RF Circuit Design References

Parent Category: 2015 HFE

By Peter Delos

Proficiency in the RF circuit design profession requires significant awareness of many areas of electrical engineering. Acquiring foundational material and digesting the engineering principles involved is a lifelong undertaking. For engineers entering the RF profession it is not always clear where to begin. Fortunately, many well written references have been published over the last few decades. The purpose of this note is to outline some of the important references with comments on their contributions. The intention is to provide a starting point for working engineers entering the RF arena, as well as a useful reference list for seasoned RF engineers.

Effort was placed on providing references that provide a comprehensive foundation through books, some IEEE papers, and many working-level application notes. As a disclaimer to the compiled reference list, there is no way to include every possible reference book or famous paper. Any detailed design or study in a particular topic will lead to additional material not cited here.

Introductory Material:

If you are brand new to RF, these books can provide a practical foundation with easy to read descriptions.

[1] American Radio Relay League, “2015 ARRL Handbook for Radio Communications,” October 2014. This is the 92nd edition. It is written as a training manual at a practical level and highly recommended.

[2] Hagen, “Radio Frequency Electronics, Circuits and Applications,” Cambridge University Press, 1996. This book provides short summaries of many topics routinely encountered.

RF and Microwave Principles:

[3] Pozar, “Microwave Engineering,” Wiley, 2011. This is a famous reference and is up to the fourth edition. It requires a background in field theory, and brings EM principles into microwave applications.

[4] Bowick, “RF Circuit Design, 2nd Edition,” Newnes, 2007. A practical read that provides very valuable information on filters, impedance matching, and amplifiers. The 1st edition came out in 1982. The fact that a 2nd edition came out 25 years later is an indicator of its value.

[5] “S-Parameter Design,” Agilent Application Note 154. Written by Hewlett-Packard, this note outlines design with S-Parameters and use of the Smith chart.

[6] Gandhi, “Microwave and Engineering Application,” Pergamon Press, 1981. This is a college textbook that complements, and in some ways is more practical, than Pozar.

[7] Krauss, Bostian, Raab, “Solid State Radio Engineering,” Wiley, 1980. A practical and thorough view of radio electronics. The emphasis on architectural considerations rather than specific implementations makes this reference still relevant today.

[8] “Reference Data for Radio Engineers,” International Telephone and Telegraph Corporation, Fourth Edition, 1956. This provides a great historical perspective of how much was already known a half century ago.

Signal and Communication Theory: These first two books are college level textbooks, heavy in math, but provide some of the fundamental theory taught at the university level.

[9] Oppenheim, Willsky, and Nawab, “Signals and Systems, 2nd Edition,” Prentice Hall, 1997.

[10] Proakis, Salehi, “Communcation Systems Engineering,” Prentice Hall, 1994. A second edition was published in 2001.

These references break down the basics of modulation and are well written:

[11] Hewlett-Packard, “Amplitude and Frequency Modulation,” Application Note 150-1, 1989

[12] Mccune, “Practical Digital Wireless Signals,” Cambridge Press, 2013

Receiver Architectures

[13] McClaning, Vito, “Radio Receiver Design,”New York, Noble Publishing, 2000. A sequential walk-through of receiver concepts and considerations.

[14] Abidi, “Direct-Conversion Radio Transceivers for Digital Communications,” IEEE, 1995

[15] Razavi, “Design Considerations for Direct-Conversion Receivers,” IEEE, 1997

[16] Murphy et al, “A Blocker-Tolerant, Noise-Cancelling Receiver Suitable for Wideband Wireless Applications,” JSSC, 2012. This received Best Paper Award at the time. Murphy outlines and includes many references for noise-cancelling receiver architectures. These methods may change how receivers are done in the future.

Waveform Generation

[17] “A Technical Tutorial on Digital Signal Synthesis,” Analog Devices, 1999

Modern waveform generation begins in the Direct Digital Synthesizer (DDS). Next it is followed by an up-conversion stage. The up-converter is conceptually a mirror of the receiver, but with different considerations. Much has been written on receiver design; less literature exists on the upconverter aspects of waveform generation. For this, the designer can refer to the mixer, filter, and amplifier references.

Phase Locked Loops

[18] Gardner, “Phaselock Techniques,”3rd Edition, Wiley, 2005

[19] Banerjee, “PLL Performance, Simulation, and Design,”4th edition, 2006

[20] Wolaver, “Phase Locked Loop Circuit Design,” Prentice Hall, 1991

[21] Brillant, “Understanding Phase Locked DRO Design Aspects,” Microwave Journal, 1999

Oscillators

[22] Rhode, Poddar, Bock, “The Design of Modern Microwave Oscillators for Wireless Applications,” Wiley, 2005. Rhode and Poddar are prolific writers with hundreds of published articles and several books.

[23] Rhea, “Oscillator Design and Computer Simulation,” Noble Publishing, 2000

[24] Kurzenknabe, “Practical Considerations in Specifications of High Stability Crystal Oscillators,” Piezo Crystal Company (Now Vectron), exact date unknown, probably ~1990. This is a great reference for anyone buying crystal oscillators.

[25] McNeilage, Searls, Ivanov, et al, “A Review of Sapphire Whispering Gallery-Mode Oscillators including technical progress and future potential of technology,” UFFC, 2004. An outline of methods used for the lowest phase noise high frequency oscillators available at the time of writing.

[26] Everard, “Fundamentals of RF Circuit Design with Low Noise Oscillators,” Wiley, 2001. A good RF book with an extended section on oscillator design.

[27] Hegazi, Eldin, Abidi, “The Designers Guide to High Purity Oscillators,” 2005. A specialized book that details integrated circuit CMOS oscillators.

Noise

[28] “Fundamentals of RF and Microwave Noise Figure Measurements,”Agilent Application Note AN57-1. This originated as a Hewlett-Packard note and is the place to start on noise figure. The fundamental theory is described along with measurement techniques.

[29] Ott, “Noise Reduction Techniques in Electronic Systems,” Wiley, 1988. A practical book written for the working engineer. This work broke new ground at its time and is still relevant today.

[30] Maas, “Noise in Linear and Nonlinear Circuits,” Artech House, 2005

Phase Noise: Although this could be considered a subset of noise, it is so important in RF it that is given its own section.

[31] “Phase Noise Characterization of Microwave Oscillators, Phase Detector Method,”Agilent Product Note 11729B-1. Another note originated by Hewlett-Packard and is the place to start on phase noise. It is online along with several other phase noise application notes.

[32] Rubiola, “Phase Noise and Frequency Stability in Oscillators,” Cambridge University Press, 2008. One of the few textbooks on the subject, a lengthy set of references are cited and online lecture notes are also available.

Some famous phase noise papers:

[33] Leeson, “A simple Model of Feedback Oscillator Noise Spectrum,” IEEE, 1966

[34] Lee, Hajimiri, “Oscillator Phase Noise: A Tutorial,” IEEE, 2000

Mixers

Frequency translation is a fundamental to RF. The methods, limitations, and additional filtering required should be understood.

[35] Henderson, “Mixers in Microwave Systems,” WJ Tech-Note, 1990. A two part application note that describes spurious charts and most of the essentials for consideration in frequency planning.

[36] Maas, “Microwave Mixers,” Artech House, 1993. A well-known reference on mixer design.

Harmonic Rejection Mixers may become a fundamental building block in the future. The concept of minimizing mixing spurious through emulating LO signals with reduced harmonics can become practical with highly integrated RFIC design. One recent paper is cited, and other also exist.

[37] Forbes, Ho, Gharpurey, “Design and Analysis of Harmonic Rejection Mixers With Programmable LO Frequency,” JSSC 2013.

Filters

Three famous books provide the foundation for much of the modern filter theory in use today.

[38] Matthaei, Young, Jones, “Microwave Filters, Impedance-Matching Networks and Coupling Structures,” Artech House, 1980

[39] Zverev, “Handbook of Filter Synthesis,” Wiley, 1967

For Active Filter Design:

[40] Valkenburg, “Analog Filter Design,” Saunders, 1982

OpAmps

A working knowledge of operational amplifiers is fundamental to electrical engineering. Several references from major semiconductor companies are cited.

[41] Jung, “Op Amp Applications,” Analog Devices, 2002

[42] Mancini, “Op Amps For Everyone,” Texas Instruments, 2001

[43] National Semiconductor, “Linear Applications Handbook,” 1994

Audio Amplifier Design

With the exception of parasitic impact, discrete circuit design techniques applied in audio are closely related to RF and IC design. The Self and Cordell books outline the essentials of discrete solid state audio design, and the O’Conner book provides a detailed design guide to tube based guitar amplifier design.

[44] Self, “Audio Power Amplifier Design 5th Edition,” Focal Press, 2013

[45] Cordell, “Designing Audio Power Amplifiers,” McGraw-Hill, 2011

[46] Self, “Small Signal Audio Design,” Focal Press, 2010

[47] O’Conner, “The Ultimate Tone,” Power Press, 1995

RF Amplifiers

[48] Gonzales, “Microwave Transistor Amplifiers,” Prentice Hall, 1997. A thorough textbook on amplifier design through S-Parameters.

[49] Ladbrooke, “MMIC Design: GaAs FETs and HEMTs,” Artech House, 1989. Old but still relevant.

RF Power Amplifiers

[50] Cripps, “Advanced Techniques in Power Amplifier Design,” Artech House, 2002. This is Cripps’ newer book. Another book listed as 2006 is a second edition of an older book.

[51] Walker (editor), “High Power GaAs FET Amplifiers,” Artech House, 1993. This is a good collection of material from multiple important authors.

[52] Kenington, “High Linearity RF Amplifier Design,” Artech House, 2000. As the title suggests, the subject of all-important linearity.

Data Converters

[53] Kester, “Analog-Digital Conversion,” Analog Devices, 2004. This is a weighty book that includes a historical perspective, architectures, sampling theory, specifications, and user considerations. The information from many other application notes is included in this reference.

IC Design

[54] Gray et al, “Analysis and Design of Analog Integrated Circuits,” Wiley, 2009. This book is referenced routinely in many IEEE papers on RFIC design. It has been a valuable resource for both the university level and the working engineer for many years. It is now up to the fifth edition.

[55] Baker, “CMOS Circuit Design, Layout, and Simulation,” Wiley, 2010. A wealth of information on CMOS design; from the transistor level through both analog and digital circuits. It is up to the 3rd edition.

[56] Allen, Holberg, “CMOS Analog Circuit Design,” Oxford Press, 2012. Also at the 3rd edition. Complementary with the Baker book, the combined use of both references provides a solid CMOS foundation. The Allen website provides very good lecture notes and a view into the book.

[57] Sedra, Smith, “Microelectronic Circuits,” Oxford Press, 2009. This has been a college textbook for several decades now and is up to the sixth edition.

[58] Razavi, “Fundamentals of Microelectronics,” Wiley, 2014. Razavi is a prolific writer. He has many other books worth considering, also. This is his latest and outlines a foundation in IC design as the title indicates.

Transistor Properties

Most circuit books have a chapter or two on transistor principles. Sometimes it is good a have a book dedicated to the topic at a practical level without going too deep into semiconductor physics.

[59] Frederiksen, “Intuitive IC Electronics: A sophisticated Primer for Engineers and Technicians,” McGraw-Hill, 1982

[60] Ashburn, “SiGe Heterojunction Bipolar Transistors,” Wiley, 2003. A comprehensive treatment of bipolar transistors; covering properties, modelling, and how they are made. This also provides a good historical perspective of improvements over the decades of development.

[61] Hastings, “The Art of Analog Layout,”Prentice Hall, 2001. Geared towards IC layout, and provides insight not considered in the schematic phase of the design.

[62] Anholt, “Electrical and Thermal Characterization of MESFETs, HEMTs and HBTs,” Artech House, 1995. Excellent basic book on modeling.

Printed Wiring Board Layout

[63] Montrose, “Printed Circuit Board Design Techniques for EMC compliance,” IEEE Press, 2000

[64] Edwards, “Foundations for Microstrip Circuit Design,” Wiley, 1992, 1981. Excellent reference with a lot of very hard-to-find information.

[65] Ott, “Partitioning and Layout of a Mixed-Signal PCB,” Printed Circuit Design Magazine, 2001. An important detail of grounding implementation in PWB layout is described.

Power Supplies and Regulation

Much literature exists on power supply design. For the RF designer it is more important to be versed in the topologies and concepts of linear and switching regulator design, since not typically working specifically in this area. For this reason, several application notes readily available on the internet are cited and only one book.

[66] Pressman, et al, “Switching Power Supply Design, Third Edition,” McGraw-Hill, 2009. Written by a seasoned engineer for working engineers. The reference provides a thorough foundation and design guidelines for numerous switching topologies.

[67] “Basic Concepts of Linear Regulator and Switching Mode Power Supplies,” Linear Technology Application Note

[68] “Basic Linear Design, Chapter 9, Power Management,” Analog Devices

[69] “Switch-Mode Power Supply Reference Manual,” On Semiconductor

Low noise RF performance starts with low noise DC power. Two application notes are cited:

[70] Teel, “Understanding Noise in Linear Regulators,” Texas Instruments Application Note

[71] Morita, “Noise Sources in Low Dropout Regulators,” Analog Devices Application Note

Digital Signal Processing: Some knowledge of signal processing after the A/D capture is very useful to aid in understanding specification requirements flowed to the RF systems.

[72] Oppenheim et al, “Discrete-Time Signal Processing,” Prentice Hall, 2009. An advanced college textbook currently at the 3rd edition.

[73] Smith, “The Scientist and Engineer’s Guide to Digital Signal Processing,” Analog Devices, 1998. A practical, working engineer’s guide to DSP concepts.

Radar: Radar is its own specialized application. However, many RF engineers will work on something related to radar at some point in their careers. These references are old, but many of the system-level approaches in use today were worked out years ago and are just being implemented with modern methods.

[74] Stimson, “Introduction to Airborne Radar,” SciTech Publishing, 1998. A very concise, practical description of radar principles. The 2nd edition was 1998. The book is popular enough that a 3rd edition was published in 2014 with additional editors.

[75] Cook, Bernfeld, “Radar Signals, An Introduction to Theory and Application,” Academic Press, 1967. Develops the theory for how radar waveforms are chosen. This was popular enough to be re-released in 1993.

[76] Skolnik, “Radar Handbook,” McGraw-Hill, 1978. A 39-chapter dissertation on radar. All the principles are still valid although some of the electronic implementations are old. A 3rd edition was released in 2008.

[77] Skolnik, “Introduction to Radar Systems,” McGraw-Hill, 1980, 1962. This is an important classic radar book.

[78] “MIT Radiation Lab Series,” 1947-1951. Although old, this series documents the volume of development work made during the World War II time period advancing radar and related technologies. These developments and technical descriptions laid the foundation for radar development through the rest of the 20th century and on to today.

Antennas: Antenna theory is fundamental to RF. The above references are geared toward RF electronics and signal processing. A completely separate list could be compiled on antennas.

[79] Balanis, “Antenna Theory, Analysis and Design,” Wiley, 1982, 1997, 2005. This is the “bible” for antenna design, currently on its 3rd edition.

[80] John L. Volakis, ”Antenna Engineering Handbook,” Fourth Edition, McGraw-Hill, 2007. This is another well-known and well-respected antenna reference.

[81] Mailloux, “Phase Array Antenna Handbook,” Artech house, 1994. The study of phased arrays is an important subject on its own, once you get past individual antennas.

Tutorial Websites

The volume of information online is incredible. Learning through this method is encouraged and a good balance to written books or papers. Many great application notes are available from semiconductor companies, RF component companies, and test equipment companies, and research institutions. A few websites are listed which bring a unique contribution to the volume of available online material.

[82] http://www.rfcafe.com/

[83] http://www.microwaves101.com/

[84] http://www.circuitsage.com/

[85] http://www.rfwireless-world.com/

[86] http://www.rf-mw.org/

[87] http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html

[88] http://ecee.colorado.edu/~bart/book/book/contents.htm

[89] http://www.tubebooks.org/technical_books_online.htm

Areas Not Covered

The following areas are not referenced specifically but are also an important aspect of the RF engineering profession. These include:

1) **Programming:** Every engineer needs some programming fluency. Programming should be an aid, not a hindrance.

2) **CAD Tools:** CAD tools have progressed to an amazing level in our lifetimes. Circuit simulators, EM modelling, PWB and IC layout tools have made things possible that otherwise wouldn't exist. Learn the CAD tools in use at your facilities and help bring the latest tools into your departments.

3) **Mathematics:** While electrical engineering college curriculum is heavy in math, later, as working engineers, it is easy to forget. Keep some old college books around, and review the basics periodically.

Acknowledgement & Final Comment

The author would like to thank the engineers who reviewed this compilation and contributed to the list of titles provided. The above list is by no means complete. It is geared towards providing a foundation and a starting point. If this can provide some help for others, then it was worth the time to compile.

About the Author:

Peter Delos is a lead RFIC Engineer in the Lockheed Martin Microwave Center at the Moorestown, NJ, facility. He received his BSEE from Va Tech in 1990 and MSEE from NJIT in 2004. He began his career as an electrical field engineer gaining experience in many types of systems, electrical problems, and a foundation in the electrical engineering profession. In 1997, he accepted a position with Lockheed Martin in Moorestown, NJ, and began Receiver/Exciter/Synthesizer design. Mr. Delos has both worked in and led many design teams on highly integrated RF and mixed signal designs. The quest for high performance in reduced footprints led to detailed RFIC designs, and in 2012 he was transferred to the Lockheed Martin RFIC Design Center.