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Mustafijur Rahman • Ramesh Harjani

Design of Low Power Integrated Radios for Emerging Standards

Springer

Mustafijur Rahman
Intel Labs
Hillsboro, OR, USA

Ramesh Harjani
Department of Electrical & Computer Engineering
University of Minnesota
Minneapolis, MN, USA

ISSN 1872-082X ISSN 2197-1854 (electronic)
Analog Circuits and Signal Processing
ISBN 978-3-030-21332-9 ISBN 978-3-030-21333-6 (eBook)
https://doi.org/10.1007/978-3-030-21333-6

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

To my dear parents....

Preface

In this book, circuit techniques pertinent to low power CMOS integrated radio design compatible with IEEE 802.15.6 standard are presented. Low power radios are in increasing demand with the advent of an era of the "Wireless Body Area Networks" and "Internet of Things". The performance of the proposed techniques have been verified by fabricating them in two standard CMOS processes: TSMC's 65 nm and IBM's 130 nm process. These designs are compatible with all the channels defined in IEEE 802.15.6 standard in the frequency range of 2.36–2.484 GHz.

First, an IEEE 802.15.6 compliant 2360–2484 MHz multiband transmitter is presented that digitally multiplexes the appropriate phases from an 800 MHz polyphase filter output to generate $\pi/4$ DQPSK signals at 2.4 GHz using injection locking. Modulation at one-third the RF frequency reduces the transmitter power consumption and enables channel selection using an integer N PLL running at 800 MHz. The modulation technique does not require phase calibration and resolves the problems of traditional injection lock-based modulators. The prototype transmitter implemented in IBM's 130 nm technology consumes 2.4 mW while delivering -10 dBm RF power at the TX output resulting in an energy efficiency of 2.5 nJ/bit at 1.2 Mbps raw data rate. The measured RMS EVM for $\pi/4$ DQPSK modulation is 3.21%.

Second, a 2.3–2.5 GHz low power low-noise 0.7 V mixer-first RF frontend for an IEEE 802.15.6 narrowband receiver is presented which uses frequency translated mutual noise cancellation based on passive coupling. Unlike traditional noise cancelling techniques, we perform symmetrical noise cancellation of a fully differential structure where each path cancels the noise of the other at IF. This prototype design realized in TSMC's 65 nm CMOS tackles the noise figure and power consumption problems of sub-1 V mixers. The figure of merit (FOM) is 10 dB higher, and the power consumption is 194 μW which is 0.5$\times$ lower than the state of the art. The local oscillator (LO) power used is only -14 dBm.

Third, a 0.7 V low power LNA combines a 1:3 frontend balun with dual-path noise and nonlinearity cancellation for improved noise performance at low power. In traditional techniques, only the noise of the main path is cancelled, while the noise of the auxiliary path is minimized by using high power. In the proposed design, the noise and nonlinearity of both the main and the auxiliary paths are mutually cancelled, allowing for low power operation. The 2.8 dB NF −10.7 dBm IIP3 LNA in TSMC's 65 nm GP process consumes 475 μW of power resulting in an FOM of 28.8 dB which is 8.2 dB better than the state of the art.

Finally, we present an 802.15.6 compliant 2.36–2.484 GHz multiband transceiver that uses an energy-efficient programmable digital power amplifier on the transit side and a zero power passive voltage gain frontend using a 1:3 balun on the receive side to achieve low power operation. A seventh harmonic injection locked oscillator and zero power passive polyphase filter generate the phases at 2.4 GHz required for phase modulation on the transmit side and for LO generation on the receive side. This enables channel selection using a 342.86 MHz PLL, i.e., at one-seventh of the RF frequency of 2.4 GHz to result in low power consumption. The prototype transmitter consumes 1.48 mW of power while delivering −9.47 dBm output power resulting in an energy efficiency of 1.52 nJ/bit at 971 kbps data rate. The measured RMS EVM for $\pi/4$ DQPSK modulation is 5.68%. The prototype receiver consumes 1.29 mW of power resulting in an energy efficiency of 1.32 nJ/bit while achieving a receiver noise figure of 10.2 dB and an IIP3 of −24.1 dBm. This design does not use offchip inductors.

Hillsboro, OR, USA Mustafijur Rahman
Minneapolis, MN, USA Ramesh Harjani

Acknowledgments

I have received immense support, inspiration, and guidance from several people to reach this stage in life, and this book shall be incomplete without expressing gratitude to them.

First and foremost, I express my most sincere gratitude to my advisor Prof. Ramesh Harjani for his guidance and motivation throughout my PhD. I am fortunate to have him as an advisor who provided me the freedom to explore on my own and at the same time guided me when I was struggling with a problem. I am grateful to him for facilitating me with a fabrication of circuits in advanced technology nodes and a well-equipped lab with test instruments. Furthermore, he has helped me acquire skills related to technical writing and making quality presentations. I am also thankful to Savita Harjani for the warm hospitality and delicious food at the get-together dinner parties at their residence which I shall miss in the future.

I would like to thank Prof. F.A. Talukdar and Dr. K.L. Baishnab for supervising my undergraduate final year project at NIT Silchar. Their support has been instrumental in publishing my undergraduate research work in analog circuit design. Furthermore, I was fortunate to earn a summer research position under Prof. Roy. P. Paily at IIT Guwahati where I was exposed to MEMS and analog circuit design using state-of-the-art CAD tools.

I would like to thank my lab-mates Martin Sturm and Mohammad Elbadry for introducing me to the steps of completing a successful tapeout in silicon. They also helped me in using the test equipments in the laboratory. I am thankful to Mohammad Elbadry for helping me in the layout of digital baseband section in the transmitter and guiding me through EM simulation steps. I can never forget Taehyoun Oh for his words of inspiration which helped in fostering strong confidence within myself throughout my PhD. I am also thankful to Anindya Saha, Saurabh Chaubey, Rakesh Kumar Palani, Hundo Shin, Xingyi Hua, and Zhiheng Wang for being great friends and lab-mates.

Furthermore, I would like to thank the people in the ECE Department whose support enable graduate students to conduct research smoothly. I would like to thank Carlos Soria and Chimai Nguyen for their support in maintaining the servers, softwares, and CAD tools. I would also like to thank Linda Bullis, Dan Dobrick, Jim Aufderhar, and Linda Jagerson for their help in purchasing components and in administrative issues.

Outside academics, I would like to thank Sri Sunil Barman in my hometown, Abhayapuri, in Assam, India, who was a retired laboratory demonstrator in a local Science College. He wrote a couple of books for designing portable radios and hobby projects using discrete components and used to present electronic projects in local science exhibitions. Being written by someone in the same town, I got excited and followed those books when I was in class VIII in school. I started designing interesting electronic projects like radio receiver and transmitter, automatic water tap using light-dependent resistor (LDR), power backup inverters, etc. Being fascinated at an early age, I decided to pursue Electronics and Communication Engineering during my undergraduate studies at NIT Silchar.

Finally, I am ever grateful to my parents for their trust and moral support. They have given me absolute freedom to pursue what I liked the most. Their blessings and good wishes have been invaluable in accomplishing my achievements.

I sincerely thank you all!

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