ANALYSIS AND STUDY OF POWER-EFFICIENT SAR ADC FOR ACTIVE RFID SENSOR

AHMAD AZZREEN BIN DALAWI

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

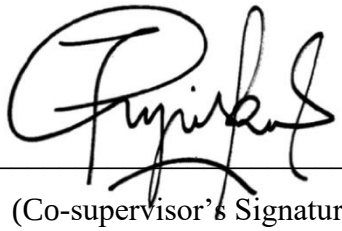
We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

(Supervisor's Signature)

Full Name : IR. DR. FAHMI BIN SAMSURI

Position : ASSOCIATE PROFESSOR

Date : 28 JUNE 2021



(Co-supervisor's Signature)

Full Name : IR. DR. AYIB ROSDI BIN ZAINUN

Position : SENIOR LECTURER

Date : 28 JUNE 2021

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

(Student's Signature)

Full Name : AHMAD AZZREEN BIN DALAWI

ID Number : MEL14004

Date : 21 JUNE 2021

ANALYSIS AND STUDY OF POWER-EFFICIENT SAR ADC FOR ACTIVE RFID SENSOR

AHMAD AZZREEN BIN DALAWI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

College of Engineering

UNIVERSITI MALAYSIA PAHANG

AUGUST 2021

ACKNOWLEDGEMENTS

Alhamdulillah, the highest thanks to God because with His will, I was able to finally completed my master's degree. It was long overdue and better late than never. I would like to express my greatest gratitude and sincere appreciation to everyone who is involved directly or indirectly in completing this research. Honestly, without their invaluable support and guidance, my research would not have been completed.

My greatest and deepest appreciation and gratitude goes to my research supervisor and co-supervisor, Associate Professor Ir. Dr. Fahmi Bin Samsuri and Ir. Dr. Ayib Rosdi Bin Zainun respectively as their guidance and untiring support throughout my research. With their visionary advice and patient mentoring, this research was executed with success.

And finally, I would like to extend my appreciation to my family members for their financial and moral support from the start of this journey until the end. Thank you.

ABSTRAK

Tesis ini memperkenalkan daftar anggaran berturut-turut (SAR) penukar analog-ke-digital (ADC) cekap tenaga teristimewa untuk sensor aktif bagi sistem tag pengenalan frekuensi radio rendah (RFID). Sebagai sebahagian daripada transformasi perkara Internet (IoT), RFID digunakan secara meluas. Dalam aplikasi di mana bekalan kuasa adalah terhad, penggunaan kuasa sentiasa menjadi kriteria yang ketara seperti litar analog seperti litar ADC, litar pengawal selia, litar penerus dan frekuensi radio (RF) adalah komponen yang biasa memerlukan kuasa dalam sistem. Biasanya, keperluan untuk prestasi bateri yang lebih lama berkait rapat dengan penggunaan kuasa rendah. Bagi sensor RFID aktif aplikasi yang memerlukan resolusi rendah dan sederhana serta penggunaan kuasa rendah, SAR ADC biasanya digunakan kerana ianya sebahagian daripada litar ADC. Oleh itu, SAR ADC yang cekap kuasa dibentangkan dalam kerja ini. Blok ADC SAR seperti blok pembanding, blok penukar digital-untuk-analog (DAC), dan blok sampler direka untuk memenuhi keperluan pengukuran prestasi penggunaan kuasa rendah. Tesis ini pada mulanya akan meneroka perbezaan antara teknik ADC dalam kerja-kerja sebelumnya. SAR ADC yang dicadangkan dibentangkan untuk meningkatkan penggunaan kuasa SAR ADC dalam aplikasi sensor RFID aktif menerusi pelaksanaan satu komparator input tunggal dengan DAC kapasitor beralih. Dalam bentuk seni bina ini, hanya terdapat satu input kepada komparator, dan hanya satu set dan kapasitor pensampelan berasingan dalam DAC kapasitor yang ditukar untuk menghasilkan paras rujukan yang diperlukan. Perbezaan voltan input dan output SAR SAR yang dicadangkan adalah petunjuk untuk reka bentuk kuasa rendah. Pengaruh kapasitansi parasit dikurangkan sehingga menjadi bukan faktor. Parameter SAR ADC adalah resolusi 8-bit, frekuensi persampelan 500 kHz, voltan bekalan 1 V dan 0.18 μm semikonductor-logam-oksida pelengkap. Penggunaan kuasa ADC SAR yang dicadangkan adalah 2.3 μW di mana peningkatan 25.8% daripada kerja sebelumnya Permintaan untuk penggunaan kuasa rendah RFID aktif sensor diperiksa dengan baik. Kesahihan reka bentuk yang dicadangkan telah dibuktikan oleh hasil simulasi.

ABSTRACT

Abstract— This thesis introduced an energy-efficient successive-approximation-register (SAR) analog-to-digital converter (ADC) specialized to the active sensors for low-power radio frequency identification (RFID) tag system. As part of the Internet of Things (IoT) transformation, RFID is widely used. In the application where the power supply is limited, power consumption is always a notable criterion as analog circuits such as the ADC circuit, regulator circuit, rectifier circuit and radio frequency (RF) are the common power demanding parts in the system. Normally, the requirement for a longer battery performance is closely related to low-power consumption. For the application active RFID sensor in which requires low to moderate resolution and speed as well as low-power consumption, SAR is usually used as its part of the ADC circuit. Therefore, the power-efficient SAR ADC is presented in this work. The block of SAR ADCs such as the comparator block, digital-to-analog converter (DAC) block, and sampler block is designed to meet the requirement of a low-power consumption performance measurement. This thesis at first will explores the differences between multiple ADC techniques in the previous works. The proposed SAR ADC is presented to enhance the power consumption of SAR ADC in the active RFID sensor application through the implementation of a single-input comparator with the switched-capacitor DAC. In this form of architecture, there is only one input to the comparator, and only one set and a split sampling capacitor in the switched capacitor DAC to generate the required reference levels. The difference in input and output voltage of the proposed SAR ADC is the indication for the low-power design. The influence of parasitic capacitance is reduced to the extent of becoming a non-factor. The parameters of the SAR ADC are the resolution of 8-bit, the sampling frequency of 500 kHz, the supply voltage of 1 V, and the 0.18 μm complementary metal-oxide-semiconductor (CMOS) technology. The power consumption of the proposed SAR ADC is 2.3 μW which is estimated at around 25.8% improvement from the previous work. The demands for low-power consumption of RFID active sensor is well examined. The validity of the proposed design has been proven by the simulation results.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

REFERENCES

Barnett, R. E., & Liu, J. (2008). An EEPROM Programming Controller for Passive UHF RFID Transponders with Gated Clock Regulation Loop and Current Surge Control. *IEEE Journal of Solid-State Circuits*, *43*(August).

Bhattacharyya, R., Kalansuriya, P., Sarma, S., & Karmakar, N. (2012). Towards SCARS : a chipless RFID sensor for pervasive surface crack detection. *2012 IEEE International Conference on RFID Technologies and Applications*, 46–51.

Caizzone, S., & DiGiampaolo, E. (2015). Wireless Passive RFID Crack Width Sensor for Structural Health Monitoring. *IEEE Sensors Journal*, *15*(12), 6767–6774. https://doi.org/10.1109/JSEN.2015.2457455

Cardullo, M. W., & Parks, W. L. (1973). *Transponder Apparatus and System*.

Catarinucci, L., Colella, R., & Tarricone, L. (2009). A cost-effective UHF RFID tag for transmission of generic sensor data in wireless sensor networks. *IEEE Transactions on Microwave Theory and Techniques*, *57*(5), 1291–1296. https://doi.org/10.1109/TMTT.2009.2017296

Chang, S. Il, & Yoon, E. (2009). A low-power area-efficient 8 bit SAR ADC using dual capacitor arrays for neural microsystems. *Proceedings of the 31st Annual International Conference of the IEEE Engineering in Medicine and Biology Society: Engineering the Future of Biomedicine, EMBC 2009*, 1647–1650. https://doi.org/10.1109/IEMBS.2009.5333068

Cho, Y.-K., Jeon, Y.-D., Nam, J.-W., & Kwon, J.-K. (2010). A 9-bit 80 MSs Successive Approximation Register Analog-to-Digital Converter With a Capacitor Reduction Technique. *IEEE Transactions on Circuits and Systems II: Express Briefs*, *57*(7), 502–506. https://doi.org/10.1109/TCSII.2010.2048387

Choi, B. S., Lee, J. W., Lee, J. J., & Park, K. T. (2011). A hierarchical algorithm for indoor mobile robot localization using RFID sensor fusion. *IEEE Transactions on Industrial Electronics*, *58*(6), 2226–2235. https://doi.org/10.1109/TIE.2011.2109330

Curty, J.-P., Joehl, N., Krummenacher, F., Dehollain, C., & Dehollain, C. (2005). A model for μ-power rectifier analysis and design. *IEEE Transactions on Circuits and Systems I: Regular Papers*, *52*(12), 2771–2779. https://doi.org/10.1109/TCSI.2005.854294

De Donno, D., Catarinucci, L., Di Serio, A., & Tarricone, L. (2013). A long-range computational RFID tag for temperature and acceleration sensing applications. *Progress In Electromagnetics Research C*, *45*(October), 223–235. https://doi.org/10.2528/PIERC13101904

De Donno, D., Catarinucci, L., & Tarricone, L. (2014). RAMSES: RFID augmented module for smart environmental sensing. *IEEE Transactions on Instrumentation and Measurement*, *63*(7), 1701–1708. https://doi.org/10.1109/TIM.2014.2298692

Dey, S., Saha, J. K., & Karmakar, N. C. (2015). Smart Sensing: Chipless RFID Solutions for the Internet of Everything. *IEEE Microwave Magazine*, *16*(10), 26–39. https://doi.org/10.1109/MMM.2015.2465711

Gasco, F., Feraboli, P., Braun, J., Smith, J., Stickler, P., & Deoto, L. (2011). Wireless strain measurement for structural testing and health monitoring of carbon fiber composites. *Composites Part A: Applied Science and Manufacturing*, *42*(9), 1263–1274. https://doi.org/10.1016/j.compositesa.2011.05.008

Glidden, R., Bockorick, C., Cooper, S., Diorio, C., Dressler, D., Gutnik, V., Hagen, C., Hara, D., Hass, T., Humes, T., Hyde, J., Pesavento, A., Oliver, R., Onen, O., Sundstrom, K., & Thomas, M. (2004). Design of ultra-low-cost UHF RFID tags for supply chain applications. *IEEE Communications Magazine*, *42*(8), 140–151. https://doi.org/10.1109/MCOM.2004.1321406

Harpe, P. (2016). Successive Approximation Analog-to-Digital Converters Improving Power Efficiency and Conversion Speed. *IEEE Solid-State Circuits Magazine*, *8*(4), 64–73. https://doi.org/10.1109/MSSC.2016.2573978

Harpe, P., Cantatore, E., & Roermund, A. van. (2013). A 10b/12b 40 kS/s SAR ADC With Data-Driven Noise Reduction Achieving up to 10.1b ENOB at 2.2 fJ/Conversion-Step. *IEEE Journal of Solid-State Circuits*, *48*(12), 3011–3018. https://doi.org/10.1109/JSSC.2013.2278471

Harpe, P., Cantatore, E., & Roermund, A. van. (2014). 11.1 An oversampled 12/14b SAR ADC with noise reduction and linearity enhancements achieving up to 79.1dB SNDR. *2014 IEEE International Solid-State Circuits Conference Digest of Technical Papers (ISSCC)*, *11*, 194–196. https://doi.org/10.1109/ISSCC.2014.6757396

Harpe, P., Zhou, C., Wang, X., Dolmans, G., & Groot, H. de. (2010). A 30fJ/conversion-step 8b 0-to-10MS/s asynchronous SAR ADC in 90nm CMOS. *2010 IEEE International Solid-State Circuits Conference - (ISSCC)*, 388–389.

https://doi.org/10.1109/ISSCC.2010.5433967

Juels, A. (2006). RFID security and privacy: A research survey. *IEEE Journal on Selected Areas in Communications*, *24*(2), 381–394. https://doi.org/10.1109/JSAC.2005.861395

Karthaus, U., & Fischer, M. (2003). Fully Integrated Passive UHF RFID Transponder IC with 16.7-μ W Minimum RF Input Power. *IEEE Journal of Solid-State Circuits*, *38*(10), 1602–1608. https://doi.org/10.1109/JSSC.2003.817249

Kim, H., Min, Y., Kim, Y., & Kim, S. (2008). A low power consumption 10-bit rail-to-rail SAR ADC using a C-2C capacitor array. *2008 IEEE International Conference on Electron Devices and Solid-State Circuits, December*, 1–4. https://doi.org/978-1-4244-2539-6

Kocer, F., & Flynn, M. P. (2005). A new transponder architecture for long-range telemetry applications. *Proceedings of the 2005 European Conference on Circuit Theory and Design*, *2*(5), 177–180. https://doi.org/10.1109/ECCTD.2005.1523022

Kotani, K., Sasaki, A., & Ito, T. (2009). High-Efficiency Differential-Drive CMOS Rectifier for UHF RFID. *IEEE Journal of Solid-State Circuits*, *44*(11), 3011–3018. https://doi.org/10.1109/JSSC.2009.2028955

Lakafosis, V., Rida, A., Vyas, R., Yang, L., Nikolaou, S., & Tentzeris, M. M. (2010). Progress towards the first wireless sensor networks consisting of inkjet-printed, paper-based RFID-enabled sensor tags. *Proceedings of the IEEE*, *98*(9), 1601–1609. https://doi.org/10.1109/JPROC.2010.2049622

Landt, J. (2005). The history of RFID. *IEEE Potentials*, *24*(4), 8–11. https://doi.org/10.1109/MP.2005.1549751

Leon-Salas, W. D., & Halmen, C. (2016). A RFID Sensor for Corrosion Monitoring in Concrete. *IEEE Sensors Journal*, *16*(1), 32–42. https://doi.org/10.1109/JSEN.2015.2476997

Li, Z., & Meng, Z. (2016). A review of the radio frequency non-destructive testing for carbon-fibre composites. *Measurement Science Review*, *16*(2), 68–76. https://doi.org/10.1515/msr-2016-0010

Lien, W. L., Choke, T. Y., Tan, Y. C., Kong, M., Low, E. C., Li, D. P., Jin, L., Zhang,

H., Leow, C. H., Chew, S. L., Dasgupta, U., Shana'A, O., Yong, C. H., Gao, T. B., Ong, G. T., Tan, W. G., Shu, W., & Heng, C. L. (2014). 9.1 A self-calibrating NFC SoC with a triple-mode reconfigurable PLL and a single-path PICC-PCD receiver in 0.11μm CMOS. *IEEE International Solid-State Circuits Conference Digest of Technical Papers (ISSCC)*, 158–159. https://doi.org/10.1109/ISSCC.2014.6757380

Liew, W.-S., Yao, L., & Lian, Y. (2008). A moving binary search SAR-ADC for low power biomedical data acquisition system. *APCCAS 2008 - 2008 IEEE Asia Pacific Conference on Circuits and Systems*, *December*, 646–649. https://doi.org/10.1109/APCCAS.2008.4746106

Liew, W.-S., Zou, X., Yao, L., & Lian, Y. (2009). A 1-V 60-μW 16-channel interface chip for implantable neural recording. *2009 IEEE Custom Integrated Circuits Conference*, *October*, 507–510. https://doi.org/10.1109/CICC.2009.5280795

Liu, C. C., Chang, S. J., Huang, G. Y., & Lin, Y. Z. (2010). A 10-bit 50-MS/s SAR ADC with a monotonic capacitor switching procedure. *IEEE Journal of Solid-State Circuits*, *45*(4), 731–740. https://doi.org/10.1109/JSSC.2010.2042254

López-Soriano, S., & Parrón, J. (2015). Wearable RFID tag antenna for healthcare applications. *2015 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)*, *October*, 287–290. https://doi.org/10.1109/APWC.2015.7300156

Mahmoud, S. A., & Nazzal, T. B. (2015). Sample and hold circuits for low-frequency signals in analog-to-digital converter. *2015 International Conference on Information and Communication Technology Research (ICTRC)*. https://doi.org/10.1109/ICTRC.2015.7156415

Meng, Z., & Lu, J. (2016). A Rule-based Service Customization Strategy for Smart Home Context-Aware Automation. *IEEE Transactions on Mobile Computing*, *15*(3), 558–571. https://doi.org/10.1109/TMC.2015.2424427

NFC Forum. (2011). *Type 4 tag operation specification*. http://apps4android.org/nfc-specifications/NFCForum-TS-Type-4-Tag_2.0.pdf

Nguyen, S. D., Pham, T. T., Blanc, E. F., Le, N. N., Dang, C. M., & Tedjini, S. (2013). Approach for quality detection of food by RFID-based wireless sensor tag. *Electronics Letters*, *49*(25), 1588–1589. https://doi.org/10.1049/el.2013.3328

Occhiuzzi, C., Paggi, C., & Marrocco, G. (2011). Passive RFID strain-sensor based on meander-line antennas. *IEEE Transactions on Antennas and Propagation*, *59*(12), 4836–4840. https://doi.org/10.1109/TAP.2011.2165517

Potyrailo, R. A., Nagraj, N., Tang, Z., Mondello, F. J., Surman, C., & Morris, W. (2012). Battery-free radio frequency identification (RFID) sensors for food quality and safety. *Journal of Agriculture and Food Chemistry*, *60*(35), 8535–8543. https://doi.org/10.1021/jf302416y

Rabuske, T., Rabuske, F., Fernandes, J., & Rodrigues, C. (2015). An 8-bit 0.35-V 5.04-fJ/Conversion-Step SAR with Background Self-Calibration. *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, *23*(7), 1–7. https://doi.org/1557-9999

Radio Frequency Identification Technology Market Size, Share & Trends Analysis Report By Product (RFID Tags, RFID Readers, and Middleware), By Frequency, By Application, By Region, And Segment Forecasts, 2018 - 2025. (2017).

Robert, P.-Y., Gosselin, B., Ayoub, A. E., & Sawan, M. (2006). An Ultra-Low-Power Successive-Approximation-Based ADC for Implantable Sensing Devices. *2006 49th IEEE International Midwest Symposium on Circuits and Systems*, 7–11. https://doi.org/10.1109/MWSCAS.2006.381981

Sekimoto, R., Shikata, A., Yoshioka, K., Kuroda, T., & Ishikuro, H. (2012). A 40nm CMOS full asynchronous nano-watt SAR ADC with 98% leakage power reduction by boosted self power gating. *2012 IEEE Asian Solid State Circuits Conference (A-SSCC)*, *6*, 161–164. https://doi.org/10.1109/IPEC.2012.6522650

Shikata, A., Sekimoto, R., Kuroda, T., & Ishikuro, H. (2014). A 0.5 V 1.1 MS/sec 6.3 fJ/Conversion-Step SAR-ADC With Tri-Level Comparator in 40 nm CMOS. *IEEE Journal of Solid-State Circuits*, *47*(4), 1022–1030. https://doi.org/10.1109/JSSC.2012.2185352

Sunny, A. I., Tian, G. Y., Zhang, J., & Pal, M. (2016). Low frequency (LF) RFID sensors and selective transient feature extraction for corrosion characterisation. *Sensors and Actuators, A: Physical*, *241*, 34–43. https://doi.org/10.1016/j.sna.2016.02.010

Verma, D., Shehzad, K., Khan, D., Kim, S. J., Pu, Y. G., Yoo, S. S., Hwang, K. C., Yang, Y., & Lee, K. Y. (2020). A design of low-power 10-bit 1-MS/s asynchronous SAR ADC for DSRC application. *Electronics (Switzerland)*, *9*(7), 1–11. https://doi.org/10.3390/electronics9071100

Wang, H., Yen, M., & Zhang, C. (2010). Low power analog circuit design for RFID sensing circuits. *2010 IEEE International Conference on RFID (IEEE RFID 2010)*, *May*, 16–21. https://doi.org/10.1109/RFID.2010.5467279

Weinstein, R. (2005). RFID: A technical overview and its application to the enterprise. *IT Professional*, *7*(3), 27–33. https://doi.org/10.1109/MITP.2005.69

Wu, M.-H., Chung, Y.-H., & Li, H.-S. (2012). A 12-bit 8.47-fJ/conversion-step 1-MS/s SAR ADC using capacitor-swapping technique. *2012 IEEE Asian Solid State Circuits Conference (A-SSCC)*, *6*, 157–160. https://doi.org/10.1109/IPEC.2012.6522649

Yakoub, M. E. M. A., Sawan, M., & Thibeault, C. (2009). A neuromimetic ultra low-power ADC for bio-sensing applications. *2009 Joint IEEE North-East Workshop on Circuits and Systems and TAISA Conference*, *October*, 1–4. https://doi.org/10.1109/NEWCAS.2009.5290440

Yang, X., Zhou, Y., Zhao, M., Huang, Z., Deng, L., & Wu, X. (2014). A 0.9V 12-bit 200-kS/s 1.07μW SAR ADC with Ladder-based Reconfigurable Time-Domain Comparator. *2014 IEEE 57th International Midwest Symposium on Circuits and Systems (MWSCAS)*, 105–108. https://doi.org/10.1109/MWSCAS.2014.6908363

Zhang, Y., & Bai, L. (2015). Rapid structural condition assessment using radio frequency identification (RFID) based wireless strain sensor. *Automation in Construction*, *54*, 1–11. https://doi.org/10.1016/j.autcon.2015.02.013.

Zhiheng Cao, Yan, S., & Li, Y. (2008). A 32mW 1.25GSs 6b 2bstep SAR ADC in 0.13μm CMOS. *2008 IEEE International Solid-State Circuits Conference - Digest of Technical Papers*, 542–634. https://doi.org/10.1109/ISSCC.2008.4523297