IDEC Journal of Integrated Circuits and Systems, VOL 3, No.1, January 2017 http://jicas.idec.or.kr

A Battery Management IC using Successive Approximation Register Analog to Digital Converter

Semi Lim, Junseok Park
Department of Secured Smart Electric Vehicle, Kookmin University
E-mail : semi2094@nate.com, jspark@kookmin.ac.kr

***Abstract* - The lithium ion battery systems has been drawing extensive attention, and a number of demands and relevant applications are increasing thereby. The lithium ion battery systems are used as a power source in wide range from small devices (e.g., mobile phone, laptops, wearable devices, etc.) to larger systems (e.g., electric vehicle, unmanned aerial vehicle, logistics systems, energy storage systems). However, their long life cycle and safe operation can be reached only if they are managed correctly. In this paper, battery management IC using high-resolution, low-power consumption 12bit SAR ADC has been proposed.**

I. INTRODUCTION

Nowadays, Batteries have been widely used in many industry application, such as charging of mobile phone, EV (Electric Vehicle), UAV (Unmanned Aerial Vehicle) and so on. A battery life heavily depends on the frequency of over-charging and over-discharging, as well as depth of discharge. Therefore, the overcharging and over-discharging occurs on regular basis, and hence, the power management becomes more important [1]. Accordingly, it is important to improve the performance of the BMS (Battery Management System) to make the battery a safe, reliable, and cost-efficient solution. In this paper, battery management IC using high-resolution, low-power consumption 12bit SAR ADC has been proposed [2].

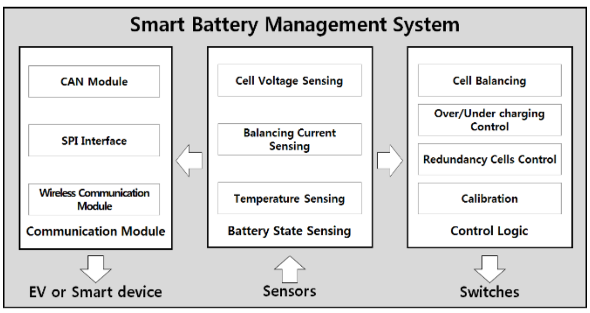

Figure 1. Function of smart battery management system

a. Corresponding author; semi2094@nate.com

Figure 1 shows the function of battery management system. And Figure 2 shows the block diagram of battery management IC. The battery management system performs battery state monitoring, battery cell balancing, restores cell trouble and calibration and communication. The detailed function of battery management system is as follows.

- Battery state monitoring
  - Cell voltage, current and temperature sensing
- Battery cell balancing
  - Active cell balancing
- Restore cell trouble and calibration
  - Finding trouble cell
  - Redundancy cells control
- Communication
  - CAN Module
  - SPI interface
  - Wireless communication module

In the active balancing method the excess charge at the higher voltage level cells is transferred to lower voltage level cells at the package to balance voltages across the cells of the battery using energy storage elements like combination of inductor-capacitor or transformer-capacitor or switched capacitor or switched inductor with controlled switches or converters [3]. The active cell balancing, which utilizes capacitive or inductive charge shuttling to transfer charge between battery cells, is significantly more efficient because energy is transferred to where it is needed instead of being bled off. But it cannot be integrated with energy storage element of large volume.

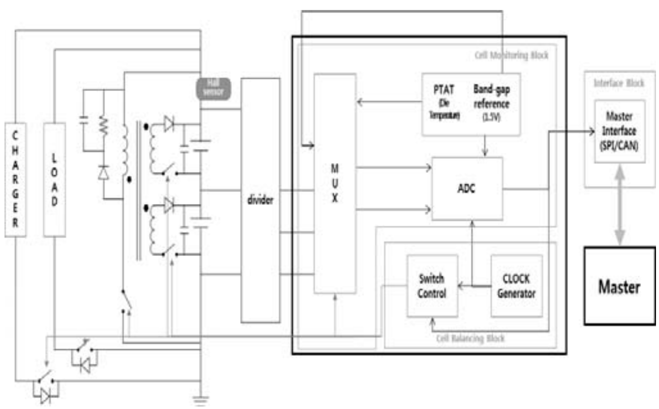

Figure 2. Block diagram of battery management IC

II. EXPERIMENTS

A. Multiplexer

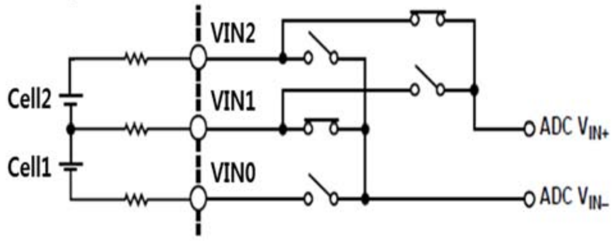

Figure 3. A multiplexer configuration during cell2 sampling

The role of a multiplexer is to select battery cell for measuring voltage. The multiplexer selects the pair of analog inputs, VIN0 to VIN2, that is to be converted [4]. The voltage of each individual cell is measured by converting the difference between adjacent analog inputs, that is, VIN1 − VIN0, VIN2 − VIN1, and so on (see Figure 3).

B. ADC driver

Many high performance ADCs are now being designed with differential inputs. A fully differential ADC design offers the advantages of good common-mode rejection, reduction in second-order distortion products, and simplified dc trim algorithms. Although they can be driven single-ended, a fully differential driver usually optimizes overall performance.

One of the most common ways to drive a differential input ADC is with a transformer. However, there are many applications where the ADCs cannot be driven with transformers because the frequency response must extend to dc. In these cases, differential drivers are required.

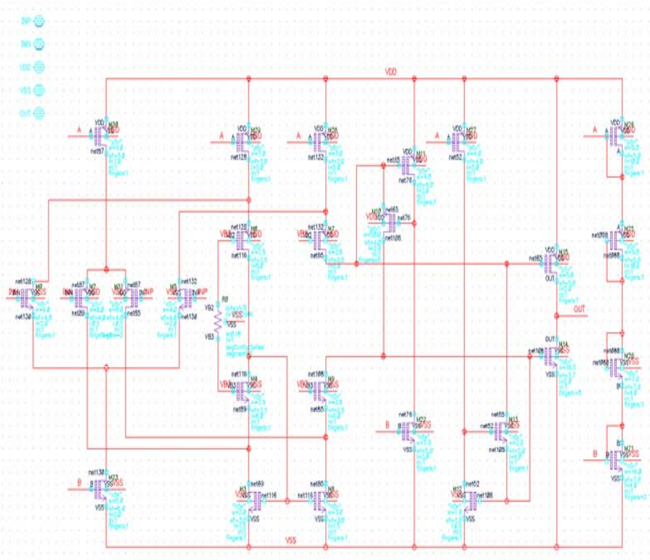

Figure 4. Schematic of ADC driver

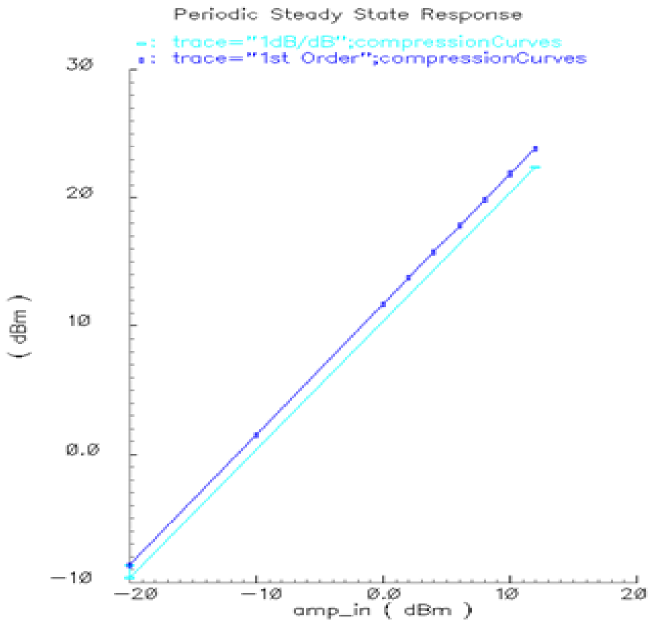

Figure 5. Linearity of ADC driver

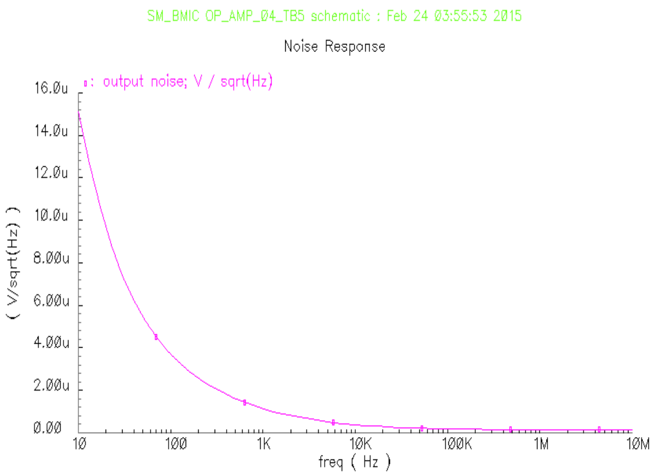

Figure 6. Noise response of ADC driver

The role of an ADC driver is to convert single ended input into differential input. Figure 4 shows the schematic of ADC Driver. An ADC should be transmitted symmetrical differential signal from ADC driver. Therefore, calibration scheme and layout to reduce noise and maintain circuit stability is applied to the ADC driver. Figure 5 shows the linearity of ADC driver. And Figure 6 shows the noise response of ADC driver.

C. LDO

The PTAT shown in Figure 7 has two Bipolar Junctions that have different areas in order to operate with different current densities [5], and Figure 6 shows the schematic of LDO.

A LDO supply reference voltage in SAR ADC. And by adding the negative temperature coefficient (TC) voltage of PTAT voltage and positive TC voltage provides the output voltage of the design bandgap voltage which does not change with temperature [6].

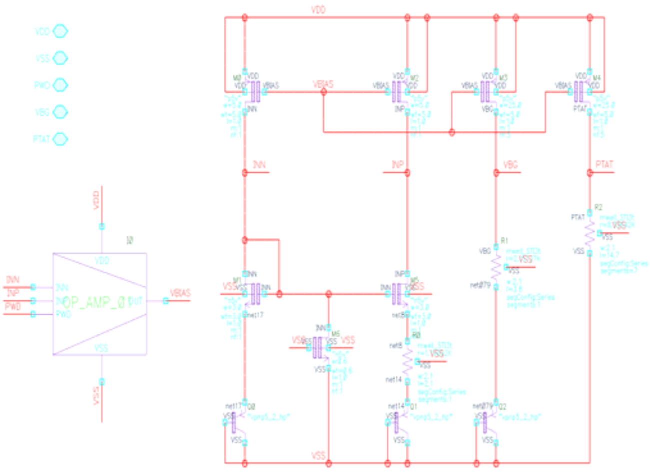

Figure 7. Schematic of PTAT

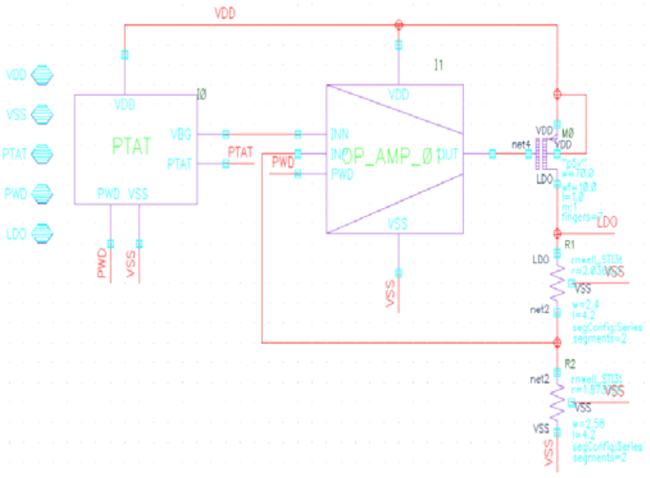

Figure 8. Schematic of PTAT and LDO

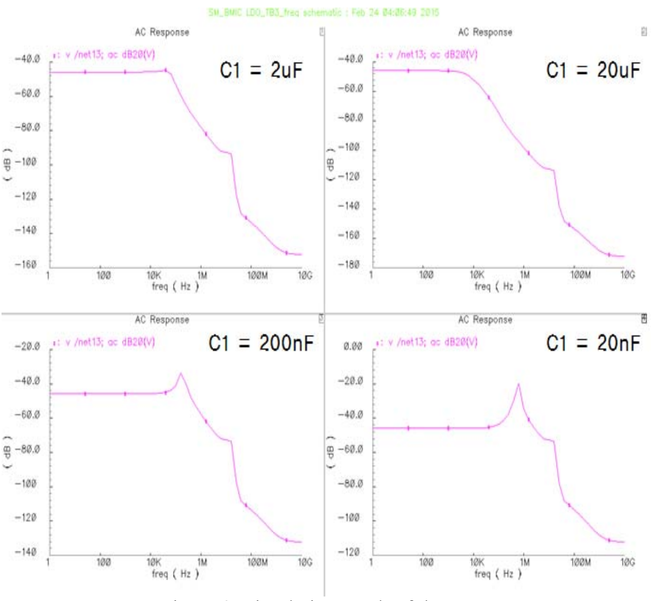

Figure 9. Simulation result of the LDO

A temperature coefficient of PTAT is 9.313PPM/°C. The reference current Iref and total current consumption of LDO is 460.545uA and 1.12345mA.

D. SAR ADC for Battery management IC

A battery management system is essential for lithium-ion battery systems. The battery management system performs several tasks, such as cell monitoring, SOC estimation, SOH estimation, cell balancing, charging control, etc. The main function of battery management system performed by a result of cell monitoring. Therefore, it is important to improve the performance of ADC. In this paper, high-resolution, low-power consumption 12bit SAR ADC for battery management system has been proposed.

The acquisition time of a voltage cell measurement is dependent on the load behavior as well as the number of cells to scan. Erratic behaving loads require fast scan times to monitor a cell's out of bounds condition. Therefore, a SAR ADC is used to achieve quick measurements in a short period of time.

A block diagram of SAR ADC is shown in Figure 9. The main components of a SAR ADC are a sample-and-hold (S/H), a digital-to-analog converter (DAC), a comparator, and a digital state machine (itself called the SAR) [7]. The scheme of DAC was designed with split weighted capacitor array to help reduce the area and power consumption. And a calibration scheme to improve the linearity performance and avoid gain error is applied to the DAC [8].

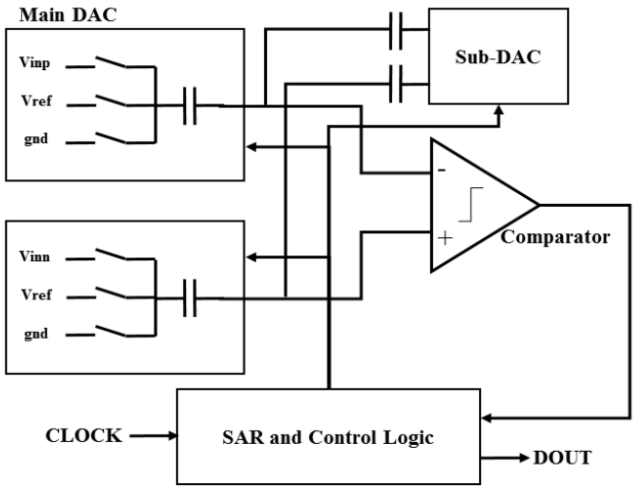

Figure 10. Block diagram of SAR ADC

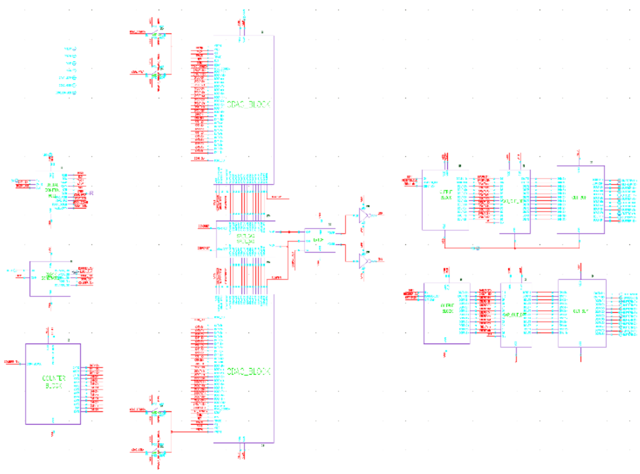

Figure 11. Schematic of SAR ADC

TABLE I.
Simulation result of the SAR ADC

Resolution	12bit
Sampling Rate	100k sample/sec
Input Range	5Vp-p
Power Consumption	3.67mW
SNDR	64.70dB
ENOB	10.78bit

The proposed 12bit SAR ADC achieves a 100k sample/sec operation speed with 1.29mW power consumption. The simulation result of ADC is shown in Table 1.

III. RESULTS AND DISCUSSION

This battery management IC contain functions required for general-purpose monitoring and management of stacked lithium ion battery as used in EV. The Figure 12 and 13 show schematic and layout of battery management IC. But this battery management IC did not operate as a design error.

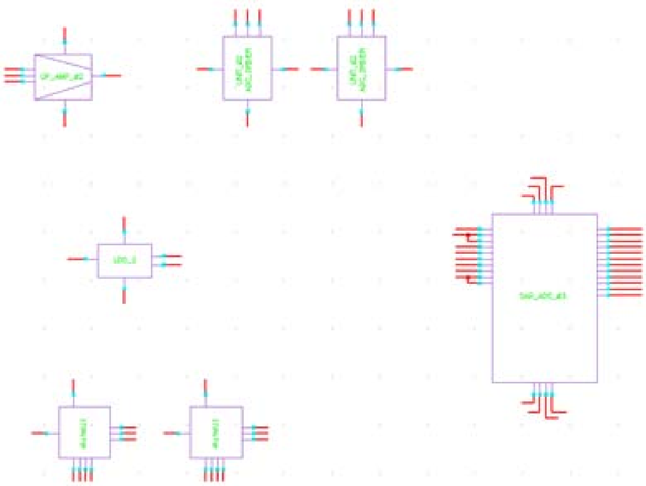

Figure 12. Schematic of battery management IC

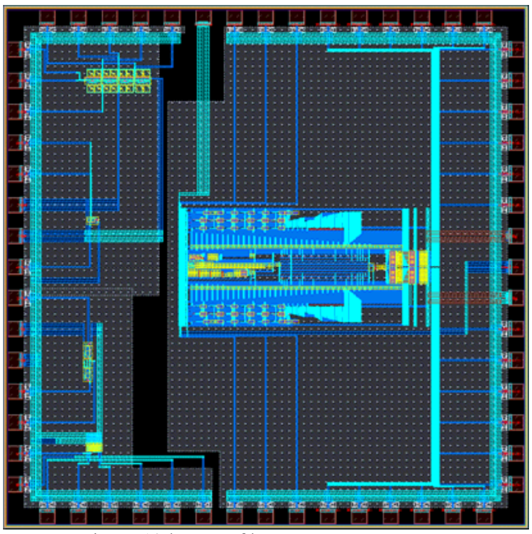

Figure 13 layout of battery management IC

IV. CONCLUSIONS

The lithium ion battery systems have been drawing extensive attention, and number of demands and relevant applications are increasing thereby. The lithium ion battery systems are used as a power source in wide range from small devices to larger systems. However, their long life cycle and safe operation can be reached only if they are managed correctly. In this paper, battery management IC using high-resolution, low-power consumption 12bit SAR ADC has been proposed. This battery management IC is fabricated in a TowerJazz 0.18um BCDMOS processes, and occupies an active area of 2350um X 2350um. It can be also applied in various battery management system applications like mobile phone, EV, UAV and so on.

ACKNOWLEDGMENT

This work was supported by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIP) (No.R7117-16-0165, Development of Hall Effect Semiconductor for Smart Car and Device).

This research was supported by IDEC (IC DESIGN EDUCATION CENTER).

REFERENCES

[1] Carter, Craig R., Lutz Kaufmann, and Alex Michel. "Behavioral supply management: a taxonomy of judgment and decision-making biases." International Journal of Physical Distribution & Logistics Management 37.8 (2007): 631-669.

[2] Rahimi-Eichi, Habiballah, et al. "Battery management system: An overview of its application in the smart grid and electric vehicles." Industrial Electronics Magazine, IEEE 7.2 (2013): 4-16.

[3] Karadeniz, M.; Sezenoğlu, C.; Balıkçı, A, "An active balancing System for electric car batteries," ELECO 2012, 29 Nov.-1 Dec. 2012.

[4] Analog Devices, "Lithium Ion Battery Monitoring System," AD7280 datasheet, 2011.

[5] Francisco, Keith R., and Jefferson A. Hora. "Very low bandgap voltage reference with high PSRR enhancement stage implemented in 90nm CMOS process Technology for LDO application." Electronics Design, Systems and Applications (ICEDSA), 2012 IEEE International Conference on. IEEE, 2012.

[6] Razavi Behzad. Design of analog CMOS integrated circuits. McGRAW-HILL INTERNATIONAL EDITION. Electrical Engineering Series., 2001.

[7] J. L. McCreary and P. R. Gray, "All-MOS charge redistribution analog-to-digital conversion techniues—Part I," IEEE J. Solid-State Circuits, vol. SC-10, no. 6, pp. 371–379, Dec. 1975.

[8] Yanfei Chen, et. Al, "Split Capacitor DAC Mismatch Calibration in Successive Approximation ADC", in Proc. IEEE Custom Integrated Circuits Conf., Sep. 2009, pp. 279-282.

Se-Mi Lim received the B.S. and M.S. degree in electrical engineering from the Kookmin University, Seoul, Korea, in 2010 and 2012, where she is currently working toward the Ph.D. degree in electrical engineering. She research interests include design of power management system, battery management, IT Convergence.

Jun-Seok Park has been a professor in School of electrical & electronics (EE) at Kookmin University, Seoul, Korea from 2003. From 1998 to 2003, he was an assistant professor in School of Information Technology at Soonchunhyang University, Asan, Korea. He received his B.S, M.S, and Ph.D degrees of EE from Kookmin University at 1991, 1993, and 1996, respectively. From 2014, He is a dean of BK21-plus SSEV (Secured Smart EV) educational group, which is supported by Ministry of Education, South Korea. He has 20 years of experience in wireless communication system, wireless power transmission and so on using RF/Microwave technology. Also, during the past years, his major research topics and concerns have been the electric vehicle (EV), where he works as a dean of BK21-plus SSEV (Secured Smart EV) educational group, which is supported by Ministry of Education, South Korea. His major interest includes: the unmanned aerial vehicle (UAV) related system planning, service providing, distribution and transmission projects, system and service quality, technical training, information systems, business improvement.

APPENDIX

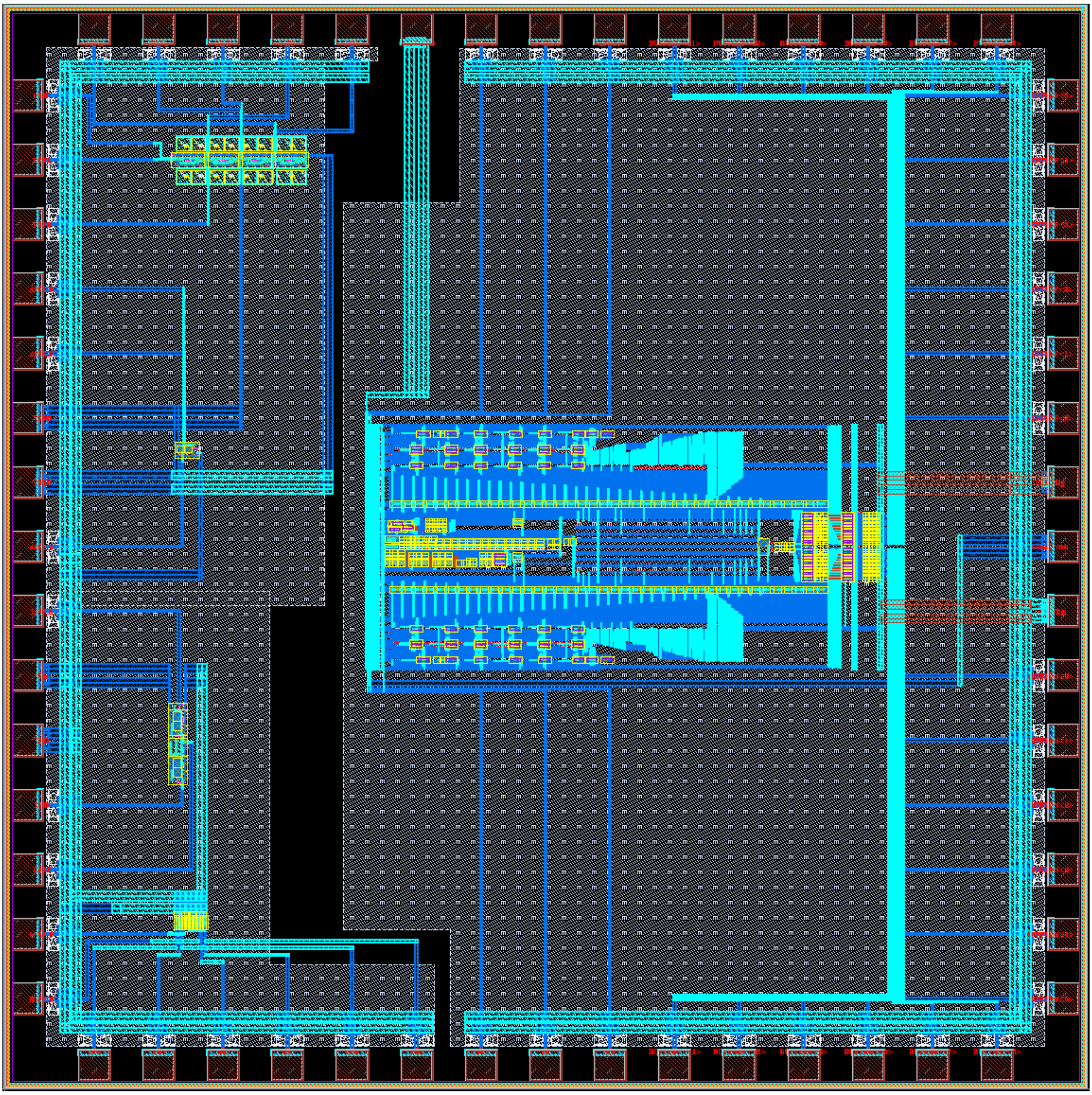

Figure 14. layout of battery management IC