

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

GEOTAB INC. AND GEOTAB USA, INC.,
Petitioners

v.

FRACTUS, S.A.
Patent Owner

Case No. IPR2025-00928
Patent No. 8,456,365

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. (“Petitioners”) in the above-captioned *inter partes* review relating to U.S. Patent No. 8,456,365 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. EX1037 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> (last checked April 25, 2025).

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 (EX1037), 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 by counsel for Petitioners 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 reasonable 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 am also informed by counsel for Petitioners 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 through the exercise of reasonable diligence (*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 for Petitioners has informed me that the subject matter of this proceeding relates to mobile communication devices including antennas for receiving or transmitting electromagnetic wave signals.

21. I have been informed by Petitioners's counsel that a "person of ordinary skill in the art at the time of the invention" (POSA) is a hypothetical person who is presumed to be familiar with the relevant field and its literature at the time of the invention. 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. Petitioners’s counsel has informed me that a POSA in this subject matter or art would have had 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 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

¹ The full text of the standard is available from the Library of Congress at <http://www.loc.gov/marc/bibliographic/> (last checked April 25, 2025).

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 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

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 April 25, 2025) (“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.

opinions section (§IV). 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 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.

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-oA-incorporation.pdf> (last checked April 25, 2025).

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 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 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> (last checked April 25, 2025).

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 (last checked April 25, 2025).

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/> (last checked April 25, 2025).

IV. OPINION REGARDING AUTHENTICITY AND PUBLIC ACCESSIBILITY

A. **Exhibit 1006. Teng, Pey-Ling, and Kin-Lu Teng. “Planar Monopole Folded into a Compact Structure for Very-Low-Profile Multiband Mobile-Phone Antenna.” *Microwave and Optical Technology Letters*, volume 33, number 1, April 5, 2002, pages 22-25 (“Teng”)**

33. I have been asked to opine on an article authored by Pey-Ling Teng and Kin-Lu Teng, EX1006, titled “Planar Monopole Folded into a Compact Structure for Very-Low-Profile Multiband Mobile-Phone Antenna,” published in *Microwave and Optical Technology Letters*, Volume 33, Number 1, April 5, 2002, pages 22-25 (“Teng”).

34. Within this declaration Teng will indicate both the article titled “Planar Monopole Folded into a Compact Structure for Very-Low-Profile Multiband Mobile-Phone Antenna,” as well as the issue of *Microwave and Optical*

Technology Letters, Volume 33, Number 1 (April 5, 2002), dependent upon context.

1. Authentication

35. I have evaluated the Teng reference three ways: (1) by assessing the copy of Teng (EX1006), provided to me by Petitioners's counsel and obtained by them from the print copy owned by the Library of Congress; (2) by assessing scans of a print copy of Teng owned by the Linda Hall Library, provided to me by the Linda Hall Library Document Delivery Service, Attachment A-1; and (3) by accessing and reviewing Teng in digital format available to me through Purdue University Libraries, Attachment A-2.

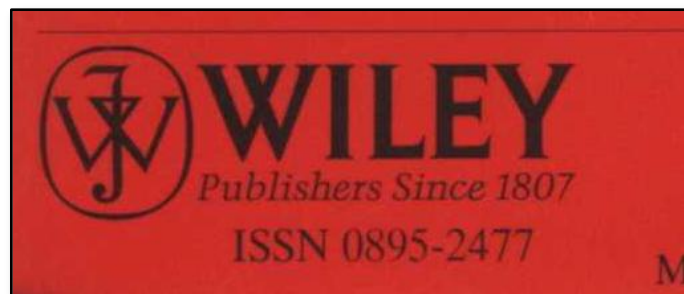
36. EX1006 (Teng), has been provided to me by Petitioners's counsel. I see no evidence that any alteration, deletion or addition of pages, etc., were made to EX1006.

37. EX1006 includes: cover of issue with table of contents, dated April 5, 2002, with a statement at the bottom of the cover that reads: "Volume 33, Number 1 was mailed the week of March 11, 2002," as shown below; publisher and publication information page; page 3 with a stamp that reads "LIBRARY OF CONGRESS JUN – 4 2002 Copyright Office," as shown below; and the Teng article, pages 22-25.



Volume 33, Number 1 was mailed the week of March 11, 2002

38. On the cover, EX1006, bottom left had corner, the publisher is identified as “Wiley[,] *Publisher Since 1807* ISSN 0895-2477,” as shown below. Wiley is today, and was in 2002-2003, an established and well-known publishing company.

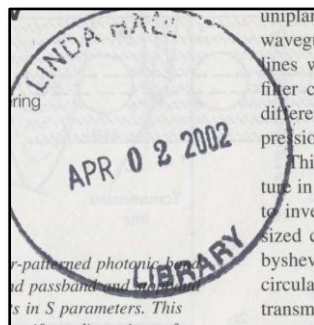


39. All identifying characteristics, such as labels and stamps on EX1006, are consistent with library practice and procedure that I have observed during my career as a professional librarian, specifically with those items held by the Library of Congress. I have no cause for doubt about the authenticity or accuracy of these identifying attributes on EX1006 (Teng).

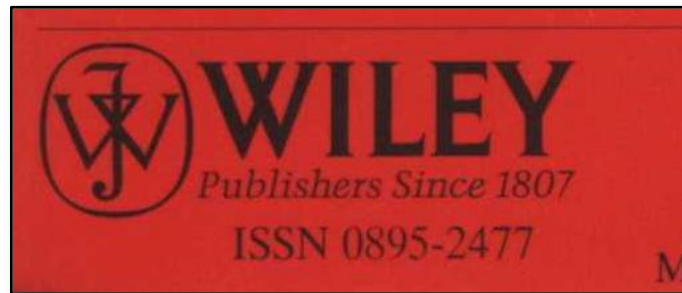
40. In addition, Teng was found within the custody of a library, the Library of Congress, one of the most likely locations for an authentic publication to be located. Evidence of the ownership of Teng by the Library of Congress will further be explored and detailed in the section below on public access (§IV.A.2).

41. Attachment A-1 was provided to me at my request on March 19, 2025, by Linda Hall Library Doc Services from the copy owned by the Linda Hall Library. Attachment A-1 includes scans of Teng; cover of issue with table of contents, dated April 5, 2002, with a statement at the bottom of the cover that reads “Volume 33, Number 1 was mailed the week of March 11, 2002,” as shown below; publisher and publication information page; page 1 (page 3 of the PDF) with a stamp that reads “LINDA HALL LIBRARY APR 02 2002,” as shown below; and the Teng article, pages 22-25.

Volume 33, Number 1 was mailed the week of March 11, 2002



42. On the cover, bottom-left-hand corner, the publisher is identified as “Wiley[,] *Publisher Since 1807* ISSN 0895-2477,” as shown below. Wiley is today, and was in 2002-2003, an established and well-known publishing company.



43. All identifying characteristics, such as stamps and notations on Attachment A-1, 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-1 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 Teng by the Linda Hall Library will further be explored and detailed in the section below on public access (§IV.A.2).

44. Attachment A-2 is a download of Teng that 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/epdf/10.1002/mop.10219?saml_referrer (last checked April 26, 2025).

45. Teng is also available from Wiley for a fee at this URL:
<https://onlinelibrary.wiley.com/doi/epdf/10.1002/mop.10219> (last checked April 26, 2025).

46. After my comparison between EX1006 (Teng), and Attachment A-1, and Attachment A-2, I found no difference between EX1006 (Teng), and Attachment A-1 and Attachment A-2.

47. Therefore, I affirm, after verifying EX1006 against Attachment A-1, and Attachment A-2, that EX1006 is a complete and accurate version of Teng.

48. Therefore, with the evidence that Teng is held in the Library of Congress (EX1006) and the Linda Hall Library (Attachment A-1), and accessing and retrieving Teng from a database through the Purdue University Libraries (Attachment A-2), I have determined that EX1006 (Teng) is an authentic document.

49. I conclude and affirm that EX1006 (Teng) is an authentic document.

2. Public Accessibility

50. Attachment A-3 is a true and correct copy of the *WorldCat* entry for *Microwave and Optical Technology Letters*. I obtained Attachment A-3 by completing a search on *WorldCat* on April 10, 2025 by searching for libraries holding this journal near Missouri, United States.

51. Attachment A-3 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, Wiley Periodicals, Inc; and ISSN: 0895-2477, 1098-2760.⁴

52. *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.

53. When I searched *WorldCat* for holdings of *Microwave and Optical Technology Letters* in Missouri, the Linda Hall Library was seventh on the list among the 687 libraries shown as holding *Microwave and Optical Technology Letters* near Missouri, United States.

54. Attachment A-4 is a download I made from the Linda Hall Library OPAC (online catalog) on April 10, 2025. The journal catalogued in this record is *Microwave and Optical Technology Letters* as verified by the OPAC record fields

⁴ Teng (EX1006) indicates that ISSN 1098-2760 is the “Online” ISSN for *Microwave and Optical Technology Letters*, available “at Wiley InterScience, www.interscience.wiley.com.” EX1006, pdf. 2.

including title: *Microwave and Optical Technology Letters*; publisher: Wiley; and ISSN: 0895-2477.

55. The record of holdings of *Microwave and Optical Technology Letters* by the Linda Hall Library is shown in the line titled: “Holdings:” that reads: “v.1(1988)-v.63:no.11(2021:Nov),” indicating that *Microwave and Optical Technology Letters* began publication in 1988 with its issue Volume 1, Number 1.

56. Evidence that the Linda Hall Library received and holds Teng is shown in the OPAC record under the heading titled: “Holdings:” as shown below, which is inclusive of Volume 33, Number 1 (April 5, 2002):

LOCATIONS

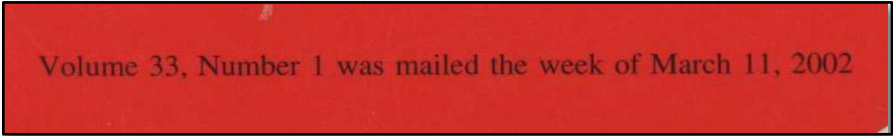
Linda Hall Library
Available , Closed Stacks - Serials ; Microwave and optical technology letters.
Holdings:
v.1(1988)-v.63:no.11(2021:Nov)
Note:
Volume index in last issue of volume.
Online only 2022.
[View less](#)

Go

57. *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*,” among others.

58. Although the nominal publication date of *Microwave and Optical Technology Letters*, Volume 33, Number 1 is April 5, 2002, 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.

59. For example, in this case, while the front cover of Teng (EX1006) indicates that the nominal publication date of Volume 33, Number 1 is April 5, 2002, at the bottom of the front cover indicates that “Volume 33, Number 1 was mailed the week of March 11, 2002,” as shown below.



Volume 33, Number 1 was mailed the week of March 11, 2002

60. The mailing of Volume 33, Number 1 during the week of March 11, 2002 is consistent with the stamped dates on Teng in the Linda Hall Library (Attachment A-1) and the Library of Congress (EX1006).

61. The date stamped on EX1006 – “JUN – 4 2002,” as shown below – indicates receipt of Teng by the Library of Congress Copyright Office on June 4, 2002. The Library of Congress receives a vast number of publications every day, and it would likely take weeks, or even a month or more, for a publication to make its way from the mail room to the intake desk where a date stamp is applied. June 4, 2002 is the date Teng (EX1006) was stamped, but Teng (EX1006) would have been received in the Library of Congress mailroom earlier (more likely than not several weeks earlier) than June 4, 2002.



62. After a date stamp is applied to a holding, it is promptly sent for shelving. The amount of time it takes to be shelved (available to the public) varies depending on the nature of the item, monograph, or journal issue. Monographs typically take longer than journals because cataloguing of monographs is more work-intensive. Journals, such as Teng, 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.

63. Therefore, the print copy of Teng (EX1006) at the Library of Congress would have been available for public access, more likely than not, by June 9, 2002.

64. Once Teng (EX1006) was entered into the general collection of the Library of Congress, members of the public could access Teng by having it taken to either the Jefferson or Adams Reading Rooms.

65. Members of the public could read, study, and make notes about a selected work in the Library of Congress Reading Rooms. Further, in the early 2000s, members of the public were permitted to make photocopies of portions of the work while in the Reading Rooms.

66. As I discussed above in this section, Attachment A-4 is a download I made from the Linda Hall Library OPAC (online catalog) on April 10, 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.”

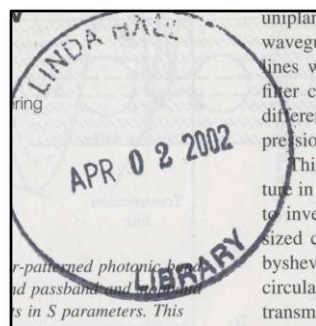
67. The record of holdings of *Microwave and Optical Technology Letters* by the Linda Hall Library is shown in the area titled: “Holdings” that reads: “v.1 (1988)-v.63:no.11(2021:Nov),” as shown below, indicating that *Microwave and Optical Technology Letters* began publication in 1988 with its issue Volume 1 and the print holdings at the Linda Hall Library start at Volume 1 and end with

Volume 63, Number 11, November, 2021 (at which point this journal become “Online only”). These dates are inclusive of the date of publication of Teng.

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](#)

68. The date stamped on Attachment A-2 – “APR 02 2002” – indicates receipt of Teng by the Linda Hall Library.



69. As I mentioned above in this section, a publication is first received in the library’s mailroom, and then is routed to an intake desk where it receives a date stamp. Thus, Teng was received in Linda Hall Library mailroom sometime before the stamp was applied on April 2, 2002. This timeline is consistent with the statement, on the cover of Teng, that it was “mailed the week of March 11, 2002,” as shown below:

Volume 33, Number 1 was mailed the week of March 11, 2002

70. The Linda Hall Library, more likely than not, received Teng sometime before the stamp was applied on April 2, 2002, therefore, individual subscribers to *Microwave and Optical Technology Letters* would also have, more likely than not, received Teng before April 2, 2002.

71. The physical copy of Teng 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 2, 2002, and sent for shelving, more likely than not, within two to five days. Therefore, Teng was, more likely than not, available for public access in the Linda Hall Library by April 7, 2002.

3. Conclusion

72. Teng (EX1006) is an authentic document and would have been publicly accessible, more likely than not, in the Library of Congress by June 9, 2002, and in the Linda Hall Library by April 7, 2002. Teng also would have been received by subscribers, more likely than not, by April 2, 2002, just as it was received in the Linda Hall Library no later than, and likely earlier than, April 2, 2002.

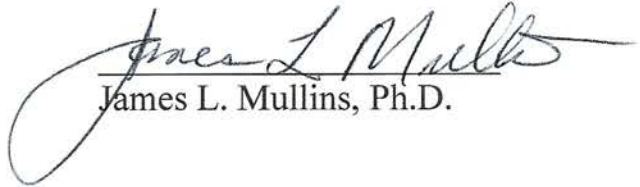
V. RIGHT TO SUPPLEMENT

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

VI. JURAT

74. 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 28, 2025


James L. Mullins, Ph.D.

Attachment

A-1



MICROWAVE AND OPTICAL TECHNOLOGY LETTERS

VOLUME 33 / NUMBER 1

APRIL 5 2002

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IMPROVED PERFORMANCE OF PHOTONIC BAND-GAP MICROSTRIPLINE STRUCTURES WITH THE USE OF CHEBYSHEV DISTRIBUTIONS

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ABSTRACT: Conventional uniform circular-patterned photonic band gaps (PBGs) have constraints in the broadband passband and stopband performance because of the high ripple heights in S parameters. This Letter suggests a novel configuration with nonuniform dimensions of circular-patterned PBG to improve both pass- and stopband bandwidths and the ripples. The dimensions of the circles are varied proportionally to the relative Chebyshev amplitudes of a 10-element PBG array, and the dispersion characteristics are analyzed. It is seen that the Chebyshev distribution of the circular-patterned PBG line produces excellent performance by suppressing ripples and yielding better selectivity at cut-offs. © 2002 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 33: 1–5, 2002; DOI 10.1002/mop.10212

Key words: microstriplines; photonic band gap; circular PBG; ripples; stopband; filters; Chebyshev distribution

1. INTRODUCTION

Planar photonic band-gap (PBG) structures are a class of periodic dielectrics that are photonic analogs of semiconductors. Electromagnetic waves behave in photonic substrates as electrons behave in semiconductors. PBG materials are periodic structures that exhibit wide bandpass and band-rejection properties at microwave and millimeter-wave frequencies. Introducing periodic perturbation such as dielectric rods, holes, and patterns in waveguides and microstrip substrates forms PBG materials. Although various configurations have been proposed in the literature, only the planar etched PBG configurations [1–4] have attracted much interest because of their ease of fabrication with photolithographic MIC, MMIC, and MEMS processes. The electromagnetic waves in a PBG material are impeded because of the periodic discontinuity, hence making a slow wave structure. Moreover, surface-wave propagation in microstrip dielectric materials is a serious problem. Surface waves reduce efficiency and gain, limit bandwidth for active and passive microwave devices, and increase end-fire radiation and cross polarization levels in antennas. PBG-engineered materials suppress surface waves [10] in dielectric slabs. Consequently, the performance of the active and passive microwave components is enhanced. Because of the unique properties of PBG materials, they are increasingly finding potential applications [5–11] in microwave and millimeter-wave frequencies because of their excellent performances in planar transmission lines, waveguides, power combiners/dividers, filters, diplexers, EMC measurements, broadband absorbers and reflectors, high-efficiency broadband power amplifiers, phased arrays, highly directive and broadband antenna elements with improved radiation performances, and many other devices.

The behavior of PBG-engineered materials can be controlled with the proper choice of different lattice structures and lattice parameters such as the filling factor, the patterns/geometries of perturbations, and the distributions of PBG patterns. Lopetegi et al.

[4] report sinusoidal and triangular patterns along with the conventional circular pattern. Laso et al. [3] report the nonuniform distribution and tapered radii of circular PBG patterns with Gaussian distribution and chirped periods. Yun and Chang [12] report uniplanar 1-D PBG structures and resonators on coplanar waveguides, slot lines, and coplanar striplines. Different resonator lines with PBG reflectors are used to investigate the band-stop filter characteristics. The reported configurations have produced different results in terms of the stopband performance and suppression of ripples at cutoff frequencies.

This study concerns the characteristics of a novel PBG structure in the form of the nonuniform distribution of circular patterns to investigate any improvement over the conventional uniform-sized circular-patterned PBGs. PBG distributions based on Chebyshev polynomials are used to taper the dimensions of the etched circular patterns on the ground plane of a standard microstrip transmission line. Although the uniform distribution of the circular patterns generates ripples, which limits the bandwidth of the band-stop transmission characteristics, the nonuniform distributions in the forms of Chebyshev polynomials yield superior performances. It has been reported in [1] that the circles with larger filling factors (> 0.25) generate ripples in the transmission and reflection characteristics of the circular-patterned PBG-assisted microstrip transmission lines. These ripples in the passband regions limit the wideband performance of the circular PBGs. It is concluded in [1] that the filling factor of such a circular-patterned PBG has an optimum value of 0.25. Because the bandwidth of the S_{21} parameter is proportional to the filling factor, such circular-patterned PBG limits the wideband applications. With the use of the nonuniform distribution of PBG patterns, both ripple and bandwidth problems are alleviated and the sensitivity of the stopband characteristics of planar PBGs is increased. The novel finding can be very useful for wideband surface-wave suppression [5–12] in planar and microstrip antennas, diplexers, filters, and amplifiers.

The following sections present the theory of Chebyshev polynomials as applied to the low side-lobe array theory and the tapered impedance matching sections. The selectivity of the low-pass filter is defined. The design procedures for uniform and nonuniform circular-patterned PBG arrays are presented next. Results of 10-element circular PBG arrays in uniform and Chebyshev distributions are presented and compared, followed by conclusions.

2. NONUNIFORM 1-D MICROSTRIP PBG DESIGN

2.1. Chebyshev Polynomial. Instead of a maximally flat passband characteristic, an equally useful characteristic is one that may permit the transmission coefficient to vary with minute ripples over the stopband [13]. This provides a considerable increase in bandwidth with respect to other distributions. This equal-ripple characteristic is obtained by making the distribution according to a Chebyshev polynomial. The basic properties of the polynomials [14] are expressed as follows:

$$T_m(z) = 2zT_{m-1}(z) - T_{m-2}(z) \quad (1)$$

where $T_m(z)$ is expressed as

$$T_m(z) = \begin{cases} \cos[m \cos^{-1}(z)], & \text{for } |z| \leq 1 \\ \cosh[m \cosh^{-1}(z)], & \text{for } |z| > 1. \end{cases} \quad (2)$$

The coefficients of the polynomial are determined for any prescribed side-lobe level. The present case uses a 10-element PBG array with a tapered distribution according to Chebyshev

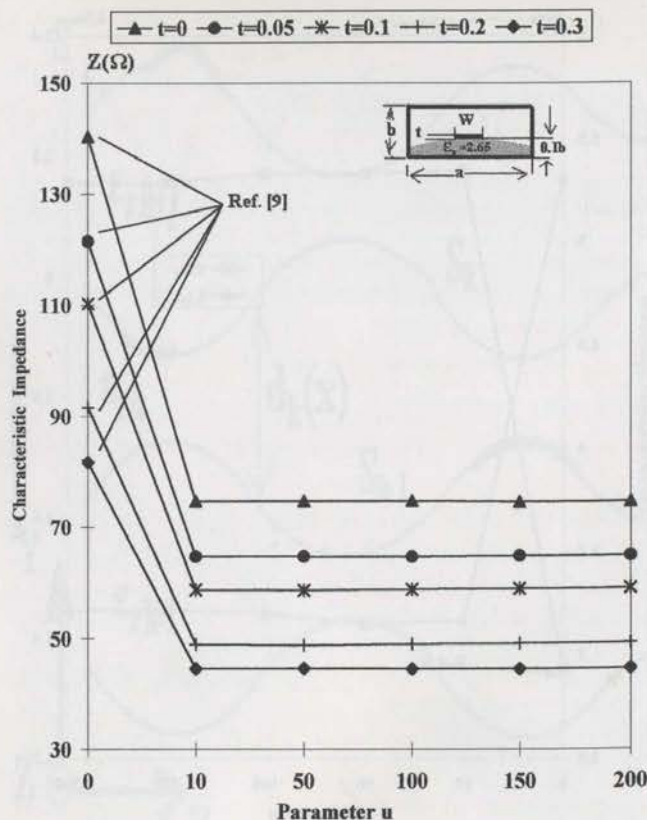


Figure 6 Variation of the static characteristic impedance versus u for different values of (t)

where the parameter u allows control of the shape of the microstrip interface (Figure 3).

Figures 4 and 5 show, respectively, the variation of the characteristic impedance (Z_L), the effective dielectric constant ($\epsilon_{r, \text{eff}, \text{stat}}$), the normalized capacitance (C/ϵ_0) and inductance (L/μ_0) as a function of the shape of the dielectric layer determined by the parameter u [3] considering: $\epsilon_{r1} = 10.185$, $\epsilon_{r2} = 1$, $W = 0.01$ mm, $b = 0.5$ mm, and $t = 0$. Comparison with [7] and [8] also shows good agreement for $u = 0$.

Table 1 shows the characteristic impedance (Z_L) of microstrip lines for $u = 0$ with different combinations of thickness t and width w of the conductor strip. Comparisons were made with Nan-Chang and Tan [9], Ivanov and Djankov [10], and Honma and Fukai [11]. The relative error made in neglecting t in [9] and [10] can reach 1.6%. Good agreement was found for all calculations.

The variation of the characteristic impedance (Z_L) for different values of strip metallization thickness, as a function of u for microstriplines with varying thickness enclosed in a rectangular waveguide, is depicted in Figure 6, with $\epsilon_{r1} = 2.65$, $\epsilon_{r2} = 1$, $W = 0.02$ mm, and $a = b = 1$ mm. It is clearly seen from these curves that Z_L decreases as t increases. Again, these results agree well with those from [9] when $u = 0$.

IV. CONCLUSIONS

In this article the method of lines is extended to the quasi-static analysis of microstrip lines printed on dielectric layers with arbitrarily varying thickness considering zero and finite metallization thickness. Our results show good agreement with data available in the literature.

Furthermore, these results are obtained with substantially smaller computational effort (CPU time and memory) with the use of these equidistant discretization lines. The advantages of the

method of lines are shorter computer time, applicability to many different structures, and high accuracy.

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PLANAR MONOPOLE FOLDED INTO A COMPACT STRUCTURE FOR VERY-LOW-PROFILE MULTIBAND MOBILE-PHONE ANTENNA

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ABSTRACT: A planar monopole consisting of three branch strips and folded into a rectangular-box-like compact structure for very-low-profile GSM/DCS/PCS multiband mobile-phone antennas is presented. The three branch strips are designed to operate as quarter-wavelength structures at 900, 1800, and 1900 MHz, respectively, and the obtained impedance bandwidths cover the required bandwidths of the GSM band (890–960 MHz), the DCS band (1710–1880 MHz), and the PCS band (1850–1990 MHz). The proposed antenna has a compact size of 6.5 mm in height, 6 mm in width, and 25 mm in length, and can be mounted on top of a mobile phone with a small distance of 3 mm to the ground plane, resulting in a very low profile of 9.5 mm (less than 3% of the wavelength at 900 MHz) from ground for the proposed antenna in practical applications. © 2002 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 33: 22–25, 2002; DOI 10.1002/mop.10219

Key words: planar monopole antennas; mobile-phone antennas; folded planar monopole antennas

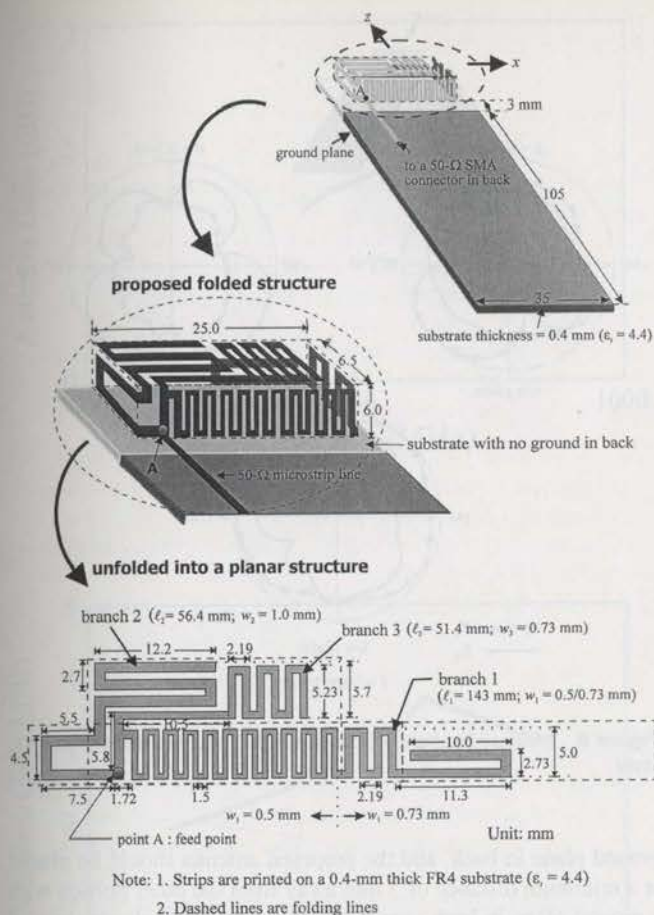


Figure 1 Proposed planar monopole folded into a compact structure for multiband mobile phone antennas

1. INTRODUCTION

Planar monopole antennas with a low profile are very attractive for mobile-phone antenna applications. Recently, a dual-band planar monopole antenna design, capable of operating in the GSM (890–960 MHz) and DCS (1710–1880 MHz) bands has been reported [1]. This design is a two-dimensional structure, and is obtained by modifying the folded loop antenna reported in [2]. Its antenna height, however, is greater than 10% of the free-space wavelength at 900 MHz, which makes it less attractive to be employed in mobile phones that demand protruded monopole antennas with a profile as low as possible.

This Letter presents a novel very-low-profile design of a planar monopole antenna consisting of three branch strips and folded into a rectangular-box-like compact structure for applications in multi-band mobile phones for GSM (890–960 MHz), DCS (1710–1880 MHz), and PCS (1850–1990 MHz) operations. The proposed antenna is first printed on a thin FR4 substrate and then folded into a three-dimensional structure like a rectangular box to achieve a much-reduced antenna height (6.5 mm only or about 2% of the wavelength at 900 MHz). Details of the proposed antenna design are described in this Letter, and experimental results of the proposed antenna are presented and discussed.

2. ANTENNA DESIGN

Figure 1 shows the proposed planar monopole folded into a rectangular-box-like compact structure for multiband mobile phone antennas. The design dimensions are given in the unfolded planar structure, whose optimal dimensions are obtained with the aid of the commercially available simulation software Ansoft HFSS

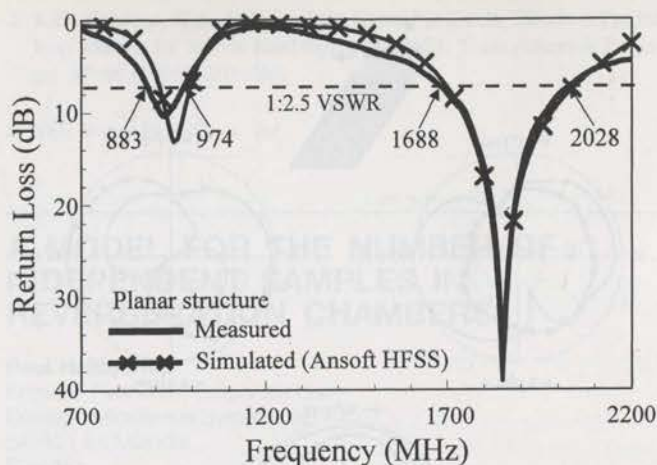


Figure 2 Measured and simulated return loss versus frequency for the proposed monopole antenna unfolded into a planar structure

(high-frequency structure simulator). The proposed monopole consists of three branch strips: Branches 1–3 shown in Figure 1. The three branches are all printed on a thin (0.4 mm) FR4 substrate, and then, by following the dashed lines shown in the figure, folded into a compact structure like a rectangular box. Branch 1 is mainly for generating a resonant mode at about 900 MHz for GSM operation. Notice that, starting from Point A (the feed point), the strip length (ℓ_1) of Branch 1 is 143 mm (about 0.43 wavelength at 900 MHz), which is meandered in the proposed design to achieve a compact structure, and owing to the coupling effect between two adjacent or nearby meandered sections, the effective electrical length will be less than the physical length. This is the reason that the strip length of Branch 1 is larger than the required 0.25 wavelength. Also notice that, at the portion close to the end of Branch 1, the strip width (0.73 mm) is designed to be larger than the other portion (0.5 mm), which is helpful in achieving a wider impedance bandwidth (> 70 MHz) for the 900-MHz band.

Branch 2 is designed for operating at about 1800 MHz for DCS band, and its strip length (ℓ_2) is 56.4 mm (about 0.34 wavelength at 1800 MHz). Branch 3 is for operating at about 1900 MHz for PCS band, and has a strip length (ℓ_3) of 51.4 mm (about 0.32 wavelength at 1900 MHz). Notice that the strip lengths of Branches 2 and 3 are closer to 0.25 wavelength than that of Branch 1, which is largely because less-meandered sections are in

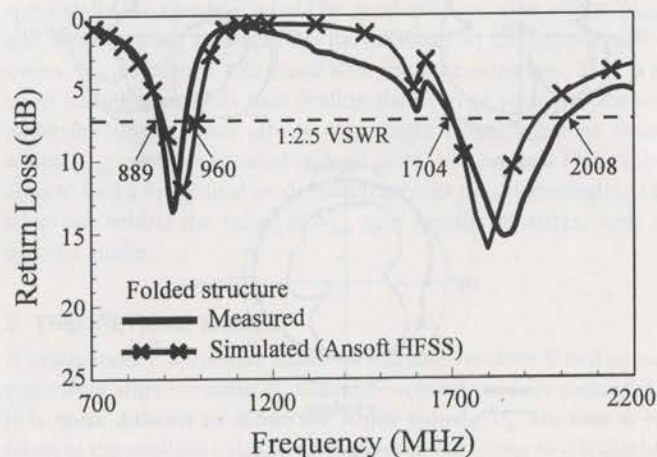


Figure 3 Measured and simulated return loss versus frequency for the proposed monopole antenna in a folded compact structure

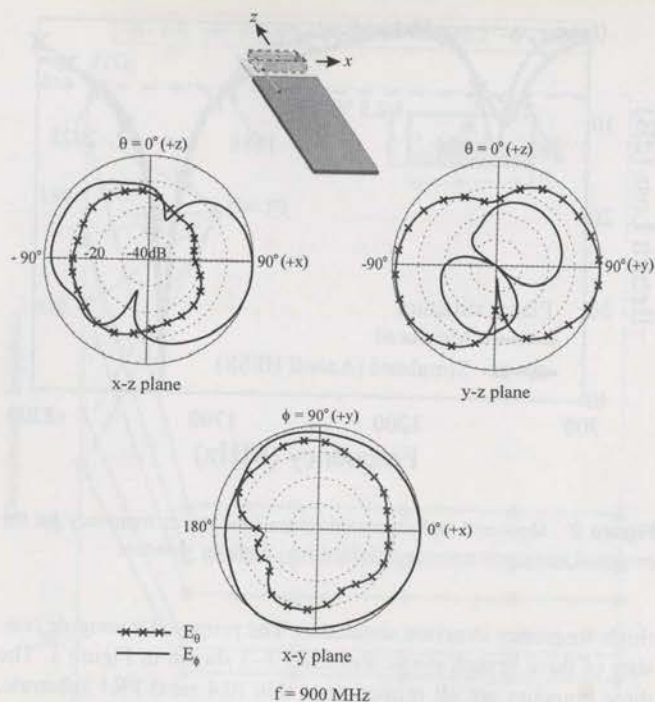


Figure 4 Measured radiation patterns for the proposed antenna at 900 MHz

Branches 2 and 3; thus the coupling effect in reducing the effective electrical length is relatively smaller. Through the combined excitation of Branches 1 and 2, an upper band centered at about 1850 MHz with a wide bandwidth of about 300 MHz covering the DCS and PCS bands can be obtained.

For experimental studies, the proposed antenna is mounted on the top portion of an FR4 substrate (thickness 0.4 mm and relative permittivity 4.4), which can be considered as the circuit board of a practical mobile handset. Notice that the top portion has no

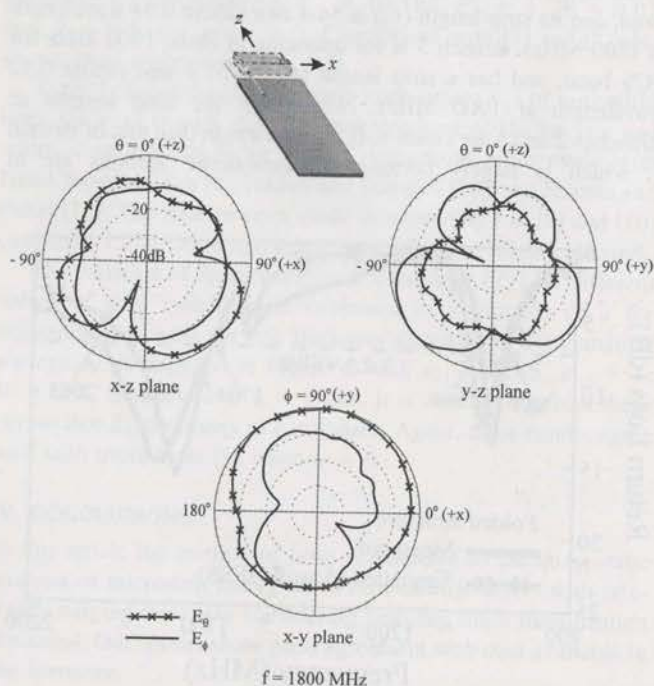


Figure 5 Measured radiation patterns for the proposed antenna at 1800 MHz

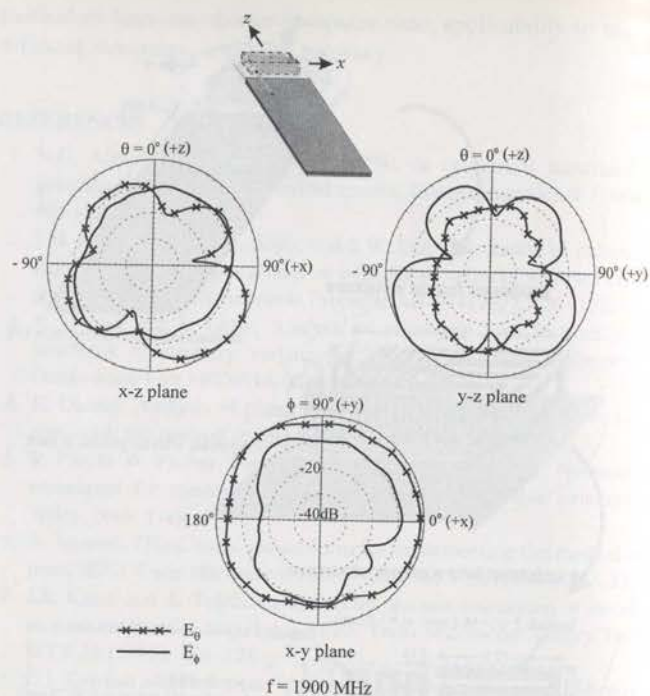


Figure 6 Measured radiation patterns for the proposed antenna at 1900 MHz

ground plane in back, and the proposed antenna should be placed at a minimum distance of 3 mm away from the other portion with a ground plane in back (see the figure), which has dimensions of $35 \times 105 \text{ mm}^2$. The proposed antenna can then be easily fed at Point A with the use of a 50- Ω microstripline printed on the FR4 substrate. In the experiment, the microstripline was further connected to a 50- Ω SMA connector placed in the ground-plane side of the FR4 substrate.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed antenna has been successfully constructed. Figure 2 shows the measured and simulated return loss against frequency for the proposed monopole antenna unfolded into a planar structure, and the results for the proposed monopole antenna in a folded compact structure are shown in Figure 3. It is first seen that good agreement between the measurement and the simulation is obtained, and some deviations between the measured data and the simulated results in Figure 3 are largely due to the construction errors. In addition, it is seen that there are slight variations in the obtained impedance bandwidths for the proposed antennas in planar and folded structures. From the obtained results in Figure 3, the lower band has a bandwidth (1:2.5 VSWR) of 889–960 MHz, covering the required GSM band. For the upper band, a bandwidth of 1704–2008 MHz is obtained, which covers the required DCS and PCS bandwidths.

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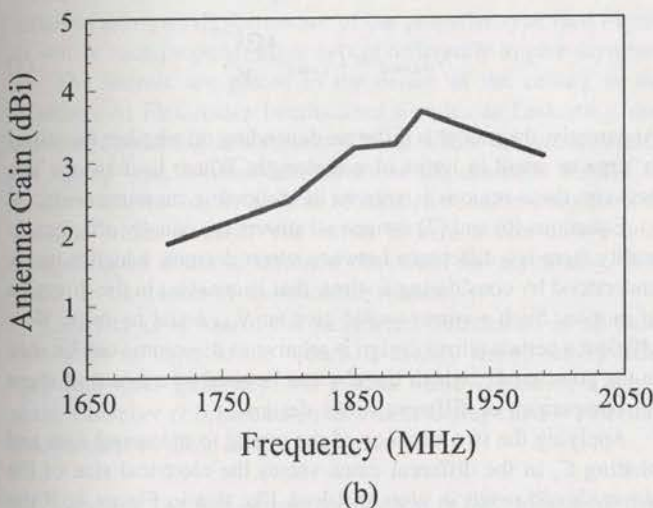
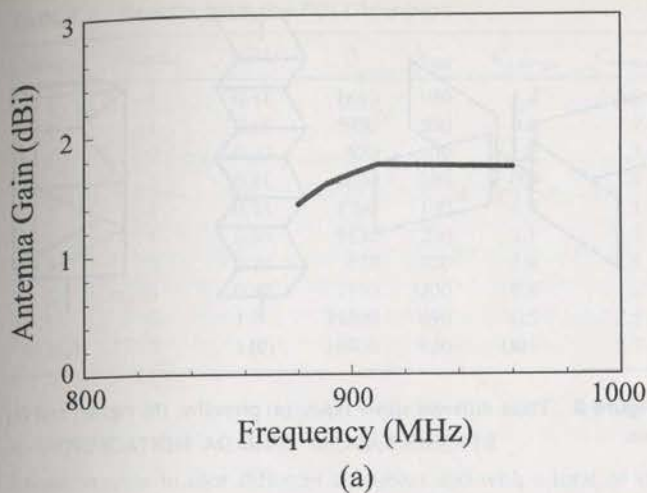


Figure 7 Measured antenna gain for the proposed antenna. (a) The GSM band (890–960 MHz). (b) The DCS (1710–1880 MHz) and PCS (1850–1990 MHz) bands

more like omnidirectional radiation than that at 1800 MHz. Measured antenna gain for the proposed antenna in the lower band for GSM operation and in the upper band for DCS and PCS operations is shown in Figures 7(a) and 7(b), respectively. The antenna gain is about 1.4–1.7 dBi for the operating frequencies in the GSM band; for the DCS and PCS operations the antenna gain ranges from about 1.9 to 3.6 dBi.

4. CONCLUSIONS

A very-low-profile planar monopole antenna suitable for applications in GSM/DCS/PCS multiband mobile phones has been proposed and implemented. The proposed antenna is folded into a rectangular-box-like structure and has a compact size of dimensions $6.5 \times 6 \times 25 \text{ mm}^3$. With the inclusion of a 3-mm distance from the ground plane in practical applications, the proposed antenna has a very low profile of 9.5 mm only (less than 3% of the wavelength at 900 MHz).

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A MODEL FOR THE NUMBER OF INDEPENDENT SAMPLES IN REVERBERATION CHAMBERS

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ABSTRACT: Antenna efficiency measurements in reverberation chambers are done by averaging a number of sampled power levels, measured while the mode stirrer rotates. The number of independent samples is the number of stirrer positions that give uncorrelated fields in the chamber, and thereby uncorrelated power levels. A larger number of samples gives a better accuracy of the measured value. This report presents a proposed theoretical model for the number of independent samples of a reverberation chamber, thereby giving a better understanding of how to optimize a chamber design. Measured data from chambers with three different types of stirrers are compared with the use of the model. © 2002 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 33: 25–28, 2002; DOI 10.1002/mop.10220

Key words: reverberation chamber; mode stirred chamber; multimode chamber; mode stirring

1. INTRODUCTION

A reverberation chamber (RC) measurement gives the efficiency of the antenna under test by the average received power over all stirrer positions. The accuracy of the value depends on how many stirrer positions there are that give uncorrelated fields in the chamber. Even if the stirrer is moved continuously, there is still a limited number of stirrer positions that give uncorrelated fields. This number is called the number of independent samples N_{ind} . A high N_{ind} is always desired. Today, RC mode-stirrer design is to some extent based on previous experience, but unfortunately also contains some guesswork. In order to design an optimal RC, specifically the stirrer, it would be good to know what affects N_{ind} and how. In order to determine the accuracy of the RC measurements, N_{ind} is usually calculated after each measurement. This is a more complex analysis than finding the average power. A better understanding of what affects N_{ind} might reveal relations from which N_{ind} can be concluded without extra calculations. This study aims to find a theoretical model that improves the understanding of what lies behind the value of N_{ind} in a specific chamber, with a specific stirrer.

2. THEORETICAL MODEL

A crude model is derived, based on chamber volume V and some equivalent stirrer volume V_s . Chamber volume is easily measured. It is more difficult to define the stirrer volume V_s , but here it is taken as the smallest cylinder within which the stirrer fits. It can of course be defined in other ways as well. Because of the arbitrary definition of stirrer volume, absolute relations are not used to begin with, but rather proportionalities. Later on the constant of propor-

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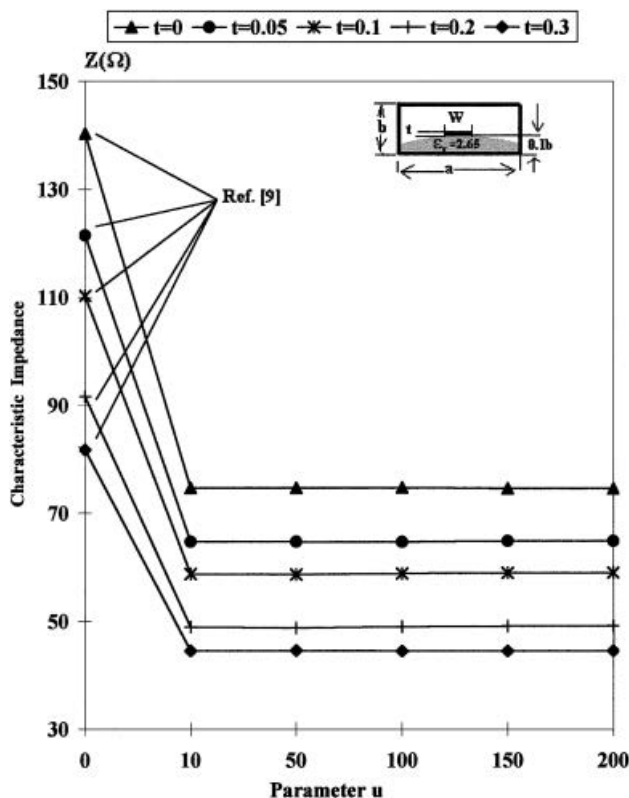


Figure 6 Variation of the static characteristic impedance versus u for different values of (t)

where the parameter u allows control of the shape of the microstrip interface (Figure 3).

Figures 4 and 5 show, respectively, the variation of the characteristic impedance (Z_L), the effective dielectric constant ($\epsilon_{r, \text{eff}, \text{stat}}$), the normalized capacitance (C/ϵ_0) and inductance (L/μ_0) as a function of the shape of the dielectric layer determined by the parameter u [3] considering: $\epsilon_{r1} = 10.185$, $\epsilon_{r2} = 1$, $W = 0.01$ mm, $b = 0.5$ mm, and $t = 0$. Comparison with [7] and [8] also shows good agreement for $u = 0$.

Table 1 shows the characteristic impedance (Z_L) of microstrip lines for $u = 0$ with different combinations of thickness t and width w of the conductor strip. Comparisons were made with Nan-Chang and Tan [9], Ivanov and Djankov [10], and Honma and Fukai [11]. The relative error made in neglecting t in [9] and [10] can reach 1.6%. Good agreement was found for all calculations.

The variation of the characteristic impedance (Z_L) for different values of strip metallization thickness, as a function of u for microstriplines with varying thickness enclosed in a rectangular waveguide, is depicted in Figure 6, with $\epsilon_{r1} = 2.65$, $\epsilon_{r2} = 1$, $W = 0.02$ mm, and $a = b = 1$ mm. It is clearly seen from these curves that Z_L decreases as t increases. Again, these results agree well with those from [9] when $u = 0$.

IV. CONCLUSIONS

In this article the method of lines is extended to the quasi-static analysis of microstrip lines printed on dielectric layers with arbitrarily varying thickness considering zero and finite metallization thickness. Our results show good agreement with data available in the literature.

Furthermore, these results are obtained with substantially smaller computational effort (CPU time and memory) with the use of these equidistant discretization lines. The advantages of the

method of lines are shorter computer time, applicability to many different structures, and high accuracy.

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PLANAR MONOPOLE FOLDED INTO A COMPACT STRUCTURE FOR VERY-LOW-PROFILE MULTIBAND MOBILE-PHONE ANTENNA

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Received 9 October 2001

ABSTRACT: A planar monopole consisting of three branch strips and folded into a rectangular-box-like compact structure for very-low-profile GSM/DCS/PCS multiband mobile-phone antennas is presented. The three branch strips are designed to operate as quarter-wavelength structures at 900, 1800, and 1900 MHz, respectively, and the obtained impedance bandwidths cover the required bandwidths of the GSM band (890–960 MHz), the DCS band (1710–1880 MHz), and the PCS band (1850–1990 MHz). The proposed antenna has a compact size of 6.5 mm in height, 6 mm in width, and 25 mm in length, and can be mounted on top of a mobile phone with a small distance of 3 mm to the ground plane, resulting in a very low profile of 9.5 mm (less than 3% of the wavelength at 900 MHz) from ground for the proposed antenna in practical applications. © 2002 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 33: 22–25, 2002; DOI 10.1002/mop.10219

Key words: planar monopole antennas; mobile-phone antennas; folded planar monopole antennas

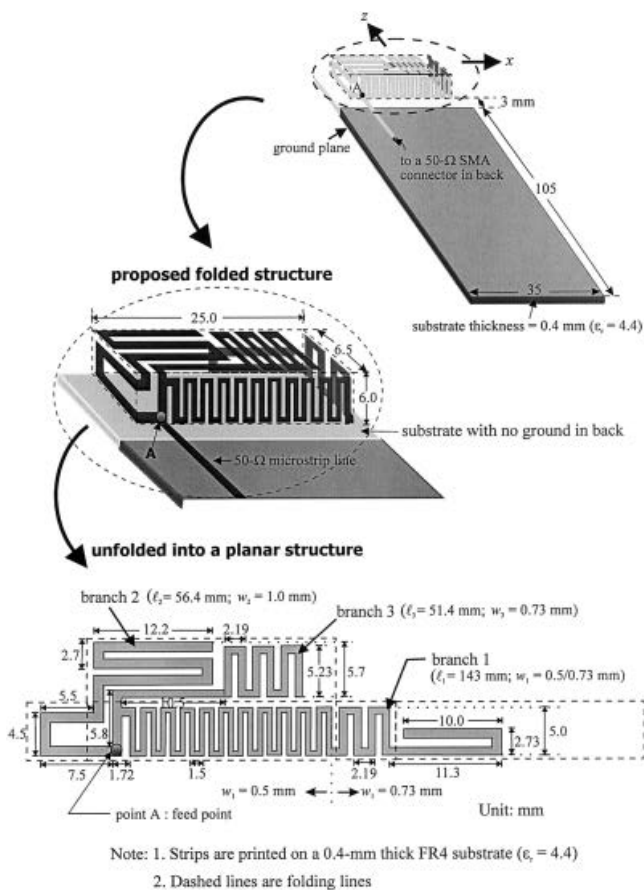


Figure 1 Proposed planar monopole folded into a compact structure for multiband mobile phone antennas

1. INTRODUCTION

Planar monopole antennas with a low profile are very attractive for mobile-phone antenna applications. Recently, a dual-band planar monopole antenna design, capable of operating in the GSM (890–960 MHz) and DCS (1710–1880 MHz) bands has been reported [1]. This design is a two-dimensional structure, and is obtained by modifying the folded loop antenna reported in [2]. Its antenna height, however, is greater than 10% of the free-space wavelength at 900 MHz, which makes it less attractive to be employed in mobile phones that demand protruded monopole antennas with a profile as low as possible.

This Letter presents a novel very-low-profile design of a planar monopole antenna consisting of three branch strips and folded into a rectangular-box-like compact structure for applications in multiband mobile phones for GSM (890–960 MHz), DCS (1710–1880 MHz), and PCS (1850–1990 MHz) operations. The proposed antenna is first printed on a thin FR4 substrate and then folded into a three-dimensional structure like a rectangular box to achieve a much-reduced antenna height (6.5 mm only or about 2% of the wavelength at 900 MHz). Details of the proposed antenna design are described in this Letter, and experimental results of the proposed antenna are presented and discussed.

2. ANTENNA DESIGN

Figure 1 shows the proposed planar monopole folded into a rectangular-box-like compact structure for multiband mobile phone antennas. The design dimensions are given in the unfolded planar structure, whose optimal dimensions are obtained with the aid of the commercially available simulation software Ansoft HFSS

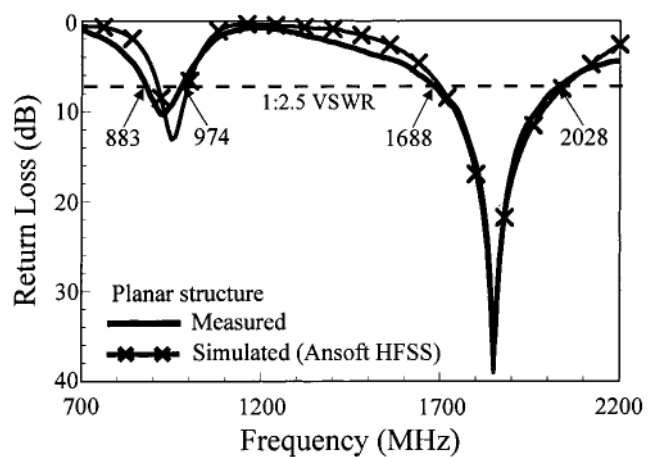


Figure 2 Measured and simulated return loss versus frequency for the proposed monopole antenna unfolded into a planar structure

(high-frequency structure simulator). The proposed monopole consists of three branch strips: Branches 1–3 shown in Figure 1. The three branches are all printed on a thin (0.4 mm) FR4 substrate, and then, by following the dashed lines shown in the figure, folded into a compact structure like a rectangular box. Branch 1 is mainly for generating a resonant mode at about 900 MHz for GSM operation. Notice that, starting from Point A (the feed point), the strip length (ℓ_1) of Branch 1 is 143 mm (about 0.43 wavelength at 900 MHz), which is meandered in the proposed design to achieve a compact structure, and owing to the coupling effect between two adjacent or nearby meandered sections, the effective electrical length will be less than the physical length. This is the reason that the strip length of Branch 1 is larger than the required 0.25 wavelength. Also notice that, at the portion close to the end of Branch 1, the strip width (0.73 mm) is designed to be larger than the other portion (0.5 mm), which is helpful in achieving a wider impedance bandwidth (> 70 MHz) for the 900-MHz band.

Branch 2 is designed for operating at about 1800 MHz for DCS band, and its strip length (ℓ_2) is 56.4 mm (about 0.34 wavelength at 1800 MHz). Branch 3 is for operating at about 1900 MHz for PCS band, and has a strip length (ℓ_3) of 51.4 mm (about 0.32 wavelength at 1900 MHz). Notice that the strip lengths of Branches 2 and 3 are closer to 0.25 wavelength than that of Branch 1, which is largely because less-meandered sections are in

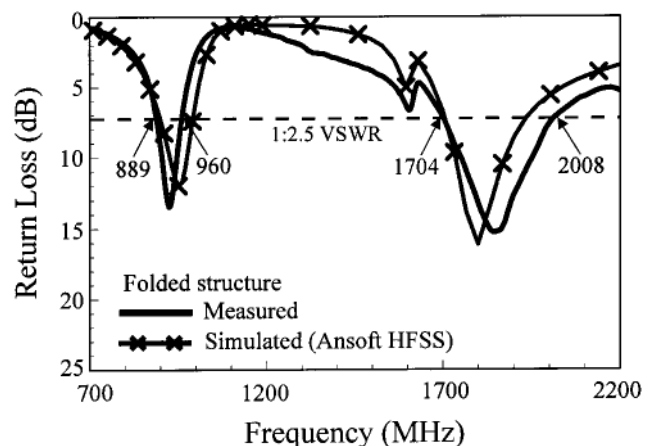


Figure 3 Measured and simulated return loss versus frequency for the proposed monopole antenna in a folded compact structure

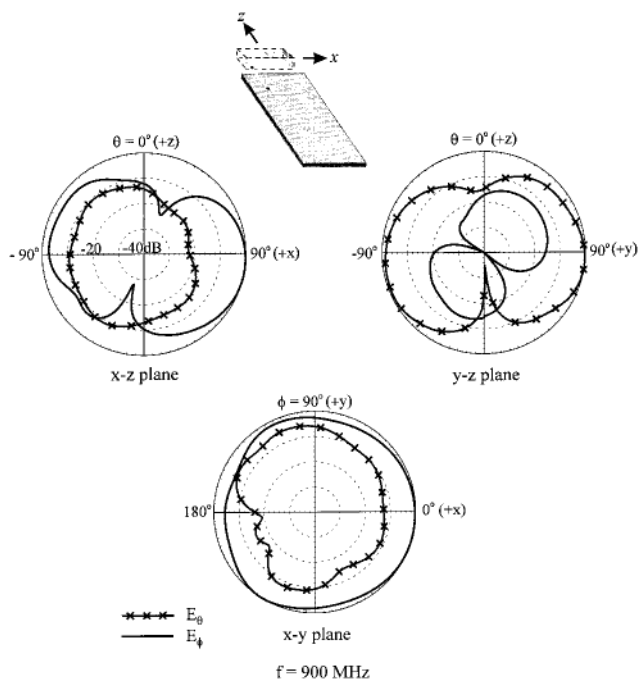


Figure 4 Measured radiation patterns for the proposed antenna at 900 MHz

Branches 2 and 3; thus the coupling effect in reducing the effective electrical length is relatively smaller. Through the combined excitation of Branches 1 and 2, an upper band centered at about 1850 MHz with a wide bandwidth of about 300 MHz covering the DCS and PCS bands can be obtained.

For experimental studies, the proposed antenna is mounted on the top portion of an FR4 substrate (thickness 0.4 mm and relative permittivity 4.4), which can be considered as the circuit board of a practical mobile handset. Notice that the top portion has no

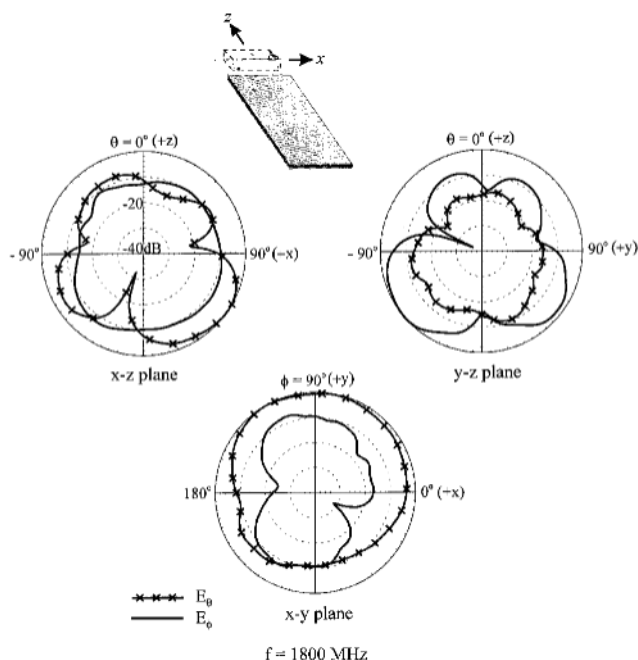


Figure 5 Measured radiation patterns for the proposed antenna at 1800 MHz

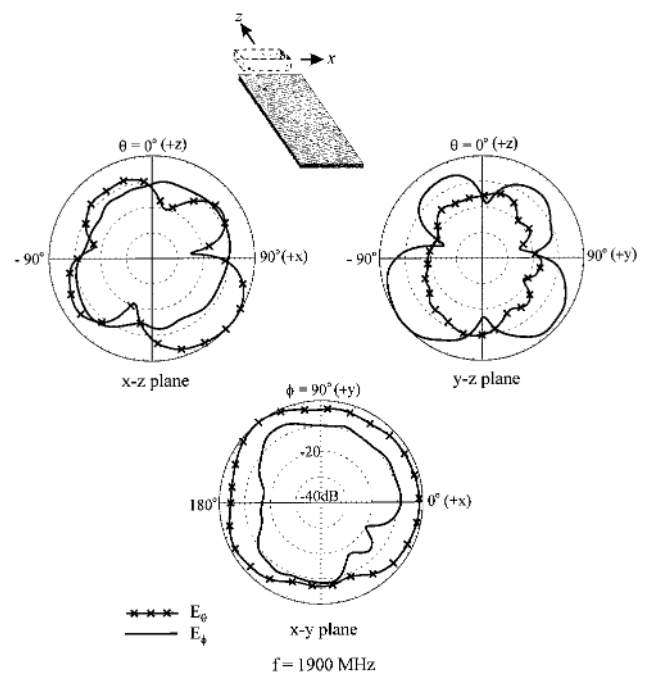


Figure 6 Measured radiation patterns for the proposed antenna at 1900 MHz

ground plane in back, and the proposed antenna should be placed at a minimum distance of 3 mm away from the other portion with a ground plane in back (see the figure), which has dimensions of $35 \times 105 \text{ mm}^2$. The proposed antenna can then be easily fed at Point A with the use of a 50- Ω microstripline printed on the FR4 substrate. In the experiment, the microstripline was further connected to a 50- Ω SMA connector placed in the ground-plane side of the FR4 substrate.

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The proposed antenna has been successfully constructed. Figure 2 shows the measured and simulated return loss against frequency for the proposed monopole antenna unfolded into a planar structure, and the results for the proposed monopole antenna in a folded compact structure are shown in Figure 3. It is first seen that good agreement between the measurement and the simulation is obtained, and some deviations between the measured data and the simulated results in Figure 3 are largely due to the construction errors. In addition, it is seen that there are slight variations in the obtained impedance bandwidths for the proposed antennas in planar and folded structures. From the obtained results in Figure 3, the lower band has a bandwidth (1:2.5 VSWR) of 889–960 MHz, covering the required GSM band. For the upper band, a bandwidth of 1704–2008 MHz is obtained, which covers the required DCS and PCS bandwidths.

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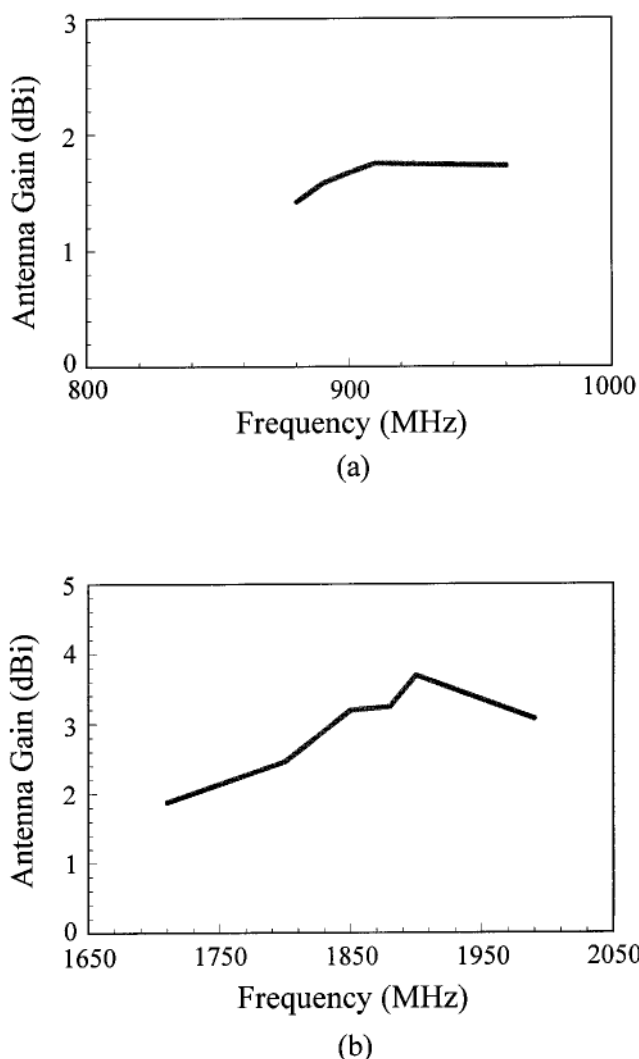


Figure 7 Measured antenna gain for the proposed antenna. (a) The GSM band (890–960 MHz). (b) The DCS (1710–1880 MHz) and PCS (1850–1990 MHz) bands

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A MODEL FOR THE NUMBER OF INDEPENDENT SAMPLES IN REVERBERATION CHAMBERS

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