CHAPTER ONE

Introduction and Overview

1.1 INTRODUCTION

Wireless communications have progressed very rapidly in recent years, and many mobile units are becoming smaller and smaller. To meet the miniaturization requirement, the antennas employed in mobile terminals must have their dimensions reduced accordingly. Planar antennas, such as microstrip and printed antennas, have the attractive features of low profile, small size, and conformability to mounting hosts [1] and are very promising candidates for satisfying this design consideration. For this reason, compact and broadband design techniques for planar antennas [2] have attracted much attention from antenna researchers. Very recently, especially after the year 2000, many novel planar antenna designs to satisfy specific bandwidth specifications of present-day mobile cellular communication systems, including the global system for mobile communication (GSM; 890–960 MHz), the digital communication system (DCS; 1710–1880 MHz), the personal communication system (PCS; 1850–1990 MHz), and the universal mobile telecommunication system (UMTS; 1920–2170 MHz), have been developed and published in the open literature. This book organizes those novel designs for applications as internal mobile phone antennas and base station antennas, and detailed design considerations and experimental results are presented.

Planar antennas are also very attractive for applications in communication devices for wireless local area network (WLAN) systems in the 2.4 GHz (2400–2484 MHz) and 5.2 GHz (5150–5350 MHz) bands. Novel planar antenna designs for achieving broadband circular polarization (CP) and dual-polarized radiation in the WLAN band for overcoming multipath fading problem to enhance system performance have been demonstrated recently. In addition, surface-mountable antennas that can be easily integrated on the circuit board of a communication device to reduce the packaging cost have also received much attention, and related new designs for WLAN operations have been reported recently. These newly developed WLAN antennas are presented and discussed.

The applications of dielectric resonator (DR) antennas [3] for WLAN operation are also addressed. Dielectric resonator antennas also have the features of low profile and small size, like the microstrip and printed antennas, and in addition, there is no metallic loss, leading to low loss for operating at higher frequencies. Furthermore, when the DR element with a very high relative permittivity is used (for example, larger than 80), the antenna can have a very low profile (less than 2 mm for operating in the 5.2 GHz WLAN band), which is very attractive for practical applications. Some related promising designs are introduced in this book. Finally, the integration of antennas for different operating bands, such as the GPS antenna, the WLAN antenna, and the DCS antenna, is discussed and details of some practical integration designs and experimental results are shown.

1.2 PIFAs FOR INTERNAL MOBILE PHONE ANTENNAS

A planar inverted-F antenna (PIFA) [4] is in general achieved by short-circuiting its radiating patch or wire to the antenna's ground plane with a shorting pin and can resonate at a much smaller antenna size for a fixed operating frequency. Owing to their compact size the designs of PIFAs have attracted much attention, and a variety of dual-band or multiband PIFAs suitable for applications in mobile phones have been demonstrated recently [5–24]. Figure 1.1 shows a typical configuration of a PIFA mounted on the top portion of a circuit board of a practical mobile phone, and some promising radiating top patches for achieving dual-band operation of the PIFA are presented in Figure 1.2. These PIFA designs usually occupy a compact volume and can be integrated within the mobile phone housing, leading to concealed or internal mobile phone antennas. Because this kind of internal antenna can avoid the damages caused by catching on things and will not break, compared with the conventional protruded whip or rod antennas used for mobile phones, it is now becoming one of the major design considerations for mobile phones. In addition, in comparison to the conventional whip antennas showing omnidirectional radiation, such PIFAs have the advantage of relatively smaller backward radiation toward the mobile phone user. This suggests that the possible electromagnetic energy absorption by the user's head can be reduced. These advantageous characteristics have led many novel PIFA designs, most of them capable of dual-band operation, to be applied in mobile phones in the market.

For the promising radiating top patch designs for the dual-frequency PIFA shown in Figure 1.2, there are two major design concepts: One design uses two different resonant paths to generate two separate resonant modes for dual-frequency operation, and the other uses the first two resonant frequencies of a single resonant path for dual-frequency operation. In the former case, the design techniques include the use of an inserted L-shaped slit or a folded slit [8, 20] (Fig. 1.2a and b), or a U-shaped slot [10, 19] (Fig. 1.2c), or inductor and capacitor (LC) resonators [12]

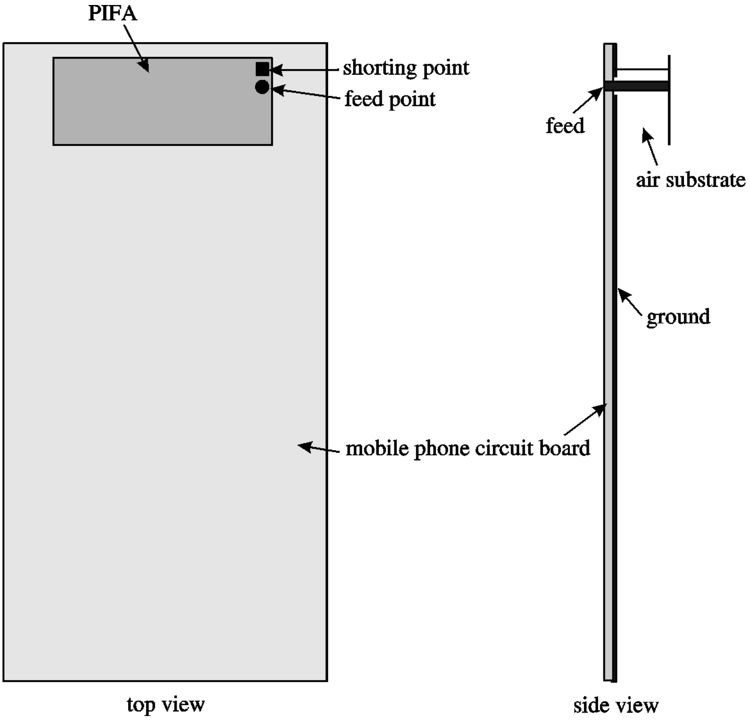

FIGURE 1.1 Geometry of a PIFA mounted on the top portion of a mobile phone circuit board.

(Fig. 1.2d), or a chip-inductor loading [14] (Fig. 1.2e) to separate the radiating top patch into two subpatches of different sizes, which provide two resonant paths of different lengths to achieve the 900/1800 MHz operation. In the latter case, the major design consideration is to adjust the antenna's first two resonant frequencies to be about 2. To achieve this goal, the techniques of using a branch-line slit to achieve a lengthened resonant path [13] (Fig. 1.2f), inserting several linear slits to meander the top patch [7, 22] (Fig. 1.2g), using a shorted spiral strip with various strip widths (Fig. 1.2h), folding a meandered top patch (Fig. 1.2i), and so on, have been successfully applied.

To include the WLAN operation in the 2.4 GHz band, designs of triple-frequency PIFAs for operations in the 900, 1800, and 2450 MHz bands have been reported, which include the use of two or three separate top patches [21], a meandered top patch [22], and a branch-line strip with a folded end [23]. The techniques of using a parasitic shorted patch placed coplanar with the driven patch [7, 11] or stacked on top of the driven patch [25–27] to enhance the operating bandwidth of the PIFA have also been reported. Recently, it was reported [28] that, by using an L-shaped ground plane (see two possible designs shown in Fig. 1.3) in place of the conventional flat ground plane, more reduction in the antenna's backward

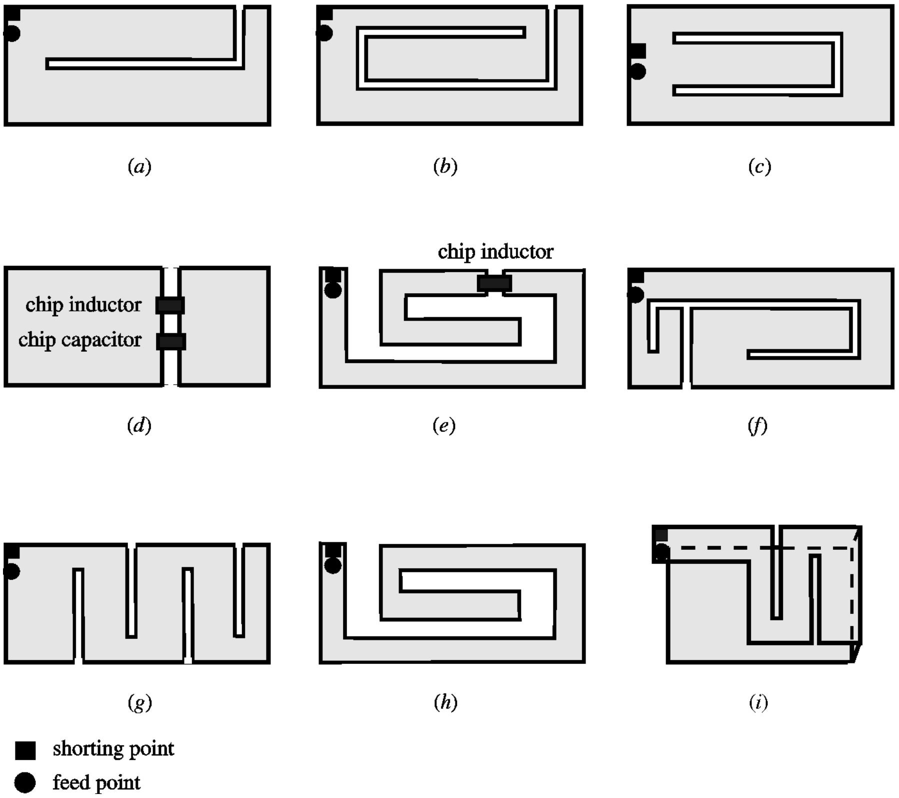

FIGURE 1.2 Some promising radiating top patches for dual-frequency PIFAs.

radiation is obtained and antenna performances are enhanced. The effects of ground plane size on the PIFA's impedance bandwidth characteristics have also been studied [29]. These recently reported results for the applications of PIFAs as internal mobile phones antennas are presented in Chapter 2.

1.3 VERY-LOW-PROFILE MONOPOLES FOR INTERNAL MOBILE PHONE ANTENNAS

Conventional monopole antennas in the form of a straight rod are usually operated with one-quarter wavelength; this means that, when operated at 900 MHz for mobile communications, the monopole antenna requires a height of about 83 mm. Because of this large antenna height, it is impossible to integrate such monopole antennas within the mobile phone housing. To reduce the monopole height, which makes the antenna less prone to breaking off, monopoles in the form of a helix or wound coil [30] or a folded loop [31] for mobile phone applications have been used. Many related designs for achieving 900/1800 MHz dual-frequency operations

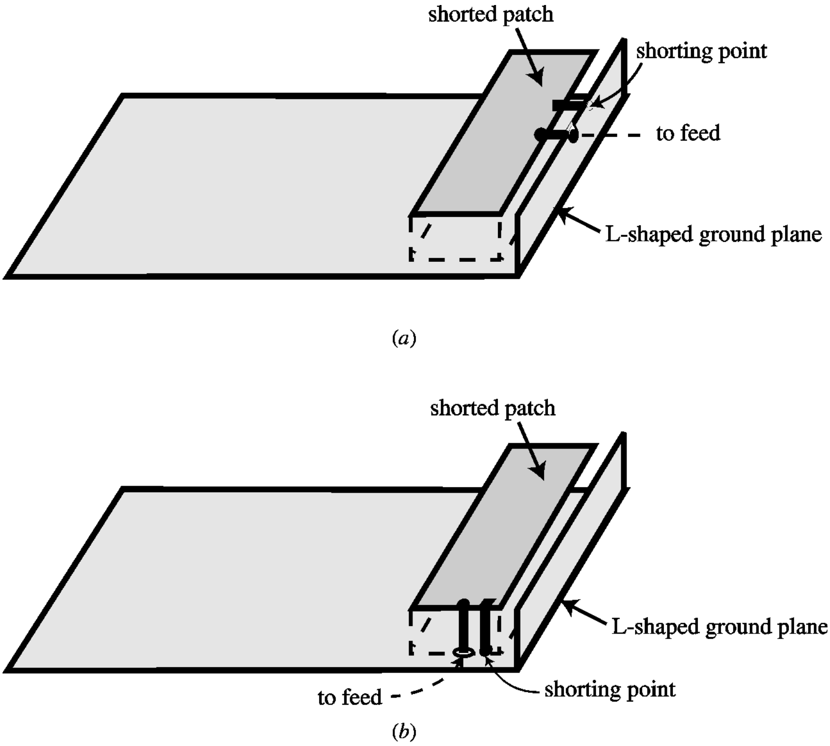

FIGURE 1.3 Geometries of a PIFA with an L-shaped ground plane. (a) The feed is in parallel with the radiating patch; (b) the feed is in perpendicular to the radiating patch.

have been reported [32–36]. A typical dual-frequency design is shown in Figure 1.4, which is a dual-frequency helical antenna with two different pitches for a GSM/DCS mobile phone [32, 33]. Figure 1.5 shows two other possible dual-frequency designs: The first design uses two helixes of different radii (the helix with a smaller radius for 1800 MHz operation is placed within the helix with a larger radius for 900 MHz operation) [32]. The second design uses a straight rod for 1800 MHz operation placed inside a uniform helix having the 900 MHz resonance [34, 35]. The design technique of configuring a folded loop to achieve two desired separate resonant frequencies for the 900 and 1800 MHz operations has also been used [36]. Although the antenna heights of these dual-frequency designs have been greatly reduced compared with that of a straight monopole, they are still larger than 10% of the wavelength of the lowest operating frequency.

To further reduce antenna height, a variety of novel dual-frequency monopole designs have been reported very recently [37–42]. These designs are mainly associated with bending, folding, or wrapping two-dimensional planar monopoles into three-dimensional structures. This technique greatly reduces the total antenna height from the ground plane of a mobile phone. Typical designs that have been reported have an antenna height of less than 15 mm (about 4% of the wavelength

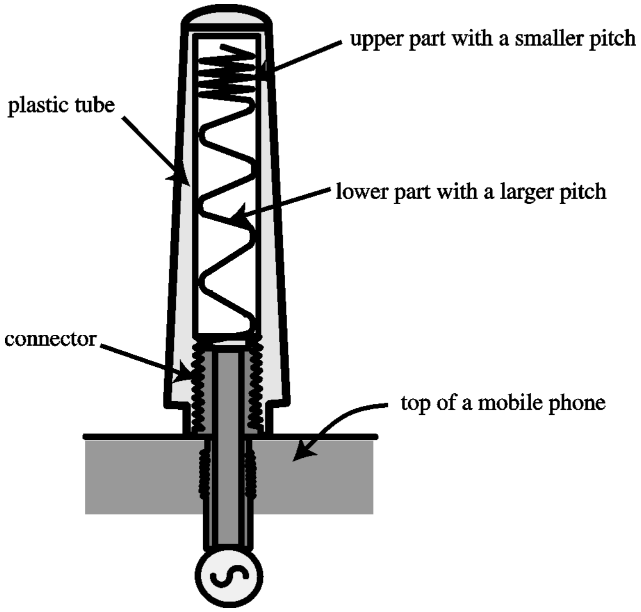

FIGURE 1.4 Geometry of a conventional dual-frequency helical antenna with two different pitches for a GSM/DCS mobile phone.

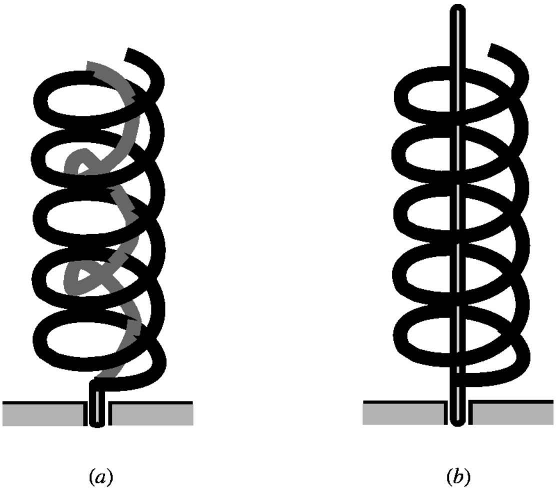
(*a*) (*b*)

FIGURE 1.5 Geometries of two types of dual-frequency helical antennas. (a) Two helixes with different radii; (b) one helix and one straight rod.

at 900 MHz). Some designs can even have an antenna height as low as 7 mm from the ground plane (about 2% of the wavelength at 900 MHz). Such antennas are very promising for placement within the mobile phone housing, that is, a concealed antenna for the mobile phone can be obtained. This kind of very-low-profile monopole designs for dual-frequency internal mobile phone antennas are described in detail in Chapter 3.

Some newly developed designs for achieving very-low-profile GSM/DCS dual-frequency monopoles for mobile phones are depicted in Figures 1.6–1.9. In Figure 1.6, dual-frequency operation is obtained by using a branch-line planar monopole comprising two printed meandered strips resonating at different frequencies [37, 39]. Because of the meandering, the antenna height from the mobile phone ground plane can be greatly reduced. Furthermore, it has been shown that, by wrapping a similar branch-line planar monopole into a rectangular boxlike structure as shown in Figure 1.7, a much reduced antenna height is obtained [37]. It should be noted that, in this design example, there are three branch lines. Among these, one is for the GSM operation, and the other two are for the DCS operation, whose impedance bandwidth also covers the operating band of the PCS system; that is, a GSM/DCS/PCS multiband operation is achieved [37].

Dual-frequency operation obtained by loading a meandered wire, which is for generating the 900 MHz resonance, to an inverted-L wire having the 1800 MHz resonance, has also been reported [40], and a typical configuration of the design is shown in Figure 1.8. Note that, in Figures 1.6–1.8, dual-frequency operations

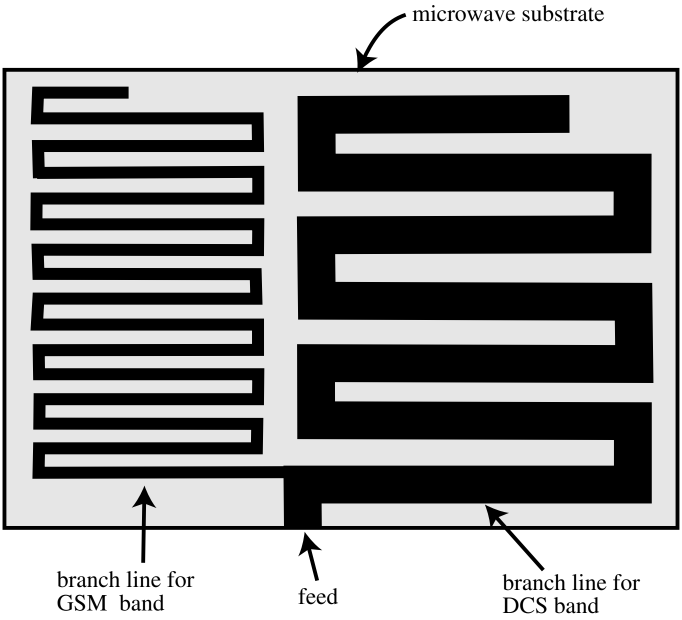

FIGURE 1.6 Geometry of a GSM/DCS dual-frequency planar branch-line monopole printed on a substrate.

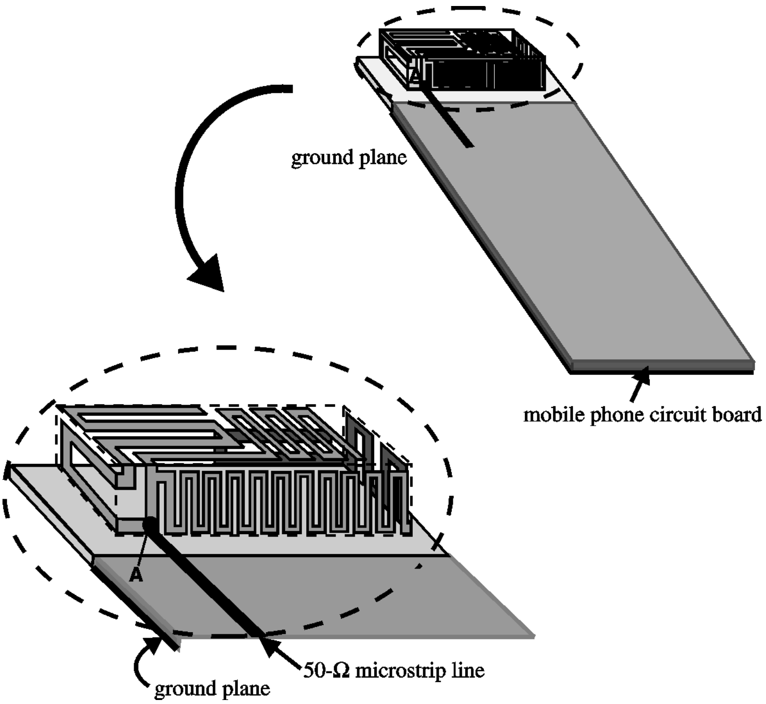

FIGURE 1.7 Geometry of a GSM/DCS/PCS multiband monopole obtained by wrapping a branch-line planar monopole and mounted on the top portion of a mobile phone circuit board.

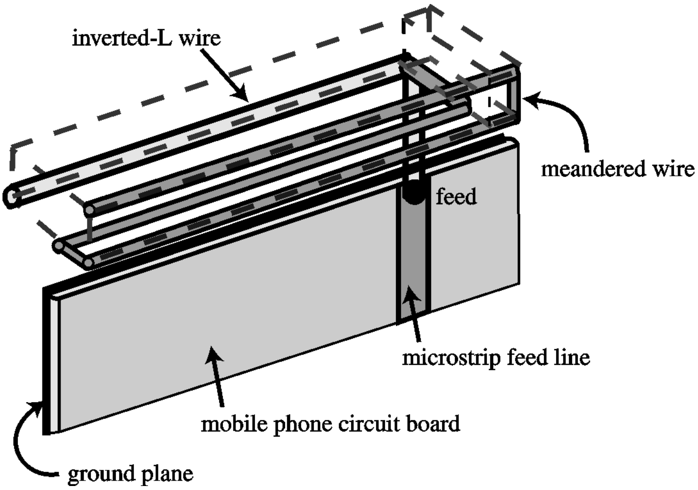

FIGURE 1.8 Geometry of a dual-frequency inverted-L wire antenna loaded with a meandered wire for a GSM/DCS mobile phone.

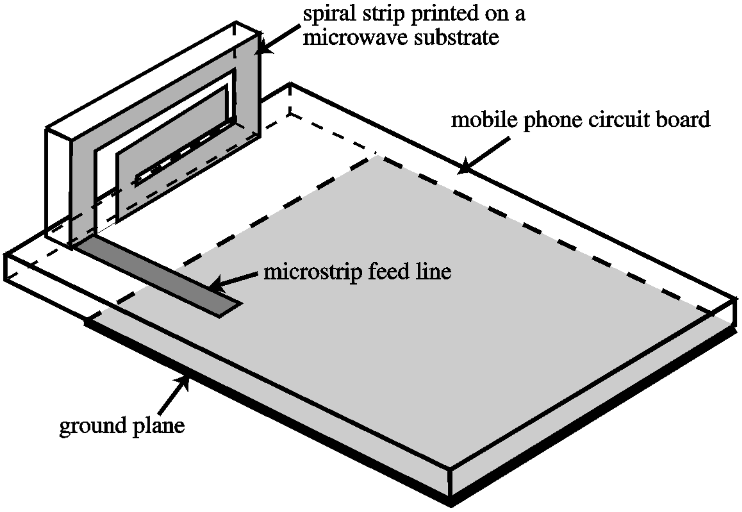

FIGURE 1.9 Geometry of a dual-frequency rectangular spiral monopole antenna mounted on the top portion of a mobile phone circuit board and positioned in perpendicular to the circuit board.

are obtained by using two separate resonant paths to generate the 900- and 1800-MHz-resonant frequencies (in Fig. 1.8, an additional resonant path is added to obtain an enhanced bandwidth for the 1800 MHz operation to cover the PCS band). This design concept has also been used in the designs shown in References 38 and 41. In Reference 38 a branch-line slit is inserted within a planar monopole to create two desired different resonant paths for the 900 and 1800 MHz resonances, and in Reference 41 a planar monopole comprising two subpatches of different sizes is wrapped into a rectangular boxlike structure to achieve 900 and 1800 MHz operations with a much reduced antenna height.

One can also use the antenna's first two resonant frequencies to achieve the 900 and 1800 MHz operations. A typical design using a rectangular spiral strip monopole is presented in Figure 1.9. The rectangular spiral strip monopole printed on a microwave substrate is mounted on the top portion of a mobile phone circuit board and positioned in perpendicular to the circuit board. With this arrangement, the distance of the rectangular spiral strip monopole from the mobile phone ground plane is greatly reduced; that is, a much reduced antenna height for the mobile phone is obtained. Also note that the spiral strip has different widths in different sections, which greatly affect the antenna's first two resonant frequencies. By utilizing this characteristic, the desired dual-frequency operation at 900 and 1800 MHz can be obtained by tuning the widths in different sections. This kind of dual-frequency rectangular spiral strip can also be folded onto a plastic chip as a surface-mountable antenna, as demonstrated in Reference 42.

The planar inverted-F antenna can also be directly printed on a mobile phone circuit board to operate as an integrated or on-board monopole antenna. A typical

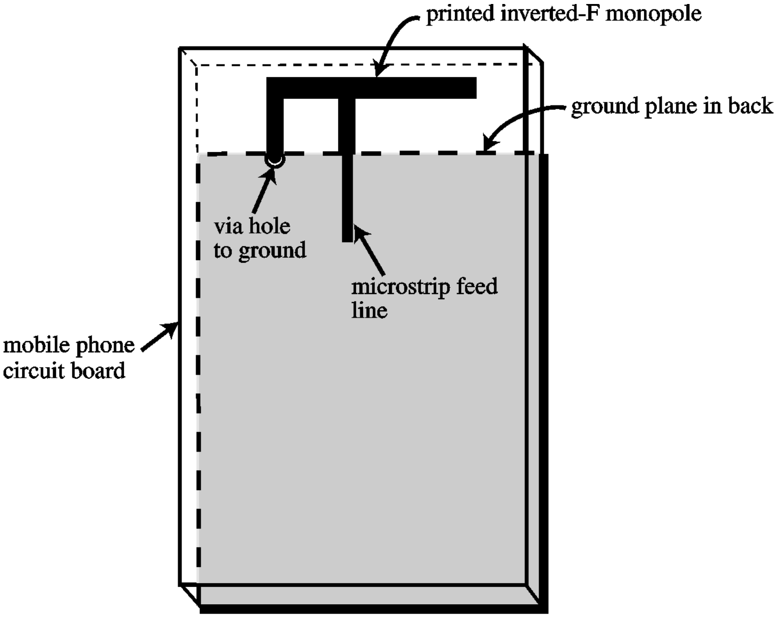

FIGURE 1.10 Geometry of an inverted-F monopole printed on a mobile phone circuit board.

design has been recently reported [43], and its geometry is shown in Figure 1.10. Monopole designs with reduced backward radiation have also been shown [44, 45] that have the advantages of enhancing antenna performance and reducing possible electromagnetic energy absorption by the user's head. These newly reported designs are discussed in detail in Chapter 3.

1.4 BASE STATION ANTENNAS FOR CELLULAR COMMUNICATION SYSTEMS

Planar antennas have also been widely applied in cellular system base stations. To achieve a broadband operation, conventional designs using a thick air-substrate patch antenna incorporating a U-slotted patch, an E-shaped patch, a wedge-shaped patch, an L-shaped probe feed, a three-dimensional transition feed, and so on, have been used [2, 46–52]. However, although wide impedance bandwidths are obtained for these designs, they usually do not cover the specific operating bandwidths of present-day cellular communication systems such as the GSM (890–960 MHz), DCS (1710–1880 MHz), PCS (1850–1990 MHz), and UMTS (1920–2170 MHz) systems.

To satisfy the specific operating bands, defined by 1.5:1 VSWR (voltage standing wave ratio), of the practical communication systems, many advanced designs have been demonstrated recently. To achieve single-band operation, a variety of designs

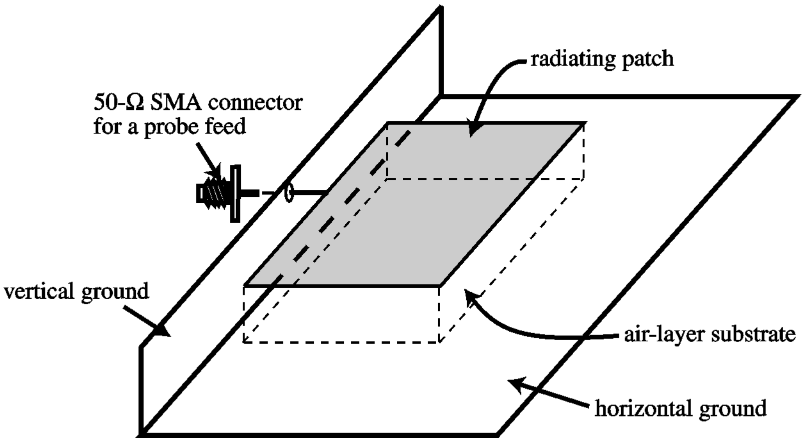

FIGURE 1.11 Geometry of a coplanar-probe-fed patch antenna for broadband operations.

using the slot-coupled feed [53], probe feed [54–59], coplanar probe feed [60], microstrip-line feed [61], and capacitively coupled feed [62, 63] have been used. Among these designs, many interesting novel design techniques are applied; for example, to avoid the large probe pin inductance introduced by a long probe pin required for a thick air-layer substrate, a very effective method of using a coplanar probe feed has been developed [60], in which the vertical ground plane added is for accommodating the coplanar probe feed (see Fig. 1.11). This design has a simple geometry, and good broadside radiation characteristics have also been obtained.

Other successful methods of using a conducting cylinder transition [54], a triangular transition patch [55], a ground plane with a small elevated portion [56], a W-shaped ground plane [57], an E-shaped patch incorporating a U-shaped ground plane [58, 59], and so on, have also been reported. In addition to the obtained wide impedance bandwidths covering the required bandwidths of the GSM, DCS, PCS, or UMTS systems, excellent radiation characteristics with much reduced cross-polarization radiation have been obtained in the designs shown in References 57 and 58. Moreover, enhanced antenna gain for the design with a W-shaped ground plane has been observed [57]. The peak antenna gain can reach about 10 dBi for a single-patch case in the DCS band. These designs are also very suitable for application in 1×N linear arrays for applications in cellular-system base stations to achieve a much larger antenna gain and a narrower beam width in the elevation plane. Two promising linear array designs are shown in Figures 1.12 and 1.13. Figure 1.12 shows the geometry of 1×2 array antenna using two W-shaped radiating patches. Note that the two feeds for the two W-shaped patches are out of phase, which can result in the cancellation of the waves that are related to the excitation of the higher-order modes and thus can lead to the reduction in cross-polarization radiation [57]. The geometry shown in Figure 1.13 is a 1×4 array antenna using four E-shaped patches, and for each E-shaped patch there are two vertical ground

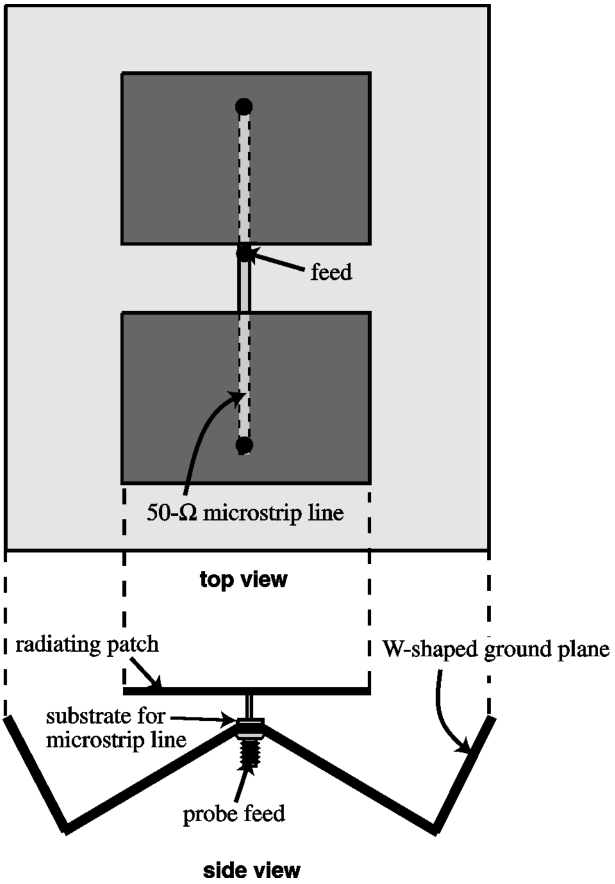

FIGURE 1.12 Geometry of a 1×2 W-shaped patch array antenna for applications in cellular system base stations.

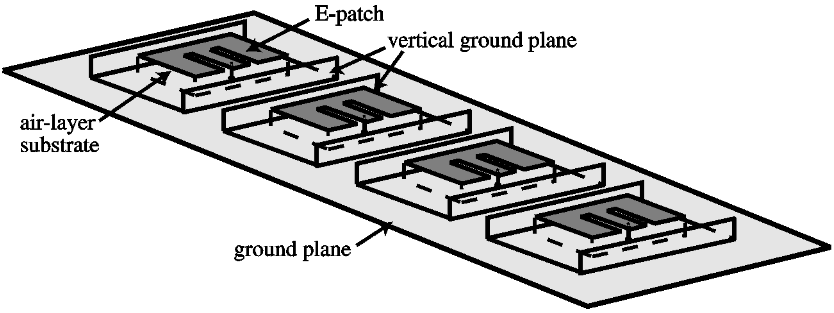

FIGURE 1.13 Geometry of a 1×4 E-patch array antenna for applications in cellular system base stations; feed network is not shown in the figure.

planes added, which can suppress the cross-polarization fields in the near fields, leading to reduced cross-polarization radiation [59].

Some novel dual-band (GSM/DCS) or multiband (GSM/DCS/PCS) designs have also been developed. The recent designs include a radiating patch incorporating a U-shaped ground plane [64] and a radiating patch incorporating a parasitic shorted patch. These designs have a more compact antenna size in comparison to the conventional design using two separate radiating patches [65]. Broadband dual-polarized patch antennas have also attracted much attention [66–72], owing to their capability of overcoming the multipath fading problem to enhance system performance. Several promising designs using two same feeds [66–69] or hybrid feeds [70, 71] to achieve high isolation (S_{21} less than -30 dB) between the two feeding ports have been reported. Much higher port decoupling (S_{21} less than -40 dB) for operating frequencies in the DCS band has been achieved in the design studied in Reference 71.

Promising designs to achieve dual-band dual-polarized radiation have also been reported. Figure 1.14 shows the geometry of a GSM/DCS dual-band dual-polarized patch antenna. This design, studied in Reference 72, consists of a rectangular ring patch for the GSM operation and a notched rectangular patch for the DCS operation, which are printed on the same layer, and each patch is aperture-coupled through two H-shaped coupling slots to generate two orthogonal linearly polarized waves. In addition to the compact dimensions obtained, this antenna shows good port decou-

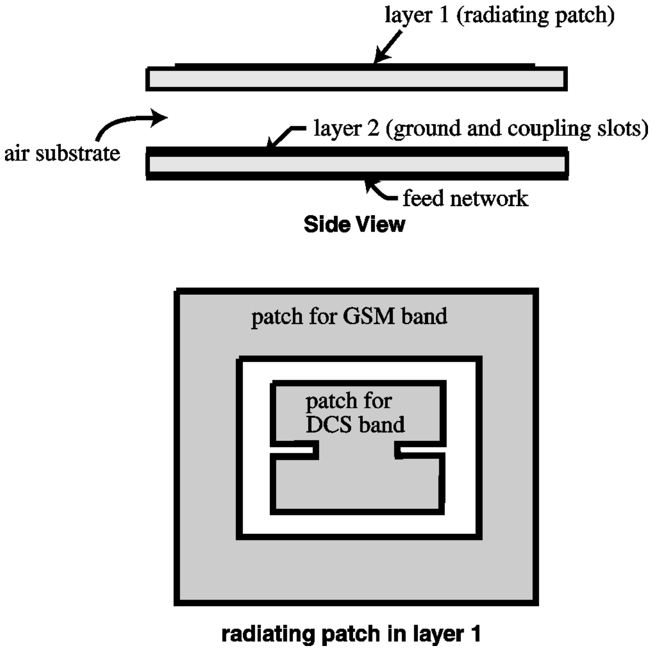

FIGURE 1.14 Geometry of a slot-coupled dual-band dual-polarized patch antenna for GSM/DCS operations; feed network and coupling slots are not shown in the figure.

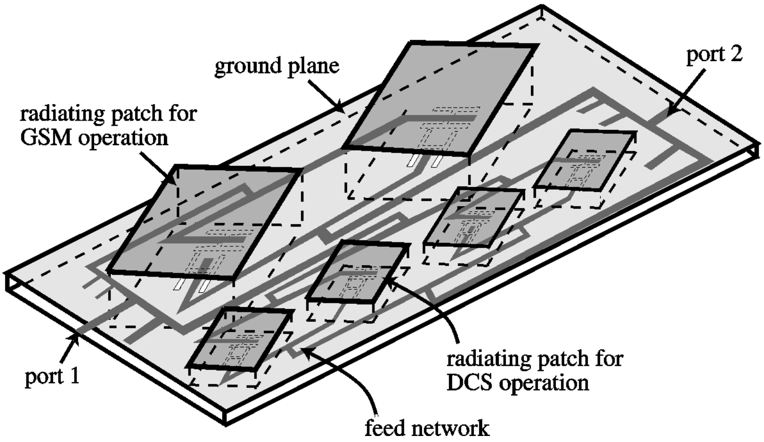

FIGURE 1.15 Geometry of an array antenna for GSM/DCS dual-band dual-polarized operations.

pling of less than −39 and −34 dB for dual linear polarizations in the GSM and DCS bands, respectively [72]. Figure 1.15 shows the promising design of a dual-polarized slot-coupled patch array for GSM/DCS base station antenna. Note that the 1×2 patch array with larger patches is for the GSM operation, and the 1×4 patch array with smaller patches is for the DCS operation. This design uses two slot-coupled feeds for each radiating patch to achieve dual-polarized radiation, and good impedance bandwidths in the GSM and DCS bands can be obtained by incorporating a properly designed feed network, whose design considerations are the same as described in Reference 72.

1.5 ANTENNAS FOR WLAN APPLICATIONS

There are in general two types of antennas to be considered for WLAN applications: one is for fixed WLAN base stations or access points, and the other is for mobile communication terminals. For base station applications, the impedance matching for operating frequencies within the WLAN bandwidth should be better than 1.5:1 VSWR or about 14 dB return loss, similar to that of the cellular system base stations. Moreover, because the wave propagation environment is usually complex for WLAN operation, the multipath fading problem can thus become a serious problem and can greatly affect the system performance. For this reason, the antennas capable of CP radiation are very attractive, because it can overcome the multipath fading problem to enhance the system performance, especially for indoor WLAN operation. However, to achieve good CP radiation for operating frequencies across a WLAN band, for example, the 2.4-GHz WLAN band (2400–2484 MHz), a two-feed design method [2] is usually required, which increases the complexity of the antenna design. Recently, a simple broadband CP design using a single-feed method has been developed. This design uses a coplanar probe feed and has a simple geometry similar to that shown in Figure 1.11. Experimental results of a constructed prototype for operating in the 2.4-GHz band showed that the antenna can have an impedance bandwidth (1.5:1 VSWR) of about 30% and a 3-dB axial-ratio CP bandwidth of about 10.4%, covering the frequency range of 2400–2484 MHz. Large antenna gain level (about 8.5 dBi) for frequencies within the CP bandwidth has also been obtained. This antenna design can be implemented with very low cost and is very suitable for WLAN access point applications. Other promising designs suitable for WLAN access-point applications, such as the use of an inverted-L patch antenna to achieve dual-band WLAN operations in the 2.4- and 5.2-GHz bands [73], have also been addressed. Details of these antenna designs and their experimental results are presented in Chapter 5.

On the other hand, the antennas for mobile communication units must have the features of small size, low cost, and good performance. For some cases, it is further required that the antennas should be surface mountable to reduce the packaging cost. For this purpose, the ceramic chip antennas [74–77] have been reported. Such chip antennas usually comprise a ceramic base and metal line patterns printed on or embedded within the base. In addition, they are compact in size and can be directly mounted on a circuit board in a communication device. The geometry of a typical ceramic chip antenna is shown in Figure 1.16. Note that, in this design, a gap is cut in the feed line for impedance tuning, and some small protruded grounds are also printed in the ceramic chip's side surfaces for easy connection to the system ground.

However, the ceramic chip antennas have a major disadvantage; that is, they tend to break easily, because the ceramic materials are fragile in nature. Furthermore, the fabrication cost of this kind of antennas is usually high. To overcome these problems, a low-cost surface-mountable antenna constructed by folding a planar monopole made of a copper plate into a rectangular disklike structure has

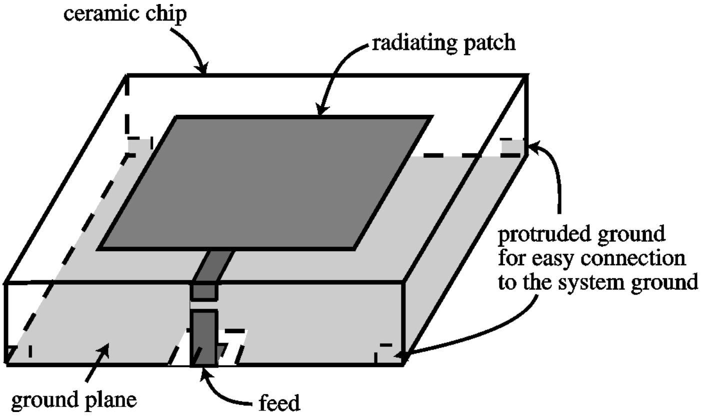

FIGURE 1.16 Geometry of a ceramic chip antenna as a surface-mountable antenna for WLAN applications.

been used [78]. This antenna uses no ceramic base and has a rigid structure of a rectangular disklike shape. In addition, the antenna can be easily fed by using a 50-Ω microstrip line, which makes it surface mountable like the ceramic chip antennas. Moreover, dual-frequency operation can also be obtained. A design example for achieving dual-band WLAN operations in the 2.4- and 5.2-GHz bands has been successfully implemented.

Several designs of the integrated monopole antenna have also been demonstrated that print and integrate a monopole on a small portion of the circuit board of a communication device [79-82]. A typical integrated monopole antenna design is shown in Figure 1.17, in which the monopole has an F shape and can perform dual-WLAN operations in the 2.4 and 5.2 GHz bands [82]. Such antennas have the advantages of occupying a very small volume of the system, decreasing the total fabrication cost, and easily integrating with the associated circuitry on the circuit board.

The printed diversity monopole antennas suitable for combating the multipath fading problem have also been available in the open literature. For this purpose, a printed dual orthogonal monopole antenna for diversity operation in the 2.4 GHz WLAN band has been devised [83], and the antenna geometry is shown in Figure 1.18. Note that the dual orthogonal straight monopoles for providing polarization diversity are printed and integrated on the same microwave substrate, and a protruded ground plane of suitable dimensions is added between the two monopoles to enhance the port decoupling between the two feeding ports. In this case, a constructed prototype for WLAN operation in the 2.4 GHz band [83] showed that the measured reflection coefficient (S_{11}) of the operating frequencies within the WLAN band is less than −20 dB, and the measured isolation (S_{21}) is less than −27 dB, which is much better than that without a protruded ground plane (less than about −12 dB). A design of the diversity monopole antenna capable of dual-band operations in the 2.4 and 5.2 GHz bands is also available and is described in Chapter 5.

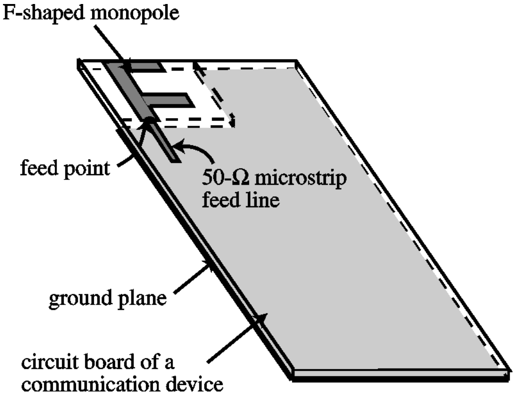

FIGURE 1.17 Geometry of an F-shaped monopole antenna integrated on the circuit board of a communication device for dual-band WLAN applications.

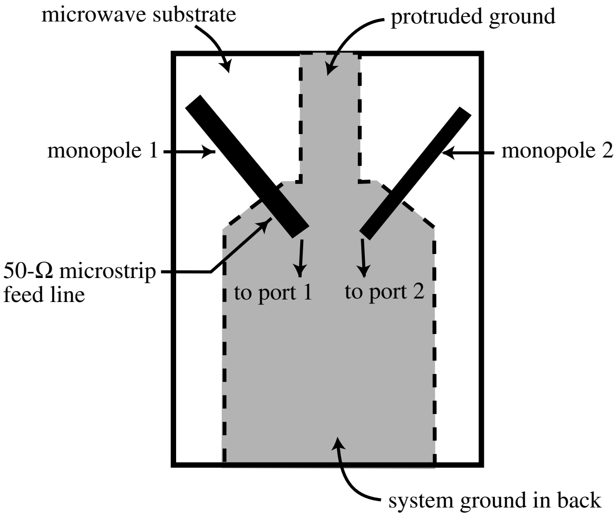

FIGURE 1.18 Geometry of an integrated diversity monopole antenna for WLAN applications.

The dual-band PIFA designs described in Section 1.2 are also very suitable for achieving dual-band WLAN operations in the 2.4 and 5.2 GHz bands. Several successful designs have been reported [10, 84, 85]. In contrast to the monopole antennas, these dual-band PIFAs can be placed directly on the ground plane of a communication device, which increases their design freedom and possible applications.

To obtain dual-polarized radiation for applications in a mobile communication unit, an interesting low-cost compact antenna design has been developed. This antenna design is obtained by applying the technique of using a slotted ground plane [86]. By embedding four linear slots, oriented in perpendicular to each other, in the ground plane of a microstrip antenna with an inexpensive FR4 substrate (thickness 1.6 mm and relative permittivity 4.4), and feeding the antenna using two probe feeds at two orthogonal positions, $\pm 45^\circ$ slanted linear polarizations can be generated. Owing to the embedded slots in the antenna's ground plane, which can lead to antenna size reduction without a sacrifice in the impedance bandwidth and antenna gain [86], this antenna provides a small size ($35 \times 35\,\mathrm{mm}^2$) for operating in the 2.4 GHz band, which makes it suitable for integration into a restricted area as a part of a WLAN personal computer memory card international association (PCMCIA) card for wireless Internet access for notebook computers. In addition, good dual-polarized performance is obtained, and the antenna has an impedance bandwidth of about 3.5% covering the 2.4 GHz WLAN band. A peak antenna gain of about 2.5 dBi for the two orthogonal linear polarizations has been obtained, and an isolation between the two feeding ports of less than -20 dB has been achieved.

1.6 DIELECTRIC RESONATOR ANTENNAS FOR WIRELESS COMMUNICATIONS

Dielectric resonator antennas have been shown to be efficient radiators [3, 87]. They require no radiating metal patch and thus have relatively lower loss compared with microstrip antennas, especially for operating at higher frequencies. Dielectric resonator antennas also have the advantage of easy excitation through the use of transmission lines such as a microstrip line [88] or a coplanar waveguide [89] (see Fig. 1.19). Many studies have also been conducted and are available in the open literature [3].

Recently, it has been shown that, when a very-high-permittivity DR element is used, the DR antenna can have a very low profile. For operating in the 5.2 GHz WLAN band, the antenna has a low profile of only 1.9 mm and occupies a small area of 10×10 mm^2, with the use of a DR element having a relative permittivity

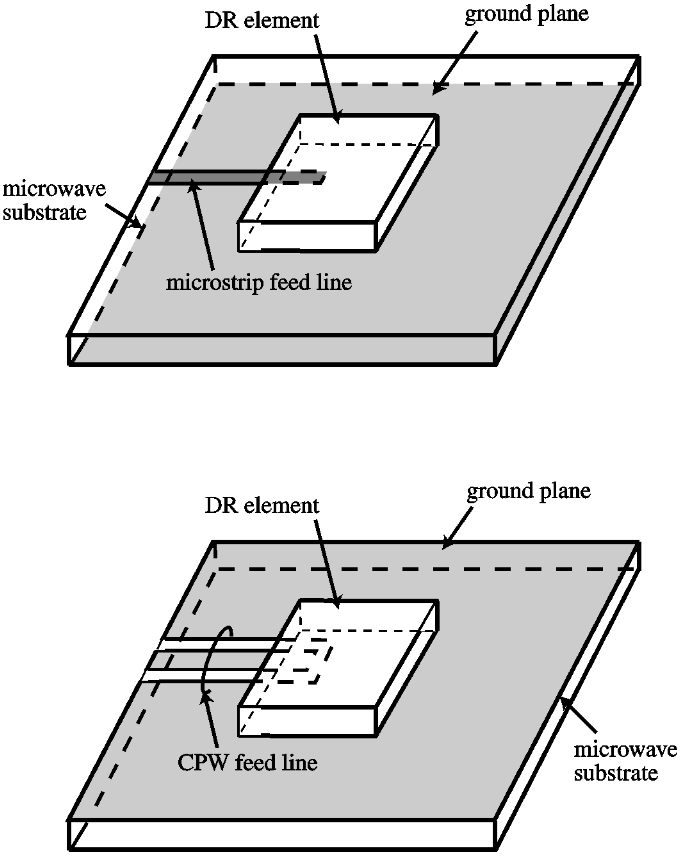

FIGURE 1.19 Low-profile, very-high-permittivity DR antennas fed by a microstrip line and a coplanar waveguide (CPW) feed.

of 90.5 [90]. Owing to its low profile and compact size, this kind of very-high-permittivity DR antenna is very suitable for WLAN applications. For this reason, many advanced designs for achieving CP radiation, broadband operation, and dual-polarized operation have been developed.

For the case of achieving CP radiation using a single feed, conventional designs are mainly based on the use of DR elements with special configurations, such as the nearly cubic DR [91], the rectangular DR with a special length-to-width ratio [92], or the cross-shaped DR [93]. In these designs, the requirement for special configurations of the DR elements increases the complexity in antenna fabrication, which makes them less attractive for practical applications. Recently, several interesting designs have been reported [88, 94–96]. These CP designs are applicable to cases with regular DR elements and are promising for practical applications. The design techniques include the use of the regular DR element fed by a cross-slot-coupled feed [94] and the use of parasitic conformal strips [95–97] and a loading patch [88].

A CP design using two DR elements has also been shown [98]. In this design, the technique of using two linearly polarized radiating elements for obtaining CP radiation was applied. Advances in very-high-permittivity DR antennas for achieving broadband operation [90] and dual-polarized radiation [99] have also been achieved. These recent advanced designs are addressed in Chapter 6, and their possible applications for WLAN operations are discussed.

1.7 INTEGRATION OF ANTENNAS FOR DIFFERENT OPERATING BANDS

For some applications, it is required that a global positioning system (GPS) antenna be integrated into a communication device to provide GPS signal reception. For this purpose, several integration designs for integrating a GPS antenna with a DCS antenna or a WLAN antenna have been devised recently [100]. Similarly, the integration of a WLAN antenna with a DCS antenna has also been shown [101]. These integration designs and the experimental results are described in detail in Chapter 7.

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