mm-Wave Silicon Power Amplifiers and Transmitters

Build high-performance, spectrally clean, energy-efficient mm-wave power amplifiers and transmitters with this cutting-edge guide to designing, modeling, analyzing, implementing, and testing new mm-wave systems.

Suitable for students, researchers, and practicing engineers, this self-contained guide provides in-depth coverage of state-of-the-art semiconductor devices and technologies; linear and nonlinear power amplifier technologies; efficient power combining systems, circuit concepts, system architectures, packaging, and system-on-a-chip realizations.

The world's foremost experts from industry and academia cover all aspects of the design process, from device technologies to system architectures. Accompanied by numerous case studies highlighting practical design techniques, trade-offs, and pitfalls, this is a superb resource for those working with high-frequency systems.

Hossein Hashemi is a Professor of Electrical Engineering, Ming Hseih Faculty Fellow, and the co-director of the Ming Hsieh Institute and Ultimate Radio Laboratory, University of Southern California.

Sanjay Raman is a Professor of Electrical and Computer Engineering at Virginia Tech, and a former Program Manager in the Microsystems Technology Office, DARPA. He is a Fellow of the IEEE.

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HOSSEIN HASHEMI
University of Southern California

SANJAY RAMAN
Virginia Tech

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Contents

Contributors

Peter Asbeck
University of California, San Diego

Steven M. Bowers
University of Virginia

James Buckwalter
University of California, Santa Barbara

Renata Camillo Castillo
IBM

Anandaroop Chakrabarti
Columbia University

Kunal Datta
University of Southern California

Kaushik Dasgupta
Intel

Brian Floyd
North Carolina State University

David Harame
Formerly of IBM, now with Global Foundries

Ali Hajimiri
California Institute of Technology

Hossein Hashemi
University of Southern California

Tian-Wei Huang
National Taiwan University

Vibhor Jain
IBM

Harish Krishnaswamy
Columbia University

Arun Natarajan
Oregon State University

Ali M. Niknejad
University of California, Berkeley

Egidio Ragonese
ST-Microelectronics

Sanjay Raman
Virginia Tech

Patrick Reynaert
Katholieke Universiteit Leuven

Antonio Scuderi
Qualcomm

Kaushik Sengupta
Princeton University

Jeng-Han Tsai
National Taiwan Normal University

Sorin P. Voinigescu
University of Toronto

Jin-Fu Yeh
National Taiwan University

Dixian Zhao
Katholieke Universiteit Leuven

Preface

Silicon has become the uncontested technology of choice for commercial radio-frequency integrated systems such as those in smartphones, tablets, and televisions. Research over the past decade has demonstrated the feasibility of realizing complex silicon integrated systems at millimeter frequencies. There is little doubt that operation at millimeter waves not only offers advantages, but also is necessary in many commercial and noncommercial applications. Millimeter-wave integrated circuits for automotive radars and high-speed wireless connectivity are already in the market. The fifth-generation wireless standards will include millimeter-wave operation as an essential component to increase the overall capacity. The volume of millimeter-wave integrated systems may soon exceed billions of units per year.

Millimeter-wave operation has a long history. Sir Jagadish Chandra Bose demonstrated transmission and reception of 60 GHz electromagnetic waves over a distance of 23 m in 1895. The application of solid-state devices in the millimeter-wave range started in the second half of the twentieth century. In the 1970s, solid-state transceivers at 60 GHz were demonstrated primarily by using diodes for signal generation, frequency conversion, and amplification. Monolithic millimeter-wave receivers and transmitters were reported in the 1980s using III–V transistors capable of providing power gain well into the millimeter-wave region. Applicability of silicon technologies, including CMOS, for radio-frequency applications was established in the 1990s. Complex silicon integrated systems at millimeter waves were reported in the 2000s, and commercial products started entering the market shortly after.

Throughout history, technology has always been a limiting factor in the amount of radio-frequency signal power that can be generated. In the absence of devices that can provide power gain, generating electromagnetic signals will be power inefficient. Early demonstrations of electromagnetic signal generation at higher frequencies typically involve nonlinear processes such as harmonic signal generation. These approaches are gradually replaced with more linear amplification approaches once supporting technologies become available. In other words, efficient high-power electromagnetic signal generation and amplification oftentimes lags the demonstration and even deployment of wireless systems operating at those frequencies. It is hence natural to see that efficient high-power generation of millimeter-wave signals using silicon technologies is an ongoing research topic nearly a decade after the early demonstrations of complex silicon millimeter-wave integrated systems.

Not too long ago, silicon was considered to be incapable of serving as a proper technology for the realization of power amplifiers even at radio frequencies. In fact, the viability of CMOS in certain commercial RF wireless systems is still a debated topic. In 2009, the US Defense Advanced Research Projects Agency (DARPA) postulated that watt-level transmitter output power can be achieved in silicon technologies with efficiencies significantly beyond the state-of-the-art and these transmitters could be linearized on-chip to support high-order digitally modulated waveforms. This led to the launching of the Efficient Linearized All-Silicon Transmitters ICs (ELASTx) program, of which we were both key players (Sanjay as founding program manager, Hossein as leader of one of the key performer teams). In June 2012, we organized a workshop at the IEEE Radio Frequency Integrated Circuits (RFIC) Symposium with an ambitious title of "Towards Watt-Level mm-Wave Efficient Silicon Power Amplifiers." The workshop included talks by prominent individuals from academia and industry, including several ELASTx team members, covering challenges and research efforts around this topic. The enthusiasm from speakers and participants was accompanied by realistic skepticism about the viability of such an outrageous proposition in the near future. It is extremely gratifying to witness watt-level silicon power amplifiers and transmitters generating millimeter-wave signals efficiently from various research groups across the world a few short years after the workshop.

The seeds of this book were planted at the same IEEE RFIC Workshop. Cambridge University Press, led by Dr Julie Lancashire, concurred with our vision that a book on the topic of silicon millimeter-wave transmitters and power amplifiers is timely. We did not want the book to be a mere collection of research results that have appeared as papers over the past few years. The intent was to draft a book that includes technology, challenges, theory, and a systematic approach towards realization of silicon millimeter-wave power amplifiers and transmitters with research results offered as proof-of-concept case studies. Most chapters of the book are written in an advanced textbook style suitable for graduate students and practicing engineers. Many graphs and tables include comprehensive data about the relevant technologies, devices, and circuits, and serve as complete up-to-date references for researchers and developers. Maintaining consistency and flow across various chapters is a challenge in a multi-authored book. The authors have been very cooperative in drafting and revising their chapters in this spirit. It has been a pleasure to work with the world's top individuals in the area of silicon millimeter-wave integrated circuits for this project. We hope that all readers learn from reading this book as much as we did.

Editing a multi-authored book, especially when the authors are all prominent busy individuals, is not an easy task. It requires great patience and support. We have been lucky to work with the wonderful team at the Cambridge University Press on this project. Dr Julie Lancashire was nothing but graciously supportive and understanding over the past two years. Elizabeth Horne and Heather Brolly provided wonderful assistance. Thank you all!