An Improved Impedance Bandwidth of Modified UWB Antenna With Staircased Parasitic Rings

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***Abstract*—In this letter, a structural modification technique of simple monopole to improve the input impedance bandwidth by using multiple staircased parasitic rings is suggested. In addition, the shape and size of parasitic rings are optimized to enhance the antenna bandwidth. The final optimized parameter values have been obtained from the parametric studies of the antenna and simple equation evaluating the resonant frequency. The electrical performances of the proposed antenna are verified in terms of the return loss and the radiation pattern by using commercially available softwares, CST MW Studio, and HFSS based on FDTD and FEM algorithms, respectively.**

***Index Terms*—Monopole, parasitic rings, ultrawideband (UWB) antenna.**

I. Introduction

UNTIL recently, much effort to overcome the technical difficulties in the ultrawideband (UWB) system has been expended by researchers and industry that delivered the regulation of spectrum mask and mitigated the interferences with other communication systems. The UWB communication systems still require the compact, novel, and light-weighted antenna covering the frequency range from 3.1 to 10.6 GHz. Especially, we are focused on the bandwidth extension from 5.54 to 16.4 or more frequency bands with the reduced volume.

Conventional monopole antenna is very popular thanks to good electrical properties such as high gain and easy realization even though it has a disadvantage of narrow bandwidth. In order to overcome the limited application area, it is necessary to enhance the impedance bandwidth. Recently, a lot of methods have been studied to extend the antenna bandwidth such as addition of the substrate [1] or several types of sleeve structure [2], [3]. However, these methods have some disadvantages like radiation loss caused by dielectric material and structural complexity increased by sleeve structure. This letter suggests a simple technique of modified sleeve monopole antenna to increase the bandwidth of the antenna without the previously described disadvantages. In general, the broadband characteristics can be achieved with sleeve monopole antenna placing the extended ground structures around simple monopole antenna [4]. By inserting an air-gap between the lowest metallic cylinder and ground plane and using staircase parasitic rings, it is shown that a different and modified sleeve monopole antenna can be obtained with an improved bandwidth.

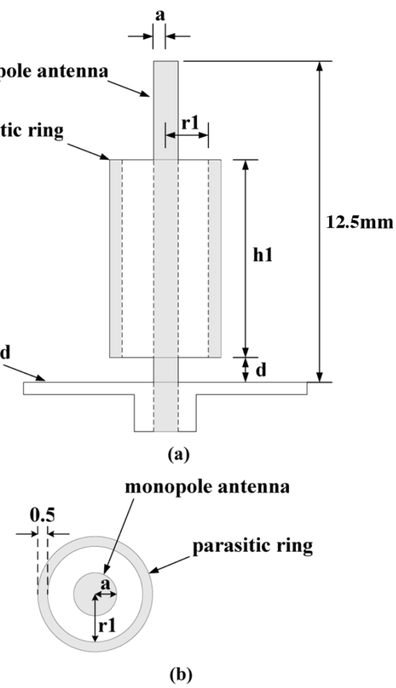

Fig. 1. The geometry of monopole antenna with the parasitic ring. (a) Side view. (b) Top view.

In Section II, the electrical performances of monopole antenna with single parasitic ring widening the input impedance bandwidth are described in terms of return loss. In addition, parametric studies, optimization, and verification using two simulators are carried out in Section II. In Section III, the modified monopole antennas with continually connected parasitic elements are optimized and analyzed. Conclusion in Section IV describes a brief summary of this letter.

II. Simple Parasitic Ring Around Monopole Antenna

In an earlier study [4], it is already observed that parasitic ring help it increase the input impedance bandwidth through simulated and numerical analysis. Thus, this letter makes an effort to find the optimized case for UWB antenna from the results of [4]–[7].

A. Antenna Configuration

Fig. 1 shows the structure of the proposed antenna in more detail. The simple monopole antenna whose height is 12.5 mm and radius is 0.65 mm is mounted on the ground plane with 80 mm $\times$ 80 mm using a coax-feeding. The parasitic rings are distributed around a quarter-wavelength monopole antenna. The parasitic ring which has the shape of a hollow circular cylinder

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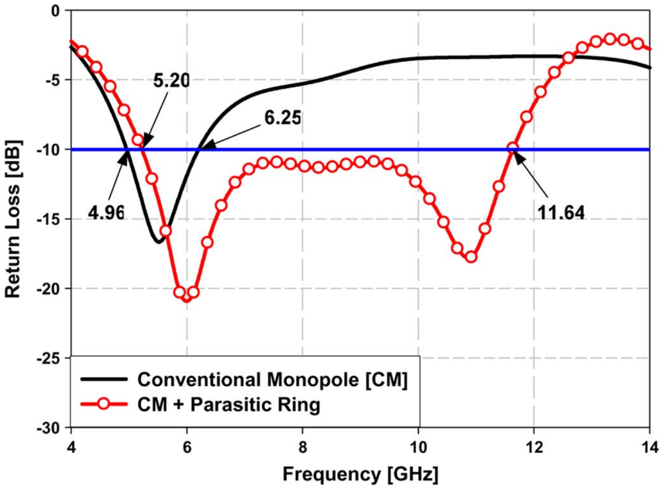

Fig. 2. Return losses showing the effect of the parasitic ring $(\mathrm{h1} = 8.5, \mathrm{r1} = 1.5, \mathrm{d} = 0.5, \mathrm{a} = 0.65)$: unit[mm].

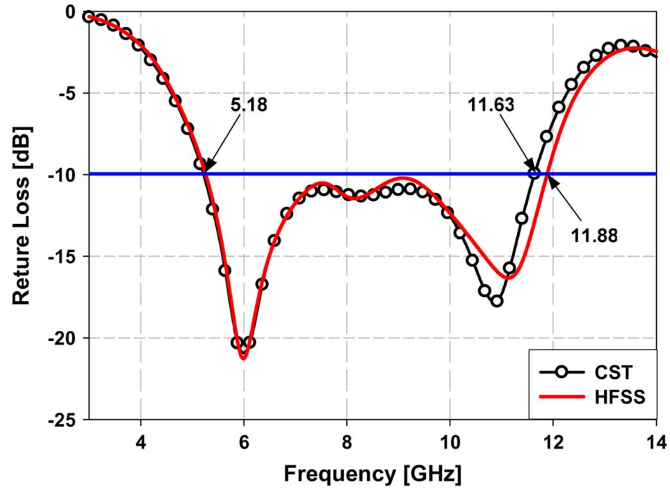

Fig. 5. The comparison between return losses when $\mathrm{h1} = 8.5$ mm and $\mathrm{r1} = 1.5$ mm.

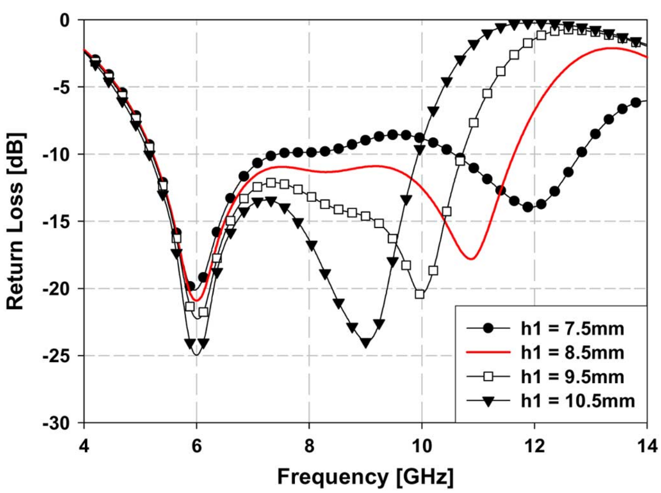

Fig. 3. Return losses with the variation of the height of the parasitic element while the other parameters remain unchanged. $(\mathrm{r1} = 1.5, \mathrm{d} = 0.5, \mathrm{a} = 0.65)$: unit[mm].

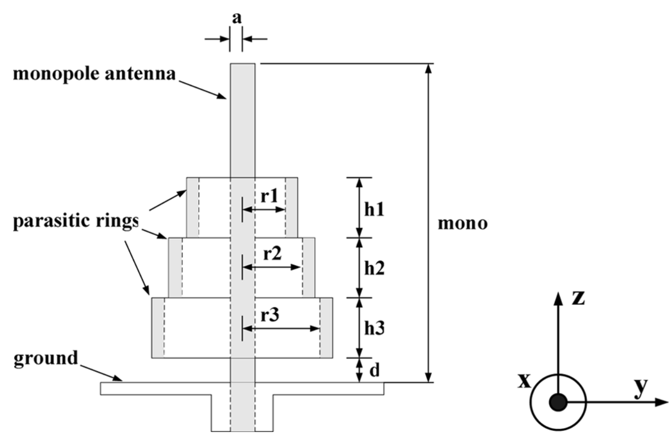

Fig. 6. Antenna geometry when $\mathrm{mono} = 12.5$ mm, $\mathrm{h1} = \mathrm{h2} = \mathrm{h3} = 2.5$ mm, $\mathrm{r1} = 1.5$ mm, $\mathrm{r2} = 2.1$ mm, $\mathrm{r3} = 3$ mm, and ground $= 80$ mm $\times$ 80 mm.

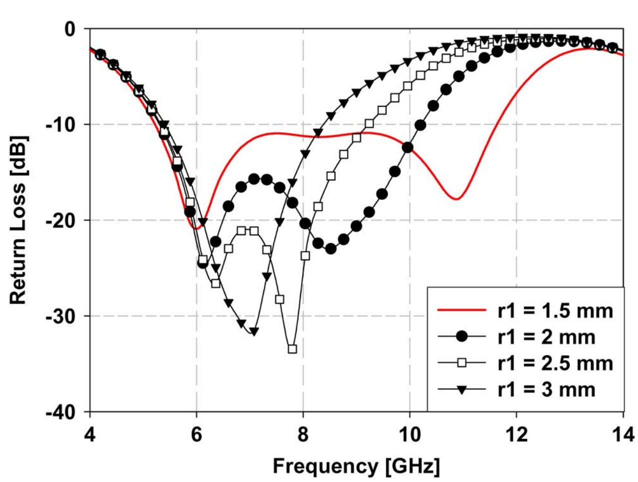

Fig. 4. Return losses with the change of the radius of the parasitic element while the other parameters remain unchanged. $(\mathrm{h1} = 8.5, \mathrm{d} = 0.5, \mathrm{a} = 0.65)$: unit[mm].

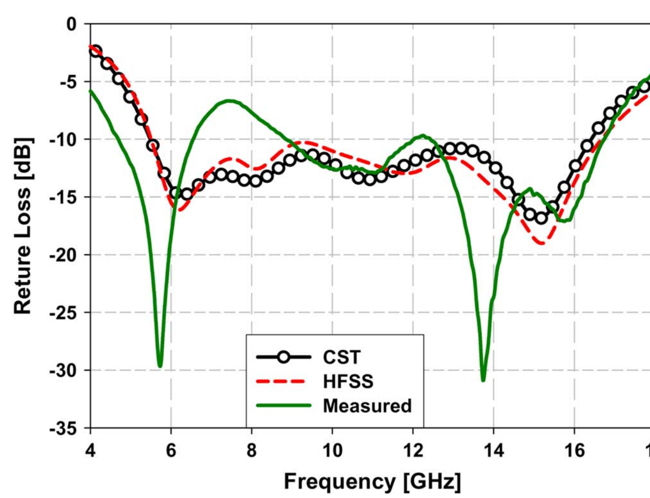

Fig. 7. Return losses of the proposed antenna with continually connected parasitic rings.

consists of height (h1) 8.5 mm, radius (r1) 1.5 mm and thickness of conductor 0.5 mm, respectively. In Fig. 1, parameter d representing the gap between ground plane and the lowest parasitic ring is assumed to be 0.5 mm for gap-voltage driven. Although the parasitic element is additionally applied to the proposed antenna, the antenna size has a small variation and still maintains nearly unchanged. Since dielectric materials are not employed,

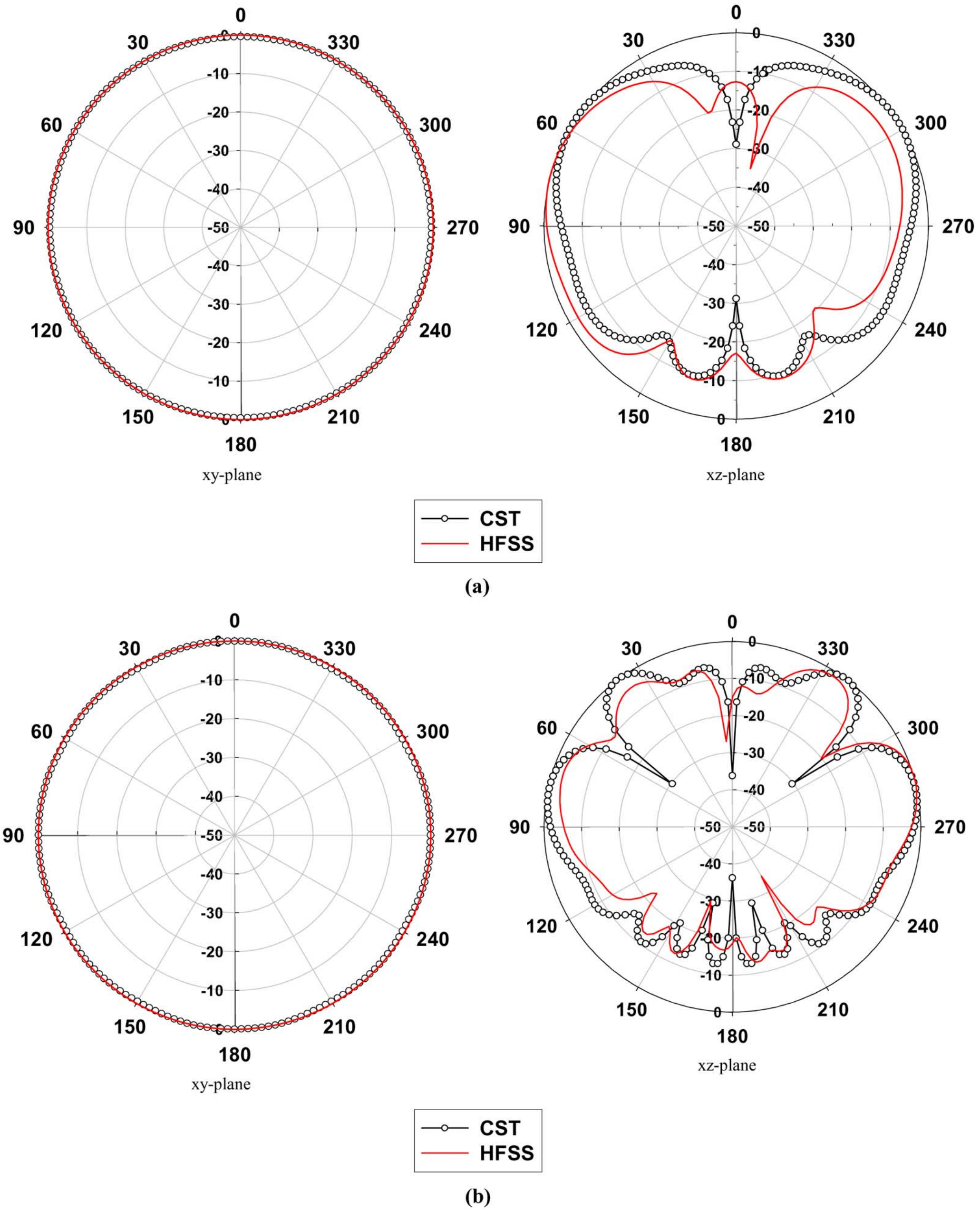

Fig. 8. Radiation patterns at resonant frequencies, (a) 6.27 and (b) 15.12 GHz.

no additional radiation loss is generated rather than conventional dielectric resonator antenna (DRA).

Fig. 2 shows the effect of the parasitic ring on the return loss of the proposed antenna. Without parasitic ring, the conventional monopole antenna resonates in the vicinity of 6 GHz due to a quarter-wavelength property. In this case, the result shows 1.24-GHz bandwidth under the 10-dB return loss requirement. On the other hand, bandwidth becomes wider by locating single parasitic ring, which makes the additional resonant point in the upper frequency, around simple monopole antenna. As shown in the Fig. 2, the impedance bandwidth increases about five times than that of nonparasitic ring case.

Once the parasitic ring is loaded around the antenna, the proper interval between monopole antenna and parasitic element creates the optimum mutual coupling. As a result, the enhancement of input impedance bandwidth can be achieved.

B. Parametric Studies, Optimization, and Verification

Since additional resonant point at the upper frequency is caused by placing an additive parasitic element around the simple monopole antenna, the resonant frequency can be finely tuned according to the variation of the shape of the proposed antenna and the parasitic rings. Parameter studies concerned with the height and radius of parasitic ring are shown in Figs. 3 and 4.

In Fig. 3, the upper resonant frequency has dependence on the height of parasitic ring while the lower frequency still keeps the resonant point. In other words, the additional or upper resonant frequency becomes lower as the height of parasitic element gets higher.

In addition to that, it is shown in Fig. 4 that the radius of the ring also affects the resonant frequency. When the radius of a ring becomes wider, the second resonant point moves to the lower band. It is owing to the reduction of the mutual coupling generated inside the parasitic ring.

Fig. 5 shows the estimated data obtained from two commercially available softwares, CST MWS and HFSS when the parasitic ring is located around monopole antenna with a small delta-gap source driven. Altogether, both return losses are nearly the same within the interested frequencies. Hence, the designed antenna in Fig. 1 is expected to have a good electrical performance.

III. Continually Connected Multiple Parasitic Rings

A. Antenna Configuration

From the fact that bandwidth improvement can be accomplished by generating the mutual coupling between monopole antenna and parasitic element, it is seen that the proposed antenna can control the resonant frequency. Accordingly, multiple parasitic rings promote much more mutual couplings which maximize the impedance bandwidth. Fig. 6 shows the geometry of the modified monopole antenna with staircased parasitic elements. The antenna is composed of three parasitic rings with different radius r1, r2, and r3, respectively. The radius (r1) of the first parasitic ring in the top layer is 1.5 mm. Continually, r2 is set to be 2.1 mm. The last parasitic element has radius 3 mm as an optimized result. Unlike the antenna in Fig. 1 which has just one parasitic ring, the optimized and modified antenna structure consists of continually connected several elements. Consequently, the impedance bandwidth can be improved so that more rings cause more mutual coupling.

B. Electrical Properties of the Proposed Antenna

The results are cross checked through two simulation softwares in a similar way to Section II. At major frequencies, the resonances occur with the proper levels, and both values using two simulators have no difference in the interested frequencies as shown in Fig. 7 with measured data.

As another important property in antenna, radiation patterns are shown in Fig. 8 on the resonant frequencies. When a coordinate shown in Fig. 6 is employed, the left polar plots of each frequency in Fig. 8 represent radiation patterns in *xy* plane. Both frequencies have omnidirectional properties in *xy* plane, while in *xz* plane, it is observed that the patterns are nearly the same as those of monopole antenna which are symmetrical.

IV. Conclusion

By applying the continually connected parasitic elements, the modified monopole antenna with staircase parasitic rings is presented. From the procedures and the results listed in this letter, it is guaranteed that the proposed antenna can offer excellent electrical properties in terms of bandwidth and radiation patterns. In the case of the proposed structural modification, the impedance bandwidth can be extended up to 8.8 times as compared with that of the conventional monopole antenna. It is thought that the mutual coupling between conventional simple monopole antenna and parasitic rings may cause the interference and generate multiple equivalent reactance components.

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