

# ISSCC 2010 Tutorial

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## RF CMOS Power Amplifiers and Linearization Techniques

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# Rf Cmos Power Amplifiers

**Kenichi Okada, Shouhei Kousai**

A red circular graphic with a gradient, appearing as a stylized arrow or a partial circle, located to the right of the authors' names.

## **Rf Cmos Power Amplifiers:**

RF CMOS Power Amplifiers: Theory, Design and Implementation Mona M. Hella, Mohammed Ismail, 2005-12-27 RF CMOS Power Amplifiers Theory Design and Implementation focuses on the design procedure and the testing issues of CMOS RF power amplifiers This is the first monograph addressing RF CMOS power amplifier design for emerging wireless standards The focus on power amplifiers for short is distance wireless personal and local area networks PAN and LAN however the design techniques are also applicable to emerging wide area networks WAN infrastructure using micro or pico cell networks The book discusses CMOS power amplifier design principles and theory and describes the architectures and tradeoffs in designing linear and nonlinear power amplifiers It then details design examples of RF CMOS power amplifiers for short distance wireless applications e g Bluetooth WLAN including designs for multi standard platforms Design aspects of RF circuits in deep submicron CMOS are also discussed RF CMOS Power Amplifiers Theory Design and Implementation serves as a reference for RF IC design engineers and RD and R D managers in industry and for graduate students conducting research in wireless semiconductor IC design in general and with CMOS technology in particular

RF CMOS Power Amplifiers: Theory, Design and Implementation Mona M. Hella, Mohammed Ismail, 2013-03-17 RF CMOS Power Amplifiers Theory Design and Implementation focuses on the design procedure and the testing issues of CMOS RF power amplifiers This is the first monograph addressing RF CMOS power amplifier design for emerging wireless standards The focus on power amplifiers for short is distance wireless personal and local area networks PAN and LAN however the design techniques are also applicable to emerging wide area networks WAN infrastructure using micro or pico cell networks The book discusses CMOS power amplifier design principles and theory and describes the architectures and tradeoffs in designing linear and nonlinear power amplifiers It then details design examples of RF CMOS power amplifiers for short distance wireless applications e g Bluetooth WLAN including designs for multi standard platforms Design aspects of RF circuits in deep submicron CMOS are also discussed RF CMOS Power Amplifiers Theory Design and Implementation serves as a reference for RF IC design engineers and RD and R D managers in industry and for graduate students conducting research in wireless semiconductor IC design in general and with CMOS technology in particular

**Linear CMOS RF Power Amplifiers** Hector Solar Ruiz, Roc Berenguer Pérez, 2013-09-14 The work establishes the design flow for the optimization of linear CMOS power amplifiers from the first steps of the design to the final IC implementation and tests The authors also focus on design guidelines of the inductor's geometrical characteristics for power applications and covers their measurement and characterization Additionally a model is proposed which would facilitate designs in terms of transistor sizing required inductor quality factors or minimum supply voltage The model considers limitations that CMOS processes can impose on implementation The book also provides different techniques and architectures that allow for optimization

Design of an RF CMOS Power Amplifier for Wireless Sensor Networks Hua Pan, 2012 The Power Amplifier PA is the last Radio Frequency RF

building block in a transmitter directly driving an antenna The low power RF input signal of the PA is amplified to a significant power RF output signal by converting DC power into RF power Since the PA consumes a majority of the power efficiency plays one of the most important roles in a PA design Designing an efficient fully integrated RF PA that can operate at low supply voltage 1.2V low power and low RF frequency 433MHz is a major challenge The class E Power Amplifier which is one type of switch mode PA is preferred in such a scenario because of its higher theoretical efficiency compared to linear power amplifiers A controllable class E RF power amplifier design implemented in 0.13 microm CMOS process is presented The circuit was designed simulated laid out fabricated and tested The PA will be integrated as a part of a complete wireless transceiver system using the same process

### **Design of RF CMOS Power Amplifiers Using Power Combining**

**Approach** [1], [2], 2013      Design and Computer-aided Optimization of RF CMOS Power Amplifiers Ravi Gupta, 1998 In recent years there has been an extensive effort to develop low cost implementations of radio frequency integrated circuits for consumer applications This thesis is a research effort in the design and implementation of integrated RF CMOS Power Amplifiers PAs A significant challenge in the implementation of RF CMOS ICs is the impact of device package and passive element parasitics on circuit performance Passive components are a critical part of any RF IC design and a process optimized for digital circuits results in inductors and capacitors with very high parasitics In this work we have developed a compact model for inductors fabricated in a digital CMOS process Measured results have been used to further refine the accuracy of the inductor model This model has been used to predict the impact of inductor parasitics on the performance of RFICs and is also simple enough to be included in a CAD tool for circuit optimization We have also studied the operation of Class A B and C power amplifiers and highlighted design issues which are specific to the implementation of integrated PAs It is shown that inductor loss has the most critical impact on the performance of integrated PAs A custom CAD tool based on the simulated annealing algorithm has been developed to optimize the performance of power amplifiers for maximum efficiency in the presence of package device and passive element parasitics This CAD tool simulates the process of load pull to determine the optimum large signal load impedance for the PA and optimizes the matching network design based on the trade off between the loss in the matching network and its impedance transformation properties This trade off is relevant in the case of high loss matching networks only as is the case in integrated RF CMOS ICs This CAD tool has been used to optimize the efficiency of balanced 100mW CMOS PAs operating at 900MHz Measured results validate the design and optimization process outlined in this work It is demonstrated that in the design of RF CMOS ICs significant benefits can be gained by incorporating parasitics into the design process by means of CAD optimization The CAD tool developed is an effort towards achieving this goal It is further proposed that CAD optimization is an essential part of the design of RF CMOS ICs in general and with the development of improved package device and passive element models CAD optimization will replace the tuning of RF circuits and result in robust fully integrated implementations of RF circuits

*Linear CMOS RF Power Amplifiers for Wireless*

*Applications* Paulo Augusto Dal Fabbro, Maher Kayal, 2010-06-22 Advances in electronics have pushed mankind to create devices ranging from credible gadgets to medical equipment to spacecraft instruments More than that modern society is getting used to if not dependent on the comfort solutions and astonishing amount of information brought by these devices One eld that has continuously bene tted from those advances is the radio frequency integrated c cuit RFIC design which in its turn has promoted countless bene ts to the mankind as a payback Wireless communications is one prominent example of what the vances in electronics have enabled and their consequences to our daily life How could anyone back in the eighties think of the possibilities opened by the wireless local area networks WLANs that can be found today in a host of places such as public libraries coffee shops trains to name just a few How can a youngster who lives this true WLAN experience nowadays imagine a world without it This book dealswith the design oflinearCMOS RF PowerAmplifiers PAs The RF PA is a very important part of the RF transceiver the device that enables wireless communications Two important aspects that are key to keep the advances in RF PA design at an accelerate pace are treated ef ciency enhancement and frequen tunable capability For this purpose the design of two different integrated circuits realizedina0 11 mtechnologyispresented eachoneaddressingadifferentaspect With respect to ef ciency enhancement the design of a dynamic supply RF power ampli er is treated making up the material of Chaps 2 to 4

*Design and Analysis of RF CMOS Power Amplifiers for Bluetooth Applications* Ying Y. Li, 2014 This thesis researches the design of transceiver front end RF amplifiers for Bluetooth applications in GPDK 45 nm CMOS technology The target of the design was to minimize the transceiver s power consumption while achieving the best device operating performances The design of a band pass low noise amplifier LNA used for the receiver and the design of a power amplifier PA used for the transmitter were presented Both amplifiers were designed in 45 nm CMOS technology with a DC supply voltage under 1 2 V to meet Bluetooth specifications at 2 45 GHz operating frequency The LNA was designed to achieve a minimum small signal gain of at least 15 dB10 with a NF less than 2 dB10 and a reasonable input range for linearity at 1 mW operating power consumption The PA was designed based on class E switching power amplifier configuration to achieve a minimum of 40% drain efficiency for 100 mW Bluetooth Class 1 output power Research on low power high performance Bluetooth device front end RF amplifiers was conducted through studies of wireless communication modulation schemes impedance matching networks and trade offs between performance parameters In summation this thesis searched for explored and analyzed possible methodologies that could be used to design RF CMOS amplifiers of Bluetooth applications

**Development of Integrated RF CMOS Power Amplifiers for Wireless Communications** Yi-Jan Emery Chen, 2001 *RF CMOS Class C Power Amplifiers for Wireless Communications*

Ramakrishna Sekhar Narayanaswami, 2001 *RF and mm-Wave Power Generation in Silicon* Hua Wang, Kaushik Sengupta, 2015-12-10 RF and mm Wave Power Generation in Silicon presents the challenges and solutions of designing power amplifiers at RF and mm Wave frequencies in a silicon based process technology It covers practical power amplifier

design methodologies energy and spectrum efficient power amplifier design examples in the RF frequency for cellular and wireless connectivity applications and power amplifier and power generation designs for enabling new communication and sensing applications in the mm Wave and THz frequencies With this book you will learn Power amplifier design fundamentals and methodologies Latest advances in silicon based RF power amplifier architectures and designs and their integration in wireless communication systems State of the art mm Wave THz power amplifier and power generation circuits and systems in silicon Extensive coverage from fundamentals to advanced design topics focusing on various layers of abstraction from device modeling and circuit design strategy to advanced digital and mixed signal architectures for highly efficient and linear power amplifiers New architectures for power amplifiers in the cellular and wireless connectivity covering detailed design methodologies and state of the art performances Detailed design techniques trade off analysis and design examples for efficiency enhancement at power back off and linear amplification for spectrally efficient non constant envelope modulations Extensive coverage of mm Wave power generation techniques from the early days of the 60 GHz research to current state of the art reconfigurable digital mm Wave PA architectures Detailed analysis of power generation challenges in the higher mm Wave and THz frequencies and novel technical solutions for a wide range of potential applications including ultrafast wireless communication to sensing imaging and spectroscopy Contributions from the world class experts from both academia and industry

*RF Power Amplifiers for Mobile Communications* Patrick Reynaert, Michiel Steyaert, 2006-11-18 This book tackles both high efficiency and high linearity power amplifier PA design in low voltage CMOS With its emphasis on theory design and implementation the book offers a guide for those actively involved in the design of fully integrated CMOS wireless transceivers Offering mathematical background as well as intuitive insight the book is essential reading for RF design engineers and researchers and is also suitable as a text book

*High-Linearity CMOS RF Front-End Circuits* Yongwang Ding, Ramesh Harjani, 2004-11-12 This book focuses on high performance radio frequency integrated circuits RF IC design in CMOS

1 Development of radio frequency ICs Wireless communications has been advancing rapidly in the past two decades Many high performance systems have been developed such as cellular systems AMPS GSM TDMA CDMA W CDMA etc GPS system global positioning system and WLAN wireless local area network systems The rapid growth of VLSI technology in both digital circuits and analog circuits provides benefits for wireless communication systems Twenty years ago not many people could imagine millions of transistors in a single chip or a complete radio for size of a penny Now not only complete radios have been put in a single chip but also more and more functions have been realized by a single chip and at a much lower price A radio transmits and receives electro magnetic signals through the air The signals are usually transmitted on high frequency carriers For example a typical voice signal requires only 30 KiloHertz bandwidth When it is transmitted by a FM radio station it is often carried by a frequency in the range of tens of megahertz to hundreds of megahertz Usually a radio is categorized by its carrier frequency such as 900 MHz radio or 5 GHz radio In general the higher the carrier frequency the

better the directivity but the more difficult the radio design

**RF CMOS Power Amplifier Class C for Wireless Communication** Azdiana Md. Yusop, 2003 *Highly Efficient CMOS Power Amplifiers at C- and S-Band for Low Supply Voltages* Jörg Carls, 2009 **Digitally-Assisted Analog and RF CMOS Circuit Design for Software-Defined Radio** Kenichi Okada, Shouhei Kousai, 2011-08-26 This book describes the state of the art in RF analog and mixed signal circuit design for Software Defined Radio SDR It synthesizes for analog RF circuit designers the most important general design approaches to take advantage of the most recent CMOS technology which can integrate millions of transistors as well as several real examples from the most recent research results *5G and E-Band Communication Circuits in Deep-Scaled CMOS* Marco Vigilante, Patrick Reynaert, 2018-02-07 This book discusses design techniques layout details and measurements of several key analog building blocks that currently limit the performance of 5G and E Band transceivers implemented in deep scaled CMOS The authors present recent developments in low noise quadrature VCOs and tunable inductor less frequency dividers Moreover the design of low loss broadband transformer based filters that realize inter stage matching power division combining and impedance transformation is discussed in great detail The design and measurements of a low noise amplifier a downconverter and a highly linear power amplifier that leverage the proposed techniques are shown All the prototypes were realized in advanced nanometer scaled CMOS technologies without RF thick to metal option **CMOS Power Device Modeling and Amplifier Circuits** Doris A. Chan, 2011 A power amplifier PA is a key part of the RF front end in transmitters for a local broadband network Today commercial PAs are made of III V HEMT and HBT technology with excellent results An integrated system on chip power amplifier circuit using CMOS technology for cost effective and spectrum efficient high speed wireless communication presents major challenges because power amplifiers have been the limiting components in RF CMOS transmitter integrated circuits ICs At high frequencies the distributed effect and power device scaling issues put other constraints on PA design such as the trade off between output power  $P_{out}$  and power added efficiency PAE Recently CMOS has become attractive for low cost and high level integration due to the advancement of NMOS performance with  $f_t$  and  $f_{max}$  100 GHz and is available from commercial CMOS foundries However the foundry provided BSIM RF model is unable to accurately predict the I V characteristics and RF behaviors  $f_t$  and  $f_{max}$  of power devices with widths of several hundred microns Therefore an advanced large signal model which is able to predict distributed nonlinear effects is crucial for the successful design of high frequency PAs The microwave lumped and distributed layout parasitic effect in the 130 nm BSIM3v3 RF and 90 nm BSIM4 RF models to accurately predict gain output power and harmonic distortions of power MOSFETs at millimeter wave frequencies The proposed power device model is verified for single devices as well as for the integrated power amplifier circuits in S band and W band applications For S band WiMAX application we have developed an accurate modeling with layout parasitic of power CMOS devices and designed lossless matching networks to achieve single end PA performance of 31 dB gain 21.4 dBm output power and 14.5% PAE at the 1 dB

compression point The measured maximum output power is 25.5 dBm and the associated PAE is 32% For W band application a compact two stage CMOS power amplifier is designed with gain boosting at the common gate transistor source degeneration for the cascode devices and LC short stub matching networks The amplifier was fabricated and demonstrated with excellent RF performance of 18 dB gain 10.8 dBm linear output power 13.3 dBm saturated power and 11.8% PAE at 80 GHz with a minimum chip area of 0.35 mm<sup>2</sup> in 90 nm CMOS technology Monolithic power combining techniques are attractive for delivering linear power over 20 dBm at W band range due to the size reduction of the combiner A W band monolithic CPW Wilkinson power combiner of two CMOS power amplifiers is implemented in 90 nm CMOS technology The 77 to 83 GHz CMOS PA achieved the 17 dB small signal gain 4.5 GHz 3 dB bandwidth 10.6 dBm linear output power 12.3 dBm saturated power and 3.9% PAE at 80 GHz

**RF Circuit Design** Richard C. Li, 2008-10-22 A Must Read for all RF RFIC Circuit Designers This book targets the four most difficult skills facing RF RFIC designers today impedance matching RF AC grounding Six Sigma design and RFIC technology Unlike most books on the market it presents readers with practical engineering design examples to explore how they re used to solve ever more complex problems The content is divided into three key parts Individual RF block circuit design Basic RF circuit design skills RF system engineering The author assumes a fundamental background in RF circuit design theory and the goal of the book is to enable readers to master the correct methodology The book includes treatment of special circuit topologies and introduces some useful schemes for simulation and layout This is a must read for RF RFIC circuit design engineers system designers working with communication systems and graduates and researchers in related fields

Millimeter-Wave Power Amplifiers Jaco du Preez, Saurabh Sinha, 2017-10-05 This book provides a detailed review of millimeter wave power amplifiers discussing design issues and performance limitations commonly encountered in light of the latest research Power amplifiers which are able to provide high levels of output power and linearity while being easily integrated with surrounding circuitry are a crucial component in wireless microwave systems The book is divided into three parts the first of which introduces readers to mm wave wireless systems and power amplifiers In turn the second focuses on design principles and EDA concepts while the third discusses future trends in power amplifier research The book provides essential information on mm wave power amplifier theory as well as the implementation options and technologies involved in their effective design equipping researchers circuit designers and practicing engineers to design model analyze test and implement high performance spectrally clean and energy efficient mm wave systems



## **Rf Cmos Power Amplifiers** Book Review: Unveiling the Magic of Language

In an electronic digital era where connections and knowledge reign supreme, the enchanting power of language has be more apparent than ever. Its capability to stir emotions, provoke thought, and instigate transformation is actually remarkable. This extraordinary book, aptly titled "**Rf Cmos Power Amplifiers**," written by a very acclaimed author, immerses readers in a captivating exploration of the significance of language and its profound impact on our existence. Throughout this critique, we will delve into the book is central themes, evaluate its unique writing style, and assess its overall influence on its readership.

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### **Table of Contents Rf Cmos Power Amplifiers**

1. Understanding the eBook Rf Cmos Power Amplifiers
  - The Rise of Digital Reading Rf Cmos Power Amplifiers
  - Advantages of eBooks Over Traditional Books
2. Identifying Rf Cmos Power Amplifiers
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Rf Cmos Power Amplifiers
  - User-Friendly Interface
4. Exploring eBook Recommendations from Rf Cmos Power Amplifiers
  - Personalized Recommendations
  - Rf Cmos Power Amplifiers User Reviews and Ratings
  - Rf Cmos Power Amplifiers and Bestseller Lists
5. Accessing Rf Cmos Power Amplifiers Free and Paid eBooks

- Rf Cmos Power Amplifiers Public Domain eBooks
- Rf Cmos Power Amplifiers eBook Subscription Services
- Rf Cmos Power Amplifiers Budget-Friendly Options
- 6. Navigating Rf Cmos Power Amplifiers eBook Formats
  - ePub, PDF, MOBI, and More
  - Rf Cmos Power Amplifiers Compatibility with Devices
  - Rf Cmos Power Amplifiers Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Rf Cmos Power Amplifiers
  - Highlighting and Note-Taking Rf Cmos Power Amplifiers
  - Interactive Elements Rf Cmos Power Amplifiers
- 8. Staying Engaged with Rf Cmos Power Amplifiers
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Rf Cmos Power Amplifiers
- 9. Balancing eBooks and Physical Books Rf Cmos Power Amplifiers
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Rf Cmos Power Amplifiers
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Rf Cmos Power Amplifiers
  - Setting Reading Goals Rf Cmos Power Amplifiers
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Rf Cmos Power Amplifiers
  - Fact-Checking eBook Content of Rf Cmos Power Amplifiers
  - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development

- Exploring Educational eBooks

#### 14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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