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A Novel Technique to Miniaturize Microstrip Antennas with a Locally Non-Homogeneous Substrate Configuration

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Abstract

Microstrip antennas are attractive for many applications because of their compact size, low profile, and light weight. Recently, the demand for the miniaturization of the personal communication equipment has been increasing along with the proliferation of personal communication systems. Thus, the development of small antenna has been highly demanded. In this paper, a new technique to reduce the overall dimension of a microstrip antenna with a locally non-homogeneous substrate configuration is proposed. The miniaturized microstrip antenna for a repeater system in a mobile communication cellular band (824~894 MHz) is designed with the proposed technique, and commercialized with low cost, light weight, and small size. Comparison between simulations, based on Agilent Technologies HFSS software, and measurements are provided. The proposed method will be more attractive for a light-weight, small-size, and low-cost microstrip array design. This paper also presents the bandwidth improvement technique for under-coupled microstrip patch antenna with a tuning stub.

Ⅰ. INTRODUCTION

Microstrip patches are currently being used for many applications. However, the size of a conventional microstrip patch antenna is still somewhat large for the frequencies of less than 2GHz. Although microstrip antennas have being used for the indoor and outdoor repeater system of a mobile communication system at a Korea cellular band(824~894 MHz) and at a KPCS(Korea Personal Communication Service) band (1.85~1.99 GHz), the size of microstrip antennas are somewhat large compared with the dimension of a repeater system, which is 150×100×40 mm at the cellular band in our case. Thus, several techniques have been proposed to effectively reduce the size of the printed radiator. High dielectric constant substrate materials have been proposed for small-size patch antennas [1], however, only poor efficiency due to surface wave excitation, narrow bandwidths, and higher material cost have been presented. Shorting posts were used in different arrangements to reduce the overall size of the printed antenna[2],[3]. Using this technique, the microstrip antenna can be made to resonate when its characteristic dimension is less than a quarter of a wavelength rather than half a wavelength which is typical for conventional microstrip antennas. Cutting slots in the radiating patch, a compact microstrip antenna has been also implemented[4],[5]. The larger slot cut in the patch will cause the patch surface current path to be much longer, and then reduce the resonant frequency. Indeed, it remains quite difficult to miniaturize such radiating elements because these efforts generally interface with electrical limitations or cost considerations regarding material requested properties. In this paper, we propose a novel method to design wide band small microstrip antenna, based upon an optimal geometrical configuration, with a

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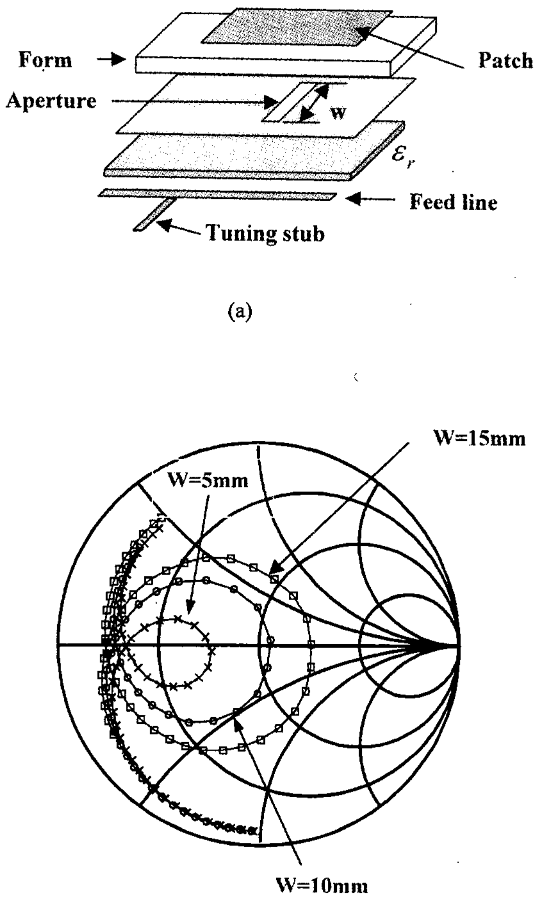
partially filled high permittivity substrateFor single microstrip antenna elements, the impedance bandwidth of only a few percent is generally the limiting factor; the pattern and directivity of a microstrip element generally vary little with respect to frequency. Most of the work in the area of bandwidth enhancement has been done to increase the impedance bandwidth of the microstrip patch element. Therefore, various techniques have been proposed for bandwidth enhancement; e.g., stacked multipatch, multilayer elements, multiple-resonator elements. All these techniques, however, are characterised by poorer radiation characteristics, complexity, and enlarged element size[6]. The method of employing a thick substrate in a coaxially fed patch antenna will limit the impedance bandwidth to less than 10% due to the large inductance introduced by the longer probe required. About 30% of bandwidth can be accomplished by employing a U-shaped slot for pro-fed patch antenna[7],[8]. The proximity coupling method has also been proposed by Pozar and Kaufman in[9]. With an impedance matching stub connected to the feed line that does not have the high back-lobe drawback, 13% bandwidth was achieved in[9]. In this paper, broad-band impedance-matching is also proposed as a method for improving the bandwidth of microstrip antennas. First, the microstrip patch antenna is fed so that the size of the impedance locus is small, which represents an under-coupled situation. Then the impedance is matched, and the impedance bandwidth is improved by using a tuning stub connected in shunt with feed line.

Ⅱ. IMPEDANCE MATCHING BY USING UNDER-COUPLING TECHNIQUE WITH A TUNING STUB

Richards et al. have reported calculated and measured values of the input impedance of a coaxial-fed rectangular microstrip patch antenna[10]. It is seen that the input resistance is largest when fed at the edge of the patch, but it can be attain the convenient value of 50 ohms when the feed position is chosen properly. It is clear that, for a coaxial feed, matching the antenna impedance to the transmission-line impedance can be achieved simply by putting the feed at the proper location. Since there is less flexibility in the case of a stripline feed, an insertion into the patch can be made. Another method is to employ aperture coupled technique where the aperture length and feed line extension are the two major parameters[11],[12]. The aperture length controls the amount of coupling, while the stub length rotates the impedance locus. As the aperture length increases, the impedance locus moves toward the right side of the Smith chart. As the stub length increases, the impedance locus rotates in a clockwise direction along a constant resistance circle[12]. As the stub approaches a quarter-wavelength long, the impedance curve crosses the real axis of the Smith chart. Therefore, the impedance of aperture coupled microstrip antenna can be matched by adjusting both aperture and stub lengths. By choosing the aperture length and feed line extension properly, it is possible to design under-coupled microstrip patch antennas. Then, the wide impedance bandwidth can be obtained by using a tuning stub. Fig. 1 shows that the bandwidth of an aperture coupled- patch antenna can be enhanced by making under-coupled patch antenna and by using a tuning stub. It should be also noticed that choosing the proper size of impedance locus could further increase the bandwidth.

Ⅲ. DESIGN AND RESULT

The performances of microstrip antennas are related to the electric field distributions at each of the extremities of the printed radiating element. The microstrip antenna with a locally inserted dielectric substrate is proposed as shown in Fig. 2. The resonant frequency of a microstrip antenna mainly depends on the length (L) of the patch, the thickness



(a)

(b)

Fig. 1. The impedance locus of an aperture coupled microstrip patch antenna with various slot lengths(W).

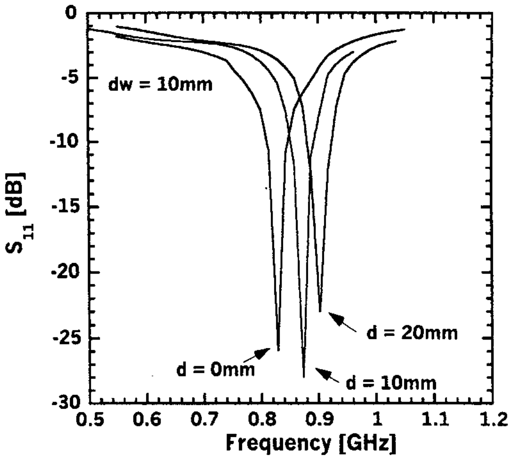


Fig. 3. The simulated resonant frequencies for the different positions of the RDB. L=152 mm, W=130 mm, h_1=1.6 mm, h_2=18 mm, $\varepsilon_{r1}=\varepsilon_{r2}=\varepsilon_{r3}=4.7$, and dw=10 mm.

($2h_1+h_2$) of the substrate, and the permittivity of the substrate. The rectangular dielectric bar ($W\times dw\times h_2$) is placed under the radiating patch with varying the distance d from the edge of the resonating patch. The calculated and measured resonant frequencies of the microstrip antenna for the different positions d of the rectangular dielectric bar (RDB) are shown in Fig. 3 and Fig. 4, respectively. It is noticed that the size of a radiating patch can be effectively minimized when the RDB is placed under the edge of the patch (d=0). Now, the width (dw) of the RDB is

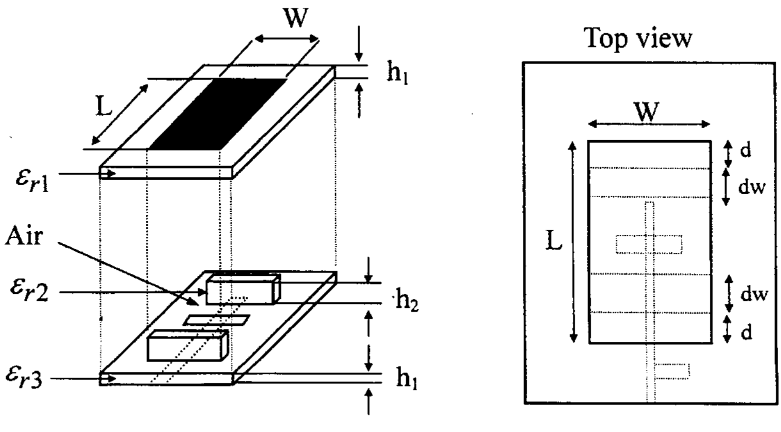


Fig. 2. The microstrip antenna with a locally inserted dielectric substrate.

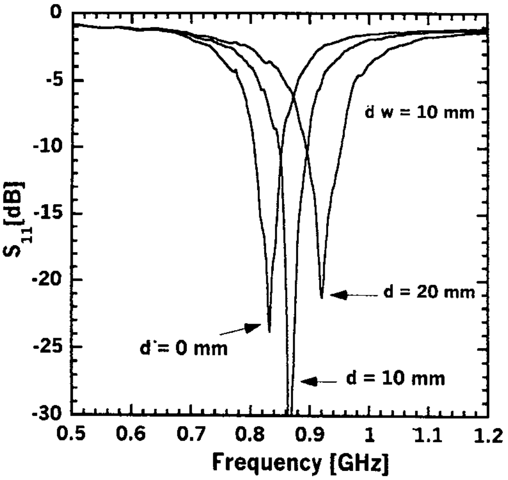


Fig. 4. The measured resonant frequencies for the different positions of the RDB. L=152 mm, W=130 mm, h_1=1.6 mm, h_2=18 mm, $\varepsilon_{r1}=\varepsilon_{r2}=\varepsilon_{r3}=4.7$, and dw=10 mm.

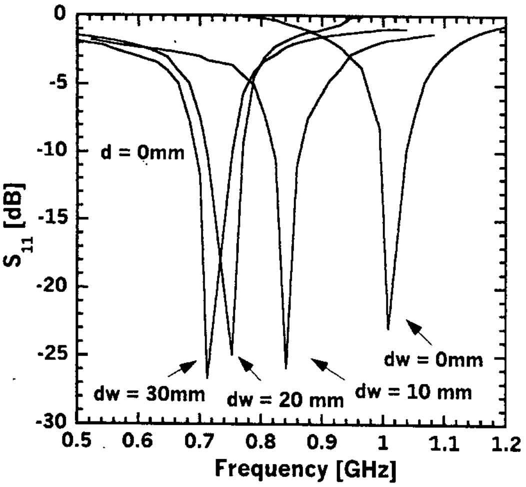


Fig. 5. The simulated resonant frequencies for the different widths(dw) of the RDB. L=152 mm, W=130 mm, h_1=1.6 mm, h_2=18 mm, $\varepsilon_{r1}=\varepsilon_{r2}=\varepsilon_{r3}=4.7$, and d=0 mm.

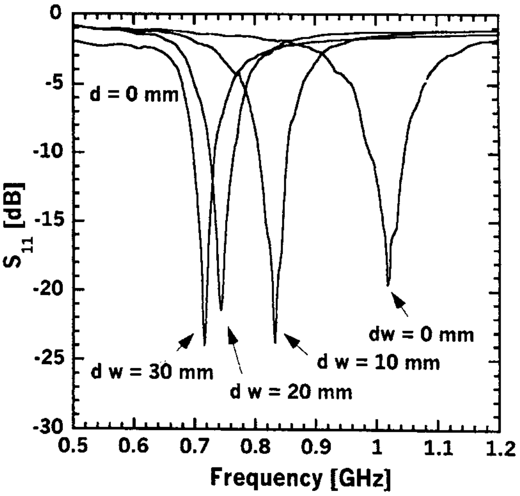


Fig. 6. The measured resonant frequencies for the different widths(dw) of the RDB. L=152 mm, W=130 mm, h_1=1.6 mm, h_2=18 mm, $\varepsilon_{r1}=\varepsilon_{r2}=\varepsilon_{r3}=4.7$, and d=0 mm.

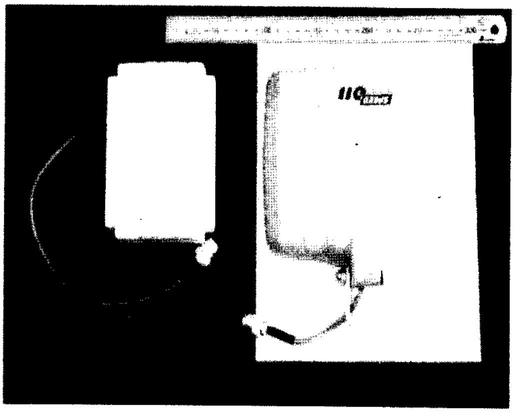


Fig. 7. The overall view of the actual microstrip antennas.

increased by filling the dielectric material from the edge of the patch (d=0). The calculated and measured resonant frequencies of the microstrip antenna for the different widths (dw) of the RDB are shown in Fig. 5 and Fig. 6, respectively. One can see that inserting RDB that has a small width compared with patch length (L), the antenna size can be significantly reduced. Therefore, a small-size, light-weight, and low-cost antenna can be designed by using the proposed method. Fig. 7 shows a commercialized patch antenna (left) with the proposed method and a conventional antenna (right) for the indoor and outdoor repeater system of a mobile communication at a cellular band. The overall dimensions for new

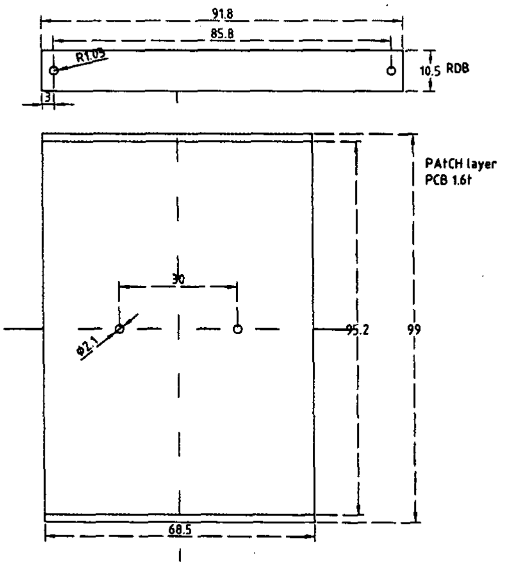


Fig. 8. Layout for patch and RDB (h_1=1.6 mm, h_2=18 mm).

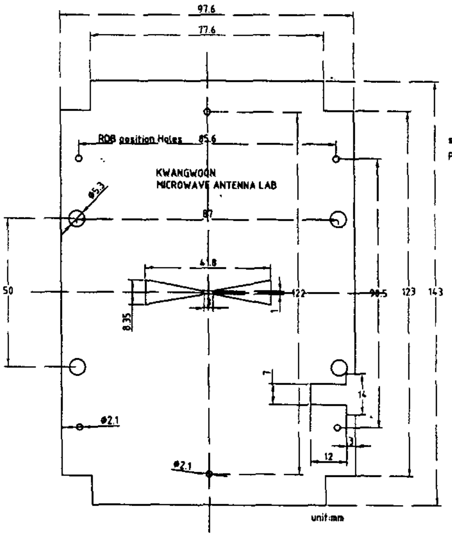


Fig. 9. Layout for slot and ground plane (h_1=1.6 mm).

and conventional antennas are 148×103×31 mm and 180×175×31 mm, respectively. Fig. 8~11 show the layouts of the commercialized patch antenna (left in Fig. 7) with the proposed method. Over 50% antenna dimension reduction is achieved with the proposed method. The gain is 6 dBi. The VSWR

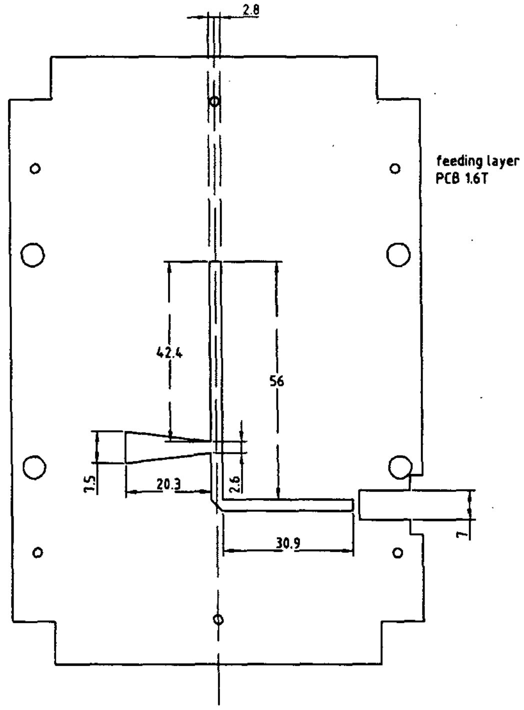


Fig. 10. Layout for feeding and tuning stub (h_1=1.6 mm).

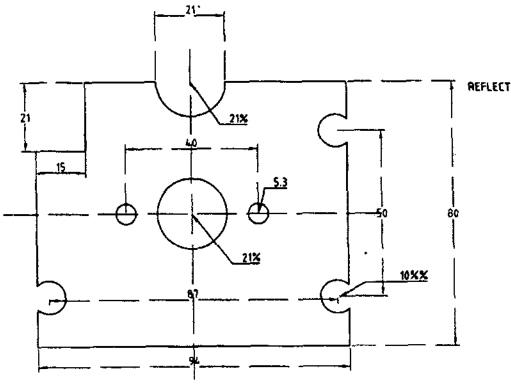


Fig. 11. Layout for reflector.(3 mm away from the ground plane).

is less than 1.3 in the range from 824 to 894 MHz as shown in Fig. 12. The radiation pattern is also shown in Fig. 13. The half power beamwidths for the horizontal and vertical patterns are 78° ±3° and 58° ±3° respectively. The reflector, which is placed 3mm away from the ground layer, was used to reduce the back radiation of the slot-coupled

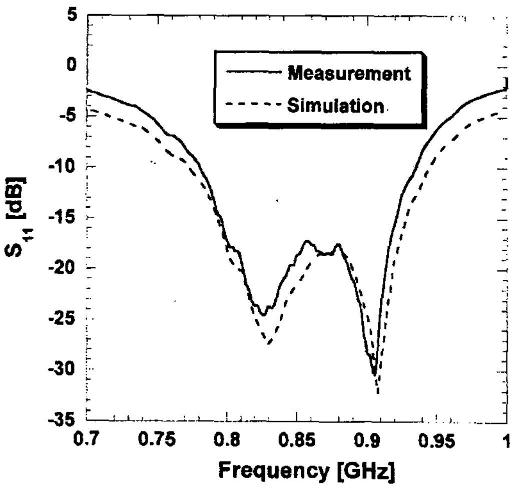


Fig. 12. S_{11} of the proposed antenna.

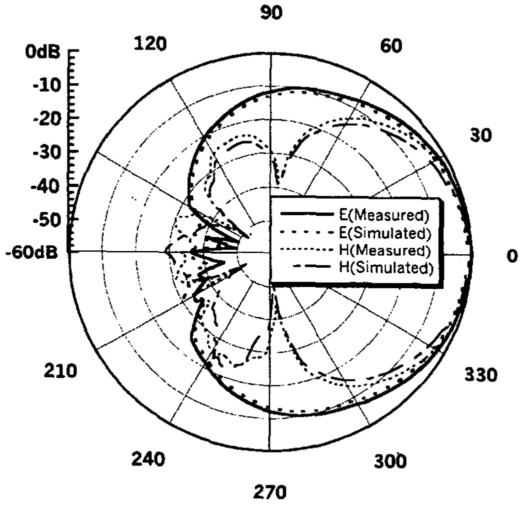


Fig. 13. The radiation pattern of the patch antenna at 836.5 MHz.

microstrip antenna. All simulation results in this paper come from Agilent Technologies HFSS software.

Ⅳ. CONCLUSION

A novel design of a miniaturized microstrip antenna has been studied. It is shown that placing the RDB under the edge of the resonating patch can reduce the dimension of microstrip antenna. The fair agreement between measurement and simulations has been shown. The bandwidth of microstrip patch antenna can be also improved by using under-coupling technique with a tuning stub. The proposed method with shorting posts and slots may obtain more reduction of the overall size of the printed antenna. In the future, this technique will be extended to an optimal geometrical combination of a low permittivity substrate with a high permittivity substrate regarding wideband and size reduction possibilities.

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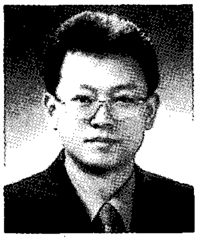

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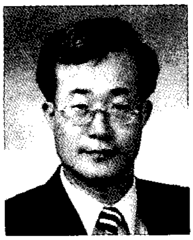

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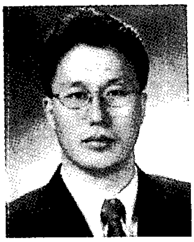

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