Small Internal Antenna Using Multiband, Wideband, and High-Isolation MIMO Techniques

Sang-Hyeong Kim, Zhe-Jun Jin, Yoon-Byung Chae, and Tae-Yeoul Yun

In this paper, a small internal antenna for a mobile handset is presented using multiband, wideband, and high-isolation multiple-input multiple-output techniques. The proposed antenna consists of three planar inverted-F antennas (PIFAs) that operate in the global system for mobile communication (GSM900), the digital communication system (DCS), the personal communication system (PCS), the universal mobile telecommunication system (UMTS), and wireless local area network (WLAN) bands with a physical size of 40 mm × 10 mm × 10 mm. A resonator attached to the folded PIFA creates dual resonances, achieving a wide bandwidth of approximately 460 MHz, covering the DCS, PCS, and UMTS bands; a meander shorting line is used to improve impedance matching. Additionally, a modified neutralization link is embedded between diversity antennas to enhance isolation, which results in a 6-dB improvement in the isolation and less than 0.1 in the envelope correlation coefficient evaluated from the far-field radiation patterns. Simulation and measurements demonstrate very similar results for *S*-parameters and radiation patterns. Peak gains show 3.73 dBi, 3.77 dBi, 3.28 dBi, 2.15 dBi, and 5.86 dBi, and antenna efficiencies show 56.15%, 72.15%, 68.59%, 52.92%, and 82.93% for GSM900, DCS, PCS, UMTS, and WLAN bands, respectively.

Keywords: Diversity, internal antenna, MIMO, multiband, PIFA.

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I. Introduction

With the rapid development of the mobile phone, including the introduction of the smartphone, multiband applications have become necessary for providing voice, data, and multimedia services [1], [2]. Mainly, the global system for mobile communication (GSM900 / 880 MHz to 960 MHz), the digital communication system (DCS / 1,710 MHz to 1,880 MHz), the personal communication system (PCS / 1,850 MHz to 1,990 MHz), and the universal mobile telecommunication system (UMTS / 1,920 MHz to 2,170 MHz) for voice (and video) call and wireless local area network (WLAN / 2,400 MHz to 2,483 MHz) for wireless data communications are used around the world. Especially in the case of WLAN services, multiple-input multiple-output (MIMO) techniques are required to increase the channel capacity between transmit and receive antennas, to support high data rates [3].

Therefore, antennas combining multiple bands with MIMO techniques have become necessary. However, conventional antennas satisfy only the multiband or the MIMO operations, with exceptions [4], [5]. In [4], the antennas occupy a large physical space because each antenna is separated at the top and bottom. The antennas in [5] do not cover many service bands. To design an internal antenna for use in modern mobile handsets, we must consider not only the limited space available but also the many service bands required. Additionally, when the distance between MIMO antennas is decreased, a mutual coupling is generated, degrading the channel capacity [6]. Therefore, an isolation technique is required to reduce the mutual coupling.

Many techniques for improving isolation between antennas have been reported [7]-[11]. A defected ground structure (DGS) [7], a mushroom-like electromagnetic band-gap (EBG),

[8], and a ground modification [9] have all been suggested to suppress the ground current flowing between antenna elements. However, each of these techniques requires a large area. A neutralization link was recently introduced to overcome the size problem; the technique has a simple structure and obtains an enhanced isolation characteristic [10], [11].

In this paper, an innovative combination of three planar inverted-F antennas (PIFAs), integrated with a multiband antenna and MIMO antennas, is presented, using a dual resonance resonator, a meander shorting line, and a modified neutralization link. The resonator and the meander shorting line are attached to the folded PIFA to obtain wide bandwidth and improve the impedance matching, respectively. In addition, the modified neutralization link, connected between the MIMO antennas, is used to enhance isolation performance. The proposed antenna is designed to operate at the GSM900, DCS, PCS, and UMTS bands as well as the MIMO WLAN band.

II. Antenna Design

1. Design

The geometry of the proposed internal antenna, shown in Fig. 1, consists of three parts. One part is Antenna 1, which covers the GSM900, DCS, PCS, and UMTS bands, and the other parts are the diversity antennas, that is, Antennas 2 and 3, which cover the WLAN band. Figure 1(a) shows a three-dimensional view. The overall size, including the ground plane, is 80 mm × 40 mm, which is an appropriate size for a mobile handset. The proposed antenna uses an FR4 substrate with a thickness of 0.8 mm, a relative permittivity of 4.4, and a loss tangent (tan δ) of 0.018. Figure 1(b) shows an unfolded view of the proposed antenna. Antenna 1 configures the folded and meandered PIFA to reduce the occupying space. Antenna 1 is mounted on the FR4 substrate, perpendicular to the top edge of the ground plane and is located between the diversity antennas. Diversity Antennas 2 and 3 are set for the MIMO system. The diversity antennas also configure the inverted-F antenna and are located at the most left and right sides; this placement reduces mutual coupling between the two antennas. All antennas are developed within 40 mm × 10 mm × 10 mm. To obtain wideband impedance matching, a resonator and a meander shorting line are used. As shown in Fig. 1(c), a modified neutralization link, used for enhancing the isolation performance, is placed under the substrate through a via-hole. To feed the proposed antenna, SMA-connected 50-Ω coaxial cables are used for each port.

The parametric study of the antennas is performed by using HFSS v10 [12], and physical parameters are presented in Table 1. The length of Antenna 1 (a quarter of wavelength ($\lambda_0/4$)) [13]

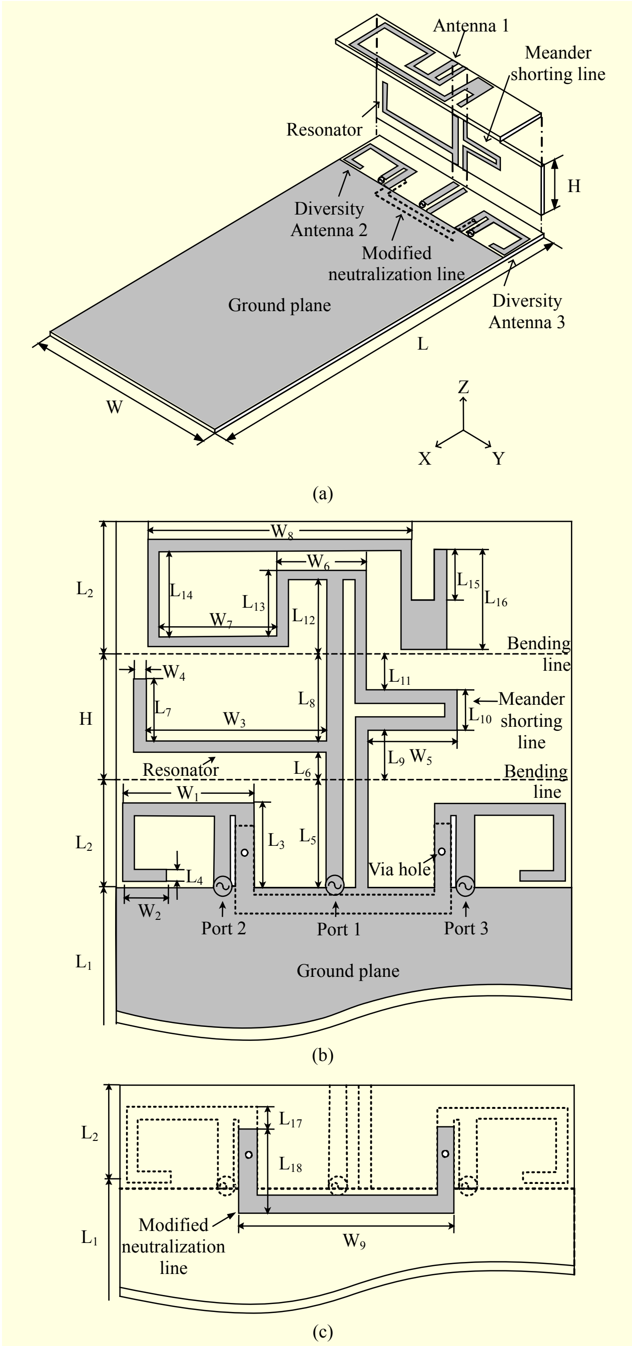

Fig. 1. Geometry of proposed internal antenna: (a) three-dimensional view, (b) unfolded front view, and (c) backside view.

is 82.1 mm ($L_5+L_6+L_8+L_{12}+W_6/2+L_{13}+W_7+L_{14}+W_8+L_{16}$) with a width of 1.5 mm for the feeding line and 1.0 mm for the others. These dimensional values correspond to a resonance at approximately 900 MHz (f_0), approximate for the GSM900 band, and generate a second higher-order resonance at approximately 1,800 MHz; the second higher-order resonance ideally occurs at $3f_0$ after the fundamental resonance at f_0 for

Table 1. Physical parameter values of proposed antenna.

Parameters	Value (mm)	Parameters	Value (mm)
L	80	L_{15}	4
L_1	70	L_{16}	8
L_2	10	L_{17}	2.5
L_3	7	L_{18}	6.5
L_4	1	W	40
L_5	9	W_1	11.5
L_6	2	W_2	3.9
L_7	5.2	W_3	16
L_8	7	W_4	1
L_9	4	W_5	9
L_{10}	3	W_6	8
L_{11}	3	W_7	10.3
L_{12}	6	W_8	23.3
L_{13}	5.5	W_9	19
L_{14}	7	H	10

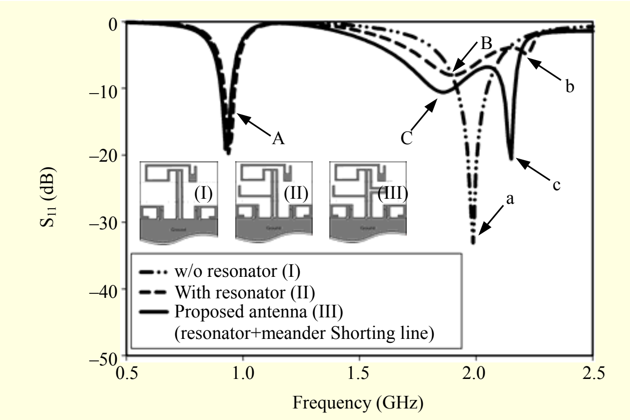

Fig. 2. S_{11} simulation results to investigate effects of adding resonator and meandering shorting line for Antenna 1.

the linear structure. In the folded or meandered structure (that is, nonlinear structure), the second higher-order resonance is generated at a different frequency due to coupling effects between the antenna elements. Because the second higher-order resonance represents a narrowband characteristic, a resonator (monopole antenna at approximately 2,200 MHz) is attached to the folded PIFA Antenna 1, to generate a dual resonance with Antenna 1 for a wideband input reflection coefficient (S_{11}) from 1,710 MHz to 2,170 MHz.

To examine the effects of adding the resonator and meandering the shorting line for Antenna 1 when diversity Antennas 2 and 3 are terminated by 50 Ω, the proposed antenna is simulated, as shown in Fig. 2. Without the resonator

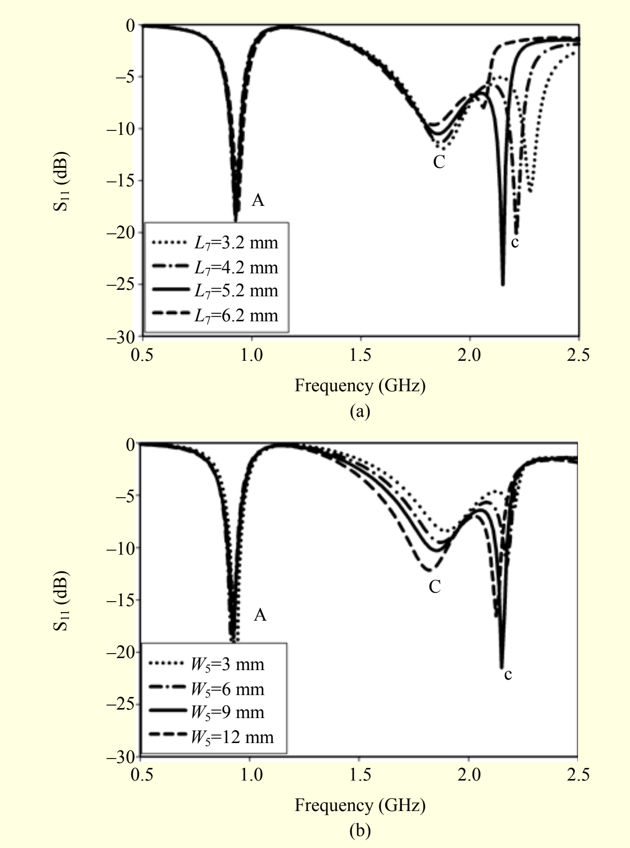

Fig. 3. S_{11} simulated to obtain bandwidth for DCS, PCS, and UMTS with variations in (a) resonator length L_7 and (b) meander shorting line W_5.

attached, Antenna 1 generates a fundamental resonance (*A*) at 900 MHz, and a second higher-order resonance (*a*) is generated. When the resonator is added, a new resonance (*b*) is generated and the second higher-order resonance (*B*) shifts slightly downward. However, the simulations show that the second higher-order resonance does not cover the DCS band and provides poor impedance matching. The shorting line is meandered to improve impedance matching, which also results in resonance frequency shifts from *B* to *C* and from *b* to *c*, as shown in Fig. 2. Thus, the proposed Antenna 1 will satisfy a wide bandwidth to cover the DCS, PCS, and UMTS operational bands.

2. Parametric Analysis

To obtain the impedance matching bandwidths (–6 dB of S_{11}) for the DCS, PCS, and UMTS bands, variations of the resonator length L_7 and the meander shorting line W_5 are studied, as shown in Figs. 3(a) and (b), respectively. When L_7 increases (from 3.2 mm to 6.2 mm, interval of 1 mm), the upper resonance (*c*) shifts toward a lower frequency while the change of the lower resonances (*A* and *C*) is insignificant, as

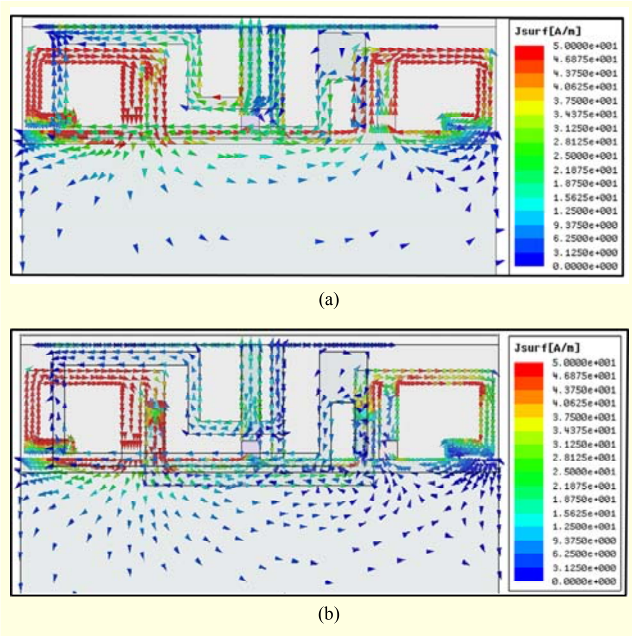

Fig. 4. Surface current distributions at 2.4 GHz: (a) without neutralization link and (b) with modified neutralization link.

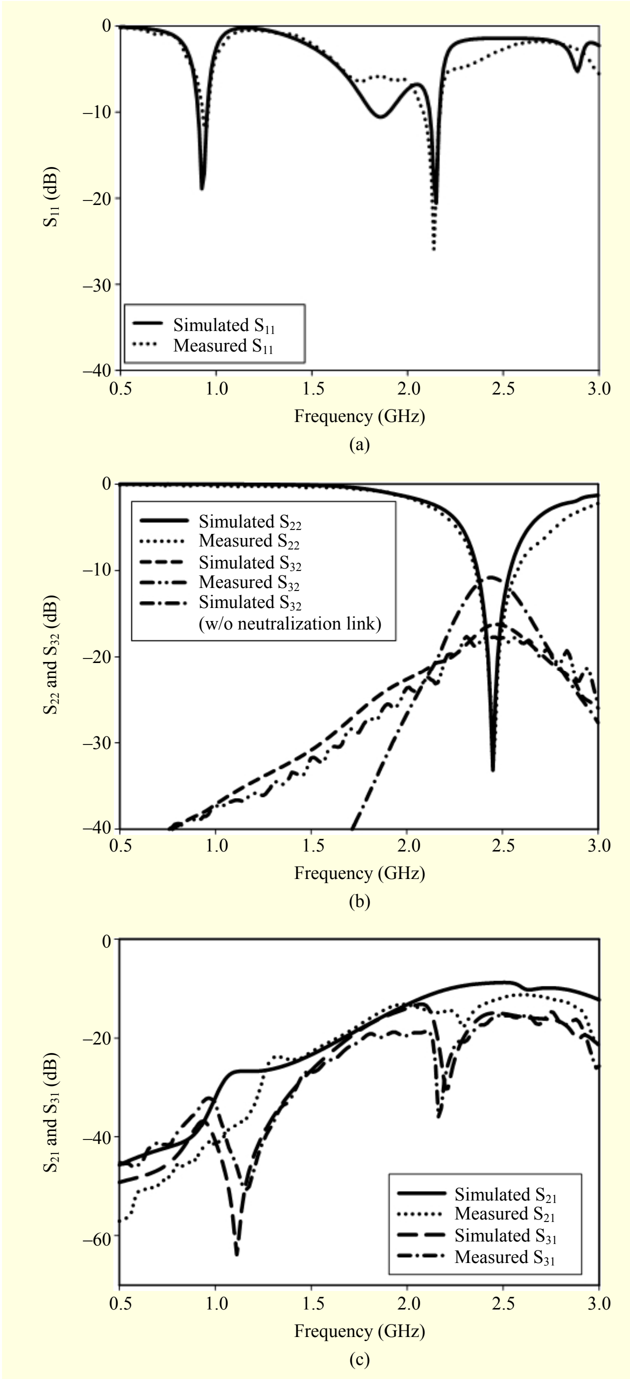

Fig. 5. Simulated and measured *S*-parameter for proposed antenna: (a) S_{11}, (b) S_{22} and S_{32}, and (c) S_{21} and S_{31}.

shown in Fig. 3(a). By adjusting L_7, wideband characteristics are realized by combining dual resonances (*C* and *c*). When W_5 increases (from 3 mm to 12 mm, interval of 3 mm), both the lower (*C*) and upper (*c*) resonances move slightly downward and the impedance matching characteristic (the magnitude of S_{11}) is improved while the fundamental resonance (*A*) is rarely changed, as shown in Fig. 3(b). The determined parameter values of L_7 and W_5 are 5.2 mm and 9 mm, respectively. By adjusting L_7 and W_5, a wide bandwidth and desirable impedance matching are obtained, covering the DCS, PCS, and UMTS operational bands.

3. Isolation

A neutralization link is modified to achieve high isolation between the diversity antennas; the detailed structure is shown in Fig. 1(c). The modified neutralization link is 28 mm in length and 1.5 mm in width, which is $\lambda_0/4$ at approximately 2.4 GHz. The link is located between the diversity antennas and printed on the backside of the ground plane to make a detour around Antenna 1, which is in the way of the neutralization link.

To understand how the modified neutralization link improves isolation, surface current distributions are investigated at 2.4 GHz when port 2 is excited and port 1 is terminated with a 50-Ω load, as shown in Fig. 4. Figure 4(a) displays the current distribution without the modified neutralization link. For this case, we excite diversity Antenna 2 on the left side, and the excited surface currents flow from the ground plane to diversity Antenna 3. Additionally, due to the physical closeness (approximately $\lambda_0/8$ at 2.4 GHz) between the diversity antennas, mutual coupling is generated. As a result, strong surface currents are induced on diversity Antenna 3 [14].

For a case with a modified neutralization link, as shown in Fig. 4(b), the surface currents induced on diversity Antenna 3 are effectively reduced. The surface currents injected through

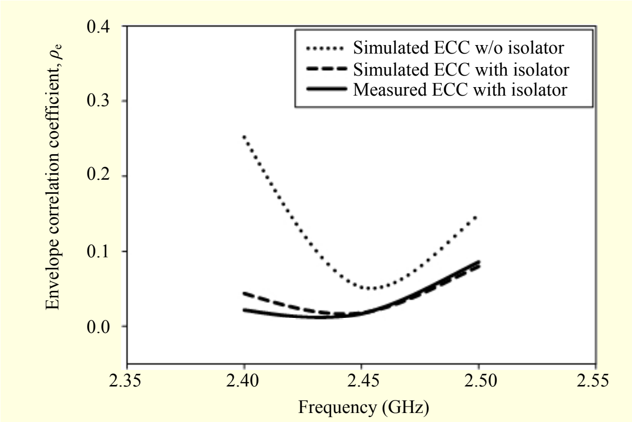

Fig. 6. Simulated and measured envelope correlation coefficient (ECC) characteristics without and with isolator.

the modified neutralization link are the opposite direction compared to the currents induced without the presence of the neutralization link [11]. Therefore, the injected surface currents and induced surface currents cancel each other out. As a result, an enhanced isolation characteristic is obtained.

III. Measurement Results

Simulated and measured *S*-parameters for the proposed antenna are presented in Fig. 5 and demonstrate very similar results. Nevertheless, the slight differences that do occur between the simulations and measurements are primarily caused by fabrication tolerance.

The measured –6-dB bandwidth results for input impedance matching are presented in Figs. 5(a) and (b); these are 94 MHz (0.879 GHz to 0.973 GHz) for the GSM900 band, 500 MHz (1.697 GHz to 2.197 GHz) for the DCS, PCS, and UMTS bands, and 220 MHz (2.359 GHz to 2.579 GHz) for the WLAN band, fully satisfying specifications. Simulated and measured S_{22} and S_{32} are shown in Fig. 5(b). Because the diversity antennas covering the WLAN band have a symmetrical structure, only S_{22} is represented. To verify the effect of the modified neutralization, simulation and measurement of S_{32} are performed. When the modified neutralization link is applied, S_{32} is greatly enhanced by at least 6 dB, whereas S_{22} remains unchanged.

The simulated and measured isolation (S_{21}, S_{31}) between each of the WLAN antennas and the mobile antenna are shown in Fig. 5(c). S_{21} is not identical with S_{31} because coupling between Antenna 1 and Antenna 2 is stronger than coupling between Antenna 1 and Antenna 3, which is caused by the asymmetric structure of Antenna 1, as shown in Fig. 1. It is well known that the total antenna efficiency is equal to the radiation efficiency*$(1-|S_{1n}|^2-|S_{2n}|^2-|S_{3n}|^2)$ for antenna "*n*" in uniform environment. For Antenna 1, the isolation (S_{21}, S_{31}) does not

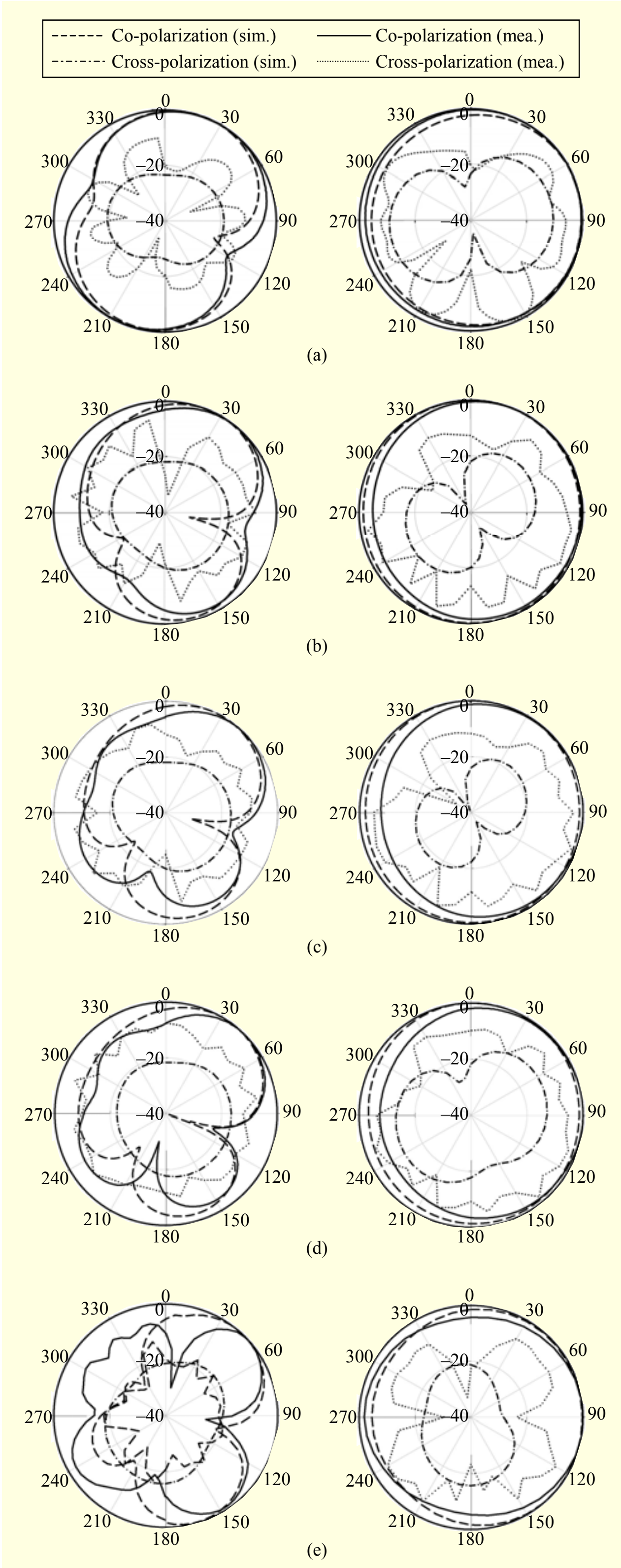

Fig. 7. Simulated (dash, dash dot) and measured (line, dot) radiation patterns for co- and cross-polarization, respectively (left: E-plane, right: H-plane): (a) 0.92 GHz (GSM900), (b) 1.8 GHz (DCS), (c) 1.9 GHz (PCS), (d) 2.02 GHz (UMTS), and (e) 2.4 GHz (WLAN).

Table 2. Performance summary of proposed antenna.

Antenna	Service bands	–6-dB bandwidth (GHz)	Peak gain (dBi)		Total antenna efficiency (%)	
			Sim.	Meas.	Sim.	Meas.
Antenna 1	GSM	0.879 to 0.973	3.29	3.73	71.80	56.15
	DCS	1.697 to 2.197	2.48	3.77	75.14	72.15
	PCS		2.79	3.28	69.98	68.59
	UMTS		2.83	2.15	58.23	52.92
Diversity Antennas 2, 3	WLAN	2.359 to 2.579	4.44	5.86	88.46	86.30

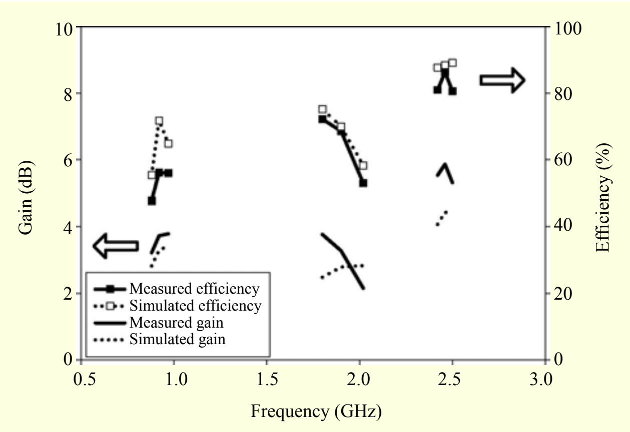

Fig. 8. Simulated and measured gain and efficiencies.

affect the total antenna efficiency significantly because the return loss (S_{11}) is much poorer than the isolation (S_{21}, S_{31}). For Antennas 2 and 3, the isolation (S_{21}, S_{31}, S_{32}) does not seriously affect the total antenna efficiency because all the measured isolations are close to –20 dB.

Figure 6 shows simulated and measured envelope correlation coefficient (ECC) characteristics without and with the isolator. The ECC is an important indicator to evaluate the diversity capability of a MIMO antenna system. The ECC between two antennas extracted from each far-field radiation pattern is given by

$$\rho = \frac{\int_0^{2\pi}\int_0^{\pi} A_{12}\sin(\theta)d\theta d\phi}{\sqrt{\int_0^{2\pi}\int_0^{\pi} A_{11}\sin(\theta)d\theta d\phi \int_0^{2\pi}\int_0^{\pi} A_{22}\sin(\theta)d\theta d\phi}}, \quad (1)$$

where

$$A_{mn}(\phi) = \Gamma E_{\theta m}(\theta,\phi)E^{*}_{\theta n}(\theta,\phi) + E_{\theta m}(\theta,\phi)E^{*}_{\theta n}(\theta,\phi)$$

in which

$$\boldsymbol{E}(\theta,\phi) = E_{\theta m}(\theta,\phi)\hat{\theta} + E_{\theta m}(\theta,\phi)\hat{\phi}$$

is the electric field pattern of antenna m=1, 2 and Γ is the cross-polarization discrimination (XPD) defined by the ratio of vertical to horizontal electric field strength of the incident field [15]. In MIMO over-the-air testing, it is assumed that either polarization is equally likely, resulting in the XPD of 1. The simulated and measured ECC are less than 0.1 over the whole WLAN band. Therefore, desirable diversity performance is expected from this result.

Figure 7 shows the simulated and measured radiation patterns in the E- (x-z) and H- (y-z) planes. Because there are three ports, ports 2 and 3 are terminated with a 50-Ω load when port 1 is excited. Likewise, ports 1 and 3 are terminated with a 50-Ω load when port 2 is excited. The measured radiation patterns are very similar to the simulated results. The radiation patterns are tilted slightly, due to the asymmetrical structure of the proposed antenna; however, because the radiation patterns have omnidirectional characteristics, the proposed antenna is suitable for use in mobile phone devices. As shown in Fig. 8, the peak gains (total antenna efficiencies) obtained are 3.73 dBi (56.15%), 3.77 dBi (72.15%), 3.28 dBi (68.59%), 2.15 dBi (52.92%), and 5.86 dBi (86.30%) at GSM900, DCS, PCS, UMTS, and WLAN operating bands, respectively. The measured performances are summarized in Table 2.

IV. Conclusion

A small internal PIFA using multiband, wideband, high-isolation MIMO techniques, covering GSM900, DCS, PCS, UMTS, and WLAN operational bands, was demonstrated using both simulations and measurements. To achieve the wide bandwidth required for DCS/PCS/UMTS services, a resonator and a meander shorting line were adopted. In addition, a modified neutralization link was incorporated to obtain the high isolation characteristic necessary for a MIMO WLAN service. Simulations and measurements demonstrated very similar results for S-parameters, ECC, and radiation patterns. Therefore, the proposed antenna combining a multiband antenna with MIMO antennas will be useful for future mobile handset applications.

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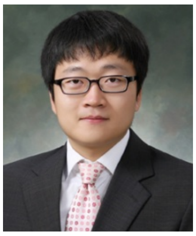

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