UNITED STATES PATENT AND TRADEMARK OFFICE

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BEFORE THE PATENT TRIAL AND APPEAL BOARD

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GEOTAB INC. AND GEOTAB USA, INC.,
Petitioners

v.

FRACTUS, S.A.,
Patent Owner

_____

Case No. IPR2025-00929
Patent No. 8,810,458

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DECLARATION OF JAMES L. MULLINS, Ph.D.

I, James L. Mullins, declare as follows:

1. My name is James L. Mullins.

2. I have been retained by petitioners Geotab Inc. and Geotab USA, Inc. in the above-captioned *inter partes* review relating to U.S. Patent No. 8,810,458 to provide opinions on various documents.

I. INTRODUCTION

3. I am presently Dean Emeritus of Libraries and Esther Ellis Norton Professor Emeritus at Purdue University. My career as a professional and academic/research librarian spanned more than 44 years, including library positions at Indiana University, Villanova University, Massachusetts Institute of Technology, and Purdue University. EX1007 is a true and correct copy of my curriculum vitae describing my background and experience.

4. In January 2018, I founded the firm Prior Art Documentation Librarian Services, LLC, located at 205 St. Cuthbert, Williamsburg, VA 23188 after purchasing the intellectual property of Prior Art Documentation, LLC located at 711 South Race Street, Urbana, IL 61801. Further information about my firm, Prior Art Documentation Librarian Services, LLC (PADLS), is available at https://www.priorartdoclib.com.

5. I have been retained by Geotab Inc. and Geotab USA, Inc. to offer my opinion on the authenticity and dates of public accessibility of various documents.

For this service, I am being paid my usual hourly fee of $275.00/hour. I have no stake in the outcome of this proceeding or any related litigation or administrative proceedings, and my compensation in no way depends on the substance of my testimony or the outcome of any proceeding.

II. QUALIFICATIONS

6. I received a Bachelor of Arts degree in History, Religion and Political Science in 1972 as well as a Master of Arts degree in Library Science in 1973 from the University of Iowa. I received my Ph.D. in Academic Library Management in 1984 from Indiana University. Over the past fifty years, I have held various positions in the field of library and information sciences.

7. I am presently Dean Emeritus of Libraries and Esther Ellis Norton Professor Emeritus at Purdue University, and have been since January 1, 2018. I have been previously employed as follows:

Dean of Libraries and Professor and Esther Ellis Norton Professor, Purdue University, West Lafayette, IN (2004-December 31, 2017)

Assistant/Associate Director for Administration, Massachusetts Institute of Technology (MIT) Libraries, Cambridge, MA (2000-2004)

University Librarian and Director, Falvey Memorial Library, Villanova University, Villanova, PA (1996-2000)

Director of Library Services, Indiana University South Bend, South Bend, IN (1978-1996)

Part-time Instructor, School of Library and Information Science, Indiana University, Bloomington, IN (1979-1996)

Associate Law Librarian, and associated titles, Indiana University School of Law, Bloomington, IN (1974-1978)

Catalog Librarian, Assistant Professor, Georgia Southern College (now University), Statesboro, GA (1973-1974)

8. I have been a member of the American Library Association ("ALA") since 1974. I served as the chair of the Research Committee of the Association of College and Research Libraries ("ACRL"). My service included the editorial board of the most prominent library journal, *College and Research Libraries*. I also served on the Standards Committee, College Section of the Association of College and Research Libraries, where I was instrumental in developing a re-issue of the *Standards for College Libraries* in 2000.

9. For over 20 years I was actively engaged in academic library professional associations on the international level including invited papers and lectures in Germany, Norway, Israel, Argentina, Australia, South Africa, New Zealand, Hong Kong, Israel, Turkey, Greece, Canada, France, Belgium, China, Japan, South Korea, Finland, Sweden, Poland, Portugal, Spain, Switzerland, Singapore, and the United Kingdom.

10. I am an author of numerous publications in the field of library science, and have given presentations in library sciences at national and international

conferences. During more than 44 years as an academic librarian and library science scholar, I have gained extensive experience with catalog records and online library management systems ("LMS") built using Machine-Readable Cataloging ("MARC") standards. As a part-time instructor at the School of Library and Information Science, Indiana University, I taught, as well as other courses, the cataloging course, "Organization of Library Materials."

11. As an academic library administrator, I have had responsibility to ensure that students were educated to identify, locate, assess, and integrate information garnered from research library resources. I have also facilitated the research of faculty colleagues either directly or through the provision of and access to the requisite print and/or digital materials and services at the universities where I worked.

12. Based on my experience identified above and detailed in my curriculum vitae (EX1007), I consider myself to be an expert in the field of library science and academic library administration. I have previously offered my opinions on the public availability and authenticity of documents in over 150 cases. I have been deposed in four cases.

III. BACKGROUND ON PUBLIC ACCESSIBILITY

A. Scope of This Declaration

13. I am not a lawyer, and I am not rendering an opinion on the legal question of whether a particular document is, or is not, a "printed publication" under the law. I am, however, rendering my expert opinion on the authenticity of particular documents referenced herein and when and how these documents were disseminated or otherwise made available to the extent that people interested and ordinarily skilled in the subject matter or art, exercising reasonable diligence, could have located the documents.

14. I am informed by counsel for Petitioners that a document is considered authentic if there is sufficient evidence to support a finding that the item is what it is claimed to be. I am also informed that authenticity can be established based on the contents of the document itself, such as the appearance, content, substance, internal patterns, or other distinctive characteristics of the document.

15. I am informed by counsel for Petitioners that a given reference qualifies as "publicly accessible" if it was disseminated or otherwise made available such that a person interested in and ordinarily skilled in the relevant subject matter or art could locate it through the exercise of ordinary diligence.

16. While I understand that the determination of public accessibility under the foregoing standard rests on a case-by-case analysis of the facts particular to an individual publication, I also understand that a document is considered "publicly accessible" if it is cataloged and indexed by a library such that a person interested in the relevant subject matter could locate it (*i.e.*, I understand that cataloging and indexing by a library is sufficient, though there are other ways that a document may qualify as "publicly accessible"). One manner of sufficient indexing is indexing according to subject matter. I understand that it is not necessary to prove someone actually looked at the document in order to show it was publicly accessible by virtue of a library's cataloging and indexing thereof. I understand that cataloging and indexing by a single library of a single instance of a particular document is sufficient for public accessibility.

17. I understand that evidence showing the specific date when a reference became publicly accessible is not necessary. Rather, routine business practices, such as general library cataloging and indexing practices, can be used to establish a date by which a reference became publicly accessible.

B. Person of Ordinary Skill in the Art

18. In forming the opinions expressed in this declaration, I have reviewed the documents and appendices referenced herein. These materials are records created in the ordinary course of business by publishers, libraries, indexing

services, and/or others. From my years of experience, I am familiar with the process for creating many of these records, and I know that these records are created by people with knowledge of the information contained within the record.

19. Further, these records are created with the expectation that researchers and other members of the public will use them. All materials cited in this declaration and its exhibits are of a type that experts in my field would reasonably rely upon and refer to in forming their opinions.

20. Counsel has informed me that the subject matter of this proceeding relates to handheld devices including antennas for receiving and transmitting electromagnetic wave signals.

21. I have been informed by counsel for Petitioners that a "person of ordinary skill in the art at the time of the inventions" (POSA) is a hypothetical person who is presumed to be familiar with the relevant field and its literature at the time of the inventions. This hypothetical person is also a person of ordinary creativity, capable of understanding the scientific and/or engineering principles applicable to the pertinent field.

22. Counsel has informed me that a POSA would have possessed at least a bachelor's degree in electrical engineering, computer science, or a similar degree and at least four years of experience in applied electromagnetics with an emphasis

on antennas. Alternatively, a POSA would have had a master's degree in electrical engineering (or similar discipline) and at least two years of similar experience.

C. Library Catalog Records and Other Resources

23. Some background on MARC (Machine-Readable Cataloging) formatted records, OCLC (addressed below), and *WorldCat* (addressed below) is helpful to understand the library catalog records discussed in this declaration. I am fully familiar with the library cataloging standard known as the MARC standard, which is an industry-wide standard method of storing and organizing library catalog information.[1] MARC practices have been consistent since the MARC format was developed by the Library of Congress in the 1960s, and by the early 1970s MARC became the U.S. national standard for disseminating bibliographic data. By the mid-1970s, MARC format became the international standard, and it persists through the present. A MARC-compatible library is one that has a catalog consisting of individual MARC records for each of its items. The underlying MARC format (computer program) underpins the online public access catalog ("OPAC") available to library users to locate a particular holding of a library. Today, MARC is the primary communications protocol for the transfer and storage

[1] The full text of the standard is available from the Library of Congress at http://www.loc.gov/marc/bibliographic/.

of bibliographic metadata in libraries.[2] The MARC practices discussed below were in place during the time frame relevant to the documents discussed herein.

24. Online Computer Library Center ("OCLC") is a not-for-profit worldwide consortium of libraries. Similar to MARC standards, OCLC's practices have been consistent from the 1970s through the present. Accordingly, the OCLC practices discussed below were in place during the time frame discussed in my opinions section. OCLC was created "to establish, maintain and operate a computerized library network and to promote the evolution of library use, of libraries themselves, and of librarianship, and to provide processes and products for the benefit of library users and libraries, including such objectives as increasing

[2] Almost every major library in the world uses a catalog that is MARC-compatible. *See, e.g.*, Library of Congress, *MARC Frequently Asked Questions (FAQ)*, https://www.loc.gov/marc/faq.html (last visited Jan. 24, 2018) ("MARC is the acronym for Machine-Readable Cataloging. It defines a data format that emerged from a Library of Congress-led initiative that began nearly forty years ago. It provides the mechanism by which computers exchange, use, and interpret bibliographic information, and its data elements make up the foundation of most library catalogs used today."). MARC is the ANSI/NISO Z39.2-1994 (reaffirmed 2009) standard for Information Interchange Format.

availability of library resources to individual library patrons and reducing the rate of rise of library per-unit costs, all for the fundamental public purpose of furthering ease of access to and use of the ever-expanding body of worldwide scientific, literary and educational knowledge and information."[3] Among other services, OCLC and its members are responsible for maintaining the *WorldCat* database (http://www.worldcat.org/), used by libraries throughout the world.

25. *WorldCat* is the world's largest public online catalog, maintained by the OCLC, a not-for-profit international library consortium, built with the records created by the thousands of libraries that are members of OCLC.

D. Periodical/Serial Publications

26. A periodical publication is a published work in a series, for example, a journal article. A library typically creates a catalog record for a periodical publication when the library receives its first issue. When the library receives subsequent issues or volumes of the periodical, the issues or volumes are checked in, often using a date stamp, added to the library's holding records, and made

[3] OCLC Online Computer Library Center, Inc., *Amended Articles of Incorporation of OCLC Online Computer Library Center, Inc.*, Third Article (OCLC, Dublin, Ohio) Revised November 30, 2016, https://www.oclc.org/content/dam/oclc/membership/articles-of-incorporation.pdf.

available and searchable very soon thereafter, normally within a few days of receipt. This practice continued up to the time when many scholarly journals ended printing a paper edition, and only published in digital format, depending upon the journal between 2005–2014.

E. Cataloging / Indexing

27. A researcher may discover material relevant to a topic of interest in a variety of ways. One common means of discovery is to search for relevant information in an index of periodicals and other publications. Having found relevant material, the researcher will then normally obtain it online, look for it in libraries, or purchase it from a publisher, a bookstore, a document delivery service, or another provider.

28. Indexing services use a wide variety of controlled vocabularies to provide subject access and other means of discovering the content of documents. The formats in which these access terms are presented vary from service to service.

29. Online indexing services commonly provide bibliographic information, abstracts, and full-text copies of the indexed publications, along with a list of the documents cited in the indexed publication. These services also often provide lists of publications that cite a given document.

F. Databases and Libraries Consulted

30. ***Wiley Online Library*** – an unrivaled range of journals, books, major reference works, and databases. Multidisciplinary collection of online resources covering life, health, and physical sciences; social science; and the humanities—850 scientific and scholarly societies around the world, and access to over 7.5 million articles from over 1,600 journals, over 21,000 online books, and hundreds of multi-volume reference works, databases, and other resources online. https://onlinelibrary.wiley.com/researchers.

31. ***Linda Hall Library*** – "The Linda Hall Library is a privately-endowed American library of science, engineering and technology located in Kansas City, Missouri … Established in 1946 through the philanthropy of Linda and Herbert F. Hall … the library is open to the public, and invites individual researchers, academic institutions, and companies from Kansas City and around the world to use the library's research-level collection. Its mission is to act as 'guardian of the collective intellectual heritage with regard to the science, technology, and engineering disciplines.'" https://en.wikipedia.org/wiki/Linda_Hall_Library.

32. ***Wisconsin TechSearch (WTS)*** – WTS is a set of services offered by the University of Wisconsin Libraries. WTS offers an array of article delivery and research services to any individual or organization who requests the specialized

skills of WTS staff in locating and retrieving information, regardless of whether the individual is affiliated with the University of Wisconsin. https://wts.wisc.edu/.

IV. OPINION REGARDING AUTHENTICITY AND PUBLIC ACCESSIBILITY

A. Exhibit 1005. Wong, Kin-Lu, Jui-Hung Chou, Saou-Wen Su, and Chih-Ming Su. "Isolation between GSM/DCS and WLAN Antennas in a PDA Phone." *Microwave and Optical Technology Letters*, Volume 45, Number 4 (May 20, 2005): pages 347-352. ("Wong")

33. I have been asked to opine on an article authored by Kin-Lu Wong, Jui-Hung Chou, Saou-Wen Su, and Chih-Ming Su, titled "Isolation between GSM/DCS and WLAN Antennas in a PDA Phone" published in *Microwave and Optical Technology Letters*, volume 45, number 4 (May 20, 2005) on pages 347-352 ("Wong").

34. Within this declaration, "Wong" will indicate both the article titled "Isolation between GSM/DCS and WLAN Antennas in a PDA Phone," as well as the issue of *Microwave and Optical Technology Letters*, volume 45, number 4 (May 20, 2005) in which that article appeared, dependent upon context.

1. Authentication

35. I have evaluated the Wong reference four ways: (1) by assessing the copy of Wong, EX1005, provided to me by counsel for Petitioners and received from the Indiana University Library; (2) by assessing scans of a print copy of Wong owned by the Library of Congress, provided to me by Wisconsin

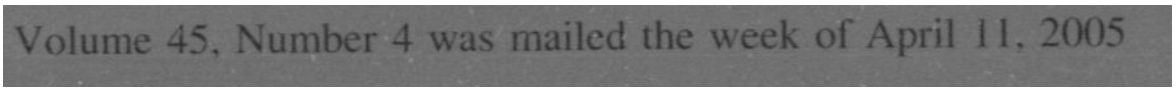
TechSearch (WTS), Attachment A-1; (3) by assessing scans of a print copy of Wong owned by the Linda Hall Library, provided to me by the Linda Hall Library Document Delivery Service, Attachment A-2; and (4) by accessing and reviewing Wong in digital format available to me through Purdue University Libraries, Attachment A-3.

36. EX1005, Wong, has been provided to me by counsel for Petitioners. I see no evidence that any alteration, deletion or addition of pages, etc., were made to EX1005, a copy obtained by counsel for Petitioners from the Indiana University Libraries. I have no reason to question whether the stamps were made by the holding library, Indiana University Libraries.

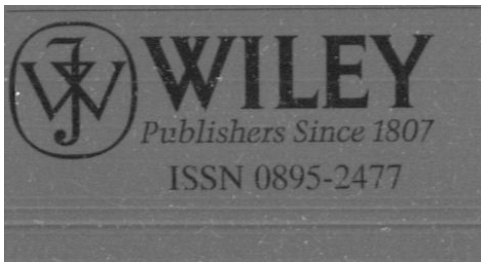
37. EX1005 has a stamp that reads: "LIBRARY APR 27 2005 INDIANA UNIVERSITY', as shown below. The date April 27, 2005 is the date on which EX1005 was stamped as received by the Indiana University Library.



38. The cover page of EX1005 states "Volume 45, Number 4 was mailed the week of April 11, 2005.", as shown below:



39. Also on the cover page of EX1005, at the bottom left hand corner, the publisher is identified: “Wiley Publishers Since 1807 with the ISSN 0895-2477”, as shown below. Wiley is today, and was in 2004-2005, an established and well-known publishing company.



40. Attachment A-1 includes scans from the print copy of Wong held by the Library of Congress obtained, at my request, by Wisconsin TechSearch (WTS) on February 24, 2025.

41. Attachment A-1 includes: bound front cover, spine, and back cover with a label and a call number stamp on the spine - as shown below; cover of issue with table of contents, dated May 20, 2005 with a statement that “Volume 45 Number 4 was mailed the week of April 11, 2005”, as shown below; and at the bottom left hand corner, the publisher is identified: Wiley Publishers Since 1807 with the ISSN 0895-2477, as shown below (Wiley is today, and was in 2004-2005, an established and well-known publishing company); publisher and publication information page; page 271 with a stamp that reads “Library of Congress MAY 18 2005 Copyright Office” as shown below; and the Wong article, pages 347 - 352.

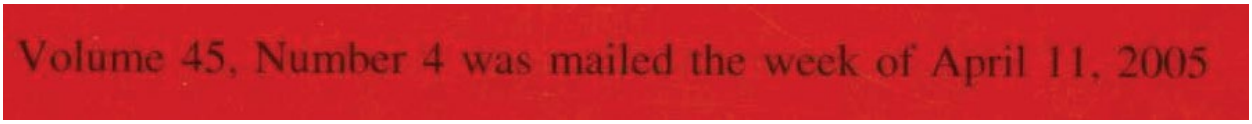


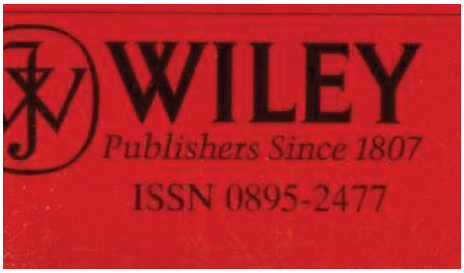


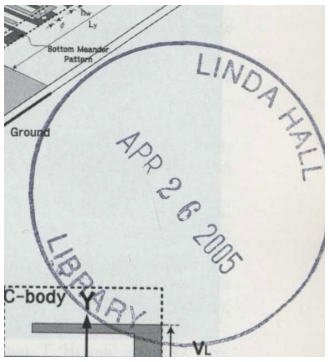
42. All identifying characteristics, such as labels and stamps on Attachment A-1, are consistent with library practice and procedure that I have observed during my career as a professional librarian, specifically with those items held by the Library of Congress. I have no cause for doubt about the authenticity or accuracy of these identifying attributes.

43. In addition, Wong was found within the custody of a library, the Library of Congress, one of the most likely locations for an authentic publication to be located. Evidence of the ownership of Wong by the Library of Congress will further be explored and detailed in the section below on public access.

44. Attachment A-2 was provided to me at my request on February 21, 2025, by Linda Hall Library Doc Services from the copy owned by the Linda Hall Library. Attachment A-2 includes scans of Wong; cover of issue with table of contents, dated May 20, 2005 with a statement that "Volume 45 Number 4 was mailed the week of April 11, 2005", as shown below and at the bottom left hand corner, the publisher is identified: "Wiley Publishers Since 1807 with the ISSN 0895-2477," as shown below (Wiley is today, and was in 2004-2005, an established and well-known publishing company); publisher and publication information page; page 271 with a stamp that reads "Linda Hall Library APR 26 2005" as shown below; and the Wong article, pages 347 - 352.







45. All identifying characteristics, such as stamps and notations on Attachment A-2, are consistent with library practice and procedure that I have observed during my career as a professional librarian. I have no cause for doubt about the authenticity or accuracy of these identifying attributes. Attachment A-2 was found within the custody of a library, the Linda Hall Library, one of the most likely locations for an authentic document to be publicly accessible. Evidence of the ownership of Wong by the Linda Hall Library will further be explored and detailed in the section below on public access.

46. Attachment A-3 is a download I made from the *Wiley Online Library* by my access as an emeritus faculty member at Purdue University at this URL: https://onlinelibrary.wiley.com/doi/pdf/10.1002/mop.20820.

47. Wong is available for a fee at URL: https://onlinelibrary.wiley.com/doi/epdf/10.1002/mop.20820

48. After my comparison between EX1005, Wong, and Attachment A-1, Attachment A-2, and Attachment A-3, I found no difference between EX1005,

Wong, and Attachment A-1, Attachment A-2, or Attachment A-3, other than colorization of figures in Attachment A-3 (the digital version of Wong).

49. Therefore, I affirm, after verifying EX1005 against Attachment A-1, Attachment A-2, and Attachment A-3, that EX1005 is a complete and accurate version of Wong.

50. Therefore, with the evidence that EX1005, Wong, is held in the Library of Congress and the Linda Hall Library, and accessing and retrieving Wong from a database through the Purdue University Libraries, I have determined that EX1005, Wong, is an authentic document.

51. I conclude and affirm that Wong, EX1005, is an authentic document.

2. Public Accessibility

52. Attachment A-4 is a true and correct copy of the *WorldCat* entry for *Microwave and Optical Technology Letters*. I obtained Attachment A-4 by completing a search on *WorldCat* on March 14, 2025 by searching for libraries holding this journal near the District of Columbia.

53. Attachment A-4 shows that *Microwave and Optical Technology Letters* is the journal associated with this *WorldCat* entry, as verified by title: *Microwave and Optical Technology Letters;* publisher: Wiley; and ISSN: 0895-2477.

54. *Microwave and Optical Technology Letters* could have been located in *WorldCat* by searching for the title of the journal: *Microwave and Optical Technology Letters*; and/or by searching the subject headings: *Microwaves* and/or *Optics*, among others.

55. When I searched *WorldCat* for holdings of *Microwave and Optical Technology Letters* in the District of Columbia, the Library of Congress was fourth on the list among the 687 libraries shown as holding it near Washington, DC.

56. Attachment A-5 is a download I made from the Library of Congress OPAC (online catalog) on March 13, 2025. The journal catalogued in this record is *Microwave and Optical Technology Letters* as verified by the OPAC record fields including title: *Microwave and Optical Technology Letters;* publisher: Wiley; and ISSN: 0895-2477.

57. The record of holdings of *Microwave and Optical Technology Letters* by the Library of Congress is shown in the line titled: "Publication History" that reads: "Vol. 1, no. 1 (Mar 1988)" indicating that *Microwave and Optical Technology Letters* began publication in March 1988 with its issue volume 1, number 1. I compared the Library of Congress Classification (call number): TK7876.M5235 with that shown on the spine of the volume in Attachment A-1 and it is the same on both.

58. Evidence that the Library of Congress received and holds Wong is shown in the OPAC record under the heading titled: "Older Receipts" as shown below which is inclusive of volume 45, number 4 (May 20, 2005).

Older receipts	v.1-v.59:no.11 (1988:Mar.-2017:Nov.)

59. *Microwave and Optical Technology Letters* could have been located in the Library of Congress OPAC by searching for the title: *Microwave and Optical Technology Letters;* and/or by searching the subject headings: *Microwaves*; and/or *Optics*, among others.

60. Although the nominal publication date of *Microwave and Optical Technology Letters*, volume 45, number 4 is May 20, 2005, from my experience and knowledge it would not be inconsistent for a journal to be published, distributed to subscribers and libraries, and received and shelved in libraries prior to the nominal publication date.

61. For example, in this case, while the front cover of Wong indicates that the nominal publication date of volume 45, number 4 is May 20, 2005, the bottom of the front cover indicates that volume 45, number 4 was mailed the week of April 11, 2005. As discussed below, mailing during the week of April 11, 2005 is consistent with the stamped dates on Wong in Indiana University Library, Linda Hall Library and the Library of Congress.

62. The date stamped on Attachment A-1, May 18 2005, as shown below, indicates processing of Wong by the Library of Congress Copyright Office on May 18, 2005. The Library of Congress receives a vast number of publications every day, and it could take weeks, or even a month or more, for a publication to make its way from the mail room to the check-in desk where a date stamp is applied. May 18, 2005 is the date Wong was stamped, but Wong would have been received in the Library of Congress mailroom earlier (likely weeks earlier) than that.



63. After a date stamp is applied to an item, a monograph or a journal issue, it is promptly sent for shelving. The amount of time it takes to be shelved, and hence available to the public, varies depending on the nature of the item. Monographs typically take longer than journals because cataloguing of monographs is more work-intensive. Journal issues, such as Wong, are, more likely than not, entered into the general collection, shelved and publicly accessible within two to five days of application of a date stamp by a library.

64. Therefore, the print copy of Wong, *Microwave and Optical Technology Letters*, volume 45, number 4 (May 20, 2005), at the Library of

Congress would have been available for public access, more likely than not, by May 23, 2005.

65. Once Wong was entered into the general collection of the Library of Congress, members of the public could access Wong, *Microwave and Optical Technology Letters*, volume 45, number 4 (May 20, 2005), by having it taken to either the Jefferson or Adams Reading Rooms.

66. Members of the public can read, study, and make notes about a selected work in the Library of Congress Reading Rooms. Further, members of the public are permitted to make photocopies of portions of the work while in the Reading Rooms.

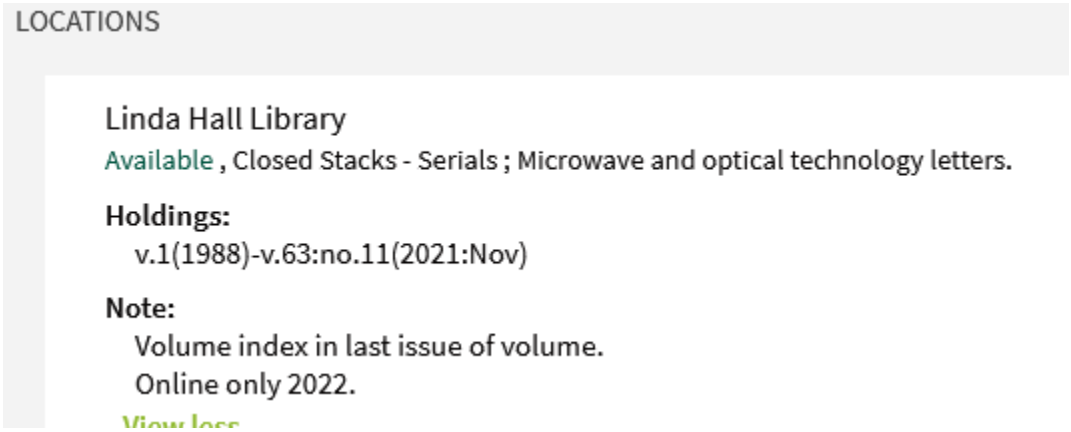
67. Attachment A-6 is the result when I searched *WorldCat* for holdings of *Microwave and Optical Technology Letters* near Missouri. The Linda Hall Library was seventh on the list among the 876 libraries shown as holding *Microwave and Optical Technology Letters* near Missouri.

68. Attachment A-6 shows that *Microwave and Optical Technology Letters* is the journal associated with this *WorldCat* entry, as verified by title: *Microwave and Optical Technology Letters;* publisher: Wiley; and ISSN: 0895-2477.

69. Attachment A-7 is a download I made from the Linda Hall Library OPAC (online catalog) on March 16, 2025. The journal cataloged in this record is

Microwave and Optical Technology Letters as verified by the OPAC record fields including title: *Microwave and Optical Technology Letters;* publisher: Wiley; and ISSN: 0895-2477.

70. The record of holdings of *Microwave and Optical Technology Letters* by the Linda Hall Library is shown in the area titled: "Holdings" that reads: "v.1 (1988)-v.63:no11(2021:Nov)," as shown below, indicating that *Microwave and Optical Technology Letters* began publication in 1988 with its issue volume 1 and the print holdings at the Linda Hall Library start at volume 1 and end with volume 63, number 11, November, 2021. These dates are inclusive of the date of publication of Wong.


LOCATIONS

Linda Hall Library
Available , Closed Stacks - Serials ; Microwave and optical technology letters.

Holdings:
v.1(1988)-v.63:no.11(2021:Nov)

Note:
Volume index in last issue of volume.
Online only 2022.

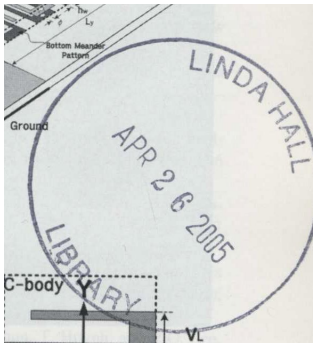
View less

71. *Microwave and Optical Technology Letters* could have been located in the Linda Hall Library OPAC by searching for the title: *Microwave and Optical Technology Letters;* and/or by searching the subject headings: *Microwaves* and/or *Optics*.

72. The date stamped on Attachment A-2, April 26 2005, as shown below, indicates receipt of Wong by the Linda Hall Library. As mentioned above, a publication is first received in the library's mailroom, and then is routed to processing where it receives a date stamp. Thus, Wong was received in Linda Hall Library mailroom sometime before the stamp was applied on April 26, 2005.

73. This timeline is consistent with the statement, on the cover of Wong, that it was mailed the week of April 11, 2005. The May 23, 2005 date stamp on the copy of Wong in the Library of Congress is also consistent with mailing the week of April 11, 2005, given the longer time it takes for publications to travel from the Library of Congress mailroom to the Library of Congress processing as I noted previously.

74. Just as the Linda Hall Library received Wong sometime before the stamp was applied on April 26, 2005, individual subscribers to *Microwave and Optical Technology Letters* would also, more likely than not, have received Wong on or before April 26, 2005.



75. The physical copy of Wong at the Linda Hall Library would have been available for public access in Linda Hall Library after it was 'checked-in', stamped with the date of April 26, 2005, and sent for shelving, more likely than not, within two to five days. Therefore Wong was, more likely than not, available for public access in Linda Hall Library by May 1, 2005.

76. As noted earlier, EX1005 itself (a scan of Wong from the Indiana University Library) was stamped as received in Indiana University Library on April 27, 2005, one day later than Attachment A-2 was stamped as received in Linda Hall Library. This reinforces that the statement on the cover of EX1005, that it was mailed the week of April 11, 2005, is accurate, and that individual subscribers to *Microwave and Optical Technology Letters* would also have received, more likely than not, Wong on or before April 26, 2005.

3. Conclusion

77. Wong, EX1005, is an authentic document and would have been publicly accessible, more likely than not, in the Library of Congress by May 28, 2005, and in the Linda Hall Library by May 1, 2005. Wong would have been received by subscribers, more likely than not, by April 26, 2005 (just as it was received in Linda Hall Library no later than, and likely earlier than, April 26, 2005).

B. Exhibit 1011. Lee, Gwo-Yun, and Kin-Lu Wong. "Quad-Band Internal Monopole Mobile Phone Antenna."

***Microwave and Optical Technology Letters*, Volume 40, Number 5, (March 4, 2004): pages 359-361. ("Lee")**

78. I have been asked to opine on an article authored by Gwo-Yun Lee and Kin-Lu Lee, EX1011, titled "Quad-Band Internal Monopole Mobile Phone Antenna" published in *Microwave and Optical Technology Letters*, volume 40, number 5 (March 4, 2004) on pages 359-361. ("Lee")

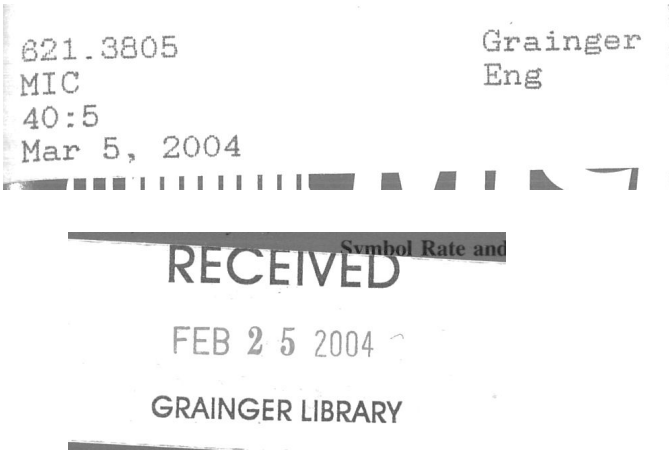
79. Within this declaration Lee will indicate both the article titled "Quad-Band Internal Monopole Mobile Phone Antenna," as well as the issue of *Microwave and Optical Technology Letters*, volume 40, number 5, (March 4, 2004), in which that article appeared, dependent upon context.

1. Authentication

80. I have evaluated the Lee reference four ways: (1) by assessing the copy of Lee, EX 1011, provided to me by counsel for Petitioners retrieved from the University of Illinois Granger Library; (2) by assessing scans of a print copy of Lee owned by the Library of Congress, provided to me by Wisconsin TechSearch (WTS), Attachment B-1; (3) by assessing scans of a print copy of Lee owned by the Linda Hall Library, provided to me by the Linda Hall Library Document Delivery Service, Attachment B-2; and (4) by accessing and reviewing Lee in digital format available to me through Purdue University Libraries, Attachment B-3.

81. EX1011, Lee, has been provided to me by counsel for Petitioners. I see no evidence that any alteration, deletion or addition of pages, etc., were made to EX1011. I have no reason to doubt that the label and stamp were made by the holding library, University of Illinois Grainger Library.

82. EX1011 has a label that reads: "621.3605 Grainger MIC ENG 40:5 Mar 5, 2004", as shown below; and a stamp that reads: "RECEIVED FEB 25, 2004 GRAINGER LIBRARY", as also shown below. February 25, 2004 is the date in which EX1011 was marked received by the Grainger Library, University of Illinois.



83. Although the nominal publication date of *Microwave and Optical Technology Letters*, volume 40, number 5 is listed as March 5, 2004, from my experience and knowledge it would not be inconsistent for a journal to be published, distributed to subscribers and libraries, and received and shelved in libraries prior to the nominal publication date.

84. In this case, the bottom of the front cover of Lee indicates that volume 40, number 5 was mailed the week of February 2, 2004, as shown below



85. For the same reasons discussed above with respect to the Wong reference, mailing of Lee during the week of February 2, 2004 is consistent with stamping of Lee during processing in the Grainger Library on February 25, 2004. It would have taken some days after mailing for Lee to arrive in the mailroom at the Grainger Library, and then additional time for Lee to move from the mailroom to processing where the February 25, 2004 stamp was applied.

86. Attachment B-1 includes scans from the print copy of Lee held by the Library of Congress obtained, at my request, by Wisconsin TechSearch (WTS) on April 4, 2025.

87. Attachment B-1 includes: bound front cover, spine, and back cover with a label and a call number stamp on the spine - as shown below; cover of issue with table of contents dated March 5, 2004, with a statement that "Volume 40, Number 5 was mailed the week of February 2, 2004", as shown below; and at the bottom left hand corner, the publisher is identified: "Wiley Publishers Since 1807 with the ISSN 0895-2477," as shown below, Wiley is today, and was in 2004-2005, an established and well-known publishing company; publisher and publication information page; page 349 with a stamp that reads "Library of

Congress APR 16 2004 Copyright Office" as shown below; and the Lee article, pages 359-361.



88. As with Wong, the publisher is identified as "Wiley Publisher since 1807 with the ISSN 0895-2477. Wiley is today, and was in 2004-2005, an established and well-known publishing company.

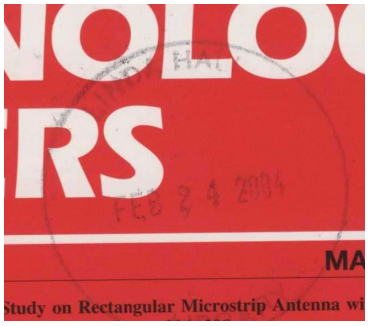
89. All identifying characteristics, such as labels and stamps on Attachment B-1, are consistent with library practice and procedure that I have

observed during my career as a professional librarian, specifically with those items held by the Library of Congress. I have no cause for doubt about the authenticity or accuracy of these identifying attributes.

90. In addition, Lee was found within the custody of a library, the Library of Congress, one of the most likely locations for an authentic publication to be located. Evidence of the ownership of Lee by the Library of Congress will further be explored and detailed in the section below on public access.

91. Attachment B-2 was provided to me at my request on April 4, 2025, by Linda Hall Library Document Services from the copy owned by the Linda Hall Library.

92. Attachment B-2 includes scans of Lee; cover of issue with table of contents dated March 5, 2004 (with the same statement previously noted above mailing during the week of February 2, 2004), with a stamp that reads: "Linda Hall Library FEB 24 2004" (faint); journal information page; and the Lee article, pages 359-361.



93. All identifying characteristics, such as stamp, on Attachment B-2, are consistent with library practice and procedure that I have observed during my career as a professional librarian. I have no cause for doubt about the authenticity or accuracy of these identifying attributes.

94. Attachment B-2 was found within the custody of a library, the Linda Hall Library, one of the most likely locations for an authentic document to be publicly accessible. Evidence of the ownership of Lee by the Linda Hall Library will further be explored and detailed in the section below on public access.

95. Attachment B-3 is the download I made through the Purdue University Libraries by my emeritus faculty position. The ability to retrieve Lee through a major research library OPAC is evidence both of Lee's authenticity and its public access.

96. Attachment B-3 is a download I made from the Wiley Online Library by my access as an emeritus faculty member at Purdue University at this URL: https://onlinelibrary.wiley.com/doi/pdf/10.1002/mop.11381.

97. Lee is available for a fee at URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/mop.11381

98. After my comparison between EX1011, Lee, and Attachment B-1, Attachment B-2, and Attachment B-3, I found no difference between EX1011, Lee, and Attachment B-1, Attachment B-2, or Attachment B-3.

99. Therefore, I affirm, after verifying EX1001 against Attachment B-1, Attachment B-2, and Attachment B-3, that EX1011 is a complete and accurate version of Lee.

100. Therefore, with evidence that Lee is held in the Grainger Library, University of Illinois; the Library of Congress; and the Linda Hall Library, and by accessing and retrieving Lee from a database through the Purdue University Libraries, I have determined that EX1011, Lee, is an authentic document.

101. I conclude and affirm that Lee, EX1011, is an authentic document.

2. Public Accessibility

102. Attachment B-4 is a true and correct copy of the *WorldCat* entry for *Microwave and Optical Technology Letters*. I obtained Attachment B-4 by completing a search on *WorldCat* on March 15, 2025 by searching for libraries holding this journal near the District of Columbia.

103. Attachment B-4 shows that *Microwave and Optical Technology Letters* is the journal associated with this *WorldCat* entry, as verified by title: *Microwave and Optical Technology Letters;* publisher: Wiley; and ISSN: 0895-2477.

104. *Microwave and Optical Technology Letters* could have been located in *WorldCat* by searching for the title of the journal: *Microwave and Optical*

Technology Letters; and/or by searching the subject headings: *Microwaves* and/or *Optics*, among others.

105. When I searched *WorldCat* for holdings of *Microwave and Optical Technology Letters* in the District of Columbia, the Library of Congress was fourth on the list among the 687 libraries shown as holding it near Washington, DC.

106. Attachment B-5 is a download I made from the Library of Congress OPAC on March 15, 2025. The journal catalogued in this record is *Microwave and Optical Technology Letters* as verified by the record fields including title: *Microwave and Optical Technology Letters;* publisher: Wiley; and ISSN: 0895-2477.

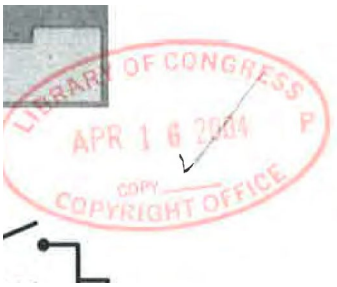
107. The record of holdings of *Microwave and Optical Technology Letters* by the Library of Congress is shown in the line titled: "Publication History" that reads: "Vol. 1, no. 1 (Mar 1988)," indicating that *Microwave and Optical Technology Letters* began publication in March 1988 with its issue volume 1, number 1. I compared the Library of Congress Classification (call number): TK7876.M5235 with that shown on the spine of the volume in Attachment B-1 and it is the same on both.

108. Evidence that the Library of Congress received and holds Lee is shown in the OPAC record under the heading titled: "Older Receipts" as shown below which is inclusive of volume 40, number 5, (March 4, 2004).

Older receipts v.1-v.59:no.11 (1988:Mar.-2017:Nov.)

109. *Microwave and Optical Technology Letters* could have been located in the Library of Congress OPAC by searching for the title: *Microwave and Optical Technology Letters;* and/or by searching the subject headings: *Microwaves*; and/or *Optics*, among others.

110. The date stamped on Attachment B-1, "APR 16 2004", as shown below, indicates processing of Lee by the Library of Congress Copyright Office on April 16, 2004. As I explained above when discussing Wong in the Library of Congress, Lee would have been shelved and available for public access, more likely than not, within two to five days.



111. Therefore, the print copy of Lee at the Library of Congress would have been available for public access, more likely than not, by April 21, 2004.

112. Once Lee was entered into the general collection of the Library of Congress, members of the public could access Lee by having the volume taken to either the Jefferson or Adams Reading Rooms.

113. Members of the public can read, study, and make notes about a selected work in the Library of Congress Reading Rooms. Further, members of the public are permitted to make photocopies of portions of the work while in the Reading Rooms.

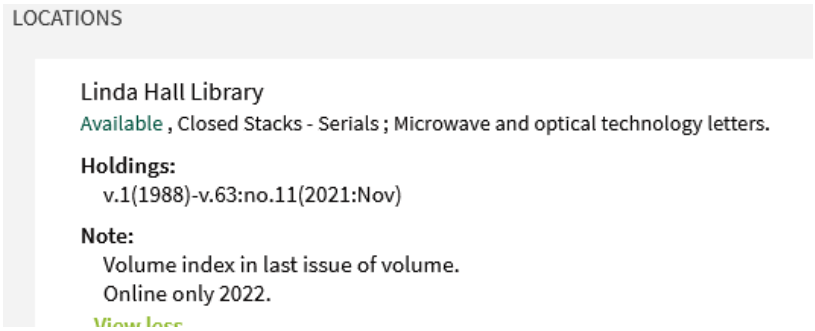
114. Attachment B-6 is the result when I searched *WorldCat* for holdings of *Microwave and Optical Technology Letters* near Missouri on March 15, 2025. The Linda Hall Library was seventh on the list among the 876 libraries shown as holding *Microwave and Optical Technology Letters* near Missouri.

115. *Microwave and Optical Technology Letters* could have been located in *WorldCat* by searching for the title of the journal: *Microwave and Optical Technology Letters*; and/or by searching the subject headings: *Microwaves* and/or *Optics*, among others.

116. Attachment B-7 is a download I made from the Linda Hall Library OPAC (online catalog) on March 16, 2025. The journal cataloged in this record is *Microwave and Optical Technology Letters* as verified by the title: *Microwave and Optical Technology Letters;* publisher: Wiley; and ISSN: 0895-2477.

117. The record of holdings of *Microwave and Optical Technology Letters* by the Linda Hall Library is shown in the area titled: "Holdings" that reads: "v.1 (1988)-v.63:no11(2021:Nov)," as shown below, indicating that *Microwave and Optical Technology Letters* began publication in 1988 with its issue volume 1

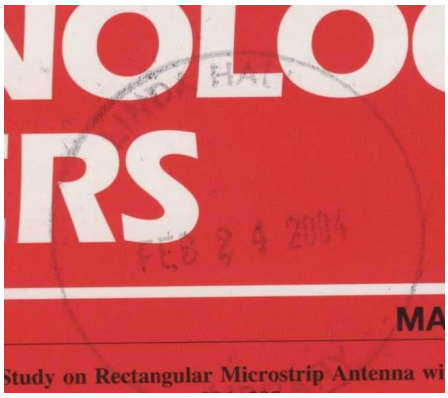
and the print holdings at the Linda Hall Library start at volume 1 and end with volume 63, number 11, November, 2021. These dates are inclusive of March 5, 2004.


LOCATIONS

Linda Hall Library
Available , Closed Stacks - Serials ; Microwave and optical technology letters.
Holdings:
v.1(1988)-v.63:no.11(2021:Nov)
Note:
Volume index in last issue of volume.
Online only 2022.
View less

118. *Microwave and Optical Technology Letters* could have been located in the Linda Hall Library OPAC by searching for the title: *Microwave and Optical Technology Letters;* and/or by searching the subject headings: *Microwaves* and/or *Optics*.

119. The date stamped on Attachment B-2, February 24, 2004, as shown below, indicates processing of Lee by the Linda Hall Library. Lee was received, more likely than not, in the Linda Hall Library mailroom sometime before the stamp was applied on February 24, 2004. This timeline is consistent with the statement, on the cover of Lee, that it was mailed during the week of February 2, 2004.



120. Just as the Linda Hall Library received Lee sometime before the stamp was applied on February 24, 2004, individual subscribers to *Microwave and Optical Technology Letters* would also have received Lee, more likely than not, on or before February 24, 2004.

121. The physical copy of Lee at the Linda Hall Library would have been available for public access in the Linda Hall Library after it was processed, stamped with the date of February 24, 2004, and sent for shelving, more likely than not, within two to five days. Therefore Lee was, more likely than not, available for public access in Linda Hall Library by March 1, 2004.

3. Conclusion

122. Lee, EX1011, is an authentic document and would have been publicly accessible, more likely than not, in the Library of Congress by April 21, 2004, and in the Linda Hall Library by March 1, 2004. Lee also would have been received by subscribers, more likely than not, by February 24, 2004 (just as it was received in the Linda Hall Library no later than, and likely earlier than, February 24, 2004).

V. RIGHT TO SUPPLEMENT

123. I reserve the right to supplement my opinions in the future to respond to any arguments that the Patent Owner raises and to take into account new information as it becomes available to me.

VI. JURAT

124. I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the full knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the U.S. Code.

Dated: April 30, 2025 By: James L. Mullins

James L. Mullins, Ph.D.

Attachment A-1

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DUAL-BAND LTCC CHIP ANTENNA DESIGN USING STACKED MEANDER PATCH FOR MOBILE HANDSETS

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ABSTRACT: *This paper presents design simulation, implementation, and measurement of a miniaturized GPS/K-PCS dual-band LTCC chip antenna for mobile communication handsets. The dimensions of the LTCC chip antenna is 9 × 15 × 1.2 mm. The meander-type radiating patch for dual-band operation is realized by using via holes with 0.3-mm height to connect upper- and lower-layer antennas. The lower meander-type antenna is to be tuned to the lower frequency (GPS) band. The upper meander antenna has a via-hole connection for the higher frequency (K-PCS) band.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 45: 271–273, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20793

Key words: *chip antenna; LTCC; meander patch; stacked structure; dual-band*

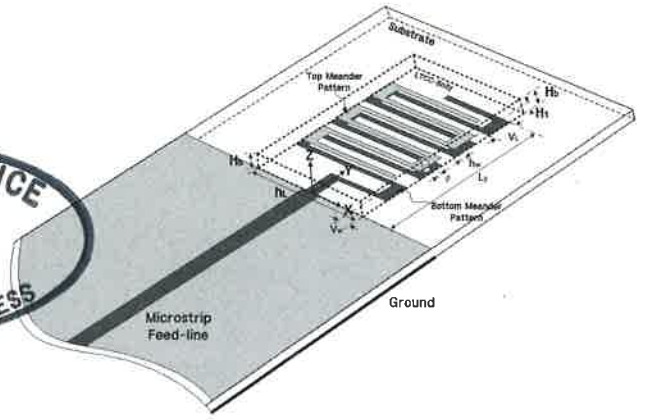
INTRODUCTION

As mobile-communication handsets become smaller and lighter, less space is available to place the antenna and RF devices. Recently, multilayer low-temperature co-fired ceramic (LTCC) technology has been extensively used for miniaturization of RF passive components and antennas. Therefore, the size reduction of the patch antenna for integration of different radio modules into the same piece of equipment is required, and compact internal antennas with multiband operation have become a popular topic in antenna research and investigations. There are a number of effective ways to reduce the size of patch antennas: use high-permittivity substrates [1], introduce shorting pins for the shifting of the null-voltage point at the edge of the radiating patch [2], use the planar inverted-F antenna (PIFA) for low-profile characteristic [3, 4]; and a combination of these approaches. Also, the basic concept to reduce the size of a microstrip patch antenna at a given resonant frequency is to increase its electrical surface-current length by changing the radiating element's shape [5, 6]. An effective method for increasing the effective surface-current path is to penetrate orthogonal slits into the boundary of the radiating patch. In this way, the excited surface-current paths are lengthened in the proposed designs, and the operating frequency is greatly lowered.

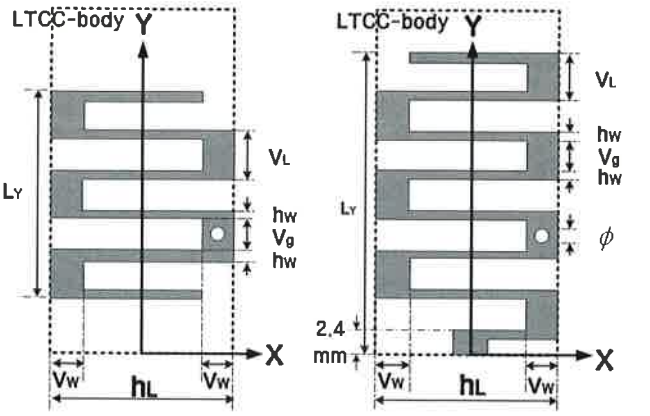
In this paper, a miniaturized GPS/K-PCS dual-band LTCC chip antenna is proposed for mobile-communication handsets. The experimental results for dual-band operation, return loss, and radiation pattern are presented.

PROPOSED ANTENNA DESIGN

The compact meander-type antenna for dual-band operation is realized in a multilayer printed LTCC-body structure. Figure 1 shows the geometry of the proposed stacked meander-type dual-band antenna mounted FR4 substrate. The dimension of LTCC chip antenna is 9 × 15 × 1.2 mm and the dielectric constant of the LTCC-body ceramic for antenna implementation is 7.8. The meander-type radiating patch for dual-band operation is realized by using via holes with 0.3-mm height to connect the upper- and lower-layer antennas. The dimension of the FR-4 circuit board is



(a)



(b)

Figure 1 Geometry and dimensions of the proposed dual-band chip antenna for mobile communication: $V_W \times V_L = 1 \times 2$ mm, $h_W \times h_L = 0.4 \times 8$ mm, $S_W = 0.2$ mm, $H_1 = 0.3$ mm, $\phi = 0.5$ mm, LTCC body ($\varepsilon_r = 7.8$) = 9 × 15 × 1.2 mm

40 × 80 × 0.8 mm and the size of the ground plane is 60 × 40 mm. A 50Ω microstrip line is used to feed the compact chip antenna, and the ground plane on the other side of the substrate is cut at the end of the microstrip feed. After a thorough parametric study of the proposed model, the optimum design parameters for the dual-band chip antenna are selected. A description of the design parameters is given in the legend of Figure 1.

EXPERIMENTAL RESULTS AND DISCUSSION

In the single-meander radiating structure, the electric fields on the each pair of the symmetrical segments in the x-direction are opposite; hence, they produce little radiation in the desired direction. On the other hand, the electric fields on the segments in the y-direction of the meander antenna have the same direction; they behave like a short dipole. Figure 2 shows the simulated y-component of the magnetic fields obtained using a CST Microwave 4.0 simulator.

It can be seen from the magnetic-field distribution that the fields on the vertical segments (y-component) of the meander have the same direction. Consequently, they behave like a short dipole in the vertical direction, consisting of seven dipoles. In this paper, the lower meander-type antenna is tuned to the GPS band and the upper meander antenna with via-hole connection is for the K-PCS band. Figure 3 shows the surface-current distribution at the two

TABLE 2 Impedance of the Half-Wavelength Resonant Printed Dipole on a Real Substrate: Analytical and Experimental Results (*h* is the Substrate Thickness)

ε_r	h/λ_0	R_{res} [Ω] [2]	R_{res} [Ω] Eq. (15)
3.25	0.1016	34.5	39
3.25	0.127	60	62
8.5	0.15	50	76

$$X_{in} \cong -\frac{30}{\sqrt{\varepsilon_{reff}}}\left\{-\frac{8\pi h}{\lambda}+\frac{8\pi h^2}{l\lambda}\right\}=\frac{120}{\sqrt{\varepsilon_{reff}}}\pi\frac{h}{l}\left(1-\frac{h}{l}\right). \tag{14}$$

The antenna complex impedance is finally obtained by combining the real and imaginary parts from Eqs. (9) and (14) as follows:

$$Z = Z_{in} = R_{in} + jX_{in} \cong \frac{600}{\sqrt{\varepsilon_{reff}}}\left(\frac{h}{l}\right)^2 + j\frac{120}{\sqrt{\varepsilon_{reff}}}\pi\frac{h}{l}\left(1-\frac{h}{l}\right). \tag{15}$$

RESULTS

Table 1 presents the impedance of a half-wavelength printed dipole on a substrate with $\varepsilon_r = 1$ (air) and for the different values of the substrate thickness. The analytical results from Eq. (15) have been compared with the numerical results simulated using the numerical electromagnetic code (NEC) for an infinite reflector plane. Very good agreement is observed between the analytical results and the numerical ones.

To investigate the effect of a real substrate and a finite ground plane, the analytical results have been compared (Table 2) with a few experimental results found in the literature [3]. The experimental tests are on the radiation resistance of a resonant printed dipole, although they may be compared with the real part of the impedance of a half-wavelength printed dipole. It can be observed that the resonance radiation impedance is not very different from the real impedance of the half-wavelength printed dipole [4]. As shown in Table 2, the results are coherent for ε_r of around 3. For the high permitivity of 8.5, this difference is important; it may be the result of the coupling beyond the "surface waves," which can be very effective in this case.

The feeding-gap effect on the experimental input impedance should also be considered in the theoretical treatment for more accuracy. The simple capacitive model of the feeding gap for a normal dipole [6] can be useful in this case.

CONCLUSION AND PERSPECTIVE

The analytical study presented here has successfully described the self impedance of a printed half-wavelength dipole on an arbitrary substrate. The obtained closed-form formulas clearly show the dependence of the dipole impedance on the dipole length as well as the substrate properties. The comparative results of the numerical simulation and the experiment have demonstrated the performance of these simple formulas. These compact formulas can be used to analyse patch antennas that are simulated by only a few thin printed dipoles.

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ISOLATION BETWEEN GSM/DCS AND WLAN ANTENNAS IN A PDA PHONE

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ABSTRACT: *The isolation performances of GSM/DCS and WLAN antennas embedded in a PDA phone for cellular/WLAN dual-network operations are studied. The two (GSM/DCS and WLAN) antennas are printed PIFAs with compact sizes and are mounted perpendicularly along the boundary of the system circuit board in order to perform as internal antennas for the PDA phone. It is found that the isolation between the two antennas is greatly dependent on their relative position inside the PDA phone. The measured and simulated results are presented, and the isolation performances are analyzed.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 45: 347–352, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20820

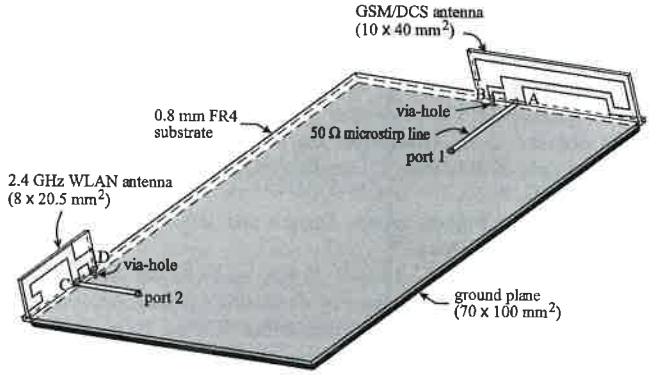
Key words: *mobile antennas; global system for mobile communication/digital communication system (GSM/DCS); wireless local area network (WLAN) antennas; planar inverted-F antennas (PIFAs); personal digital assistant (PDA) phones*

1. INTRODUCTION

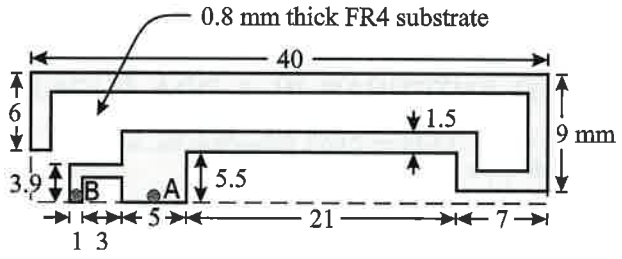
Integration of cellular and WLAN communication networks can provide users with ubiquitous or seamless data services [1]. For such an integrated cellular/WLAN network application, many dual-mode or dual-network wireless devices (such as PDA phones) are expected to emerge in the market in the near future. For this application, it is required that a PDA phone be equipped with two antennas, for example, one GSM/DCS (890–960 MHz/1710–1880 MHz) antenna for cellular operation and one WLAN antenna for 2.4-GHz (2400–2484 MHz) WLAN operation [2]. However, due to the limited space available inside a PDA phone, special care is required for achieving optimized isolation between the two antennas in order to avoid performance degradation.

In this paper, we present a study on the isolation of two promising internal antennas (one GSM/DCS antenna and one 2.4-GHz WLAN antenna) for a PDA phone for cellular/WLAN dual-network operations. Both the GSM/DCS and WLAN antennas are printed PIFAs with compact sizes (see Fig. 1) and can be concealed within the casing of a PDA phone for operation as

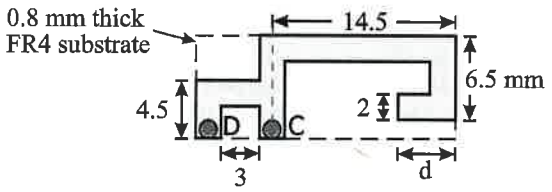
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(a)



(b)



(c)

Figure 1 (a) Configuration of the internal GSM/DCS and WLAN antennas for a PDA phone for cellular/WLAN dual-network operations; (b) dimensions of the GSM/DCS antenna; (c) dimensions of the WLAN antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

internal antennas. In this study, as in most conventional mobile-phone-antenna designs [2], the GSM/DCS antenna is arranged to be fixed at the top edge of the system circuit board. The WLAN antenna is then mounted at various possible locations along the boundary of the system ground plane. At each possible location, the isolation between the GSM/DCS and WLAN antennas is measured and analyzed. The simulation results obtained using Ansoft high-frequency structure simulator (HFSS) simulation software are also presented for comparison. The optimized isolation between the two antennas is discussed.

2. ARRANGEMENT OF TWO INTERNAL ANTENNAS FOR CELLULAR/WLAN DUAL-NETWORK OPERATIONS

Figure 1(a) shows the promising internal GSM/DCS and WLAN antennas for a PDA phone. Both antennas are printed on 0.8-mm-thick FR4 substrate and are in the form of a PIFA with a folded radiating arm in order to achieve a compact structure [3]. The GSM/DCS antenna occupies a small area of 10×40 mm^2 and is fixed at the top edge of a system circuit board having a ground plane of 100-mm length and 70-mm width in this study, which is a reasonable size for practical PDA phones. Also note that the GSM/DCS antenna is mounted perpendicularly to the system circuit board [4–6] and has a height of 10 mm only, which is less than the thickness of most PDA phones, thus making it possible to conceal the antenna within the casing of the PDA phone as an internal antenna. Given the design dimensions shown in Figure 1(b), the GSM/DCS antenna can generate two separate resonant modes at about 900 and 1800 MHz to cover the GSM (890–960 MHz) and DCS (1710–1880 MHz) bands.

The WLAN antenna, whose design dimensions are given in Figure 1(c), is designed for operating in the 2.4-GHz band (2400–2484 MHz). This antenna occupies a compact area of 8×20.5 mm^2 and is also printed on 0.8-mm-thick FR4 substrate. Similar to the GSM/DCS antenna, the WLAN antenna can also be concealed within the casing of the PDA phone as an internal antenna.

The WLAN antenna is then moved along the boundary (locations P1 to P10 shown in Fig. 2) of the system circuit board in order to determine the optimized isolation to the GSM/DCS antenna. Note that there are two kinds of orientations (cases A and B) of the WLAN antenna mounted along the boundary of the system circuit board. Cases A and B represent the WLAN antenna extending [from point D (shorting point) to point C (feeding point) to the radiating arm of the antenna] counterclockwise and clockwise, respectively, at each specified location. The configuration shown in Figure 1 is denoted as case A at location P4 in this study.

Also note that, at the end of the radiating arm of the WLAN antenna [see Fig. 1(c)], there is tuning length of d (about 2.0–4.5 mm in this study) for tuning the antenna's resonant frequency to be at about 2.45 GHz at each possible location shown in Figure 2. This is because, for each location in this study, the isolation or

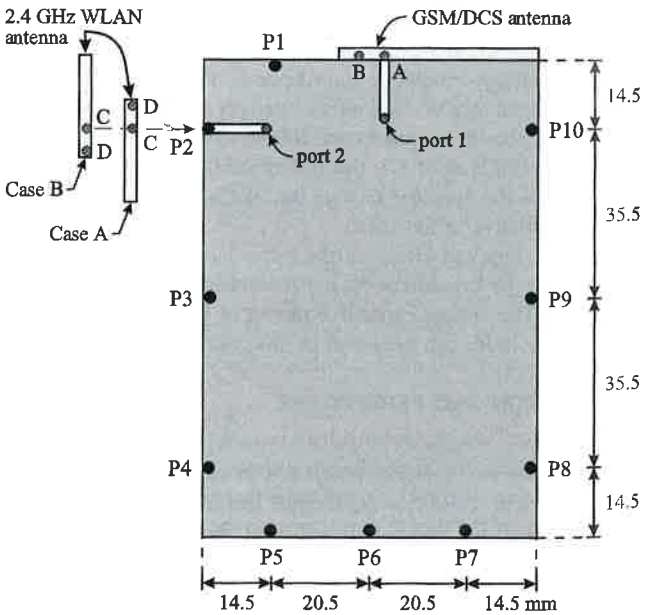
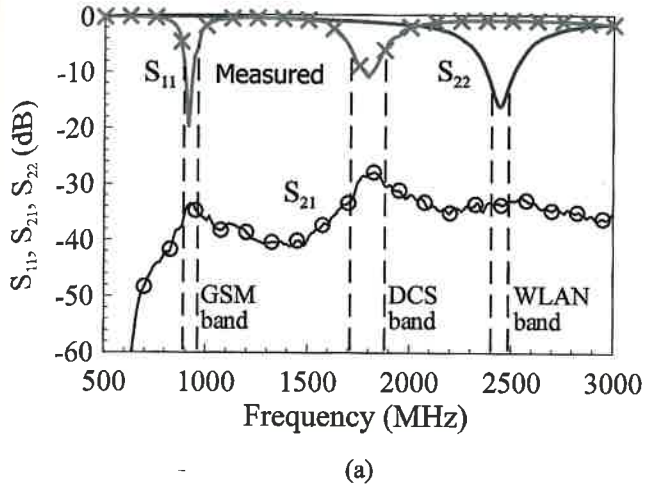


Figure 2 Locations (P1 to P10) of the WLAN antenna with the GSM/DCS antenna fixed at the top edge of the system ground plane; cases A and B represent the WLAN antenna extending (from point D to point C to the radiating arm of the antenna) counterclockwise and clockwise, respectively, at each specified location. The configuration shown in Fig. 1 is for case A at location P4. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]



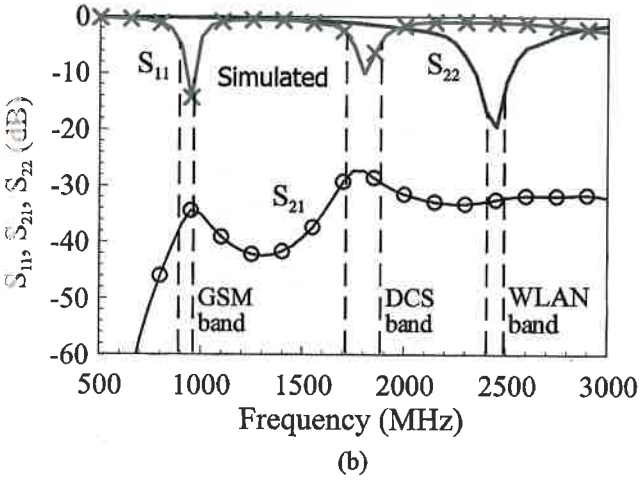


Figure 3 Reflection coefficients (S_{11} for GSM/DCS antenna, S_{22} for WLAN antenna) and isolation (S_{21}) between the two antennas for case A at location P4: (a) measured results; (b) simulated results. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

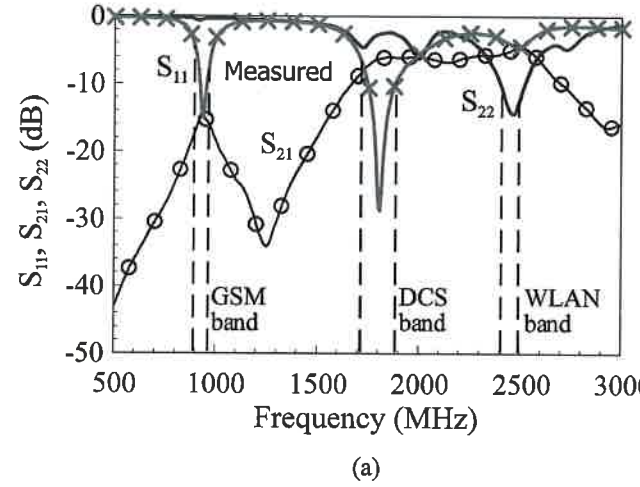
coupling between the two antennas is different, which tends to cause some shifting of the resonant frequency of the WLAN antenna. By slightly adjusting the length d, the WLAN antenna at each location can easily be tuned to cover the operating bandwidth of the 2.4-GHz band. On the other hand, the shifting of the resonant frequencies of the GSM/DCS antenna is found to be relatively small, which is largely because it is fixed at the top edge of the system circuit board in the study, unlike the WLAN antenna mounted at various locations of P1 to P10 in this study. Thus, no adjusting of the design dimensions shown in Figure 1(b) is required for the GSM/DCS antenna.

3. RESULTS AND DISCUSSION

The configuration shown in Figure 1, in which the WLAN antenna is at location P4 with case A orientation, is studied first. The measured reflection coefficients (S_{11} for the GSM/DCS antenna, S_{22} for the WLAN antenna) and isolation ($S_{21}0$ between the two antennas are shown in Figure 3(a). The simulated results obtained using Ansoft HFSS are presented in Figure 3(b). Reasonable agreement between the measurement and simulation results is obtained. It is also seen that the GSM/DCS antenna generates two separate resonant modes covering the operating bands of GSM and DCS systems. Similarly, for the WLAN antenna, a resonant mode is also successfully excited to cover the 2.4-GHz WLAN band. As for the isolation, the maximum S_{21} within the GSM, DCS, and WLAN bands is −33.6, −27.9, and −33.0 dB, respectively, which is quite good for practical applications.

On the other hand, when the WLAN antenna is mounted at location P10 with case A orientation, the obtained isolation is quickly degraded. The measured and simulated S parameters are shown in Figures 4(a) and 4(b), respectively. Again, reasonable agreement between measurement and simulation results is observed, and the maximum S_{21} within the GSM, DCS, and WLAN bands is only −14.9, −5.9, and −4.6 dB, respectively, which are not acceptable for practical applications.

The WLAN antenna mounted at various locations (P1 to P10) for both cases A and B are then extensively studied. The measured



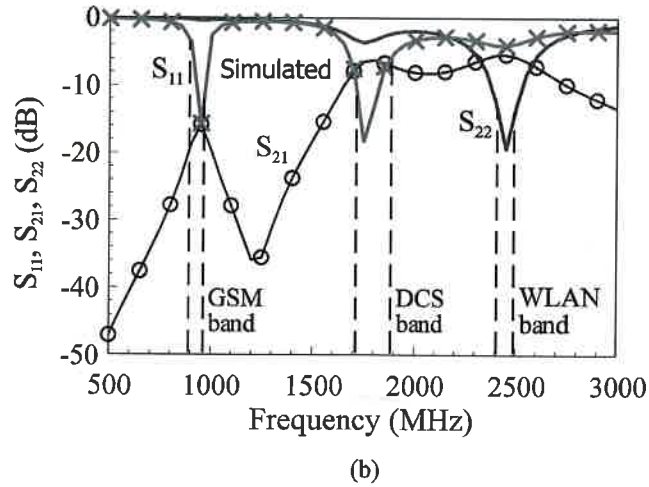


Figure 4 Reflection coefficients (S_{11} for GSM/DCS antenna, S_{22} for WLAN antenna) and isolation (S_{21}) between the two antennas for case A at location P10: (a) measured results; (b) simulated results. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

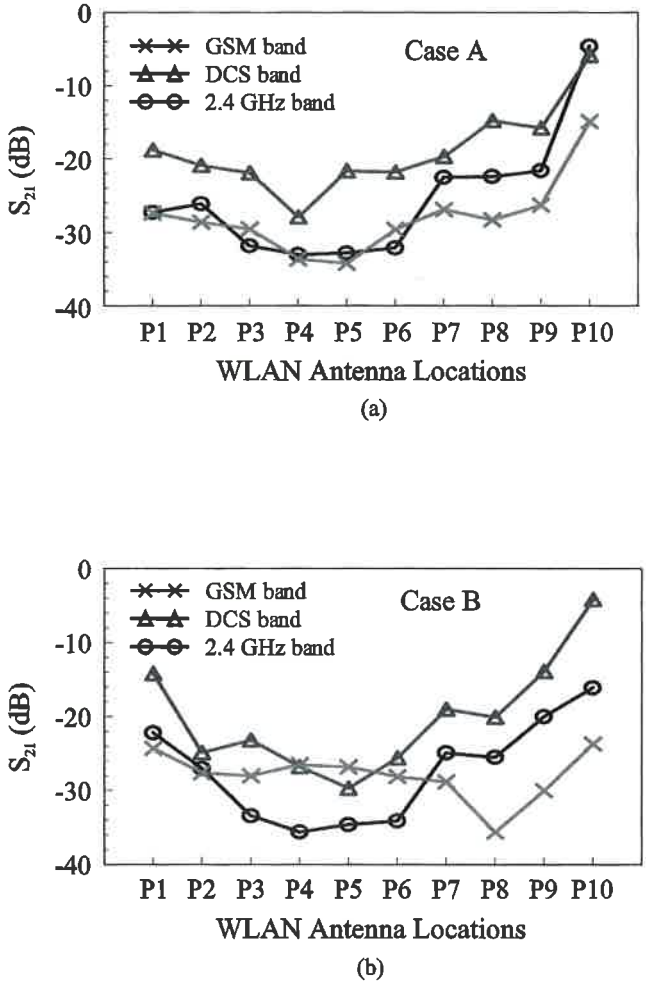


Figure 5 Measured maximum isolation (S_{21}) within the GSM, DCS, and WLAN bands at different locations from P1 to P10: (a) case A; (b) case B. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE 1 Measured Maximum Isolation (S_{21}) Within the GSM, DCS, and WLAN Bands, Respectively, at Different Locations (P1 to P10) of the WLAN Antenna Shown in Fig. 2

Location	Case	Max. S_{21} [dB] in GSM band	Max. S_{21} [dB] in DCS band	Max. S_{21} [dB] in WLAN band
P1	A	−27.4	−18.8	−27.3
	B	−24.3	−14.2	−22.2
P2	A	−28.6	−20.9	−26.1
	B	−27.6	−24.9	−27.0
P3	A	−29.5	−21.9	−31.8
	B	−28.0	−23.2	−33.4
P4	A	−33.6	−27.9	−33.0
	B	−26.5	−26.8	−35.6
P5	A	−34.2	−21.6	−32.8
	B	−26.8	−29.7	−34.6
P6	A	−29.6	−21.8	−32.1
	B	−28.1	−25.6	−34.1
P7	A	−26.9	−19.7	−22.5
	B	−28.8	−19.0	−24.9
P8	A	−28.3	−14.8	−22.4
	B	−35.6	−19.8	−25.5
P9	A	−26.3	−15.8	−21.6
	B	−30.0	−13.9	−20.0
P10	A	−14.9	−5.9	−4.6
	B	−23.7	−4.2	−16.1

maximum isolation (S_{21}) within the GSM, DCS, and WLAN bands at different locations from P1 to P10 is shown in Figure 5(a) for case A and in Figure 5(b) for case B. The corresponding measured data are also listed in Table 1 for comparison. From the results shown, a significant dependence of the isolation on the location and orientation of the WLAN antenna is seen. By comparing the obtained results, it can be concluded that the isolation obtained at location P4 for case A orientation is optimal among all the locations and orientations of the WLAN antennas studied here.

To further analyze the isolation behavior between the two antennas, the excited surface-current distributions in the ground plane of the system circuit board are studied. By using Ansoft simulation software HFSS, the simulated surface-current distributions in the system ground plane are obtained, and the results are shown in Figures 6–8. For Figures 6 and 7, the results are obtained when the WLAN antenna is excited at 925 MHz (the center frequency of the GSM band) and 1795 MHz (the center frequency of the DCS band), respectively, with the GSM/DCS antenna terminated to a 50Ω load. Whereas in Figure 8, the GSM/DCS antenna is excited at 2442 MHz (the center frequency of the 2.4-GHz WLAN band) with the WLAN antenna terminated to a 50Ω load.

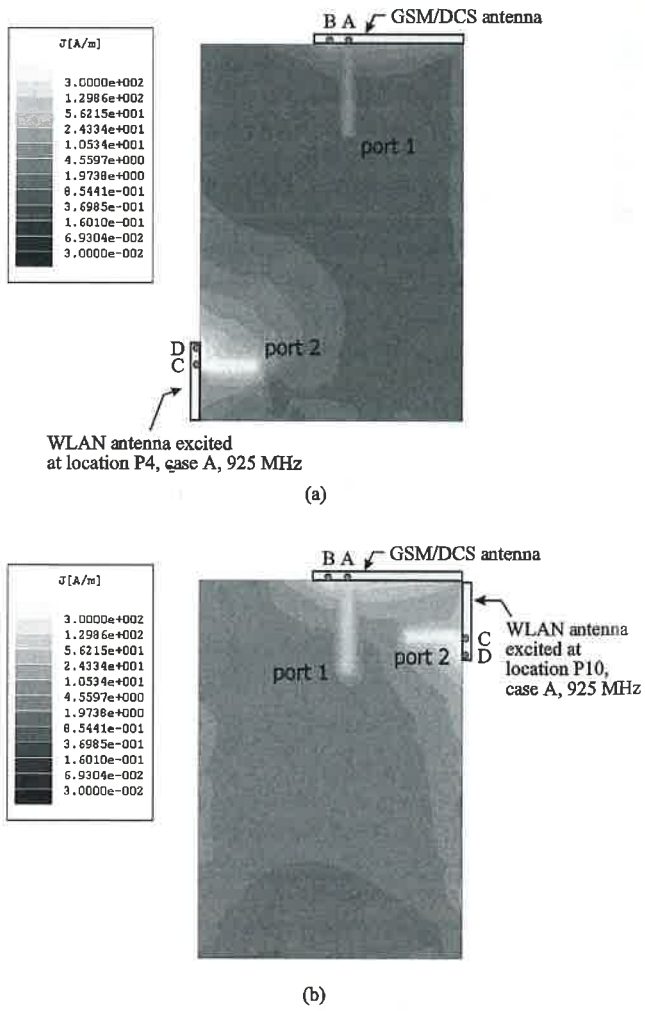
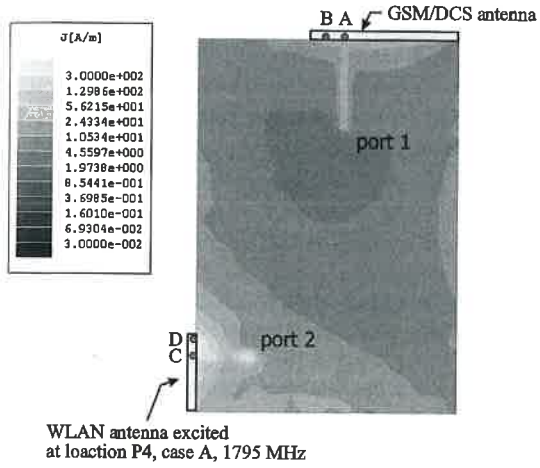


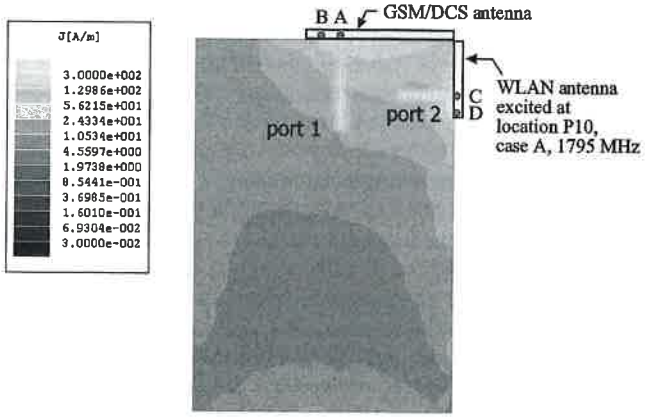
Figure 6 Simulated surface-current distributions in the system ground plane for case A; the WLAN antenna is excited at 925 MHz with the GSM/DCS antenna terminated to a 50Ω load: (a) at location P4; (b) at location P10. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

The results shown in Figures 6–8 suggest that the isolation between the two antennas is strongly related to the excited surface-current distributions in the system ground plane. By comparing Figure 6(a) (location P4 with case A, the same as the study in Fig. 3) to Figure 6(b) (location P10 for case A, the same as the study in Fig. 4), it is clearly seen that the excited surface currents near the GSM/DCS antenna are much stronger in Figure 6(b) than in Figure 6(a). This behavior may explain the reason for the poor isolation obtained in the GSM band for location P10 with case A shown in Figure 4.

Similarly, by comparing Figure 7(a) (location P4 with case A, the same as the study in Fig. 3) to Figure 7(b) (location P10 for case A, the same as the study in Fig. 4), much stronger excited surface currents near the GSM/DCS antennas in Figure 7(b) are seen. This behavior may also explain the reason for the poor isolation obtained in the DCS band for location P10 with case A shown in Figure 4. Finally, the obtained results shown in Figure 8 also indicate that much stronger surface currents are excited near the WLAN antenna in Figure 8(b) than in Figure 8(a). This may also lead to the poor isolation obtained in the 2.4-GHz WLAN band for location P10 with case A shown in Figure 4.

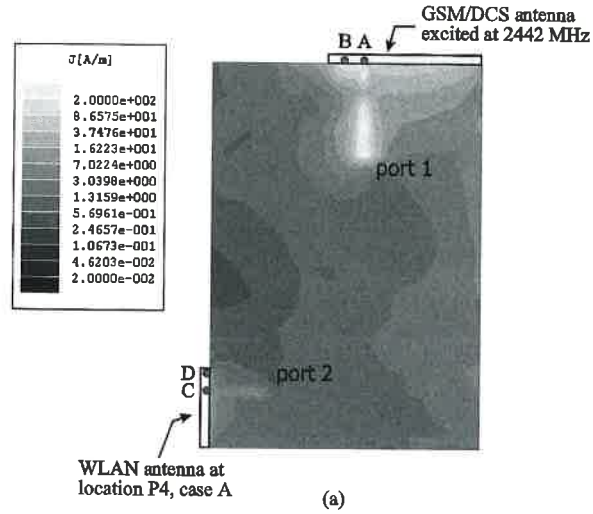


(a)

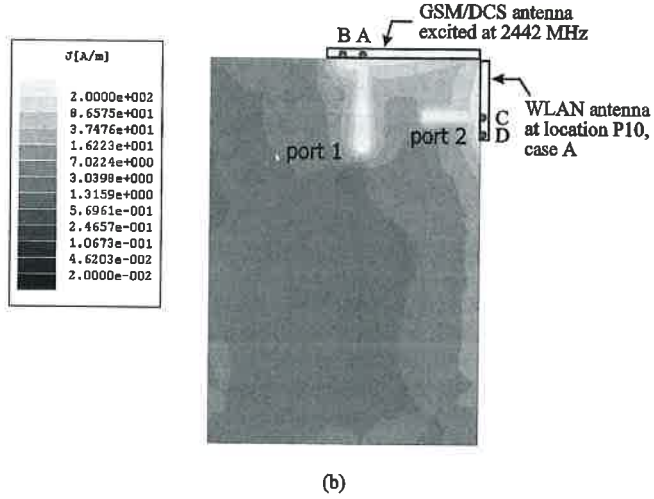


(b)

Figure 7 Simulated surface-current distributions in the system ground plane for case A; the WLAN antenna is excited at 1795 MHz with the GSM/DCS antenna terminated to a 50Ω load: (a) at location P4; (b) at location P10. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]



(a)



(b)

Figure 8 Simulated surface-current distributions in the system ground plane for case A; the GSM/DCS antenna is excited at 2442 MHz with the WLAN antenna terminated to a 50Ω load: (a) at location P4; (b) at location P10. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

4. CONCLUSION

Experimental and simulation studies for the isolation performances between two internal PIFA antennas for GSM/DCS and WLAN operations for a PDA phone have been presented. The results indicate that the isolation of the two antennas is greatly affected by their relative location inside the PDA phone. When the GSM/DCS antenna fixed at the top edge of the system circuit board, optimized or near-optimized isolation is achieved when the WLAN antenna is placed near the bottom edge of the system circuit board (location P4 in this study), with the WLAN antenna having its radiating arm extending away from the GSM/DCS antenna (case A in this study). It has also been observed that the isolation is strongly related to the excited surface-current distributions in the ground plane of the system circuit board of the PDA phone.

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WIDEBAND FOLDED-PATCH ANTENNAS FED BY L-SHAPED PROBE

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ABSTRACT: *Simple folded-patch antennas fed by an L-shape probe are designed and studied experimentally. This simple antenna structure with thick air substrate attains a projection-length reduction of about 30% with reference to the conventional half-wave patch antenna. This antenna attains an impedance bandwidth of 35% and a gain of 6 dBi.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 45: 352–355, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20821

Key words: *microstrip antennas; wideband antennas*

1. INTRODUCTION

Microstrip-patch antennas have the attractive features of low profile and light weight. However, the size of the microstrip antenna may be too large for some applications, especially when the operating frequency is low. There are a number of proposed techniques to reduce the size of the conventional half-wave microstrip-patch antenna, such as using high-dielectric-substrate material, adding shorting pins, adding a shorting wall, or cutting slots on the patch. One of the designs is the shorted quarter-wave patch antenna [1–3], which can reduce the resonant length by half [3]. However, the cross-polarization level is high, thus leading to a significant gain reduction [1]. In the proposed multilayer patch technique [4–5], a rectangular patch antenna is folded into several layers; this would introduce a complicated structure, which may not be favored by manufacturers.

On the other hand, the L-shaped probe [6] has been applied successfully to microstrip-antenna design. This is a feeding technique to enhance the bandwidth of patch antennas, which is also applicable to thick-substrate antennas. The L-shaped probe incorporated with the radiating patch introduces a capacitance in order to partially suppress the inductance introduced by the probe itself. Compared with the capacitor-patch technique, which is based on a similar principle of operation, the L-shaped probe does not require the feed probe to be soldered to the capacitor patch. Bending a straight probe into an L-shaped probe is easy during fabrication, especially for an array design. With the use of a shorted quarter-wave patch fed by an L-shaped probe, the bandwidth achieved is about 39% [6].

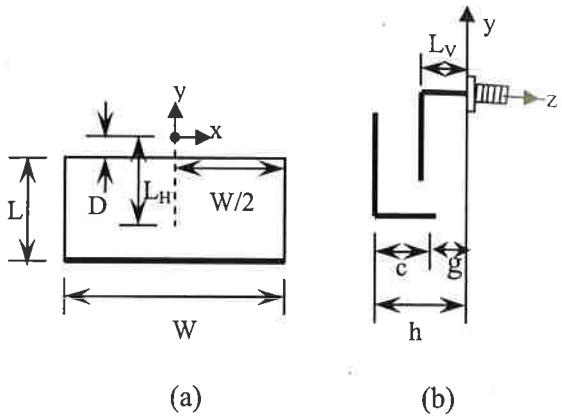


Figure 1 Geometry of the folded-patch antenna with L-probe feed: (a) top view; (b) side view

The shorted quarter-wave patch antenna fed by an L-shaped probe [2] combines the advantages of small size and wide bandwidth. However, large cross-polarization level in the H-plane and small gain are a weakness of this antenna design. Improving the performance of this antenna is challenging and of practical interest.

In this paper, a comprehensive experimental study of simple folded-patch microstrip-patch antennas with an L-shaped probe feed is presented. The results of these antennas will be compared with those of a similar antenna that has a simple and small-size structure—a quarter-wave microstrip-patch antenna shorted by a shorting wall fed by an L-shaped probe.

2. GEOMETRY

The geometry of the antenna is shown in Figure 1. A 2-mm-thick aluminum ground plane with dimensions 250 × 250 mm is used. A 0.07-mm-thick copper foil (foil shielding tape no. 1181 by 3M) is used to construct the folded antenna patches. The copper foil is taped on top of 1.5-mm-thick foam with a dielectric constant $\approx$1.06. Air is filled in the rest of the space, and the dielectric constant is assumed to be unity.

The design of this antenna is derived from the quarter-wave patch antenna shorted by a shorting wall. The patch is constructed by folding a rectangular-shape patch in a right angle, which is similar to the patch of a shorted quarter-wave antenna, while the vertical patch is not connected to the ground. This disconnection introduces one more radiation slot, which may improve the gain of this antenna. The L-shaped probe is constructed by bending a copper wire of 1-mm diameter and connecting it to a 50Ω 3.5-mm SMA connector mounted on the ground plane.

Several sets of the proposed antenna are constructed and their dimensions are tabulated in Table 1. Sets 3 and 6 are the shorted quarter-wave patch antennas, which have similar dimensions to those of our proposed antennas. The disconnection of the patch from the ground plane changed the electrical characteristic of the antenna; hence, the proposed antennas require a longer resonant length in order to match at a lower frequency. The projection length of the proposed antenna is about a quarter-wavelength long, especially when the gap g between the vertical patch and ground plane is small (sets 1 and 4).

The projection length of the proposed antennas is reduced. For the thick-substrate antennas, the projection length of set 1 is about $0.23\lambda_0$, whereas the projection length of the conventional half-wave patch antenna with similar thickness is about $0.33\lambda_0$, where

Attachment A-2

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DUAL-BAND LTCC CHIP ANTENNA DESIGN USING STACKED MEANDER PATCH FOR MOBILE HANDSETS

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Received 29 October 2004

ABSTRACT: *This paper presents design simulation, implementation, and measurement of a miniaturized GPS/K-PCS dual-band LTCC chip antenna for mobile communication handsets. The dimensions of the LTCC chip antenna is 9 × 15 × 1.2 mm. The meander-type radiating patch for dual-band operation is realized by using via holes with 0.3-mm height to connect upper- and lower-layer antennas. The lower meander-type antenna is to be tuned to the lower frequency (GPS) band. The upper meander antenna has a via-hole connection for the higher frequency (K-PCS) band.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 45: 271–273, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20793

Key words: *chip antenna; LTCC; meander patch; stacked structure; dual-band*

INTRODUCTION

As mobile-communication handsets become smaller and lighter, less space is available to place the antenna and RF devices. Recently, multilayer low-temperature co-fired ceramic (LTCC) technology has been extensively used for miniaturization of RF passive components and antennas. Therefore, the size reduction of the patch antenna for integration of different radio modules into the same piece of equipment is required, and compact internal antennas with multiband operation have become a popular topic in antenna research and investigations. There are a number of effective ways to reduce the size of patch antennas: use high-permittivity substrates [1], introduce shorting pins for the shifting of the null-voltage point at the edge of the radiating patch [2], use the planar inverted-F antenna (PIFA) for low-profile characteristic [3, 4]; and a combination of these approaches. Also, the basic concept to reduce the size of a microstrip patch antenna at a given resonant frequency is to increase its electrical surface-current length by changing the radiating element's shape [5, 6]. An effective method for increasing the effective surface-current path is to penetrate orthogonal slits into the boundary of the radiating patch. In this way, the excited surface-current paths are lengthened in the proposed designs, and the operating frequency is greatly lowered.

In this paper, a miniaturized GPS/K-PCS dual-band LTCC chip antenna is proposed for mobile-communication handsets. The experimental results for dual-band operation, return loss, and radiation pattern are presented.

PROPOSED ANTENNA DESIGN

The compact meander-type antenna for dual-band operation is realized in a multilayer printed LTCC-body structure. Figure 1 shows the geometry of the proposed stacked meander-type dual-band antenna mounted FR4 substrate. The dimension of LTCC chip antenna is 9 × 15 × 1.2 mm and the dielectric constant of the LTCC-body ceramic for antenna implementation is 7.8. The meander-type radiating patch for dual-band operation is realized by using via holes with 0.3-mm height to connect the upper- and lower-layer antennas. The dimension of the FR-4 circuit board is

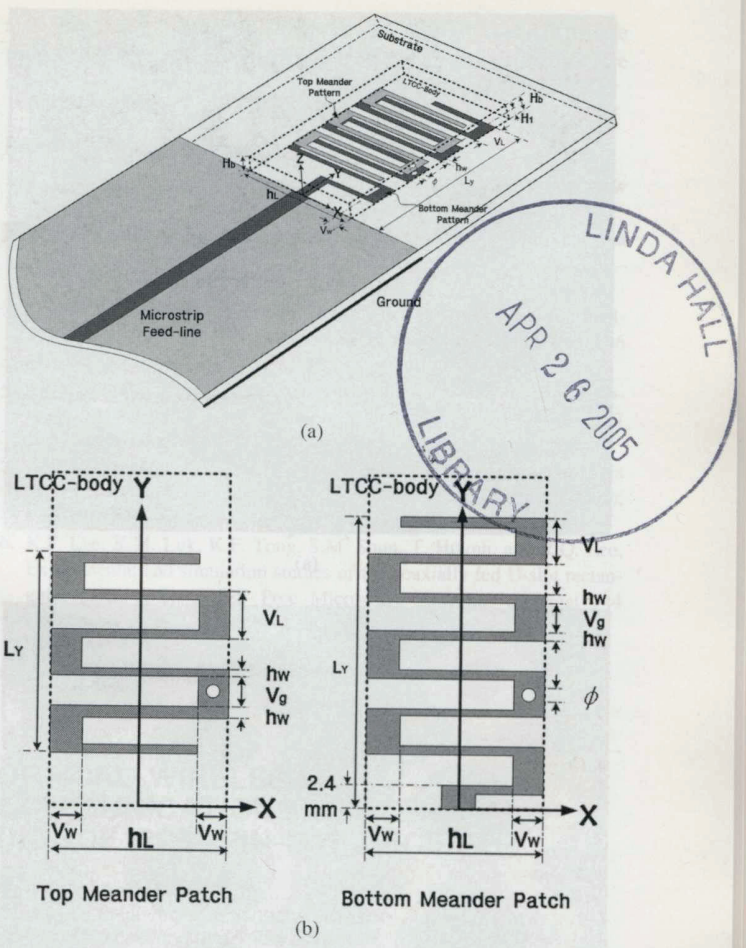


Figure 1 Geometry and dimensions of the proposed dual-band chip antenna for mobile communication: $V_W \times V_L = 1 \times 2$ mm, $h_W \times h_L = 0.4 \times 8$ mm, $S_W = 0.2$ mm, $H_1 = 0.3$ mm, $\phi = 0.5$ mm, LTCC body ($\varepsilon_r = 7.8$) = 9 × 15 × 1.2 mm

40 × 80 × 0.8 mm and the size of the ground plane is 60 × 40 mm. A 50Ω microstrip line is used to feed the compact chip antenna, and the ground plane on the other side of the substrate is cut at the end of the microstrip feed. After a thorough parametric study of the proposed model, the optimum design parameters for the dual-band chip antenna are selected. A description of the design parameters is given in the legend of Figure 1.

EXPERIMENTAL RESULTS AND DISCUSSION

In the single-meander radiating structure, the electric fields on the each pair of the symmetrical segments in the x-direction are opposite; hence, they produce little radiation in the desired direction. On the other hand, the electric fields on the segments in the y-direction of the meander antenna have the same direction; they behave like a short dipole. Figure 2 shows the simulated y-component of the magnetic fields obtained using a CST Microwave 4.0 simulator.

It can be seen from the magnetic-field distribution that the fields on the vertical segments (y-component) of the meander have the same direction. Consequently, they behave like a short dipole in the vertical direction, consisting of seven dipoles. In this paper, the lower meander-type antenna is tuned to the GPS band and the upper meander antenna with via-hole connection is for the K-PCS band. Figure 3 shows the surface-current distribution at the two

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TABLE 2 Impedance of the Half-Wavelength Resonant Printed Dipole on a Real Substrate: Analytical and Experimental Results (*h* is the Substrate Thickness)

ε_r	h/λ_0	R_{res} [Ω] [2]	R_{res} [Ω] Eq. (15)
3.25	0.1016	34.5	39
3.25	0.127	60	62
8.5	0.15	50	76

$$X_{in} \cong -\frac{30}{\sqrt{\varepsilon_{reff}}}\left\{-\frac{8\pi h}{\lambda}+\frac{8\pi h^2}{l\lambda}\right\}=\frac{120}{\sqrt{\varepsilon_{reff}}}\pi\frac{h}{l}\left(1-\frac{h}{l}\right). \tag{14}$$

The antenna complex impedance is finally obtained by combining the real and imaginary parts from Eqs. (9) and (14) as follows:

$$Z = Z_{in} = R_{in} + jX_{in} \cong \frac{600}{\sqrt{\varepsilon_{reff}}}\left(\frac{h}{l}\right)^2 + j\frac{120}{\sqrt{\varepsilon_{reff}}}\pi\frac{h}{l}\left(1-\frac{h}{l}\right). \tag{15}$$

RESULTS

Table 1 presents the impedance of a half-wavelength printed dipole on a substrate with $\varepsilon_r = 1$ (air) and for the different values of the substrate thickness. The analytical results from Eq. (15) have been compared with the numerical results simulated using the numerical electromagnetic code (NEC) for an infinite reflector plane. Very good agreement is observed between the analytical results and the numerical ones.

To investigate the effect of a real substrate and a finite ground plane, the analytical results have been compared (Table 2) with a few experimental results found in the literature [3]. The experimental tests are on the radiation resistance of a resonant printed dipole, although they may be compared with the real part of the impedance of a half-wavelength printed dipole. It can be observed that the resonance radiation impedance is not very different from the real impedance of the half-wavelength printed dipole [4]. As shown in Table 2, the results are coherent for ε_r of around 3. For the high permitivity of 8.5, this difference is important; it may be the result of the coupling beyond the "surface waves," which can be very effective in this case.

The feeding-gap effect on the experimental input impedance should also be considered in the theoretical treatment for more accuracy. The simple capacitive model of the feeding gap for a normal dipole [6] can be useful in this case.

CONCLUSION AND PERSPECTIVE

The analytical study presented here has successfully described the self impedance of a printed half-wavelength dipole on an arbitrary substrate. The obtained closed-form formulas clearly show the dependence of the dipole impedance on the dipole length as well as the substrate properties. The comparative results of the numerical simulation and the experiment have demonstrated the performance of these simple formulas. These compact formulas can be used to analyse patch antennas that are simulated by only a few thin printed dipoles.

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ISOLATION BETWEEN GSM/DCS AND WLAN ANTENNAS IN A PDA PHONE

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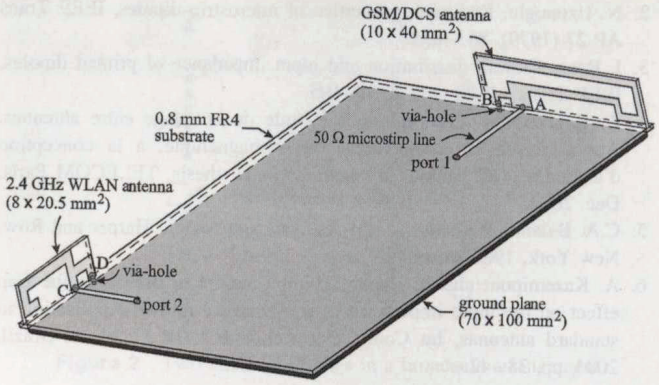
ABSTRACT: *The isolation performances of GSM/DCS and WLAN antennas embedded in a PDA phone for cellular/WLAN dual-network operations are studied. The two (GSM/DCS and WLAN) antennas are printed PIFAs with compact sizes and are mounted perpendicularly along the boundary of the system circuit board in order to perform as internal antennas for the PDA phone. It is found that the isolation between the two antennas is greatly dependent on their relative position inside the PDA phone. The measured and simulated results are presented, and the isolation performances are analyzed.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 45: 347–352, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20820

Key words: *mobile antennas; global system for mobile communication/digital communication system (GSM/DCS); wireless local area network (WLAN) antennas; planar inverted-F antennas (PIFAs); personal digital assistant (PDA) phones*

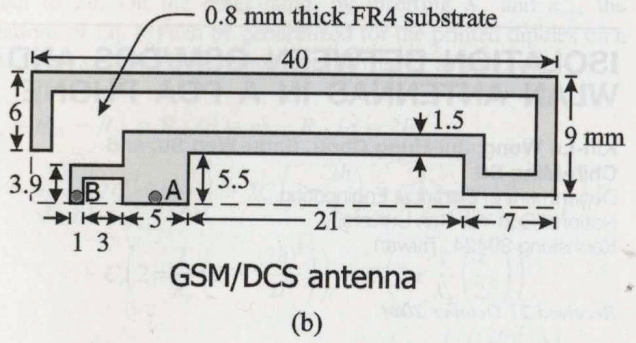
1. INTRODUCTION

Integration of cellular and WLAN communication networks can provide users with ubiquitous or seamless data services [1]. For such an integrated cellular/WLAN network application, many dual-mode or dual-network wireless devices (such as PDA phones) are expected to emerge in the market in the near future. For this application, it is required that a PDA phone be equipped with two antennas, for example, one GSM/DCS (890–960 MHz/1710–1880 MHz) antenna for cellular operation and one WLAN antenna for 2.4-GHz (2400–2484 MHz) WLAN operation [2]. However, due to the limited space available inside a PDA phone, special care is required for achieving optimized isolation between the two antennas in order to avoid performance degradation.

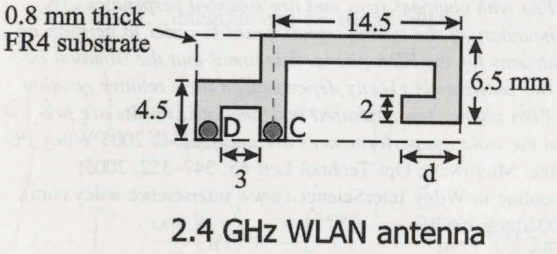
In this paper, we present a study on the isolation of two promising internal antennas (one GSM/DCS antenna and one 2.4-GHz WLAN antenna) for a PDA phone for cellular/WLAN dual-network operations. Both the GSM/DCS and WLAN antennas are printed PIFAs with compact sizes (see Fig. 1) and can be concealed within the casing of a PDA phone for operation as



(a)



(b)



(c)

Figure 1 (a) Configuration of the internal GSM/DCS and WLAN antennas for a PDA phone for cellular/WLAN dual-network operations; (b) dimensions of the GSM/DCS antenna; (c) dimensions of the WLAN antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

internal antennas. In this study, as in most conventional mobile-phone-antenna designs [2], the GSM/DCS antenna is arranged to be fixed at the top edge of the system circuit board. The WLAN antenna is then mounted at various possible locations along the boundary of the system ground plane. At each possible location, the isolation between the GSM/DCS and WLAN antennas is measured and analyzed. The simulation results obtained using Ansoft high-frequency structure simulator (HFSS) simulation software are also presented for comparison. The optimized isolation between the two antennas is discussed.

2. ARRANGEMENT OF TWO INTERNAL ANTENNAS FOR CELLULAR/WLAN DUAL-NETWORK OPERATIONS

Figure 1(a) shows the promising internal GSM/DCS and WLAN antennas for a PDA phone. Both antennas are printed on 0.8-mm-thick FR4 substrate and are in the form of a PIFA with a folded radiating arm in order to achieve a compact structure [3]. The GSM/DCS antenna occupies a small area of 10×40 mm^2 and is fixed at the top edge of a system circuit board having a ground plane of 100-mm length and 70-mm width in this study, which is a reasonable size for practical PDA phones. Also note that the GSM/DCS antenna is mounted perpendicularly to the system circuit board [4–6] and has a height of 10 mm only, which is less than the thickness of most PDA phones, thus making it possible to conceal the antenna within the casing of the PDA phone as an internal antenna. Given the design dimensions shown in Figure 1(b), the GSM/DCS antenna can generate two separate resonant modes at about 900 and 1800 MHz to cover the GSM (890–960 MHz) and DCS (1710–1880 MHz) bands.

The WLAN antenna, whose design dimensions are given in Figure 1(c), is designed for operating in the 2.4-GHz band (2400–2484 MHz). This antenna occupies a compact area of 8×20.5 mm^2 and is also printed on 0.8-mm-thick FR4 substrate. Similar to the GSM/DCS antenna, the WLAN antenna can also be concealed within the casing of the PDA phone as an internal antenna.

The WLAN antenna is then moved along the boundary (locations P1 to P10 shown in Fig. 2) of the system circuit board in order to determine the optimized isolation to the GSM/DCS antenna. Note that there are two kinds of orientations (cases A and B) of the WLAN antenna mounted along the boundary of the system circuit board. Cases A and B represent the WLAN antenna extending [from point D (shorting point) to point C (feeding point) to the radiating arm of the antenna] counterclockwise and clockwise, respectively, at each specified location. The configuration shown in Figure 1 is denoted as case A at location P4 in this study.

Also note that, at the end of the radiating arm of the WLAN antenna [see Fig. 1(c)], there is tuning length of d (about 2.0–4.5 mm in this study) for tuning the antenna's resonant frequency to be at about 2.45 GHz at each possible location shown in Figure 2. This is because, for each location in this study, the isolation or

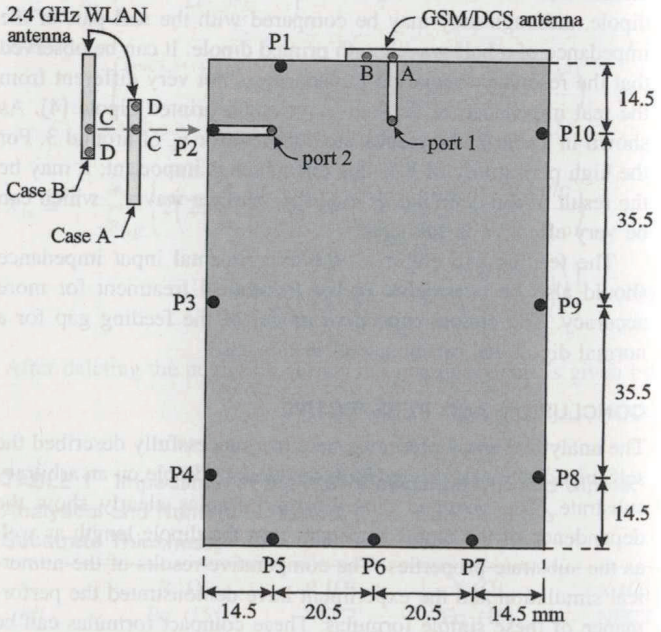


Figure 2 Locations (P1 to P10) of the WLAN antenna with the GSM/DCS antenna fixed at the top edge of the system ground plane; cases A and B represent the WLAN antenna extending (from point D to point C to the radiating arm of the antenna) counterclockwise and clockwise, respectively, at each specified location. The configuration shown in Fig. 1 is for case A at location P4. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

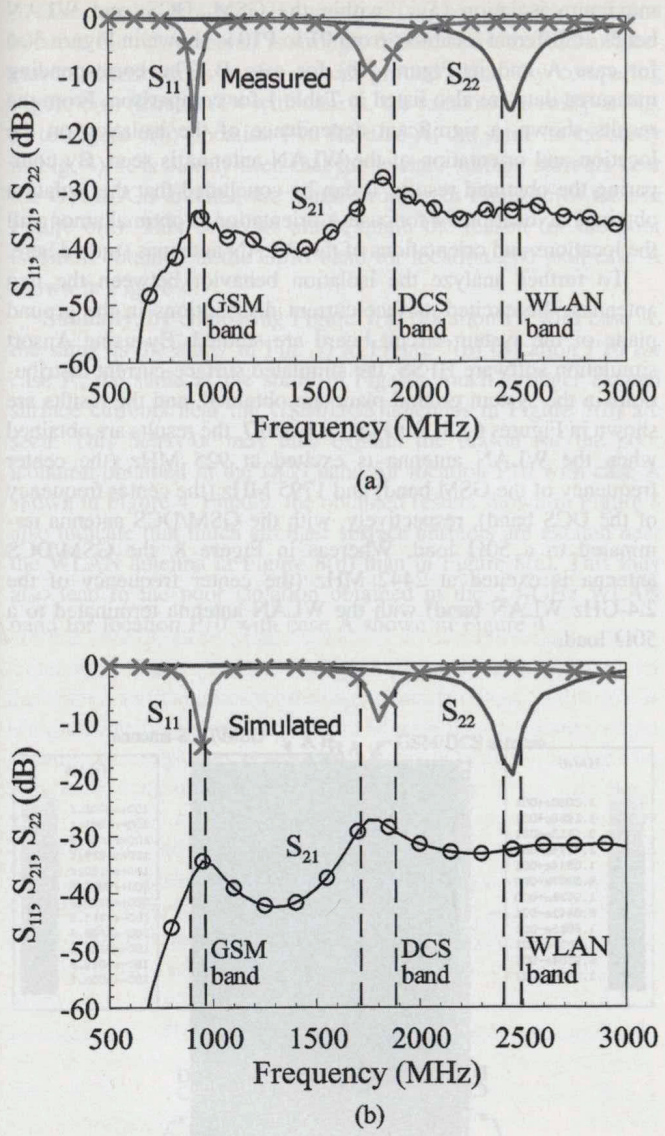


Figure 3 Reflection coefficients (S_{11} for GSM/DCS antenna, S_{22} for WLAN antenna) and isolation (S_{21}) between the two antennas for case A at location P4: (a) measured results; (b) simulated results. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

coupling between the two antennas is different, which tends to cause some shifting of the resonant frequency of the WLAN antenna. By slightly adjusting the length d, the WLAN antenna at each location can easily be tuned to cover the operating bandwidth of the 2.4-GHz band. On the other hand, the shifting of the resonant frequencies of the GSM/DCS antenna is found to be relatively small, which is largely because it is fixed at the top edge of the system circuit board in the study, unlike the WLAN antenna mounted at various locations of P1 to P10 in this study. Thus, no adjusting of the design dimensions shown in Figure 1(b) is required for the GSM/DCS antenna.

3. RESULTS AND DISCUSSION

The configuration shown in Figure 1, in which the WLAN antenna is at location P4 with case A orientation, is studied first. The measured reflection coefficients (S_{11} for the GSM/DCS antenna, S_{22} for the WLAN antenna) and isolation ($S_{21}0$ between the two antennas are shown in Figure 3(a). The simulated results obtained using Ansoft HFSS are presented in Figure 3(b). Reasonable agreement between the measurement and simulation results is obtained. It is also seen that the GSM/DCS antenna generates two separate resonant modes covering the operating bands of GSM and DCS systems. Similarly, for the WLAN antenna, a resonant mode is also successfully excited to cover the 2.4-GHz WLAN band. As for the isolation, the maximum S_{21} within the GSM, DCS, and WLAN bands is −33.6, −27.9, and −33.0 dB, respectively, which is quite good for practical applications.

On the other hand, when the WLAN antenna is mounted at location P10 with case A orientation, the obtained isolation is quickly degraded. The measured and simulated S parameters are shown in Figures 4(a) and 4(b), respectively. Again, reasonable agreement between measurement and simulation results is observed, and the maximum S_{21} within the GSM, DCS, and WLAN bands is only −14.9, −5.9, and −4.6 dB, respectively, which are not acceptable for practical applications.

The WLAN antenna mounted at various locations (P1 to P10) for both cases A and B are then extensively studied. The measured

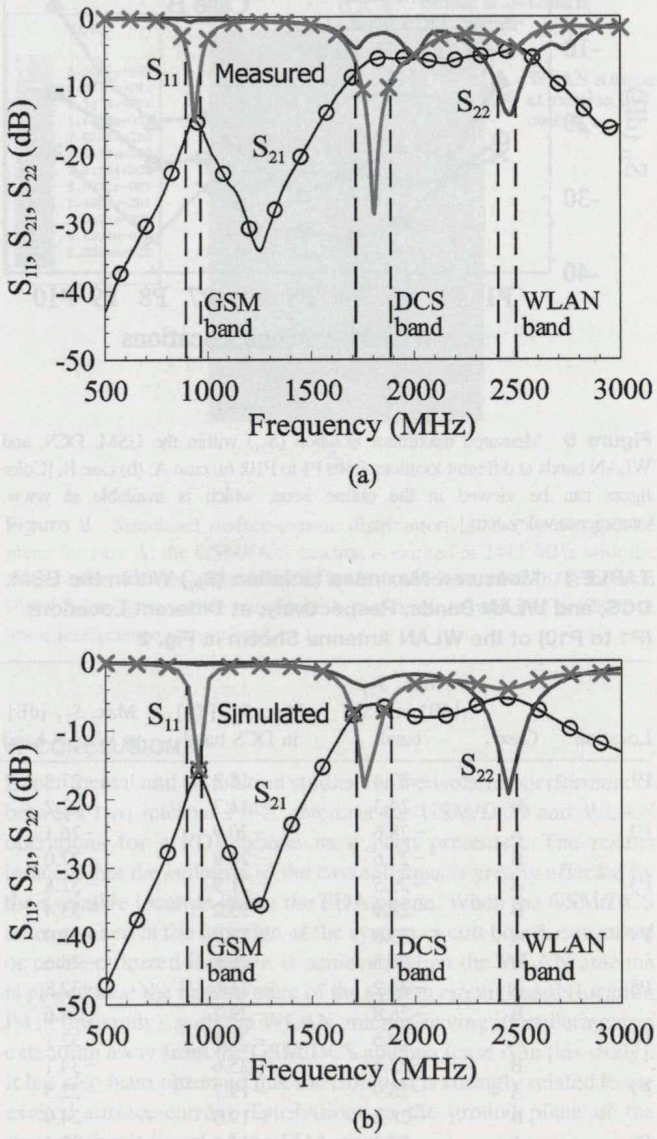
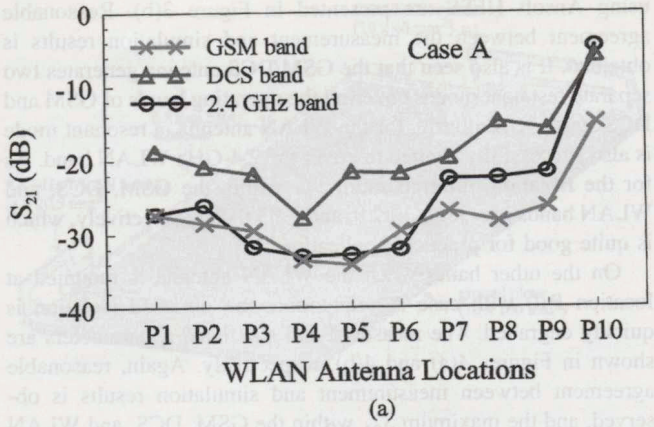


Figure 4 Reflection coefficients (S_{11} for GSM/DCS antenna, S_{22} for WLAN antenna) and isolation (S_{21}) between the two antennas for case A at location P10: (a) measured results; (b) simulated results. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]



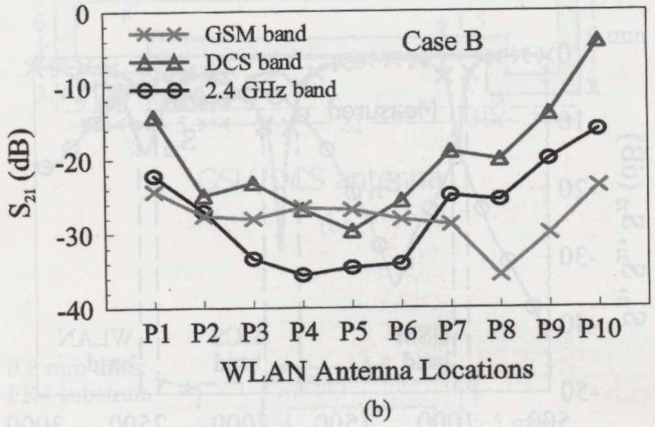


Figure 5 Measured maximum isolation (S_{21}) within the GSM, DCS, and WLAN bands at different locations from P1 to P10: (a) case A; (b) case B. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE 1 Measured Maximum Isolation (S_{21}) Within the GSM, DCS, and WLAN Bands, Respectively, at Different Locations (P1 to P10) of the WLAN Antenna Shown in Fig. 2

Location	Case	Max. S_{21} [dB] in GSM band	Max. S_{21} [dB] in DCS band	Max. S_{21} [dB] in WLAN band
P1	A	−27.4	−18.8	−27.3
	B	−24.3	−14.2	−22.2
P2	A	−28.6	−20.9	−26.1
	B	−27.6	−24.9	−27.0
P3	A	−29.5	−21.9	−31.8
	B	−28.0	−23.2	−33.4
P4	A	−33.6	−27.9	−33.0
	B	−26.5	−26.8	−35.6
P5	A	−34.2	−21.6	−32.8
	B	−26.8	−29.7	−34.6
P6	A	−29.6	−21.8	−32.1
	B	−28.1	−25.6	−34.1
P7	A	−26.9	−19.7	−22.5
	B	−28.8	−19.0	−24.9
P8	A	−28.3	−14.8	−22.4
	B	−35.6	−19.8	−25.5
P9	A	−26.3	−15.8	−21.6
	B	−30.0	−13.9	−20.0
P10	A	−14.9	−5.9	−4.6
	B	−23.7	−4.2	−16.1

maximum isolation (S_{21}) within the GSM, DCS, and WLAN bands at different locations from P1 to P10 is shown in Figure 5(a) for case A and in Figure 5(b) for case B. The corresponding measured data are also listed in Table 1 for comparison. From the results shown, a significant dependence of the isolation on the location and orientation of the WLAN antenna is seen. By comparing the obtained results, it can be concluded that the isolation obtained at location P4 for case A orientation is optimal among all the locations and orientations of the WLAN antennas studied here.

To further analyze the isolation behavior between the two antennas, the excited surface-current distributions in the ground plane of the system circuit board are studied. By using Ansoft simulation software HFSS, the simulated surface-current distributions in the system ground plane are obtained, and the results are shown in Figures 6–8. For Figures 6 and 7, the results are obtained when the WLAN antenna is excited at 925 MHz (the center frequency of the GSM band) and 1795 MHz (the center frequency of the DCS band), respectively, with the GSM/DCS antenna terminated to a 50Ω load. Whereas in Figure 8, the GSM/DCS antenna is excited at 2442 MHz (the center frequency of the 2.4-GHz WLAN band) with the WLAN antenna terminated to a 50Ω load.

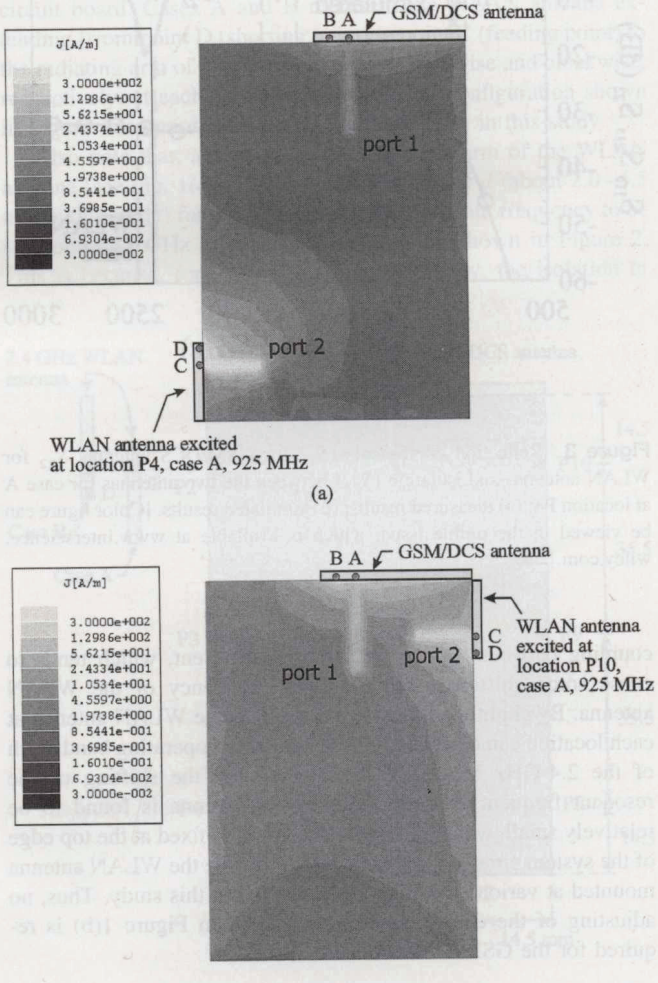


Figure 6 Simulated surface-current distributions in the system ground plane for case A; the WLAN antenna is excited at 925 MHz with the GSM/DCS antenna terminated to a 50Ω load: (a) at location P4; (b) at location P10. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

The results shown in Figures 6–8 suggest that the isolation between the two antennas is strongly related to the excited surface-current distributions in the system ground plane. By comparing Figure 6(a) (location P4 with case A, the same as the study in Fig. 3) to Figure 6(b) (location P10 for case A, the same as the study in Fig. 4), it is clearly seen that the excited surface currents near the GSM/DCS antenna are much stronger in Figure 6(b) than in Figure 6(a). This behavior may explain the reason for the poor isolation obtained in the GSM band for location P10 with case A shown in Figure 4.

Similarly, by comparing Figure 7(a) (location P4 with case A, the same as the study in Fig. 3) to Figure 7(b) (location P10 for case A, the same as the study in Fig. 4), much stronger excited surface currents near the GSM/DCS antennas in Figure 7(b) are seen. This behavior may also explain the reason for the poor isolation obtained in the DCS band for location P10 with case A shown in Figure 4. Finally, the obtained results shown in Figure 8 also indicate that much stronger surface currents are excited near the WLAN antenna in Figure 8(b) than in Figure 8(a). This may also lead to the poor isolation obtained in the 2.4-GHz WLAN band for location P10 with case A shown in Figure 4.

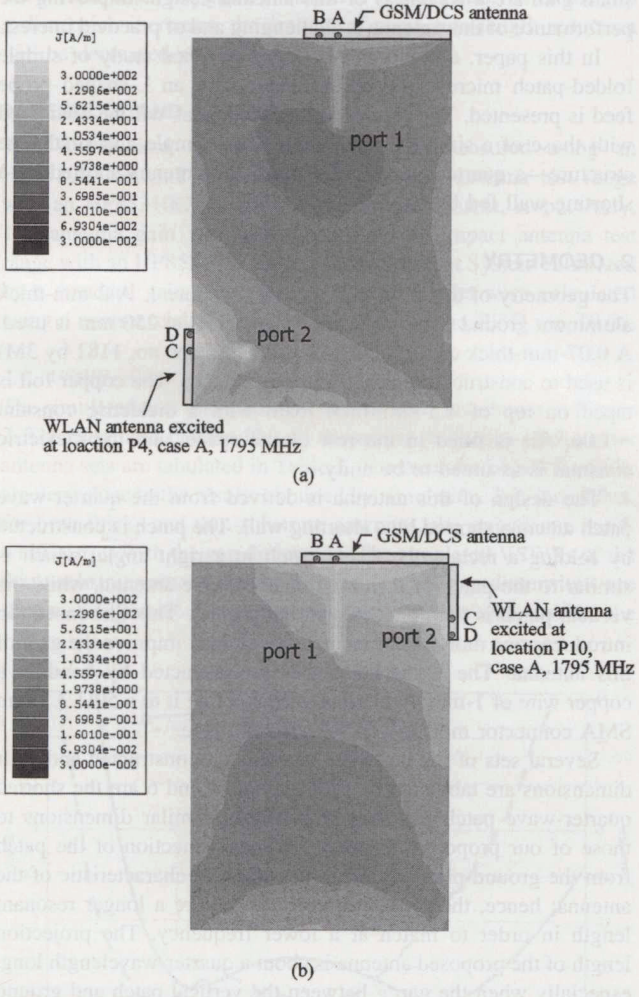


Figure 7 Simulated surface-current distributions in the system ground plane for case A; the WLAN antenna is excited at 1795 MHz with the GSM/DCS antenna terminated to a 50Ω load: (a) at location P4; (b) at location P10. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

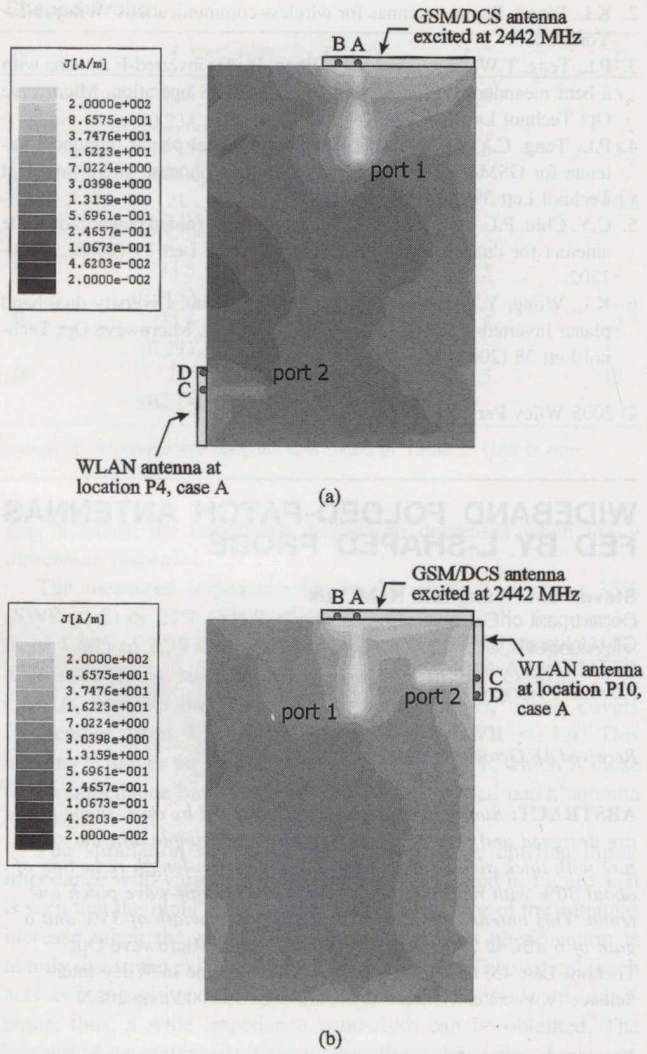


Figure 8 Simulated surface-current distributions in the system ground plane for case A; the GSM/DCS antenna is excited at 2442 MHz with the WLAN antenna terminated to a 50Ω load: (a) at location P4; (b) at location P10. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

4. CONCLUSION

Experimental and simulation studies for the isolation performances between two internal PIFA antennas for GSM/DCS and WLAN operations for a PDA phone have been presented. The results indicate that the isolation of the two antennas is greatly affected by their relative location inside the PDA phone. When the GSM/DCS antenna fixed at the top edge of the system circuit board, optimized or near-optimized isolation is achieved when the WLAN antenna is placed near the bottom edge of the system circuit board (location P4 in this study), with the WLAN antenna having its radiating arm extending away from the GSM/DCS antenna (case A in this study). It has also been observed that the isolation is strongly related to the excited surface-current distributions in the ground plane of the system circuit board of the PDA phone.

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WIDEBAND FOLDED-PATCH ANTENNAS FED BY L-SHAPED PROBE

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ABSTRACT: *Simple folded-patch antennas fed by an L-shape probe are designed and studied experimentally. This simple antenna structure with thick air substrate attains a projection-length reduction of about 30% with reference to the conventional half-wave patch antenna. This antenna attains an impedance bandwidth of 35% and a gain of 6 dBi.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 45: 352–355, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20821

Key words: *microstrip antennas; wideband antennas*

1. INTRODUCTION

Microstrip-patch antennas have the attractive features of low profile and light weight. However, the size of the microstrip antenna may be too large for some applications, especially when the operating frequency is low. There are a number of proposed techniques to reduce the size of the conventional half-wave microstrip-patch antenna, such as using high-dielectric-substrate material, adding shorting pins, adding a shorting wall, or cutting slots on the patch. One of the designs is the shorted quarter-wave patch antenna [1–3], which can reduce the resonant length by half [3]. However, the cross-polarization level is high, thus leading to a significant gain reduction [1]. In the proposed multilayer patch technique [4–5], a rectangular patch antenna is folded into several layers; this would introduce a complicated structure, which may not be favored by manufacturers.

On the other hand, the L-shaped probe [6] has been applied successfully to microstrip-antenna design. This is a feeding technique to enhance the bandwidth of patch antennas, which is also applicable to thick-substrate antennas. The L-shaped probe incorporated with the radiating patch introduces a capacitance in order to partially suppress the inductance introduced by the probe itself. Compared with the capacitor-patch technique, which is based on a similar principle of operation, the L-shaped probe does not require the feed probe to be soldered to the capacitor patch. Bending a straight probe into an L-shaped probe is easy during fabrication, especially for an array design. With the use of a shorted quarter-wave patch fed by an L-shaped probe, the bandwidth achieved is about 39% [6].

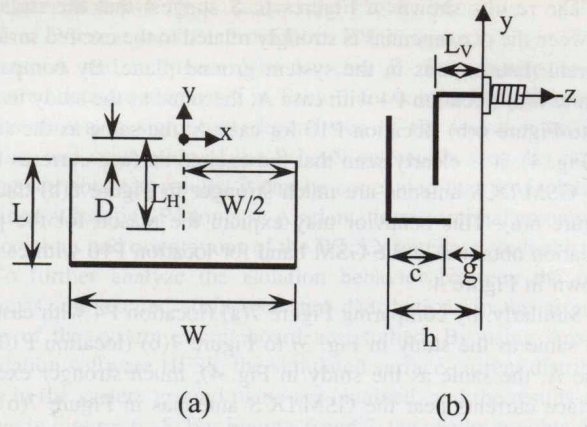


Figure 1 Geometry of the folded-patch antenna with L-probe feed: (a) top view; (b) side view

The shorted quarter-wave patch antenna fed by an L-shaped probe [2] combines the advantages of small size and wide bandwidth. However, large cross-polarization level in the H-plane and small gain are a weakness of this antenna design. Improving the performance of this antenna is challenging and of practical interest.

In this paper, a comprehensive experimental study of simple folded-patch microstrip-patch antennas with an L-shaped probe feed is presented. The results of these antennas will be compared with those of a similar antenna that has a simple and small-size structure—a quarter-wave microstrip-patch antenna shorted by a shorting wall fed by an L-shaped probe.

2. GEOMETRY

The geometry of the antenna is shown in Figure 1. A 2-mm-thick aluminum ground plane with dimensions 250 × 250 mm is used. A 0.07-mm-thick copper foil (foil shielding tape no. 1181 by 3M) is used to construct the folded antenna patches. The copper foil is taped on top of 1.5-mm-thick foam with a dielectric constant $\approx$1.06. Air is filled in the rest of the space, and the dielectric constant is assumed to be unity.

The design of this antenna is derived from the quarter-wave patch antenna shorted by a shorting wall. The patch is constructed by folding a rectangular-shape patch in a right angle, which is similar to the patch of a shorted quarter-wave antenna, while the vertical patch is not connected to the ground. This disconnection introduces one more radiation slot, which may improve the gain of this antenna. The L-shaped probe is constructed by bending a copper wire of 1-mm diameter and connecting it to a 50Ω 3.5-mm SMA connector mounted on the ground plane.

Several sets of the proposed antenna are constructed and their dimensions are tabulated in Table 1. Sets 3 and 6 are the shorted quarter-wave patch antennas, which have similar dimensions to those of our proposed antennas. The disconnection of the patch from the ground plane changed the electrical characteristic of the antenna; hence, the proposed antennas require a longer resonant length in order to match at a lower frequency. The projection length of the proposed antenna is about a quarter-wavelength long, especially when the gap g between the vertical patch and ground plane is small (sets 1 and 4).

The projection length of the proposed antennas is reduced. For the thick-substrate antennas, the projection length of set 1 is about $0.23\lambda_0$, whereas the projection length of the conventional half-wave patch antenna with similar thickness is about $0.33\lambda_0$, where

Attachment A-3

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TABLE 2 Impedance of the Half-Wavelength Resonant Printed Dipole on a Real Substrate: Analytical and Experimental Results (*h* is the Substrate Thickness)

ε_r	h/λ_0	R_{res} [Ω] [2]	R_{res} [Ω] Eq. (15)
3.25	0.1016	34.5	39
3.25	0.127	60	62
8.5	0.15	50	76

$$X_{in} \cong -\frac{30}{\sqrt{\varepsilon_{reff}}}\left\{-\frac{8\pi h}{\lambda}+\frac{8\pi h^2}{l\lambda}\right\}=\frac{120}{\sqrt{\varepsilon_{reff}}}\pi\frac{h}{l}\left(1-\frac{h}{l}\right). \tag{14}$$

The antenna complex impedance is finally obtained by combining the real and imaginary parts from Eqs. (9) and (14) as follows:

$$Z = Z_{in} = R_{in} + jX_{in} \cong \frac{600}{\sqrt{\varepsilon_{reff}}}\left(\frac{h}{l}\right)^2 + j\frac{120}{\sqrt{\varepsilon_{reff}}}\pi\frac{h}{l}\left(1-\frac{h}{l}\right). \tag{15}$$

RESULTS

Table 1 presents the impedance of a half-wavelength printed dipole on a substrate with $\varepsilon_r = 1$ (air) and for the different values of the substrate thickness. The analytical results from Eq. (15) have been compared with the numerical results simulated using the numerical electromagnetic code (NEC) for an infinite reflector plane. Very good agreement is observed between the analytical results and the numerical ones.

To investigate the effect of a real substrate and a finite ground plane, the analytical results have been compared (Table 2) with a few experimental results found in the literature [3]. The experimental tests are on the radiation resistance of a resonant printed dipole, although they may be compared with the real part of the impedance of a half-wavelength printed dipole. It can be observed that the resonance radiation impedance is not very different from the real impedance of the half-wavelength printed dipole [4]. As shown in Table 2, the results are coherent for ε_r of around 3. For the high permitivity of 8.5, this difference is important; it may be the result of the coupling beyond the "surface waves," which can be very effective in this case.

The feeding-gap effect on the experimental input impedance should also be considered in the theoretical treatment for more accuracy. The simple capacitive model of the feeding gap for a normal dipole [6] can be useful in this case.

CONCLUSION AND PERSPECTIVE

The analytical study presented here has successfully described the self impedance of a printed half-wavelength dipole on an arbitrary substrate. The obtained closed-form formulas clearly show the dependence of the dipole impedance on the dipole length as well as the substrate properties. The comparative results of the numerical simulation and the experiment have demonstrated the performance of these simple formulas. These compact formulas can be used to analyse patch antennas that are simulated by only a few thin printed dipoles.

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ISOLATION BETWEEN GSM/DCS AND WLAN ANTENNAS IN A PDA PHONE

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ABSTRACT: *The isolation performances of GSM/DCS and WLAN antennas embedded in a PDA phone for cellular/WLAN dual-network operations are studied. The two (GSM/DCS and WLAN) antennas are printed PIFAs with compact sizes and are mounted perpendicularly along the boundary of the system circuit board in order to perform as internal antennas for the PDA phone. It is found that the isolation between the two antennas is greatly dependent on their relative position inside the PDA phone. The measured and simulated results are presented, and the isolation performances are analyzed.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 45: 347–352, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20820

Key words: *mobile antennas; global system for mobile communication/digital communication system (GSM/DCS); wireless local area network (WLAN) antennas; planar inverted-F antennas (PIFAs); personal digital assistant (PDA) phones*

1. INTRODUCTION

Integration of cellular and WLAN communication networks can provide users with ubiquitous or seamless data services [1]. For such an integrated cellular/WLAN network application, many dual-mode or dual-network wireless devices (such as PDA phones) are expected to emerge in the market in the near future. For this application, it is required that a PDA phone be equipped with two antennas, for example, one GSM/DCS (890–960 MHz/1710–1880 MHz) antenna for cellular operation and one WLAN antenna for 2.4-GHz (2400–2484 MHz) WLAN operation [2]. However, due to the limited space available inside a PDA phone, special care is required for achieving optimized isolation between the two antennas in order to avoid performance degradation.

In this paper, we present a study on the isolation of two promising internal antennas (one GSM/DCS antenna and one 2.4-GHz WLAN antenna) for a PDA phone for cellular/WLAN dual-network operations. Both the GSM/DCS and WLAN antennas are printed PIFAs with compact sizes (see Fig. 1) and can be concealed within the casing of a PDA phone for operation as

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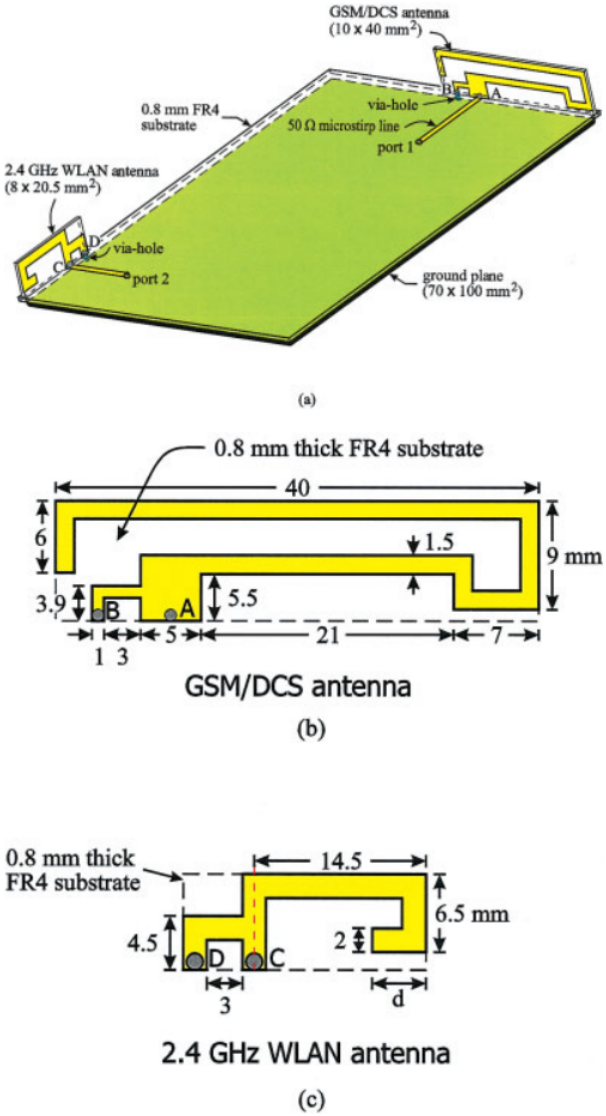


Figure 1 (a) Configuration of the internal GSM/DCS and WLAN antennas for a PDA phone for cellular/WLAN dual-network operations; (b) dimensions of the GSM/DCS antenna; (c) dimensions of the WLAN antenna. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

internal antennas. In this study, as in most conventional mobile-phone-antenna designs [2], the GSM/DCS antenna is arranged to be fixed at the top edge of the system circuit board. The WLAN antenna is then mounted at various possible locations along the boundary of the system ground plane. At each possible location, the isolation between the GSM/DCS and WLAN antennas is measured and analyzed. The simulation results obtained using Ansoft high-frequency structure simulator (HFSS) simulation software are also presented for comparison. The optimized isolation between the two antennas is discussed.

2. ARRANGEMENT OF TWO INTERNAL ANTENNAS FOR CELLULAR/WLAN DUAL-NETWORK OPERATIONS

Figure 1(a) shows the promising internal GSM/DCS and WLAN antennas for a PDA phone. Both antennas are printed on 0.8-mm-thick FR4 substrate and are in the form of a PIFA with a folded radiating arm in order to achieve a compact structure [3]. The GSM/DCS antenna occupies a small area of 10×40 mm^2 and is fixed at the top edge of a system circuit board having a ground plane of 100-mm length and 70-mm width in this study, which is a reasonable size for practical PDA phones. Also note that the GSM/DCS antenna is mounted perpendicularly to the system circuit board [4–6] and has a height of 10 mm only, which is less than the thickness of most PDA phones, thus making it possible to conceal the antenna within the casing of the PDA phone as an internal antenna. Given the design dimensions shown in Figure 1(b), the GSM/DCS antenna can generate two separate resonant modes at about 900 and 1800 MHz to cover the GSM (890–960 MHz) and DCS (1710–1880 MHz) bands.

The WLAN antenna, whose design dimensions are given in Figure 1(c), is designed for operating in the 2.4-GHz band (2400–2484 MHz). This antenna occupies a compact area of 8×20.5 mm^2 and is also printed on 0.8-mm-thick FR4 substrate. Similar to the GSM/DCS antenna, the WLAN antenna can also be concealed within the casing of the PDA phone as an internal antenna.

The WLAN antenna is then moved along the boundary (locations P1 to P10 shown in Fig. 2) of the system circuit board in order to determine the optimized isolation to the GSM/DCS antenna. Note that there are two kinds of orientations (cases A and B) of the WLAN antenna mounted along the boundary of the system circuit board. Cases A and B represent the WLAN antenna extending [from point D (shorting point) to point C (feeding point) to the radiating arm of the antenna] counterclockwise and clockwise, respectively, at each specified location. The configuration shown in Figure 1 is denoted as case A at location P4 in this study.

Also note that, at the end of the radiating arm of the WLAN antenna [see Fig. 1(c)], there is tuning length of d (about 2.0–4.5 mm in this study) for tuning the antenna's resonant frequency to be at about 2.45 GHz at each possible location shown in Figure 2. This is because, for each location in this study, the isolation or

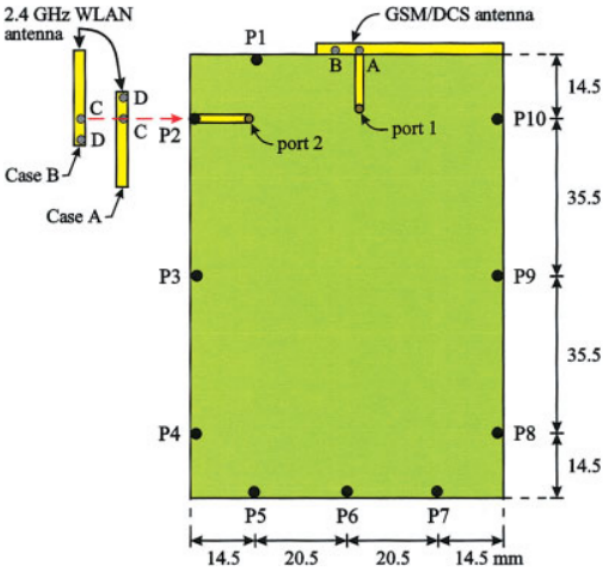


Figure 2 Locations (P1 to P10) of the WLAN antenna with the GSM/DCS antenna fixed at the top edge of the system ground plane; cases A and B represent the WLAN antenna extending (from point D to point C to the radiating arm of the antenna) counterclockwise and clockwise, respectively, at each specified location. The configuration shown in Fig. 1 is for case A at location P4. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

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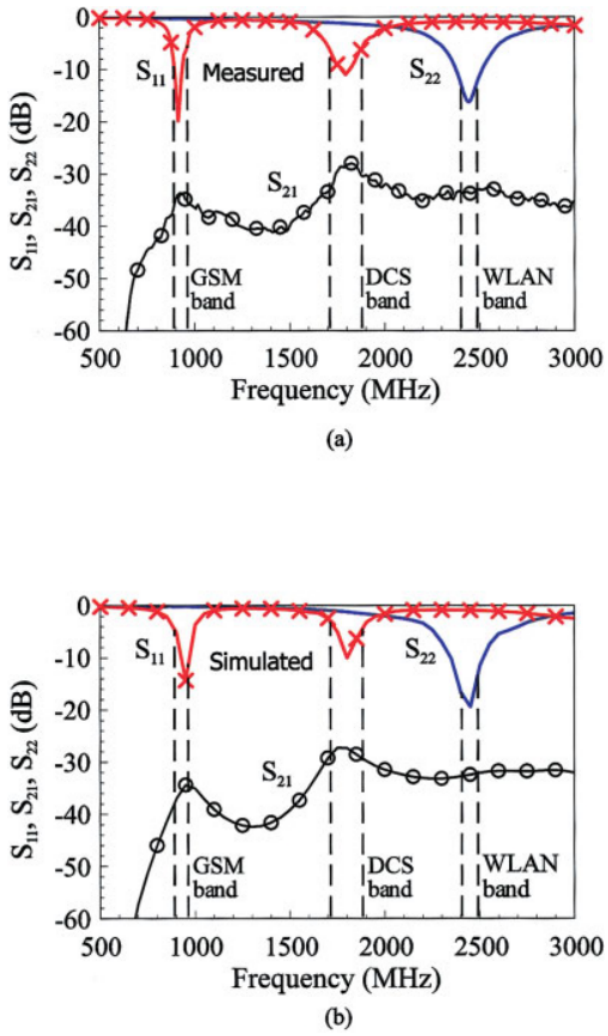


Figure 3 Reflection coefficients (S_{11} for GSM/DCS antenna, S_{22} for WLAN antenna) and isolation (S_{21}) between the two antennas for case A at location P4: (a) measured results; (b) simulated results. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

coupling between the two antennas is different, which tends to cause some shifting of the resonant frequency of the WLAN antenna. By slightly adjusting the length d, the WLAN antenna at each location can easily be tuned to cover the operating bandwidth of the 2.4-GHz band. On the other hand, the shifting of the resonant frequencies of the GSM/DCS antenna is found to be relatively small, which is largely because it is fixed at the top edge of the system circuit board in the study, unlike the WLAN antenna mounted at various locations of P1 to P10 in this study. Thus, no adjusting of the design dimensions shown in Figure 1(b) is required for the GSM/DCS antenna.

3. RESULTS AND DISCUSSION

The configuration shown in Figure 1, in which the WLAN antenna is at location P4 with case A orientation, is studied first. The measured reflection coefficients (S_{11} for the GSM/DCS antenna, S_{22} for the WLAN antenna) and isolation ($S_{21}0$ between the two antennas are shown in Figure 3(a). The simulated results obtained using Ansoft HFSS are presented in Figure 3(b). Reasonable agreement between the measurement and simulation results is obtained. It is also seen that the GSM/DCS antenna generates two separate resonant modes covering the operating bands of GSM and DCS systems. Similarly, for the WLAN antenna, a resonant mode is also successfully excited to cover the 2.4-GHz WLAN band. As for the isolation, the maximum S_{21} within the GSM, DCS, and WLAN bands is −33.6, −27.9, and −33.0 dB, respectively, which is quite good for practical applications.

On the other hand, when the WLAN antenna is mounted at location P10 with case A orientation, the obtained isolation is quickly degraded. The measured and simulated S parameters are shown in Figures 4(a) and 4(b), respectively. Again, reasonable agreement between measurement and simulation results is observed, and the maximum S_{21} within the GSM, DCS, and WLAN bands is only −14.9, −5.9, and −4.6 dB, respectively, which are not acceptable for practical applications.

The WLAN antenna mounted at various locations (P1 to P10) for both cases A and B are then extensively studied. The measured

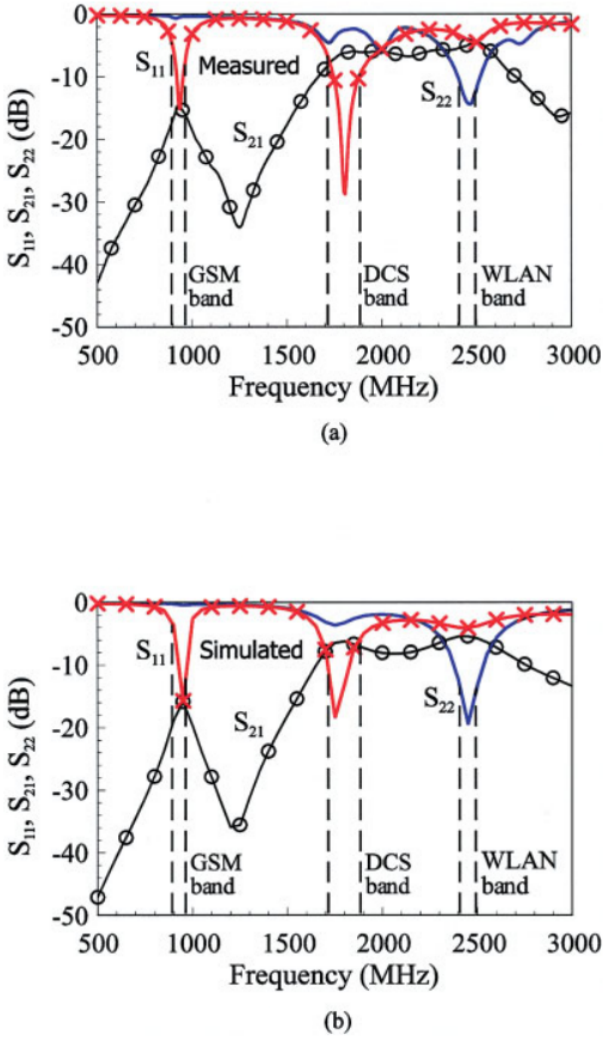


Figure 4 Reflection coefficients (S_{11} for GSM/DCS antenna, S_{22} for WLAN antenna) and isolation (S_{21}) between the two antennas for case A at location P10: (a) measured results; (b) simulated results. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

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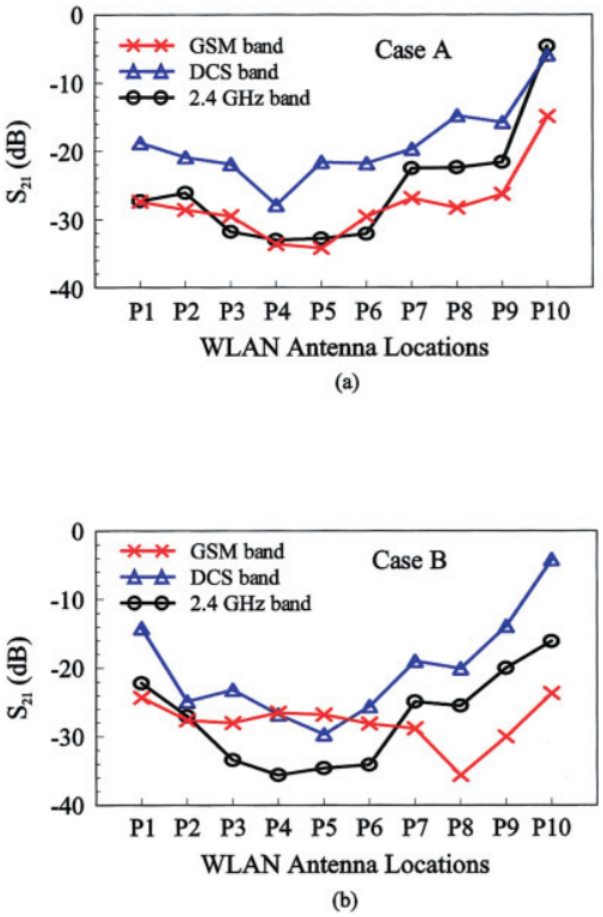


Figure 5 Measured maximum isolation (S_{21}) within the GSM, DCS, and WLAN bands at different locations from P1 to P10: (a) case A; (b) case B. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE 1 Measured Maximum Isolation (S_{21}) Within the GSM, DCS, and WLAN Bands, Respectively, at Different Locations (P1 to P10) of the WLAN Antenna Shown in Fig. 2

Location	Case	Max. S_{21} [dB] in GSM band	Max. S_{21} [dB] in DCS band	Max. S_{21} [dB] in WLAN band
P1	A	−27.4	−18.8	−27.3
	B	−24.3	−14.2	−22.2
P2	A	−28.6	−20.9	−26.1
	B	−27.6	−24.9	−27.0
P3	A	−29.5	−21.9	−31.8
	B	−28.0	−23.2	−33.4
P4	A	−33.6	−27.9	−33.0
	B	−26.5	−26.8	−35.6
P5	A	−34.2	−21.6	−32.8
	B	−26.8	−29.7	−34.6
P6	A	−29.6	−21.8	−32.1
	B	−28.1	−25.6	−34.1
P7	A	−26.9	−19.7	−22.5
	B	−28.8	−19.0	−24.9
P8	A	−28.3	−14.8	−22.4
	B	−35.6	−19.8	−25.5
P9	A	−26.3	−15.8	−21.6
	B	−30.0	−13.9	−20.0
P10	A	−14.9	−5.9	−4.6
	B	−23.7	−4.2	−16.1

maximum isolation (S_{21}) within the GSM, DCS, and WLAN bands at different locations from P1 to P10 is shown in Figure 5(a) for case A and in Figure 5(b) for case B. The corresponding measured data are also listed in Table 1 for comparison. From the results shown, a significant dependence of the isolation on the location and orientation of the WLAN antenna is seen. By comparing the obtained results, it can be concluded that the isolation obtained at location P4 for case A orientation is optimal among all the locations and orientations of the WLAN antennas studied here.

To further analyze the isolation behavior between the two antennas, the excited surface-current distributions in the ground plane of the system circuit board are studied. By using Ansoft simulation software HFSS, the simulated surface-current distributions in the system ground plane are obtained, and the results are shown in Figures 6–8. For Figures 6 and 7, the results are obtained when the WLAN antenna is excited at 925 MHz (the center frequency of the GSM band) and 1795 MHz (the center frequency of the DCS band), respectively, with the GSM/DCS antenna terminated to a 50Ω load. Whereas in Figure 8, the GSM/DCS antenna is excited at 2442 MHz (the center frequency of the 2.4-GHz WLAN band) with the WLAN antenna terminated to a 50Ω load.

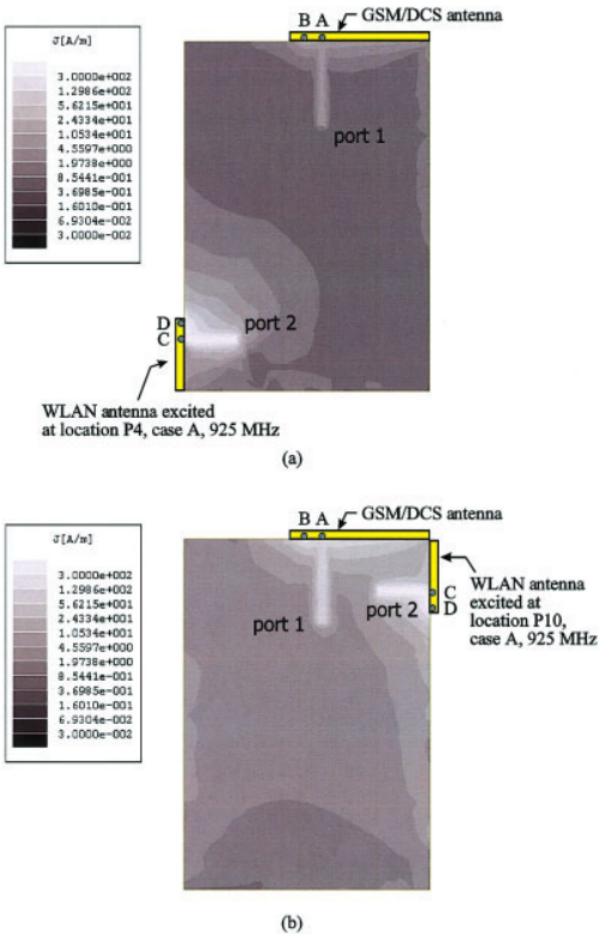


Figure 6 Simulated surface-current distributions in the system ground plane for case A; the WLAN antenna is excited at 925 MHz with the GSM/DCS antenna terminated to a 50Ω load: (a) at location P4; (b) at location P10. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

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The results shown in Figures 6–8 suggest that the isolation between the two antennas is strongly related to the excited surface-current distributions in the system ground plane. By comparing Figure 6(a) (location P4 with case A, the same as the study in Fig. 3) to Figure 6(b) (location P10 for case A, the same as the study in Fig. 4), it is clearly seen that the excited surface currents near the GSM/DCS antenna are much stronger in Figure 6(b) than in Figure 6(a). This behavior may explain the reason for the poor isolation obtained in the GSM band for location P10 with case A shown in Figure 4.

Similarly, by comparing Figure 7(a) (location P4 with case A, the same as the study in Fig. 3) to Figure 7(b) (location P10 for case A, the same as the study in Fig. 4), much stronger excited surface currents near the GSM/DCS antennas in Figure 7(b) are seen. This behavior may also explain the reason for the poor isolation obtained in the DCS band for location P10 with case A shown in Figure 4. Finally, the obtained results shown in Figure 8 also indicate that much stronger surface currents are excited near the WLAN antenna in Figure 8(b) than in Figure 8(a). This may also lead to the poor isolation obtained in the 2.4-GHz WLAN band for location P10 with case A shown in Figure 4.

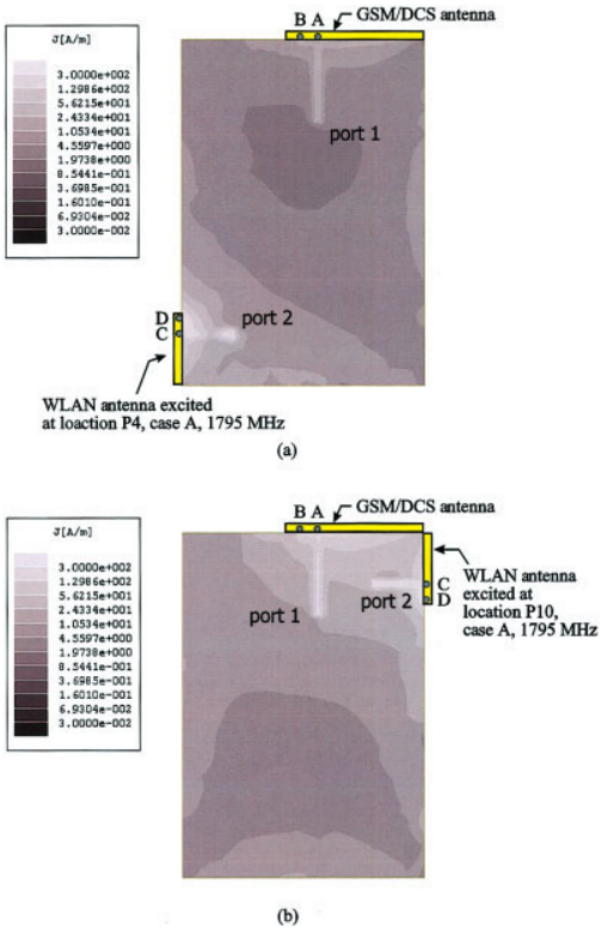


Figure 7 Simulated surface-current distributions in the system ground plane for case A; the WLAN antenna is excited at 1795 MHz with the GSM/DCS antenna terminated to a 50Ω load: (a) at location P4; (b) at location P10. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

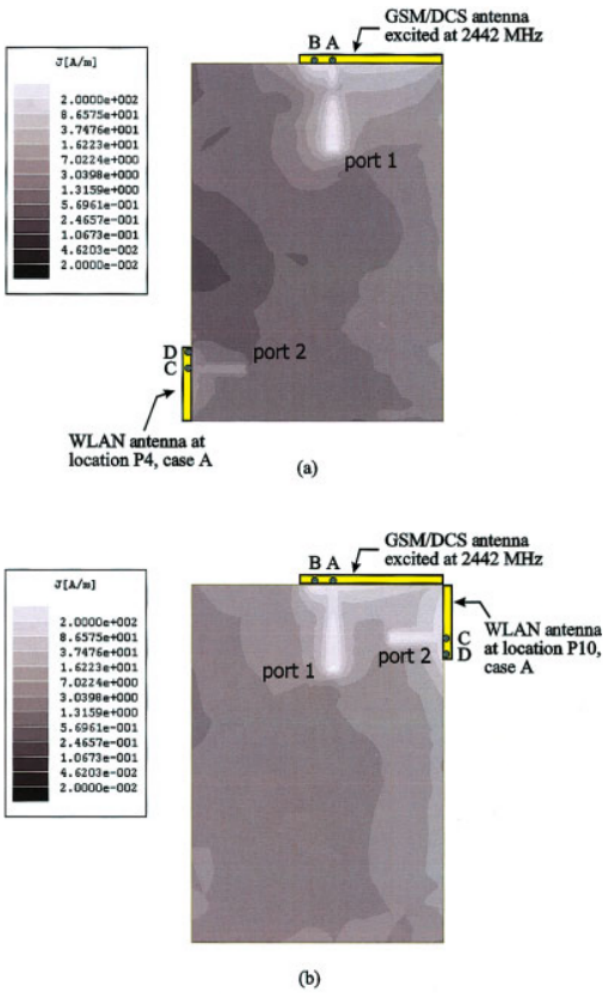


Figure 8 Simulated surface-current distributions in the system ground plane for case A; the GSM/DCS antenna is excited at 2442 MHz with the WLAN antenna terminated to a 50Ω load: (a) at location P4; (b) at location P10. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

4. CONCLUSION

Experimental and simulation studies for the isolation performances between two internal PIFA antennas for GSM/DCS and WLAN operations for a PDA phone have been presented. The results indicate that the isolation of the two antennas is greatly affected by their relative location inside the PDA phone. When the GSM/DCS antenna fixed at the top edge of the system circuit board, optimized or near-optimized isolation is achieved when the WLAN antenna is placed near the bottom edge of the system circuit board (location P4 in this study), with the WLAN antenna having its radiating arm extending away from the GSM/DCS antenna (case A in this study). It has also been observed that the isolation is strongly related to the excited surface-current distributions in the ground plane of the system circuit board of the PDA phone.

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WIDEBAND FOLDED-PATCH ANTENNAS FED BY L-SHAPED PROBE

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ABSTRACT: *Simple folded-patch antennas fed by an L-shape probe are designed and studied experimentally. This simple antenna structure with thick air substrate attains a projection-length reduction of about 30% with reference to the conventional half-wave patch antenna. This antenna attains an impedance bandwidth of 35% and a gain of 6 dBi.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 45: 352–355, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20821

Key words: *microstrip antennas; wideband antennas*

1. INTRODUCTION

Microstrip-patch antennas have the attractive features of low profile and light weight. However, the size of the microstrip antenna may be too large for some applications, especially when the operating frequency is low. There are a number of proposed techniques to reduce the size of the conventional half-wave microstrip-patch antenna, such as using high-dielectric-substrate material, adding shorting pins, adding a shorting wall, or cutting slots on the patch. One of the designs is the shorted quarter-wave patch antenna [1–3], which can reduce the resonant length by half [3]. However, the cross-polarization level is high, thus leading to a significant gain reduction [1]. In the proposed multilayer patch technique [4–5], a rectangular patch antenna is folded into several layers; this would introduce a complicated structure, which may not be favored by manufacturers.

On the other hand, the L-shaped probe [6] has been applied successfully to microstrip-antenna design. This is a feeding technique to enhance the bandwidth of patch antennas, which is also applicable to thick-substrate antennas. The L-shaped probe incorporated with the radiating patch introduces a capacitance in order to partially suppress the inductance introduced by the probe itself. Compared with the capacitor-patch technique, which is based on a similar principle of operation, the L-shaped probe does not require the feed probe to be soldered to the capacitor patch. Bending a straight probe into an L-shaped probe is easy during fabrication, especially for an array design. With the use of a shorted quarter-wave patch fed by an L-shaped probe, the bandwidth achieved is about 39% [6].

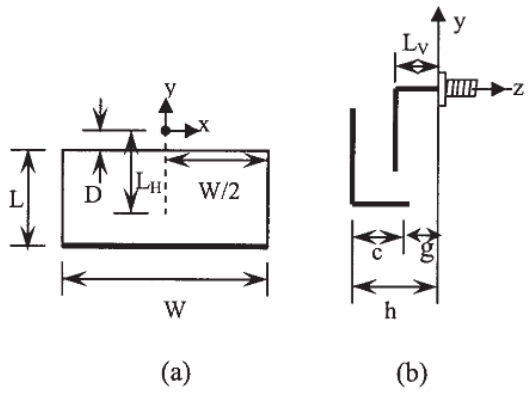


Figure 1 Geometry of the folded-patch antenna with L-probe feed: (a) top view; (b) side view

The shorted quarter-wave patch antenna fed by an L-shaped probe [2] combines the advantages of small size and wide bandwidth. However, large cross-polarization level in the H-plane and small gain are a weakness of this antenna design. Improving the performance of this antenna is challenging and of practical interest.

In this paper, a comprehensive experimental study of simple folded-patch microstrip-patch antennas with an L-shaped probe feed is presented. The results of these antennas will be compared with those of a similar antenna that has a simple and small-size structure—a quarter-wave microstrip-patch antenna shorted by a shorting wall fed by an L-shaped probe.

2. GEOMETRY

The geometry of the antenna is shown in Figure 1. A 2-mm-thick aluminum ground plane with dimensions 250 × 250 mm is used. A 0.07-mm-thick copper foil (foil shielding tape no. 1181 by 3M) is used to construct the folded antenna patches. The copper foil is taped on top of 1.5-mm-thick foam with a dielectric constant ≈1.06. Air is filled in the rest of the space, and the dielectric constant is assumed to be unity.

The design of this antenna is derived from the quarter-wave patch antenna shorted by a shorting wall. The patch is constructed by folding a rectangular-shape patch in a right angle, which is similar to the patch of a shorted quarter-wave antenna, while the vertical patch is not connected to the ground. This disconnection introduces one more radiation slot, which may improve the gain of this antenna. The L-shaped probe is constructed by bending a copper wire of 1-mm diameter and connecting it to a 50Ω 3.5-mm SMA connector mounted on the ground plane.

Several sets of the proposed antenna are constructed and their dimensions are tabulated in Table 1. Sets 3 and 6 are the shorted quarter-wave patch antennas, which have similar dimensions to those of our proposed antennas. The disconnection of the patch from the ground plane changed the electrical characteristic of the antenna; hence, the proposed antennas require a longer resonant length in order to match at a lower frequency. The projection length of the proposed antenna is about a quarter-wavelength long, especially when the gap g between the vertical patch and ground plane is small (sets 1 and 4).

The projection length of the proposed antennas is reduced. For the thick-substrate antennas, the projection length of set 1 is about $0.23\lambda_0$, whereas the projection length of the conventional half-wave patch antenna with similar thickness is about $0.33\lambda_0$, where

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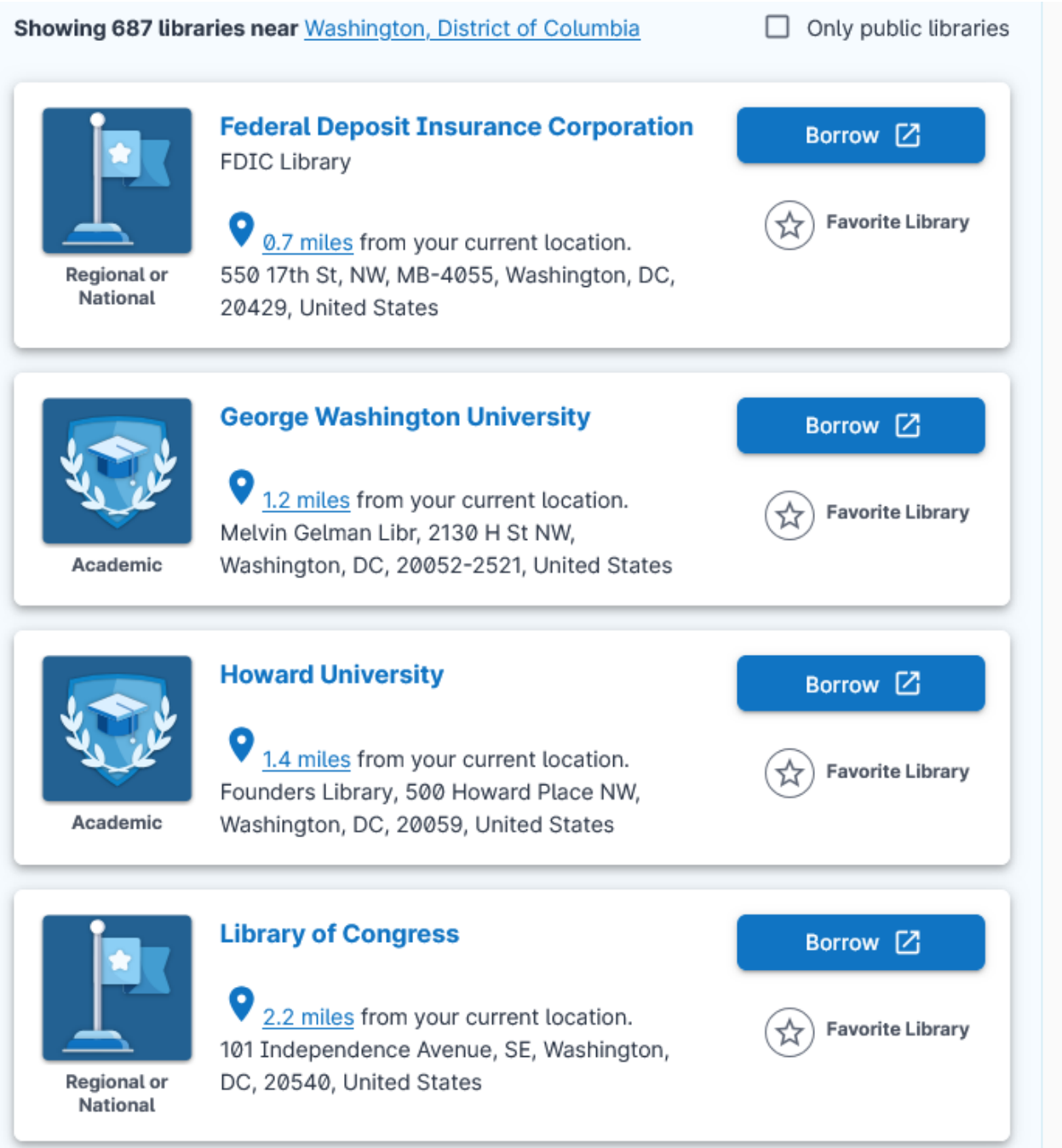
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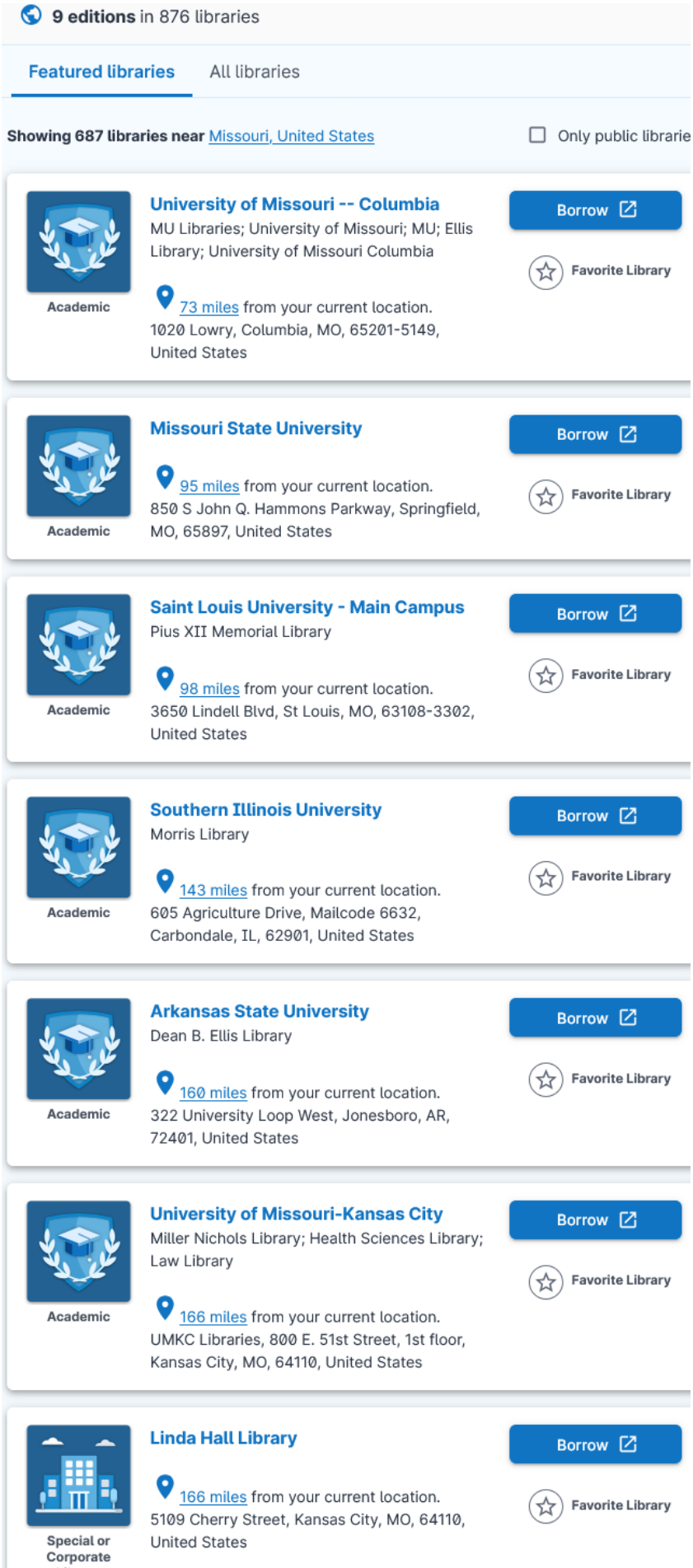
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HIGH-PERFORMANCE V-BAND MONOLITHIC QUADRUPLE SUB-HARMONIC MIXER WITH ANTI-PARALLEL DIODE PAIR

Won-Young Uhm, Woo-Suk Sul, Han-Shin Lee, Sam-Dong Kim, Hyung-Moo Park, and Jin-Koo Rhee
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ABSTRACT: *A high-performance V-band quadruple subharmonic mixer monolithic circuit is fabricated using the millimeter-wave monolithic integrated circuit (MIMIC) process. Due to the superior features of the anti-parallel diode pair (APDP) and the utilization of a quarter of fundamental frequency, the proposed subharmonic mixer shows good conversion-gain and isolation characteristics. Maximum conversion gain of 0.8 dB at an LO frequency of 14.5 GHz and an RF frequency of 60.4 GHz is measured. Both LO-to-RF and LO-to-IF isolations are higher than 50 dB in the operation mode.* © 2004 Wiley Periodicals, Inc.
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Key words: *APDP; PHEMT; Subharmonic mixer; MIMIC; coplanar waveguide*

1. INTRODUCTION

Millimeter-wave frequency has been highly regarded as an attractive alternative to microwave frequencies because of the increasing demand for high-capacity and high-speed wireless data transmission of very low error rate. Mixers are obviously one of the key components of receivers in wireless transceiver systems [1]. However, down-converting a received RF signal of high frequency, such as 60 GHz, is a great challenge. For example, an intermediate frequency (IF) outputted from the mixer will be separated by only a small amount of offset in frequency from the RF signal, when a relatively low-frequency fundamental signal is used for the local oscillator (LO) source. To give a higher offset in frequency to the IF signal, a stable and high-performance LO operating at a higher frequency for the LO signal source is required. This gives rise to a large increase in the total manufacturing cost of the transceiver system because reliable oscillators operating at such high frequencies are currently very difficult to achieve and expensive. Subharmonic mixers offer an alternative to fundamental mixers when n^{th} harmonics of the LO frequency are utilized for the mixers. This approach allows the use of LOs operating at a relatively low frequency, at which the output-power and phase-noise performances are superior to the fundamental frequency mixers [2]. Recently, much research effort has been made to develop a reliable alternative to LO sources by utilizing frequency doublers or improving the fundamental-frequency mixers. However, the subharmonic approach is still the most attractive one due to many advantageous device features, such as high isolation [3, 4].

In this paper, we propose a high-performance V-band quadruple subharmonic mixer monolithic circuit for millimeter-wave application, based on the superior feature of the anti-parallel diode pair (APDP). We employ a quarter of fundamental frequency for the LO signal and provide more stable frequency sources than conventional methods that use a half frequency. To achieve high performance in the conversion-gain and isolation characteristics, pseudomorphic high-electron mobility transistors (PHEMTs) are appropriately positioned to each port for maximizing the quarter frequencies. For the fabrication of the quadruple subharmonic mixer, our design library for the GaAs-based 0.1-μm gate-length PHEMT diodes and the coplanar waveguide (CPW) is used [5].

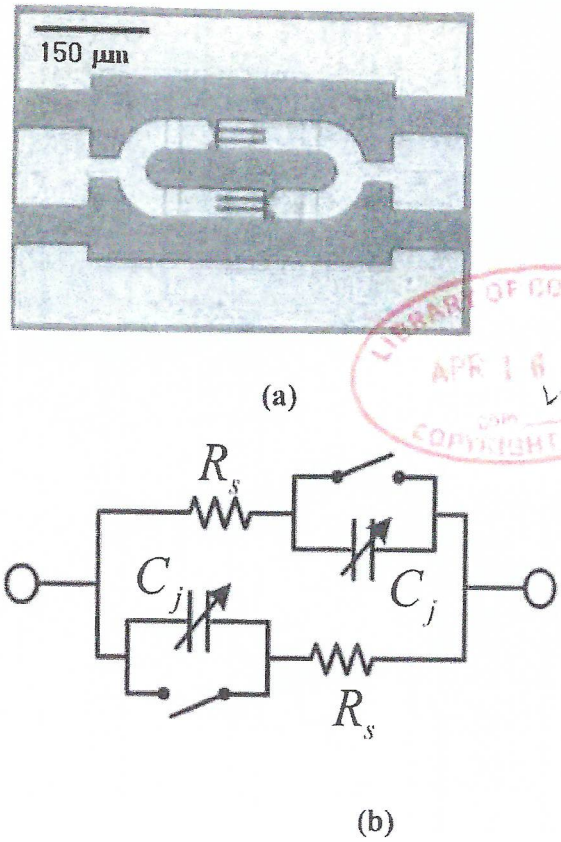


Figure 1 (a) APDP and (b) an equivalent circuit for the PHEMT diodes (junction capacitance C_j; series resistance R_s)

2. ACTIVE AND PASSIVE COMPONENTS

Both APDP and the PHEMTs are the essential components in our subharmonic mixer design. The PHEMT diodes used in this study were fabricated by interconnecting the source and drain, as shown in Figure 1(a). Both the diode anode's area, which corresponds to the gate of the HEMT in this work, and the doping concentration of the epitaxial layer are key parameters for designing the APDP. These parameters determine the series resistance R_s and the junction capacitance C_j, as illustrated by an equivalent circuit in Figure 1(b).

Model parameters for the PHEMTs diode were extracted by using a nonlinear model and the measurement data of the fabricated PHEMT diodes with 70-μm unit gate width and two gate fingers (hereafter, called 70 × 2 μm). From this analysis, an R_s of 9.9Ω and a zero-bias C_j of 0.093 pF were obtained, respectively. From the PHEMT diodes, a cutoff frequency f_T of ~180 GHz was estimated by using the extracted diode parameters. The fabricated 0.1-μm PHEMTs exhibited a maximum drain current density $I_{d,max}$ of ~373.5 mA/mm and a maximum extrinsic transconductance g_m of ~522.4 mS/mm, a maximum frequency of oscillation f_{max} of ~180 GHz, and an f_T of 113 GHz.

We established a library for the CPW transmission lines of various characteristic impedances (35, 50, and 70Ω), including the discontinuity patterns. The library also includes 800Å Ti thin-film resistors and metal-insulator-metal (MIM) capacitors of 900Å

finite-integration software to solve the microwave propagation for a microstrip device with such a photo-induced load.

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QUAD-BAND INTERNAL MONOPOLE MOBILE-PHONE ANTENNA

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ABSTRACT: *A novel internal monopole antenna suitable for applications in AMPS/GSM/DCS/PCS quad-band mobile phones is presented. The antenna comprises two orthogonal wideband monopole elements for operation at about 900 and 1850 MHz, covering the APMS/GSM (824–894/890–960 MHz) and DCS/PCS (1710–1880/1850–1990 MHz) bands, respectively. The quad-band monopole antenna is also arranged in a compact structure such that it has a low profile (only 6 mm in this study) and protrudes from the top edge of the system ground plane of a communications device, thus making it very promising as an internal antenna, built-in within the device's casing.* © 2004 Wiley Periodicals, Inc. Microwave Opt Technol Lett 40: 359–361, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.11381

Key words: *antennas; monopole antennas; quad-band antennas; mobile antennas*

1. INTRODUCTION

A variety of low-profile planar monopole antennas for dual- or triple-band operation in the global system for mobile communication (GSM, 890–960 MHz), the digital communication system (DCS, 1710–1880 MHz) and personal communication system (PCS, 1850–1990 MHz) have recently been demonstrated [1–4]. These planar monopole antennas have the attractive feature of low profile in appearance, thereby making them very promising as internal antennas, built-in or concealed within the casing of a communications device. In this paper, we propose another novel dual-frequency planar monopole antenna for application as an internal mobile-phone antenna. In addition, the proposed antenna has wide impedance bandwidths for both its two operating frequencies, thus making the antenna capable of quad-band operation in the advanced mobile phone system (APMS, 824–894 MHz), GSM (890–960 MHz), DCS (1710–1880 MHz), and PCS (1850–1990 MHz) bands. Details of the proposed antenna are described, and the experimental results of a constructed prototype are presented.

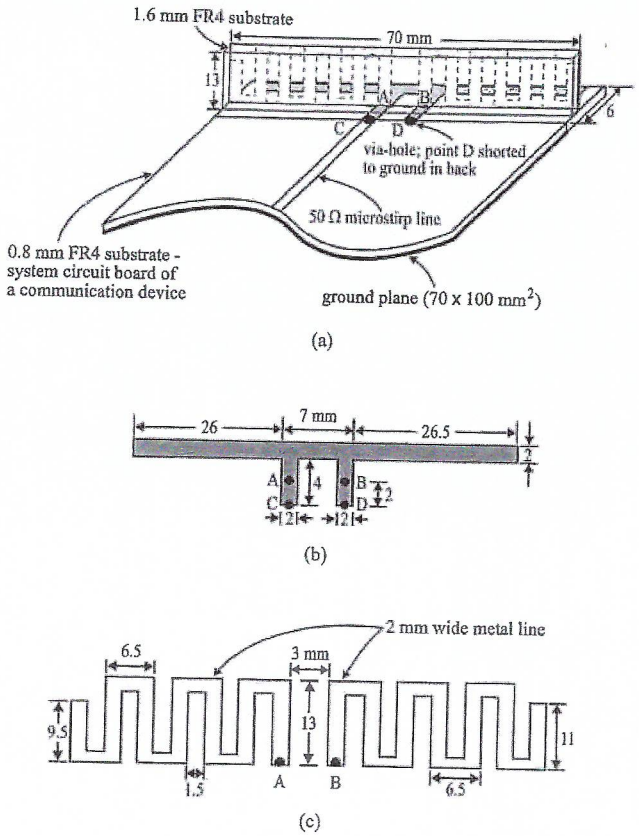


Figure 1 (a) Proposed quad-band internal monopole mobile-phone antenna mounted on the top portion (ungrounded portion) of the system circuit board of a communications device; (b) printed metal line on the system circuit board (high-frequency element); (c) printed metal line mounted vertically on the system circuit board (low-frequency element)

2. DESIGN CONSIDERATIONS

Figure 1(a) shows the geometry of the proposed antenna mounted on the top portion (ungrounded portion) of a grounded FR4 substrate, which has a size about that of the system circuit board of a communications device, such as a practical personal digital assistant (PDA) phone. A ground plane of size 70×100 mm^2, which does not cover the top portion (70×6 mm^2) of the substrate that accommodates the proposed antenna, is printed on the back surface of the FR4 substrate.

The proposed antenna comprises two orthogonal wideband monopole elements for operation at about 900 and 1850 MHz, respectively. The first wideband monopole element [high-frequency element, see Fig. 1(b)] is printed on the system circuit board and is a shorted π-shape monopole formed by a π-shape matching bridge connecting two metal lines of different lengths (26 and 26.5 mm, in this study) extended in opposite directions. These two metal lines of different lengths provide two resonant paths of slightly different lengths. This condition effectively results in the excitation of two closely spaced resonant modes at

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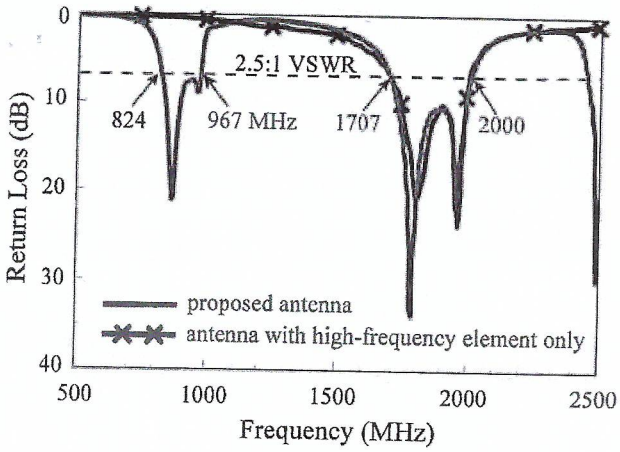


Figure 2 Measured return loss for the proposed antenna and the antenna with the high-frequency element only

about 1850 MHz, in this design, which lead to a wide operating band covering the DSC and PCS bands. For the π-shape matching bridge, its open end at point C is connected to a 50Ω microstrip feed line printed on the front surface of the FR4 substrate, and the open end at point D is short-circuited to the ground plane in back through a via-hole in the substrate.

The second wideband monopole element [low-frequency element, see Fig. 1(c)] is printed on a 1.6-mm FR4 substrate, which serves as a supporter for the second element, and then is mounted orthogonally and connected to the matching bridge of the first element at points A and B. The second element also has two metal lines of slightly different lengths, which are meandered to achieve a compact structure, extended in opposite directions for providing two closely spaced resonant modes in order to form a wide operating band at about 900 MHz. This obtained low-frequency operating band covers the AMPS and GSM bands in this design. Also note that, through controlling the size of the π-shape matching bridge [its optimal dimensions are given in Fig. 1(b)], good impedance matching for both the low- and high-frequency operating bands of the proposed antenna is easily achieved.

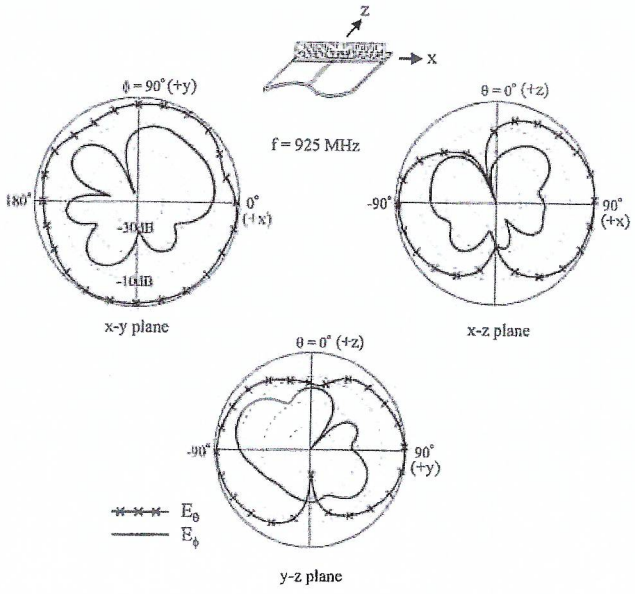


Figure 4 Measured radiation patterns at 925 MHz

3. EXPERIMENTAL RESULTS AND DISCUSSION

Based on the design dimensions shown in Figure 1, which are obtained with the aid of the Ansoft simulation software high-frequency structure simulator (HFSS), a prototype of the proposed antenna was constructed and tested. Figure 2 shows the measured return loss of the constructed prototype. The result for the case with the presence of the high-frequency element only is also shown for comparison. From the results it is clearly seen that, as designed, each monopole element in the proposed antenna generates two closely spaced resonant modes to form a wide operating band at about 900 or 1850 MHz. The impedance bandwidths (2.5:1 VSWR) obtained for the two operating bands cover the required bandwidths of the APMS/GSM and DCS/PCS bands.

The radiation characteristics were also studied. Figures 3–6 show the measured radiation patterns at center frequencies (854, 925, 1795, and 1920 MHz) of the AMPS, GSM, DCS, and PCS

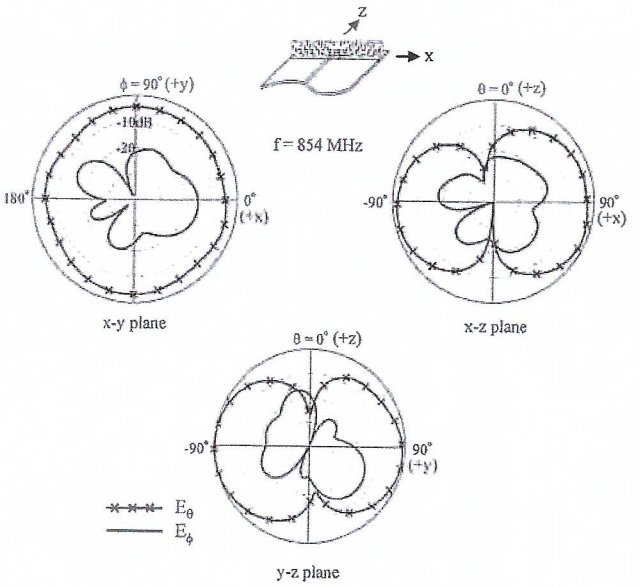


Figure 3 Measured radiation patterns at 854 MHz

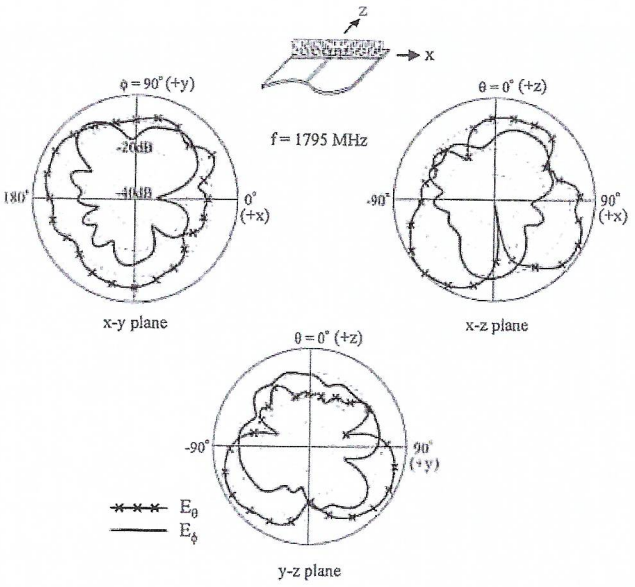


Figure 5 Measured radiation patterns at 1795 MHz

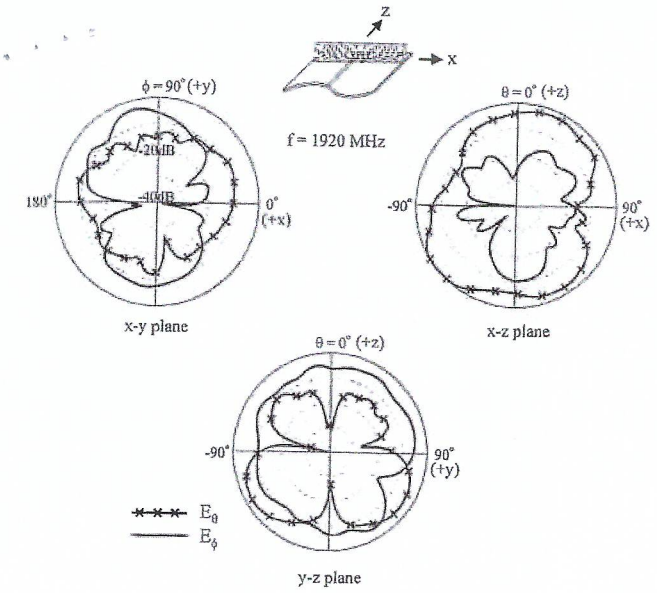
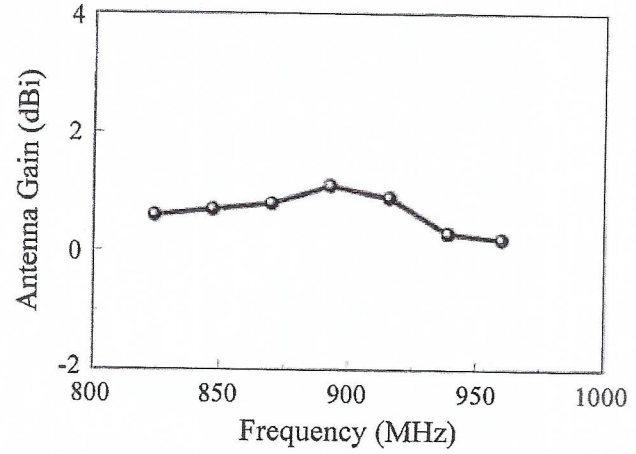
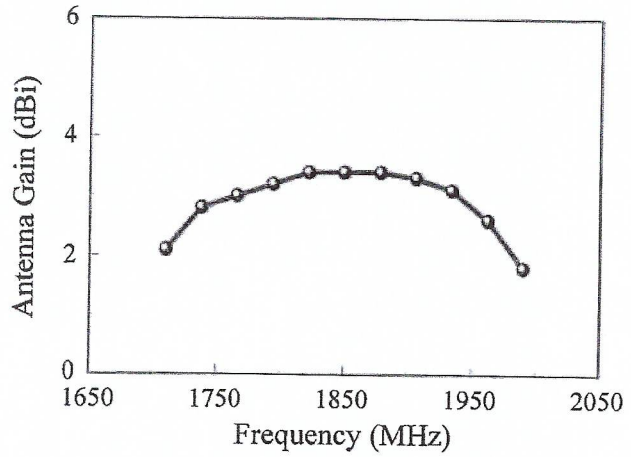


Figure 6 Measured radiation patterns at 1920 MHz



(a)



(b)

Figure 7 Measured antenna gain across the (a) AMPS/GSM (824–894/890–960 MHz) and (b) DCS/PCS (1710–1880/1850–1990 MHz) bands

bands, respectively. Note that the three radiation patterns shown in each figure are all normalized with respect to the measured peak antenna gain of the antenna. Monopolelike radiation patterns for lower frequencies are shown in Figures 3 and 4 and are much smoother than those shown in Figures 5 and 6 for higher frequencies. The radiation characteristics observed are similar to those obtained for other low-profile planar monopole mobile phone antennas in [1–4]. Figure 7 shows the measured antenna gain for frequencies across the AMPS, GSM, DCS, and PCS bands. The peak antenna gain for operating frequencies across the AMPS and GSM bands is about 0.2–1.1 dBi [see Fig. 7(a)], and that for DCS and PCS bands is about 1.8–3.4 dBi [see Fig. 7(b)].

4. CONCLUSION

A novel quad-band internal monopole mobile-phone antenna for AMPS, GSM, DCS, and PCS operations has been proposed, and a prototype has been successfully implemented. The proposed antenna can generate four resonant modes, two for each operating bands at about 900 and 1850 MHz, covering the AMPS/GSM and DCS/PCS bands, respectively. Good radiating characteristics have also been observed across the operating bands.

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NUMERICAL STUDY OF POLARIZATION-DEPENDENT FOCUSING FOR A BILAYER PLANAR FSS REFLECTIVE LENS AT MILLIMETER WAVELENGTHS

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Received 21 August 2003

ABSTRACT: *In this paper, we numerically analyze the polarization-dependent focusing properties of a planar reflective lens formed by two parallel layers of nonuniform "gangbuster" surfaces (GSs) above a ground plane. Since these GSs consist of superdense arrays of thin finite-length parallel metallic wires, the desired phase patterns on such a lens surface are achieved by adjusting the lengths of these metallic wires for appropriate polarization components. In our analysis, we use the method of moments (MoM) and the transmission-lines analogy, along with the surface-equivalence theorem, to estimate the field intensity in the focal plane.* © 2004 Wiley Periodicals, Inc. Microwave Opt Technol Lett 40: 361–365, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.11382

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finite-integration software to solve the microwave propagation for a microstrip device with such a photo-induced load.

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QUAD-BAND INTERNAL MONOPOLE MOBILE-PHONE ANTENNA

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ABSTRACT: *A novel internal monopole antenna suitable for applications in AMPS/GSM/DCS/PCS quad-band mobile phones is presented. The antenna comprises two orthogonal wideband monopole elements for operation at about 900 and 1850 MHz, covering the APMS/GSM (824–894/890–960 MHz) and DCS/PCS (1710–1880/1850–1990 MHz) bands, respectively. The quad-band monopole antenna is also arranged in a compact structure such that it has a low profile (only 6 mm in this study) and protrudes from the top edge of the system ground plane of a communications device, thus making it very promising as an internal antenna, built-in within the device's casing.* © 2004 Wiley Periodicals, Inc. Microwave Opt Technol Lett 40: 359–361, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.11381

Key words: *antennas; monopole antennas; quad-band antennas; mobile antennas*

1. INTRODUCTION

A variety of low-profile planar monopole antennas for dual- or triple-band operation in the global system for mobile communication (GSM, 890–960 MHz), the digital communication system (DCS, 1710–1880 MHz) and personal communication system (PCS, 1850–1990 MHz) have recently been demonstrated [1–4]. These planar monopole antennas have the attractive feature of low profile in appearance, thereby making them very promising as internal antennas, built-in or concealed within the casing of a communications device. In this paper, we propose another novel dual-frequency planar monopole antenna for application as an internal mobile-phone antenna. In addition, the proposed antenna has wide impedance bandwidths for both its two operating frequencies, thus making the antenna capable of quad-band operation in the advanced mobile phone system (APMS, 824–894 MHz), GSM (890–960 MHz), DCS (1710–1880 MHz), and PCS (1850–1990 MHz) bands. Details of the proposed antenna are described, and the experimental results of a constructed prototype are presented.

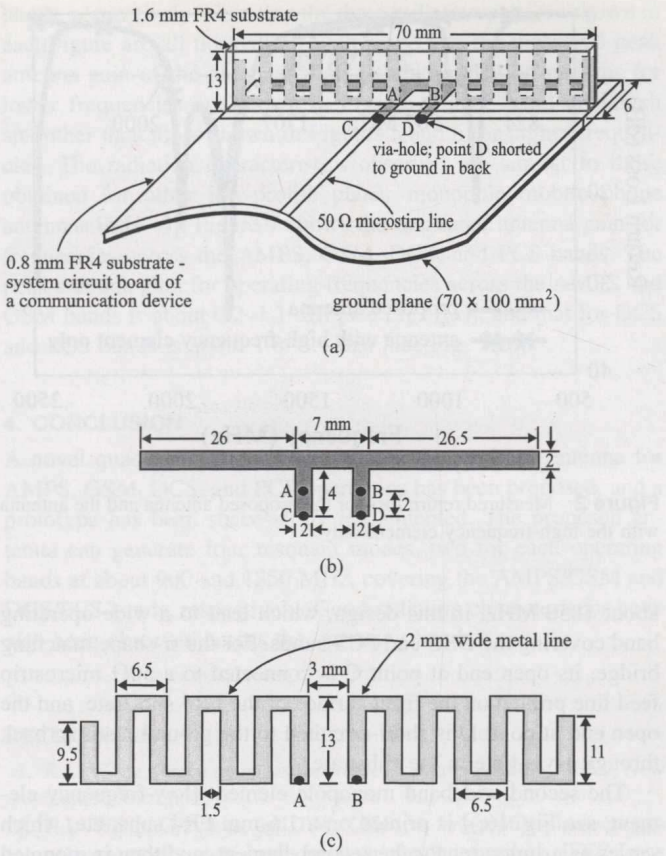


Figure 1 (a) Proposed quad-band internal monopole mobile-phone antenna mounted on the top portion (ungrounded portion) of the system circuit board of a communications device; (b) printed metal line on the system circuit board (high-frequency element); (c) printed metal line mounted vertically on the system circuit board (low-frequency element)

2. DESIGN CONSIDERATIONS

Figure 1(a) shows the geometry of the proposed antenna mounted on the top portion (ungrounded portion) of a grounded FR4 substrate, which has a size about that of the system circuit board of a communications device, such as a practical personal digital assistant (PDA) phone. A ground plane of size 70×100 mm^2, which does not cover the top portion (70×6 mm^2) of the substrate that accommodates the proposed antenna, is printed on the back surface of the FR4 substrate.

The proposed antenna comprises two orthogonal wideband monopole elements for operation at about 900 and 1850 MHz, respectively. The first wideband monopole element [high-frequency element, see Fig. 1(b)] is printed on the system circuit board and is a shorted π-shape monopole formed by a π-shape matching bridge connecting two metal lines of different lengths (26 and 26.5 mm, in this study) extended in opposite directions. These two metal lines of different lengths provide two resonant paths of slightly different lengths. This condition effectively results in the excitation of two closely spaced resonant modes at

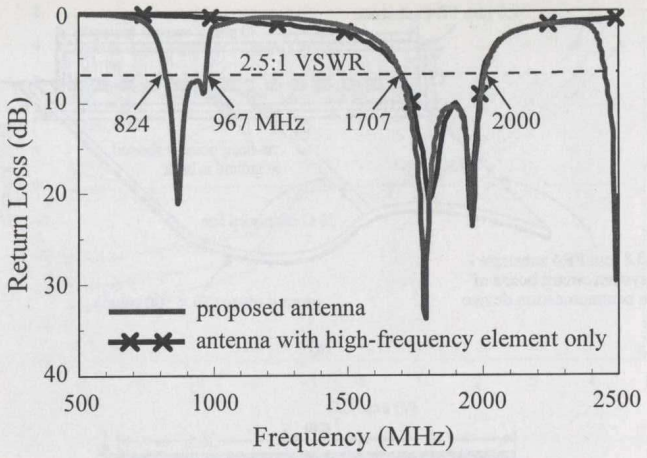


Figure 2 Measured return loss for the proposed antenna and the antenna with the high-frequency element only

about 1850 MHz, in this design, which lead to a wide operating band covering the DSC and PCS bands. For the π-shape matching bridge, its open end at point C is connected to a 50Ω microstrip feed line printed on the front surface of the FR4 substrate, and the open end at point D is short-circuited to the ground plane in back through a via-hole in the substrate.

The second wideband monopole element [low-frequency element, see Fig. 1(c)] is printed on a 1.6-mm FR4 substrate, which serves as a supporter for the second element, and then is mounted orthogonally and connected to the matching bridge of the first element at points A and B. The second element also has two metal lines of slightly different lengths, which are meandered to achieve a compact structure, extended in opposite directions for providing two closely spaced resonant modes in order to form a wide operating band at about 900 MHz. This obtained low-frequency operating band covers the AMPS and GSM bands in this design. Also note that, through controlling the size of the π-shape matching bridge [its optimal dimensions are given in Fig. 1(b)], good impedance matching for both the low- and high-frequency operating bands of the proposed antenna is easily achieved.

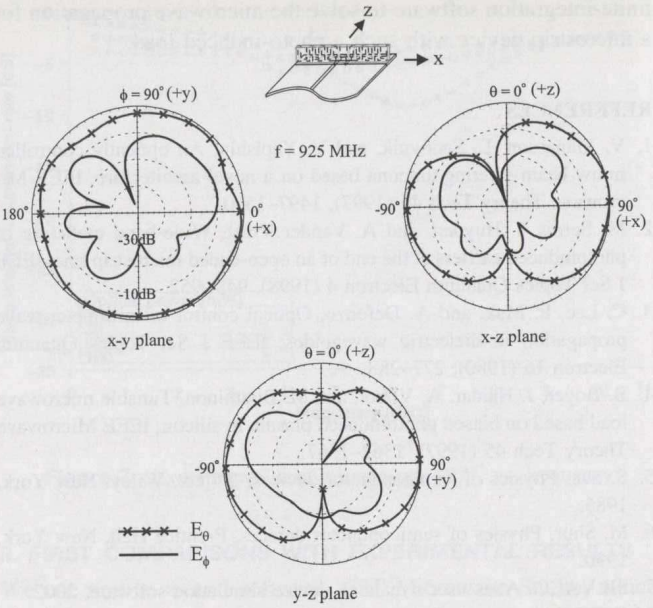


Figure 4 Measured radiation patterns at 925 MHz

3. EXPERIMENTAL RESULTS AND DISCUSSION

Based on the design dimensions shown in Figure 1, which are obtained with the aid of the Ansoft simulation software high-frequency structure simulator (HFSS), a prototype of the proposed antenna was constructed and tested. Figure 2 shows the measured return loss of the constructed prototype. The result for the case with the presence of the high-frequency element only is also shown for comparison. From the results it is clearly seen that, as designed, each monopole element in the proposed antenna generates two closely spaced resonant modes to form a wide operating band at about 900 or 1850 MHz. The impedance bandwidths (2.5:1 VSWR) obtained for the two operating bands cover the required bandwidths of the APMS/GSM and DCS/PCS bands.

The radiation characteristics were also studied. Figures 3–6 show the measured radiation patterns at center frequencies (854, 925, 1795, and 1920 MHz) of the AMPS, GSM, DCS, and PCS

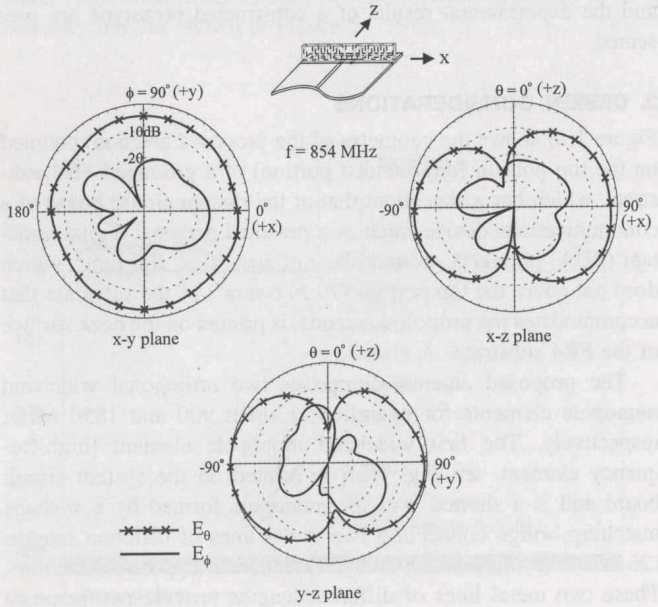


Figure 3 Measured radiation patterns at 854 MHz

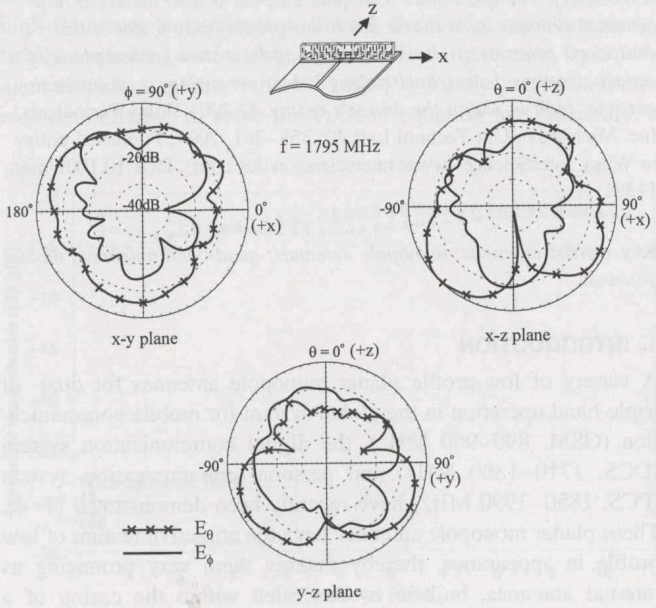


Figure 5 Measured radiation patterns at 1795 MHz

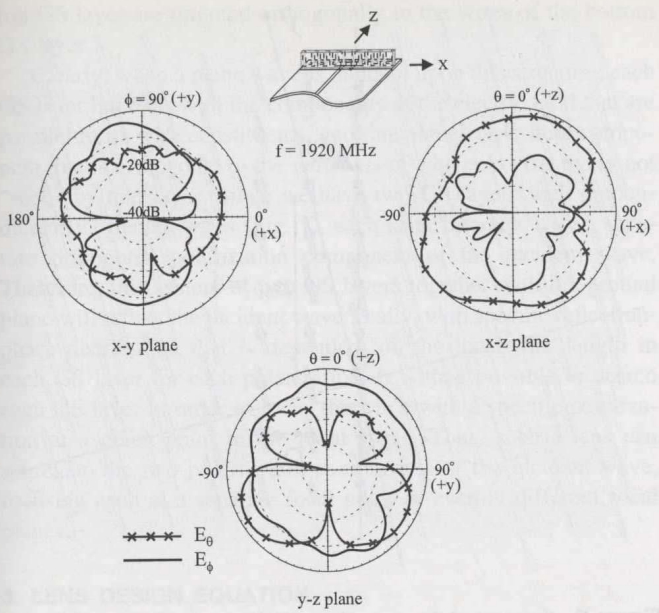
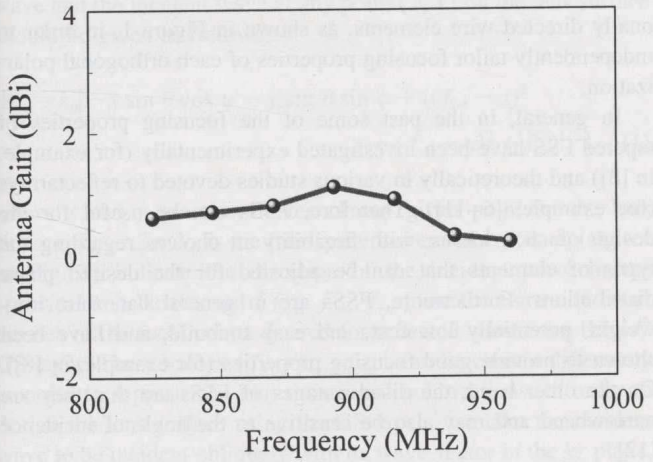
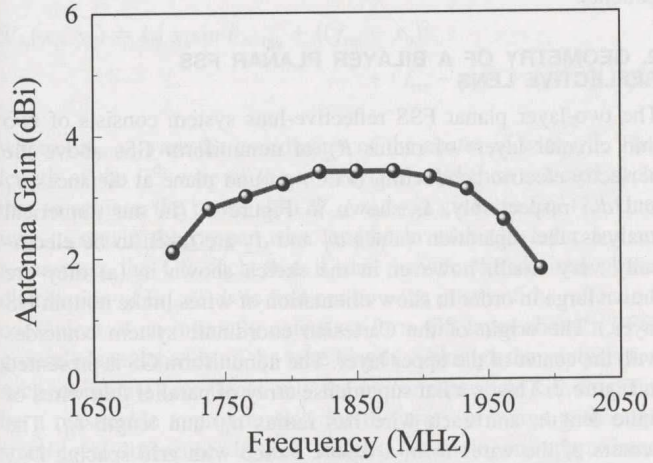


Figure 6 Measured radiation patterns at 1920 MHz



(a)



(b)

Figure 7 Measured antenna gain across the (a) AMPS/GSM (824–894/890–960 MHz) and (b) DCS/PCS (1710–1880/1850–1990 MHz) bands

bands, respectively. Note that the three radiation patterns shown in each figure are all normalized with respect to the measured peak antenna gain of the antenna. Monopolelike radiation patterns for lower frequencies are shown in Figures 3 and 4 and are much smoother than those shown in Figures 5 and 6 for higher frequencies. The radiation characteristics observed are similar to those obtained for other low-profile planar monopole mobile phone antennas in [1–4]. Figure 7 shows the measured antenna gain for frequencies across the AMPS, GSM, DCS, and PCS bands. The peak antenna gain for operating frequencies across the AMPS and GSM bands is about 0.2–1.1 dBi [see Fig. 7(a)], and that for DCS and PCS bands is about 1.8–3.4 dBi [see Fig. 7(b)].

4. CONCLUSION

A novel quad-band internal monopole mobile-phone antenna for AMPS, GSM, DCS, and PCS operations has been proposed, and a prototype has been successfully implemented. The proposed antenna can generate four resonant modes, two for each operating bands at about 900 and 1850 MHz, covering the AMPS/GSM and DCS/PCS bands, respectively. Good radiating characteristics have also been observed across the operating bands.

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NUMERICAL STUDY OF POLARIZATION-DEPENDENT FOCUSING FOR A BILAYER PLANAR FSS REFLECTIVE LENS AT MILLIMETER WAVELENGTHS

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ABSTRACT: *In this paper, we numerically analyze the polarization-dependent focusing properties of a planar reflective lens formed by two parallel layers of nonuniform "gangbuster" surfaces (GSs) above a ground plane. Since these GSs consist of superdense arrays of thin finite-length parallel metallic wires, the desired phase patterns on such a lens surface are achieved by adjusting the lengths of these metallic wires for appropriate polarization components. In our analysis, we use the method of moments (MoM) and the transmission-lines analogy, along with the surface-equivalence theorem, to estimate the field intensity in the focal plane.* © 2004 Wiley Periodicals, Inc. Microwave Opt Technol Lett 40: 361–365, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.11382

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finite-integration software to solve the microwave propagation for a microstrip device with such a photo-induced load.

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QUAD-BAND INTERNAL MONOPOLE MOBILE-PHONE ANTENNA

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ABSTRACT: *A novel internal monopole antenna suitable for applications in AMPS/GSM/DCS/PCS quad-band mobile phones is presented. The antenna comprises two orthogonal wideband monopole elements for operation at about 900 and 1850 MHz, covering the APMS/GSM (824–894/890–960 MHz) and DCS/PCS (1710–1880/1850–1990 MHz) bands, respectively. The quad-band monopole antenna is also arranged in a compact structure such that it has a low profile (only 6 mm in this study) and protrudes from the top edge of the system ground plane of a communications device, thus making it very promising as an internal antenna, built-in within the device's casing.* © 2004 Wiley Periodicals, Inc. Microwave Opt Technol Lett 40: 359–361, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.11381

Key words: *antennas; monopole antennas; quad-band antennas; mobile antennas*

1. INTRODUCTION

A variety of low-profile planar monopole antennas for dual- or triple-band operation in the global system for mobile communication (GSM, 890–960 MHz), the digital communication system (DCS, 1710–1880 MHz) and personal communication system (PCS, 1850–1990 MHz) have recently been demonstrated [1–4]. These planar monopole antennas have the attractive feature of low profile in appearance, thereby making them very promising as internal antennas, built-in or concealed within the casing of a communications device. In this paper, we propose another novel dual-frequency planar monopole antenna for application as an internal mobile-phone antenna. In addition, the proposed antenna has wide impedance bandwidths for both its two operating frequencies, thus making the antenna capable of quad-band operation in the advanced mobile phone system (APMS, 824–894 MHz), GSM (890–960 MHz), DCS (1710–1880 MHz), and PCS (1850–1990 MHz) bands. Details of the proposed antenna are described, and the experimental results of a constructed prototype are presented.

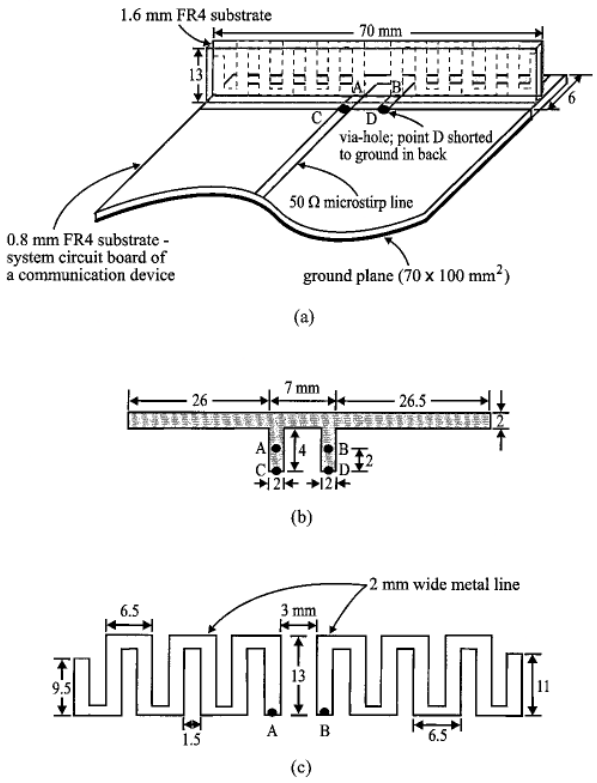


Figure 1 (a) Proposed quad-band internal monopole mobile-phone antenna mounted on the top portion (ungrounded portion) of the system circuit board of a communications device; (b) printed metal line on the system circuit board (high-frequency element); (c) printed metal line mounted vertically on the system circuit board (low-frequency element)

2. DESIGN CONSIDERATIONS

Figure 1(a) shows the geometry of the proposed antenna mounted on the top portion (ungrounded portion) of a grounded FR4 substrate, which has a size about that of the system circuit board of a communications device, such as a practical personal digital assistant (PDA) phone. A ground plane of size 70×100 mm^2, which does not cover the top portion (70×6 mm^2) of the substrate that accommodates the proposed antenna, is printed on the back surface of the FR4 substrate.

The proposed antenna comprises two orthogonal wideband monopole elements for operation at about 900 and 1850 MHz, respectively. The first wideband monopole element [high-frequency element, see Fig. 1(b)] is printed on the system circuit board and is a shorted π-shape monopole formed by a π-shape matching bridge connecting two metal lines of different lengths (26 and 26.5 mm, in this study) extended in opposite directions. These two metal lines of different lengths provide two resonant paths of slightly different lengths. This condition effectively results in the excitation of two closely spaced resonant modes at

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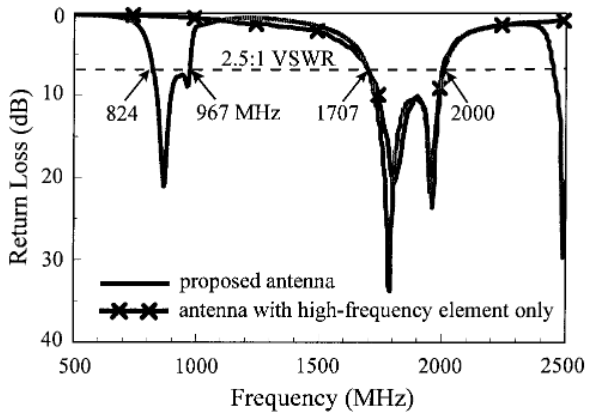


Figure 2 Measured return loss for the proposed antenna and the antenna with the high-frequency element only

about 1850 MHz, in this design, which lead to a wide operating band covering the DSC and PCS bands. For the π-shape matching bridge, its open end at point C is connected to a 50Ω microstrip feed line printed on the front surface of the FR4 substrate, and the open end at point D is short-circuited to the ground plane in back through a via-hole in the substrate.

The second wideband monopole element [low-frequency element, see Fig. 1(c)] is printed on a 1.6-mm FR4 substrate, which serves as a supporter for the second element, and then is mounted orthogonally and connected to the matching bridge of the first element at points A and B. The second element also has two metal lines of slightly different lengths, which are meandered to achieve a compact structure, extended in opposite directions for providing two closely spaced resonant modes in order to form a wide operating band at about 900 MHz. This obtained low-frequency operating band covers the AMPS and GSM bands in this design. Also note that, through controlling the size of the π-shape matching bridge [its optimal dimensions are given in Fig. 1(b)], good impedance matching for both the low- and high-frequency operating bands of the proposed antenna is easily achieved.

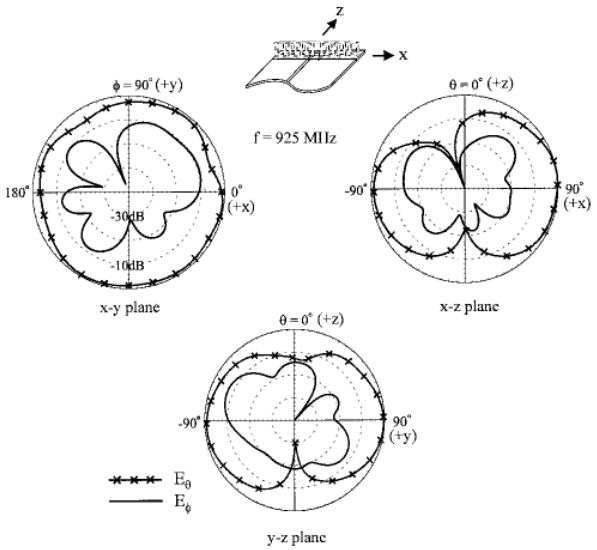


Figure 4 Measured radiation patterns at 925 MHz

3. EXPERIMENTAL RESULTS AND DISCUSSION

Based on the design dimensions shown in Figure 1, which are obtained with the aid of the Ansoft simulation software high-frequency structure simulator (HFSS), a prototype of the proposed antenna was constructed and tested. Figure 2 shows the measured return loss of the constructed prototype. The result for the case with the presence of the high-frequency element only is also shown for comparison. From the results it is clearly seen that, as designed, each monopole element in the proposed antenna generates two closely spaced resonant modes to form a wide operating band at about 900 or 1850 MHz. The impedance bandwidths (2.5:1 VSWR) obtained for the two operating bands cover the required bandwidths of the APMS/GSM and DCS/PCS bands.

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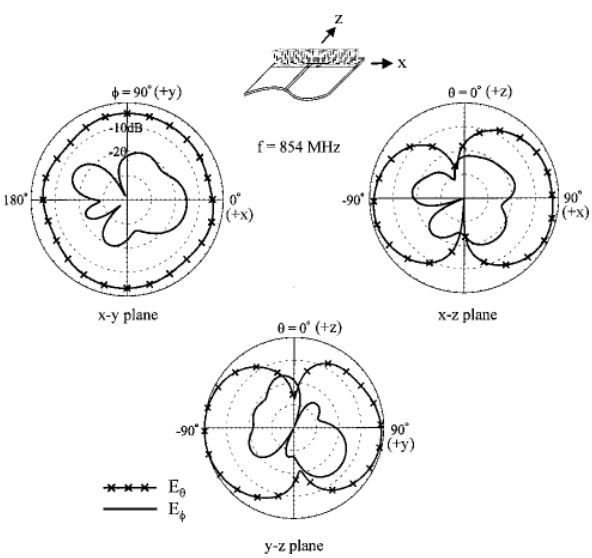


Figure 3 Measured radiation patterns at 854 MHz

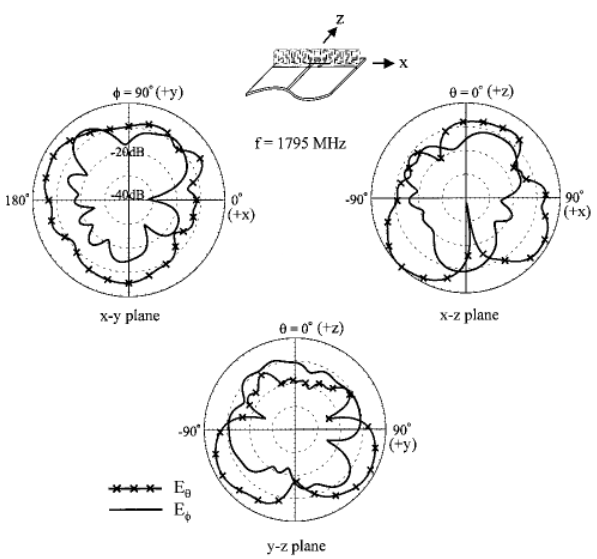


Figure 5 Measured radiation patterns at 1795 MHz

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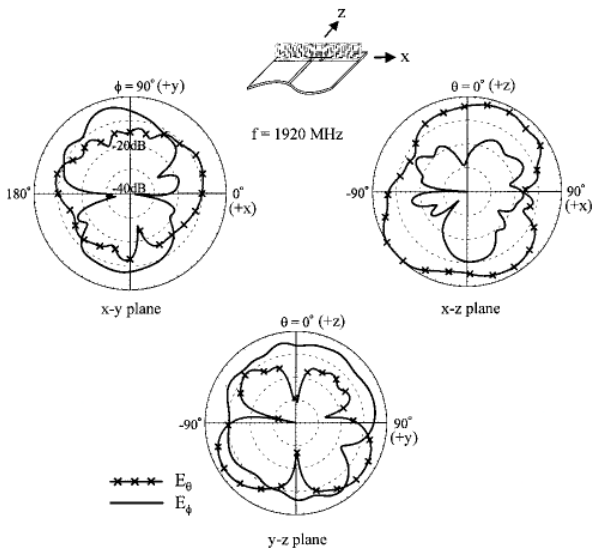
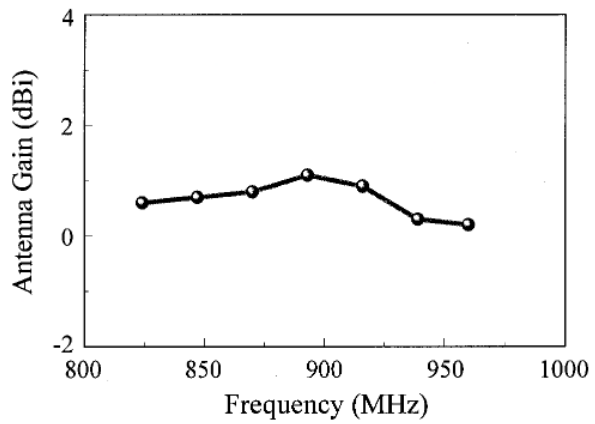


Figure 6 Measured radiation patterns at 1920 MHz



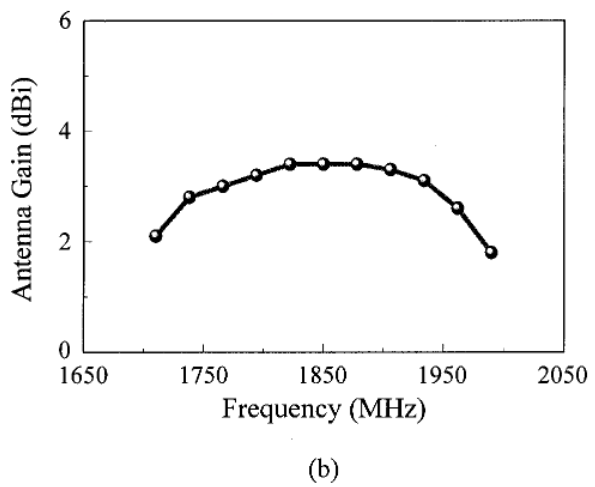


Figure 7 Measured antenna gain across the (a) AMPS/GSM (824–894/890–960 MHz) and (b) DCS/PCS (1710–1880/1850–1990 MHz) bands

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REFERENCES

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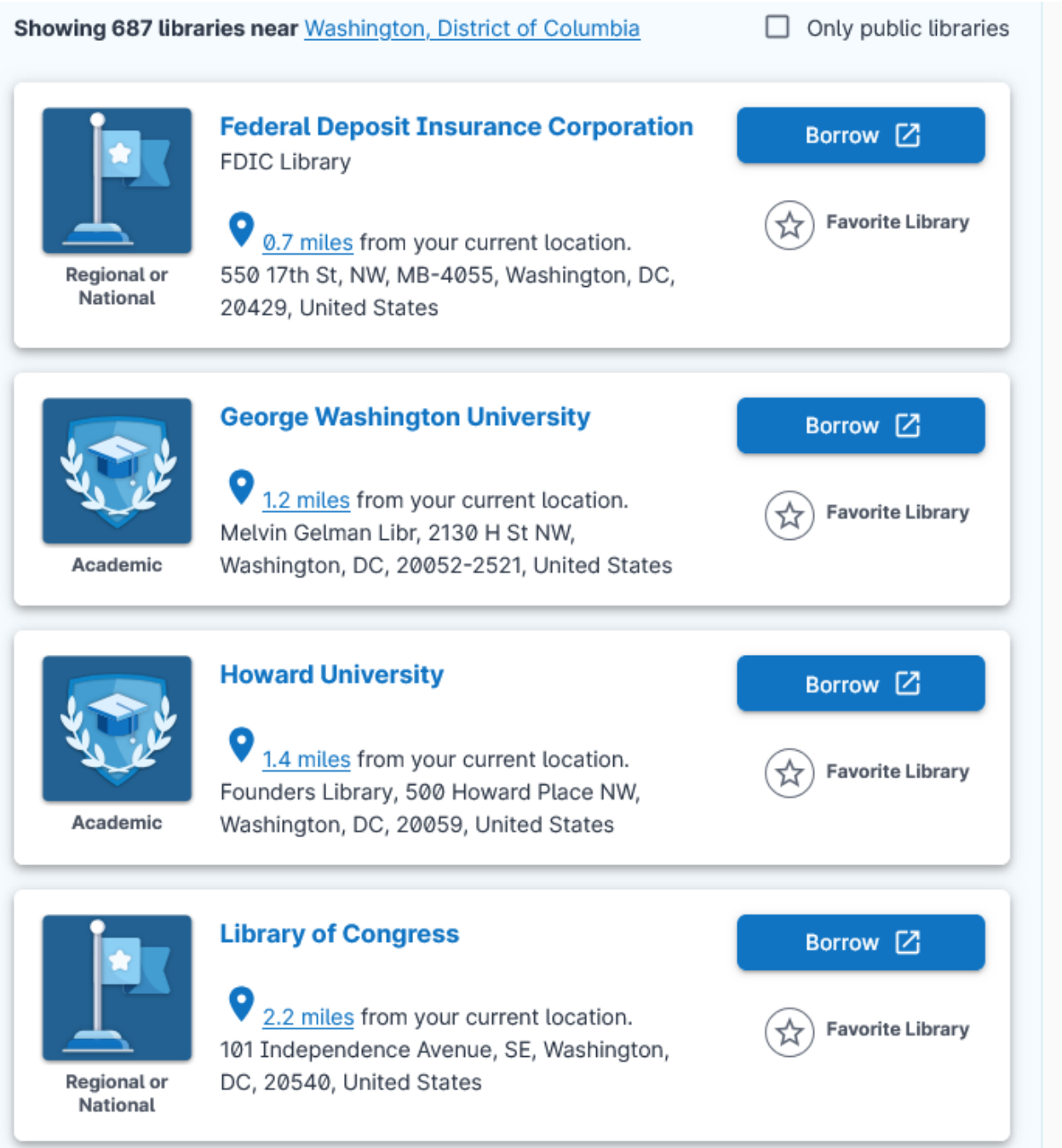
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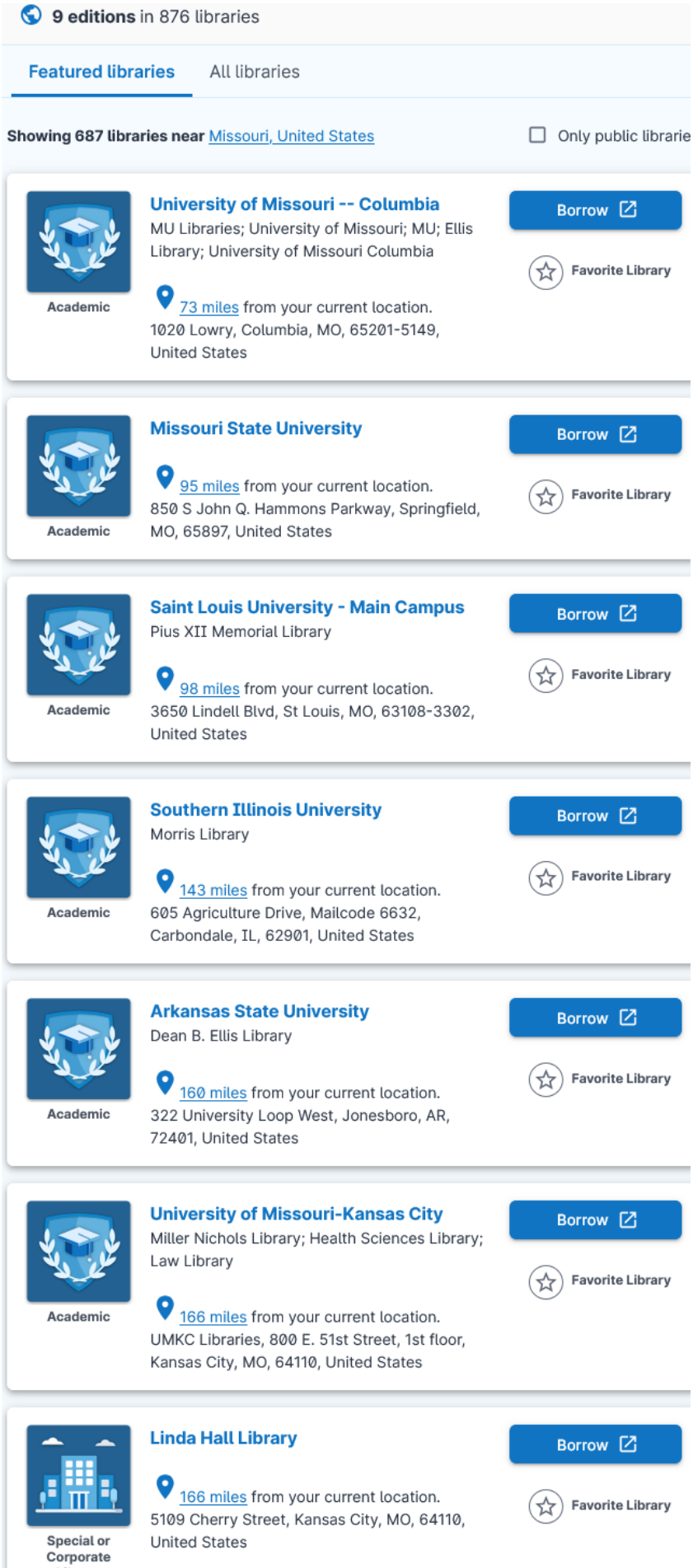
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