Application of Inductive Loadings for the Dual and Broad Banding of CPW-Fed Ring Antennas

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Abstract ─ The broad banding of a printed ring antenna is achieved through inductive loadings by open-circuited radial line sections distributed around its periphery. The bandwidth of the stub loaded ring antenna is significantly enhanced without minor degradation of its radiation patterns, which may be realized by the appropriate design of widths, lengths, and angular spacings of open circuited radial lines. Dual-band performance can also be obtained by the application of the proposed method. The proposed antenna configuration is verified by computer simulation together with fabrication and measurement.

Index Terms ─ CPW-fed ring antenna, dual-band antenna, ring antenna, stub loadings, wideband antenna.

I. INTRODUCTION

Printed antennas having low profiles and high compatibility of integration with other circuit elements usually find applications in wireless communication systems. However, they suffer from the disadvantages of low gain and narrow bandwidths, which limit their applications [1]. In this paper, a technique is presented to transform a single-band antenna into dual-band and wideband antennas. In this technique, the radiating edges of antennas are loaded by some stubs, which produce parallel inductances. Open- and short-circuited stubs may be used for the generation of inductive loadings. However, such a device requires a ground plane under the patch. The ground plane here does not extend under the proposed ring antenna. Consequently, we use such inductive in our antenna loadings. Now, we may make the radiating structure wideband by making it first to operate in a dual-band condition and then by controlling its second resonance frequency through taking it closer to the first one. The proposed structure for producing dual- and wide band operations has the advantages of being planar and compact as compared with other configurations, such as slot loaded [2-6] and stacked patch antennas [7].

In Section 2, the analysis and design of a simple resonant ring antenna is described. In Section 3, the ring antenna is loaded by radial stubs, which is designed for dual-band operation. It is shown that it operates at integral multiples of its fundamental frequency. A parametric study and variation of its geometrical dimensions, may lead to its dual-band operation and eventual wideband performance. The return loss bandwidth of 80% has been achieved in the S band (2~4GHz) and higher frequencies. Two prototype models of the proposed antennas have been fabricated and measured, which verify their effectiveness.

II. ANALYSIS OF THE PRINTED RING ANTENNA

The proposed antenna design technique is illustrated by a CPW-fed ring antenna, which may be excited by a resonant or non-resonant mode. We adopt the resonant mode. The circumference

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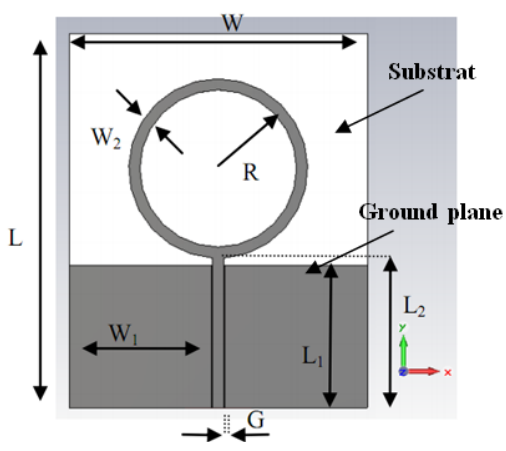
of the ring should be equal to the effective wavelength at the resonance frequency [8-10]. In this case, the current distributions on the antenna consist of two equiphase components, which generate its broadside radiation. The antenna feed may be in the form of microstrip line, coplanar waveguide (CPW) or a coaxial probe-feed. The CPW feed is selected, which may provide capability for assembly of components and integration with other components. As shown in Fig. 1, the characteristic impedance is 50 ohms, the width of the ring strip and feed line are taken equal. The substrate FR4 is selected, with ε_r=4.9, thickness h=7.87mm and loss tangent of 0.025.

The antenna behavior is analyzed by the CST simulation software. Its response as the reflection coefficient versus frequency is drawn in Fig. 2 and its radiation patterns are drawn in Fig. 3. Since there is no ground plane, the patterns of the antenna are identical on its both sides. The bandwidth is defined as the frequency interval where the reflection coefficient is less than -10dB. The return loss bandwidth at the center frequency of 2.55GHz is about 35%, where its simulated gain is about 1.1 dBi at 3GHz. Observe that the antenna has almost omnidirectional radiation pattern in the X-Z plane, as shown in Fig. 3. The optimum length of the CPW line (L_1) should be selected for the best input impedance matching.



W	W_1	W_2	L	L_1	L_2	G	R
32	15.4	0.63	40	14.2	15	0.18	10

Fig. 1. CPW ring antenna1 (dimensions are in millimeters).

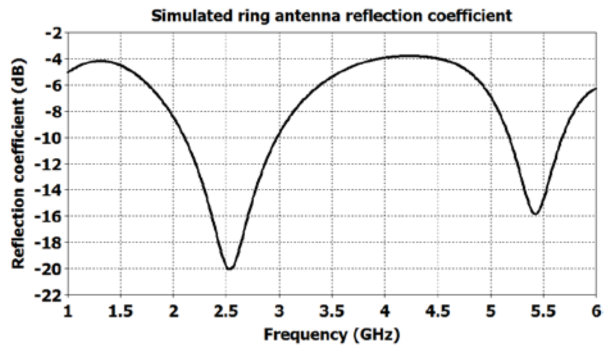


Fig. 2. CPW ring antenna1 reflection coefficient.

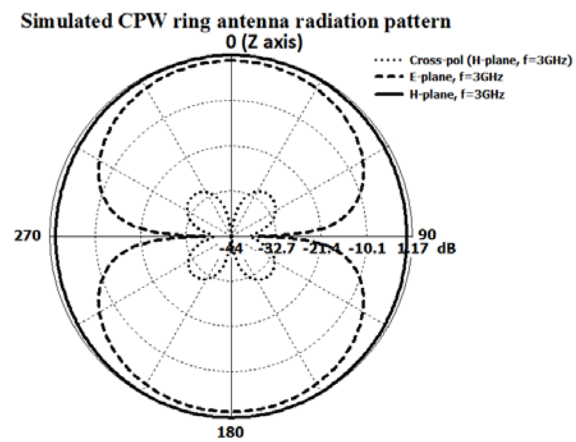
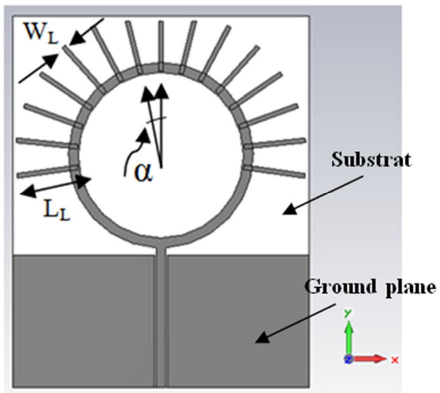


Fig. 3. CPW ring antenna1 radiation pattern at 3GHz. (dashed) E-plane (y-z plane); (solid) H-plane (x-z plane); (dotted) cross-polar (H-plane).

III. ANALYSIS OF THE INDUCTIVELY LOADED RING ANTENNA

The radial stubs are placed on the periphery of the ring, which produce an inductive loading. The number of stubs, their lengths, widths and angular spacings may be considered as parameters, which provide as many degrees of freedom for the antenna design. The implementation of the proposed technique on the ring antenna is shown in Fig. 4. The dimensions of the main structure are the same as in Fig. 1.

The reflection coefficient of the ring with inductive loading is drawn in Fig. 5, which shows that the radial stubs make the antenna resonate at two frequency bands. The return loss bandwidth at the center frequency 2.55GHz is about 60% and that at 4.75GHz is about 12%. Also, its performance in the first band has improved. Figures 2 and 5 show that the two ring antennas (with and without radial stubs) are both dual-band. However, observe that the second band of antenna1 (shown in Fig. 2) is due to its resonance nature, whereas the second band in antenna2 are somewhat displaced from its natural resonance frequency.



W	W_1	W_2	L	L_1	L_2
32	15.4	0.63	40	14.2	15
G	R	W_L	L_L	α	N
0.18	10	0.5	6	14°	15

Fig. 4. Loaded CPW ring antenna2 (dimensions are in millimeters).

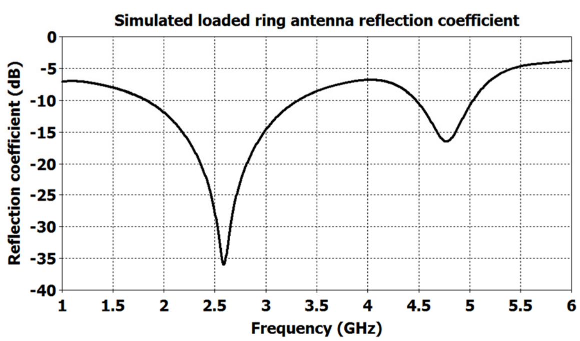
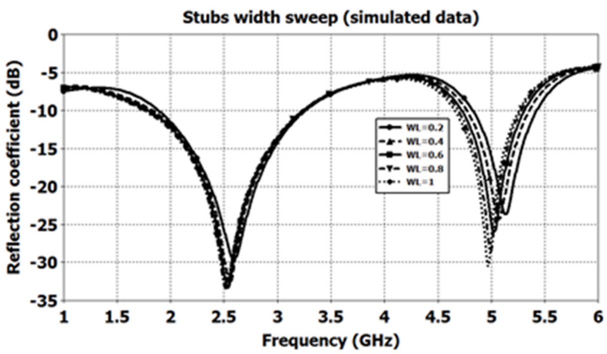


Fig. 5. Loaded CPW ring antenna2 reflection coefficient.

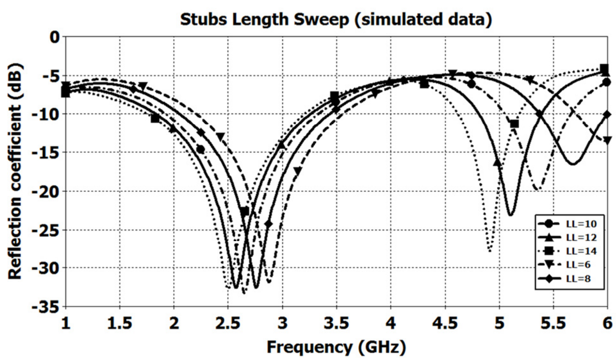
A parametric study and simulation of the antenna design parameters (namely the lengths, widths, angular spacings, and number of stubs) are performed and its results are indicated in Fig. 6. The stub widths are selected as narrow as possible (to provide higher inductive effects), which are restricted by our available photolithography technology and achievement of reasonable strength. The computer simulation results show that as the stub widths increase, the second band gradually approaches the first band, as shown in Fig. 6 (a). Therefore, the variation of this parameter may lead to the broad banding of the antenna. The second resonance frequency may be highly changed by varying the lengths of the stubs, but the first resonance frequency remains relatively constant by their variations. This phenomenon is shown in Fig. 6 (b). The number of stubs and their angular spacings affect the improvement of the antenna return loss and its wideband performance. Therefore, it may be inferred that by the proposed method, the second resonance frequency may be controlled to design a dual-band or a wideband antenna.

The current distribution may reveal the effect of antenna design parameters on its performance. The current distributions on the simple and loaded ring antenna are shown in Fig. 7 at two frequency bands. Observe that the stubs have practically no effect on the first band, but generate a new current distribution in the second band. Four different current distributions appear on the four quadrants of the ring, in such a way that the current distribution on the upper half semicircle is in phase with that on the lower one. They effectively give rise to broadside radiation. The opposite stubs with anti-phase current distributions cancel the effect of each other. Minor current distributions appear on the stubs at the lower frequency band, because their lengths are relatively short and their inductive effect is negligible. In the second upper frequency band, as shown in Fig. 7 (c, d), the current distributions are quite intensive on the stubs. They enforce each other, because they are codirectional. This is a useful property, because shorter stubs may be used for antenna miniaturization. Furthermore, such current distributions on stubs produce relatively strong magnetic fields and energy around the stubs, leading to high inductive loadings of antenna. However, the stubs have negligible capacitive effect, due to the absence of a ground plane under them and their thin thicknesses and relatively wide spacings.

Symmetrical placement of stubs on the ring antenna edges leads to effective cancellation of cross-polarized radiation fields, as shown in Fig. 7 (d). The x-directed current component on combline stubs on the two sides of ring antenna are in opposite directions, and consequently cancel the effects of each other, which is the cause of cross-polarized radiation. For the verification of this effect, refer to the co-polar and cross-polar radiation patterns of the stub loaded ring antenna. Consequently, we may conclude from the above results that the proposed stub loading of the ring antenna is quite effective in making a dual-band antenna from a single-band one and also the second resonance frequency may be readily adjusted. Such an antenna may be used for WLAN systems.



(a)



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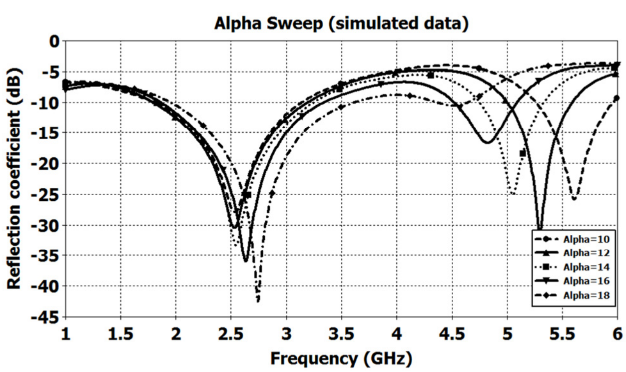
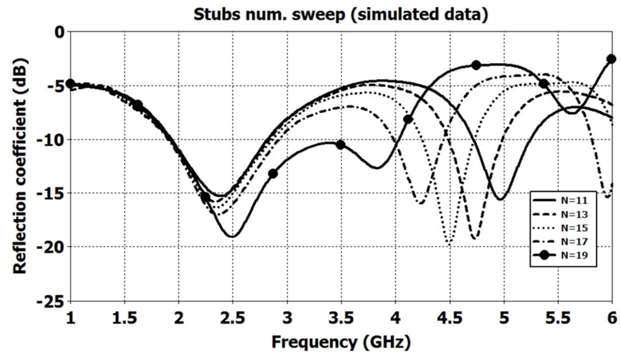
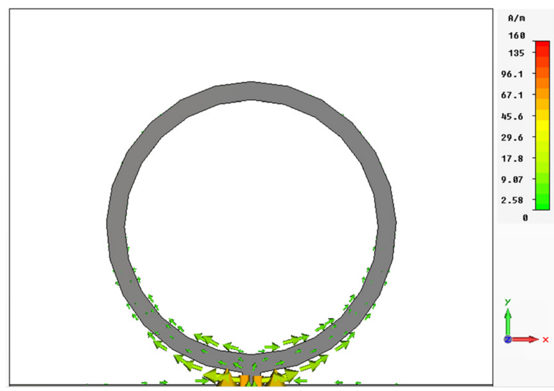


(c)

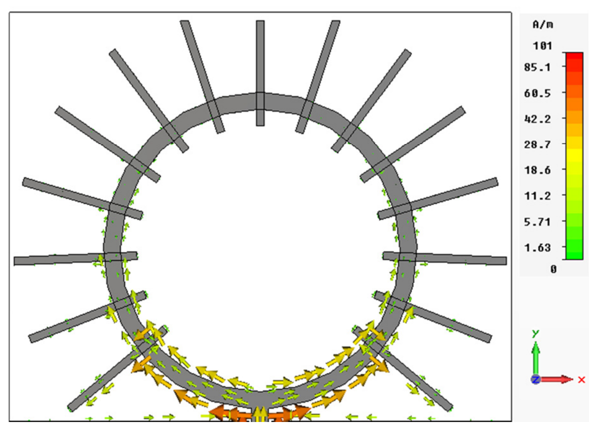


(d)

Fig. 6. Parametric study of loaded ring antenna. (a) stub width; (b) stub length; (c) stub displacement; (d) number of stubs.



(a)



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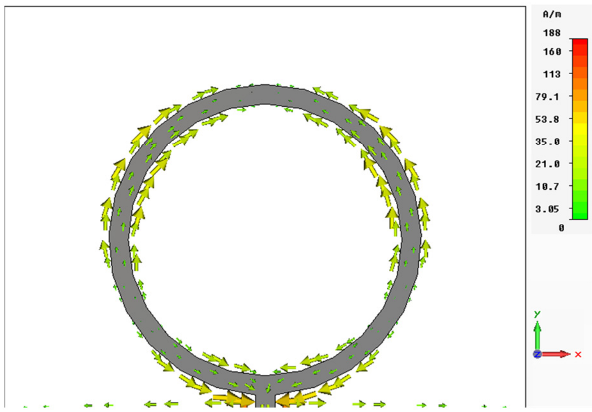
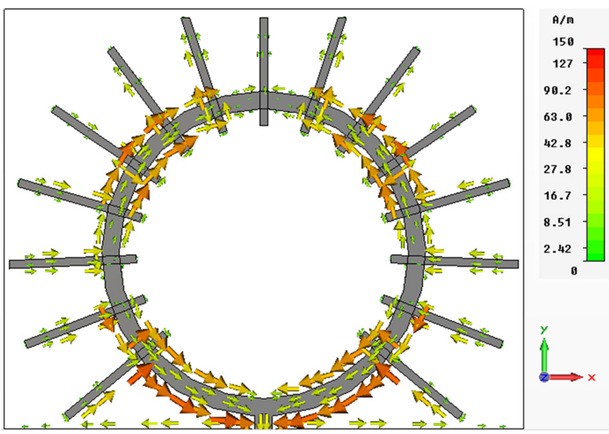


(c)

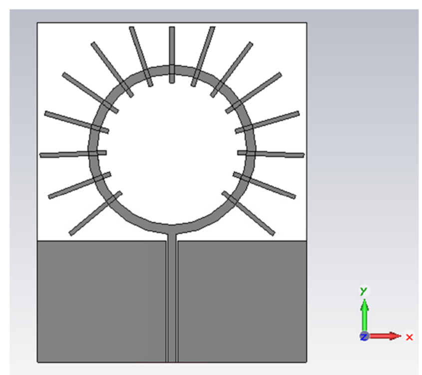


(d)

Fig. 7. Simple and loaded ring antenna current distributions. (a, b) at 2.5GHz (first band); (c, d) at 5.25GHz (second band).

IV. BANDWIDTH ENHANCEMENT VIA INDUCTIVE LOADING

Observe that the dual-band application can be achieved by stub loadings. We may utilize these dual-band characteristics of the antenna to make it wideband, based on the same principles used for increasing the bandwidths of filters [11]. Consequently, we try to bring the two resonance frequencies closer together, in order to make the antenna radiation performance wideband. The optimizer using the genetic algorithm in the CST simulation software is used for the parametric analysis of the antenna to obtain dual-band and wideband performances. Then, the number, size and angular spacing of branch lines are optimized to obtain a wide frequency response as much as realizable. The first and second resonance frequencies may be drawn together by varying the stub lengths and obtain a relatively wideband performance for the antenna. Of course, the number and angular spacing of stubs should be optimized to achieve the best return loss, as may be observed from Fig. 6(c, d). The geometrical configuration of the designed wideband ring antenna with stub loadings is drawn in Fig. 8. Its reflection coefficient versus frequency and radiation patterns are drawn in Figs. 9 and 10, respectively. Observe that its return loss bandwidth is 80% at the center frequency of 3.15GHz. The computer simulation may actually be carried out for different resonance frequencies, but the curves are given for a single frequency to avoid crowding the figures. Also the radiation patterns are not adversely affected by the addition of stubs.



W	W_1	W_2	L	L_1	L_2
32	15.4	0.63	40	14.2	15
G	R	W_L	L_L	α	N
0.18	10	0.5	7	18.5°	15

Fig. 8. Optimum loaded ring antenna reflection coefficient. Dimensions are in millimeters.

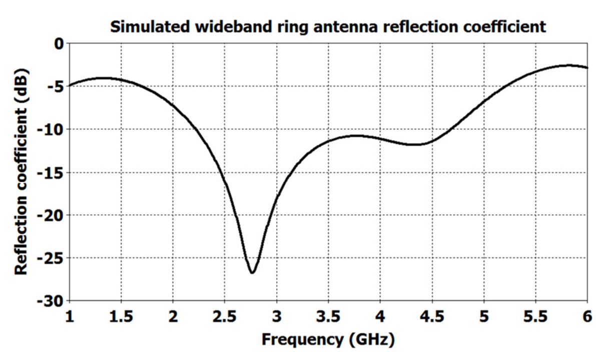


Fig. 9. Optimum loaded ring antenna reflection coefficient.

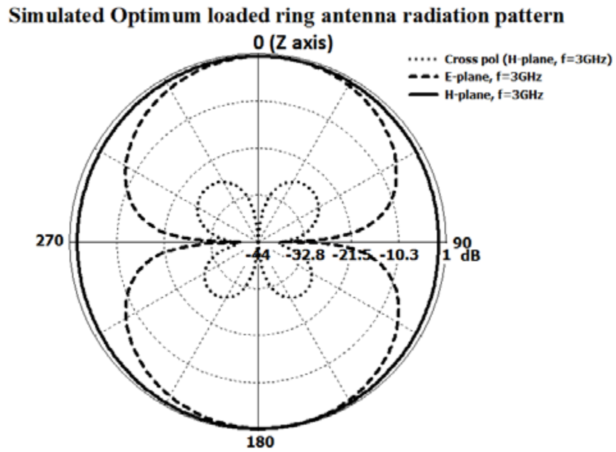
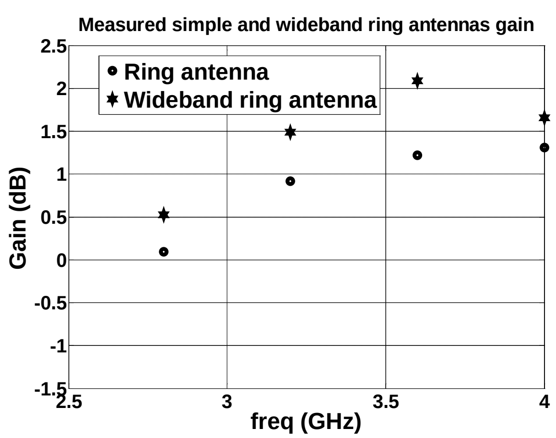
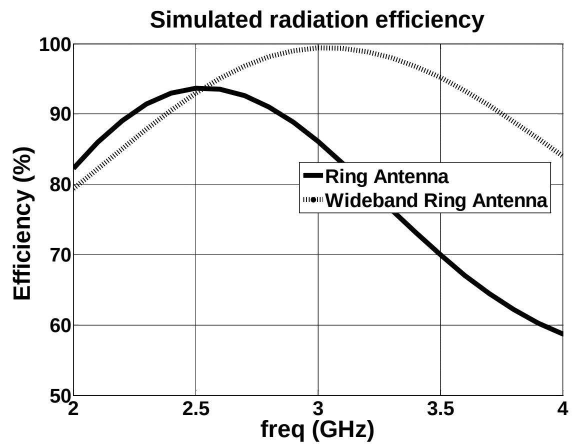


Fig. 10. Optimum loaded ring antenna radiation pattern at 3GHz. (dashed) E-plane (y-z plane); (solid) H-plane (x-z plane); (dotted) cross-polar (H-plane).

The results of simulation for the radiation efficiency of antennas and the measurement of antenna gain are given in Fig. 11. The gain of loaded antenna is a somewhat greater than the simple ring antenna. The reason may be due to the increase of current path length, as is evident from Fig. 7(d), which has led to the effective enlargement of antenna. As reducing antenna size leads to reduction of antenna's gain and efficiency [12, 13], increase in the radiation efficiency of loaded antenna may be due to current path increase.



(a)



(b)

Fig. 11. Ring antenna and wideband ring antennas (a) radiation efficiencies; and (b) gains versus frequency.

V. EXPERIMENTAL RESULTS AND COMPARISON

A simple and a stub loaded ring antenna are fabricated and measured, as shown in Figs. 1 and 8, respectively. Their photographs are shown in Fig. 12. Their reflection coefficients as obtained by simulation results and measurement data are shown in Figs. 13 and 14, respectively. Observe that the relative bandwidth of the stub loaded ring antenna has increased by about 230% relative to the simple ring antenna. The variation between the simulation results and measurement data may be due to the fabrication tolerance and approximations made in the computer simulation.

The far field pattern of the fabricated ring antenna is measured at the frequency of 3GHz and compared with the simulation results in Fig. 15. The patterns of the fabricated loaded ring antenna is measured at two frequencies (3, 4 GHz) and drawn in Fig. 16, together with computer simulation results for comparison. Observe that the stub loading of the ring antenna has little effect on the radiation pattern of the original ring antenna in the wide frequency band from 1.8 to 4GHz.

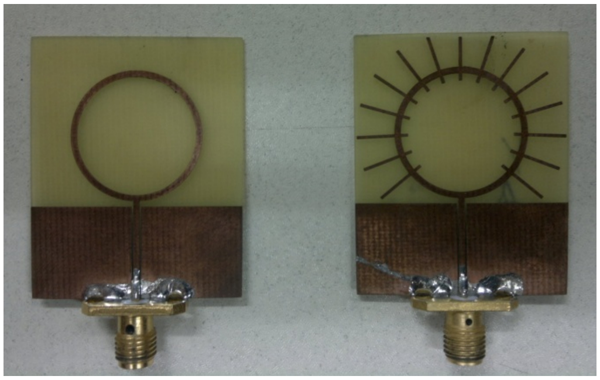


Fig. 12. Photographs of the ring and optimum loaded ring antennas.

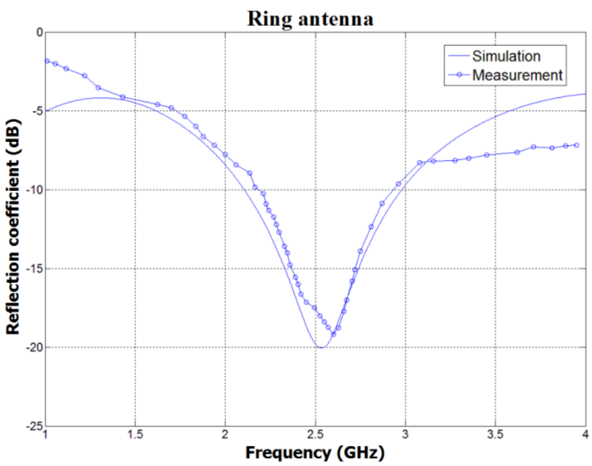


Fig. 13. Simulated and measured reflection coefficients of the simple ring antenna.

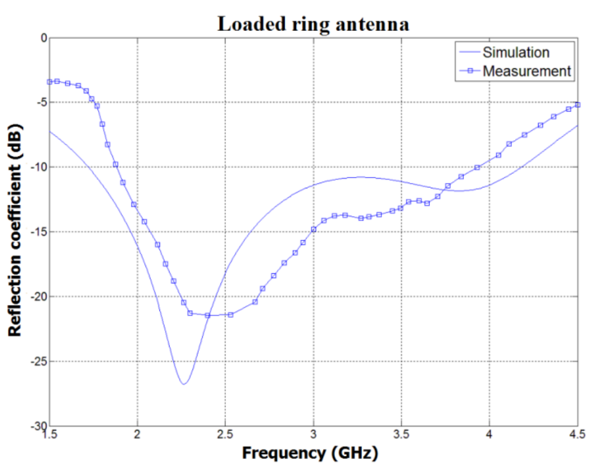


Fig. 14. Simulated and measured reflection coefficients of the optimum loaded ring antenna.

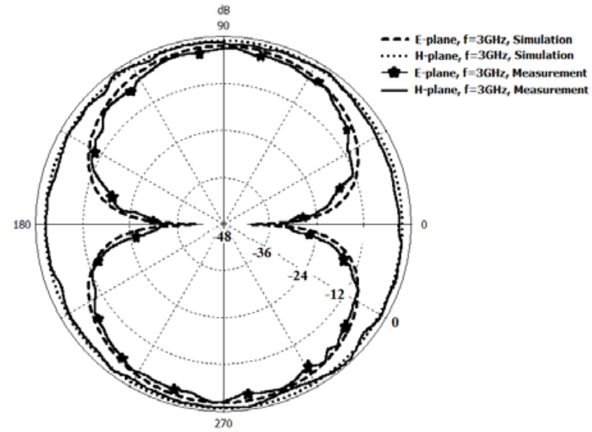


Fig. 15. Simple ring antenna normalized radiation patterns at 3GHz (E-plane (yoz)).

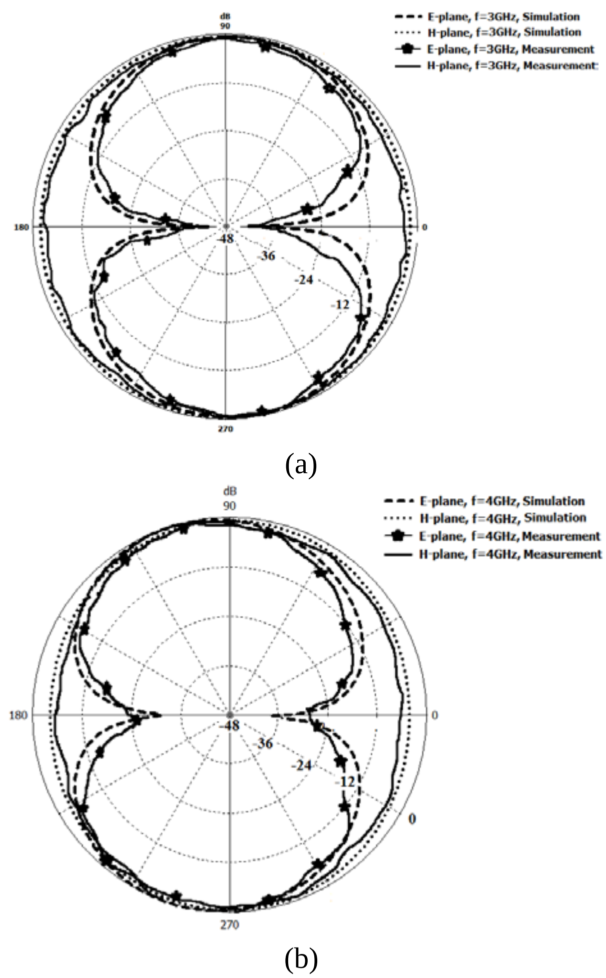


Fig. 16. Optimum loaded ring antenna normalized radiation patterns. at: (a) 3GHz; (b) 4GHz.

VI. CONCLUSION

It is demonstrated that the inductive loading of a CPW ring antenna by open-circuited radial line sections spaced around its periphery is a potential and an effective method for its dual-banding and broad banding performance, without any degradation of its radiation pattern. The proper design of the loaded ring antenna (in terms of the determination of lengths and widths of line sections and their spacings,) has actually achieved a 230% increases in antenna relative frequency bandwidth with excellent stability of the radiation pattern. Consequently, the stub loadings of an antenna by open-circuited line sections may be introduced as an effective method for enhancing frequency bandwidths and dual banding of antennas.

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