

Preface

In the age where telecommunication has become a standard, almost every portable device has some kind of transmitter and receiver allowing it to connect to a cellular network or available Wi-fi networks. We are also driving cars that are smarter, equipped with new technologies, such as radars for collision detection. Other types of radars are used in both civilian and military applications. Nowadays, we even receive signals from satellites on our phones from global positioning systems. The spectrum around us is full of transmitted signals waiting to be received. Current trends toward increased wireless connectivity and the need to stay connected everywhere and at all times call for extremely high data rates. In the world of today, most wireless networks operate in frequency bands measured in low gigahertz (GHz). Typically, this is done through channels with moderate bandwidth. To keep up with the trends of increased data transmission rates, new and innovative ideas are needed. Part of research efforts is directed at increasing the bandwidth of the channels that are used for wireless communication. One of the areas of investigation is transmission in the millimeter-wave regime, ranging from 30 to 300 GHz, where there is an abundance of bandwidth.

Transmission in the millimeter-wave part of the spectrum comes with much greater challenges than, for example, in the radio frequency (RF) or microwave part of the spectrum. Receiving the transmitted signal poses a whole new set of challenges. The low-noise amplifier (LNA) is the first component that appears in the front ends of most microwave and millimeter-wave receivers after an antenna (except, perhaps, a low-loss bandpass filter for signal selection). The performance of an RF and millimeter-wave receiver is therefore largely dependent on the performance of the LNA that is used.

Primarily, the LNA is tasked with amplifying a signal while introducing as little noise into the signal as possible. This is a necessity, because the signal received by the antenna is already submerged in noise; thus before the signal can be processed, it needs to be amplified with the smallest possible amount of additional noise introduced in this process. As technologies such as silicon-germanium BiCMOS and Silicon CMOS continue to evolve, so too does the number of low-cost, high-performance transceiver systems that operate in the millimeter-wave region.

Most attempts to realize these transceiver systems are in integrated circuits (ICs), which offer the benefits of reduced size and lower cost.

The purpose of this book is twofold. The first goal of the book is to bring together the theory behind millimeter-wave circuit operation with the theory of low-noise amplification. Its second goal is to present new research in this multidisciplinary field, by dissecting the common LNA configurations and typical specifications into parts, which are then optimized separately over several chapters to suggest improvements in the current state-of-the-art designs.

This, therefore, allows for the book to be divided into two parts, with Chap. 1 serving as the introduction to research. The first part contextualizes LNA theory and supporting multidisciplinary concepts, while the second part deals with the state of the art in LNA research for the millimeter-wave regime and somewhat more advanced topics associated with LNAs.

Chapter 1 gives the reader ample background on the importance of LNAs and some of the challenges that are unique to millimeter-wave research, and serves to formulate the research questions and establish this book as a comprehensive research resource for LNAs that operate in the millimeter-wave regime.

Part I presents a detailed analysis of the current body of knowledge when it comes to LNAs, specifically for millimeter applications. This includes detailed analysis of two-port modeling, practical means of amplifier analysis, gain equations, stability issues, various noise aspects, broadband techniques, and amplifier linearity. This is complemented by some telecommunication aspects associated with LNAs, including placing the millimeter-wave range in the context of the other transmission bands and a detailed review of millimeter-wave prospects, investigation into current antenna efforts and modulation schemes. Also in Part I, the technologies for LNA implementations are discussed. The latest developments in various high- f_T and f_{MAX} transistors are investigated in an attempt to evaluate suitable semiconductor devices for LNA implementation at millimeter-wave frequencies. This is followed by the complete small-signal model analysis of both MOSFETs (and variations thereof) and HBTs. Transistor noise modeling, paramount for LNAs, is also discussed together with substrates for discrete LNA implementations. Furthermore, the feasibility of passives at frequencies up to millimeter-wave bands is presented. This refers to both lumped passives (resistors, capacitors, inductors) and transmission line passives, with some innovative ideas. Traditionally, lumped passives have been unsuitable for millimeter-wave because of their high parasitics, but with recent technology improvements, the use of lumped passives is also possible and is discussed at some length. Finally, various LNA configurations and the design theory of these, devised from first principles of amplifier operation, are discussed. Techniques such as simultaneous matching for power and noise, as well as bandwidth enhancement, are discussed for both narrowband and wideband applications.

In Part II, state-of-the-art LNA configurations and means for their deployment are discussed. Some complex practical LNA configurations are looked at, and the latest research efforts, with the focus on linearization and optimization, exclusively in the millimeter-wave regime, are presented. Weaknesses of state-of-the-art

configurations are considered, thereby opening up opportunities for looking at ways of optimizing these state-of-the-art configurations. The focus then shifts toward research areas that are still under development. The topics include the influence of wavelength, layout, cross-talk, bonding, and packaging onto LNA performance, among others. Advanced fabrication technologies used to decrease the parasitics of passive and active devices and therefore optimize circuits such as LNAs are also explored. Different packaging technologies such as silicon-on-chip and silicon-on-package are discussed as alternatives to IC implementation. Minimization of the parasitic effects of passives by introducing innovative ideas for their construction is another of the topics explored here. Alternative design methodologies, such as LNA/antenna co-design, are considered. Part II also looks at the current extent and availability of electronic design automation (EDA) for use when designing LNAs. Ongoing research efforts into automated LNA design and optimization are furthermore investigated. A number of EDA options for high-quality passive components (inductors), matching, LNAs, and even complete receivers are proposed. Finally, remaining research gaps in LNA research for the millimeter-wave regime and future directions are explored. The book concludes with the authors' proposal for streamlined automated LNA design flow, which focuses on the design of the LNA as a collection of highly optimized subsystems (parts).

The authors would like to recognize Dr. Riëtte de Lange, Director of Research Productivity & Improvement of Staff Qualifications, Strategic Initiatives and Administration, University of Johannesburg, South Africa, for her coordination.

Furthermore, the authors would like to recognize the support of technical reviewers, as well as language and graphic editors, who've all contributed to this process. We value the system of scholarly peer review and the approach that this adds to the production of research text that adds to the body of scientific knowledge.

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<http://www.springer.com/978-3-319-69019-3>

Millimeter-Wave Low Noise Amplifiers

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2018, XVIII, 334 p. 264 illus., 46 illus. in color.,

Hardcover

ISBN: 978-3-319-69019-3