 7. Comparison between the measured and computed (a) return loss, and (b) VSWR, for the rectangular slot antenna of $W1$, $L1$, $W2$, $L2$ and $L3 = 11$, 7, 6, 1, and 1.

3. FINAL ANTENNA DESIGN

A rectangular slot antenna with a patch stub of $(W1, L1, W2, L2$ and $L3) = (11, 7, 6, 1,$ and $1\,\mathrm{mm})$ is simulated using HFSS to verify the results of ADS simulations. In HFSS, a finite ground plane of a size of $20 \times 25\,\mathrm{mm}^2$ is used. The return loss and VSWR are computed using ADS and Ansoft HFSS, and measured using a 8510 vector network analyzer and are shown in Fig. 7 along with a prototype of the final antenna design. Although good agreement can be seen, there are small discrepancies between the computed and measured results, which may occur because of the effect of the SMA connector and fabrication

imperfections. The measured results show that the antenna operates over a wide range that extends from 8 GHz to more than 23.5 GHz, with an impedance bandwidth of more than 98%. Compared to the triangle slot antenna presented in [12], this antenna has a much wider bandwidth (42% more) and a smaller size (1 mm less) that allows for more separation distance between elements in an array environment, which in turn reduces the coupling and improves the scanning range.

ADS Momentum considers an infinite substrate even when the antenna has a finite ground plane, and as a result, it produces zero fields in the x-y plane. Therefore, HFSS is used instead to compute the radiation pattern. The gain in the x-z (H-plane) and the y-z (E-plane) is computed for frequencies from 8 to 19 GHz, which almost covers the entire operating band, and the results are shown in Fig. 8. All patterns are normalized to a maximum and minimum of 6 and -44 dB, respectively, with 10 dB/div. The lower half is removed because of the pattern symmetry around the z-axis. The minimum, maximum, and average gains in the entire operating band are 4, 6, and 5 dB, respectively. A good radiation pattern is obtained between 8 and 15 GHz. Low cross polarization is obtserved between 8 and 12 GHz, and the level starts to exceed -10 dB at 13 GHz, and starts to exceed the co-polarized fields at 16 GHz. Consequently, the usable bandwidth depends on the application for which this antenna will be used. The applications that accept high cross polarization levels can use this antenna up to 16 GHz. In wireless communication applications where the antenna is required to receive the signal from any direction with any polarization, the entire operating band of this antenna can be utilized. For many radar applications and phased arrays, the usable bandwidth is confined between 8 and 12 GHz, which still covers the entire X-band. The radiation patterns are measured at 8, 10 and 12 GHz, and presented in Fig. 9. Good agreement is obtained between the measurements and the simulation results of HFSS.

Unconventional array configurations can further improve the radiation patterns and significantly decrease the cross polarization level at high frequencies, and consequently increase the usable bandwidth for this antenna for such applications. To prove this, a two-element array in y-axis is constructed as shown in Fig. 10, where the second element is flipped 180° around the x-axis. This array is simulated using ADS and HFSS, and a comparison between the computed coupling is shown in Fig. 11. The average coupling between elements over the entire band is around -20 dB. The radiation patterns are computed using HFSS at 8 to 16 GHz, and presented in Fig. 12. The cross polarized fields are cancelled because of the symmetry of this array configuration in the E and H-planes. At the same time, good copolarized fields are
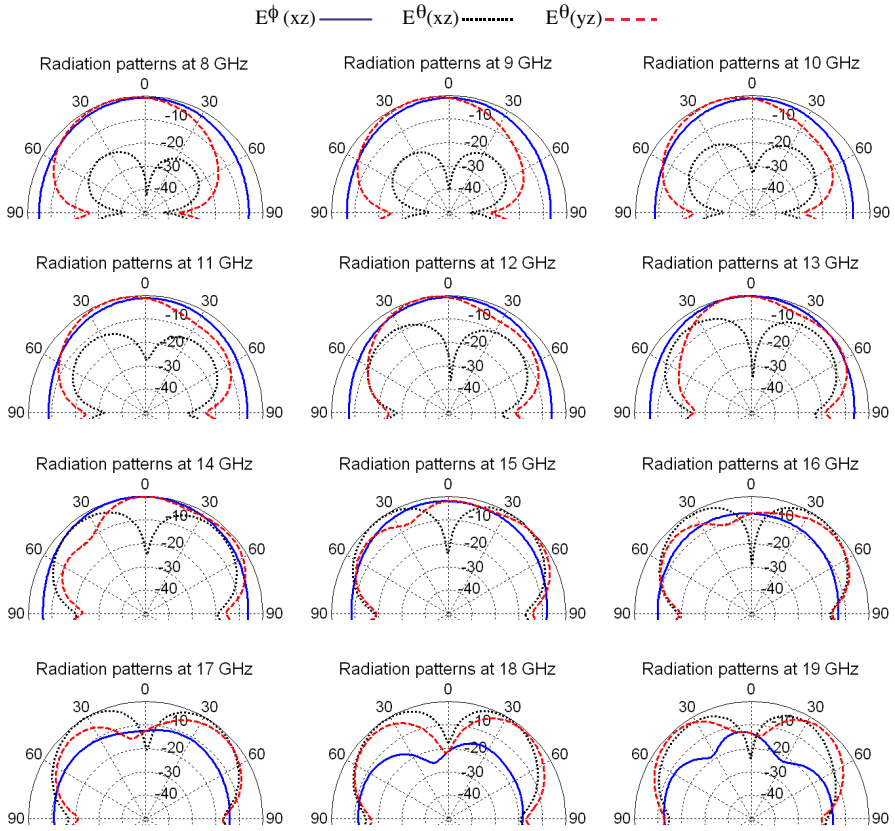
E^ϕ (xz) ——— E^θ(xz) ·········· E^θ(yz) - - - -

Radiation patterns at 8 GHz

Radiation patterns at 9 GHz

Radiation patterns at 10 GHz

Radiation patterns at 11 GHz

Radiation patterns at 12 GHz

Radiation patterns at 13 GHz

Radiation patterns at 14 GHz

Radiation patterns at 15 GHz

Radiation patterns at 16 GHz

Radiation patterns at 17 GHz

Radiation patterns at 18 GHz

Radiation patterns at 19 GHz

Figure 8. Computed radiation patterns for the antenna of $W1$, $L1$, $W2$, $L2$ and $L3 = 11$, 7, 6, 1, and 1.

E^ϕ (xz) ——— E^θ(xz) ·········· E^θ(yz) - - - -

Radiation patterns at 8 GHz

Radiation patterns at 10 GHz

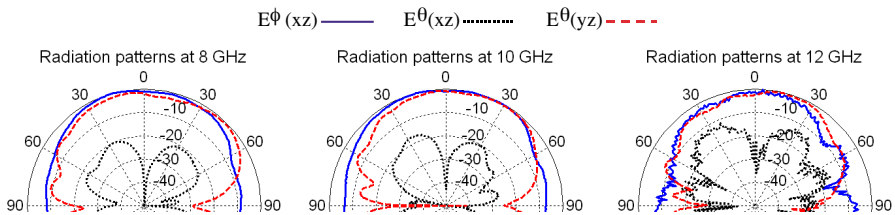Radiation patterns at 12 GHz

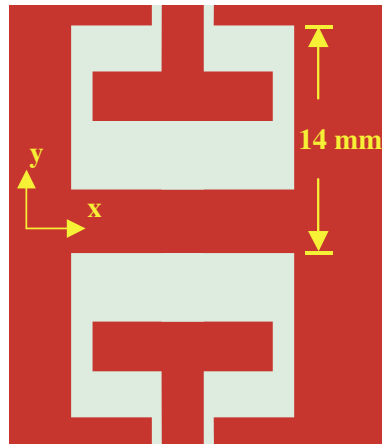**Figure 9.** Measured radiation patterns in the X-band.

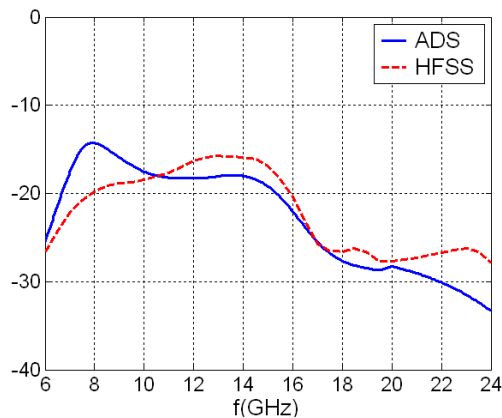**Figure 10.** Two-element array configuration.

Figure 11. Computed coupling for the two-element array in Fig. 9.

obtained in the E and H-planes up to 16 GHz. Therefore, by using this array configuration, the usable bandwidth exceeds 67% for phased arrays and radar applications.

Finally, to show the scanning capability of this antenna in the X-band, the copolarized gain in the x-z plane is computed using HFSS for a linear array consisting of 32 elements in the x-direction at $0°$, $30°$, and $60°$, and is presented in Fig. 13. Dolph-Tschebyscheff coefficients are used to obtain a -30 dB sidelobe level. The maximum gain of the array is 19 dB, and no grating lobe arises up to a $60°$ scanning angle.
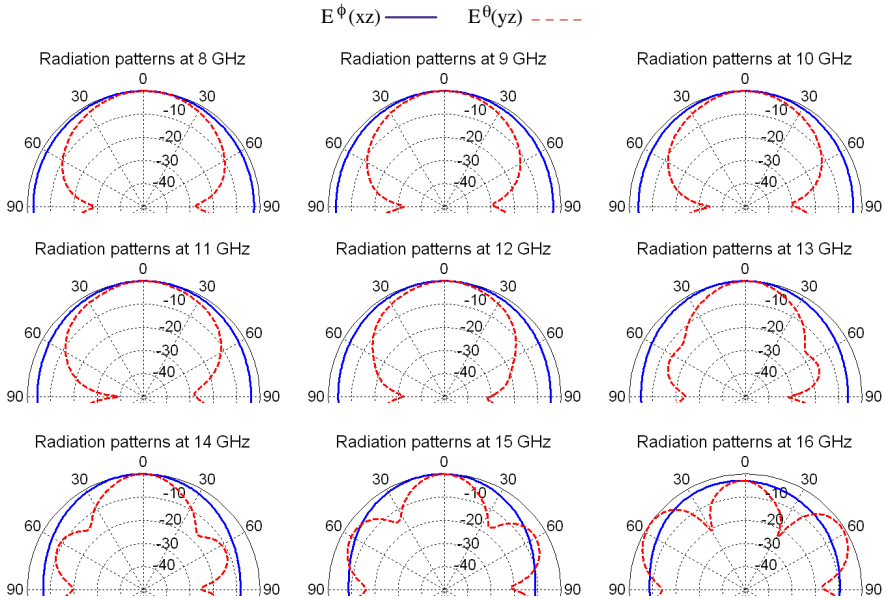
$E^{\phi}(xz)$ —— $E^{\theta}(yz)$ - - - -

Radiation patterns at 8 GHz

Radiation patterns at 9 GHz

Radiation patterns at 10 GHz

Radiation patterns at 11 GHz

Radiation patterns at 12 GHz

Radiation patterns at 13 GHz

Radiation patterns at 14 GHz

Radiation patterns at 15 GHz

Radiation patterns at 16 GHz

Figure 12. Computed gain for the two-element array in Fig. 9.
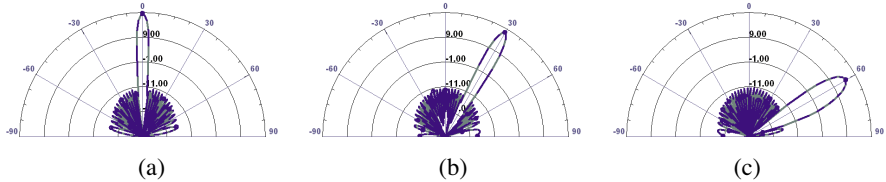
(a)   (b)   (c)

Figure 13. Computed copolarized gain in the x-z plane for 32-element array in x-direction at $10\,\text{GHz}$, with a steering angle of (a) $0°$, (b) $30°$, and $60°$.

4. CONCLUSION

The rectangular slot antenna with a patch stub has a smaller size and wider bandwidth than the triangle slot antenna with a tuning stub presented in [12]. The antenna has 98% impedance bandwidth, 6 dB average gain, and acceptable radiation characteristics that make this class of antennas a good candidate for a variety of communication applications. An array configuration is suggested for phased array applications that provides more than 61% usable bandwidth with $60°$ scanning range using only 32 elements in a linear array.

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