A Novel SWB Small Rhombic Microstrip Antenna with Parasitic Rectangle into Slot of the Feed Line

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Abstract **—** In this letter, a rhombic monopole antenna with a parasitic rectangle into slot of the feed line is proposed to broaden impedance bandwidth. The antenna has a compact size with 19 × 16mm^2 which has been printed on a FR4 substrate with thickness of 1mm. The measurements show that the antenna has reflection coefficient better than -10dB from 2.9 up to 29GHz. Meanwhile, the measured patterns and gain are presented later in the paper.

Index Terms **—** Rhombic microstrip monopole antenna, super wide band (SWB), ultra wide band (UWB).

I. INTRODUCTION

On February 14, 2002, in the United States, the Federal Communications Commission (FCC) dedicated the 3.1-10.6GHz spectrum for commercial application of UWB technology [1]. The ultra-wideband (UWB) antenna is a key component of UWB technology and wireless communication. With the development of high-speed integrated circuits and the requirement of the miniaturization and integration, the research and application of UWB planar antennas have been growing rapidly.

The UWB technology creates constructive solutions for future wireless communication systems due to various advantages such as high immunity to multi path interference, small emission power and high data rate, large bandwidth, low cost for short range access and remote sensing applications. Various wideband antennas have been interesting subjects in antenna designs and have found important applications in military and civilian systems which can be mentioned to UWB and SWB.

There are two major differences between them; SWB antenna is a key component of electronic counterwork equipment in the information warfare; while the ultra-wideband (UWB) antenna is widely used in impulse radar and communication systems. Another difference is their actual frequency range; frequency range of an indoor UWB communication antenna is from 3.1 to 10.6GHz with a ratio bandwidth of 3.4:1, while ratio bandwidth of the SWB antenna is more than 10:1 [2].

Nowadays, various planar antennas with capability of SWB have been presented. SWB antennas must meet different requirements like broad impedance bandwidth, constant gain on desirable band, and small electrical size. With development of UWB and SWB technologies, the antennas have found different shapes such as rectangular, elliptical, triangular, polygonal, and fractal [3-14].

In this letter, a small rhombic monopole antenna with a novel microstrip feed-line for the

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SWB application is proposed. The presented antenna with nearly low size and broad bandwidth was successfully fabricated. The measured results show acceptable agreement with the simulated results. The rest of the paper describes the antenna design in Section II. The discussion on results is presented in Section III, followed by conclusive comments in Section IV.

II. ANTENNA DESIGN

The geometrical configuration of the proposed antenna is depicted in Figure 1.

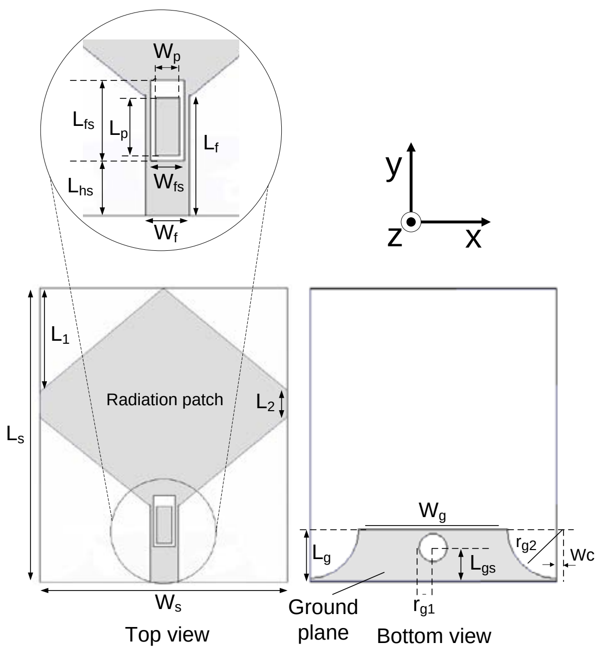

Fig. 1. Geometry of the antenna.

The parameters values are summarized in Table 1.

Table 1: Parametric values of the fabricated antenna (unit: mm)

W_s	L_s	L_1	L_2	W_c	L_f
16	19	6.67	1.64	0.3	5
W_{fs}	L_{fs}	L_{hs}	W_g	r_{g2}	L_g
1.4	3.3	2.3	10	3.2	3.4
W_f	W_p	L_p	r_{g1}	L_{gs}	ε_r
1.8	1	2.1	0.9	2.2	4.4

The antenna consists of a rhombic patch and a partial ground which there is a rectangular slot on the feed line and a circular slot on the ground, right behind the feed line. Meanwhile, there is a parasitic component in the rectangular slot that has effect on the bandwidth. The antenna has been printed on both sides of an FR4 microwave substrate with a thickness of 1 mm and dielectric constant of 4.4. The total size ($L_s \times W_s$) of the proposed antenna is $19 \times 16 mm^2$ which is almost compact. Note that the radiation patch is connected to the feed line with characteristic impedance 50 ohm which has a length and width of 5mm and 1.8 mm respectively. The proposed antenna is located in the x-y plane and the normal direction is parallel to the z-axis. It should be mentioned that the patch was rectangle basically, and then some modifications were performed on the rectangular patch, feed line, and ground plane. In order to increase the impedance bandwidth of the antenna, the following measures have been applied.

(a) Transforming the rectangular patch into a rhombic patch by etching four corners of the rectangle.
(b) Etching the upper corners of the ground in the form of a circular arc with radios of r_{g2}.
(c) Etching a circular slot with radios of r_{g1} from the ground plane.
(d) Etching a rectangular slot with width of W_{fs} and length of L_{fs} from the feed line.
(e) Adding a rectangular parasitic element with width of W_p and length of L_p into the rectangular slot in the feed line.

By selecting the optimal parameters mentioned in Table 1, the proposed antenna can be tuned to operate within the UWB and SWB bands. Figure 2 exhibits a photograph of the fabricated antenna.

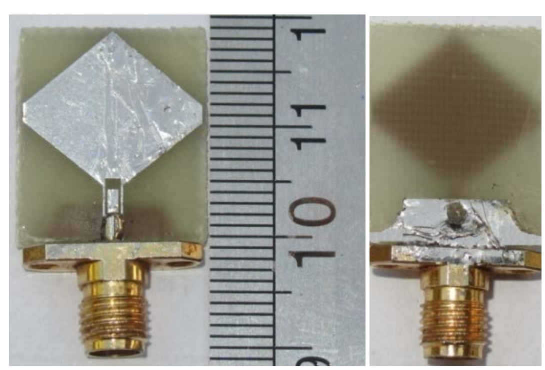

Fig. 2. Photograph of the fabricated antenna.

III. RESULTS AND DISCUSSION

In this section, simulated and measured results of the proposed rhombic monopole antenna are presented. Note that the simulated reflection coefficient results are obtained by using Ansoft HFSS11 [15]. As mentioned before, the proposed antenna used a novel technique to increase bandwidth. This technique uses a rectangular slot into the feed line which is caused to enhance the bandwidth of the middle and upper band. Figure 3 exhibits effect of the width of rectangular slot into the feed line on the reflection coefficient characteristics. If the reflection coefficient characteristics of the antennas #1 and #4 are compared with each other, it is exactly apparent that the band width of the proposed antenna from 7 up to 30GHz has been improved by this technique.

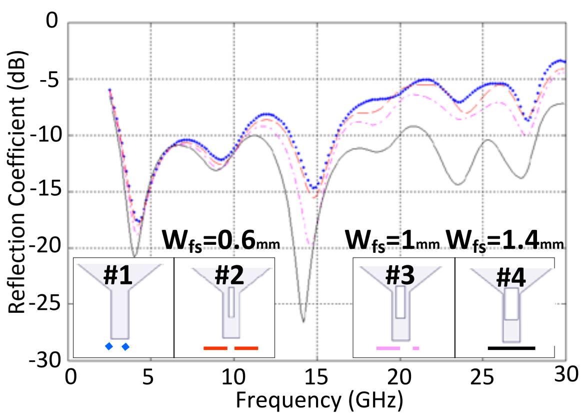

Fig. 3. Effect of the width of rectangular slot into the feed line on the reflection coefficient characteristics.

Another technique to increase the bandwidth for the upper band above 20GHz is by using a rectangle parasitic element in the rectangular slot of the feed line. As shown in Figure 4 with changing of the length of L_p the bandwidth of the proposed antenna from 22 up to 28GHz has been improved more than 5dB. The current distribution on the ground and patch of the proposed antenna at 6; the resonant frequencies is exhibited respectively in Figures 5 and 6. From Figure 5, we can conclude that three parts of the ground have an important role to create the resonances, which consist of the top edge of ground (W_g), circular arcs (r_{g2}), and around the circular slot. With regard to Figure 5 at all resonant frequencies except 9 GHz, width of the top edge of the ground (W_g) has a major effect. The most influence of the circular arc is at three frequencies of 9, 23.75, and 27.25GHz. Of course, this leads to confirm that the performance of the antenna is a bit dependent to the circular arc ratios of the ground plane, but it has a high depends to its width in the other words, the portion of the ground plane close to the patch acts as the part of the radiating structure [16, 17].

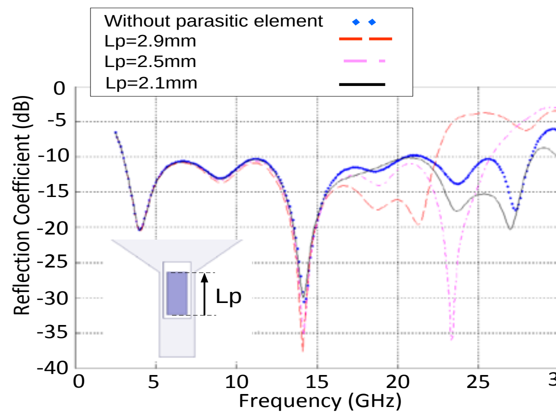

Fig. 4. Effect of the length of the parasitic rectangle (L_p) into rectangular slot on the reflection coefficient characteristics.

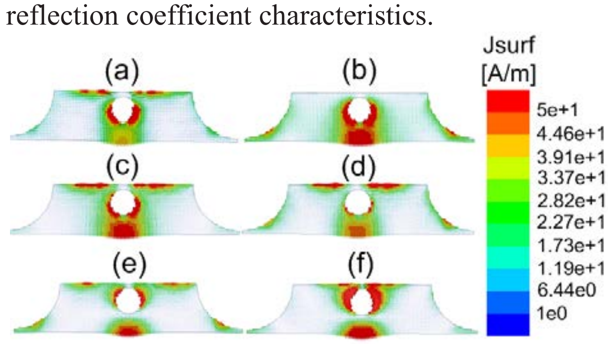

Fig. 5. Simulated current distribution on the ground at frequencies (a) 4GHz, (b) 9GHz, (c) 14.25GHz, (d) 18.5GHz, (e) 23.75GHz, (f) 27.25GHz.

However, it also leads to a disadvantage, i.e., when this type of antenna is integrated with printed circuit board, the RF circuit cannot be very close to the ground plane. Another point is that the existence of circular slot on the ground almost for all resonant frequencies is effective especially at frequencies of 9, 14.25, and 27.25GHz. The simulated current distributions on the patch at six resonant frequencies for the optimal design are presented in Figure 6. The current is mainly distributed along the edge of the rhombic patch, which indicates that the first resonant frequency is associated with the dimension of the rhombic patch. Its first resonance is about 4GHz, and the $2\times W_s/\lambda=0.22$ where λ is the wavelength corresponding to the first resonant frequency, lower than the determined that $2\times W_s/\lambda$ equivalent about 0.25 [18]. Other order harmonics of the antenna in Figure 6 is completely clear.

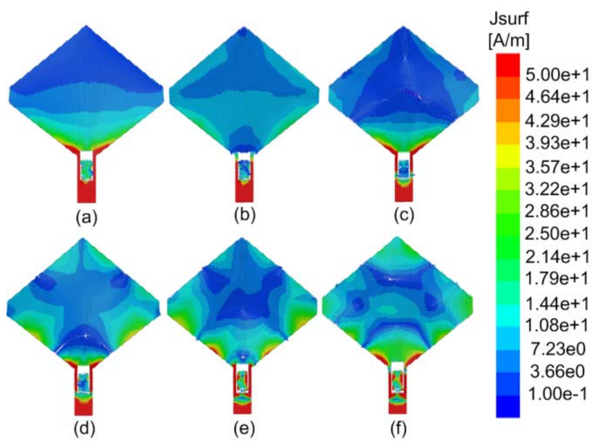

Fig. 6. Simulated current distribution on the patch at frequencies (a) 4GHz, (b) 9GHz, (c) 14.25GHz, (d) 18.5GHz, (d) 23.75GHz, (d) 27.25GHz.

The measured gain of the antenna is shown in Figure 7. The minimum gain is appeared at the initial frequencies due to the compact size of the antenna, but the maximum gain is between frequencies of 9 up to 10GHz with values of nearly 4.5dBi.

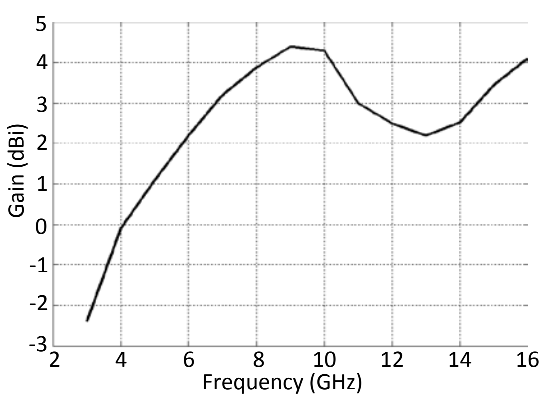

Fig.7. Measured gain of the proposed antenna.

The reflection coefficient of the antenna has been measured by using an Agilent E8363B network analyzer in its full operational span (50MHz - 40GHz). The results of measured and simulated reflection coefficient of the presented antenna are exhibited in Figure 8. The simulated results have been accomplished by the two software, HFSS and CST [19]. Regarding to Figure 8, the resonant frequencies have a good agreement with each other except initial band which its reason is being ideal of materials in CST simulator. The measured results also are almost similar to the expected results, so the results of the reflection coefficient are acceptable.

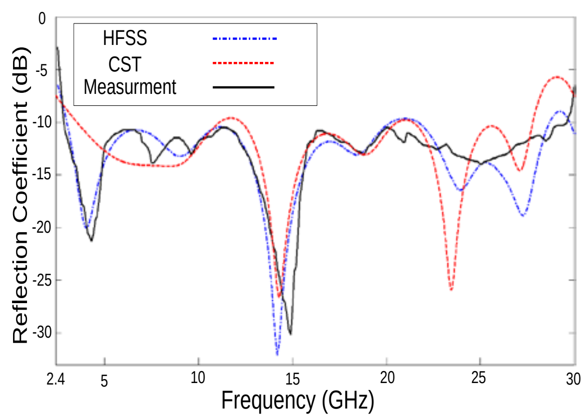

Fig.8. Simulated and measured reflection coefficient of the proposed antenna.

The key in the UWB antenna design is to obtain a good linearity of the phase of the radiated field because the antenna should be able to transmit the electrical pulse with minimal distortion. Usually, the group delay is used to evaluate the phase response of the transfer function because it is defined as the rate of change of the total phase shift with respect to angular frequency. Ideally, when the phase response is strictly linear, the group delay is constant.

$$group\ delay = -\frac{d\theta(w)}{dw}\ . \quad (1)$$

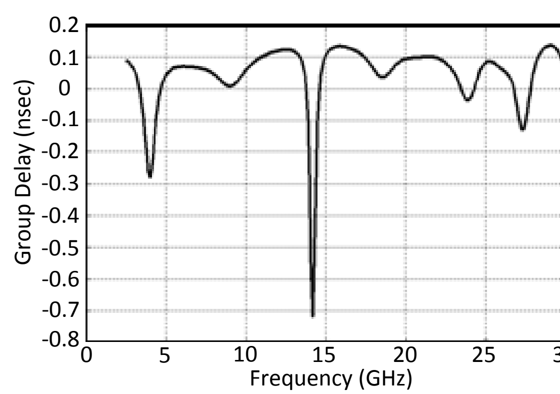

Fig. 9. Simulated group delay versus frequency for the proposed antenna.

As depicted from the Figure 9, the group delay variation of the proposed antennas at the resonant frequencies with respect to other frequencies is more. In spite of it, the group delay variation is less than 0.7ns over the frequency band from 2.5 up to 30GHz which ensure us pulse transmitted or received by the antenna will not distort seriously and will retain its shape. Therefore, the proposed antenna is suitable for modern UWB communication systems. The measured normalized radiation patterns at three frequencies of 3, 7, and 11GHz, respectively, in Figures 10 and 11 are exactly apparent. As was previously predicted, the pattern of the antenna in the H-plane is non-directional and it is nearly bi-directional in E-plane which is desirable.

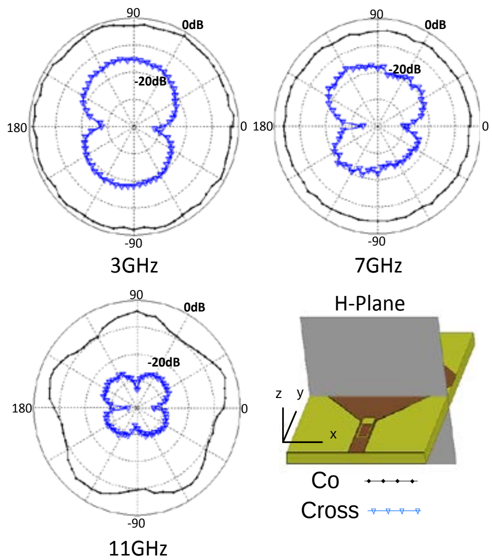

Fig.10. Measured normalized radiation patterns of the proposed antenna in H-plane.

IV. CONCLUSION

A new compact monopole microstrip antenna is proposed for the SWB and UWB applications. The proposed antenna consists of rhombic patch, partial ground, and microstrip feed-line which by using some techniques on the feed-line and ground, impedance bandwidth of the proposed antenna has been increased, in the other words; the bandwidth is from 2.9 up to 29GHz which confirms UWB and SWB characteristic of the antenna. The measurement indicates that the antenna radiation patterns are non directional in H-plane and almost bidirectional in E-plane. In addition, the antenna has nearly compact size of 19×16mm^2.

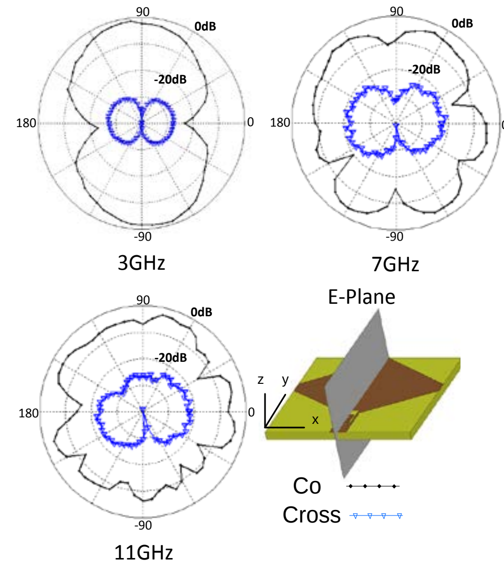

Fig.11. Measured normalized radiation pattern of the proposed antenna in E-plane.

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