UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

KANGXI COMMUNICATION TECHNOLOGIES (SHANGHAI) CO., LTD.

Petitioner,

v.

SKYWORKS SOLUTIONS, INC.

Patent Owner.

(U.S. Patent No. 7,409,200)
Inter Partes Review No.: IPR2025-00912

DECLARATION OF INGRID HSIEH-YEE, PH.D.

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I, Ingrid Hsieh-Yee, declare as follows:

I. INTRODUCTION AND QUALIFICATIONS

1. I am over the age of eighteen and otherwise competent to make this declaration.

2. I have been retained by counsel for Petitioner to provide my expert opinion in connection with the above-captioned proceedings ("IPR") regarding the public availability of certain prior art references in relation to U.S. Patent Number 7,409,200.

3. I am being compensated for my time in connection with this IPR at my current consulting rate. I am also being reimbursed for any reasonable expenses associated with my work and testimony in this investigation. My compensation is not contingent on the results of my study, the substance of my opinions, or the outcome of this matter.

A. Qualifications and Professional Experience

4. My complete qualifications and professional experience are described in my academic curriculum vitae (**Appendix A**). The following is a brief summary of my relevant qualifications and professional experience.

5. I was a professor in the Department of Library and Information Science at the Catholic University of America for 32 years and was conferred the title of Professor Emerita in December 2022. I have experience working in an academic

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library, a medical library, and a legislative library. I hold a Ph.D. and a Masters in Library and Information Studies from the University of Wisconsin-Madison.

6. I am an expert on library cataloging and classification and have published two editions on this subject, *Organizing Audiovisual and Electronic Resources for Access: A Cataloging Guide* (2000 and 2006). I taught a variety of courses, including Cataloging and Classification, Advanced Cataloging and Classification, Organization of Internet Resources, Organization of Information, Metadata, Digital Content Creation and Management, Internet Searches and Web Design, Information Literacy Instruction, Advanced Information Retrieval and Analysis Strategies, and The Information Professions in Society. I am familiar with metadata schema design and implementation. In my teaching, I covered the design and implementation of metadata in databases, search engines, digital repositories, digital libraries, and digital archives. I also covered how information organization affects the discovery and access to digital resources on the Internet. My research interests cover cataloging and classification, information organization, metadata, information retrieval, information architecture, digital collections, scholarly communication, social media, user interaction with information systems, and others

II. BACKGROUND OF LIBRARY CATALOGING

A. Machine-Readable Cataloging ("MARC")

7. I am very familiar with a library cataloging encoding standard known

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as the "Machine-Readable Cataloging" standard, also known as "MARC," which became the national standard for sharing bibliographic data in the United States by 1971 and the international standard by 1973. MARC is the primary communications protocol for the transfer and storage of bibliographic metadata in libraries. Experts in my field reasonably rely upon MARC records when forming their opinions.

8. A MARC record consists of several fields, each of which contains specific data about the work. Each field is identified by a standardized, unique, three-digit code corresponding to the type of data that follows. **Appendix B** is a true and correct copy of Parts VII to X of "Understanding MARC Bibliographic: Machine-Readable Cataloging" (https://www.loc.gov/marc/umb/um07to10.html), a brief description and tutorial published by the Library of Congress in 2009 that explains commonly used MARC fields. For example, the personal author of a work is recorded in Field 100, the title is recorded in Field 245, publisher information is recorded in Field 260, the physical volume and characteristics of a publication are recorded in Field 300, and topical subjects are recorded in Fields 650. More details of MARC21 format for Bibliographic Data are available on the Library of Congress website at https://www.loc.gov/marc/bibliographic/.

9. I am very familiar with library cataloging and processing practices and the relationships between OCLC (Online Computer Library Center) and library catalogs, and how libraries create and share their records to help the public discover

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and access information.

10. OCLC is the largest bibliographic network of the world, and its WorldCat database contains more than 559 million records from thousands of member institutions (many of which are libraries of some type) in more than 100 countries. OCLC was founded in 1967 to promote and support library cooperation. According to the third article of the "Amended Articles of Incorporation of OCLC [Online Computer Library Center], Inc.," 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" (source: https://www.oclc.org/content/dam/oclc/membership/articles-of-incorporation.pdf).

11. OCLC members can contribute original cataloging records in MARC to the system or derive cataloging records from existing records, an activity referred to as "copy cataloging." When an OCLC participating institution acquires a work, it can create an original MARC record for the work in OCLC's Connexion system (a system for catalogers to create and share MARC records), and the system will

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automatically generate a code for the date of record creation in the yymmdd format, and the creating library's OCLC symbol is recorded in subfield "a" of the 040 field. Once the MARC record is in Connexion, it becomes available to other OCLC members for adoption to their local online catalogs (*i.e.*, copy cataloging).

12. After a MARC record is created in Connexion, it also becomes searchable and viewable on WorldCat.org, which is a free web portal for users to explore more than 10,000 libraries worldwide. Records in WorldCat.org, however, are not presented in MARC fields. Instead, the data elements are labeled to help users interpret the records. Thus, the information stored in MARC records in Connexion is available to the interested public through the user-friendly WorldCat web portal. WorldCat records can also be searched on OCLC FirstSearch, a subscription-based search system that provides access to many proprietary databases, including the WorldCat database.

B. Library Online Catalogs

13. Library online catalogs gained acceptance in the early 1980s and many libraries migrated their systems to the World Wide Web in the mid-1990s. Library online catalogs are based on MARC records that represent their collections in order to help the public understand what materials are publicly accessible in those libraries. Most libraries with online catalogs have made their catalogs freely available on the Web. These online catalogs offer user-friendly search interfaces. Strong user interest

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in keyword searches and the popularity of Google have led to the "googlization" of library search systems. As a result, many library catalogs nowadays provide a single search box for users to conduct keyword searches, with additional support for searches by author, title, subject terms, and other data elements such as ISBN (International Standard Book Number). Library catalogs these days also offer features for users to narrow their search results by language, year, format, and other elements. Many libraries display MARC records on their online catalogs with labels for the data elements to help the public interpret MARC records. Many libraries also offer the option to display MARC records in MARC fields.

14. Libraries create MARC records for works they acquire, including books, serials, motion pictures, and publications in other formats. Monograph cataloging is fairly common in libraries, and most libraries make a newly cataloged monograph available to the public soon after the cataloging work is completed, usually within a week. Libraries can create original cataloging records or use an existing record in the OCLC WorldCat database to create a copy cataloging record. As soon as the cataloging record is completed, it is added to the library's online catalog for users. If the record is an original record, it is also entered into the OCLC system. If it is a copy cataloging record, the library's holding symbol is attached to the existing original record in the OCLC system to facilitate searching and interlibrary loan.

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15. The cataloging of serials and the serial check-in process are discussed here to show how libraries usually provide access to newly received serial issues. According to the glossary of the *RDA: Resource Description and Access* cataloging standard, a serial is "a mode of issuance of a manifestation issued in successive parts, usually bearing numbering, that has no predetermined conclusion. A serial includes a periodical, monographic series, newspaper, etc." (RDA Glossary at https://original.rdatoolkit.org/rdagloss_rdaregistry.info-termList-ModeIssue-1003_1.html (subscription required for access); cited in https://www.ccslib.org/Catalogers/index.php/Category:Serials). Because the publisher of a serial makes new issues of the serial available successively, a customary cataloging practice is to create one bibliographic record for the serial, and the serial record (encoded in MARC) typically provides information on the beginning date and frequency of the serial, not the dates of individual issues. In other words, libraries typically do not create MARC records for individual issues of a serial. Instead, they rely on a serial check-in system to track the receipt of new issues. A common check-in practice is to date stamp a new issue when it arrives. This practice has become automated since the late 1990s, and libraries now vary in how they share the receipt date of a new serial issue with the public. Some libraries use a date stamp, some affix a label to indicate the receipt date, some pencil in the receipt date, and some do not provide the information to the public.

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16. The serial check-in process usually takes less than an hour, and one of the steps involves placing a date stamp on the new issue to document the date the issue is checked in. After that, the holdings information of the serial is updated in the library's catalog so that users know which issues are available for request or access. After serial check-in is completed, the new issue is placed on the shelf with the previous issues of the serial. Libraries with a public periodical room typically place new issues in the periodical room for easy user access. Because information presented in serials often reflects latest discovery, a general practice of libraries is to make new issues of serials available for user access soon after they are checked in, usually within a week.

17. I am personally familiar with many online catalogs, databases, and search engines. In preparing for this declaration, I used the following authoritative information systems to search for records:

- Google Scholar (https://scholar.google.com/)
- Internet Archive (https://archive.org/)
- Libraries.org, a directory of libraries throughout the world (https://librarytechnology.org/libraries/)
- Online catalog of the Library of Congress (https://catalog.loc.gov/)
- Online catalog of the Linda Hall Library (https://catalog.lindahall.org/discovery/search?vid=01LINDAHALL_I

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NST:LHL)

- Public catalog of the US Copyright Office (https://cocatalog.loc.gov/cgi-bin/Pwebrecon.cgi?DB=local&PAGE=First)
- WorldCat.org (https://search.worldcat.org/)

C. Scope of this Declaration

18. I have been asked to offer opinions on the public availability dates of the following documents:

- Magoon, R., Molnar, A., Zachan, J., Hatcher, G., & Rhee, W. (2002, December). A single-chip quad-band (850/900/1800/1900 MHz) direct conversion GSM/GPRS RF transceiver with integrated VCOs and fractional-N synthesizer, *IEEE Journal of Solid-State Circuits*, *37*(12), 1710-1720, **Ex. 1006** ("*Magoon*"); and
- Ngompe, E., Ayvazian, M., Glasbrener, M., Megahed, M., Vakilian, N., & Domino, W. (2003, June). Architecture and performance overview of a highly integrated 13/spl times/13 mm Single-Package Radio (SPR) module for dualband EGSM900/GSM1800 applications, *IEEE Radio Frequency Integrated Circuits (RFIC) Symposium, 2003* (pp. 387-390), **Ex. 1007** ("*Ngompe*").

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19. I am informed by counsel and understand that a given reference is "published" upon a satisfactory showing that such a document has been disseminated or otherwise made publicly available to the extent that persons interested and ordinarily skilled in the subject matter or art could locate it exercising reasonable diligence and obtain the document. I have also been informed by counsel and understand that materials available in a library constitute "printed publications" if they are catalogued and indexed according to general library practices and protocols that make the references available and accessible to members of the interested public.

20. I have been informed by counsel that U.S. Patent 7,409,200 claims October 8, 2003 as its earliest priority date. I have assessed public accessibility of the documents referenced below as of this claimed priority date.

21. I have been informed by counsel that the subject matter of this proceeding generally relates to signal conditioning circuits and semiconductor chip design and packaging for radio frequency applications.

22. I have been informed by counsel and understand 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 inventions. I have been informed by counsel that this hypothetical person is also a person of ordinary creativity, capable of understanding the scientific principles and literature applicable to the pertinent field.

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23. I have been informed by counsel that a person of ordinary skill in the art as of October 8, 2003, would have knowledge of the scientific literature and have skills relating to signal conditioning circuits and semiconductor chip design and packaging for radio frequency applications. A person of ordinary skill in this subject matter or art would have possessed a bachelor's degree in electrical or electronics engineering, or an equivalent degree or equivalent training, and approximately three years of experience working with RF circuit design and packaging and/or similar technology. Less professional experience could be remedied by additional education, and vice versa.

24. It is my opinion that such a person would have been actively engaged in learning about the field, possibly through formal instruction and through bibliographic resources. By at least October 8, 2003, such a person would have had access to a vast array of print and electronic resources, including at least the documents referenced below.

D. Evidence Considered in Forming My Opinion

25. In the preparation of this declaration, I have reviewed **Ex. 1006** and **Ex. 1007** referenced in paragraph 18 above, and any other documents I reference herein. Each of these is a type of material that experts in my field would reasonably rely upon when forming their opinions. I have provided a further description of materials I considered in **Appendix C**.

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III. Authenticity and Public Availability of *Magoon* (Ex. 1006)

A. Authentication

26. **Ex. 1006** is a true and correct copy of "A single-chip quad-band (850/900/1800/1900 MHz) direct conversion GSM/GPRS RF transceiver with integrated VCOs and fractional-N synthesizer," ("*Magoon*"), by Magoon et al., *IEEE Journal of Solid-State*, 37(12), 1710-1720, that I received from counsel. This journal issue has an issue date of "December 2002." This copy is presented as **Ex. 1006** in this declaration.

27. Page 1 is internal page 1710 that shows the title, authors, abstract, and index terms. The top of the page shows *Magoon* appears in "IEEE Journal of Solid-State Circuits, Vol. 37, No 12, December 2002." The bottom of the page shows the manuscript was "received April 30, 2002; revised July 2, 2002," the article's digital object identifier is "10.1109/JSSC.2002.804356," and the article appears in a journal whose ISSN (International Standard Serial Number) is "0018-9200." It also shows *Magoon* has a "2002" copyright date and IEEE (the Institute of Electrical and Electronics Engineers) holds the copyright. **Ex. 1006** shows *Magoon* has a total of 11 pages in eight sections and includes 20 figures, eight equations, three tables, and 20 references.

28. To authenticate **Ex. 1006**, I searched WorldCat.org (a free web portal) for records, and a record for *Magoon* at https://search.worldcat.org/title/5859258515

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shows that the Library of Congress (LC) is one of the holding libraries of the journal that contains *Magoon*. After verifying the holdings information in the online catalog of LC, I requested a copy of *Magoon* from LC through a document vendor. This LC copy is presented as **Ex. 1006A** in this declaration.

29. **Ex. 1006A** is a true and correct copy of *Magoon*. Page 1 shows the cover and spine of a bound volume identified as "37 July-Dec 2002" of *IEEE Journal of Solid-State Circuits* that has "TK 7871.85 .I23" as its call number. Page 2 is the issue cover that shows this journal is a publication of the IEEE Solid-State Circuits Society, and this issue is volume 37, number 12 that has an issue date of "December 2002," an ISSN of"0018-9200," and a CODEN of "IJSCBC." CODEN "are unique six-character codes that identify serial and non-serial publications produced worldwide," according to the International CODEN Service (https://www.cas.org/services/coden). The issue front cover includes the table of contents that continues on page 3 of **Ex. 1006A** and shows *Magoon* is included in the "Wireless and RF Papers" section and begins on page 1710. Page 4 is the copyright page that shows this journal is published monthly by IEEE, and has a "2002" copyright date with the publisher as the copyright holder. Page 5 is the title page that shows a date stamp of "Copyright Office JAN 9 2003 Library of Congress" and pages 6 and 7 are the scanned copies of the title page with different resolutions to make the date stamp more legible. Page 8 is the back cover that shows the rest of the table of

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contents.

30. Pages 9 to 19 (internal pages 1710 to 1720) are the full text of *Magoon*. I have closely compared **Ex. 1006** with the copy from the Library of Congress (**Ex. 1006A**), and found them to have the same content for *Magoon*.

31. **Ex. 1006** is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, and there are no visible alterations to the document. Furthermore, **Ex. 1006** has the same content as **Ex. 1006A**, which is from a journal issue held by the Library of Congress. Based on my review and analysis, it is my opinion that **Ex. 1006** is authentic.

B. Records of Library of Congress

32. To determine the public availability date of *Magoon*, I obtained records for the journal containing this article from the online catalog of the Library of Congress. **Ex. 1006B** is a true and correct copy of the bibliographic and MARC records for *IEEE Journal of Solid-State Circuits*. I personally located, identified, and obtained these records. They are the type of records experts in my field would reasonably rely upon when forming their opinions.

33. Pages 1 to 4 of **Ex. 1006B** are the bibliographic record that shows *IEEE Journal of Solid-State Circuits* is a publication "[i]ssued by the IEEE Solid-State Circuits Council" and the IEEE Solid-State Circuits Society has been the issuing agency since 1997. The record also shows the Institute of Electrical and Electronics

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Engineers of New York, N.Y. has been publishing this journal since 1966. In addition, the record shows this journal's ISSN (International Standard Serial Number) is 0018-9200, the journal has been published monthly since 1991, and its CODEN (a unique six-character code that identifies journals) is "IJSCBC." The ISSN, CODEN, title, publisher, and publication frequency match the information presented in the LC copy of *Magoon* (**Ex. 1006A**), confirming this record represents the journal containing *Magoon*. The Item Availability area on pages 3 and 4 shows Library of Congress has two copies of this journal, the journal call number is "TK7871.85 .I23," users can request access at the Jefferson or Adams Building Reading Rooms, and the status of the issues is "Not Charged" (meaning available for user request).

34. Pages 5 to 8 are the MARC record for the journal containing *Magoon*. The first six digits of Field 008 show the MARC record was created on "750901" (*i.e.*, September 1, 1975), and the code of "c19669999" following the record creation date indicates the journal is a continuing resource that began publication in 1966 and has no end date of publication yet. Subfields "a" and "c" of Field 040 shows MUL (the Minnesota Union List) created the original record, and subfield "d" shows "DLC" modified the original record later. According to the *Directory of OCLC Members* (https://www.oclc.org/en/contacts/libraries.html), "DLC" is the OCLC library symbol for the Library of Congress.

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35. Field 022 shows the ISSN of the journal. Field 030 shows the CODEN for this journal. Field 245 shows the title and subtitle, and Fields 246 show two variant titles are included to help users discover this journal. Field 260 shows the publisher information. Field 362 shows the journal began in September 1966, and Field 310 shows the publication frequency has been "Monthly" since 1991. Fields 710 show the two issuing bodies are included in the MARC record to help users discover this journal.

36. The subjects of this journal are represented in Field 050 by a Library of Congress Classification (LCC) number of "TK7871.85" that represents general works on "Semiconductors" (source: Library of Congress Classification, Schedule T, at https://www.loc.gov/aba/publications/FreeLCC/LCC_T2019TEXT.pdf). Subjects are also represented in Fields 650 by three Library of Congress subject headings with "Semiconductors," "Integrated circuits," and "Solid state electronics" as the main topics, each followed by "Periodicals" as a form subheading encoded in subfield "v" ("|v") to indicate the main topics are treated in a journal. These subject representations enable users to conduct subject searches to discover the journal that contains *Magoon*.

37. This MARC record (**Ex. 1006B**) shows that *IEEE Journal of Solid-State Circuits* is a long-running journal and the MARC record makes this journal discoverable. The date stamp of "JAN 9 2003" on **Ex. 1006A** informs my opinion

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that this MARC record was discoverable in the online catalog of the Library of Congress by at least by that date. This means that by January 9, 2003, interested users would be able to discover this journal by its ISSN, CODEN, title, variant titles, and two issuing bodies of the journal. They would also be able to conduct subject searches to discover this journal.

38. The "JAN 9 2003" date stamp on **Ex. 1006A** shows the Library of Congress received the issue containing *Magoon* on January 9, 2003. As discussed above, a customary library practice is to place a newly received journal issue through the serial check-in process to document its receipt, and the new issue is usually processed promptly to make it publicly accessible, usually within a week after serial check-in is completed. It is therefore my opinion that the issue containing *Magoon* became publicly accessible at the Library of Congress by January 16, 2003.

39. As evidence that the Library of Congress had an online catalog in operation in 2003 when the library received the journal issue containing *Magoon*, I obtained a profile of the library at https://librarytechnology.org/library/2263 from libraries.org, a directory of libraries throughout the world. I personally located, identified, and obtained this profile. This is the type of record experts in my field would reasonably rely upon when forming their opinions. This profile is presented as **Ex. 1006C** in this declaration.

40. The Technology Profile on page 2 of **Ex. 1006C** shows the Library of

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Congress began using Voyager as their online catalog in 1998, and changed to Folio – EBSCO Information in 2023. These dates mean that in 2003 interested users were able to use the Voyager system to search for the journal containing *Magoon* and access this article at the Library of Congress.

C. Copyright Record

41. **Ex. 1006D** is a true and correct copy of the copyright registration record for vol. 37 of *IEEE Journal of Solid-State Circuits* that contains *Magoon*. I personally located, identified, and obtained this record from the public catalog of the US Copyright Office. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

42. The title, ISSN, and copyright claimant match the information presented in **Ex. 1006**, **Ex. 1006A**, and the records of the Library of Congress (**Ex. 1006B**), confirming this record represents the journal that contains *Magoon.* The "Issues Registered" field shows vol. 37, no. 12 has an issue date of "Dec02," and a publication date of "2002-12-02" (*i.e.*, December 2, 2002). These dates align well with the date stamp that shows Library of Congress received the journal issue containing *Magoon* on January 9, 2003.

D. Internet Archive Records

43. To determine the public availability date of *Magoon* on the Internet, I searched Internet Archive for records and found that the webpage for the "Most-Read

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Recent Articles in the 2002 *Journal of Solid-State Circuits*" archived by Internet Archive on April 8, 2003, included *Magoon*, and interested users could follow a link to IEEE Xplore to access this article. It is therefore my opinion that *Magoon* was accessible to JSSC members and subscribers to IEEE Xplore by April 8, 2003. My discovery is discussed below.

44. Internet Archive is a digital library that archives scholarly materials, cultural artifacts, and other web resources on the Internet and provides the public with free access to its collections. I have used the Internet Archive in the past and am familiar with their practice of assigning an extended URL to an archived resource in the format of http://www.archive.org/web/[Year in yyyy][Month in mm][Day in dd][Time code in hh:mm:ss]/[Archived URL] to show the point of time the archived file was captured. Since Internet Archive usually does not archive web resources the moment they appear on the Internet, and a web resource must be available first before it can be archived, the archive date of a file captured by the Internet Archive is typically later than the date when the file first became publicly accessible on the Internet. In other words, the archive date means the archived file was available before, and definitely no later than, the archive date.

45. **Ex. 1006E** is a true and correct copy of the webpage for the "Most-Read Recent Articles in the 2002 *Journal of Solid-State Circuits*." I personally located, identified, and obtained this archived copy from Internet Archive. This is the

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type of record experts in my field would reasonably rely upon when forming their opinions.

46. Page 1 is a screen capture of a Wayback Machine calendar that shows this webpage at http://sscs.org/jssc/hotreads02.htm was archived 20 times between "8 Apr 2003" and "12 Dec 2009" and this particular copy was archived on "APR 08 2003" and available at https://web.archive.org/web/20030408094604/sscs.org/jssc/hotreads02.htm. Pages 2 to 4 are the PDF of this archived copy that informs visitors to this list that the links below "will launch IEEE Xplore and request member authentication." Each entry on the list includes the title, authors, issue date and a link to IEEE Xplore, and *Magoo* is the second article on this list. This archived copy informs my opinion that *Magoon* was accessible to members of the Solid-State Circuits Society no later than April 8, 2003.

47. As evidence that members of the Solid-State Circuits Society (SSC) had free access to JSSC articles in 2003, I located an archived copy of the webpage of "Membership in the Solid-State Circuits Society, 2-Publications." I personally located, identified, and obtained this record Internet Archive. This is the type of record experts in my field would reasonably rely upon when forming their opinions. This record is presented as **Ex. 1006F** in this declaration.

48. **Ex. 1006F** is a screen capture of a Wayback Machine calendar that

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shows the webpage for SSC membership at http://sscs.org/membership/membership2.htm was archived 26 times between "10 Oct 1999" and "4 Jul 2008" and this particular copy was archived on "DEC 19 2002" and available at https://web.archive.org/web/20021219065900/sscs.org/membership/membership2.htm. Pages 2 and 3 are the PDF of this archived copy that explains that three publications are free with SSCS membership, including the "On-line access to the JSSC via IEEE Xplore," CD-ROM of the previous two years of the Journal, and the SSCS Newsletter. In addition, the "Journal of Solid-State Circuits (Print Issues of JSSC is now by subscription)" area on page 3 informs visitors to this webpage that since 2003, the journal "is available free to new IEEE SSCS members only by online access through IEEE Xplore. Print issues are available by a separate subscription."

49. Internet Archive records (**Ex. 1006E** and **Ex. 1006F**) inform my opinion that by April 8, 2003, interested users would be able to discover that *Magoon* was one of the most-read articles in the 2002 issues of the *IEEE Journal of Solid-State Circuits*, and members of the Solid-State Circuits Society could follow the link to IEEE Xplore to access the full text of *Magoon*. Users who subscribed to the print version of this journal would receive their print issue.

E. Usage Records

50. Actual usage of a publication is reflected by other publications that

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make reference to it. I have reviewed citations to *Magoon* on Google Scholar and Semantic Scholar to compile a list of early citations. **Ex. 1006G** presents four citations published in 2003, and shows that the earliest citation appeared in June 2003, supporting my opinion that *Magoon* was publicly accessible at the Library of Congress by January 16, 2003, and became publicly accessible on the Internet by April 8, 2003.

F. Summary of My Opinion on *Magoon*

51. **Ex. 1006** is authentic because it contains no signs to raise suspicion about its authenticity. In addition, this copy has the same content as the copy held by the Library of Congress (**Ex. 1006A**).

52. The MARC record of the Library of Congress (**Ex. 1006B**) shows *IEEE Journal on Solid-State Circuits* is a long-running journal, and the MARC record has made this journal discoverable in the library's catalog. The date stamp on the Library of Congress copy of *Magoon* (**Ex. 1006A**) shows the library received the journal issue containing *Magoon* on January 9, 2003. It is therefore my opinion that *Magoon* became discoverable in the online catalog of the Library of Congress by at least January 9, 2003, and the physical issue would publicly accessible at the Library of Congress by January 16, 2003.

53. The "Most-Read Recent Articles in the 2002 *IEEE Journal on Solid-State Circuits*" archived by Internet Archive on April 8, 2003 (**Ex. 1006E**), shows

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Magoon was on this list and members of the Solid-State Circuits Society could access the full text of *Magoon* via the link to IEEE Xplore on this webpage. It is therefore my opinion that *Magoon* was publicly accessible by April 8, 2003 on the Internet. Citation history shows at least four citations to *Magoon* were published in 2003, and the earliest citations appeared in June 2003 (**Ex. 1006G**).

54. Based on the documents and records I have analyzed, *Magoon* was publicly accessible at the Library of Congress by January 16, 2003, and became discoverable and accessible on the Internet by April 8, 2003. My opinions are supporting by four citations to *Magoon* that were published in June, July, and September of 2003.

IV. Authenticity and Public Availability of *Ngompe* (Ex. 1007)

A. Authentication

55. **Ex. 1007** is a true and correct copy of "Architecture and performance overview of a highly integrated 13/spl times/13 mm Single-Package Radio (SPR) module for dualband EGSM900/GSM1800 applications," ("*Ngompe*"), by Ngompe et al., *IEEE Radio Frequency Integrated Circuits (RFIC) Symposium, 2003*, pp. 387-390, that I obtained from the Linda Hall Library. When I began researching this article, I searched WorldCat (the free web portal) for records for *Ngompe*, and a WorldCat record (https://search.worldcat.org/title/4799487552) showed that the Linda Hall Library was one of the libraries holding the conference proceedings

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containing *Ngompe*. After verifying the holdings information of the Linda Hall Library, I requested a copy of *Ngompe* from the library's document delivery service. This library copy is presented as **Ex. 1007** in this declaration.

56. Page 1 is internal page 387 that shows the title, authors, and abstract. The top of the page shows an article identifier of "TU1C-2" and the bottom shows *Ngompe* has a "2003" copyright date and IEEE (the Institute of Electrical and Electronics Engineers) holds the copyright. This page also shows this article appears in "2003 IEEE Radio Frequency Integrated Circuits Symposium" whose International Standard Book Number (ISBN) is "0-7803-7694-3." **Ex. 1007** shows *Ngompe* has a total of four pages in eight sections and includes seven figures and three references.

57. Page 5 is the cover of the *2003 IEEE Radio Frequency Integrated Circuits (RFIC) Symposium* that shows the conference name, location, and dates and indicates this work is a "Digest of Papers" from the Symposium and Tina Quach is the digest editor. It also shows the IEEE Microwave Theory and Techniques Society, the IEEE Electron Device Society, and the IEEE Solid States Circuits Society sponsored the Symposium, and the IEEE catalog number for this work is "03CH37410." Page 6 is the title page that shows the name of the Symposium, the title of this work, the editor, three sponsors, and the IEEE catalog number. Page 7 is the copyright page that shows this work has a "2003" copyright date and IEEE holds

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the copyright. The copyright page also shows the IEEE catalog number, ISBN, ISSN, and the ISBN for the CD ROM version of this work. The top of the page shows a hand-written call number of "TK6541 .I444 1003." Page 8 is the symposium schedule and the left side of this page shows a date notation of "7-1-03" that indicates this conference proceedings containing *Ngompe* was added to the Linda Hall Library collections on that date. The knowledge of this date annotation practice is based on my personal knowledge and experience with the Linda Hall Library and their collections. The bottom of this page shows a stamp of "Linda Hall Library Kansas City, Mo." The table of contents of the Technical Program begins on page 9 (internal page xv). Pages 10 to 12 are select pages from the table of contents, and page 12 (internal page xxxii) shows the papers presented at "Session TU1C: Transceivers for Cellular 2G and 3G Systems," including *Ngompe*, which is identified as "TU1C-2" and scheduled for presentation at 1:40 p.m. This page also shows *Ngompe* begins on page 387 of the digest.

58. **Ex. 1007A** is a true and correct copy of *Ngompe* obtained from IEEE by counsel. Page 1 is internal page 387 that shows the title, authors, and abstract. The top of the page shows an article identifier of "TU1C-2" and the bottom shows *Ngompe* has a "2003" copyright date and IEEE (the Institute of Electrical and Electronics Engineers) holds the copyright. This page also shows this article appears in "2003 IEEE Radio Frequency Integrated Circuits Symposium" whose

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International Standard Book Number (ISBN) is "0-7803-7694-3." **Ex. 1007A** shows *Ngompe* has a total of four pages in eight sections and includes seven figures and three references. I have closely compared the Linda Hall Library copy (**Ex. 1007)** with this IEEE copy (**Ex. 1007A**) and found them to have the same content for *Ngompe*.

59. **Ex. 1007** is in a condition that creates no suspicion about its authenticity. Specifically, this copy is not missing any intermediate pages, and there are no visible alterations to the document. Furthermore, the library copy of *Ngompe* (**Ex. 1007**) has the same content as the publisher's copy (**Ex. 1007A)**. Based on my review and analysis, it is my opinion that **Ex. 1007** is authentic.

B. IEEE Metadata Record

60. To determine the public availability date of *Ngompe* on the Internet, I obtained the metadata record for this article from IEEE Xplore, the digital library of IEEE. **Ex. 1007B** is a true and correct copy of the metadata record for *Ngompe*. I personally located, identified, and obtained this record. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

61. Page 1 shows the title, authors, and publisher of *Ngompe*, and indicates this article has two citations and 172 full text views in IEEE Xplore. The record shows the abstract, where the paper was published, date and location of the conference, the article doi, and the "Date Added to IEEE Xplore" field shows "28 July 2003" as the

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date when the metadata record was added to IEEE Xplore and became discoverable in this system. Since the general public can search IEEE Xplore freely, it is my opinion that, as of July 28, 2003, interested users would be able to discover the metadata record for *Ngompe* in IEEE Xplore, and use it to access this article. Users affiliated with an institutional subscriber to IEEE Xplore would be able to access this article for free, and users without subscriptions could purchase the article from IEEE online.

62. As evidence that IEEE Xplore was publicly accessible when the metadata record for *Ngompe* was added to this system in July 2003, I obtained a copy of the IEEE Xplore website archived by Internet Archive. I personally located, identified, and obtained this archived copy. This the type of record experts in my field would reasonably rely upon when forming their opinions. This Internet Archive copy is presented as **Ex. 1007C** in this declaration.

63. Internet Archive is a digital library that archives scholarly materials, cultural artifacts, and other web resources on the Internet and provides the public with free access to its collections. I have used the Internet Archive in the past and am familiar with their practice of assigning an extended URL to an archived resource in the format of http://www.archive.org/web/[Year in yyyy][Month in mm][Day in dd][Time code in hh:mm:ss]/[Archived URL] to show the point of time the archived file was captured. Since Internet Archive usually does not archive web resources the

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moment they appear on the Internet, and a web resource must be available first before it can be archived, the archive date of a file captured by the Internet Archive is typically later than the date when the file first became publicly accessible. In other words, the archive date means the archived file was typically available before, and definitely no later than, the archive date.

64. Page 1 of **Ex. 1007C** is a screen capture of a Wayback Machine calendar that shows the IEEE Xplore website (http://ieeexplore.ieee.org/lpdocs/epic03/) was archived 115 times between "7 Apr 2000" and "2 Dec 2024" and this particular copy was archived on "FEB 07 2001" and available at https://web.archive.org/web/20010207003457/http://ieeexplore.ieee.org/lpdocs/epic03/. Page 2 is the PDF of this archived copy that explains that "IEEE Xplore provides full-text access to IEEE transactions, journals, magazines and conference proceedings published since 1988 and all current IEEE standards." Under "Free to All," the archived copy shows the general public can have "[a]ccess to tables of contents of IEEE transactions, journals, magazines, conference proceedings and standards." The archived copy also explains that users affiliated with corporate, government and university subscribers "can search and access abstract/citation records, and full-text documents of the IEEE online publications to which" the institutions subscribe.

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65. **Ex. 1007C** informs my opinion that IEEE Xplore was available to the general public for searching since at least 2001, and individual subscribers and users affiliated with institutional subscribers have been able to access full text of documents freely. Non-subscribers have been able to purchase the full text of documents after they have identified abstract/citation records in IEEE Xplore.

C. Copyright Registration Record

66. **Ex. 1007D** is a true and correct copy of the copyright registration record for *2003 IEEE Radio Frequency Integrated Circuits (RFIC) Symposium : Digest of Papers* that contains *Ngompe*. I personally located, identified, and obtained this record from the public catalog of the US Copyright Office. The title, editor, imprint, and copyright claimant match the information presented in **Ex. 1007**, confirming this record represents the conference proceedings that contains *Ngompe*. The "Date of Publication" field shows this conference proceedings was published on "2003-06-08" (*i.e.*, June 8, 2003), and the "Registration Number / Date" field shows this work was registered with the US Copyright Office on "2005-03-15" (*i.e.*, March 15, 2005), with a registration number of "TX0006119186."

D. Records of Linda Hall Library

67. To determine the public availability date of *Ngompe* at libraries, I obtained records for *2003 IEEE Radio Frequency Integrated Circuits (RFIC) Symposium : Digest of Papers* ("*RFIC Digest*") that contains *Ngompe* from the online

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catalog of the Linda Hall Library. **Ex. 1007E** is a true and correct copy of the bibliographic and MARC records for *RFIC Digest*. I personally located, identified, and obtained these records. They are the type of records experts in my field would reasonably rely upon when forming their opinions.

68. Pages 1 to 4 of **Ex. 1007E** are the bibliographic record that shows the title of this publication and indicates this work is available at "Linda Hall Library Books – 2nd Floor (TK6541 .I444 2003)." The record details on page 3 shows the title, other titles, conference name, editor, sponsors, subjects, identifiers, publisher, creation date, format, and general notes. The title, conference name, editor, sponsors, ISBN, and IEEE catalog number match the information presented in **Ex. 1007**, confirming this record represents *RFIC Digest*.

69. Page 5 is a copy of the MARC record. The first six digits of Field 008 show the MARC record was created on "030630" (*i.e.*, June 30, 2003), and the "s2003" code following the record creation date indicates this work has a single publication date of 2003. Field 005 is a machine-generated field that records the last time the Linda Hall Library modified their MARC record, and it shows the last record modification date was "20030701063700" (*i.e.*, July 1, 2003, at 6 a.m. and 37 minutes). Subfields "a" and "c" of Field 040 shows "NAT" created the original record and entered it into the OCLC WorldCat database, and subfield "d" shows "LHL" modified the original record later. According to the *Directory of OCLC Members*

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(https://www.oclc.org/en/contacts/libraries.html), "NAT" is the OCLC library symbol for the Langley Research Center of NASA, and "LHL" is the OCLC library symbol for the Linda Hall Library. The "7-01-03" date annotation in **Ex. 1007** shows *RFIC Digest* was added to the Linda Hall Library collections on July 1, 2003. This date stamp and the data from Fields 008, 005, and 040 of the MARC record (**Ex. 1007E**) inform my opinion that the Linda Hall Library used the NASA record to create their copy cataloging record and completed it on July 1, 2003, making *RFIC Digest* discoverable in their online catalog from that date on. A customary library practice is to process a newly cataloged work promptly for public access, usually within a week after the cataloging work is completed. It is therefore my opinion that *RFIC Digest* that contains *Ngompe* became publicly discoverable at the Linda Hall Library on July 1, 2003. After processing, the physical copy would become publicly accessible by July 8, 2003.

70. Fields 020 of the MARC record shows the 10-digit and 13-digit ISBNs, Field 111 shows the conference name is used as the corporate author of this work, Field 245 shows the title, subtitles, editor, and sponsors, and Fields 246 show two variant titles are included to help users discover *RFIC Digest*. Field 260 shows the publisher information, and Field 300 shows the physical details. Field 500 shows the IEEE catalog number for this work ("03CH37410"), and Field 504 shows this work includes bibliographical references and index. Field 700 shows the editor is included.

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Fields 710 show the three sponsors are also included to help the discovery of this work.

71. The subjects of *RFIC Digest* are represented in Field 090 by a Library of Congress Classification (LCC) number of "TK6541" that represents congresses on "Radio" (source: Library of Congress Classification, Schedule T, at https://www.loc.gov/aba/publications/FreeLCC/LCC_T2019TEXT.pdf), and in Fields 650 by four Library of Congress subject headings, with "Radio frequency," "Integrated circuits," "Wireless communication systems," and "Silicon" as the main headings, each followed by "Congresses" as a form subheading encoded in subfield "v" ("|v") to indicate the main topics are treated at a conference. These subject representations enable users to conduct subject searches to discover *RFIC Digest* that contains *Ngompe*.

72. This MARC record (**Ex. 1007E**) shows that the Linda Hall Library created a copy cataloging record for *RFIC Digest* that contains *Ngompe* on July 1, 2003. As of that date, interested users could search for this work by the ISBNs, conference name, title, variant titles, digest editor, and three conference sponsors. They could also conduct subject searches to discover this work.

73. As evidence that the Linda Hall Library had an online catalog in operation in 2003 when the library added *RFIC Digest* that contains *Ngompe* to their collections, I obtained a profile of the library at

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https://librarytechnology.org/library/2294 from libraries.org, a directory of libraries throughout the world. I personally located, identified, and obtained this profile. This is the type of record experts in my field would reasonably rely upon when forming their opinions. This profile is presented as **Ex. 1007F** in this declaration.

74. The Technology Profile on page 2 of **Ex. 1007F** shows the Linda Hall Library began using Horizon as their online catalog in 1994, and changed to Voyager in 2010. These dates mean that in 2003 interested users were able to use the Horizon system to search for *RFIC Digest* that contains *Ngompe* and access this article at the Linda Hall Library.

E. RFIC Symposium Registration Form

75. As evidence that *RFIC Digest* that contains *Ngompe* was publicly available in 2003, I obtained the registration form for the 2003 RFIC Symposium from Internet Archive. I personally located, identified, and obtained this record. This is the type of record experts in my field would reasonably rely upon when forming their opinions.

76. **Ex. 1007G** is a true and correct copy the "Advance Conference Registration" form. Page 1 is a screen capture of a Wayback Machine calendar that shows this file was captured four times between "11 June 2003" and "20 Nov 2008" and this particular copy was archived on "JUN 11 2003" and available at https://web.archive.org/web/20030611144832/http://www.ims2003.org/attendee/reg

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istration_form.pdf. Page 2 is the PDF of the archived copy that shows the RFIC Symposium registration includes "Exhibits, RFIC Sessions & Reception, Digest & CD ROM." **Ex. 1007G** informs my opinion that by June 11, 2003, interested users would have discovered the registration form and learned that the registration for the RFIC Symposium would include a copy of the digest and a CD ROM. This means that at the time of the RFIC Symposium in June 2003, symposium attendees would receive their copies of the digest that contains *Ngompe*.

F. Summary of My Opinion on *Ngompe*

77. The copy of *Ngompe* from the Linda Hall Library (**Ex. 1007**) is authentic because it contains no signs to raise suspicion about its authenticity. In addition, this copy has the same content as the publisher copy (**Ex. 1007A**).

78. The IEEE metadata record for *Ngompe* (**Ex. 1007B**) shows the record was added to IEEE Xplore on July 28, 2003, which means that, as of that date, the general public would be able to discover this record in IEEE Xplore. After they have discovered the metadata record for *Ngompe*, interested users affiliated with institutional subscribers to IEEE Xplore would be able to access the full text of *Ngompe* for free. Users without subscriptions would be able to purchase the article from IEEE online.

79. The copyright registration record for *RFIC Digest* (**Ex. 1007D**) shows this work was published on June 8, 2003. The MARC record for this work from the

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Linda Hall Library (**Ex. 1007E**) shows the library completed their copy cataloging record for *RFIC Digest* on July 1, 2003, and added this work to their collections. Interested users could conduct subject searches to discover *RFIC Digest*. They could also discover this work by its ISBNs, conference name, title, variant titles, editor, and sponsors of the conference.

80. The Advance Registration Form for the 2003 RFIC Symposium archived by Internet Archive on June 11, 2003 (**Ex. 1007G**) shows symposium registrants would receive a digest, meaning attendees of the 2003 RFIC Symposium would have access to *RFIC Digest* at the event.

81. Based on the documents and records I have analyzed, *RFIC Digest* that contains *Ngompe* was publicly discoverable in the online catalog of the Linda Hall Library from July 1, 2003 on. The physical copy, after processing, would become publicly accessible at this library by July 8, 2003. The digest was included in the registration for the 2003 RFIC Symposium, meaning at the time of the Symposium in June 2003, attendees would have access to the digest that includes *Ngompe*. IEEE metadata shows *Ngompe* became discoverable in IEEE Xplore from July 28, 2003 on. After the metadata record for *Ngompe* was discovered, interested users affiliated with institutional subscribers to IEEE Xplore would be able to access the full text of this article freely, and users without subscriptions could purchase the article from IEEE online.

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V. Conclusion

82. In signing this Declaration, I recognize that the Declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross-examination in this proceeding. If required, I will appear for cross-examination at the appropriate time.

83. I hereby declare that all statements made herein of my own knowledge are true and that all statements are made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. §1035.

Dated: 3-13-2025

Respectfully submitted,

Ingrid Hsieh-Yee

Ingrid Hsieh-Yee, Ph.D.
Annapolis, Maryland

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APPENDIX A

Ingrid Hsieh-Yee

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Education

Ph.D. 1990. Library and Information Studies, University of Wisconsin-Madison
Minors: Sociology and Psychology

M.A. 1984. Library and Information Studies, University of Wisconsin-Madison.

M.A. 1983. Comparative Literature, University of Wisconsin-Madison.

B.A. 1980. Foreign Languages and Literature, National Taiwan University.

Work Experience

Professor, School/Dept. of Library and Information Science, Catholic University of America, 1990-2022 (Assistant Professor, 1990-1996; Associate Professor, 1997-2004; Professor 2004-2022; Professor Emerita 2022)

Co-Chair, Dept. of Library and Information Science, Catholic University of America, June 2015-August 2016.

Acting Dean, School of Library and Information Science, Catholic University of America, January 2010-June 2012.

Cataloger, Dept. of Legislative Reference Library, Annapolis, Maryland, 1989-1990.

Lecturer, School of Library and Information Studies, University of Wisconsin-Madison, 1988.

Teaching Assistant, School of Library and Information Studies, University of Wisconsin-Madison, 1986-1988.

Cataloger, Health Sciences Library, University of Wisconsin-Madison, 1984-1986.

Areas of Teaching and Research Interests

Information Organization and Access; Metadata; Cataloging & Classification; Information Architecture; Information Retrieval; Digital Collections; Social Media; Scholarly

Communication; Information Behavior; Health Informatics; Human Computer Interaction; Usability Studies

Grants & Honors

Cultural Heritage Information Management Project. IMLS grant. Amount: $498,741. Period: Aug. 2012 to July 2015. Co-PI with Dr. Youngok Choi.

D.C. Health Information Technology (HIT4): Building Capacity & Providing Access in Our Nation's Capital. Dept. of Labor H2B Training Grant. Grant amount: $4,175,500. Grant period: Nov. 2011 to Dec. 2015. Partner with the Metropolitan School of Professional Studies of the Catholic University of America, Children's National Medical Center, D.C. Department of Employment Services, Holy Cross Hospital, Howard University, Center for Urban Progress, Providence Hospital, and Sibley Memorial Hospital.

Capital Health Careers Project. Department of Labor Healthcare Sector and Other High Growth and Emerging Industries Grant. Grant amount: $4,953,999. Grant period: March 2010 – February 2013. Awarded to a group of healthcare organizations and educational institutions in Washington, D.C. Providence Health Foundation of Providence Hospital (Lead institution). Part of the grant supported the development of a Master's degree program in Information Technology with a concentration in Health Information Technology offered by the School of Library and Information Science.

The Washington D.C. School Librarians Project. IMLS grant. Grant amount: $412,660. Grant period: Aug. 2007 – June 2011. The School partnered with the District of Columbia Public Schools (DCPS) and the District of Columbia Library Association to educate and mentor school media specialists for the DCPS system. PI, Jan. 2010 to June 2011.

SIG Member of the Year, American Society for Information Science and Technology (2009).

Most Outstanding Paper of *OCLC Systems & Services* (2001).

ALISE Research Grant (2001).

Most Outstanding Paper of *OCLC Systems & Services* (2000).

Research Grant from ERIC (1999-2000).

Best Research Paper Award; Association for Library and Information Science Education (1998).

Research Grants, Catholic University of America. 1991, 1992, 1993, 1996, 1998, 1999, 2004, 2005, 2006, 2007, 2013-14.

Cooperative Faculty Research Grant, Consortium of Universities in the Washington Metropolitan Area (1993-1994).

Cooperative Research Grant, Council on Library Resources (1993-1994).

Journal of the American Society for Information Science Best Paper Award (1993).

ASIS/ISI Information Science Doctoral Dissertation Scholarship (1989).

HEA Title IIB Fellowship (Dept. of Education) (1989)

Chinese-American Librarians Association Scholarship (1987).

Beta Phi Mu (1985).

Vilas Fellowship, University of Wisconsin-Madison. 1984

Publications

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a Digital Teaching Commons to Enhance Metadata Teaching, Learning and Research. *Proceedings of the National Conference of the Association of College and Research Libraries, Baltimore, MD*, pp. 26-31.

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Hsieh-Yee, I. (2006). *Organizing Audiovisual and Electronic Resources for Access: A Cataloging Guide*. 2nd ed. Westport, Conn.: Libraries Unlimited.

NISO A Framework of Guidance for Building Good Digital Collections. 2nd ed. Bethesda, MD: National Information Standards Organization, 2004. Framework Advisory Group: Grace Agnew, Liz Bishoff, Priscilla Caplan (Chair), Rebecca Gunther and Ingrid Hsieh-Yee.

Hsieh-Yee, I. (2004). Cataloging and Metadata Education in North American LIS Programs. *Library Resources & Technical Services,* 48(1): 59-68.

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Hsieh-Yee, I. (1998). Search Tactics of Web Users in Searching for Texts, Graphics, Known Items and Subjects: A Search Simulation Study. *Reference Librarian,* 60: 61-85. (Received the 1997 Best ALISE Research Paper Award.)

Hsieh-Yee, I. (1997). Access to OCLC and Internet Resources: LIS Educators' Views and Teaching Practices. *RQ,* 36: 569-86.

Hsieh-Yee, I. (1997). Teaching Online and CD-ROM Resources: LIS Educators' Views and Practices. *Journal of Education for Library and Information Science,* 38: 14-34.

Hsieh-Yee, I. (1996). The Cataloging Practices of Special Libraries and Their Relationship with OCLC. *Special Libraries,* 87: 10-20.

Hsieh-Yee, I. (1996). Modifying Cataloging Practice and OCLC Infrastructure for Effective Organization of Internet Resources. In *Proceedings of the OCLC Internet Cataloging Colloquium*. [Online]. Available: http://www.oclc.org/oclc/man/colloq/hsieh.htm

Hsieh-Yee, I. (1996). Student Use of Online Catalogs and Other Information Channels. *College & Research Libraries,* 57: 161-175.

Hsieh-Yee, I. (1995). Ten entries in James S. C. Hu (Ed.), *Encyclopedia of Library & Information Science*, 913, 1028-29, 1036, 1037, 1145-46, 1514, 1575, 1763-64, 2216-27, 2378-79. Taipei, Taiwan: Sino-American Publishing. (Topics include "Advanced Technology/Libraries," "Information Ethics," "Instruction on Cataloging and Classification," "Instruction on Reference Services.")

Hsieh-Yee, I. (1993). Effects of Search Experience and Subject Knowledge on Online Search Behavior: Measuring the Search Tactics of Novice and Experienced Searchers. *Journal of the American Society for Information Science,* 44: 161-174. (Received the 1993 Best JASIS Paper Award.)

Works in Progress

Hsieh-Yee, I. Actionable lessons for debunking false information: A comparative analysis of literacy lessons in communication and library and information science

Hsieh-Yee, I. Representing diverse voices and communities in cataloging and indexing: The evolution of controlled vocabularies

Hsieh-Yee, I. Information Organization and Retrieval in Practice (a monograph scheduled for completion and publication in 2023)

Presentations

Bailey, T. & Hsieh-Yee, I. (February 2020). The Phenomena of Sharing Misinformation and the Need for Information Literacy. Presented at the 2020 Bridging the Spectrum Symposium, Washington, D.C., February 14, 2020.

Hsieh-Yee, I. and Fragan-Fly, J. (May 2018) Trends, Design & Strategies for Digital Scholarship Services. Presented at the 2018 Maryland/Delaware Library Association Conference, Cambridge, MD.

Hsieh-Yee, I. (February, 2018) Research Data Management: What It Takes to Succeed. Presented at the 10th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. (February, 2017) *Research Data Management: New Competencies and Opportunities for Information Professionals*. Presented at the 9th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. and Lawton, P. (February, 2017) *Enhancing Catholic Portal Searches with User Terms and LCSH*. Presented at the 9th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. (2016, October) *Visualizing Data for Information*. Presented at the 2016 Virginia Library Association Conference, Hot Springs, VA.

Hsieh-Yee, I. (2016, August) *Religious Materials Toolbox for Archivists: Solutions to Problems Facing the Profession*. Presented at Archives * Records 2016, Atlanta, GA.

Hsieh-Yee, I. and Lawton, P. (2016, March) *Enhancing Retrieval of Catholic Materials with LCSH Knowledge Structure*. Presented at the 2016 Catholic Library Association Conference, San Diego, CA.

Fagan-Fry, J. and Hsieh-Yee, I. (2016, February) *Approaches to Digital Scholarship at Top Universities around the World: Scholarly Publishing in the Digital Age.* Presented at the 8th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee and Fagan-Fry, J. (2016, January) *Innovative Services for Digital Scholarship at Top 100 Research Libraries of the World*. Poster presented at the 2016 Annual Conference of the Association for Library and Information Science Education, Boston, Mass.

Hsieh-Yee, I. and Lawton, P. (2015, June). *Crowdsourcing terms for CRRA portal themes.* Poster presented at the third CRRA symposium and annual meeting, Bringing the created toward the Creator: Liturgical art and design since Vatican II. Catholic Theological Union, Chicago, Illinois.

Hsieh-Yee, I. and Lawton, P. (2015, February). *Crowdsourcing terms for thematic exploration in the Catholic Portal.* Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I., James, R., and Fagan-Fry, J. (2015, February). *Support for digital scholarship at top university libraries of the world*. Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I., Zhang, S., Lin, K., and Cherry, S. (2015, February). *Thus said the end users: Summon experience and support for research workflows*. Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

Yontz, E., Hsieh-Yee, I., & Houston, S. (2015, February). *Healthy Heroes Summer Reading Club: Developing healthy youth at public libraries.* 11th Annual Jean Mills Health Symposium, Greenville, North Carolina.

Yontz, E., Hsieh-Yee, I., and Houston, S. (2015, January). *Healthy youth and libraries: A pilot study.* Association for Library & Information Science Education (ALISE) Annual Conference, Chicago, Illinois.

Hsieh-Yee, I. (2014, May). *Linking CRRA resources to portal themes via authority files*. Presented at the Catholic Research Resources Alliance 2014 Membership Meeting, Marquette, WI.

Hsieh-Yee, I. (2014, April). *Enhancing subject access to CRRA resources*. Presented at the 2014 Catholic Library Association Conference, Pittsburgh, PA.

Hsieh-Yee, I. (2014, January). *Health Information Technology Program: Educational entrepreneurship in action*. Presented at the 2014 annual Conference of the Association for Library and Information Science Education, Philadelphia, PA

Hsieh-Yee, I., Zhang, S., Lin, K., and Cherry, S. (2014, January). *Discovering information through Summon: An analysis of user search strategies and search success*. Paper presented at the 6th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. (2012, December). *National Digital Stewardship Alliance and SLIS at CUA: An Educational Partnership*. Paper presented at Best Practices Exchange: Acquiring, Preserving, and Providing Access to Government Information in the Digital Era, Annapolis, MD

Choi, Y. and Hsieh-Yee, I. (2010, January). *Finding Images in an OPAC: Analysis of User Queries, Subject Headings, and Description Notes*. Paper presented at 2nd Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. and Coogan, J. (2010, January). *Google Scholar vs. Academic Search Premier: What Libraries and Searchers Need to Know*. Paper presented at 2nd Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2009, November). *Information Science Education: An LIS School's Perspective*. Paper presented at Annual Meeting of the American Society for Information Science and Technology, Vancouver, British Columbia, Canada.

Hsieh-Yee, I., Menard, E., Ya-Ning Chen, A., Shu-Jiun Chen, S., Kalfatovic, M. R., Wisser. K. M. (2009, November). *Information Organization in Libraries, Archives and Museums: Converging Practices and Collaboration Opportunities*. Presented at Annual Meeting of the American Society for Information Science and Technology, Vancouver, British Columbia, Canada. (Organizer and moderator of this panel.)

Hsieh-Yee, I. and Coogan, J. (2009, July). *Catching up to Google Scholar: The Retrieval Power of Academic Search Premier and Google Scholar*. Poster presented at American Library Association Conference, Chicago, Illinois.

Hsieh-Yee, I., with the CUA Scholarly Communications Project Team. (2009, January). *Digital Scholarship@CUA: Developing an Institutional Repository for CUA*. Poster presented at 1st Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Wise, M., Cylke, K., and Hsieh-Yee, I. **(**2009, January). *Digital Talking Books: Meeting the Needs of the Blind and the Handicapped*. Paper presented at the Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2009, January). *User Expectations of MERIC*. Presented at the Information Organization Competencies for the 21st Century Discussion Session of the 2009 Conference of the Association for Library and Information Science Education, Denver, Colorado.

Choi, Y., and Hsieh-Yee, I. (2008,November). *Subject Access for Images in an OPAC.* Annual Meeting of the American Society for Information Science and Technology, Columbus, Ohio. (Also co-organized a panel on Retrieving and Using Visual Resources: Challenges and Opportunities for Research and Education.)

Hsieh-Yee, I. (2008, June). *Educating Cataloging Professionals in a Changing Information Environment*. National Taiwan University, Taipei, Taiwan.

Vellucci, S. L., Moen, W.E., Hsieh-Yee, I., Marson, B., and Wisser, K. (2008, January) *Building a Metadata Education and Research Community through MERIC (Metadata Education and Research Information Commons): Demo and Stakeholder Input*. A panel presented at the 2008 Conference of the Association for Library and Information Science Education, Philadelphia, Pennsylvania.

Hsieh-Yee, I., Choi,Y. and Kules, B. (2007, October). *Searching for Books and Images in OPAC: Effects of LCSH, TOC and Subject Domains.* A poster presented at the American Society for Information Science and Technology Annual Meeting, Milwaukee, Wisconsin.

Hsieh-Yee, I. and Coogan, J. (2007, August) *Google Scholar vs. Academic Search Premier: A Comparative Analysis.* Presented to the Faculty and Staff of the University of the District

of Columbia.

Hsieh-Yee, I. and Coogan, J. (2007, June). *Google Scholar vs. Academic Search Premier: A Comparative Analysis*. Presented to the Washington Research Library Consortium Community, Catholic University of America, Washington, D.C.

Hsieh-Yee, I., Choi, Y., and Kules, B.. (2007, June). *What Users Need for Subject Access: Table of Contents or Subject Headings?* A poster presented at the 2007 American Library Association Annual Conference, Washington, D.C., June 2007.

Choi, Y., Hsieh-Yee, I., and Kules, B. (2007, June). *Retrieval Effectiveness of TOC and LCSH.* A paper presented at the Joint Conference on Digital Libraries 2007, Vancouver, Canada.

Vellucci, S. L., Hsieh-Yee, I., and Moen, W.E. (2007, May). *If We Build It, Will They Come? Building a Community of Practice for Metadata Stakeholders.* A poster presented at the Rutgers University Research Day, Bridgeton, New Jersey.

Hsieh-Yee, I. (2007, May). *Federated Searching: User Experience & Perceptions.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I. (2007, May). *Search Performance of Google Scholar and Academic Search Premier.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I. (2007, May) *MERIC: Building a Digital Commons for Metadata Education & Research.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I., and Coogan, J. (2007, March/April). *A Comparative Analysis of Google Scholar and Academic Search Premier.* Poster presented at the Association of College & Research Libraries 13th National Conference, Baltimore, Maryland.

Vellucci, S. L. and Hsieh-Yee, I. (2007, March/April) *They Didn't Teach Me That in Library School! Building a Digital Teaching Commons to Enhance Metadata Teaching, Learning and Research*. On-site presentation and Webcast by Elluminate. A contributed paper presented at the Association of College & Research Libraries 13th National Conference, Baltimore, Maryland. The acceptance rate for contributed paper was 20%. This paper was one of 10 conference papers chosen for live webcast during the conference.

Moen, W., Hsieh-Yee, I. and Vellucci, S.L. (2007, January) *A DSpace Foundation for a Teaching & Research Commons: The Metadata Education and Research Information Commons.* A poster session presented at the Open Repositories Conference 2007, San Antonio, Texas.

Tang, R., Hsieh-Yee, I., and Zhang, S. (2006, November) *User Perception of MetaLib Combined Search*. Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas, Nov. 2006.

Hsieh-Yee, I. (2006, November). *Federated Searching: User Perceptions, System Design, and Library Instructions.* Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas. (Panel organizer, moderator, presenter).

Hsieh-Yee, I. (2006, November). *Building a Digital Teaching Commons to Enhance Teaching and Learning: The MERIC Experience and Challenges.* Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas. (Panel organizer, moderator, presenter)

Hsieh-Yee, I. (2006, September). *Search Performance of Google Scholar and Academic Search Premier.* Paper presented at the ERIC Publishers Meeting, Washington, D.C.

Hsieh-Yee, I., Zhang, S., and Rong Tang, R. (2006, June). *User Perceptions of a Federated Search System*. Poster presented at Joint Conference on Digital Libraries, Chapel Hill, North Carolina.

Hsieh-Yee, I. and Zhang, S. (2006, June). *Preparing Users for Federated Search: Implications of a MetaLib User Perceptions Study.* Paper presented at the 2006 Ex Libris User Groups of North America Conference, Knoxville, Tennessee.

Hsieh-Yee, I. (2006, January). *MERIC Organizations and Navigation*. Paper presented at the 2006 ALISE Annual Conference, San Antonio, Texas.

Hsieh-Yee, I. (2006, January). *Metadata and Cataloging Education: Recommended Competencies.* Paper presented at the 2006 ALISE Annual Conference, San Antonio, Texas.

Hsieh-Yee, I. (2005, November). *Digital Library Evaluation: Progress & Next Steps.* Presentation at the Annual Meeting of the American Society for Information Science & Technology, Charlotte, North Carolina.

Hsieh-Yee, I. (2005, August). *Providing Access to Digital Content: Issues for DL Managers.* Presentation at MDK12 Digital Library Steering Committee Meeting, Columbia, Maryland.

Hsieh-Yee, I. (2005, April). *Enhancing Teaching and Learning: The Role of School Library Media Specialists.* Presentation at Meeting of the Baltimore County Public School System School Media Specialists, Baltimore, Maryland.

Hsieh-Yee, I. (2005, January). *Subject Access and Users: Insights & Inspirations from Marcia J. Bates.* Paper presented at the Historical Perspectives SIG, 2005 Conference of the Association for Library and Information Science Education, Boston, Massachusetts.

Hsieh-Yee, I. (2005, January). *Electronic Resource Management: Practice, Employer Expectations, & CE Interests.* Paper presented at Technical Services Education SIG, 2005 Conference of the Association for Library and Information Science Education, Boston, Massachusetts.

Hsieh-Yee, I. (2004, October). *Library Professionals for the Digital Age: Competencies & Preparation.* Paper presented at Bibliographic Access Management Team meeting, Library of Congress, Washington, D.C.

Hsieh-Yee, I. (2004, January). *Cataloging and metadata expertise for the digital era.* Presented at Preparing 21st Century Cataloging and Metadata Professionals: A Workshop for Educators and Trainers, San Diego and sponsored by ALCTS, ALISE, LC, and OCLC.

Hsieh-Yee, I. (2004, January). *Educating catalogers for the digital era.* Paper presented at the Technical Services SIG, 2004 Conference of the Association for Library and Information Science Education, San Diego.

Hsieh-Yee, I. (2003, July). *Cataloging Education for the 21st Century.* A presentation at the Library of Congress, Washington, D.C.

Hsieh-Yee, I. (2002, January) *Metadata Education and Research Priorities: A Delphi Study of Metadata Experts.* Presentation at the 2002 Conference of the Association for Library and Information Science Education, New Orleans.

Hsieh-Yee, I. (2001, November). *A Delphi Study of Metadata: Preliminary Findings.* Poster session at the 2001 Annual Meeting of the American Society for Information Science & Technology, Washington, D.C.

Hsieh-Yee, I. (2001, June). *Resources on Asian American Children: Analysis of Retrieval by Search Engines and WorldCat.* Presentation at the National Conference on Asian Pacific American Librarians, San Francisco.

Hsieh-Yee, I. (2001, January). *Delphi Study on Metadata: Project Design.* Presentation at Research Awards Session, Association for Library & Information Science Education, Washington, D.C.

Hsieh-Yee, I. (2000, May). *Web Search Behavior Research: Progress and Implications.* Presentation at the Symposium on Evaluating Library and Information Science Research, University of Wisconsin-Madison, Madison, Wisconsin.

Hsieh-Yee, I. (2000, March). *ERIC User Services: Evaluation in a Decentralized Environment.* Presentation at the National ERIC Joint Directors/Technical Meeting, Arlington, Virginia.

Hsieh-Yee, I. (2000, January). *Enhancing Learning with Web Technology.* Presentation at Faculty Conversations, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2000, January). *From Surrogates to Objects: CUA's Approaches to Organizing Electronic Resources.* Paper presentation at the Annual Conference of the Association for Library and Information Science Education, San Antonio, Texas.

Yee, P., and Hsieh-Yee, I. (1997, November). *Individual Differences in Search Behavior on the WWW.* A poster session presented at the 38th Annual Meeting of the Psychonomic Society, Philadelphia, Pennsylvania.

Hsieh-Yee, I. (1997, April). *Research + Marketing + Preparation = Job!* Presented at the "Workshop on Resume and Interview Techniques," Special Libraries Association, Student Chapter, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (1997, February). *Creating CyberCatalogers: Education and Training.* Presentation at ALA's Midwinter Meeting, Washington, D.C.

Hsieh-Yee, I. (1997, February). *Search Tactics of Web Users in Searching for Texts, Graphics, Known Items and Subjects: A Search Simulation Study.* Presented at the Conference of the Association for Library and Information Science Education, Washington, D.C.

Hsieh-Yee, Ingrid. "Beginning Your Special Library/Information Center Career." Presented at SLA's "Career Day," Jan. 11, 1997, Catholic University of America.

Hsieh-Yee, I. (1996, September). *The Roles of Library and Information Scientists in Managing Electronic Information.* Presentation at Hamilton College, Clinton, New York.

Hsieh-Yee, I. (1996, May). *The Future of Cataloging as a Profession.* Presented at "The Cataloging Forum, Library of Congress, Washington, D.C.

Hsieh-Yee, I. (1994, October). *The Impact of the Internet on OPACs.* Presented at the Third Workshop on User Interfaces for OPACs, Library of Congress, Washington, D.C.

Reports

Hsieh-Yee, I., with Knowledge Management Competencies and Performance Action Group of the Federal Knowledge Management Initiative. "From Knowledge Management Competencies to Improved Organizational Performance." April 9, 2009.

Hsieh-Yee, I., with Knowledge Practices Action Group of the Federal Knowledge Management Initiative. "KM Practice in Government Agencies: Findings and Recommendations." April 9, 2009.

Hsieh-Yee, I. "Delphi Study on Metadata." 2001. Three quarterly reports submitted to the Association for Library and Information Science Education.

Hsieh-Yee, I. "College Students' Information Channels: Patterns of Use and Possible Factors in Channel Selection." 1995. Submitted to the Catholic University of America.

Hsieh-Yee, I. "The Information-Seeking Patterns of Scholars and Their Use of an Online Information System." 1994. Submitted to the Council on Library Resources.

Book Reviews

Review of *The Measurement and Evaluation of Library Services*, by Sharon L. Baker and F. Wilfrid Lancaster. *Information Processing and Management* 30 (1994): 450-52.

Review of *Subject Access to Films and Videos, by Sheila S. Intner and William E. Studwell; and Cataloging Unpublished Nonprint Materials*, by Verna Urbanski with Bao Chu Chang and Bernard L. Karon. *Information Processing and Management* 30 (1994): 449-50.

Review of *Automated Information Retrieval in Libraries: A Management Handbook*, by Vicki Anders. *Journal of Library and Information Science* 19 (1993): 98-100.

Review of *Full Text Databases*, by Carol Tenopir and Jung Soon Ro. *Information Processing and Management* 28 (1992): 667-68.

Review of *Descriptive Cataloging for the AACR2R And USMARC: A How-to-Do It Workbook*, by Larry Millsap and Terry Ellen Ferl. *Information Processing and Management* 28 (1992): 809-11.

Review of *MARC Manual: Understanding and Using MARC Records*, by Deborah J. Byrne. *Information Processing and Management* 28 (1992): 537-38.

Service

Professional Associations and Societies

- Library of Congress. RDA Training Program for the Profession. Co-authored with Tim Carlton. 2013-2014.
- 2014 Digital Preservation Outreach & Education Survey. Contributed to the design of the survey, 2014.
- National Digital Stewardship Alliance. Outreach Committee. 2011-2014.
- National Digital Stewardship Residency Program. Advisory Group, 2012-2013.
- FEDLINK Health Information Technology Advisory Council, 2011-2015.

- 2012 Joint Conference on Digital Libraries. Program Planning Committee, Pre-Conference Proposals Review Committee, 2012
- Catholic Research Resources Alliance. Five-Year Strategic Plan Task Force, 2011-2012
- Institute of Museum and Library Services. Grant reviewer. 2004, 2005, 2010.

- Association for Library and Information Science Education.
  * ALISE Bodan Wynar Research Paper Award Committee, 2015, 2016, 2017
  * ALISE Eugene Garfield Dissertation Award Competition, Jury, 2013, 2014
  * ALISE Research Grant Competition Committee. Chair, 2012
  * Pratt-Severn Faculty Innovation Award. Chair, 2009, 2010
  * ALISE Doctoral Poster Jury, 2012
  * "Information Organization Competencies for the 21st Century" Discussion session leader. 2009 Conference of the Association for Library and Information Science Education.
  * Assisted Technical Services SIG Convener in organizing a program, ""Building a Metadata Education and Research Community through MERIC (Metadata Education and Research Information Commons): Demo and Stakeholder Input" for the 2008 ALISE conference.
  * Association for Library Collections and Technical Services/Association for Library and Information Science Education (ALCTS/ALISE) Metadata Education and Research Information Center (MERIC) Advisory Board, Co-Chair (with Sherry Vellucci), 2005-2007. Chair, 2008-2009 (leading the effort to build MERIC, a repository and collaborative space for metadata educators, practitioners, and researchers)
  * Technical Services SIG, Convener, 2004-2005. Organized a program on "Electronic Resources Management: Current Practices, Employer Expectations, and Teaching Strategies" for the 2005 conference in Boston, Massachusetts.
  * Technical Services SIG, Convener, 2003-2004. Organized a program on "Organizing Information with Metadata: Desired Competencies and Teaching Innovations" for the 2004 conference.
  * Technical Services SIG, Convener, 1999-2000. Organized a program on "Teaching the Organization of Electronic Resources" for the 2000 conference.
  * Curriculum SIG, Co-convener (with Sibyl Moses), 1996-97. Organized a program on "Government Information Policy" for the 1997 conference.

- American Society for Information Science & Technology.
  * Reviewer, Conference program panel submissions and poster submissions, 2005, 2006, 2007, 2009, 2011, 2012, 2013, 2014, 2015, 2016, 2017
  * Nomination Committee, 2009-2011
  * Information Science Education Special Interest Group. American Society for Information Science and Technology. Chair-Elect, 2007-2008. Chair 2008-2009.
  * Committee on Information Science Education. 1999-2006.
  * Committee on Information Science Education. Organizing Committee for an orientation program for students at ASIS annual meetings, 1999-2001
  * Committee on Information Science Education. Sub-committee on Student Welfare (focusing on issues related to master's education), 1998-2001

* SIG ED. Organizing Committee for the "Seminar on Research and Career Development" for junior researchers. 1995-96 (chair), 1997-2001
* ISI Doctoral Dissertation Proposal Scholarship Jury, 1997; 2001, 2002
* Pratt-Severn Best Student Research Paper Award Jury. Chair. 1997
* 1998 Midyear Meeting (referee of contributed papers), 1997
* Organizer and moderator of the ASIS Doctoral Forum and the Doctoral Research Seminar 1994-1995
* SIG Human Computer Interaction. Chair-Elect, Chair, 1993-1995
* Doctoral Forum Award Jury, 1995
* Best Student Paper Award Jury, 1995

- American Library Association.
  * Committee on Accreditation, External Review Panelist, 2009- (site visiting team 2013-2014; site visiting team 2016-2017)
  * Association for Library Collections and Technical Services Task Force on Competencies and Education for a Career in Cataloging, member, 2008-2009
  * Facilitator for "What They Don't Teach in Library School: Competencies, Education and Employer Expectations for a Career in Cataloging," an Association for Library Collections and Technical Services Preconference, June 22, 2007 in Washington, D.C. Also a local liaison for bringing this program to the Catholic University of America.
  * Facilitator for a discussion on "Effect of Electronic Resources on Technical Services" at ALA's Midwinter Meeting held in Feb. 1997 in Washington, D.C.
  * International Relations Committee, Subcommittee Task Force for IFLA and China, 1994-1997

- Virginia Association of School Librarians. Scholarships and Awards Committee. 2010-2012

- Federal Knowledge Management Initiative, Knowledge Management Practices Action Group. Member. 2009 (leading the effort to build a knowledge management repository)
- Federal Knowledge Management Initiative, Knowledge Management Competencies & Learning Action Group. Member. 2009 (developing an action plan for helping government knowledge workers and government agencies to develop knowledge management competencies)
- National Center for Education Statistics. Technical Review Panel. 2008.
- External evaluator for a case of promotion to full professorship. University of Tennessee. 2008.
- National Information Standards Organization (NISO). Advisory Board, Revision of "IMLS Framework of Guidance for Building Good Digital Collections," 2004, 2007.
- Library of Congress, Bibliographic Control of Web Resources: A Library of Congress Action Plan. Principal Investigator of Action Item 5.1, focusing on cataloging and metadata education for students and new librarians, 2002-2003. (worked with the Association for Library Collections and Technical Services, Education Task Force)

- Chinese American Librarians Association
  * Chinese American Librarians Association Outstanding Library Leadership Award in Memory of Dr. Margaret Chang Fung, Award Committee, 2016-2017
  * Achievement Award Jury, 2000-2001
  * CALA Goal 2000 Task Force, 1997
  * Scholarship Committee, 1995, 1996-1997 (chair)
  * Board of Directors, 1994-1997
  * Publication Committee, 1993-1995
  * International Relations Committee, 1993-1996

- Sailor[SM] Assessment Advisory Group (An impact study of Sailor, Maryland's Public Information Network), 1995

- Editorial boards
  Journal of Library & Information Science. Editorial Board, 2012-
  Chinese American Librarians Association, *Occasional Papers Series*. Editorial Board, 2009-2016.
  Library Quarterly. Editorial Board, 2003-2008
  Bulletin of the Medical Library Association, 1994-97
  Newsletter editor for the Chinese American Librarians Association, 1989-92

- Referee for the following journals
  Information Processing and Management
  Journal of Digital Information
  Journal of Education for Library and Information Science
  Journal of Information Science
  Journal of Library & Information Science
  Journal of Library Metadata
  Journal of the American Society for Information Science & Technology
  Library and Information Science Research
  Library Quarterly

- Expert reviewer, "Digital Library" course, Evaluation module, University of North Carolina, Chapel Hill, 2007-2008.
- Expert reviewer, "Information Organization" course, University of Michigan, Ann Arbor. 2007.

Catholic University of America

- Academic Senate Committee on Appointments and Promotions, 2005-2008
- Academic Senate Committee on Committees and Rules, 2009-2012, 2019-2022
- Academic Senate representative (for School of Arts & Sciences), 2017-2020

- Academic Senate representative (for School of Library & Information Science) 2003-2012
- Academic Senate Library Committee, Interim Chair (2007), Member, 2008-2012
- Academic Senate Committee on Computing, 1995-2003

- President's Administrative Council, 2010-2012
- Deans' Council, 2010-2012
- Academic Leadership Group, 2010-2012
- Graduate Board, 2010-2012

- School of Arts & Sciences, Committee on Appointments and Promotions, 2015-2019
- School of Arts & Sciences, Academic Council, 2015-2016.
- School of Arts & Sciences, Ordinary Professor Group, 2013-
- Doctoral Dissertation Defense Committee, Chair, Dept. of Psychology, 2016, 2017, 2018, 2019, 2020, 2021, 2022
- Doctoral Dissertation Defense Committee, Chair, Dept. of Education, 2014, 2015, 2017, 2018, 2019
- Doctoral Dissertation Defense Committee, Chair, National Catholic School of Social Services, 2019, 2020, 2021
- Doctoral Dissertation Defense Committee, Chair, School of Nursing, 2006, 2008
- CUA Scholarly Communication Project Team, Member (2007), Chair, 2008-2009
- Dean Search Committee, 1992-1994, 1998-1999, 2002-2003, 2006-2007
- Fulbright Review Panel, 2006
- CUA Service Learning Advisory Board, 2001-2002
- CUA Faculty Conversations on Enhancing Teaching and Learning through Technology, Planning Group, 1999-2001
- CUA Initiative on Technology and Teaching, 1998-2001

Dept. of Library and Information Science

- Admissions Committee, 2007-2009, Chair 2010-2012, Member 2013-2015, Member 2018-2022
- Appointments and Promotions Committee, 1991-2022
- Student advisement, 1990-2022
- 4+1 Bachelor to Master program, Program Advisor, 2014-2022
- LIS Minor, Advisor, 2017-2022
- Curriculum Committee, 2020-21 (Member), 2021-2022 (Chair)
- Scholarship & Awards Committee, 2016-2018, 2020-21
- Comprehensive examination editor, 2020-21
- Symposium, Colloquium, Lecture Series Committee, May 2018-May 2020 (Chair)
- Symposium and Colloquium Committee, fall 2016-May 2018
- Bridging the Spectrum Symposium session moderator, 2018, 2019, 2020, 2021

- Organization of Information Core Course Outcomes Assessment, 2019, 2020
- The Information Professions in Society Core Course Outcomes Assessment, 2019, 2020
- Community Services Librarianship, Course of Study Review and Revision, 2020
- Organization of Information, Course of Study Review and Revision, 2019
- Organization of Information, Competency and Course Offerings Review, 2018-2019
- Accreditation presentation, Chair, June 2015-August 2016
- Interim Co-Chair, June 2015-August 2016.
- Blended/OWL Learning Committee, spring 2016-2018
- Technology Committee, fall 2016-2017
- Comprehensive examination editor, 2016-2017, reader (every year since 1990)
- LIS Advisory Board, 2015-2016 (chair); fall 2016- May 2018 (member)
- Committee on Planning and Assessment, 2015-2016 (chair)
- Senior Faculty Committee, 2014-2016.
- Accreditation Steering Committee, 2014-2016 (Chair, 2015-2016)
- Accreditation Students Standard Committee, co-chair, 2014-2016
- Accreditation Mission, Goals, and Objectives Standard Committee, co-chair, 2014-2016
- Accreditation Curriculum Standard, member 2014-2-16
- Accreditation Administration and Finance Standard, member 2014-2016
- Cultural Heritage Information Management Project (IMLS-funded), Co-PI, 2012-2015
- Cultural Heritage Information Management Forum (scheduled for June 2015), Co-Organizer, 2013-2015
- Health Information Technology Interim Review Committee, 2015 (chair)
- Health Sciences Librarianship Advisory Group, 2015- (chair)
- Comprehensive examination editors, 2013-2014, 2016-2017
- National Digital Stewardship Alliance liaison, 2011-2014
- Advisory Board, Chair 2010-2012
- Academic Honesty Committee, Chair, 2008-2012
- Blended Learning Committee, 2010-2012
- Colloquium Committee, 2010-2012
- Comprehensive Examination Administration, 2010-2012
- Cultural Heritage Information Management Advisory Committee, 2010-2012 (chair), 2013-
- Curriculum Committee, 1991-2003, 2007-2009, Chair 2010-2012, member 2013-
- Curriculum Subcommittee on Comprehensive Examination, Chair 2009-2012
- Health Information Technology Advisory Board, Chair 2010-2012. Member 2013-
- Health Sciences Advisory Committee, 2009, Chair 2010-2012. Member 2013-
- HIT Expert Forum, Chair 2012. Member 2013-2015
- Health Information Technology Student Group Advisor, 2011-2012
- State Council for Higher Education of Virginia, SLIS Representative, 2010-2012
- Symposium Planning Committee, 2010-2012
- Website Management Team, Chair, 2010-2012
- Urban School Librarianship Project (IMLS-Funded), PI, 2007-2011 (chair, 2010-11)

- Failing Grades Committee, 1995-1997 (chair), 2000-2001 (chair), 2004-2005 (chair), 2007 (chair)-2011
- Faculty Search Committee, 1994-1998, 2002-2004, 2006 (chair), Fall 2007-2009, Chair fall 2009-2012
- Recruitment Committee, Chair 2010-2012
- Strategic Planning Committee, Chair 2010-2012
- Technology Committee, 2010-2012
- Accreditation Advisory Committee, 2007-2009
- Accreditation Coordinating Committee, 2007-2009
- Accreditation Steering Committee, 2007-2009
- SLIS Advisory Group, 2007-2009
- Accreditation Curriculum Standard Committee, Co-chair, 2007-2009
- Accreditation Faculty Standard Committee, Co-chair, 2007-2009
- LSC 551 Information Organization Review Team, Co-chair, 2008-2009, 2015-2016.
- Curriculum Subcommittee on Portfolios, 2009
- LSC 555 Information Systems in Libraries and Information Centers Review Team, contributor, 2008-2009
- Redesign of LSC 730 Use and Users of Libraries and Information. 2009-
- Development of a metadata institute that was taught as LSC 715 Organization of Internet Resources in 2008. The institute is being revised and will be offered in 2010 under a new course title.
- Development of lesson plans, assignments, and evaluation rubrics for LSC 606, Cataloging and Classification, for the School's NCATE accreditation. 2008
- Howard and Mathilde Rovelstad Scholarship Committee, Chair, 2004-2007
- Assistant Dean Search Committee, Chair, Fall 2007
- Liaison to the Association for Library Collections and Technical Services to bring its preconference program, Cataloging Education and Employer Expectations, to CUA during the 2007 American Library Association Annual Meeting in Washington, D.C.
- Organizer of the colloquium presentation and reception for Tamar Sadeh of Ex Libris on PRIMO June 2007
- Practicum review and design (work with potential supervisors, such as the American Indian Museum internship description revision) 2006-
- Comprehensive examinations (edits, proctoring, and grading), 1990-
- SLIS Web site redesign: Comments and suggestions. Fall 2007
- Conducted surveys of current students and alumni in preparation for the 2005 re-accreditation, 2004-2005
- Technology Committee, 1992-1999 (chair, 1996-1998), 2002-2003 (member)
- Colloquia Committee 1997-1999, 2002-2003.
- Advisor of the CUA Student Chapter of the American Society for Information Science and Technology, 2002-2003
- Visiting Professor Search Committee, 1999, 2000, 2001
- Leader, Participation in the CORC experiment, 1999-2000
- Advisor of the Special Libraries Association Student Chapter, 1993-1999; the group was recognized for outstanding leadership by SLA in 1999.

- COA planning Committee, Task Force on Electronic Presentation of SLIS Reports (team leader) 1997-1998
- COA Planning Committee, Subcommittee on Technology 1996-1998
- NLM practicum coordinator, 1997-1998
- Computer Literacy Workshops: Assisted with the development and evaluation of the workshops, 1996-1998
- Leader, Participation in the InterCat project, 1995-1997

APPENDIX B

MARC 21 Reference Materials

Part VII: A Summary of Commonly Used MARC 21 Fields
Part VIII: A List of Other Fields Often Seen in MARC Records
Part IX: The Leader
Part X: Field 008 for Books

Part VII:

A Summary of Commonly Used MARC 21 Fields

This is a summary of the MARC 21 tags used most frequently by libraries in entering their own bibliographic records. For full listings of all MARC 21 tags, indicators, and subfield codes, see *MARC 21 Format for Bibliographic Data*.

In the explanations on these pages:

Tags -- The tags (3-digit numbers) are followed by the names of the fields they represent. In this summary, and in the *MARC 21 Format for Bibliographic Data*, if a tag can appear more than once in one bibliographic record, it is labeled repeatable (R). If it can only be used once, it is labeled non-repeatable (NR). For example, a catalog record can have several subjects, so the tags for subject added entries (6XX) are labeled repeatable (R).

Indicators -- The use of indicators is explained in fields where they are used. Indicators are one-digit numbers. Beginning with the 010 field, in every field -- following the tag -- are two character positions, one for Indicator 1 and one for Indicator 2. The indicators are not actually defined in all fields, however. And it is possible that a 2nd indicator will be used, while the 1st indicator remains undefined (or vice versa). When an indicator is undefined, the character position will be represented by the character # (for blank space).

Subfield codes -- All the data in each field (beginning with the 010 field) is divided into subfields, each of which is preceded by a delimiter-subfield code combination. The most common subfield codes used with each tag are shown. Each subfield code is preceded by the character $, signifying a delimiter. The name of the subfield follows the code.

In general, every field MUST have a subfield 'a' (**$a**). One exception that is often seen is in Field 020 (ISBN), when the ISBN information (subfield **$a**) is unavailable but the price (subfield **$c**) is known. Some subfields are repeatable. In this summary, repeatability is noted for only the more common repeatable subfields.

Examples: Examples follow the explanation for each field. For clarity, one space has been placed between the tag and the first indicator, one space has been placed between the second indicator and the first delimiter- subfield code, and one space has been inserted between the delimiter-subfield code and the subfield data.

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010 Library of Congress Control Number -- (LCCN)
(NR, or Not Repeatable
Indicators undefined.
Subfield used most often:
$a -- Library of Congress control number

```
Example:    010 ##  $a ###86000988#
```

020 International Standard Book Number -- (ISBN)
(R, or Repeatable)
Indicators undefined.
Subfields used most often:
$a -- International Standard Book Number
$c -- Terms of availability (often a price)
$z -- Cancelled/invalid ISBN (R)

```
Example:    020 ##  $a 0877547637
```

040 Cataloging source -- (NR)
Indicators undefined.
Subfields used most often:
$a -- Original cataloging agency
$c -- Transcribing agency
$d -- Modifying agency (R)

```
Example:    040 ## $a DLC
                   $c DLC
                   $d gwhs
```

100 Main entry -- Personal name -- (primary author)
(NR; there can be only one main entry)
Indicator 1: Type of personal name entry element
0 -- Forename
1 -- Surname (this is the most common form)
3 -- Family name
Indicator 2 undefined.
Indicator 2 became obsolete in 1990. Older records may display 0 or 1
Subfields used most often:
$a -- Personal name
$b -- Numeration

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$c -- Titles and other words associated with a name (R)
$q -- Fuller form of name
$d -- Dates associated with a name (generally, year of birth)

```
Example:    100 1# $a Gregory, Ruth W.
                   $q (Ruth Wilhelme),
                   $d 1910–
```

130 Main entry -- Uniform title -- (NR)

Indicator 1: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

Indicator 2 undefined.

Indicator 2 became obsolete in 1990. (See 100 above.)

Subfields used most often:

$a -- Uniform title
$p -- Name of part/section of a work (R)
$l -- Language of a work
$s -- Version
$f -- Date of a work

```
Example:    130 0# $a Bible.
                   $p O.T.
                   $p Psalms.
```

240 Uniform title (NR)

Indicator 1: Uniform title printed or displayed

0 -- Not printed or displayed
1 -- Printed or displayed (most common)

Indicator 2: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

Subfields used most often:

$a -- Uniform title
$l -- Language of a work
$f -- Date of a work

```
Example:    240 10 $a Ile mystérieuse.
                   $l English.
                   $f 1978
```


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245 Title Statement (NR)

Indicator 1: Title added entry

(Should the title be indexed as a title added entry?)

0 -- No title added entry

(indicates a title main entry; i.e. no author is given)

1 -- Title added entry

(the proper indicator when an author given in 1XX; the most common situation)

Indicator 2: Nonfiling characters

0-9 -- Number of nonfiling characters present, including spaces; usually set at zero, except when the title begins with an article; e.g., for *The robe*, the second indicator would be set to 4. The letters *T*, *h*, *e*, and the space following them are then ignored in alphabetizing titles. The record will be automatically filed under "*r*" -- for *Robe*.

Subfields used most often:

$a -- Title proper

$h -- Medium (often used for non-book media)

$p -- Name of part/section of a work (R)

$b -- Reminder of title (subtitles, etc.)

$c -- Remainder of title page transcription/Statement of responsibility

```
Example:    245 14 $a The DNA story :
                   $b a documentary history of gene
                      cloning /
                   $c James D. Watson, John Tooze.
```

246 Varying form of title (R)

Indicator 1: Note/title added entry controller

1 -- Note, title added entry

3 -- No note, title added entry

Indicator 2: Type of title

-- No information provided

0 -- Portion of title

1 -- Parallel title

4 -- Cover title

8 -- Spine title

Subfield used most often:

$a -- Title proper

```
Example:    246 3# $a Four corners power review
```

250 Edition statement (NR)

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Indicators undefined.
Subfield used most often:
$a -- Edition statement

```
Example:    250 ## $a 6th ed.
```

260 Publication, distribution, etc. (Imprint) (R)
Indicator 1: Sequence of publishing statements
-- No information provided
Indicator 2: Undefined
Subfields used most often:
$a -- Place of publication, distribution, etc. (R)
$b -- Name of publisher, distributor, etc. (R)
$c -- Date of publication, distribution, etc. (R)

```
Example:    260 ## $a New York :
                   $b Chelsea House,
                   $c 1986.
```

300 Physical description (R)
Indicators undefined.
Subfields used most often:
$a -- Extent (number of pages) (R)
$b -- Other physical details (usually illustration information)
$c -- Dimensions (cm.) (R)
$e -- Accompanying material (for example, "teacher's guide" or "manual")

```
Example:    300 ## $a 139 p. :
                   $b ill. ;
                   $c 24 cm.
```

440 Series statement / Added entry--Title
This field was made obsolete in 2008 to simplify the series statement. See 490 and 830.

490 Series statement (No added entry is traced from field) (R)
Indicator 1: Specifies whether series is traced (whether an 8XX tag is also present)
0 -- Series not traced
1 -- Series traced (8XX is in record)
Indicator 2 undefined.
Subfield used most often:

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$a -- Series statement (R)
$v -- Volume number (R)

```
Example:    490 1# $a Colonial American craftsmen
```

500 General note (R)
Indicators undefined.
Subfield used most often:
$a -- General note (Used when no specialized note field has been defined for the information. Examples: Notes regarding the index; the source of the title; variations in title; descriptions of the nature, form, or scope of the item.)

```
Example:    500 ##  $a Includes index.
```

504 Bibliography, etc. note (R)
Indicators undefined.
Subfield used most often:
$a -- Bibliography, etc. note

```
Example:    504 ## $a Includes bibliographical
                      references.
```

505 Formatted contents note (R)
Indicator 1: Type of contents note
0 -- Complete contents
1 -- Incomplete contents (used with multivolume set when some volumes are not yet published)
2 -- Partial contents
Indicator 2: Level of content designation
-- Basic
Subfield used most often:
$a -- Formatted contents note

```
Example:    505 0# $a Pride and prejudice -- Emma
                      -- Northanger Abbey.
```

520 Summary, etc. note (R)
Indicator 1: Display constant controller
-- Summary

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0067

1 -- Review
2 -- Scope and content
3 -- Abstract

Indicator 2 undefined

Subfields used most often

$a -- Summary, abstract, or annotation
$b -- Expansion of summary note

```
Example:    520 ## $a This basic guide to parliamentary
                     procedure tells how to conduct
                     and participate in a meeting
                     properly.
```

600 Subject added entry -- Personal name (R)

Indicator 1: Type of personal name entry element

0 -- Forename
1 -- Surname (this is the most common form)
3 -- Family name

Indicator 2: Subject heading system/thesaurus (identifies the specific list or file which was used)

0 -- Library of Congress Subject Headings
1 -- LC subject headings for children's literature
2 -- Medical Subject Headings
3 -- National Agricultural Library subject authority file
4 -- Source not specified
5 -- Canadian Subject Headings
6 -- Répertoire de vedettes-matière
7 -- Source specified in subfield $2

(Note regarding Sears subject headings: The MARC 21 format does not provide an assigned indicator for Sears subject headings. Therefore, an indicator of 7 is used, and the MARC defined code "sears" is placed in subfield $2.)

Subfields used most often:

$a -- Personal name (surname and forename)
$b -- Numeration
$c -- Titles and other words associated with a name (R)
$q -- Fuller form of name
$d -- Dates associated with a name (generally, year of birth)
$t -- Title of a work
$v -- Form subdivision (R)
$x -- General subdivision (R)
$y -- Chronological subdivision (R)
$z -- Geographic subdivision (R)
$2 -- Source of heading or term (used with 2nd indicator of 7)

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```
Example:    600 10 $a Shakespeare, William,
                   $d 1564-1616
                   $x Comedies
                   $x Stage history.
```

```
Example:    600 10 $a Shakespeare, William,
                   $d 1564-1616
                   $x Knowledge
                   $z Rome
                   $v Congresses.
```

Notice that subfields $v, $x, and $z in the 600 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

610 Subject added entry -- Corporate name (R)

*Indicator 1:*Type of corporate name entry element

0 -- Inverted name (not used with AACR2)

1 -- Jurisdiction name

2 -- Name in direct order

Indicator 2: Subject heading system/thesaurus.

See indicator 2 under 600

Subfields used most often:

$a -- Corporate name or jurisdiction name as entry element

$b -- Subordinate unit (R)

$v -- Form subdivision (R)

$x -- General subdivision (R)

$y -- Chronological subdivision (R)

$z -- Geographic subdivision (R)

$2 -- Source of heading or term (used with 2nd indicator of 7)

```
Example:    610 10 $a United States.
                   $b Army Air Forces
                   $v Biography.
```

650 Subject added entry -- Topical term (Most subject headings fit here.) (R)

Indicator 1: Level of subject

-- No information provided

Indicator 2: Subject heading system/thesaurus

(identifies the specific list or file which was used)

0 -- Library of Congress Subject Headings

1 -- LC subject headings for children's literature

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2 -- Medical Subject Headings
3 -- National Agricultural Library subject authority file
4 -- Source not specified
5 -- Canadian Subject Headings
6 -- Répertoire de vedettes-matière
7 -- Source specified in subfield $2

Note regarding Sears subject headings: The MARC 21 format does not provide an assigned indicator for Sears subject headings. Therefore, an indicator of 7 is used, and the MARC defined code "sears" is placed in subfield $2.)

Subfields used most often:
$a -- Topical term
$v -- Form subdivision (R)
$x -- General subdivision (R)
$y -- Chronological subdivision (R)
$z -- Geographic subdivision (R)
$2 -- Source of heading or term used with 2nd indicator of 7)

```
Example:    650 #0 $a Theater
                   $z United States
                   $v Biography
                   $v Dictionaries.
```

Notice that subfields $v, $x, and $z in the 650 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

651 Subject added entry -- Geographic name (R)
Indicator 1: undefined.
Indicator 2: Subject heading system/thesaurus.
See indicator 2 under 600
Subfields used most often:
$a -- Geographic name
$v -- Form subdivision (R)
$x -- General subdivision (R)
$y -- Chronological subdivision (R)
$z -- Geographic subdivision (R)
$2 -- Source of heading or term (used with 2nd indicator of 7)

```
Example:    651 #0 $a United States
                   $x History
                   $v Chronology.
```


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Notice that subfields $v, $x, and $z in the 651 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

700 Added entry -- Personal name (R)

Indicator 1: Type of personal name entry element

0 -- Forename

1 -- Surname (this is the most common form)

3 -- Family name

Indicator 2: Type of added entry

-- No information provided (most common; co-authors, editors, etc.)

2 -- Analytical entry (The values for Indicator 2 changed in 1994 with Format Integration, and older records may display additional values. An analytical entry involves an author/title of an item contained in a work.)

Subfields used most often:

$a -- Personal name

$b -- Numeration

$c -- Titles and other words associated with a name (R)

$q -- Fuller form of name

$d -- Dates associated with a name (generally, year of birth)

$e -- Relator term (such as ill.) (R)

$4 -- Relator code (R)

```
Example:    700 1# $a Baldridge, Letitia.
```

710 Added entry -- Corporate name (R)

Indicator 1: Type of corporate name entry element

0 -- Inverted name (not used with AACR2)

1 -- Jurisdiction name

2 -- Name in direct order

Indicator 2: Type of added entry.

See Indicator 2 under 700

-- No information provided

2 -- Analytical entry

Subfields used most often:

$a -- Corporate name or jurisdiction name as entry element

$b -- Subordinate unit (R)

```
Example:    710 2# $a Sunburst Communications (Firm)
```

740 Added entry -- Uncontrolled related/analytical title (R)

Indicator 1: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including

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0071

spaces)

*Indicator 2:*Type of added entry. See Indicator 2 under 700

-- No information provided

2 -- Analytical entry

(This field was redefined in 1994 with Format Integration. Prior to 1994, the field was also used for variant titles, such as a different wording on a spine title. In records created since Format Integration, those variant tiles appear in a 246 field.)

Subfield used most often:

$a -- Title

```
Example:    740 02 $a Uncle Vanya.
```

800 Series added entry -- Personal name (R)

Indicator 1: Type of personal name entry element

0 -- Forename

1 -- Surname

3 -- Family name

Indicator 2 undefined.

Subfields used most often:

$a -- Personal name

$b -- Numeration

$c -- Titles and other words associated with a name (R)

$q -- Fuller form of name

$d -- Dates associated with a name (generally, year of birth)

$t -- Title of a work (the series)

$v -- Volume number

```
Example:    800 1# $a Fisher, Leonard Everett.
                   $t Colonial American craftsmen.
```

830 Series added entry -- Uniform title (R)

Indicator 1 undefined.

Indicator 2: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

Subfield used most often:

$a -- Uniform title

$v -- Volume number

```
Example:    830 #0 $a Railroads of America (Macmillan)
```


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Part VIII:

A List of Other Fields Often Seen in MARC Records

001	Control number
003	Control number identifier
005	Date and time of latest transaction
006	Fixed-length data elements -- additional material characteristics
007	Physical description fixed field
008	Fixed length data elements (See Part X)
022	International Standard Serial Number (ISSN)
037	Source of acquisition
041	Language code
043	Geographic area code
050	Library of Congress call number
060	National Library of Medicine call number
082	Dewey Decimal classification number (the one recommended by the Library of Congress; locally-assigned call numbers may appear elsewhere)
110	Main entry -- Corporate name (less frequent under AACR2 rules)
256	Computer file characteristics
263	Projected publication date (indicates a CIP -- Cataloging in Publication -- record)
306	Playing time
508	Creation/production credits note
510	Citation/references note (review sources)
511	Participant or performer note
521	Target audience note (first indicator: 0 = reading grade level, 1 = interest age level, 2 = interest grade level, 3 = special audience characteristics, 4 = motivation interest level)
530	Additional physical form available note
538	System details note
586	Awards note
656	Index term -- Occupation
730	Added entry -- Uniform title
852	Location
856	Electronic location and access
9XX	Reserved for local use. (They are used by vendors, systems, or individual libraries to exchange additional data)

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Part IX:

The Leader

There are 24 positions in the Leader, numbered from 00 to 23. For fuller explanation, see the *MARC 21 Format for Bibliographic Data*.

00-04 Record length (calculated by the computer for each record)

05 Record status
- a = increase in encoding level
- c = corrected or revised
- d = deleted
- n = new
- p = increase in encoding from prepublication (previous CIP)

06 Type of record
- a = language material
- c = printed music
- d = manuscript music
- e = cartographic material
- f = manuscript cartographic material
- g = projected medium
- i = nonmusical sound recording
- j = musical sound recording
- k = 2-dimensional nonprojectable graphic
- m = computer file
- o = kit
- p = mixed materials
- r = 3-dimensional artifact or naturally occurring object
- t = manuscript language material

07 Bibliographic level
- a = monographic component part
- b = serial component part
- c = collection
- d = subunit
- i = integrating resource
- m = monograph/item
- s = serial

08 Type of control
- # = no specified type
- a = archival

09 Character coding scheme
- # = MARC-8
- a = UCS/Unicode

10 Indicator count (always "2")

11 Subfield code count (always "2")

12-16 Base address of data (calculated by the computer for each record)

17 Encoding level
- # = full level

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1 = full level, material not examined
2 = less-than-full level, material not examined
3 = abbreviated level
4 = core level
5 = partial (preliminary) level
7 = minimal level
8 = prepublication level (CIP)
u = unknown
z = not applicable

18 Descriptive cataloging form
= non-ISBD
a = AACR2
i = ISBD
u = unknown

19 Multipart resource record level
= Not specified or not applicable
a = Set
b = Part with independent title
c = Part with dependent title

20 Length of the length-of-field portion (always "4")
21 Length of the starting-character-position portion (always "5")
22 Length of the implementation-defined portion (always "0")
23 Undefined (always "0")

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Part X:

Field 008 for Books

Field 008 is used for Fixed Length Data Elements ("Fixed Field Codes"). There are 40 character positions in field 008, numbered from 00-39. Undefined positions must contain either a blank (#) or a fill character (|). Positions 00-17 and 35-39 are defined the same way for all media.

The information shown here for positions 18-34 applies only to books. For explanation of all the positions below and for positions 18-34 for other media, see the *MARC 21 Format for Bibliographic Data*.

Note that field 008 has no indicators or subfield codes.

00-05 Date entered on file (YYMMDD),
where Y=year, M=month, and D=day

06 Type of date/publication status:
b = no dates given; B.C. date involved
e = detailed date
s = single known date/probable date
m = multiple dates
r = reprint/reissue date (Date 1) and original date (Date 2)

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0075

n = dates unknown
q = questionable date
t = publication date and copyright date
| = no attempt to code

07-10 Date 1/beginning date of publication

11-14 Date 2/ending date of publication

Date fields contain the year(s) of publication. The type of date(s) in these elements are specified in fixed field element 06: Type of date/publication status. (For further details, see the field 008 description in the *MARC 21 Format for Bibliographic Data*.)

15-17 Place of publication, production, or execution

For example:
pk# = Pakistan
cau = California (US)

(For a full list of codes used in these positions, see the *MARC Code List for Countries*.)

18-21 Illustrations (up to 4 codes):

= no illustrations
a = illustrations
b = maps
c = portraits
d = charts
e = plans
f = plates
g = music
h = facsimiles
i = coats of arms
j = genealogical tables
k = forms
l = samples
m = phonodisc, phonowire, etc.
o = photographs
p = illuminations
| = no attempt to code

22 Target audience:

= unknown or not specified
a = preschool
b = primary
c = pre-adolescent
d = adolescent
e = adult
f = specialized
g = general
j = juvenile
| = no attempt to code

23 Form of item:

= none of the following
a = microfilm

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b = microfiche
c = microopaque
d = large print
f = braille
r = regular print reproduction
s = electronic
| = no attempt to code

24-27 Nature of contents (up to 4):
= no specified nature of contents
a = abstracts/summaries
b = bibliographies (is one or contains one)
c = catalogs
d = dictionaries
e = encyclopedias
f = handbooks
g = legal articles
i = indexes
j = patent document
k = discographies
l = legislation
m = theses
n = surveys of literature
o = reviews
p = programmed texts
q = filmographies
r = directories
s = statistics
t = technical reports
u = standards/specifications
v = legal cases and notes
w = law reports and digests
z = treaties
| = no attempt to code

28 Government publication:
= not a government publication
i = international intergovernmental
f = federal/national
a = autonomous or semi-autonomous component
s = state, provincial, territorial, dependent, etc.
m = multistate
c = multilocal
l = local
z = other type of government publication
o = government publication -- level undetermined
u = unknown if item is government publication
| = no attempt to code

29 Conference publication:
0 = not a conference publication
1 = conference publication

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| = no attempt to code

30 Festschrift:
0 = not a festschrift
1 = festschrift
| = no attempt to code

31 Index:
0 = no index
1 = index present
| = no attempt to code

32 Undefined (since 1990) (Earlier records may contain the values 0 or 1)
= Undefined
| = no attempt to code

33 Literary form:
0 = not fiction (not further specified)
1 = fiction (not further specified)
c = comic strips
d = dramas
e = essays
f = novels
h = humor, satires, etc.
i = letters
j = short stories
m = mixed forms
p = poetry
s = speeches
u = unknown
| = no attempt to code

34 Biography:
= no biographical material
a = autobiography
b = individual biography
c = collective biography
d = contains biographical information
| = no attempt to code

35-37 Language:
A three-letter code. For example: eng fre ger spa rus ita

(For a full list of codes used in these positions, see the *MARC Code List for Languages*.)

38 Modified record:
= not modified
x = missing characters (because of characters unavailable in MARC character set)
s = shortened
d = "dashed-on" information omitted
r = completely romanized/printed cards in script
o = completely romanized/printed cards romanized
| = no attempt to code

39 Cataloging source:

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= national bibliographic agency
c = cooperative cataloging program
d = other sources
u = unknown
| = no attempt to code

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APPENDIX C

Appendix C. Materials Considered

Exhibit	Description
1006	Magoon, R., Molnar, A., Zachan, J., Hatcher, G., & Rhee, W. (2002, December). A single-chip quad-band (850/900/1800/1900 MHz) direct conversion GSM/GPRS RF transceiver with integrated VCOs and fractional-N synthesizer, *IEEE Journal of Solid-State Circuits*, *37*(12), 1710-1720 ("*Magoon*").
1006A	Copy of *Magoon*, obtained from the Library of Congress.
1006B	Bibliographic and MARC serial records for *IEEE Journal of Solid-State Circuits*, available at https://lccn.loc.gov/89657065 from the online catalog of the Library of Congress.
1006C	Profile of the Library of Congress, available at https://librarytechnology.org/library/2263.
1006D	Copyright registration record for volume 37 of *IEEE Journal of Solid-State Circuits that contains Magoon*, available at https://cocatalog.loc.gov/cgi-bin/Pwebrecon.cgi?v1=24&ti=1,24&Search%5FArg=IEEE%20Journal%20of%20Solid%2DState%20Circuits&Search%5FCode=TALL&CNT=25&PID=DjauxxrV09WaHbOY_hvALj3aXzSpy&SEQ=20250311215721&SID=1 from the public catalog of the US Copyright Office.
1006E	"Most-Read Recent Articles in the 2002 *Journal of Solid-State Circuits*" archived by Internet Archive on April 8, 2003, and available at https://web.archive.org/web/20030408094604/sscs.org/jssc/hotreads02.htm.
1006F	"Membership in the Solid-State Circuits Society 2-3Publications," archived by Internet Archive on **December 19, 2002**, and available at https://web.archive.org/web/20021219065900/sscs.org/membership/membership2.htm.
1006G	Citations to *Magoon*, obtained from Google Scholar.

1007	Ngompe, E., Ayvazian, M., Glasbrener, M., Megahed, M., Vakilian, N., & Domino, W. (2003, June). Architecture and performance overview of a highly integrated 13/spl times/13 mm Single-Package Radio (SPR) module for dualband EGSM900/GSM1800 applications, *IEEE Radio Frequency Integrated Circuits (RFIC) Symposium, 2003* (pp. 387-390) ("*Ngompe*").
1007A	Copy of *Ngompe*, obtained from IEEE Xplore.
1007B	IEEE metadata record for *Ngompe*, available at https://ieeexplore.ieee.org/abstract/document/1213968.
1007C	Website of IEEE Xplore archived by Internet Archive on February 7, 2001, available at https://web.archive.org/web/20010207003457/http://ieeexplore.ieee.org/lpdocs/epic03/
1007D	Copyright registration record for *IEEE Radio Frequency Integrated Circuits (RFIC) Symposium, 2003*, available at https://cocatalog.loc.gov/cgi-bin/Pwebrecon.cgi?v1=6&ti=1,6&Search%5FArg=IEEE%20Radio%20Frequency%20Integrated%20Circuits%20%28RFIC%29&Search%5FCode=TALL&CNT=25&PID=T6LbjeyKv8IGyo7kbzRg5__aTYYpX&SEQ=20250312211425&SID=1from the public catalog of the US Copyright Office.
1007E	Bibliographic and MARC records for *IEEE Radio Frequency Integrated Circuits (RFIC) Symposium, 2003*, available at https://catalog.lindahall.org/permalink/01LINDAHALL_INST/19lda7s/alma993743393405961 from the online catalog of the Linda Hall Library.
1007F	Profile of the Linda Hall Library, available at https://librarytechnology.org/library/2294.
1007G	"Advance Conference Registration" for the 2003 RFIC Symposium, archived by Internet Archive on June 11, 2003, available at https://web.archive.org/web/20030611144832/http://www.ims2003.org/attendee/registration_form.pdf.

App A	Hsieh-Yee CV
App B	Parts VII to X of Understanding MARC Bibliographic, available at https://www.loc.gov/marc/umb/um07to10.html from the Library of Congress.

EX-1006

A Single-Chip Quad-Band (850/900/1800/1900 MHz) Direct Conversion GSM/GPRS RF Transceiver with Integrated VCOs and Fractional-N Synthesizer

Rahul Magoon, *Member, IEEE*, Alyosha Molnar, Jeff Zachan, *Member, IEEE*, Geoff Hatcher, *Member, IEEE*, and Woogeun Rhee, *Member, IEEE*

***Abstract*—Recent trends in the integration of entire systems on-chip have spurred the development of homodyne radios as alternatives to the more mature yet harder to integrate superheterodyne architectures. This paper presents a monolithic device that integrates all of the functions necessary to implement a multiband homodyne global system for mobile telecommunications radio except for the power amplifier (PA) and radio frequency (RF) passives. The single BiCMOS chip includes a quad-band direct conversion receiver that down converts RF to quadrature analog baseband. The front-end circuitry is followed by a low-dc-offset, high-dynamic-range, analog I/Q baseband chain. The transmit section is comprised of a quad-band up-conversion transmit phase-locked loop (PLL) including on chip transmit voltage-controlled oscillators (VCOs). The stringent GSM receive band phase noise specifications are met without the use of surface acoustic wave filters. A single $\Sigma\Delta$ fractional-N synthesizer locking a fully integrated ultrahigh frequency VCO generates the system local oscillator signal.**

***Index Terms*—BiCMOS, calibration, direct conversion, frequency dividers, g_mC filters, GPRS, GSM, land mobile radio cellular systems, microwave circuits, modulation, noise, phase-locked loops, power amplifiers, quad band, receivers, system on chip (SOC), transceivers, transmitters, UHF, voltage-controlled oscillators.**

I. Introduction

As MODERN cell phones become ubiquitous, the critical factors in their manufacture become cost, size, and time to market. The high integration of radio ICs reduces board area and complexity while cutting component cost and system design time. Low-cost manufacturers desire freedom to choose the cheapest and most reliable IC for each main handset function. In this context, the interface between the transceiver and the various baseband ICs available on the market becomes important. Radio receiver outputs need to be able to interface to low-dynamic-range analog-to-digital converters (ADCs) through a simple I/Q interface and require little or no digital post processing. Direct conversion and low intermediate frequency (IF) receivers permit increased integration, lower cost, and reduce radio complexity by removing the need for external IF surface acoustic wave (SAW) filters and multiple local oscillator (LO) signals. However, many direct conversion receiver (DCR) implementations [1] and all low IF receivers still require wide dynamic range ADCs.

This work presents a DCR that avoids the traditional problems by means of frequency planning, floor planning, and calibration techniques. The receiver includes a low-dc-offset, high-input-dynamic-range analog I/Q baseband chain capable of interfacing to 9-b ADCs. The transmitter architecture is based on the commonly used translational loop. A single integrated LO provides the channel selection for both the transmitter and the receiver. All VCOs and phase-locked loops (PLLs) are on chip [2].

II. Device Overview

A block diagram of the transceiver, including the necessary external RF components, is shown in Fig. 1. The only required external components, excluding impedance matching and loop filter components, are receive band select SAW filters, a switchplexer, and a power amplifier (PA). Standard differential analog I/Q interfaces are used for the transmitter inputs and for the receiver outputs.

The receive path consists of three single-ended low-noise amplifiers (LNAs) that drive two sets of quadrature subharmonic mixers (SHMs) whose outputs are combined in a common I/Q analog baseband chain. The baseband chains include low-pass channel select filtering, programmable gain, and dc offset correction. A fully integrated translational loop transmitter locks two wide-band on-chip oscillators (one for 1800/1900 MHz, and the other for 850/900 MHz). The loop also includes a down-conversion feedback mixer and a quadrature modulator, along with a phase frequency detector and charge pump. Frequency synthesis is completely integrated including a UHF oscillator and fractional-N PLL. Several stages of LO processing are required to ease the design of the UHF oscillator and to provide quad-band functionality. One of the benefits of complete LO integration is that the only RF signals present on pins or bond wires are the received inputs at the LNAs and the transmitted outputs to the PA.

The transceiver incorporates a three-wire serial interface programming bus providing frequency control, gain control, and broad testability of integrated blocks. A test port is provided for

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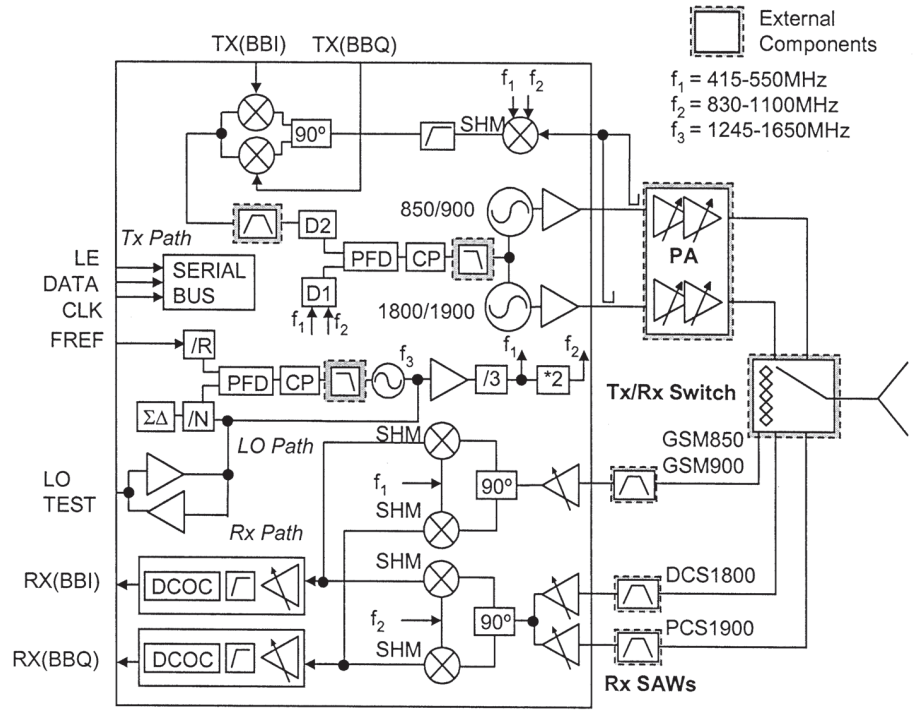


Fig. 1. Top-level schematic of transceiver, with external RF components.

monitoring the LO during testing and is disabled during normal operation. Separate transmit, receive, and synthesizer control input pins permit enabling from the digital baseband.

III. DCR

The direct conversion approach presents several unique design challenges. All of these have to do with the generation of excessive or time-varying dc offsets at the outputs of the receiver. Aside from simple process and layout related mismatches, the two primary sources of dc are LO leakage to the RF inputs and even-order nonlinearities in the receive path. While constant dc offsets can be calibrated out, mechanisms that result in unpredictable time-varying dc offsets must be suppressed by a careful choice of architecture and circuit design.

1) DC Offsets: DC offsets can corrupt data in systems such as global system for mobile telecommunications (GSM), where information is present down to dc. It is possible to subtract offsets in the DSP, provided they are constant over a given receive slot. Large dc offsets may overload the ADC or some portion of the analog baseband, causing the received signal to clip, corrupting information before correction in the DSP is possible. Signal independent dc can be generated in several ways. One way is through mismatches in the mixer and baseband. Offsets from mismatches can pose a problem since most of the receiver's gain appears after the mixer, and so even small offsets, once gained up, can overwhelm the receiver. Fortunately, fixed dc offsets may be corrected by activating the mixer and baseband early and performing a closed-loop calibration.

A second source of dc offsets comes from the LO signal coupling onto the receive chain at some point before the mixer. This signal, once present, is down converted to dc. As shown in Fig. 2(a), the LO signal may couple to the output and or the input of the LNA or reradiate and reflect off an external surface and be picked up by the antenna. In the first case, simple dc offset calibration may be used. In the second case, calibration is also possible but may be inaccurate if interfering signals are present on the antenna. The third case, however, represents an unpredictable situation leading to a time-varying dc signal. LO re radiation must thus be minimized by design.

2) IIP2: Another way that dc can be generated is through second-order nonlinearity in the signal path. These nonlinearities cause strong out of band signals to be converted to dc, as in

$$F(x) = a_1 \cdot x + a_2 \cdot x^2$$
$$F(A \cdot \cos(\omega t)) = a_1 \cdot A \cdot \cos(\omega t) + \frac{1}{2} \cdot a_2 \cdot A^2[1 + \cos(2 \cdot \omega t)] \quad (1)$$

and are collectively characterized by the second-order intercept point, IIP2 of the receiver. See Fig. 3. IIP2 effects can be caused by two distinct mechanisms. One mechanism involves simple even-order nonlinearities in the mixer or baseband. This phenomenon is characteristic of single-ended circuits and is even possible in differential circuits if asymmetries are present. The other mechanism involves large RF blocking signals coupling onto the LO chain and phase modulating the LO signal. See Figs. 2(b) and 4. Since one of the resulting side bands corresponds to the original RF signal, the RF is down converted to dc as shown in

$$LO' = LO + k \cdot RF_{\text{blocker}}$$
$$= \cos(\omega_{LO} \cdot t) + k \cdot \cos(\omega_{RF} \cdot t)$$

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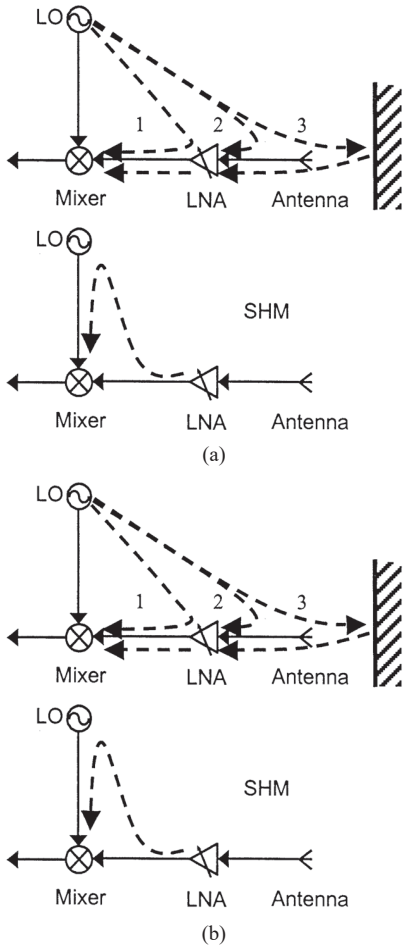


Fig. 2. Coupling paths that can cause dc offsets. (a) LO to RF coupling. (b) RF to LO coupling.

$$RF \cdot LO' = \frac{1}{2}\left[A \cdot \cos((\omega_{RF} \pm \omega_{LO}) \cdot t)\right] + k \cdot A^2[1 + \cos(2 \cdot \omega_{RF} t)]. \quad (2)$$

IIP2 performance is especially important in cases where blocker strength varies unpredictably in the middle of a receive slot. In these cases, dc offset calibration is impossible and DSP algorithms are less effective. It is this situation, specified for GSM by the AM suppression test [3], which sets the lower bound on IIP2 in a GSM DCR. For example, in the EGSM band, the radio must be able to reliably continue receiving a signal at -99 dBm when a -31-dBm signal at 6-MHz offset unexpectedly turns on mid slot. The required IIP2 can be calculated as

$$\begin{aligned} IIP2_{\text{req}}(\text{dBm}) &= 2 \cdot P_{\text{blocker}}(\text{dBm}) \\ &\quad - (P_{\text{signal}} - SNR_{\text{req}} + 3\ \text{dB}) \\ IIP2_{\text{req}} &= 2 \cdot (-31\ \text{dBm}) \\ &\quad - (-99\ \text{dBm} - 9\ \text{dB} + 3\ \text{dB}) \\ &= +43\ \text{dBm (at the antenna)} \\ IIP2_{\text{req}} &= +40\ \text{dBm (at the LNA input, assuming} \\ &\qquad 3\ \text{dB front end loss}). \end{aligned} \quad (3)$$

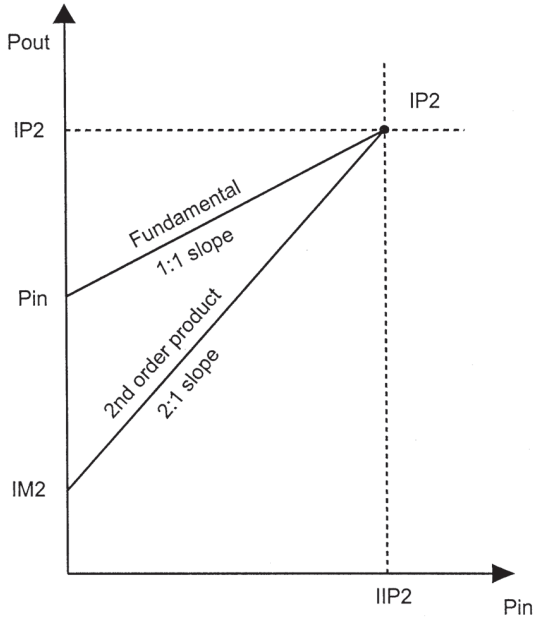


Fig. 3. Second-order intercept diagram. Both axes are in dBm.

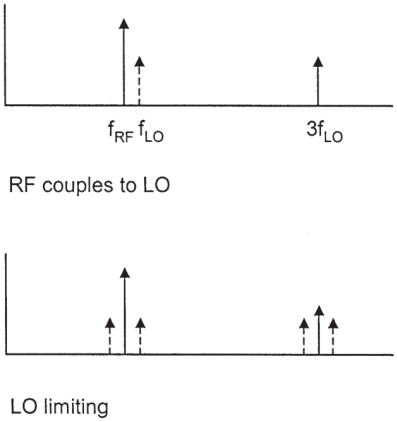


Fig. 4. Modulation of LO by RF.

A. Ratioed LO Frequency Plan

LO and RF self mixing can both be reduced using offset frequency architectures [4]. One method for generating offset LO signals is through a combination of frequency dividers and multipliers. In such a system, subharmonic LOs signals should be of even order relative to the received signal. This requirement arises from the common use of differential hard switched circuits in dividers, LO buffers, and mixers. Hard switched differential circuits tend to generate odd harmonics of the switching frequency and also respond to interfering signals close to their odd harmonics, as if they were sidebands of the fundamental.

In the LO chain presented here and shown in Fig. 1, a single LO provides a signal in the range from 1250 to 1650 MHz. This signal is fed to a frequency divide-by-three circuit, which generates a subharmonic LO signal in the range 415 to 550 MHz. This signal is then passed directly to a 1/2 LO SHM to down convert received signals in the 850-MHz US cellular and 900-MHz EGSM bands. Alternately, for high band operation, the signal is passed to a frequency doubler generating an LO signal from 830

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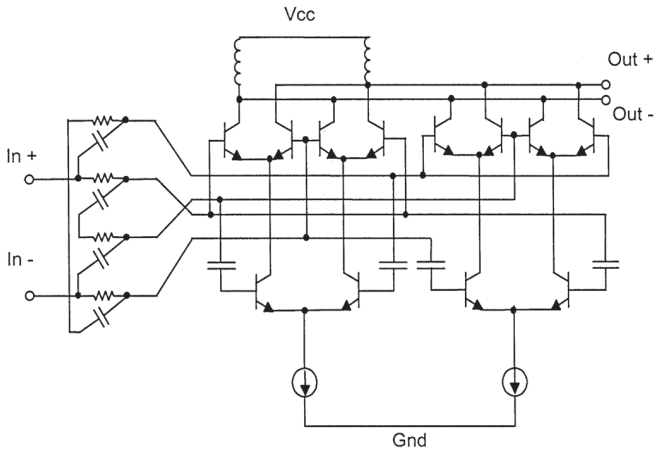


Fig. 5. Low-output harmonic doubler.

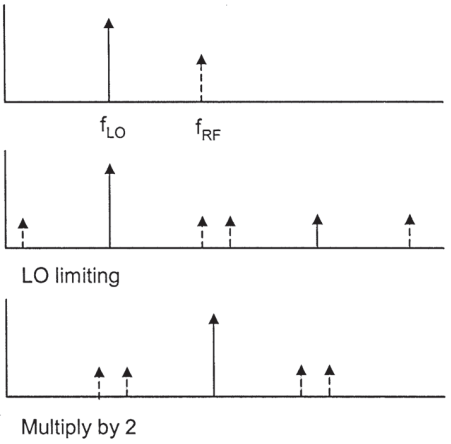


Fig. 6. Modulation of 1/2 LO by RF.

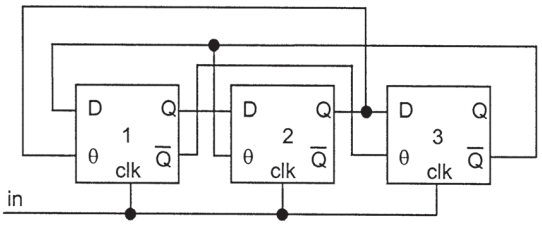


Fig. 7. Architecture of frequency divide-by-three with 50% duty cycle.

MHz to 1.1 GHz. This LO signal is then fed to a 1/2 LO SHM to down convert signals in the 1800-MHz DCS and 1900-MHz PCS bands.

1) Frequency Doubling and 1/2 LO Mixers: The use of a subharmonic LO signal clearly reduces LO reradiation and self mixing. Since the reradiated LO signal will be present at 1/2 or 1/4 the received frequency, it will not be down converted to baseband. In addition, RF coupling onto a subharmonic LO will not modulate the LO signal in a fashion that can degrade IIP2.

The implementation of the frequency doubling function is critical. Typically, frequency doubling in both SHM [9] and frequency doublers is implemented by multiplying two signals of the same frequency that are phase split by 90 degrees, as represented by

$$\sin(\omega t) \cdot \cos(\omega t) = \frac{1}{2} \cdot \sin(2\omega t). \tag{4}$$

An efficient doubling circuit makes use of hard switched phase split signals instead of sinusoidal signals. The circuit shown in Fig. 5 accomplishes frequency doubling as follows. An RC polyphase filter provides the quadrature phase split. The resulting signal then drives a pair of hard switched Gilbert multipliers [6]. The use of two such multipliers, whose outputs are summed and whose inputs are cross coupled, provides higher order symmetry [7]. This symmetry guarantees low-output even-order harmonics (provided that the phase split is accurate).

Since (4) essentially represents the up conversion of one signal by the other, it should be clear that the sidebands of either signal will be up converted with their frequency offsets intact, as shown in Fig. 6. In other words, RF signals coupling onto a subharmonic LO will generate sidebands at offsets equal to the frequency difference between the subharmonic LO signal and RF signal. Even after the fundamental frequency is doubled in the frequency doubler or SHM, this offset is maintained resulting in sidebands at, for example, $F_{RF} \pm F_{LO}$, where $F_{LO} \sim 1/2F_{RF}$. Such sidebands will not align with the original received signal, and will not result in IIP2 degradation.

2) Divide by Three: Although subharmonics do not reradiate at the RF frequency, they can generate harmonics that do. The VCO generating the LO signal includes relatively large structures in its resonant tank and operates at relatively high power. To avoid problems with VCO-generated harmonics, the oscillator runs at three times the subharmonic frequency and is followed by a lower power divide-by-three circuit. The analysis of the interaction between even-order subharmonic signals and received signals also applies to odd multiples of even-order subharmonics. LO signals at 3/2 and 3/4 the receive frequency are as insensitive to coupling as those at 1/2 and 1/4. As an additional benefit, VCOs can more easily be integrated in the 1.5-GHz range than in the 0.5-GHz range as discussed later in this paper.

Two problems arise from the implementation of a frequency divide-by-three. The first results from the fact that most odd-order frequency dividers generate outputs with non 50% duty cycles. This results in generation of strong even-order harmonics, obviating the use of an even-order subharmonic LO. The second problem is more subtle. As mentioned before, doubling of frequencies typically involves quadrature split inputs. If polyphase filters are used to generate quadrature, the input signals are required to be sinusoidal. Therefore, the reduction of higher harmonics at the output of the frequency divide-by-three is very important [8].

A true 50% duty cycle frequency divide-by-three was implemented using three phase-switchable level-sensitive latches connected in a loop. Each latch, in addition to its data and clock inputs, has a third input which is denoted by θ. This input toggles the latch between triggering on the positive and negative levels of the clock. Proper interconnection of Q, D, and θ between latches (shown in Fig. 7) results in a signal of 1/3 the clock frequency propagating through the loop by one latch each 1/2 clock cycle. The resulting waveforms are shown in Fig. 8(a). Implementation of such latches in differential emitter coupled logic (ECL) permits the necessary signal inversions without asymmetry.

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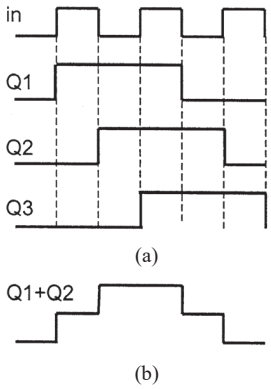


Fig. 8. (a) Internal states of divide-by-three. (b) Output generated by summing two internal states.

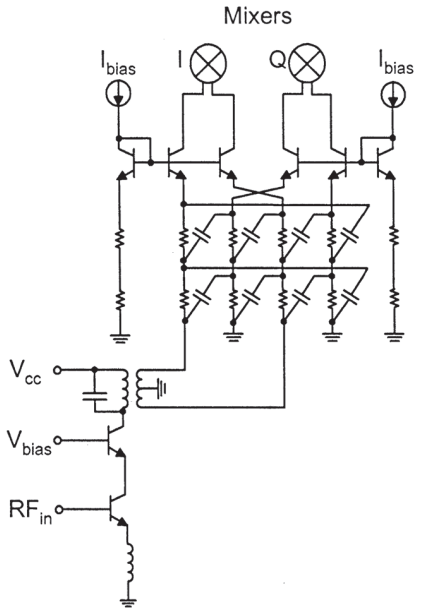


Fig. 9. LNA, RF path phase split, and mixer RF port.

In order to suppress the strong third harmonic present in the square wave outputs of this divider, one additional step is needed. Each of the three latches has as its output a signal 60° delayed from the previous stage. Summation of two such signals results in an output with a fundamental 30° shifted from the first, with slightly less than twice the amplitude. The third harmonics of the summed signals, however, are 180° split and as a result they completely cancel. The resulting much more sinusoidal signal is shown in Fig. 8(b).

3) RF Path Quadrature Generation: Simple 90° phase splitting of the subharmonic LO is insufficient to generate I/Q receiver outputs because upon frequency doubling; the phase also doubles to 180°. The use of 45° splits has also been explored [9]; however, most schemes are either very lossy or lose accuracy over process variations. As an alternative, quadrature may be generated in the RF path. An RF path phase splitter is shown in Fig. 9. A two-stage polyphase filter guarantees amplitude matching across band and process. By incorporating this structure as degeneration for the replica biasing of the common base RF port of the mixer, one can implement the phase split without any extra voltage headroom. The use of a common base RF port provides significant isolation between the mixer core and LNA, attenuating any LO signal that might couple back to the LNA and potentially self mix.

TABLE I
RECEIVER PERFORMANCE. SENSITIVITY NUMBERS INCLUDE LOSSES FROM FRONT-END FILTERS AND SWITCHPLEXER

Receiver	*850/900MHz*	*1800MHz*	*1900MHz*
NF	3.1dB	3.6dB	4.1dB
LO re-radiation	-110dBm	-105dBm	-103dBm
IQ phase match	1°	1°	1°
IQ amplitude match	0.5dB	0.5dB	0.5dB
Gain range	10-105dB	10-100dB	10-100dB
Typical sensitivity	-109dBm	-107dBm	-107dBm
Required sensitivity [3]	*-102dBm*	*-100dBm*	*-102dBm*
IIP2 over channels (cal.)	> 50dBm	> 50dBm	> 50dBm
3dB baseband BW	98kHz	98kHz	98kHz
Group delay to 100kHz	< 0.3μs	< 0.3μs	< 0.3μs
Rejection at 3MHz	> 120dB	> 120dB	> 120dB
Sensitivity with blocker	-105.5dBm	-104dBm	-104dBm
Req'd sens. with blocker [3]	*-99dBm*	*-97dBm*	*-97dBm*
Bias current (incl. Synth.)	75mA	80mA	80mA
Operating voltage	2.7-3.6V	2.7-3.6V	2.7-3.6V

4) Results: Reradiation of on-frequency LO signal measured at the LNA input is −110 dBm in GSM, −105 dBm in DCS, and −103 dBm in PCS. In addition, the subharmonic LO chain exhibits good phase noise as evidenced by the fact that the worst case blockers desensitize the receiver by less than 4 dB. The RF path phase split is effective in generating quadrature accurate to 1° and 0.5 dB measured at the baseband outputs. The NF measured for the whole receiver is 3.1 dB in GSM, 3.6 dB in DCS, and 4.1 dB in PCS. See Table I. As compared to traditional superheterodyne receivers, power is saved by replacing the IF strip with baseband amplifiers and filters and by removing one local oscillator. Unfortunately, these power benefits tend to be balanced out by the greater complexity and integration of the LO chain. The receiver (including PLL and oscillator) consumes 75 and 80 mA from 2.7 V in GSM and DCS modes, respectively.

B. IIP2 Cancellation

Although the frequency plan described above is effective in suppressing RF self mixing, simple second-order nonlinearity still limits IIP2. IIP2 in a purely differential structure (such as a double balanced mixer) is theoretically infinite. All IIP2 effects must therefore be a consequence of asymmetry. Although most asymmetries can be reduced by careful layout and design, imperfections will always be present due to device mismatch. In order to compensate for this problem, an IIP2 cancellation scheme was developed. This scheme essentially introduces an intentional (digitally programmable) asymmetry into the mixer in order to null blocker induced dc offsets, thereby canceling IIP2. This calibration provides a 15-dB improvement in receiver IIP2 across the band, raising it from better than 35 dBm to better than 50 dBm for all bands. Fig. 10 shows the effect on dc of a blocker at a 6-MHz offset ramping from −30 to −24 dBm in the presence of a −99-dBm wanted signal.

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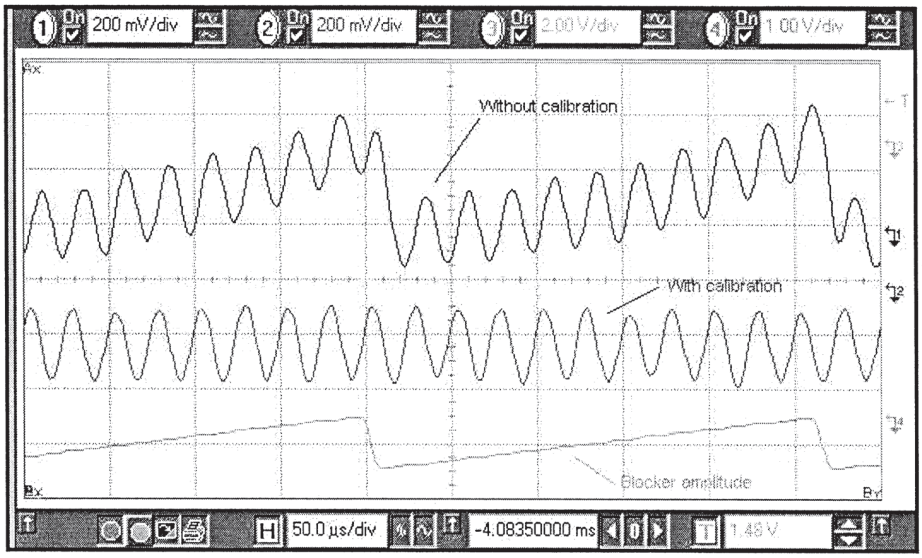


Fig. 10. Effects of AM modulated blocker (bottom curve) on received signal with and without IIP2 calibration.

C. Baseband Circuitry

One of the benefits of the DCR is the migration of all the functions usually present in the IF strip to baseband. In principle, any function performed at an IF of several hundred megahertz is easier to implement at several hundred kilohertz with less power consumption and higher integration. However, the standard challenges associated with high dynamic range are then complicated by a new set of problems including dc offsets, flicker noise, and even-order nonlinearities [10].

Without the benefit of a high Q channel select filter and wide range IF PGA, the baseband is forced to deal with the full range of blocker and signal strengths present at the mixer output. In addition, the baseband must be able to handle the entire possible range of signal and blocker strengths without significantly degrading the noise performance of the receiver or compressing the wanted signal. A GSM receiver with an NF of 3 dB and a 1-dB compression point of -22 dBm requires a dynamic range of approximately 95 dB. To avoid undesired degradation, this translates to a dynamic range of more than 105 dB in the baseband.

In this design, the distribution of gain and filtering is designed to attenuate far out blockers early in the chain to ease headroom requirements for later stages (see Figs. 11 and 12). The current mode output of the mixer is directly coupled to a folded cascode stage implementing two real poles set by resistor and capacitor combinations with 40 dB of effective gain. This stage is followed by a Sallen Key filter, which implements two complex conjugate poles and 10 dB of gain. Such *RC*-based filters and amplifiers have very high dynamic range, but must be wide band enough to avoid inband interference from process variations. Once the far out blockers (1.6 MHz, 3 MHz, and beyond) are attenuated, the dynamic range requirements of the following stages are relaxed. Lower dynamic range permits the use of low power and tightly controlled g_mC filters to remove the closer blockers (200 kHz, 400 kHz, and 600 kHz). A continuous time filter [11] was used instead of a switched capacitor filter [12] due to concerns that the reference clock would couple to the on chip LNA and VCOs. Gain stages are interleaved with the filters to increase wanted signal strength and to ease noise restrictions. In order to avoid compression at higher desired signal levels, the gain is made programmable. See Fig. 13.

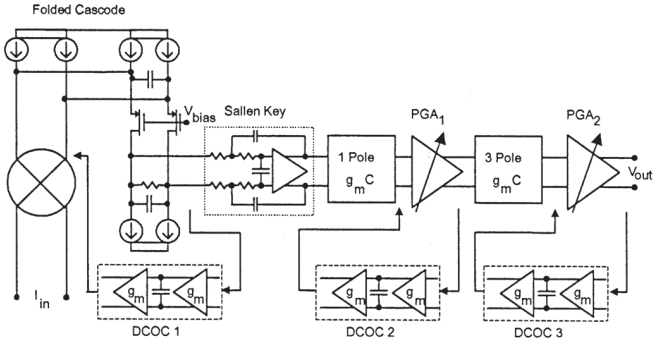


Fig. 11. Mixer output and baseband chain.

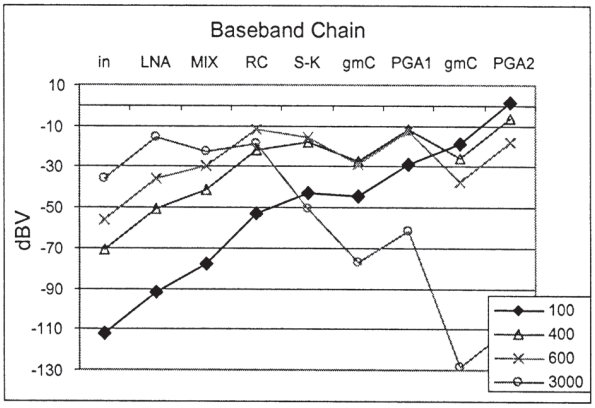


Fig. 12. Baseband chain level diagram.

Since dc offsets caused by mismatch can completely compress the output of the baseband at high gain, the stages were designed with low input referred dc offset. Every high gain stage

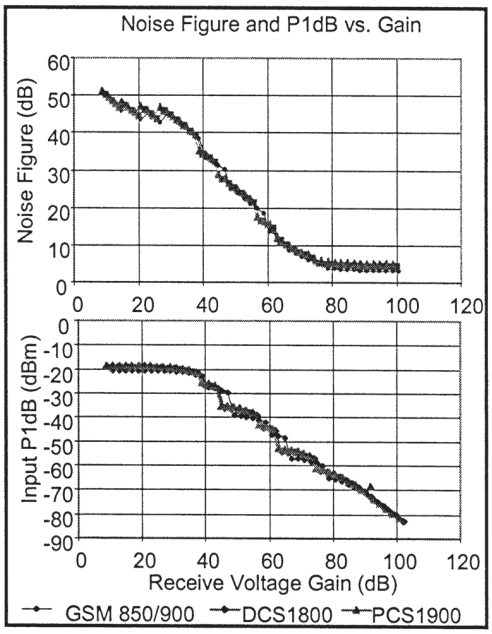


Fig. 13. In-band compression point and noise figure over gain.

is accompanied by a dc offset loop set to calibrate out its residual dc.

1) Folded Cascode Mixer Output: To ease headroom requirements at the output of the mixer core, a PFET folded cascode carries the signal in current mode to a transimpedance output. To reduce the magnitude of the far out blocking signals, a capacitor is connected across the output of the mixer core. This capacitor interacts with the input impedance of the folded cascode to form a real pole.

Removal of the dominant blockers means that the bias through the cascode can be much less than that through the mixer. Large voltage swings are kept absent from the output of the mixer core by the low impedance of the cascode. The current mode signal from the folded cascode is driven into a shunt RC, where the signal is converted into a voltage and simultaneously filtered a second time. After two poles of filtering, the dynamic range requirements are reduced from 105 to 85 dB. Any in-band gain or delay variation resulting from these real poles is compensated by the Sallen Key stage that follows them.

2) Low-Offset, Low-Noise g_mC Filter: The g_mC filters make use of feedback to minimize noise and dc offset generation. The unit g_mC cell is shown in Fig. 14. A standard two quadrant Gilbert multiplier is used [6]. A degenerated transconductance connects to a pair of diodes providing predistortion before driving an undegenerated differential pair. The resulting circuit produces a linear stage with transconductance given by

$$G_m = \frac{I_{\text{out, diff}}}{V_{\text{in, diff}}} = \frac{I_{\text{tune}}}{R_e \cdot I_{\text{bias}}}. \tag{5}$$

Generally, g_mC filters make use of separate transconductors for each feedforward and feedback path. In this design, area and power savings are realized by using only one predistortion

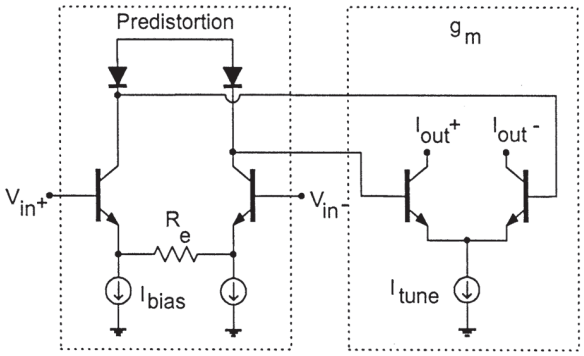


Fig. 14. Tunable g_m stage.

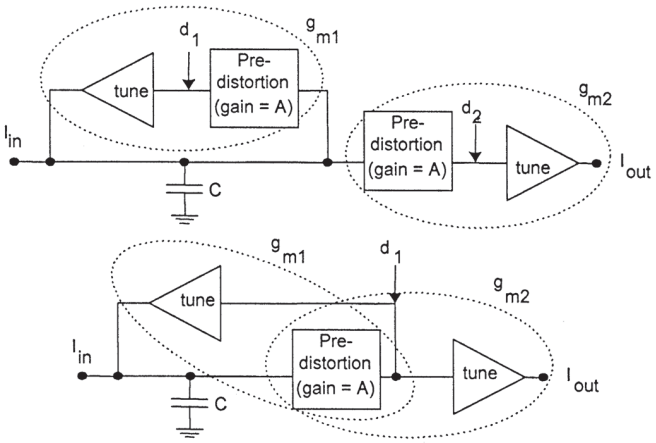


Fig. 15. Two implementations of a single pole g_mC filter.

stage for each capacitor. Multiple transconductances are implemented by connecting multiple tunable differential pairs to each predistortion stage. Each transconductance can be represented by a predistortion stage with small-signal voltage gain A and a tunable stage which, together with A, yields g_m. Separate and shared predistortion implementations of a single pole design are shown in Fig. 15. The transfer function for both designs is given by

$$\frac{I_{\text{out}}}{I_{in}} = \frac{G_{m2}}{sC + G_{m1}}. \tag{6}$$

The effects of noise or dc offsets introduced by the predistortion stages are very different in these two implementations. These effects can be modeled by perturbations d_1 and d_2 after each predistortion stage. The responses to these perturbations for the separate case and the combined case are given by

$$I_{\text{out}} = \frac{G_{m2}}{A}\left[d_2 + d_1 \cdot \left(\frac{G_{m1}}{G_{m1} + sC}\right)\right] \tag{7}$$

$$I_{\text{out}} = \frac{G_{m2}}{A} \cdot \left(d_1 \cdot \frac{sC}{G_{m1} + sC}\right). \tag{8}$$

The combined case yields two advantages. First, d_2 is no longer present. Second, d_1 is suppressed in band by the presence of the sC term in the numerator. Indeed, at dc, the perturbation is completely eliminated, reducing flicker noise and dc offsets in

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TABLE II
SYNTHESIZER SUMMARY

Synthesizer	
Tuning range	1250MHz -1650MHz
Resolution	3Hz
Settling time (to 100ppm)	175μs
Req'd settling time (to 100ppm) [3]	*287μs*
PN @ 100kHz	-106dBc/Hz
PN @ 400kHz	-124dBc/Hz
PN @ 3MHz	-141dBc/Hz
Bias current	28mA

this stage. This suppression means matching and flicker noise are of little concern in the design of predistortion stages, and therefore the designs can be optimized for very small size and low power. In a similar fashion, the predistortion reuse can be extended to nth-order g_mC filters containing real and or complex poles.

IV. LO and Frequency Synthesis

In order to accommodate a quad-band transceiver capable of GPRS operation, a wide-tuning, fast-locking PLL is necessary. A fractional-N architecture [14] is chosen with a nominal loop bandwidth of 25 kHz achieving lock times of less than 175 μs. Due to stringent noise specifications and process limitations, a standard varactor-based VCO system is unacceptable. A hybrid technique is used where the UHF is centered digitally before the analog PLL is engaged. The digital calibration adjusts a switched capacitor array to bring the VCO's frequency within a few megahertz of the desired frequency. Once the calibration is complete, the analog loop provides the fine-tuning. See Table II.

A. UHF VCO

The UHF VCO is based on a standard negative g_m topology coupled to an *LC* tank [15]. The negative g_m is created by a cross-coupled PFET pair. A PMOS core was used instead of an NMOS core not only because the buried channel PMOS device inherently has lower $1/f$ noise, but also to isolate the devices from the substrate.

The differential *LC* tank consists of a pair of on-chip spiral inductors oriented to reject common mode magnetic pickup, a varactor, and a binary weighted capacitor array [16]. The switched capacitor array is designed to provide the highest Q possible and still provide the necessary $C_{\rm on}/C_{\rm off}$ ratio needed to achieve the required tuning range. The inductor size is optimized for a quality factor (Q) of about 9 and self-resonant frequency (SRF) of about 9 GHz to help noise performance and tuning range.

B. Fractional-N PLL

The fractional-N PLL [14] is used to offer fast channel switching and arbitrarily fine frequency resolution and to alleviate design constraints for phase noise and reference spurious, as shown in Fig. 16. The fine frequency resolution is accomplished by interpolating a fractional division using an oversampled $\Delta\Sigma$ modulator with coarse integer divider.

The fractional-N synthesizer consists of a P/FD and charge pump that have four different settings for phase detector gain as well as a polarity bit. The 8/9 prescaler consists of a dual modulus 4/5 divider and a toggle flip-flop. A third-order $\Delta\Sigma$ modulator is used. It has two additional out-of-band poles to filter out the quantization noise at high frequencies. The 3-b output of the $\Delta\Sigma$ modulator is fed to a control block that provides randomized data to the counters.

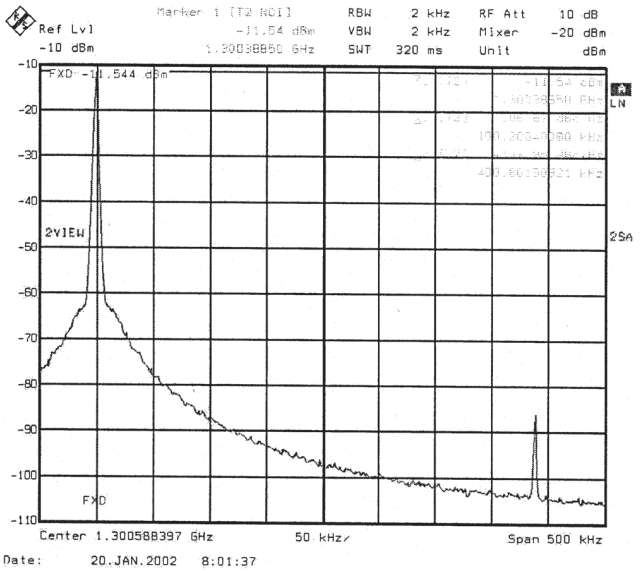


Fig. 16. LO spectrum.

V. Translation Loop Transmitter

The transmitter consists of a frequency translation up-conversion loop [17] with in-loop vector modulation. One LO signal provides both the down-converted and reference IF signals. Because it is generated by dividing down the LO, the channel-dependent IF prevents pulling between the VCOs and LO to IF crossover spurs. The use of selectable frequency dividers and programmable charge pump gain and polarity adds flexibility for frequency planning. The transmit PLL meets the required GSM spectral mask with margin, as shown in Fig. 17. Many of the LO blocks are shared with the receiver, reducing area.

The I/Q vector modulators in the feedback path of the transmitter PLL use a harmonic cancellation technique to reduce IM3 spurs. The modulator performs third-harmonic cancellation by generating two phase-split IF signals that are 60° phase shifted from each other. Using these signals to drive the switching core of the modulator results in third-harmonic terms 180° apart. When the outputs are summed, this technique provides over 20 dB of third-harmonic suppression and allows the external IF filter to be a simple *LC* shunt filter.

Completely differential, integrated VCOs in the transmitter as well as the LO avoid unwanted interaction through bond wires. The transmit VCOs cover all four bands and meet the stringent out-of-band noise specifications of the GSM standard [3]. See Table III. The same digital frequency centering technique is used for the transmitter that is used for the UHF PLL. Since both PLLs are on the same chip and the transmit and UHF frequencies are related through known band select and divide ratio information, the transmit channel request for the digital centering

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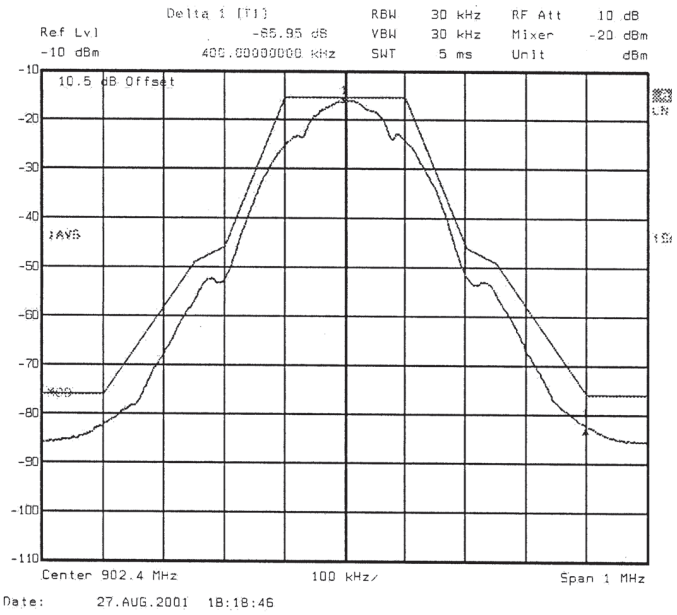


Fig. 17. GSM output spectrum.

TABLE III
TRANSMITTER SUMMARY

Transmitter	*850/900MHz*	*1800/1900MHz*
Phase error	1.5°	1.6°
Req'd phase error (RMS) [3]	*<5°*	*<5°*
200kHz noise	-36dBc/30kHz	-36dBc/30kHz
Req'd 200kHz noise [3]	*-30dBc/30kHz*	*-30dBc/30kHz*
400kHz noise	-64dBc/30kHz	-65dBc/30kHz
Req'd 400kHz noise [3]	*-60dBc/30kHz*	*-60dBc/30kHz*
20MHz noise	-164dBc/Hz	-158dBc/Hz
Req'd 20MHz noise [3]	*-161dBc/Hz*	*-155dBc/Hz*
Bias current (incl. Synth.)	130mA	120mA
Operating voltage	2.7-3.6V	2.7-3.6V

is calculated through a decoder block each time the device is programmed for a new LO channel.

VI. Integration Issues

A. Observability and Controllability

The device is made programmable via a serial bus to facilitate testing, debugging, and optimization. The simplest way to use digital control in an RF SOC is by turning off and bypassing blocks. An example is in a completely integrated LO chain. A bidirectional LO port buffer allows observation of the UHF VCO or the use of an external LO (Fig. 18). Normally, the buffer takes the UHF VCO as an input and drives the LO chain. If the VCO is to be monitored, an extra buffer is activated, driving external inductive loads through the LO port. Alternately, a separate buffer may be biased, using the LO pads as inputs. Such a capability makes it possible to distinguish between problems in the oscillator, the PLL, and the LO buffers or mixers and characterize them separately.

A second way digital control can be used is in the modification of circuit properties. For example, individually modulating the bias currents of RF blocks and observing the effects can often reveal sources of excessive noise or nonlinearity in an RF chain. In addition, such controllability allows for software optimization of circuits, permitting system designers to tradeoff performance and power consumption in the different sections of a receive or transmit chain. See Fig. 19.

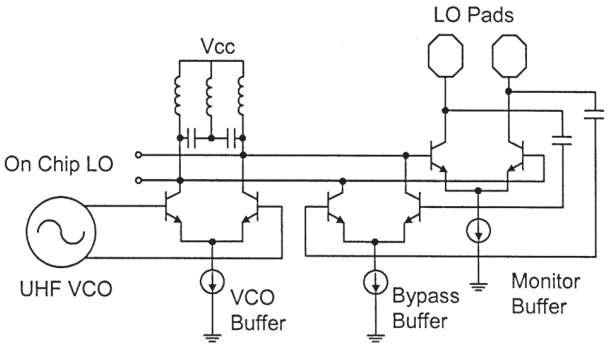


Fig. 18. LO test buffer.

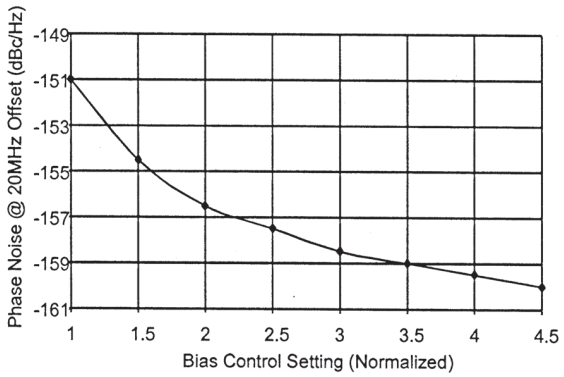


Fig. 19. Programmable bias in DCS/PCS transmitter VCO.

B. Layout

This level of radio integration [18] raises the risk of unwanted coupling of signals between circuits. Careful top-level layout reduces such risks. Specifically, as shown in Fig. 20, the sigma–delta UHF VCO transmit VCOs and LNAs have been situated in the extreme four corners of the chip. To prevent switching noise in the fractional-N synthesizer from interfering with the LNAs, the two circuits are separated by the low-noise baseband analog circuitry. n- and p-type substrate contacts under the baseband supply and ground shunt synthesizer switching noise in the substrate. The degradation of receiver NF due to the synthesizer is less than 0.2 dB.

VII. Process Selection

The transceiver was designed in a 0.35-μm BiCMOS process [19] with NPN $f_t = 35$ GHz. The RF and analog signal paths made extensive use of the high-performance NPN devices, benefiting from their higher speed, better matching, and lower flicker noise. The availability of bipolar junction transistors (BJTs) did not preclude the use of CMOS in those RF applications where CMOS is superior (e.g., in VCOs). Since BJTs provide higher, more predictable g_m and f_t, they were used in the receivers LNAs. Although BJTs are often maligned for their nonlinearity, when combined with high speed, strongly non-

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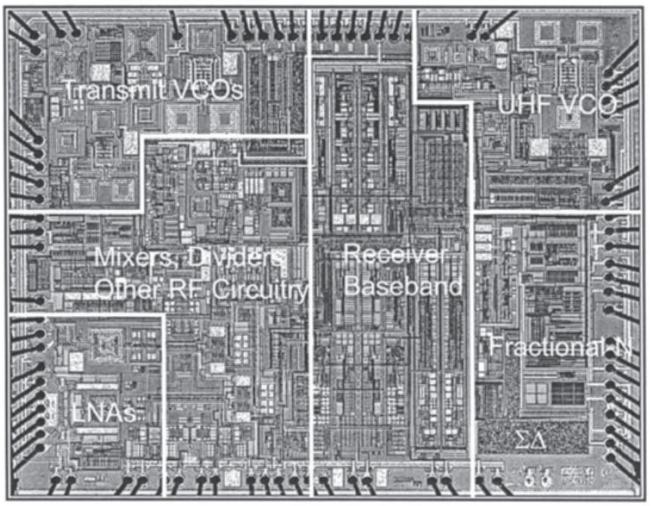


Fig. 20. Microphotograph of transceiver.

linear circuits are ideal for implementing mixers. In addition, since BJTs rely on the behavior of junctions in bulk silicon, rather than surface oxide interfaces, both matching and flicker noise are better in high-speed BJTs than comparable speed MOSFETs. Both mismatch and flicker noise have important consequences for the signal quality at the baseband output of the mixers in a DCR, implying that such mixers are best implemented in BJTs.

CMOS logic was used extensively in the frequency synthesizer as well as an effective means for digital controllability. CMOS was also used in the design of compact, low-power analog circuits. FET current mirrors are generally smaller than standard degenerated BJT mirrors (especially when lateral PNPs are being used). The fact that MOSFET gates draw no real current found use in the implementation of track and hold circuits for dc offset correction in the receiver.

Two properties of CMOS were exploited in the design of RF blocks. The gate of a CMOS transistor looks predominantly capacitive and generates no gate shot noise. In addition, CMOS transistors can be driven deep into the triode region and recover at speeds comparable to their turn-on times without generating excessive noise. In BJTs, deep saturation leads to degradation in β, f_t and all relevant capacitances and noise mechanisms. These properties of CMOS can be used for circuits where very strong signals are needed in combination with low wide-band noise [20].

The inductors were implemented in a 3-μm-thick third metal layer, permitting construction of high Q resonant tanks on chip. MIM capacitors between the second and third metal layers provided very high Q capacitance with a minimum of backside parasitic.

VIII. Conclusion

We have presented a quad-band GSM transceiver that integrates all of the active components of the radio except for the PA. The chip includes a direct conversion receiver, frequency synthesizer, transmitter, and all the VCOs. The IC meets the required specifications for GPRS class 12 with margin [3].

Acknowledgment

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A Single-Chip Quad-Band (850/900/1800/1900 MHz) Direct Conversion GSM/GPRS RF Transceiver with Integrated VCOs and Fractional-N Synthesizer

Rahul Magoon, *Member, IEEE*, Alyosha Molnar, Jeff Zachan, *Member, IEEE*, Geoff Hatcher, *Member, IEEE*, and Woogeun Rhee, *Member, IEEE*

***Abstract*—Recent trends in the integration of entire systems on-chip have spurred the development of homodyne radios as alternatives to the more mature yet harder to integrate superheterodyne architectures. This paper presents a monolithic device that integrates all of the functions necessary to implement a multiband homodyne global system for mobile telecommunications radio except for the power amplifier (PA) and radio frequency (RF) passives. The single BiCMOS chip includes a quad-band direct conversion receiver that down converts RF to quadrature analog baseband. The front-end circuitry is followed by a low-dc-offset, high-dynamic-range, analog I/Q baseband chain. The transmit section is comprised of a quad-band up-conversion transmit phase-locked loop (PLL) including on chip transmit voltage-controlled oscillators (VCOs). The stringent GSM receive band phase noise specifications are met without the use of surface acoustic wave filters. A single $\Sigma\Delta$ fractional-N synthesizer locking a fully integrated ultrahigh frequency VCO generates the system local oscillator signal.**

***Index Terms*—BiCMOS, calibration, direct conversion, frequency dividers, g_mC filters, GPRS, GSM, land mobile radio cellular systems, microwave circuits, modulation, noise, phase-locked loops, power amplifiers, quad band, receivers, system on chip (SOC), transceivers, transmitters, UHF, voltage-controlled oscillators.**

I. Introduction

As MODERN cell phones become ubiquitous, the critical factors in their manufacture become cost, size, and time to market. The high integration of radio ICs reduces board area and complexity while cutting component cost and system design time. Low-cost manufacturers desire freedom to choose the cheapest and most reliable IC for each main handset function. In this context, the interface between the transceiver and the various baseband ICs available on the market becomes important. Radio receiver outputs need to be able to interface to low-dynamic-range analog-to-digital converters (ADCs) through a simple I/Q interface and require little or no digital post processing. Direct conversion and low intermediate frequency (IF) receivers permit increased integration, lower cost, and reduce radio complexity by removing the need for external IF surface acoustic wave (SAW) filters and multiple local oscillator (LO) signals. However, many direct conversion receiver (DCR) implementations [1] and all low IF receivers still require wide dynamic range ADCs.

This work presents a DCR that avoids the traditional problems by means of frequency planning, floor planning, and calibration techniques. The receiver includes a low-dc-offset, high-input-dynamic-range analog I/Q baseband chain capable of interfacing to 9-b ADCs. The transmitter architecture is based on the commonly used translational loop. A single integrated LO provides the channel selection for both the transmitter and the receiver. All VCOs and phase-locked loops (PLLs) are on chip [2].

II. Device Overview

A block diagram of the transceiver, including the necessary external RF components, is shown in Fig. 1. The only required external components, excluding impedance matching and loop filter components, are receive band select SAW filters, a switchplexer, and a power amplifier (PA). Standard differential analog I/Q interfaces are used for the transmitter inputs and for the receiver outputs.

The receive path consists of three single-ended low-noise amplifiers (LNAs) that drive two sets of quadrature subharmonic mixers (SHMs) whose outputs are combined in a common I/Q analog baseband chain. The baseband chains include low-pass channel select filtering, programmable gain, and dc offset correction. A fully integrated translational loop transmitter locks two wide-band on-chip oscillators (one for 1800/1900 MHz, and the other for 850/900 MHz). The loop also includes a down-conversion feedback mixer and a quadrature modulator, along with a phase frequency detector and charge pump. Frequency synthesis is completely integrated including a UHF oscillator and fractional-N PLL. Several stages of LO processing are required to ease the design of the UHF oscillator and to provide quad-band functionality. One of the benefits of complete LO integration is that the only RF signals present on pins or bond wires are the received inputs at the LNAs and the transmitted outputs to the PA.

The transceiver incorporates a three-wire serial interface programming bus providing frequency control, gain control, and broad testability of integrated blocks. A test port is provided for

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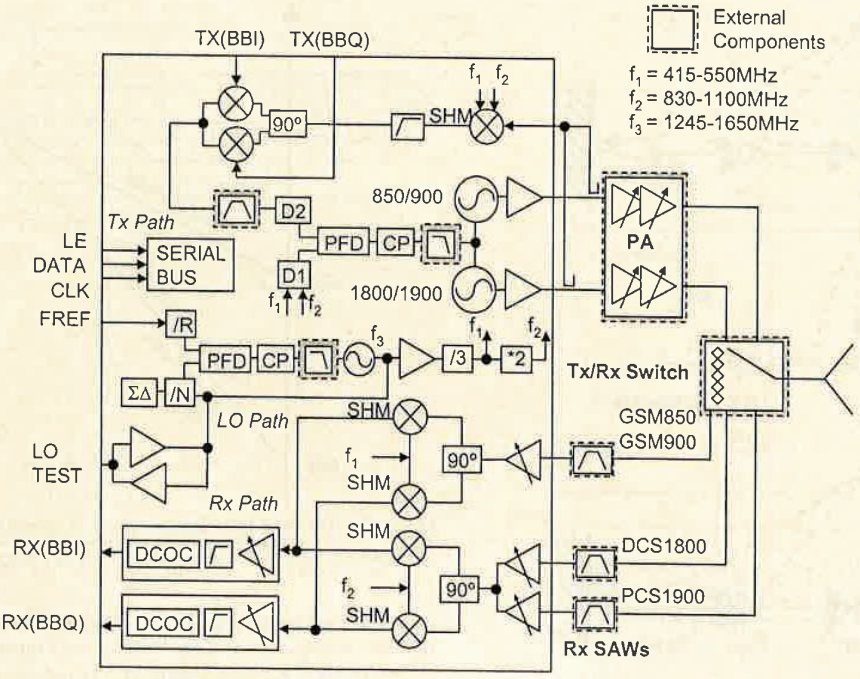


Fig. 1. Top-level schematic of transceiver, with external RF components.

monitoring the LO during testing and is disabled during normal operation. Separate transmit, receive, and synthesizer control input pins permit enabling from the digital baseband.

III. DCR

The direct conversion approach presents several unique design challenges. All of these have to do with the generation of excessive or time-varying dc offsets at the outputs of the receiver. Aside from simple process and layout related mismatches, the two primary sources of dc are LO leakage to the RF inputs and even-order nonlinearities in the receive path. While constant dc offsets can be calibrated out, mechanisms that result in unpredictable time-varying dc offsets must be suppressed by a careful choice of architecture and circuit design.

1) DC Offsets: DC offsets can corrupt data in systems such as global system for mobile telecommunications (GSM), where information is present down to dc. It is possible to subtract offsets in the DSP, provided they are constant over a given receive slot. Large dc offsets may overload the ADC or some portion of the analog baseband, causing the received signal to clip, corrupting information before correction in the DSP is possible. Signal independent dc can be generated in several ways. One way is through mismatches in the mixer and baseband. Offsets from mismatches can pose a problem since most of the receiver's gain appears after the mixer, and so even small offsets, once gained up, can overwhelm the receiver. Fortunately, fixed dc offsets may be corrected by activating the mixer and baseband early and performing a closed-loop calibration.

A second source of dc offsets comes from the LO signal coupling onto the receive chain at some point before the mixer. This signal, once present, is down converted to dc. As shown in Fig. 2(a), the LO signal may couple to the output and or the input of the LNA or reradiate and reflect off an external surface and be picked up by the antenna. In the first case, simple dc offset calibration may be used. In the second case, calibration is also possible but may be inaccurate if interfering signals are present on the antenna. The third case, however, represents an unpredictable situation leading to a time-varying dc signal. LO re radiation must thus be minimized by design.

2) IIP2: Another way that dc can be generated is through second-order nonlinearity in the signal path. These nonlinearities cause strong out of band signals to be converted to dc, as in

$$F(x) = a_1 \cdot x + a_2 \cdot x^2$$

$$F(A \cdot \cos(\omega t)) = a_1 \cdot A \cdot \cos(\omega t) + \frac{1}{2} \cdot a_2 \cdot A^2[1 + \cos(2 \cdot \omega t)] \quad (1)$$

and are collectively characterized by the second-order intercept point, IIP2 of the receiver. See Fig. 3. IIP2 effects can be caused by two distinct mechanisms. One mechanism involves simple even-order nonlinearities in the mixer or baseband. This phenomenon is characteristic of single-ended circuits and is even possible in differential circuits if asymmetries are present. The other mechanism involves large RF blocking signals coupling onto the LO chain and phase modulating the LO signal. See Figs. 2(b) and 4. Since one of the resulting side bands corresponds to the original RF signal, the RF is down converted to dc as shown in

$$LO' = LO + k \cdot RF_{\text{blocker}}$$

$$= \cos(\omega_{LO} \cdot t) + k \cdot \cos(\omega_{RF} \cdot t)$$

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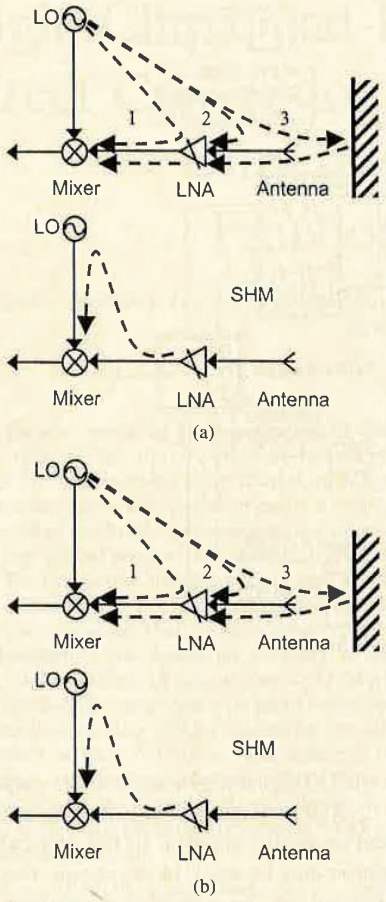


Fig. 2. Coupling paths that can cause dc offsets. (a) LO to RF coupling. (b) RF to LO coupling.

$$RF \cdot LO' = \frac{1}{2}\left[A \cdot \cos((\omega_{RF} \pm \omega_{LO}) \cdot t)\right] + k \cdot A^2[1 + \cos(2 \cdot \omega_{RF} t)]. \quad (2)$$

IIP2 performance is especially important in cases where blocker strength varies unpredictably in the middle of a receive slot. In these cases, dc offset calibration is impossible and DSP algorithms are less effective. It is this situation, specified for GSM by the AM suppression test [3], which sets the lower bound on IIP2 in a GSM DCR. For example, in the EGSM band, the radio must be able to reliably continue receiving a signal at -99 dBm when a -31-dBm signal at 6-MHz offset unexpectedly turns on mid slot. The required IIP2 can be calculated as

$$\begin{aligned} IIP2_{\text{req}}(\text{dBm}) &= 2 \cdot P_{\text{blocker}}(\text{dBm}) \\ &\quad - (P_{\text{signal}} - SNR_{\text{req}} + 3\ \text{dB}) \\ IIP2_{\text{req}} &= 2 \cdot (-31\ \text{dBm}) \\ &\quad - (-99\ \text{dBm} - 9\ \text{dB} + 3\ \text{dB}) \\ &= +43\ \text{dBm (at the antenna)} \\ IIP2_{\text{req}} &= +40\ \text{dBm (at the LNA input, assuming} \\ &\quad 3\ \text{dB front end loss}). \end{aligned} \quad (3)$$

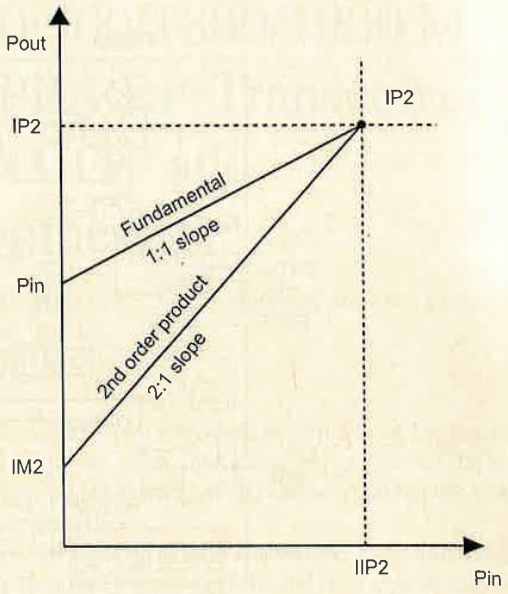


Fig. 3. Second-order intercept diagram. Both axes are in dBm.

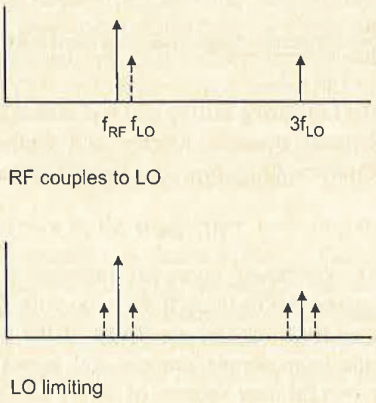


Fig. 4. Modulation of LO by RF.

A. Ratioed LO Frequency Plan

LO and RF self mixing can both be reduced using offset frequency architectures [4]. One method for generating offset LO signals is through a combination of frequency dividers and multipliers. In such a system, subharmonic LOs signals should be of even order relative to the received signal. This requirement arises from the common use of differential hard switched circuits in dividers, LO buffers, and mixers. Hard switched differential circuits tend to generate odd harmonics of the switching frequency and also respond to interfering signals close to their odd harmonics, as if they were sidebands of the fundamental.

In the LO chain presented here and shown in Fig. 1, a single LO provides a signal in the range from 1250 to 1650 MHz. This signal is fed to a frequency divide-by-three circuit, which generates a subharmonic LO signal in the range 415 to 550 MHz. This signal is then passed directly to a 1/2 LO SHM to down convert received signals in the 850-MHz US cellular and 900-MHz EGSM bands. Alternately, for high band operation, the signal is passed to a frequency doubler generating an LO signal from 830

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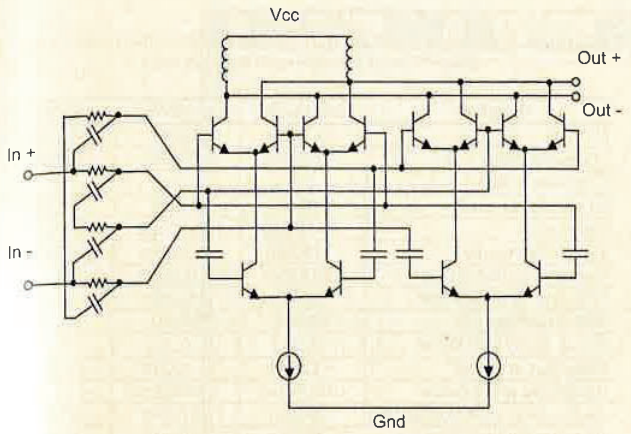


Fig. 5. Low-output harmonic doubler.

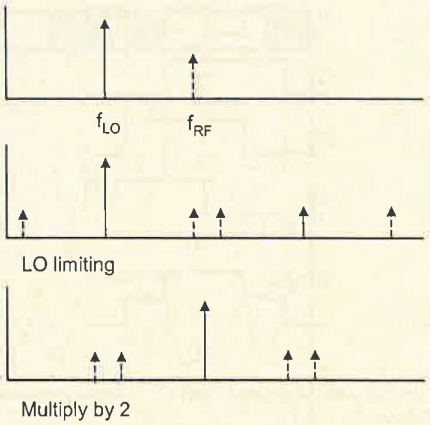


Fig. 6. Modulation of 1/2 LO by RF.

MHz to 1.1 GHz. This LO signal is then fed to a 1/2 LO SHM to down convert signals in the 1800-MHz DCS and 1900-MHz PCS bands.

1) Frequency Doubling and 1/2 LO Mixers: The use of a subharmonic LO signal clearly reduces LO reradiation and self mixing. Since the reradiated LO signal will be present at 1/2 or 1/4 the received frequency, it will not be down converted to baseband. In addition, RF coupling onto a subharmonic LO will not modulate the LO signal in a fashion that can degrade IIP2.

The implementation of the frequency doubling function is critical. Typically, frequency doubling in both SHM [9] and frequency doublers is implemented by multiplying two signals of the same frequency that are phase split by 90 degrees, as represented by

$$\sin(\omega t) \cdot \cos(\omega t) = \frac{1}{2} \cdot \sin(2\omega t). \tag{4}$$

An efficient doubling circuit makes use of hard switched phase split signals instead of sinusoidal signals. The circuit shown in Fig. 5 accomplishes frequency doubling as follows. An RC polyphase filter provides the quadrature phase split. The resulting signal then drives a pair of hard switched Gilbert multipliers [6]. The use of two such multipliers, whose outputs are summed and whose inputs are cross coupled, provides higher order symmetry [7]. This symmetry guarantees low-output even-order harmonics (provided that the phase split is accurate).

Since (4) essentially represents the up conversion of one signal by the other, it should be clear that the sidebands of either signal will be up converted with their frequency offsets intact, as shown in Fig. 6. In other words, RF signals coupling onto a subharmonic LO will generate sidebands at offsets equal to the frequency difference between the subharmonic LO signal and RF signal. Even after the fundamental frequency is doubled in the frequency doubler or SHM, this offset is maintained resulting in sidebands at, for example, $F_{RF} \pm F_{LO}$, where $F_{LO} \sim 1/2F_{RF}$. Such sidebands will not align with the original received signal, and will not result in IIP2 degradation.

2) Divide by Three: Although subharmonics do not reradiate at the RF frequency, they can generate harmonics that do. The VCO generating the LO signal includes relatively large structures in its resonant tank and operates at relatively high power. To avoid problems with VCO-generated harmonics, the oscillator runs at three times the subharmonic frequency and is followed by a lower power divide-by-three circuit. The analysis of the interaction between even-order subharmonic signals and received signals also applies to odd multiples of even-order subharmonics. LO signals at 3/2 and 3/4 the receive frequency are as insensitive to coupling as those at 1/2 and 1/4. As an additional benefit, VCOs can more easily be integrated in the 1.5-GHz range than in the 0.5-GHz range as discussed later in this paper.

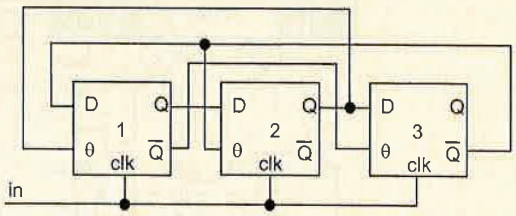


Fig. 7. Architecture of frequency divide-by-three with 50% duty cycle.

Two problems arise from the implementation of a frequency divide-by-three. The first results from the fact that most odd-order frequency dividers generate outputs with non 50% duty cycles. This results in generation of strong even-order harmonics, obviating the use of an even-order subharmonic LO. The second problem is more subtle. As mentioned before, doubling of frequencies typically involves quadrature split inputs. If polyphase filters are used to generate quadrature, the input signals are required to be sinusoidal. Therefore, the reduction of higher harmonics at the output of the frequency divide-by-three is very important [8].

A true 50% duty cycle frequency divide-by-three was implemented using three phase-switchable level-sensitive latches connected in a loop. Each latch, in addition to its data and clock inputs, has a third input which is denoted by θ. This input toggles the latch between triggering on the positive and negative levels of the clock. Proper interconnection of Q, D, and θ between latches (shown in Fig. 7) results in a signal of 1/3 the clock frequency propagating through the loop by one latch each 1/2 clock cycle. The resulting waveforms are shown in Fig. 8(a). Implementation of such latches in differential emitter coupled logic (ECL) permits the necessary signal inversions without asymmetry.

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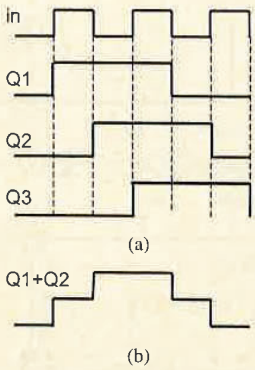


Fig. 8. (a) Internal states of divide-by-three. (b) Output generated by summing two internal states.

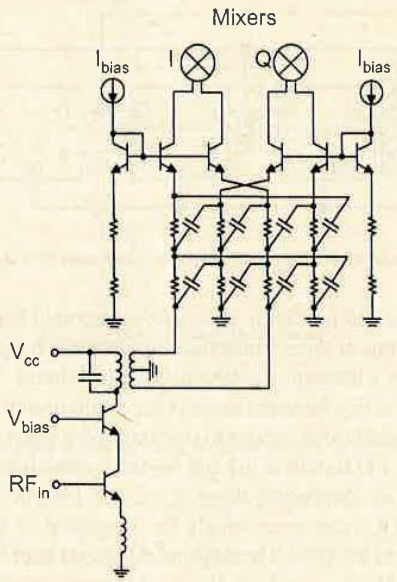


Fig. 9. LNA, RF path phase split, and mixer RF port.

In order to suppress the strong third harmonic present in the square wave outputs of this divider, one additional step is needed. Each of the three latches has as its output a signal 60° delayed from the previous stage. Summation of two such signals results in an output with a fundamental 30° shifted from the first, with slightly less than twice the amplitude. The third harmonics of the summed signals, however, are 180° split and as a result they completely cancel. The resulting much more sinusoidal signal is shown in Fig. 8(b).

3) RF Path Quadrature Generation: Simple 90° phase splitting of the subharmonic LO is insufficient to generate I/Q receiver outputs because upon frequency doubling; the phase also doubles to 180°. The use of 45° splits has also been explored [9]; however, most schemes are either very lossy or lose accuracy over process variations. As an alternative, quadrature may be generated in the RF path. An RF path phase splitter is shown in Fig. 9. A two-stage polyphase filter guarantees amplitude matching across band and process. By incorporating this structure as degeneration for the replica biasing of the common base RF port of the mixer, one can implement the phase split without any extra voltage headroom. The use of a common base RF port provides significant isolation between the mixer core and LNA, attenuating any LO signal that might couple back to the LNA and potentially self mix.

TABLE I
RECEIVER PERFORMANCE. SENSITIVITY NUMBERS INCLUDE LOSSES FROM FRONT-END FILTERS AND SWITCHPLEXER

Receiver	850/900MHz	1800MHz	1900MHz
NF	3.1dB	3.6dB	4.1dB
LO re-radiation	-110dBm	-105dBm	-103dBm
IQ phase match	1°	1°	1°
IQ amplitude match	0.5dB	0.5dB	0.5dB
Gain range	10-105dB	10-100dB	10-100dB
Typical sensitivity	-109dBm	-107dBm	-107dBm
Required sensitivity [3]	*-102dBm*	*-100dBm*	*-102dBm*
IIP2 over channels (cal.)	> 50dBm	> 50dBm	> 50dBm
3dB baseband BW	98kHz	98kHz	98kHz
Group delay to 100kHz	< 0.3μs	< 0.3μs	< 0.3μs
Rejection at 3MHz	> 120dB	> 120dB	> 120dB
Sensitivity with blocker	-105.5dBm	-104dBm	-104dBm
Req'd sens. with blocker [3]	*-99dBm*	*-97dBm*	*-97dBm*
Bias current (incl. Synth.)	75mA	80mA	80mA
Operating voltage	2.7-3.6V	2.7-3.6V	2.7-3.6V

4) Results: Reradiation of on-frequency LO signal measured at the LNA input is −110 dBm in GSM, −105 dBm in DCS, and −103 dBm in PCS. In addition, the subharmonic LO chain exhibits good phase noise as evidenced by the fact that the worst case blockers desensitize the receiver by less than 4 dB. The RF path phase split is effective in generating quadrature accurate to 1° and 0.5 dB measured at the baseband outputs. The NF measured for the whole receiver is 3.1 dB in GSM, 3.6 dB in DCS, and 4.1 dB in PCS. See Table I. As compared to traditional superheterodyne receivers, power is saved by replacing the IF strip with baseband amplifiers and filters and by removing one local oscillator. Unfortunately, these power benefits tend to be balanced out by the greater complexity and integration of the LO chain. The receiver (including PLL and oscillator) consumes 75 and 80 mA from 2.7 V in GSM and DCS modes, respectively.

B. IIP2 Cancellation

Although the frequency plan described above is effective in suppressing RF self mixing, simple second-order nonlinearity still limits IIP2. IIP2 in a purely differential structure (such as a double balanced mixer) is theoretically infinite. All IIP2 effects must therefore be a consequence of asymmetry. Although most asymmetries can be reduced by careful layout and design, imperfections will always be present due to device mismatch. In order to compensate for this problem, an IIP2 cancellation scheme was developed. This scheme essentially introduces an intentional (digitally programmable) asymmetry into the mixer in order to null blocker induced dc offsets, thereby canceling IIP2. This calibration provides a 15-dB improvement in receiver IIP2 across the band, raising it from better than 35 dBm to better than 50 dBm for all bands. Fig. 10 shows the effect on dc of a blocker at a 6-MHz offset ramping from −30 to −24 dBm in the presence of a −99-dBm wanted signal.

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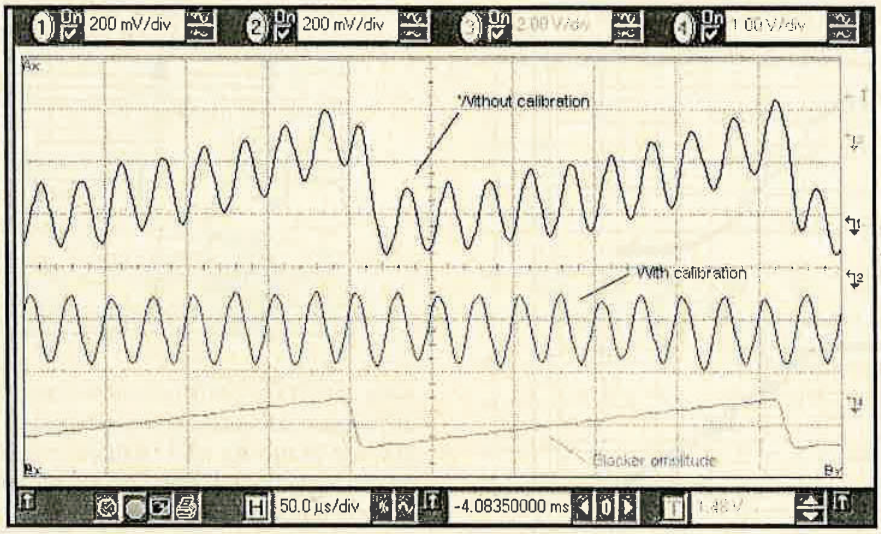


Fig. 10. Effects of AM modulated blocker (bottom curve) on received signal with and without IIP2 calibration.

C. Baseband Circuitry

One of the benefits of the DCR is the migration of all the functions usually present in the IF strip to baseband. In principle, any function performed at an IF of several hundred megahertz is easier to implement at several hundred kilohertz with less power consumption and higher integration. However, the standard challenges associated with high dynamic range are then complicated by a new set of problems including dc offsets, flicker noise, and even-order nonlinearities [10].

Without the benefit of a high Q channel select filter and wide range IF PGA, the baseband is forced to deal with the full range of blocker and signal strengths present at the mixer output. In addition, the baseband must be able to handle the entire possible range of signal and blocker strengths without significantly degrading the noise performance of the receiver or compressing the wanted signal. A GSM receiver with an NF of 3 dB and a 1-dB compression point of -22 dBm requires a dynamic range of approximately 95 dB. To avoid undesired degradation, this translates to a dynamic range of more than 105 dB in the baseband.

In this design, the distribution of gain and filtering is designed to attenuate far out blockers early in the chain to ease headroom requirements for later stages (see Figs. 11 and 12). The current mode output of the mixer is directly coupled to a folded cascode stage implementing two real poles set by resistor and capacitor combinations with 40 dB of effective gain. This stage is followed by a Sallen Key filter, which implements two complex conjugate poles and 10 dB of gain. Such *RC*-based filters and amplifiers have very high dynamic range, but must be wide band enough to avoid inband interference from process variations. Once the far out blockers (1.6 MHz, 3 MHz, and beyond) are attenuated, the dynamic range requirements of the following stages are relaxed. Lower dynamic range permits the use of low power and tightly controlled g_mC filters to remove the closer blockers (200 kHz, 400 kHz, and 600 kHz). A continuous time filter [11] was used instead of a switched capacitor filter [12] due to concerns that the reference clock would couple to the on

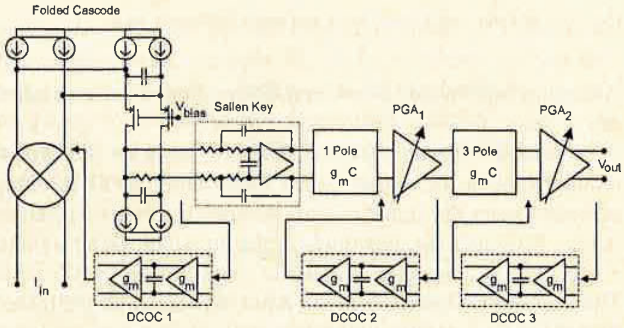


Fig. 11. Mixer output and baseband chain.

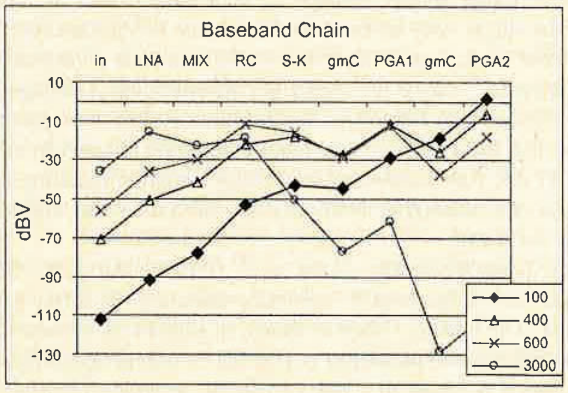


Fig. 12. Baseband chain level diagram.

chip LNA and VCOs. Gain stages are interleaved with the filters to increase wanted signal strength and to ease noise restrictions. In order to avoid compression at higher desired signal levels, the gain is made programmable. See Fig. 13.

Since dc offsets caused by mismatch can completely compress the output of the baseband at high gain, the stages were designed with low input referred dc offset. Every high gain stage

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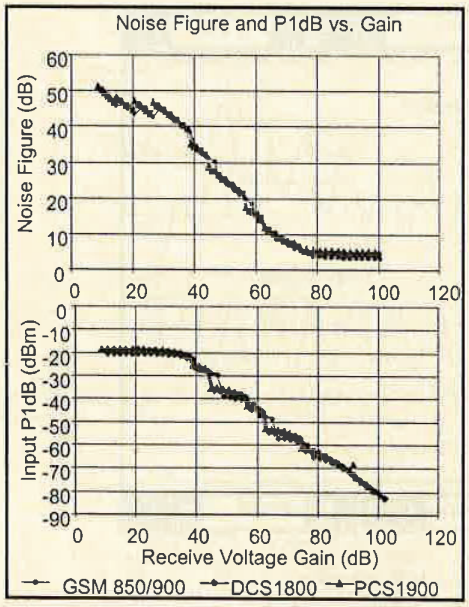


Fig. 13. In-band compression point and noise figure over gain.

is accompanied by a dc offset loop set to calibrate out its residual dc.

1) Folded Cascode Mixer Output: To ease headroom requirements at the output of the mixer core, a PFET folded cascode carries the signal in current mode to a transimpedance output. To reduce the magnitude of the far out blocking signals, a capacitor is connected across the output of the mixer core. This capacitor interacts with the input impedance of the folded cascode to form a real pole.

Removal of the dominant blockers means that the bias through the cascode can be much less than that through the mixer. Large voltage swings are kept absent from the output of the mixer core by the low impedance of the cascode. The current mode signal from the folded cascode is driven into a shunt RC, where the signal is converted into a voltage and simultaneously filtered a second time. After two poles of filtering, the dynamic range requirements are reduced from 105 to 85 dB. Any in-band gain or delay variation resulting from these real poles is compensated by the Sallen Key stage that follows them.

2) Low-Offset, Low-Noise g_mC Filter: The g_mC filters make use of feedback to minimize noise and dc offset generation. The unit g_mC cell is shown in Fig. 14. A standard two quadrant Gilbert multiplier is used [6]. A degenerated transconductance connects to a pair of diodes providing predistortion before driving an undegenerated differential pair. The resulting circuit produces a linear stage with transconductance given by

$$G_m = \frac{I_{\text{out, diff}}}{V_{\text{in, diff}}} = \frac{I_{\text{tune}}}{R_e \cdot I_{\text{bias}}}. \tag{5}$$

Generally, g_mC filters make use of separate transconductors for each feedforward and feedback path. In this design, area and power savings are realized by using only one predistortion

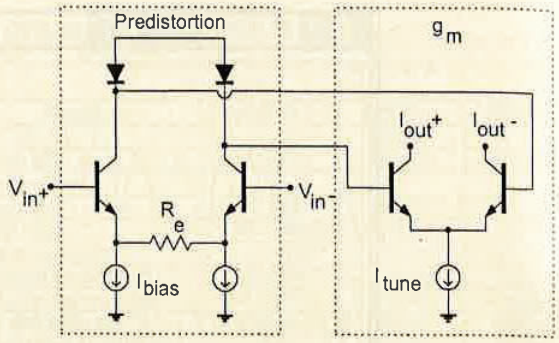


Fig. 14. Tunable g_m stage.

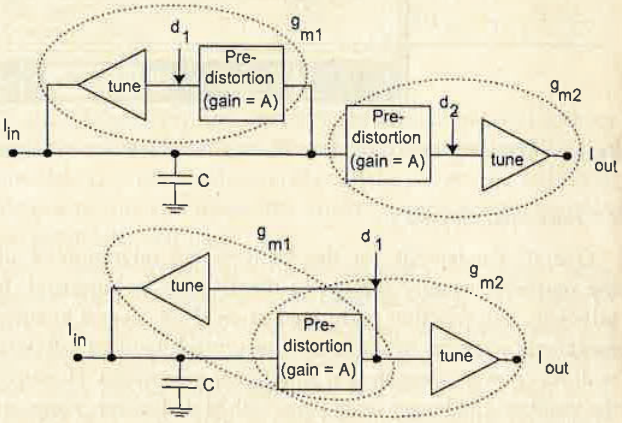


Fig. 15. Two implementations of a single pole g_mC filter.

stage for each capacitor. Multiple transconductances are implemented by connecting multiple tunable differential pairs to each predistortion stage. Each transconductance can be represented by a predistortion stage with small-signal voltage gain A and a tunable stage which, together with A, yields g_m. Separate and shared predistortion implementations of a single pole design are shown in Fig. 15. The transfer function for both designs is given by

$$\frac{I_{\text{out}}}{I_{in}} = \frac{G_{m2}}{sC + G_{m1}}. \tag{6}$$

The effects of noise or dc offsets introduced by the predistortion stages are very different in these two implementations. These effects can be modeled by perturbations d_1 and d_2 after each predistortion stage. The responses to these perturbations for the separate case and the combined case are given by

$$I_{\text{out}} = \frac{G_{m2}}{A}\left[d_2 + d_1 \cdot \left(\frac{G_{m1}}{G_{m1} + sC}\right)\right] \tag{7}$$

$$I_{\text{out}} = \frac{G_{m2}}{A} \cdot \left(d_1 \cdot \frac{sC}{G_{m1} + sC}\right). \tag{8}$$

The combined case yields two advantages. First, d_2 is no longer present. Second, d_1 is suppressed in band by the presence of the sC term in the numerator. Indeed, at dc, the perturbation is completely eliminated, reducing flicker noise and dc offsets in

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TABLE II
SYNTHESIZER SUMMARY

Synthesizer	
Tuning range	1250MHz -1650MHz
Resolution	3Hz
Settling time (to 100ppm)	175μs
Req'd settling time (to 100ppm) [3]	*287μs*
PN @ 100kHz	-106dBc/Hz
PN @ 400kHz	-124dBc/Hz
PN @ 3MHz	-141dBc/Hz
Bias current	28mA

this stage. This suppression means matching and flicker noise are of little concern in the design of predistortion stages, and therefore the designs can be optimized for very small size and low power. In a similar fashion, the predistortion reuse can be extended to nth-order g_mC filters containing real and or complex poles.

IV. LO and Frequency Synthesis

In order to accommodate a quad-band transceiver capable of GPRS operation, a wide-tuning, fast-locking PLL is necessary. A fractional-N architecture [14] is chosen with a nominal loop bandwidth of 25 kHz achieving lock times of less than 175 μs. Due to stringent noise specifications and process limitations, a standard varactor-based VCO system is unacceptable. A hybrid technique is used where the UHF is centered digitally before the analog PLL is engaged. The digital calibration adjusts a switched capacitor array to bring the VCO's frequency within a few megahertz of the desired frequency. Once the calibration is complete, the analog loop provides the fine-tuning. See Table II.

A. UHF VCO

The UHF VCO is based on a standard negative g_m topology coupled to an LC tank [15]. The negative g_m is created by a cross-coupled PFET pair. A PMOS core was used instead of an NMOS core not only because the buried channel PMOS device inherently has lower $1/f$ noise, but also to isolate the devices from the substrate.

The differential LC tank consists of a pair of on-chip spiral inductors oriented to reject common mode magnetic pickup, a varactor, and a binary weighted capacitor array [16]. The switched capacitor array is designed to provide the highest Q possible and still provide the necessary $C_{\text{on}}/C_{\text{off}}$ ratio needed to achieve the required tuning range. The inductor size is optimized for a quality factor (Q) of about 9 and self-resonant frequency (SRF) of about 9 GHz to help noise performance and tuning range.

B. Fractional-N PLL

The fractional-N PLL [14] is used to offer fast channel switching and arbitrarily fine frequency resolution and to alleviate design constraints for phase noise and reference spurious, as shown in Fig. 16. The fine frequency resolution is accomplished by interpolating a fractional division using an oversampled $\Delta\Sigma$ modulator with coarse integer divider.

The fractional-N synthesizer consists of a P/FD and charge pump that have four different settings for phase detector gain as well as a polarity bit. The 8/9 prescaler consists of a dual modulus 4/5 divider and a toggle flip-flop. A third-order $\Delta\Sigma$ modulator is used. It has two additional out-of-band poles to filter out the quantization noise at high frequencies. The 3-b output of the $\Delta\Sigma$ modulator is fed to a control block that provides randomized data to the counters.

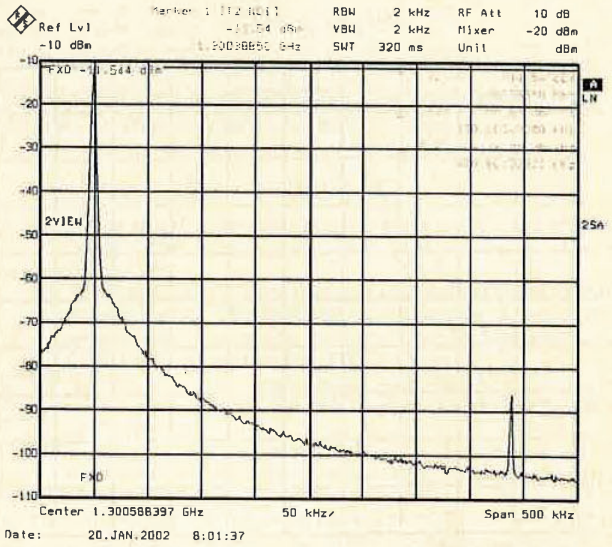


Fig. 16. LO spectrum.

V. Translation Loop Transmitter

The transmitter consists of a frequency translation up-conversion loop [17] with in-loop vector modulation. One LO signal provides both the down-converted and reference IF signals. Because it is generated by dividing down the LO, the channel-dependent IF prevents pulling between the VCOs and LO to IF crossover spurs. The use of selectable frequency dividers and programmable charge pump gain and polarity adds flexibility for frequency planning. The transmit PLL meets the required GSM spectral mask with margin, as shown in Fig. 17. Many of the LO blocks are shared with the receiver, reducing area.

The I/Q vector modulators in the feedback path of the transmitter PLL use a harmonic cancellation technique to reduce IM3 spurs. The modulator performs third-harmonic cancellation by generating two phase-split IF signals that are 60° phase shifted from each other. Using these signals to drive the switching core of the modulator results in third-harmonic terms 180° apart. When the outputs are summed, this technique provides over 20 dB of third-harmonic suppression and allows the external IF filter to be a simple LC shunt filter.

Completely differential, integrated VCOs in the transmitter as well as the LO avoid unwanted interaction through bond wires. The transmit VCOs cover all four bands and meet the stringent out-of-band noise specifications of the GSM standard [3]. See Table III. The same digital frequency centering technique is used for the transmitter that is used for the UHF PLL. Since both PLLs are on the same chip and the transmit and UHF frequencies are related through known band select and divide ratio information, the transmit channel request for the digital centering

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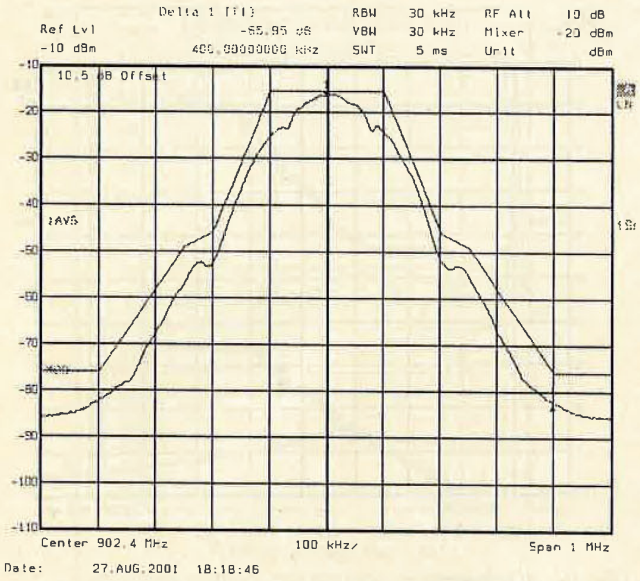


Fig. 17. GSM output spectrum.

TABLE III
TRANSMITTER SUMMARY

Transmitter	*850/900MHz*	*1800/1900MHz*
Phase error	1.5°	1.6°
Req'd phase error (RMS) [3]	*<5°*	*<5°*
200kHz noise	-36dBc/30kHz	-36dBc/30kHz
Req'd 200kHz noise [3]	*-30dBc/30kHz*	*-30dBc/30kHz*
400kHz noise	-64dBc/30kHz	-65dBc/30kHz
Req'd 400kHz noise [3]	*-60dBc/30kHz*	*-60dBc/30kHz*
20MHz noise	-164dBc/Hz	-158dBc/Hz
Req'd 20MHz noise [3]	*-161dBc/Hz*	*-155dBc/Hz*
Bias current (incl. Synth.)	130mA	120mA
Operating voltage	2.7-3.6V	2.7-3.6V

is calculated through a decoder block each time the device is programmed for a new LO channel.

VI. Integration Issues

A. Observability and Controllability

The device is made programmable via a serial bus to facilitate testing, debugging, and optimization. The simplest way to use digital control in an RF SOC is by turning off and bypassing blocks. An example is in a completely integrated LO chain. A bidirectional LO port buffer allows observation of the UHF VCO or the use of an external LO (Fig. 18). Normally, the buffer takes the UHF VCO as an input and drives the LO chain. If the VCO is to be monitored, an extra buffer is activated, driving external inductive loads through the LO port. Alternately, a separate buffer may be biased, using the LO pads as inputs. Such a capability makes it possible to distinguish between problems in the oscillator, the PLL, and the LO buffers or mixers and characterize them separately.

A second way digital control can be used is in the modification of circuit properties. For example, individually modulating the bias currents of RF blocks and observing the effects can often reveal sources of excessive noise or nonlinearity in an RF chain. In addition, such controllability allows for software optimization of circuits, permitting system designers to tradeoff performance and power consumption in the different sections of a receive or transmit chain. See Fig. 19.

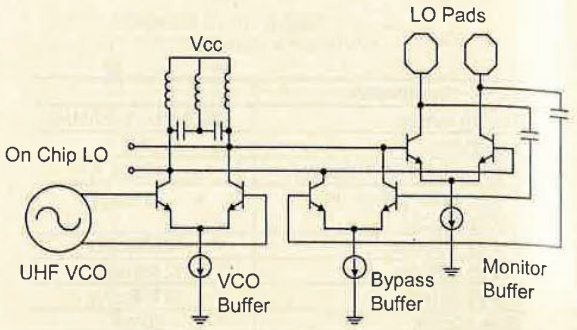


Fig. 18. LO test buffer.

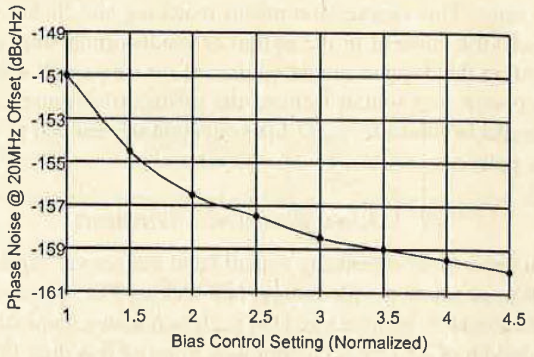


Fig. 19. Programmable bias in DCS/PCS transmitter VCO.

B. Layout

This level of radio integration [18] raises the risk of unwanted coupling of signals between circuits. Careful top-level layout reduces such risks. Specifically, as shown in Fig. 20, the sigma–delta UHF VCO transmit VCOs and LNAs have been situated in the extreme four corners of the chip. To prevent switching noise in the fractional-N synthesizer from interfering with the LNAs, the two circuits are separated by the low-noise baseband analog circuitry. n- and p-type substrate contacts under the baseband supply and ground shunt synthesizer switching noise in the substrate. The degradation of receiver NF due to the synthesizer is less than 0.2 dB.

VII. Process Selection

The transceiver was designed in a 0.35-μm BiCMOS process [19] with NPN $f_t = 35$ GHz. The RF and analog signal paths made extensive use of the high-performance NPN devices, benefiting from their higher speed, better matching, and lower flicker noise. The availability of bipolar junction transistors (BJTs) did not preclude the use of CMOS in those RF applications where CMOS is superior (e.g., in VCOs). Since BJTs provide higher, more predictable g_m and f_t, they were used in the receivers LNAs. Although BJTs are often maligned for their nonlinearity, when combined with high speed, strongly non-

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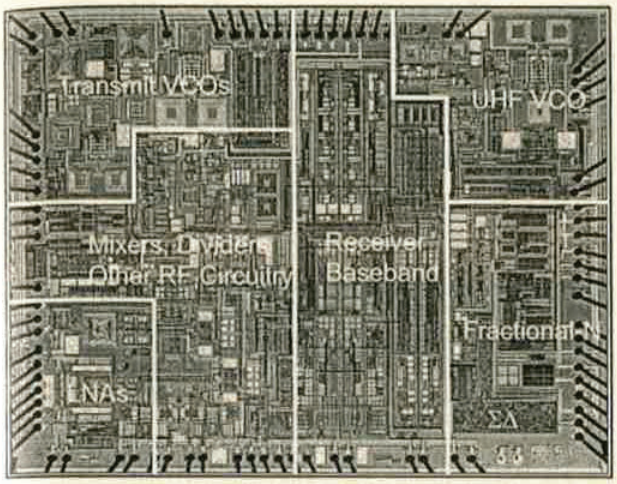


Fig. 20. Microphotograph of transceiver.

linear circuits are ideal for implementing mixers. In addition, since BJTs rely on the behavior of junctions in bulk silicon, rather than surface oxide interfaces, both matching and flicker noise are better in high-speed BJTs than comparable speed MOSFETs. Both mismatch and flicker noise have important consequences for the signal quality at the baseband output of the mixers in a DCR, implying that such mixers are best implemented in BJTs.

CMOS logic was used extensively in the frequency synthesizer as well as an effective means for digital controllability. CMOS was also used in the design of compact, low-power analog circuits. FET current mirrors are generally smaller than standard degenerated BJT mirrors (especially when lateral PNPs are being used). The fact that MOSFET gates draw no real current found use in the implementation of track and hold circuits for dc offset correction in the receiver.

Two properties of CMOS were exploited in the design of RF blocks. The gate of a CMOS transistor looks predominantly capacitive and generates no gate shot noise. In addition, CMOS transistors can be driven deep into the triode region and recover at speeds comparable to their turn-on times without generating excessive noise. In BJTs, deep saturation leads to degradation in β, f_t and all relevant capacitances and noise mechanisms. These properties of CMOS can be used for circuits where very strong signals are needed in combination with low wide-band noise [20].

The inductors were implemented in a 3-μm-thick third metal layer, permitting construction of high Q resonant tanks on chip. MIM capacitors between the second and third metal layers provided very high Q capacitance with a minimum of backside parasitic.

VIII. Conclusion

We have presented a quad-band GSM transceiver that integrates all of the active components of the radio except for the PA. The chip includes a direct conversion receiver, frequency synthesizer, transmitter, and all the VCOs. The IC meets the required specifications for GPRS class 12 with margin [3].

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042	__	|**a** nsdp |**a** pcc
050	00	|**a** TK7871.85 |**b** .I23
210	0_	|**a** IEEE j. solid-state circuits
222	_0	|**a** IEEE journal of solid-state circuits
245	00	|**a** IEEE journal of solid-state circuits.
246	3_	|**a** Institute of Electrical and Electronics Engineers journal of solid state circuits
246	30	|**a** Journal of solid-state circuits
260	__	|**a** New York, N.Y. : |**b** Institute of Electrical and Electronics Engineers, |**c** ©1966-
300	__	|**a** volumes : |**b** illustrations ; |**c** 28 cm
310	__	|**a** Monthly, |**b** 1991-

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321	__	|**a** Quarterly, |**b** 1966-
321	__	|**a** Bimonthly, |**b** <1986->
336	__	|**a** text |**b** txt |**2** rdacontent
337	__	|**a** unmediated |**b** n |**2** rdamedia
338	__	|**a** volume |**b** nc |**2** rdacarrier
362	0_	|**a** Vol. SC-1, no. 1 (Sept. 1966)-
510	2_	|**a** Chemical abstracts |**x** 0009-2258 |**b** 1966-1982
530	__	|**a** Also issued on CD-ROM.
550	__	|**a** Issued by the IEEE Solid-State Circuits Council; by: IEEE Solid-State Circuits Society, 1997-
588	__	|**a** Latest issue consulted: Vol. 51, no. 12 (Dec. 2016) (surrogate).
590	__	|**a** SERBIB/SERLOC merged record
650	_0	|**a** Semiconductors |**v** Periodicals.
650	_0	|**a** Integrated circuits |**v** Periodicals.
650	_0	|**a** Solid state electronics |**v** Periodicals.
650	_6	|**a** Électronique de l'état solide |**v** Périodiques.
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776	08	|**i** Online version: |**t** IEEE journal of solid-state circuits |**x** 1558-173X |**w** (DLC) 2005214279 |**w** (OCoLC)44608277
859	41	|**u** http://ieeexplore.ieee.org/servlet/opac?punumber=4
853	33	|**8** 1 |**a** v. |**b** no. |**u** 6 |**v** r |**i** (year) |**j** (month) |**w** b |**x** 02
863	40	|**8** 1 |**a** <5>- |**i** <1970>- |**x** provisional
890	__	|**a** IEEE journal of solid-state circuits. |**i** 89-657065
906	__	|**a** 7 |**b** cbc |**c** serials |**d** 3 |**e** ncip |**f** 19 |**g** n-oclcserc
920	__	|**a** Keep 1
923	__	|**d** 20020725 |**s** Group Registration
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985	__	|**e** eserial 200406
991	__	|**b** c-GenColl |**h** TK7871.85 |**i** .I23 |**w** SERIALS
991	__	|**b** c-GenColl |**h** TK7871.85 |**i** .I23 |**p** 00050772172 |**t** Copy 1 |**v** 1-2:Sept-Dec * 1966 |

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		w CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00032911122 **|t** Copy 1 **|v** 28:1993 * 1993 **|w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00032910786 **|t** Copy 1 **|v** 29:1994 * 1994 **|w** CCF
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991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00057703611 **|t** Copy 1 **|v** 31 May-Aug * 1996 **|** **w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00057703933 **|t** Copy 1 **|v** 31 Sept-Dec * 1996 **|** **w** CCF
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991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00027986894 **|t** Copy 1 **|v** 15 1980 * 8888 **|w** CCF
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991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00001496451 **|t** Copy 1 **|v** 18:1-6 * 8888 **|w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00027962932 **|t** Copy 1 **|v** 20:1-6 * 8888 **|w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00027962920 **|t** Copy 1 **|v** 21:1-6 * 8888 **|w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00027962919 **|t** Copy 1 **|v** 22:1-6 * 8888 **|w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00001496463 **|t** Copy 1 **|v** 23:1-5 * 1988 **|w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00027948844 **|t** Copy 1 **|v** 24:1-6 * 8888 **|w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00027948832 **|t** Copy 1 **|v** 25:1-3 * 8888 **|w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00027948820 **|t** Copy 1 **|v** 25:4-6 * 8888 **|w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 00027948819 **|t** Copy 1 **|v** 26:1-6 * 1991 **|w** CCF
991	__	**|b** c-GenColl **|h** TK7871.85 **|i** .I23 **|p** 0000149644A **|t** Copy 1 **|v** 27:1-6 * 8888 **|w** CCF
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Previous Automation System	Voyager	1998
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Electronic Resource Management	Electronic Resource Management	
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Title: IEEE journal of solid-state circuits : a publication of the IEEE Solid-State Circuits Council / editor, P. R. Gray [i.e. Paul R. Gray ... et al.].
Serial Publication Year: 2002
Serial Key Title: IEEE journal of solid-state circuits
Imprint: New York : IEEE.
ISSN: 0018-9200
Description: print material.
Frequency: Bimonthly; monthly beginning v. 26, no. 1, Jan. 1991.
Description based on: Vol. SC-12, no. 5, Oct. 1977.
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6, Jun02.; Pub. 2002-05-28; Reg. 2002-11-26; TX0005623116
7, Jul02.; Pub. 2002-07-01; Reg. 2002-11-26; TX0005623116
8, Aug02.; Pub. 2002-07-22; Reg. 2002-11-26; TX0005623116
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v. 37, no. 10, Oct02.; Pub. 2002-09-25; Reg. 2003-04-11; TX0005703078
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v. 37, no. 12, Dec02.; Pub. 2002-12-02; Reg. 2003-04-11; TX0005703078
Other Title: Journal of solid-state circuits
Names: Gray, Paul R.
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A single-chip quad-band (850/900/1800/1900 MHz) direct conversion GSM/GPRS RF transceiver with integrated VCOS and fractional-N synthesizer	Magoon, R.; Molnar, A.; Zachan, J.; Hatcher, G.; Rhee, W.	Dec 2002 IEEE Xplore
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A 1-v 10.7-MHz switched-opamp bandpass Signal Delta modulator using double-sampling finite-gain-compensation technique	Cheung, V.S.L.; Luong, H.C.; Wing-Hung Ki	Oct 2002 IEEE Xplore
A wide-band rf front-end for multiband multistandard high-linearity low-IF wireless receiver	Adiseno; Ismail, M.; Olsson, H.;	Sept 2002 IEEE Xplore
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Prospects of CMOS technology for high-speed optical communication circuits	B. Razavi	Sep 2002 IEEE Xplore

published from April to August

A fully integrated 900-MHz CMOS wireless receiver with on-chip RF and IF filters and 79-dB image rejection	Chunbing Guo; Chi-Wa Lo; Yu-Wing Choi; Hsu, I.; Kan, T.; Leung, D.; Chan, A.; Luong, H.C.	Aug 2002 IEEE Xplore
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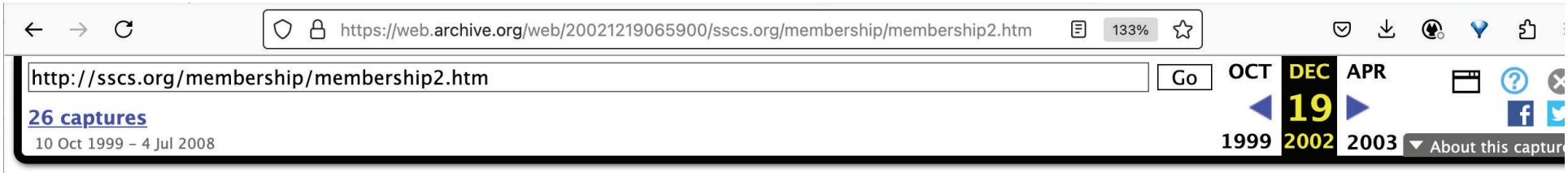
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Ex. 1006G

Early Citations to Magoon

Source Document

Magoon, R., Molnar, A., Zachan, J., Hatcher, G., & Rhee, W. (2002, December). A single-chip quad-band (850/900/1800/1900 MHz) direct conversion GSM/GPRS RF transceiver with integrated VCOs and fractional-N synthesizer, *IEEE Journal of Solid-State Circuits*, *37*(12), 1710-1720.

2003 Citations (in chronological order)

Craninckx, J., & Donnay, S. (2003, June). 4G terminals: how are we going to design them?. In *Proceedings of the 40th annual Design Automation Conference* (pp. 79-84).

Petrov, A. R. (2003, July). System approach for low 1/f noise, high IP2 dynamic range CMOS mixer design. In *Proceedings of the 15th Biennial University/Government/Industry Microelectronics Symposium (Cat. No. 03CH37488)* (pp. 74-77). IEEE.

Leenarts, & Vaucher. (2003, September). Frequency synthesizers for RF transceivers. In 2003 Proceedings of the Bipolar/BiCMOS Circuits and Technology Meeting (IEEE Cat. No. 03CH37440) (pp. 189-196). IEEE.

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EX-1007

Architecture and Performance Overview of a Highly Integrated 13x13mm Single-Package Radio (SPR) Module for Dualband EGSM900 / GSM1800 Applications

Emmanuel Ngompe, Mark Ayvazian, Michael Glasbrener,
Mohamed Megahed, Nooshin Vakilian, William Domino

Skyworks Solutions, Inc.
5221 California Ave., Irvine, CA 92612 USA

Abstract **– The RF system architecture and the performance overview for a very highly-integrated Single Package Radio (SPR) module for dual-band EGSM900/GSM1800 applications is presented. The module realizes all the RF functions required for the dual-band GSM application. These functions as well as their implementations are described. The integrated LO generation consists of reference oscillator circuitry, a UHF oscillator, and delta-sigma fractional-N synthesizer. The receiver is based on a direct-conversion (zero-IF) architecture with the front-end selectivity performed by the two integrated SAW filters. The transmitter is comprised of an upconversion-loop transmit chain with two high-power transmit oscillators, a dual-band power amplifier, detector-based transmit power control, transmit/receive switch, duplex filter and all other necessary filters. Diverse die technologies are utilized to apply the optimum process for each function. The SPR module is implemented on a low cost 4-layer laminate substrate and overall dimensions are 13x13x1.8 mm. Measured results against GSM specifications are presented.**

I. INTRODUCTION

Advances in transceiver design for the purpose of integration have recently made possible a great reduction in the physical size of the RF section of the typical cellular handset. In the GSM area, this has come about through the integration of several key circuit blocks which previously had existed only as discrete components. Such integration has required not only new circuit development but development of radio system architectures either diverging from the traditional, or made newly practical by the use of self-correction techniques.

Here the integration of the GSM handset transceiver is taken a step further, where a single-package radio is made practical by the aforementioned integration. In this paper we describe the RF architecture of a dual-band (EGSM900/GSM1800) single-package radio, which provides all RF functions required in a GSM handset from baseband signals to the antenna.

II. PHYSICAL ATTRIBUTES

The SPR module is shown in Fig. 1.

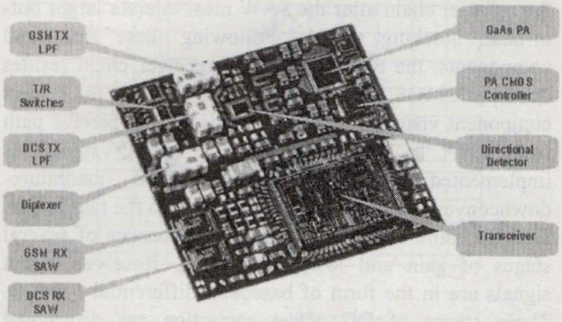


Fig. 1 SPR shown without overmold, showing location of components

Its overall dimensions are 13 x 13 x 1.8mm, including the plastic overmold which is not shown. Fig. 1 also shows the location of the major components. The substrate is a four-layer laminate. The assembly consists of a combination of chip-on-board with wire bonding, and reflow-soldered SMT components. Details of the layout design are discussed in [1].

Not shown is the land pattern on the bottom side of the laminate substrate. It consists of 40 land pads plus a large ground area in the center.

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III. GENERAL SYSTEM ARCHITECTURE

The block diagram of the SPR module is shown in Fig. 2. At the antenna port is a multilayer ceramic diplexer that separates the 900MHz and 1800MHz bands. Then for each band there is a SP2T GaAs PHEMT transmit/receive switch.

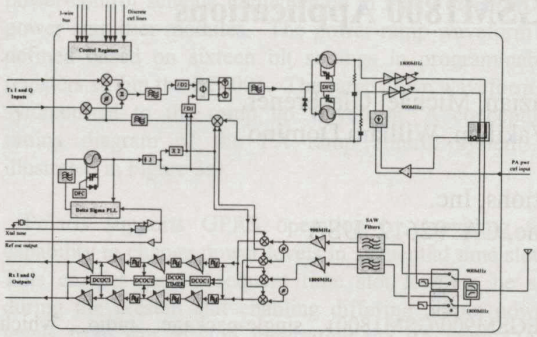


Fig. 2 SPR Block Diagram

In each receive path is placed one RF SAW filter just prior to the LNA. These SAW filters are chip-scale-packaged SMT components which are placed internal to the module. Since the receiver is a direct-conversion type, there are no post-LNA image-reject SAWs needed, but the lack of a second SAW filter for each path means that the receiver chain after the SAW must tolerate larger out-of-band blocking signals. Following these front end components, the remainder of the receiver chain resides on the BiCMOS transceiver die [2], which is the largest component visible in Fig. 1. On this die the receive path from LNA to baseband output I and Q signals is implemented. There is an LNA and quadrature-downconversion mixer for each band, then the two mixers feed the same baseband chain, which consists of several stages of gain and lowpass filtering. Receiver output signals are in the form of baseband differential I and Q. Three stages of DC offset correction are distributed through the baseband chain, from the mixer output to the end of the chain.

Also on the same BiCMOS transceiver die is the transmitter section which accepts differential baseband I and Q signals and performs quadrature modulation to drive the GaAs HBT power amplifier from a VCO. Here a quadrature modulator resides inside an upconversion phase-locked-loop. Using "crossed" I and Q signals, the modulator removes the VCO modulation to keep the loop locked to an unmodulated IF reference. There are two transmit VCOs, one for 900MHz and one for 1800MHz. These drive a two-stage 900MHz power amplifier and a three-stage 1800MHz power amplifier. Transmit power control is performed by a closed-loop system utilizing output power detection and power amplifier bias current control. The power control loop accepts an analog control voltage input.

The SPR module includes a 26MHz crystal oscillator. , though the crystal unit itself is connected externally. A fractional-N phase-locked loop uses this crystal oscillator for reference, and provides the local oscillator signals for both transmitter and receiver. There is no auxiliary PLL, as the direct-conversion receiver does not require it, and the transmitter IF is derived by division of the main local oscillator.

IV. RECEIVER

The receiver provides a gain control range of over 100dB in 2dB steps. Large gain steps (18-20dB) are provided at the LNA and mixer, and the small steps in the baseband chain. The steps are controlled via the 3-wire bus. Typically the gain is controlled (by AGC software in the DSP/μC to which the SPR interfaces) to achieve a baseband output setpoint of 30-60mVrms. At –102dBm antenna input, for instance, the voltage gain is 88dB.

The baseband filtering chain includes two real poles at the mixer output to achieve an early knockdown of blocking signals at >3MHz offset, then two more real poles plus two conjugate pole pairs for the main channel filtering. The real poles also help in keeping the group delay distortion well under 1μs over 100kHz. Overall the baseband 3dB bandwidth is 95kHz. This filtering characteristic insures that both the adjacent (200kHz) and 2^{nd}-adjacent (400kHz) interfering signals are attenuated below the desired signal. This maximizes the flexibility of this receiver regarding interface to various A/D converters with differing post-A/D digital filtering.

Since the receiver is of the direct conversion type [3], DC offsets and 2^{nd}-order distortion required close control in the design. DC offsets originating at the mixer are compensated by the aforementioned DC offset control loops in the baseband chain. DC due to local oscillator leak to the LNA input is reduced by the subharmonic mixer architecture. This also greatly reduces the extent to which local oscillator power can leak from the antenna port, as shown in baseband receiver output signal with such an intermittent (but otherwise unmodulated) blocker; blocker DC is minimal.

Fig. 3.

2^{nd}-order distortion remains low enough such that the blocking signal of the GSM AM-suppression test

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produces a DC offset well under –9dBc. Characterized as 2nd-order intercept point (IP2), this equates to an input IP2 of >43dBm. This high IP2 also means the receiver is resistant to AM-modulated blockers. Fig. 4 shows a baseband receiver output signal with such an intermittent (but otherwise unmodulated) blocker; blocker DC is minimal.

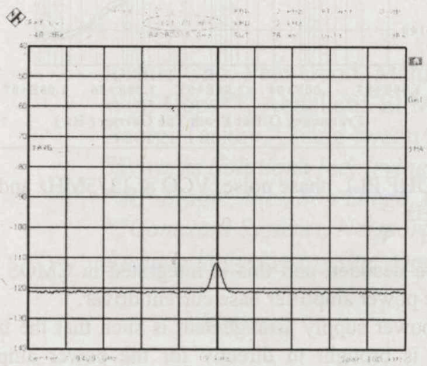


Fig. 3 RX Local Oscillator Leakage, GSM1800

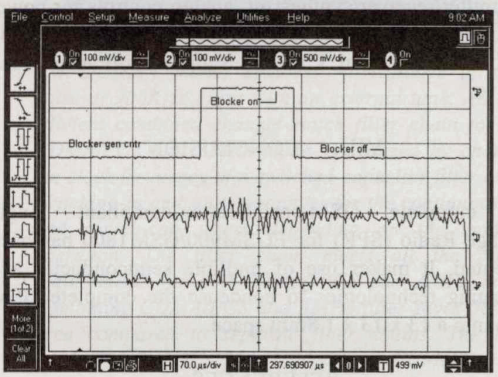


Fig. 4 RX I and Q DC result with intermittent blocker, EGSM900

V. TRANSMITTER

To help minimize the size of the SPR there is no auxiliary PLL, and the transmit IF is derived by a division of the main local oscillator, therefore the IF cannot be a fixed frequency. Rather, the IF is confined to a range of about 100MHz +/- 20MHz. This is accomplished by the use of independent programmable dividers at the phase detector input. To allow these to be independent, the modulator is placed inside the loop, such that its output is unmodulated. The flexibility in the divide ratios allows for both the minimization of the IF range and the avoidance of spurious-prone local oscillator frequencies.

As with any GSM upconversion loop transmitter, the intent is to minimize receive-band noise with little or no filtering in the transmit chain. Here the transmit VCOs put out enough power to drive the two-stage 900MHz PA and 3-stage 1800MHz PA (typically 11dBm and 7dBm respectively). At each transmit burst the VCO is first centered by a digital frequency centering loop which switches in additional tank capacitance, before the upconversion PLL begins to lock. This makes it possible for one VCO to cover the range of 824-915MHz and the other 1710-1910MHz.

The SPR transmit output power is suitable for mobile EGSM900 class 4 (2W) and GSM1800 class 1 (1W). Power is controlled by a power-sensing loop which uses a GaAs combined directional coupler and detector. The power ramp is shown in Fig. 5.

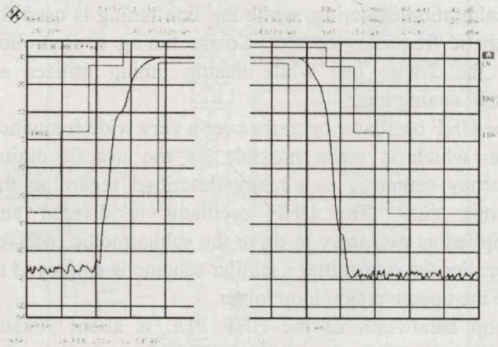


Fig. 5 Transmit Power Ramp, GSM1800

A transmit phase error measurement is given in Fig. 6.

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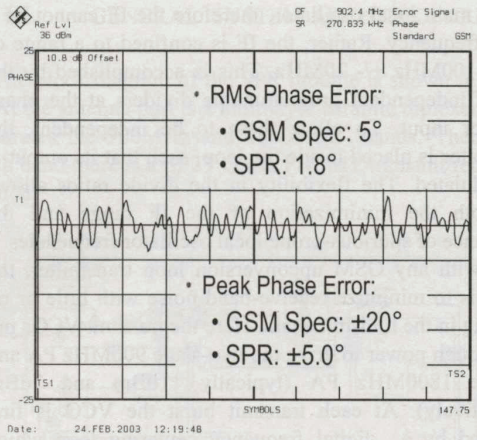


Figure 6 Transmit phase error, EGSM900, 5°/div

VI. LOCAL OSCILLATORS

All local oscillator signals on the SPR are derived from a single UHF oscillator, which is referenced to the crystal oscillator. Tuning for the crystal oscillator includes both coarse digital tuning via a capacitor array, and fine analog tuning via a varactor. Normally the coarse tuning is used for calibration/centering, while the fine tuning is used for automatic frequency control. Coarse tuning is controlled over the 3-wire bus while analog tuning utilizes an external analog input.

The UHF oscillator operates over a very wide frequency range, which is made possible by the use of digital frequency centering as already described regarding the transmit VCO. The UHF oscillator is divided and multiplied as necessary to drive the subharmonic receiver mixer. For the transmitter a similar scheme is employed to drive the upconversion loop mixer.

Loop bandwidth of the UHF PLL is about 30kHz. Including the DFC process, the UHF PLL settles in under 200μs, which makes the SPR suitable for multislot GPRS operation. Typical phase noise is shown in Fig. 7.

VII. SYSTEM INTEGRATION

At the front end of the SPR, the T/R switch function is performed by GaAs PHEMT switches. On the transmit side each switch is preceded by a multilayer ceramic lowpass filter for harmonic attenuation, and the switches themselves are low in harmonic generation. They do

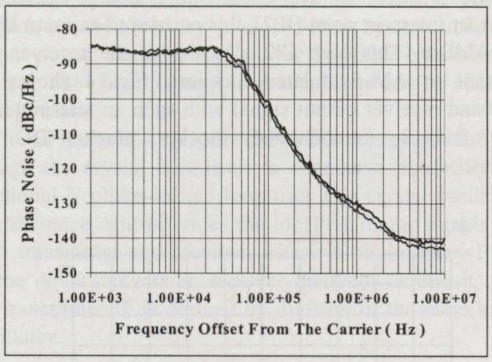


Fig. 7 UHF PLL phase noise, VCO at 1375MHz and 1500MHz

require a decoder, and this is integrated in CMOS along with the power amplifier base current driver.

The power supply arrangement is such that the battery voltage is brought in directly for the power amplifier, while regulated supplies are used elsewhere. Power supply filtering is integrated on the module.

The interface consists of 3-wire bus, enables for transmitter/receiver/synthesizer, analog controls for power amplifier control and crystal tuning, and the analog baseband differential I and Q signals for transmit and receive.

VIII. CONCLUSION

A complete GSM-specification-compliant Single Package Radio (SPR) for EGSM900/GSM1800 has been presented. It makes use of multiple semiconductor and packaging technologies to condense the complete GSM radio into a 13 x 13 x 1.8mm space.

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[2] A. Molnar, R. Magoon, G. Hatcher, J. Zachan, W. Rhee, M. Damgaard, W. Domino, N.Vakilian, "A Single Chip Quad Band (850/900/1800/1900MHz) Direct Conversion GSM/GPRS RF Transceiver with Integrated VCOs and Fractional-N Synthesizer" *2002 IEEE International Solid-State Circuits Conference Digest of Technical Papers,* vol. 1, pp. 232,233,462

[3] A. Mashour, W. Domino, N. Beamish, "On the Direct Conversion Receiver – A Tutorial", *Microwave Journal*, vol.44, no. 6, June 2001

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2003 IEEE Radio Frequency Integrated Circuits Symposium Schedule

The 2003 RFIC Symposium will be held at the Pennsylvania Convention Center (PCC). The headquarters hotel is the Marriott Hotel which is just across the street from the PCC. The RFIC Reception will be held on Sunday June 8, 2003 at the PCC Grand Hall. The RFIC Symposium is held in conjunction with the International Microwave Symposium (IMS). Two Joint IMS/RFIC sessions are scheduled. These include Session TU4D and Session IFTU.

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Sunday June 8, 2003

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Co-Chair: S. L. Lloyd, *Skyworks Solutions, Inc.*

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EX-1007A

Architecture and Performance Overview of a Highly Integrated 13x13mm Single-Package Radio (SPR) Module for Dualband EGSM900 / GSM1800 Applications

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Abstract – **The RF system architecture and the performance overview for a very highly-integrated Single Package Radio (SPR) module for dual-band EGSM900/GSM1800 applications is presented. The module realizes all the RF functions required for the dual-band GSM application. These functions as well as their implementations are described. The integrated LO generation consists of reference oscillator circuitry, a UHF oscillator, and delta-sigma fractional-N synthesizer. The receiver is based on a direct-conversion (zero-IF) architecture with the front-end selectivity performed by the two integrated SAW filters. The transmitter is comprised of an upconversion-loop transmit chain with two high-power transmit oscillators, a dual-band power amplifier, detector-based transmit power control, transmit/receive switch, duplex filter and all other necessary filters. Diverse die technologies are utilized to apply the optimum process for each function. The SPR module is implemented on a low cost 4-layer laminate substrate and overall dimensions are 13x13x1.8 mm. Measured results against GSM specifications are presented.**

I. INTRODUCTION

Advances in transceiver design for the purpose of integration have recently made possible a great reduction in the physical size of the RF section of the typical cellular handset. In the GSM area, this has come about through the integration of several key circuit blocks which previously had existed only as discrete components. Such integration has required not only new circuit development but development of radio system architectures either diverging from the traditional, or made newly practical by the use of self-correction techniques.

Here the integration of the GSM handset transceiver is taken a step further, where a single-package radio is made practical by the aforementioned integration. In this paper we describe the RF architecture of a dual-band (EGSM900/GSM1800) single-package radio, which provides all RF functions required in a GSM handset from baseband signals to the antenna.

II. PHYSICAL ATTRIBUTES

The SPR module is shown in Fig. 1.

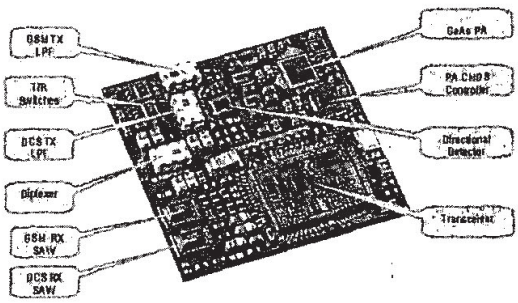


Fig. 1 SPR shown without overmold, showing location of components

Its overall dimensions are 13 x 13 x 1.8mm, including the plastic overmold which is not shown. Fig. 1 also shows the location of the major components. The substrate is a four-layer laminate. The assembly consists of a combination of chip-on-board with wire bonding, and reflow-soldered SMT components. Details of the layout design are discussed in [1].

Not shown is the land pattern on the bottom side of the laminate substrate. It consists of 40 land pads plus a large ground area in the center.

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III. GENERAL SYSTEM ARCHITECTURE

The block diagram of the SPR module is shown in Fig. 2. At the antenna port is a multilayer ceramic diplexer that separates the 900MHz and 1800MHz bands. Then for each band there is a SP2T GaAs PHEMT transmit/receive switch.

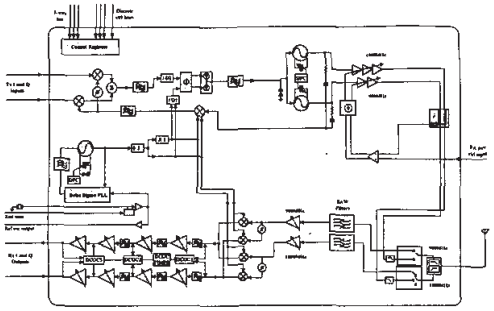


Fig. 2 SPR Block Diagram

In each receive path is placed one RF SAW filter just prior to the LNA. These SAW filters are chip-scale-packaged SMT components which are placed internal to the module. Since the receiver is a direct-conversion type, there are no post-LNA image-reject SAWs needed, but the lack of a second SAW filter for each path means that the receiver chain after the SAW must tolerate larger out-of-band blocking signals. Following these front end components, the remainder of the receiver chain resides on the BiCMOS transceiver die [2], which is the largest component visible in Fig. 1. On this die the receive path from LNA to baseband output I and Q signals is implemented. There is an LNA and quadrature-downconversion mixer for each band, then the two mixers feed the same baseband chain, which consists of several stages of gain and lowpass filtering. Receiver output signals are in the form of baseband differential I and Q. Three stages of DC offset correction are distributed through the baseband chain, from the mixer output to the end of the chain.

Also on the same BiCMOS transceiver die is the transmitter section which accepts differential baseband I and Q signals and performs quadrature modulation to drive the GaAs HBT power amplifier from a VCO. Here a quadrature modulator resides inside an upconversion phase-locked-loop. Using "crossed" I and Q signals, the modulator removes the VCO modulation to keep the loop locked to an unmodulated IF reference. There are two transmit VCOs, one for 900MHz and one for 1800MHz. These drive a two-stage 900MHz power amplifier and a three-stage 1800MHz power amplifier. Transmit power control is performed by a closed-loop system utilizing output power detection and power amplifier bias current control. The power control loop accepts an analog control voltage input.

The SPR module includes a 26MHz crystal oscillator. , though the crystal unit itself is connected externally. A fractional-N phase-locked loop uses this crystal oscillator for reference, and provides the local oscillator signals for both transmitter and receiver. There is no auxiliary PLL, as the direct-conversion receiver does not require it, and the transmitter IF is derived by division of the main local oscillator.

IV. RECEIVER

The receiver provides a gain control range of over 100dB in 2dB steps. Large gain steps (18-20dB) are provided at the LNA and mixer, and the small steps in the baseband chain. The steps are controlled via the 3-wire bus. Typically the gain is controlled (by AGC software in the DSP/μC to which the SPR interfaces) to achieve a baseband output setpoint of 30-60mVrms. At –102dBm antenna input, for instance, the voltage gain is 88dB.

The baseband filtering chain includes two real poles at the mixer output to achieve an early knockdown of blocking signals at >3MHz offset, then two more real poles plus two conjugate pole pairs for the main channel filtering. The real poles also help in keeping the group delay distortion well under 1μs over 100kHz. Overall the baseband 3dB bandwidth is 95kHz. This filtering characteristic insures that both the adjacent (200kHz) and 2^{nd}-adjacent (400kHz) interfering signals are attenuated below the desired signal. This maximizes the flexibility of this receiver regarding interface to various A/D converters with differing post-A/D digital filtering.

Since the receiver is of the direct conversion type [3], DC offsets and 2^{nd}-order distortion required close control in the design. DC offsets originating at the mixer are compensated by the aforementioned DC offset control loops in the baseband chain. DC due to local oscillator leak to the LNA input is reduced by the subharmonic mixer architecture. This also greatly reduces the extent to which local oscillator power can leak from the antenna port, as shown in baseband receiver output signal with such an intermittent (but otherwise unmodulated) blocker; blocker DC is minimal.

Fig. 3.

2^{nd}-order distortion remains low enough such that the blocking signal of the GSM AM-suppression test

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produces a DC offset well under –9dBc. Characterized as 2nd-order intercept point (IP2), this equates to an input IP2 of >43dBm. This high IP2 also means the receiver is resistant to AM-modulated blockers. Fig. 4 shows a baseband receiver output signal with such an intermittent (but otherwise unmodulated) blocker; blocker DC is minimal.

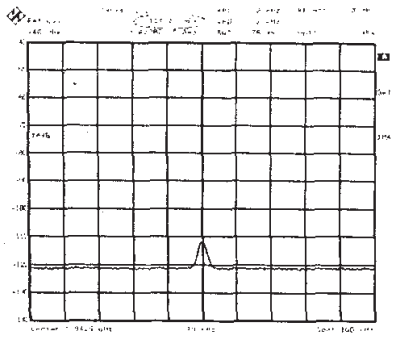


Fig. 3 RX Local Oscillator Leakage, GSM1800

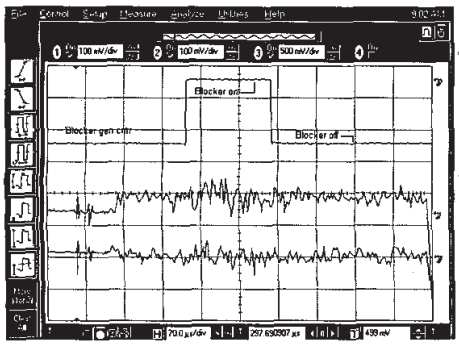


Fig. 4 RX I and Q DC result with intermittent blocker, EGSM900

V. TRANSMITTER

To help minimize the size of the SPR there is no auxiliary PLL, and the transmit IF is derived by a division of the main local oscillator, therefore the IF cannot be a fixed frequency. Rather, the IF is confined to a range of about 100MHz +/- 20MHz. This is accomplished by the use of independent programmable dividers at the phase detector input. To allow these to be independent, the modulator is placed inside the loop, such that its output is unmodulated. The flexibility in the divide ratios allows for both the minimization of the IF range and the avoidance of spurious-prone local oscillator frequencies.

As with any GSM upconversion loop transmitter, the intent is to minimize receive-band noise with little or no filtering in the transmit chain. Here the transmit VCOs put out enough power to drive the two-stage 900MHz PA and 3-stage 1800MHz PA (typically 11dBm and 7dBm respectively). At each transmit burst the VCO is first centered by a digital frequency centering loop which switches in additional tank capacitance, before the upconversion PLL begins to lock. This makes it possible for one VCO to cover the range of 824-915MHz and the other 1710-1910MHz.

The SPR transmit output power is suitable for mobile EGSM900 class 4 (2W) and GSM1800 class 1 (1W). Power is controlled by a power-sensing loop which uses a GaAs combined directional coupler and detector. The power ramp is shown in Fig. 5.

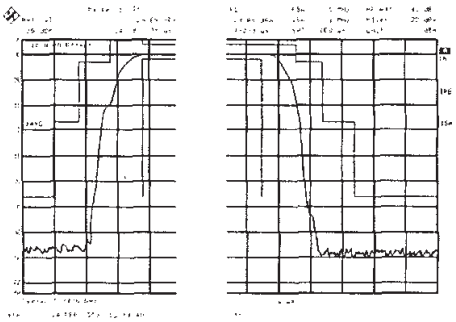


Fig. 5 Transmit Power Ramp, GSM1800

A transmit phase error measurement is given in Fig. 6.

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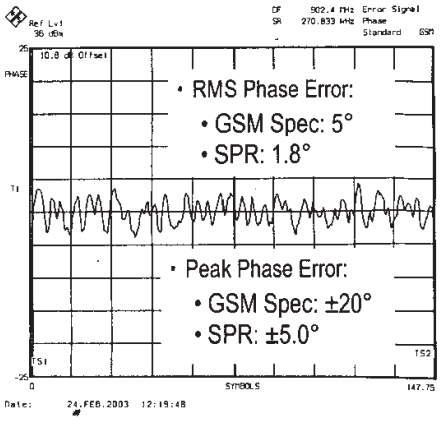


Figure 6 Transmit phase error, EGSM900, 5°/div

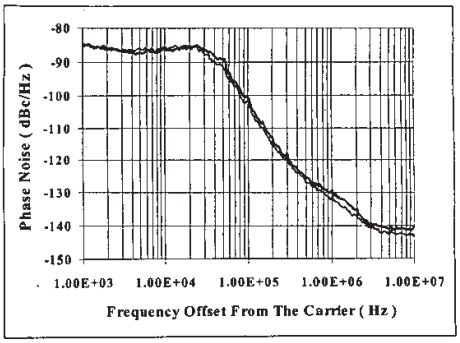


Fig. 7 UHF PLL phase noise, VCO at 1375MHz and 1500MHz

VI. LOCAL OSCILLATORS

All local oscillator signals on the SPR are derived from a single UHF oscillator, which is referenced to the crystal oscillator. Tuning for the crystal oscillator includes both coarse digital tuning via a capacitor array, and fine analog tuning via a varactor. Normally the coarse tuning is used for calibration/centering, while the fine tuning is used for automatic frequency control. Coarse tuning is controlled over the 3-wire bus while analog tuning utilizes an external analog input.

The UHF oscillator operates over a very wide frequency range, which is made possible by the use of digital frequency centering as already described regarding the transmit VCO. The UHF oscillator is divided and multiplied as necessary to drive the subharmonic receiver mixer. For the transmitter a similar scheme is employed to drive the upconversion loop mixer.

Loop bandwidth of the UHF PLL is about 30kHz. Including the DFC process, the UHF PLL settles in under 200μs, which makes the SPR suitable for multislot GPRS operation. Typical phase noise is shown in Fig. 7.

VII. SYSTEM INTEGRATION

At the front end of the SPR, the T/R switch function is performed by GaAs PHEMT switches. On the transmit side each switch is preceded by a multilayer ceramic lowpass filter for harmonic attenuation, and the switches themselves are low in harmonic generation. They do require a decoder, and this is integrated in CMOS along with the power amplifier base current driver.

The power supply arrangement is such that the battery voltage is brought in directly for the power amplifier, while regulated supplies are used elsewhere. Power supply filtering is integrated on the module.

The interface consists of 3-wire bus, enables for transmitter/receiver/synthesizer, analog controls for power amplifier control and crystal tuning, and the analog baseband differential I and Q signals for transmit and receive.

VIII. CONCLUSION

A complete GSM-specification-compliant Single Package Radio (SPR) for EGSM900/GSM1800 has been presented. It makes use of multiple semiconductor and packaging technologies to condense the complete GSM radio into a 13 x 13 x 1.8mm space.

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Organizational structure: The library is part of a **privately-funded** organization. It operates on a **Non-profit** financial model.

Collection size	860,000	**volumes**
Annual Circulation	30,000	**transactions**

Technology Profile		
	Product Name	**Year Contracted**
Current Automation System	**Alma**	**2018**



Linda Hall Library



map location✔

Related Libraries

- Libraries located in **Kansas City** (Missouri)
- Libraries located in **Jackson** county (Missouri)
- **View map of libraries in Jackson County**
- **all Independent Research libs in Missouri**

About libraries.org

libraries.org is a free directory of libraries throughout the world.

This directory is a component of **Library Technology Guides**.

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Previous Automation System	**Voyager**	2010
Previous Automation System	**Horizon**	1994
Previous Automation System	**None**	
Discovery Service (w/index)	**Ex Libris CDI**	2010
Discovery Interface	**Primo**	**2010**
Digital Collection Management	**CONTENTdm**	
Web Content Management	**WordPress**	
Item ID Type	Barcode	

The library's automation system is hosted by the vendor through an **Software-as-a-Service** (**SaaS**) arrangement.

This library is responsible for the procurement of the library automation system.

Please **contact Marshall Breeding** to report corrections about information listed for this library.

Automation Survey: We are conducting a study on the automation systems used in libraries. This survey should be completed by a person familiar with your libraries use of **Alma**.

Respond to the 2024 Library Automation Perceptions Survey

Identifiers	
libraries.org ID	2294
OCLC Symbol	LHL
WorldCat Registry ID	**99283**

Record History: This listing was created on Aug 11, 1998 and was last modified on Dec 10, 2024.

Updates: Corrections or Updates? Registered members of Library Technology Guides can submit updates to library listings in libraries.org. **Registration** is free and easy. Already registered? **login**. Or, you can report corrections just by sending a message to **Marshall Breeding**.

libraries.org | Update this Entry | Library Technology Guides

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EX-1007G

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1 of 2 Automatic Zoom

Advance Conference Registration



IEEE MTT-S MICROWAVE WEEK EVENTS

June 8–13, 2003 ✦ Philadelphia, PA ✦ IMS ✦ RFIC ✦ ARFTG

Each conference attendee must submit a separate registration form. A copy of this form may be used. Deadline for advance registration via fax or mail is April 27, 2003. Registration deadline via Website is May 5, 2003. Afterwards, on-site fees apply and will be approximately 30% higher.

IEEE

NAME _____ (Last) _____ (First)

AFFILIATION _____ (Company, Etc.) _____ (Mail Stop)

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The Wayback Machine - https://web.archive.org/web/20030611144832/http://www.ims2003.org:80/attendee/registration_for…

Advance Conference Registration

IEEE MTT-S MICROWAVE WEEK EVENTS

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NAME _____ (Last) _____ (First)

AFFILIATION _____ (Company, Etc.) _____ (Mail Stop)

ADDRESS _____ (Street)

_____ (City) _____ (State/Prov.) _____ (Postal Code) _____ (Country)

_____ (e-mail Address)

US/CANADA TEL. _____ INT'L TEL. _____

IEEE MEMBER ❑ Yes ❑ No IEEE Membership No.* _____

*Must be given and valid IEEE card presented at Symposium to qualify for member discount. An invalid number will void this registration.

MTT-S MEMBER ❑ *Yes* ❑ *No*

ARFTG MEMBER ❑ *Yes* ❑ *No*

Name of Guest _____ *For a complimentary badge for plenary session and exhibits*

❑ *CHECK IF DISABILITY ACCOMMODATION REQUIRED*

To register, check ☑ the appropriate boxes and enter corresponding fees in the Remittance column.

ONLY PAID ATTENDEES WILL BE ADMITTED TO THE WORKSHOPS AND TECHNICAL SESSIONS.

INTERNATIONAL MICROWAVE SYMPOSIUM *(Tue., Wed. & Thur.)*
(INCLUDES EXHIBITS AND APS)

	IEEE Member	Non Member	Remittance
All IMS Sessions (Includes IMS CD ROM and Abstract Book, ***no*** Digest.)	❑ $350	❑ $525	$ _____
All IMS Sessions (Includes Abstract Book, ***no*** IMS CD ROM or Digest.)	❑ $300	❑ $475	$ _____
Single-Day Registration (Includes IMS CD ROM and Abstract Book, ***no*** Digest.)	❑ $175	❑ $250	$ _____
Student, Retiree, Life Member (Includes IMS CD ROM and Abstract Book, ***no*** Digest.)	❑ $ 50	❑ $ 75	$ _____
RFIC SYMPOSIUM *(Mon. & Tue.)* (INCLUDES EXHIBITS, RFIC SESSIONS & RECEPTION, DIGEST & CD ROM.)	❑ $175	❑ $250	$ _____
RFIC Reception Only	❑ $ 45	❑ $ 55	$ _____

ARFTG – MICROWAVE MEASUREMENT CONFERENCE *(Fri.)*
(INCLUDES EXHIBITS, BREAKFAST, LUNCH, ARFTG MEMBERSHIP, DIGEST AND ARFTG EXHIBITION.)

ARFTG or IEEE Member	❑ $175	$ _____
ARFTG/IEEE Non-member	❑ $225	$ _____
ARFTG Student, Retiree	❑ $110	$ _____

ADDITIONAL DIGESTS AND CD ROMS
(**FOR PICKUP ON-SITE ONLY.** SEPARATE DIGESTS AND CD ROMS WILL BE AVAILABLE AFTER THE SYMPOSIUM FROM THE IEEE.)

IMS Digest	Qty. ___ @	❑ $ 75	❑ $125	$ _____
IMS, RFIC and ARFTG CD ROM	Qty. ___ @	❑ $ 50	❑ $100	$ _____
RFIC Digest	Qty. ___ @	❑ $ 40	❑ $ 55	$ _____
ARFTG Digest	Qty. ___ @	❑ $ 25**	❑ $ 45	$ _____
ARFTG Microwave Measurement Conference Digest Compilation				
CD ROM 1982–2001	Qty. ___ @	❑ $ 65**	❑ $ 90	$ _____

**ARFTG OR IEEE MEMBER PRICE

PANEL SESSIONS (INCLUDES BOX LUNCH. SEE REVERSE SIDE FOR SCHEDULE.)

PMA:	Will There Ever Be a Single Wireless World Standard?	❑ $25	$ _____
PTUA:	Surface Mount Technology: BGA versus Lead Frame	❑ $25	$ _____
PTUB:	The Future of Education in the Area of Microwaves	❑ $25	$ _____
PWA:	Issues Related to Commercial Uses of Ultra-wideband Communications	❑ $25	$ _____
PTHA:	RF MEMS Business Ventures and Issues	❑ $25	$ _____

AWARDS BANQUET (WED. EVENING) MARRIOTT Qty. ___ @$60 $ _____

SOCIAL EVENT (TUESDAY EVENING)
SPECIALTY CRUISE ON THE SPIRIT OF PHILADELPHIA Qty. ___ @$60 $ _____

WORKSHOPS AND TUTORIALS For paid attendees only.
(SEE BACK OF THIS PAGE FOR TITLES.)

	IEEE Member	Non member	Student/Retiree/ Life Member
Full Day	$150	$200	$100
Half Day	$100	$150	$ 75

Sunday			Monday			Friday		
❑ WSA	(Full Day)	$____	❑ WMA	(Full Day)	$____	❑ WFA	(Full Day)	$____
❑ WSB	(Full Day)	$____	❑ WMB	(Full Day)	$____	❑ WFB	(Full Day)	$____
❑ WSC	(Full Day)	$____	❑ WMC	(Full Day)	$____	❑ WFC	(Full Day)	$____
❑ WSD	(Full Day)	$____	❑ WMD	(Full Day)	$____	❑ WFD	(Full Day)	$____
❑ WSE	(Full Day)	$____	❑ WME	(Full Day)	$____	❑ WFE	(Full Day)	$____
❑ WSF	(Full Day)	$____	❑ WMF	(Morning)	$____	❑ WFF	(Full Day)	$____
❑ WSG	(Full Day)	$____	❑ WMG	(Morning)	$____	❑ WFG	(Morning)	$____
❑ WSH	(Full Day)	$____	❑ WMH	(Morning)	$____	❑ WFH	(Morning)	$____
❑ WSI	(Morning)	$____	❑ WMI	(Morning)	$____	❑ WFI	(Morning)	$____
❑ WSJ	(Afternoon)	$____	❑ WMJ	(Afternoon)	$____	❑ WFJ	(Morning)	$____
❑ WSK	(Afternoon)	$____	❑ WMK	(Afternoon)	$____			
			❑ WML	(Afternoon)	$____			
			❑ WMM	(Afternoon)	$____			

WORKSHOPS TOTAL $ _____

TUTORIALS (SEE BACK OF THIS PAGE FOR TITLES.) SUNDAY/FRIDAY

❑ TSA (Half Day) $____ ❑ TSB (Full Day) $____ ❑ TFA (Half Day) $____

TUTORIAL TOTAL $ _____

Full-day workshops and Tutorials include continental breakfast, lunch and afternoon refreshments. Morning workshops include continental breakfast and lunch. Afternoon workshops include lunch and afternoon refreshments. Registration includes Workshop CD ROM. Workshop presenters' notes will be available at the workshop.

GUEST PROGRAMS	Qty. Adult	Qty. Child*	Total
GSA: Atlantic City, NJ (Full Day) (No one under 18 is permitted in casinos)	___ @$35		$_____
GSB: Philadelphia Historic Sites (Half Day)	___ @$34		$_____
GSC: Philadelphia Historic Sites & Physick House (Full Day)	___ @$70		$_____
GSD: Valley Forge (Half Day)	___ @$68	___ @$60	$_____
GSE: Brandywine Valley (Full Day)	___ @$98	___ @$65	$_____
GSF: Philadelphia Museum of Art & Rodin Museum (Half Day)	___ @$74	___ @$65	$_____
GSG: Historic New Hope & Mule Barge Ride (Full Day)	___ @$88	___ @$84	$_____
GSH: Franklin Institute Science Center (Half Day)	___ @$45		$_____
GSI: Pennsylvania Dutch Country (Full Day)	___ @$65	___ @$60	$_____
GSJ: Chadds Ford Winery & Brandywine River Museum (Half Day)	___ @$70		$_____
*Children under 12 years			**GUEST PROGRAM TOTAL** _____

The only acceptable forms of payment are check, money order, MasterCard, VISA or American Express.
Make your check or money order (US $ ONLY on a US Bank or Traveler's Check) payable to: ***IEEE/MTT S***

TOTAL REMITTANCE $ _____
INDIVIDUAL PAYMENT MUST ACCOMPANY FORM

❑ MasterCard ❑ VISA ❑ American Express

Card # _____ Exp. Date ____

Signature _____

(Signature must accompany credit card payment)

Written requests for refunds will be honored if received by April 27, 2003.

MAIL COMPLETED FORM AND PAYMENT TO: MTT-S Registration, 685 Canton Street, Norwood, MA 02062
For information or handicap special needs only (phone registration is not available) (781) 769-9750.

PLEASE FAX (781) 769-5037 OR MAIL; DO ***NOT*** FORWARD HARD COPY IF FAXED
REGISTRATION IS AVAILABLE ONLINE AT WWW.MTT-SREGISTRATION.COM

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