CELLULAR/DCS/US-PCS Triple-Band Internal Antenna with a Novel Feeding Structure

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Abstract—This paper presents a novel feeding structure of the triple-band internal antenna which covers CELLULAR/DCS/US-PCS bands. The proposed antenna consists of a U-slot patch radiator with a shorting post connected with ground plane and symmetric feeding lines with respective a feeding and shorting posts on both faces of the fixed FR-4 substrate. Through the simulation and experimental results, the proposed antenna is confirmed to have the features of less interference with a human head/body, broad bandwidth, desirable radiation patterns and efficiency for triple-band applications.

Index Terms—Novel feeding structure, triple-band, U-slot, symmetric feeding lines, interference, broad bandwidth, radiation patterns, efficiency.

I. INTRODUCTION

Now, mobile handsets are at the front of generation of new innovation. It is not a simple concept of wireless telephone anymore. It becomes a necessity in the modern human life because it includes telecommunication as well as television, Internet, digital camera/camcorder capacity and so on. As this change comes, consumers want them not only to smaller, lower profile, more attractive and convenient but also safe to human body. These desires can come true with using internal antenna, which has ability to reduce SAR as how it is designed. Nevertheless of these merits, former internal antennas have a lower gain, narrower bandwidth, and more sensibility than external antennas do. In most cases, internal antenna is in the nature of concentrative surface currents and thus antenna performances drop off when contacting with human head or body. Inversely, with a uniform surface current distribution, the antenna has a possibility to be insensible to human contact [1]-[2]. In this paper, antenna performances, such as size, radiation efficiency, radiation pattern, insensibility to human contact and SAR, are achieved with a feeding structure and not modifying radiator. The proposed feeding structure has some important design concepts. In basically proposed feeding part, a radiator is fed by electromagnetic coupling through symmetric formed feed lines with a feed point and a short point. The short point of feed line plays a role in reducing resonant frequency, which is same as a short pin on radiator. In addition, since mutually symmetric feed lines couple equal energy to the radiator in same phase, the antenna has a symmetric energy density special in lower frequency. Since a handset comes in contact with random points of human body, it is quite probable that it can be insensible when contacting with human head or body and obtain a low SAR as the antenna has more uniform current distribution. (This is due to a fact that SAR and the charge concentration has very close relationship). The thickness of dielectric substrate and the length of feed line control the energy coupled to the radiator and it is possible to match the impedance in wide band. In this work, in order to certify an effect of the proposed feeding method, performances of the proposed antenna are shown in comparison with three other antennas formed in general structures by simulation and measurements.

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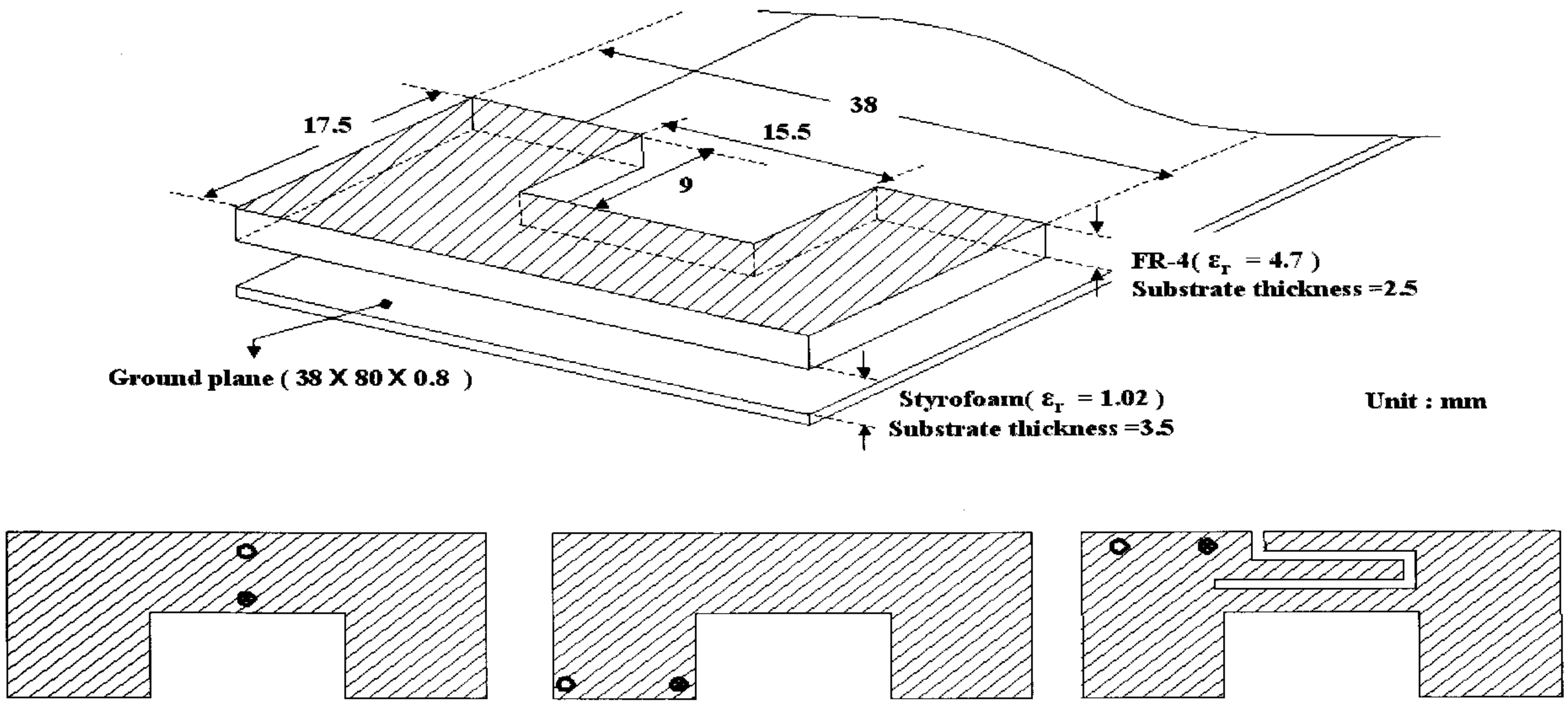
II. DESIGN CONSIDERATIONS

Three reference antennas with a fixed dimension as shown in fig. 1(a) are presented in fig. 1(b)-(d). As shown in fig. 1(a), the truncated part with 15.5 by 9 by 2.5 mm dimension is set for assembling battery with rear housing of actual handset. The reference dimension is equally applied to reference antennas as well as the proposed antenna for reliable comparison. The reference antenna 1 and 2 have a feed and short points at the center and side area on same radiator, respectively. The reference antenna 3 has two open points on radiator by slit, which is the most popular PIFA for multi-band applications [3]. Fig. 2 shows return losses of three reference antennas simulated by a full-wave method of moments (MoM) software package called IE3D [4]. The reference antenna 2 has lower frequency about 500MHz compared to that of antenna 1. In conventional PIFA, resonant frequency is determined by distance between short point and open point of radiator because impedance on short point is about 0Ω. Therefore, in a view of reduction of antenna size, antenna 2 has better performance than that of antenna 1. However, it leads opposite result for uniform current distribution on radiator and ground plane.



(a) (b) (c)

Fig. 1 Three reference antennas with a fixed dimension. (Feeding post O and shorting post ●)
(a) reference antenna 1, (b) reference antenna 2 and (c) reference antenna 3.

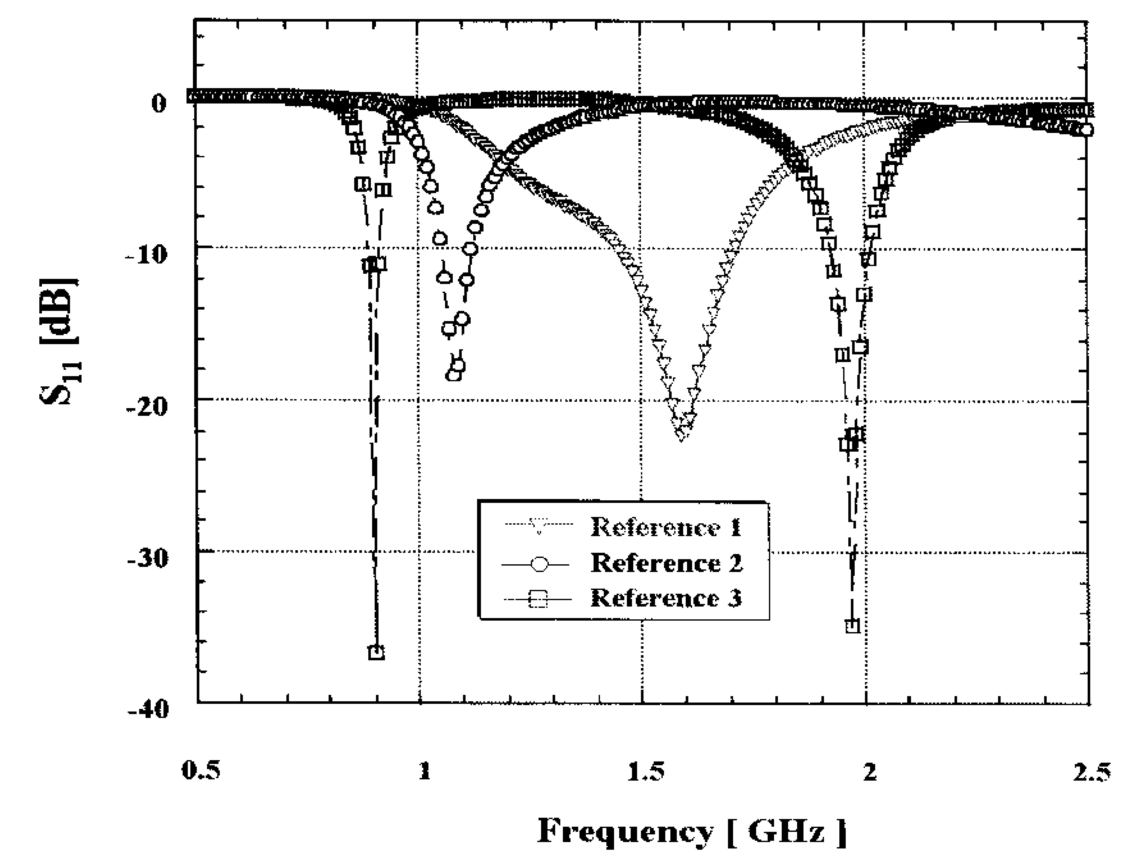
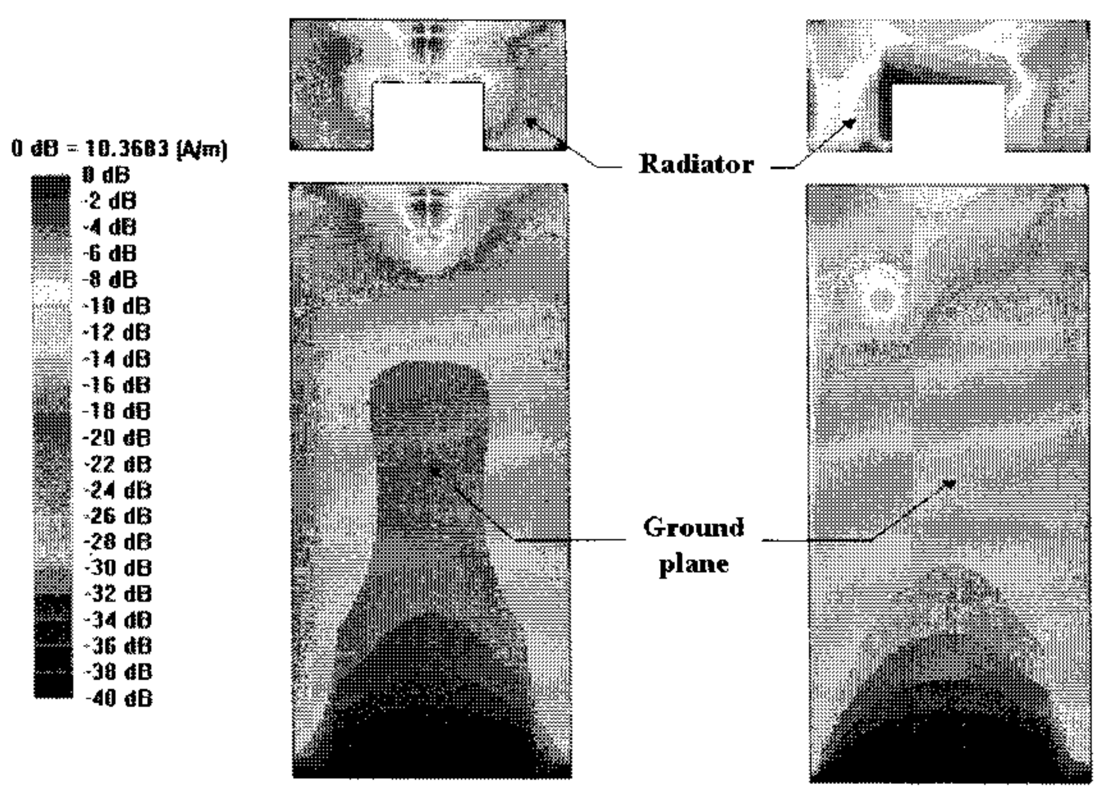


Fig. 2 Return losses of three reference antennas simulated by a full-wave method of moments (MoM) software package called IE3D.



(a) (b)
(b)

Fig. 3 Surface current distributions of (a) reference antenna 1 and (b) 2 at resonant frequencies.

Fig. 3(a) and (b) shows surface current distributions of antenna 1 and 2 at resonance frequencies. As shown in fig. 3, antenna 1 has exact symmetric distribution on observation planes but it is not for antenna 2 because surface current concentrates on side area around the short point. Therefore, the first design consideration for the proposed antenna is how to make current distribution and resonant frequency like respective antenna 1 and 2 at the same time. In probability, uniform current distribution contributes to enhancement of insensibility to human head/body and specific absorption rate because a working handset with internal antenna contacts with human head/body at random. The second design consideration is observed through antenna 3. As shown in fig. 2, it has the bandwidth of about 4.5% and 8.6%(VSWR< 3) in lower and higher bands, respectively. However, in CELLULAR/DCS/US-PCS triple-band application, an antenna is required to have the bandwidth of about 15.1%(VSWR< 3) to cover DCS and US-PCS bands at the same time. In addition, conventional PIFA like antenna 3 has direction pattern in H-plane because radiation pattern of electrical small antenna is more dependent on shorting position at higher frequency. So, the second consideration is that the proposed antenna has wider bandwidth (about twice bandwidth than that of antenna 3) and non-directional H-plane pattern at higher frequency.

III. DESIGN AND DISCUSSION

Fig. 4 represents the proposed feeding structure and an antenna with it. To demonstrate the effects of the proposed feeding structure, only feeding method of reference antenna 1 is modified. The proposed feeding structure consists of a feed line with feeding post and another feed line with shorting post connected to a ground, and they are symmetrical with respect to a radiator. The length of one feed line is 0.23λg at 1.92GHz and overall length of feed lines is 0.212λg at 859MHz. There is a gap of 1mm between two symmetrical feed lines.

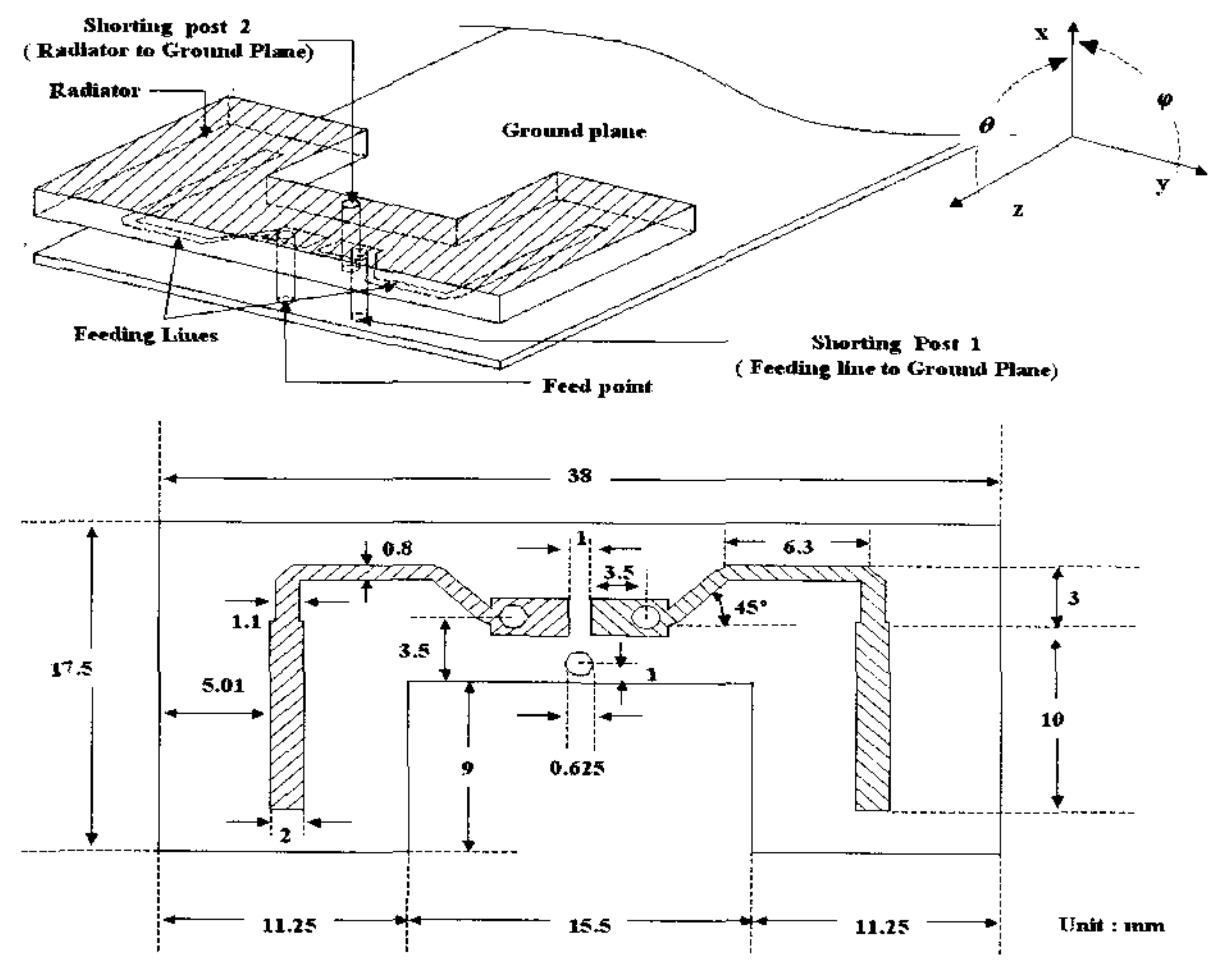


Fig. 4 Antenna with the proposed feeding structure

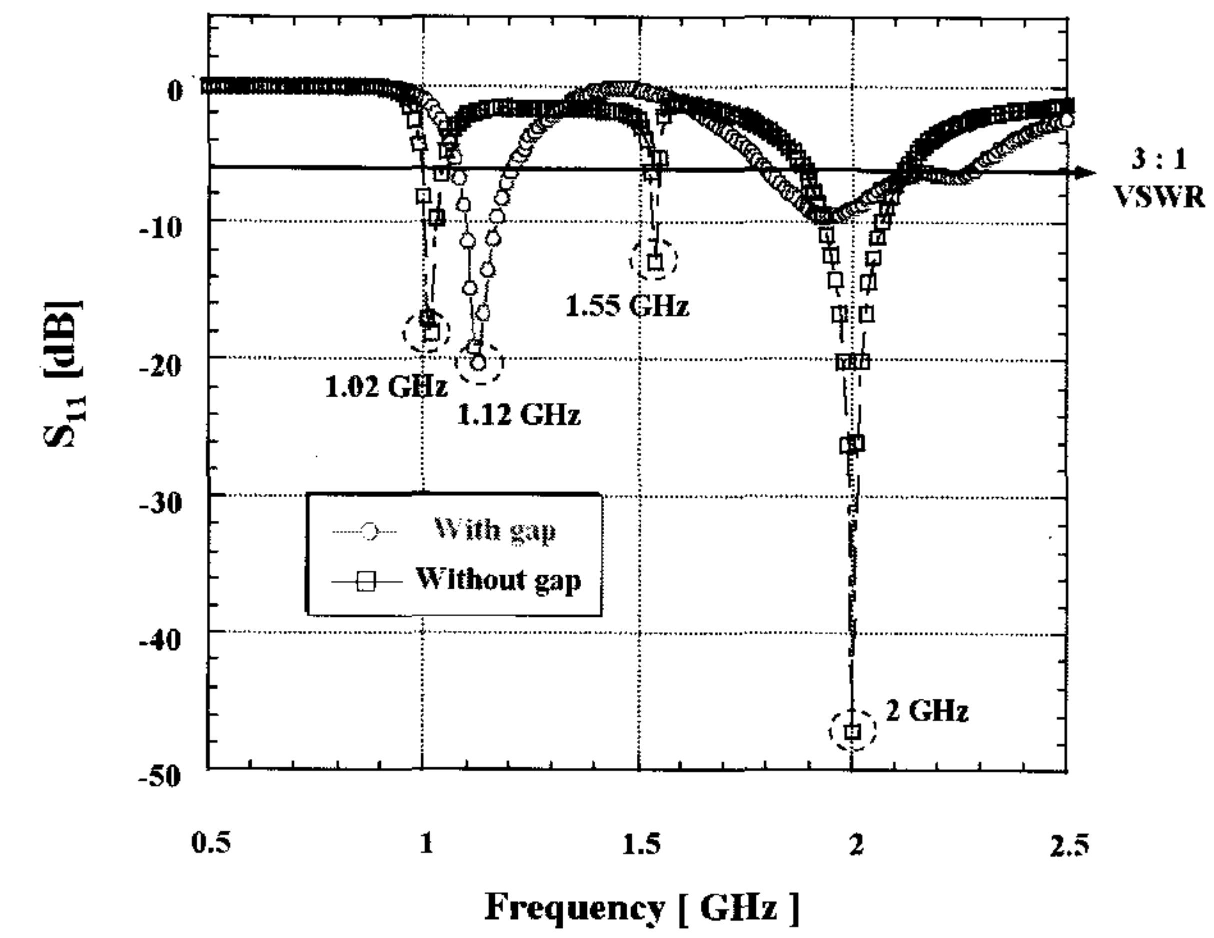


Fig. 5 Return loss with/without gap

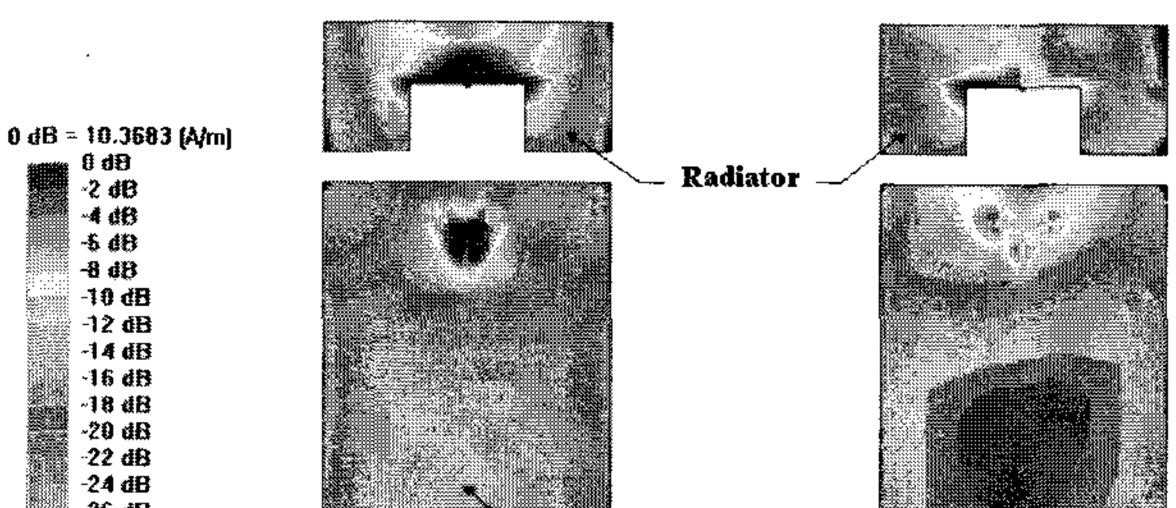


Fig. 6 Surface current distribution on radiator and ground plane with 1mm gap between feed lines

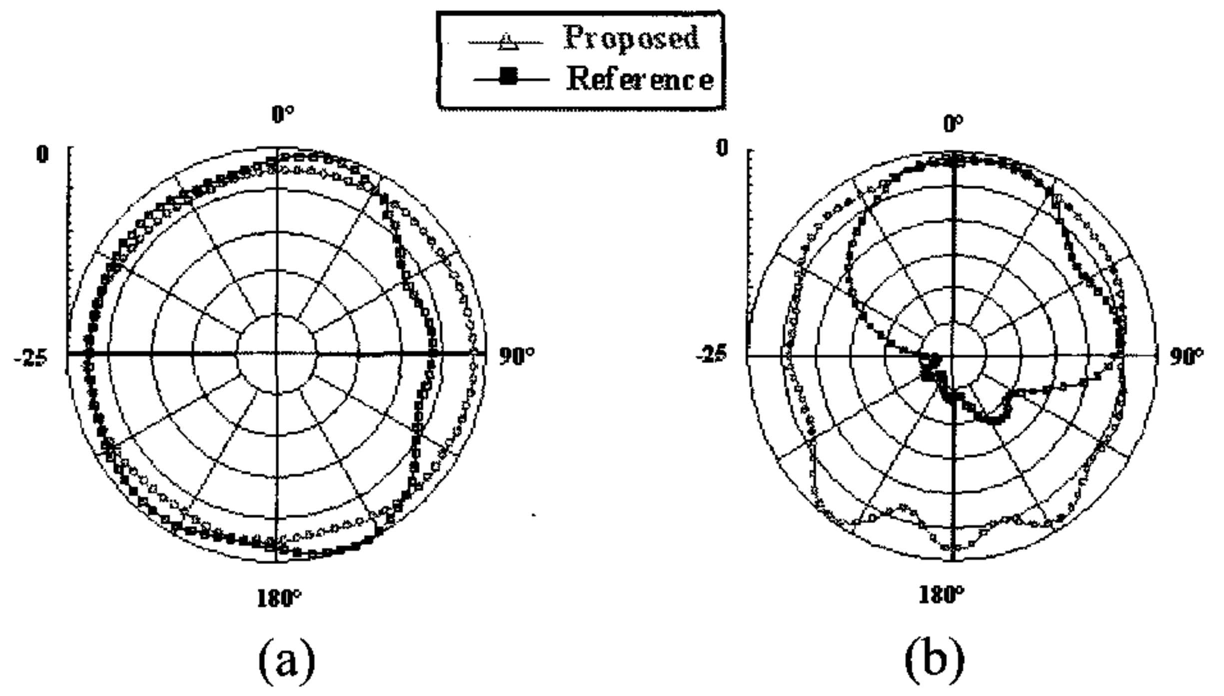


Fig.7 Simulated H-plane radiation patterns of the proposed antenna and reference antenna 3
(a) in lower frequency band and
(b) in higher frequency band.

The shorting post on the feed line supplies the energy coupling to radiator with lower frequency and it contributes to reduce the antenna size. The gap between the feed lines and the substrate thickness are the most important factors that determine amount of coupling energies. It said that these factors are closely connected with antenna impedance bandwidth. Fig. 5 shows each return loss result in the case with a gap and without it. When it has a gap of 1mm, the antenna resonates at 1.02GHz and 2.05GHz. The impedance bandwidth (VSWR<3) is about 11.6% and 23.4% at each resonant frequency. However, without a gap, the resonant frequencies are 1.02GHz, 1.55GHz and 2GHz and the bandwidth (VSWR<3) is about 4.9%, 1.3% and 12% at each frequency. At 1.55GHz resonant frequency, the feed structure radiates alone and it operates as a PIFA. Fig. 5 provides a possibility that there are various methods to realize multi-band operation dependent on existence of a gap. Fig. 6 displays surface current distribution on radiator and ground plane of the antenna whose feed line with 1mm gap. As shown, surface current distribution of the proposed antenna at 1.12GHz is similar to that of reference antenna 1 at 1.6GHz. This is due to the fact that perfectly symmetrical feed lines supply the radiator with equal energy and phase. While on the other, at higher frequency, a feed line with feeding post is mainly activated and it makes the antenna matched in wider band since it acts like a short impedance transformer. As a result, at lower frequency, the antenna with the proposed feeding structure has surface current density like as reference antenna 1 and resonant frequency identical with that of reference antenna 2. Also, at higher frequency, its bandwidth is about three times as wide as reference antenna 3. Fig. 7 shows H-plane patterns of the proposed antenna and reference antenna 3 obtained by simulator. In lower band, both antennas have almost omni-directional pattern. However, in higher band, the proposed antenna has lower value of about 13dB than that in reference antenna 3 as difference between the maximum gain and minimum. Generally, radiation pattern of an antenna such as PIFA at high frequencies depends on a location of shorting post. Thus the proposed antenna can be obtained more omni-directional pattern than PIFA with a common feeding structure at these frequencies.

Based on analysis of the antenna shown in Fig. 4, an antenna for triple band of Cellular/DCS/USPCS is designed and Fig. 8 shows it. As shown in Fig. 5, the final antenna is required to lower a resonant frequency about 260MHz than the antenna in Fig. 4. U-slot in Fig. 8 is used to drop the resonant frequency of the antenna and it increases surface current density. Thus it takes the current a delay to reach open end of the antenna without any transformation [5]. The slot effects on a resonant frequency are determined by its position and size. In case of Fig. 4, its resonant frequency needs more perturbation at low frequency than high frequency.

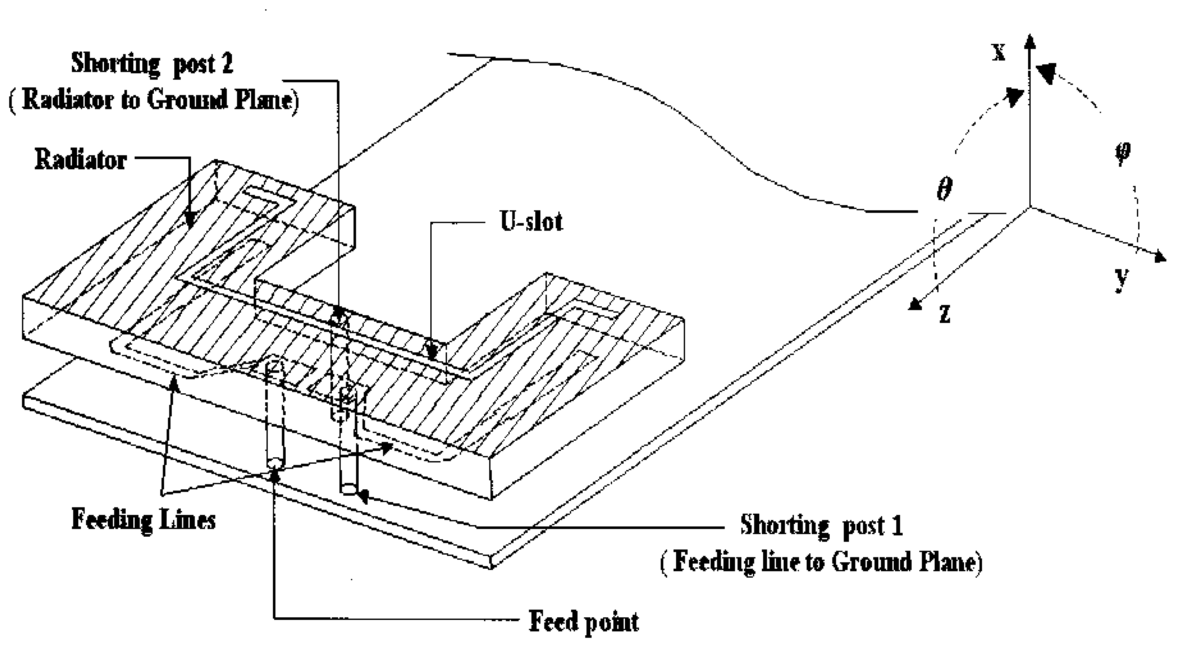


Fig. 8 Antenna with U-slot for triple band of Cellular /DCS/USPCS

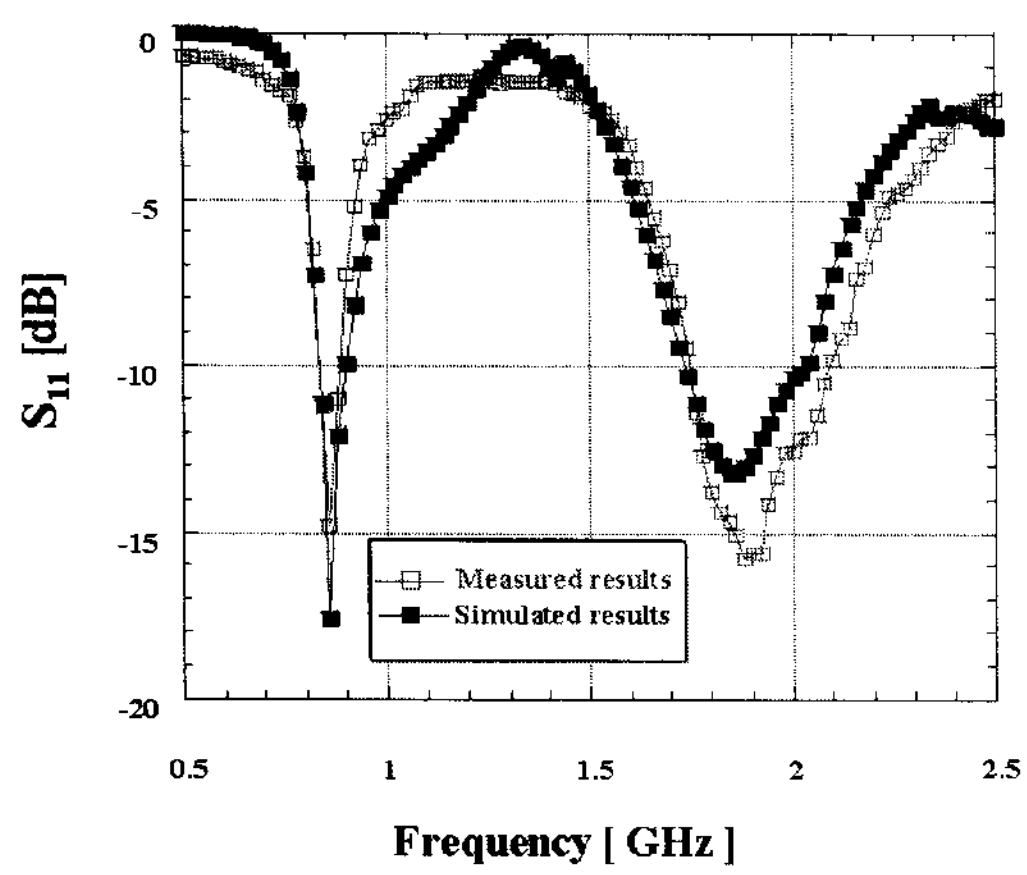


Fig. 9 Simulated and measured return loss of U-slotted antenna

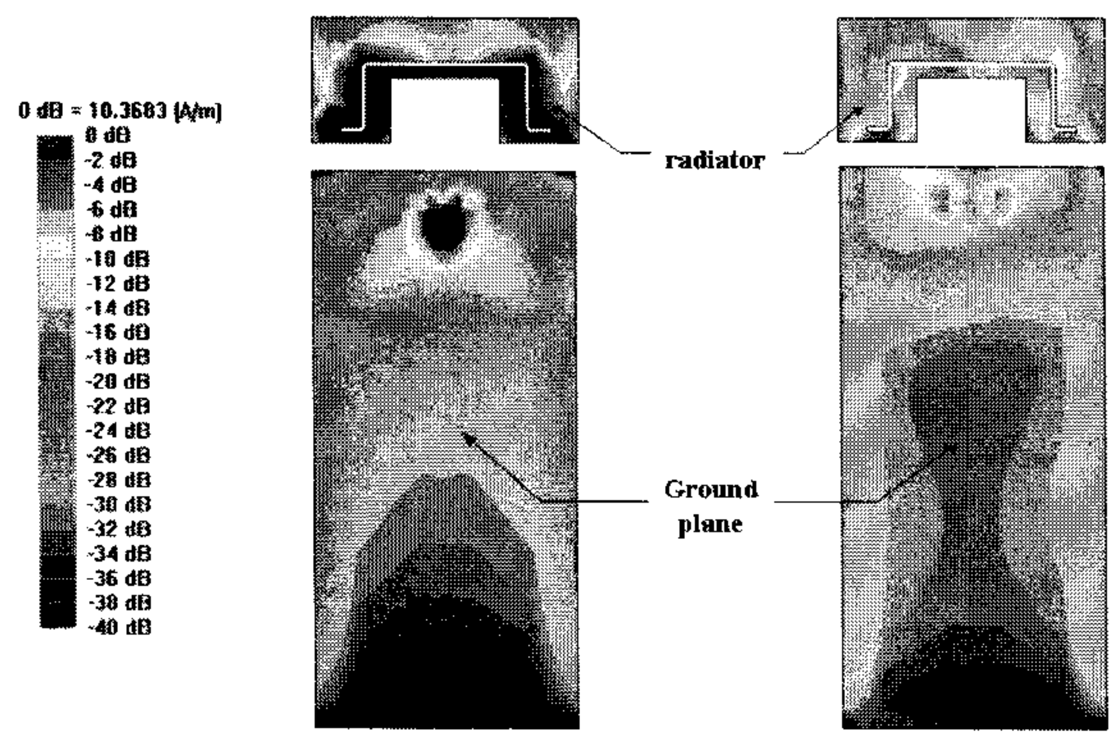


Fig. 10 Surface current distribution of U-slotted antenna

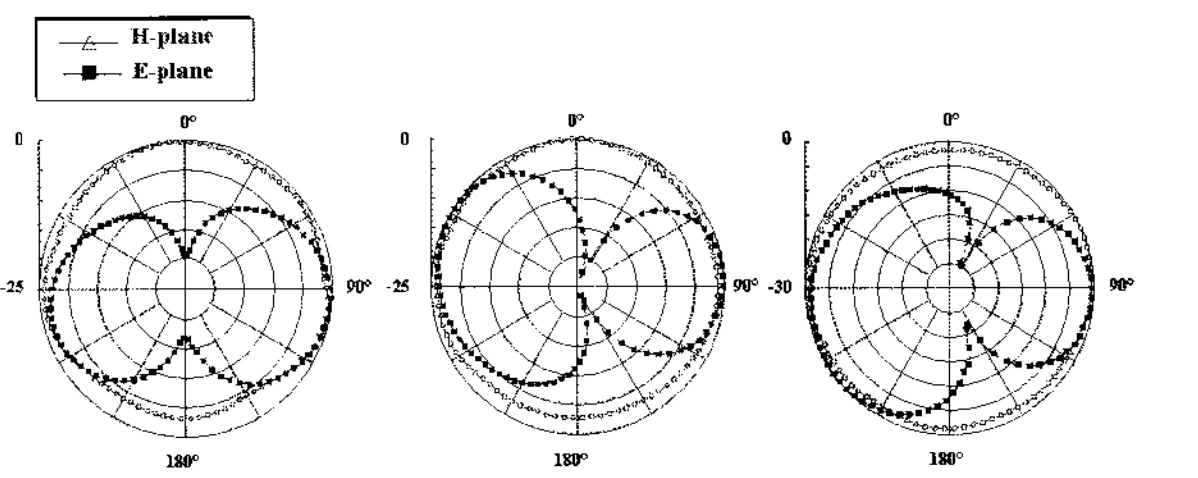


Fig. 11 Measured normalized radiation patterns of U-slotted antenna

Therefore it is appropriate to locate a slot between shorting post of the radiator and feed lines. And this is because surface currents are concentrated on the region in low frequency band and relatively not in high frequency band. The simulated and measured return loss of the U-slotted antenna is shown in Fig. 9. The measured bandwidth (VSWR<3) is around 11.6% and 30%, which is enough to meet triple band of Cellular/DCS/US-PCS. Also, as shown in Fig.10, the proposed antenna keeps symmetric all over the structure. In Cellular band, it allows the antenna to have uniform surface current distributions on observation planes, which are symmetrical with respect to the shorting post on radiator. Fig. 11 represents radiation patterns at each resonant frequency and they are almost omni-directional in all operating band. The measured each peak gain is 0.4, 1.2 and 0.5dBi in Cellular/DCS/US-PCS bands, respectively.

IV. CONCLUSION

In this paper, an antenna with a novel feeding structure consisted of symmetrical feed lines is proposed. It is shown that this antenna with a novel feeding structure contributes to lower resonant frequency, more symmetrical surface current distribution, wider bandwidth and more omni-directional patterns. The antenna is measured in Anechoic chamber with size of 10m by 6m by 4m, which is large enough to measure far-fields. Also, the effects due to a cable are minimized with using absorbers and a cap [6]. In next work, this antenna is applied to an active handset and insensibility is tested with performing SAR test and a Phantom.

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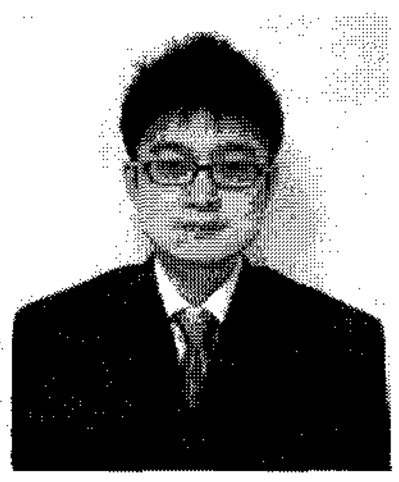

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