Compact and Broadband Microstrip Antennas. Kin-Lu Wong

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Preface

In order to meet the miniaturization requirements of portable communication equipment, researchers have given much attention recently to compact microstrip antennas. Many related compact designs with broadband dual-frequency operation, dual-polarized radiation, circularly polarized radiation, and enhanced antenna gain have been reported. Many significant advances in improving the inherent narrow operating bandwidth of microstrip antennas have been published in the open literature since 1997. By using presently available techniques, one can easily achieve an impedance bandwidth (1:2 voltage standing wave ratio) of larger than 25% for a probe-fed single-patch microstrip antenna. Other feeding methods such as the use of an aperture-coupled feed, a capacitively coupled feed, or a three-dimensional microstrip transition feed can yield impedance bandwidths greater than 40% with good radiation characteristics for a single-patch microstrip antenna. In addition, various designs for achieving broadband circularly polarized radiation, broadband dual-frequency operation, and broadband dual-polarized radiation have been demonstrated. Taking broadband circularly polarized radiation as an example, some recently reported designs exhibit a 3-dB axial-ratio bandwidth greater than 40% for a single-patch microstrip antenna.

Since 1997, the author and his graduate students at National Sun Yat-Sen University, Kaohsiung, Taiwan, have published more than 100 refereed journal papers on the subject of compact and broadband microstrip antennas. These results along with many other advanced designs reported recently by antenna researchers are scattered in many technical journals, and it is the intention of this book to organize these advanced designs in the areas of compact and broadband microstrip antennas.

The microstrip antenna designs covered in this book are divided into two groups: compact microstrip antennas and broadband microstrip antennas. The book is organized into nine chapters. Chapter 1 presents an introduction and overview of recent advances in the design of both compact and broadband microstrip antennas. Chapters 2–6 describe in detail advanced designs for compact microstrip antennas, compact broadband microstrip antennas, compact dual-frequency and dual-polarized microstrip antennas, compact circularly polarized microstrip antennas, and compact microstrip antennas with enhanced gain, respectively. Chapters 7–9 are devoted respectively to advanced designs for broadband microstrip antennas, broadband dual-frequency and dual-polarized microstrip antennas, and broadband and dual-band circularly polarized microstrip antennas.

Chapter 2 introduces recent advances in compact microstrip antennas. Based on recent compact design techniques, such as using a shorted patch, a meandered patch, a meandered ground plane, an inverted U-shaped patch, a planar inverted-L patch, among others, microstrip antenna designs are discussed in the different sections of this chapter. Details of antenna designs and experimental results are presented.

Chapter 3 discusses compact broadband microstrip antenna designs. Design techniques for achieving broadband operation with a reduced antenna size are described. Related techniques include the use of a shorted patch with a thick air substrate, stacked shorted patches, chip-resistor loading, chip-resistor and chip-capacitor loading, and slot loading in the radiating patch or ground plane. Chapter 4 presents designs for compact dual-frequency and dual-polarized microstrip antennas. Recent advances in regular-size dual-frequency designs are first discussed, and then designs for achieving compact dual-frequency operation with same-polarization and orthogonal polarization planes are described in detail. Both regular-size and compact dual-frequency designs are discussed, which should give the reader a more complete view of recent developments in dual-frequency design. Advances in compact dual-polarized design are also reviewed, and design examples are given.

Advances in compact circularly polarized (CP) microstrip antennas are considered in Chapter 5. Examples of compact CP designs, including those using a probe feed, an edge-fed microstrip-line feed, or an inset-microstrip-line feed, are presented. Designs for achieving gain-enhanced compact microstrip antennas are included in Chapter 6. Some design examples for active compact microstrip antennas and gain-enhanced compact circularly polarized microstrip antennas are given.

Chapter 7 is devoted to recent advances in broadband microstrip antennas. Advances in broadband microstrip antennas with, for example, additional microstrip resonators, an air or a foam substrate, slot loading, or integrated reactive loading are presented and discussed in detail. Broadband designs with reduced cross-polarization radiation are presented. Chapter 8 presents broadband dual-frequency and dual-polarized microstrip antennas. Various design examples are presented, and design considerations for achieving high isolation and low cross-polarization for broadband dual-polarized radiation are addressed.

Finally, in Chapter 9, advances in broadband and dual-band circularly polarized microstrip antennas are discussed. Related broadband designs with single-feed excitation, two-feed excitation with a 90° phase shift, and four-feed excitation with 0°–90°–180°–270° phase shifts are studied. In addition to obtaining a wide axial-ratio bandwidth, it is shown how to improve CP quality in the entire radiation pattern to achieve wide-angle CP coverage, and related designs are presented. Recent advances in dual-band CP radiation are included in this chapter.

This book is intended to organize new advanced designs of compact and broadband microstrip antennas, mainly those reported since 1997. Over 100 advanced microstrip antenna designs and their detailed experimental results are included. It is believed that this book can be a very useful design reference on compact and broadband microstrip antennas for antenna scientists and engineers.

KIN-LU WONG
Kaohsiung, Taiwan

Compact and Broadband Microstrip Antennas

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CHAPTER ONE

Introduction and Overview

1.1 INTRODUCTION

Conventional microstrip antennas in general have a conducting patch printed on a grounded microwave substrate, and have the attractive features of low profile, light weight, easy fabrication, and conformability to mounting hosts [1]. However, microstrip antennas inherently have a narrow bandwidth, and bandwidth enhancement is usually demanded for practical applications. In addition, applications in present-day mobile communication systems usually require smaller antenna size in order to meet the miniaturization requirements of mobile units. Thus, size reduction and bandwidth enhancement are becoming major design considerations for practical applications of microstrip antennas. For this reason, studies to achieve compact and broadband operations of microstrip antennas have greatly increased. Much significant progress in the design of compact microstrip antennas with broadband, dual-frequency, dual-polarized, circularly polarized, and gain-enhanced operations have been reported over the past several years. In addition, various novel broadband microstrip antenna designs with dual-frequency, dual-polarized, and circularly polarized operations have been published in the open literature. This book organizes and presents these recently reported novel designs for compact and broadband microstrip antennas.

1.2 COMPACT MICROSTRIP ANTENNAS

Many techniques have been reported to reduce the size of microstrip antennas at a fixed operating frequency. In general, microstrip antennas are half-wavelength structures and are operated at the fundamental resonant mode TM_{01} or TM_{10}, with a resonant frequency given by (valid for a rectangular microstrip antenna with a thin microwave substrate)

$$f \cong \frac{c}{2L\sqrt{\varepsilon_r}}, \qquad (1.1)$$

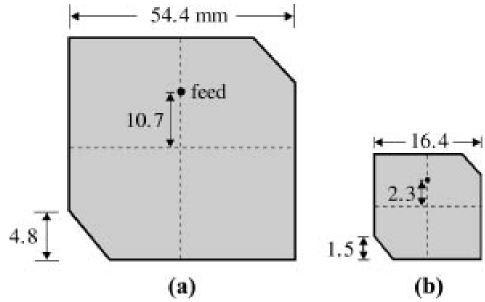

FIGURE 1.1 Circularly polarized corner-truncated square microstrip antennas for GPS application at 1575 MHz. (a) Design with a microwave substrate ($\varepsilon_r = 3.0$, $h = 1.524$ mm); (b) design with a ceramic substrate ($\varepsilon_r = 28.2$, $h = 4.75$ mm). Dimensions are in millimeters and not to scale.

where c is the speed of light, L is the patch length of the rectangular microstrip antenna, and ε_r is the relative permittivity of the grounded microwave substrate. From (1.1), it is found that the radiating patch of the microstrip antenna has a resonant length approximately proportional to $1/\sqrt{\varepsilon_r}$, and the use of a microwave substrate with a larger permittivity thus can result in a smaller physical antenna length at a fixed operating frequency. Figure 1.1 shows a comparison of the required dimensions for two circularly polarized corner-truncated square microstrip antennas with different substrates for global positioning system (GPS) application. The first design uses a microwave substrate with relative permittivity $\varepsilon_r = 3.0$ and thickness $h = 1.524$ mm; the second design uses a high-permittivity or ceramic substrate with $\varepsilon_r = 28.2$ and $h = 4.75$ mm. The relatively larger substrate thickness for the second design is needed to obtain the required circular polarization (CP) bandwidth for GPS application. From the patch areas of the two designs, it can be seen that the second design has a patch size about 10% of that of the first design. This reduction in antenna size can be expected from (1.1), from which the antenna's fundamental resonant frequency of the design with $\varepsilon_r = 28.2$ is expected to be only about 0.326 times that of the design with $\varepsilon_r = 3.0$ for a fixed patch size. This result suggests that an antenna size reduction as large as about 90% can be obtained if the design with $\varepsilon_r = 28.2$ is used instead of the case with $\varepsilon_r = 3.0$ for a fixed operating frequency.

The use of an edge-shorted patch for size reduction is also well known [see the geometry in Figure 1.2(a)], and makes a microstrip antenna act as a quarter-wavelength structure and thus can reduce the antenna's physical length by half at a fixed operating frequency. When a shorting plate (also called a partial shorting wall) [see Figure 1.2(b)] or a shorting pin [Figure 1.2(c)] is used instead of a shorting wall, the antenna's fundamental resonant frequency can be further lowered and further size reduction can be obtained. In this case, the diameter of a shorting-pin-loaded circular microstrip patch [2] or the linear dimension of a shorting-pin-loaded rectangular microstrip patch [3] can be as small as one-third of that of the corresponding microstrip patch without a shorting pin at the same operating frequency. This suggests that an antenna size reduction of about 89% can be obtained. Moreover, by applying the

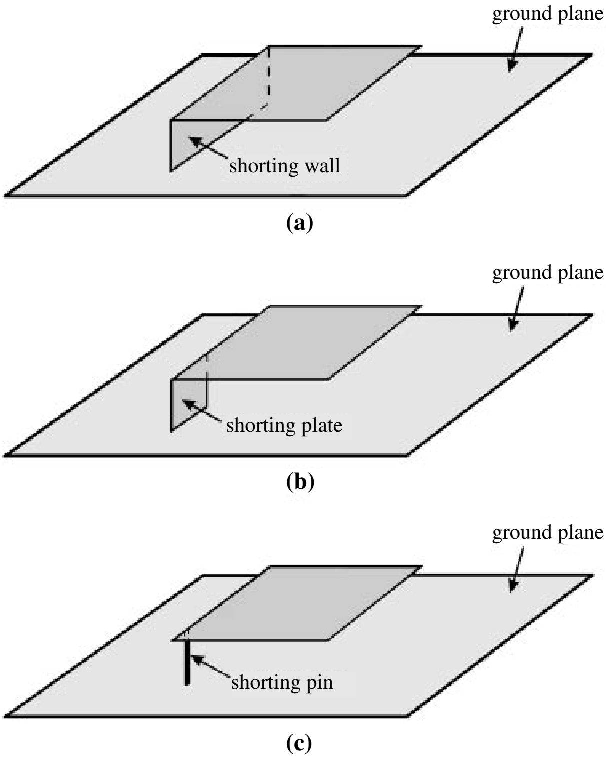

FIGURE 1.2 Geometries of a rectangular patch antenna with (a) a shorting wall, (b) a shorting plate or partial shorting wall, and (c) a shorting pin. The feeds are not shown.

shorting-pin loading technique to an equilateral-triangular microstrip antenna, the size reduction can be made even greater, reaching as large as 94% [4]. This is largely because an equilateral-triangular microstrip antenna operates at its fundamental resonant mode, whose null-voltage point is at two-thirds of the distance from the triangle tip to the bottom side of the triangle; when a shorting pin is loaded at the triangle tip, a larger shifting of the null-voltage point compared to the cases of shorted rectangular and circular microstrip antennas occurs, leading to a greatly lowered antenna fundamental resonant frequency.

Meandering the excited patch surface current paths in the antenna's radiating patch is also an effective method for achieving a lowered fundamental resonant frequency for the microstrip antenna [3, 5–8]. For the case of a rectangular radiating patch, the meandering can be achieved by inserting several narrow slits at the patch's nonradiating edges. It can be seen in Figure 1.3(a) that the excited patch's surface currents are effectively meandered, leading to a greatly lengthened current path for a fixed patch linear dimension. This behavior results in a greatly lowered antenna fundamental resonant frequency, and thus a large antenna size reduction at a fixed operating frequency can be obtained. Figure 1.3(b) shows similar design, cutting a pair of triangular

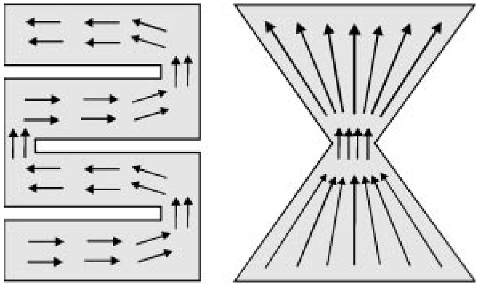

FIGURE 1.3 Surface current distributions for meandered rectangular microstrip patches with (a) meandering slits and (b) a pair of triangular notches cut at the patch's nonradiating edges.

notches at the patch's nonradiating edges to lengthen the excited patch surface current path [8]. The resulting geometry is referred to as a bow-tie patch. Compared to a rectangular patch with the same linear dimension, a bow-tie patch will have a lower resonant frequency, and thus a size reduction can be obtained for bow-tie microstrip antennas at a given operating frequency.

The technique for lengthening the excited patch surface current path mentioned above is based on a coplanar or single-layer microstrip structure. Surface current lengthening for a fixed patch projection area can also be obtained by using an inverted U-shaped patch [Figure 1.4(a)], a folded patch [Figure 1.4(b)], or a double-folded patch [Figure 1.4(c)]. With these microstrip patches, the resonant frequency can be greatly lowered [9, 10] compared to a regular single-layer microstrip antenna with the same projection area. Note that the resonant frequency is greatly lowered due to the bending of the patch surface current paths along the antenna's resonant or excitation direction, and that no lateral current components are generated, in contrast to the case of the meandering technique shown in Figure 1.3. Probably for this reason, it has been observed that compact microstrip antennas using the bending technique described here have good cross-polarization levels for frequencies within the operating bandwidth.

By embedding suitable slots in the radiating patch, compact operation of microstrip antennas can be obtained. Figure 1.5 shows some slotted patches suitable for the design of compact microstrip antennas. In Figure 1.5(a), the embedded slot is a cross slot, whose two orthogonal arms can be of unequal [11] or equal [12–14] lengths. This kind of slotted patch causes meandering of the patch surface current path in two orthogonal directions and is suitable for achieving compact circularly polarized radiation [11, 12] or compact dual-frequency operation with orthogonal polarizations [13, 14]. Similarly, designs with a pair of bent slots [15] [Figure 1.5(b)], a group of four bent slots [16, 17] [Figure 1.5(c)], four 90°-spaced inserted slits [18] [Figure 1.5(d)], a perforated square patch or a square-ring patch with a cross strip [19] [Figure 1.5(e)], a circular slot [20] [Figure 1.5(f)], a square slot [21] [Figure 1.5(g)], an offset circular slot [22] [Figure 1.5(h)], and a perforated tip-truncated triangular patch [23] [Figure 1.5(i)] have been successfully applied to achieve compact circularly polarized or compact dual-frequency microstrip antennas.