INTERNATIONAL JOURNAL OF RECENT TRENDS IN ENGINEERING & RESEARCH
Impact Factor 4.101 ISSN -2455-1457
RECENT ADVANCES IN ELECTRONICS & COMMUNICATION ENGINEERING (RAECE-2K17)

RFID TECHNOLOGY BASED MEASURING FOR MONITORING ION CONCENTRATION IN RADIO FREQUENCY COMMUNICATION

T. ANKITHA
Student,ECE Department
Nalla Narasimha Reddy Educational Society's Group of Institutions

P.BHARATHI BHAVANI
Student,ECE Department
Nalla Narasimha Reddy Educational Society's Group of Institutions

P.SANDHYA
Student,ECE Department
Nalla Narasimha Reddy Educational Society's Group of Institutions

Abstract: In this paper, a novel approach for concrete chloride ion concentration measuring based on passive and wireless sensor tag is proposed. The chloride ion sensor based on RFID communication protocol is consisting of an energy harvesting and management circuit, a low dropout voltage regulator, a MCU, a RFID tag chip and a pair of electrodes. The proposed sensor harvests energy radiated by the RFID reader to power its circuitry. To improve the stability of power supply, a three-stage boost rectifier is customized to rectify the harvested power into dc power and step-up the voltage. Since the measured data is wirelessly transmitted, it contains miscellaneous noises which would decrease the accuracy of measuring. Thus, in this paper, the wavelet denoising method is adopted to denoise the raw data. Besides, a monitoring software is developed to display the measurement results in real-time. The measurement results indicate that the proposed passive sensor tag can achieve a reliable communication distance of 16.3 m and can reliably measure the chloride ion concentration in concrete.

Keywords: RFID technology; wireless measuring; concrete chloride ion concentration; monitoring

1. Introduction

The chloride in concrete is one of the major reasons of deterioration of concrete structures [1–5]. To avoid the corrosion-induced damage, effective prevention, including monitoring of the aggressiveness of the environment is of great significance. Therefore, the monitoring for chloride ion concentration plays a vital role in estimating its service life and maintenance cycle.The commonly used procedure includes collecting the concrete powder samples at various depths of which are then used to quantify the total chloride content [6]. Although this approach has been well-established, the disadvantages of its being invasive and time-cost limit it being widely employed. The probes for continuous monitoring are another approach to measure the chloride ion concentration [7]. They need to be embedded in the concrete before casting, but it can only realize practically instantaneous measurement of chloride content. The method using the Ag/AgCl electrode to measure the chloride ion content [8–11]. However, this method is an unreliable intermittent measurement. Montemoretal. [7] presented a non-destructive chloride-sensitive sensor, but it requires high implementation costs. Hence, a non-invasive and cost-effective method is still urgently demanded. In recent years, various kinds of wireless sensors have been widely employed in industrial fields due to their fast deployment and wireless features. Generally, the wireless sensors utilize technologies of ZigBee, Bluetooth and wireless local area networks to realize wireless communication [12–14]. However, the high power consumption, large device size, and low flexibility limit its popularity. Nowadays, wireless sensors based on passive Radio Frequency Identification (RFID) technology have arisen great interest due to their low power consumption and high flexibility [16]. Most RFID-based sensors operate on ultra-high frequency (UHF) to realize long communication distance and fast transmission speed. The RFID-based sensor is capable of communicating with the reader based on zero-powered backscatter mechanism, resulting in the advantages of simple architecture, low power and low cost compared with these technologies discussed above.

The passive wireless sensors convert the received RF signals from RFID reader into stable DC supply voltage for their own circuits. A customized power harvesting and management circuit is proposed to utilize the received power with high efficiency. An Ag/AgCl chloride ion selective electrode is employed to perform as a sensor to detect the potential of the concrete, which can reflect the chloride ion concentration of concrete.A customized energy harvesting and management circuit is proposed to improve the efficiency of RF power utilization

Materials and Methods

RFID Sensor Technology

The RFID system generally consists of RFID tag and RFID reader. Figure 1 shows the basic protocol. The RFID tag returns data to the reader based on backscatter mechanism, and the communication between the tag and reader follows the EPC Class-1 Generation-2 protocol. Within the communication distance, the reader is sent select instruction by carrier wave to the tag to change the tag's status. Then the Query instruction is sent by the reader to the tag and the tag response with RN16. After that, the reader sends ACK instruction to obtain the ID message and CRC code. Finally, Req_RN is sent to acquire the Handle response.

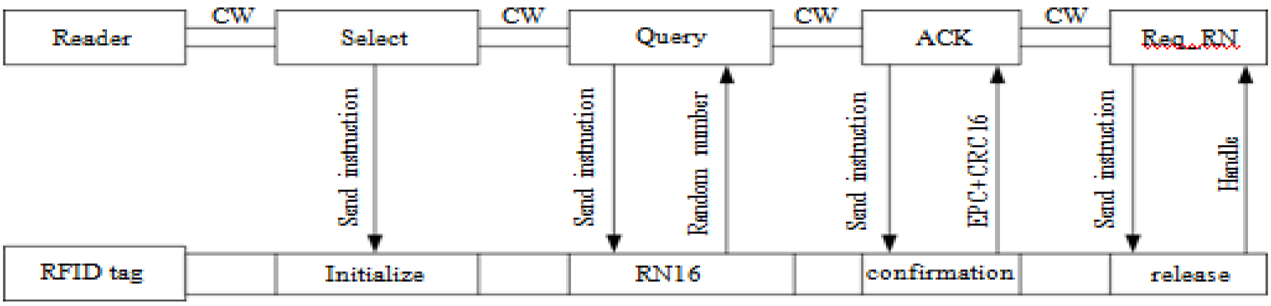


Figure 1. Schematic diagram of radio frequency communication.

Figure 2 illustrates the memory organization comparison between conventional RFID tag and the proposed tag in this paper. A prominent merit of the proposed tag is the capability of its memory being accessed by the MCU via I^2C interface. Generally, the (Electronic Product Code) EPC area in the tag memory can be organized by users, thus in this paper, the measured sensor data are stored in the EPC area. ID message is employed to identify the tag, and cyclic redundancy check (CRC) is adopted to check the integrity and accuracy of data transmission.

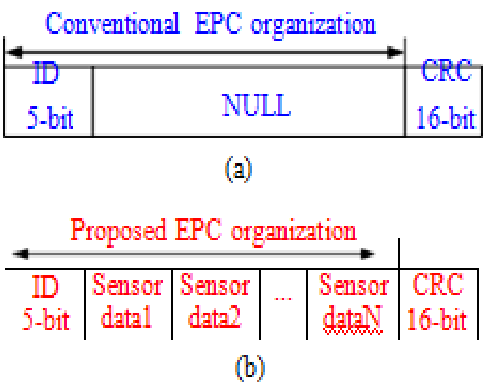


Figure 2. EPC area coding scheme of RF Tag chip: (**a**) conventional organization strategy; (**b**) proposed organization strategy.

RFID Sensor Tag Topology

Figure 3 draws the block diagram of the exploited RFID sensor tag (hereafter called tag). The proposed tag operates in full passive mode with ultra-high frequency (915 MHz), a 50-Ω microstrip antenna is employed for both communication and energy harvesting. A LC impedance-matching network consisting of a RF inductor (L1) and a ceramic trimmer capacitor (C1) is adopted to realize maximum power transfer efficiency. Then, a three-stage boost rectifier is used to convert the received UHF RFID energy by the tag to dc power and step-up the output voltage. When the input voltage of the boost rectifier is 0.35 V or higher, it can generate a 2.4 V output voltage, which would be the input of a 1.8 V low dropout (LDO) voltage regulator. The SMS7630 zero-bias Schottky diodes (D1–D6) are selected as rectifying devices due to their high sensitivity at the operating frequency of the tag.

The RFID chip adopted in this paper is Monza X-8K which can provide a UHF air interface as well as an I^2C interface. This design strategy adopts an ultra-low power MCU MSP430 MCU which can provide 64 kB RAM and a 12-bit 200-ksps Analog-to-Digital Converter (ADC). The MCU consumes 100 μA in measurement mode.

The sensor employed to monitor the chloride ions working electrode; both of the electrodes are immersed into the concrete. These two electrodes will generate a voltage difference, and its value would change in different chloride concentrations. The Ag used in this paper has a diameter of 1mm and 99.99% purity, which consists of reference electrode and Ag/Agcl is pasted with a thick layer of Ag/Agcl paste. A thick layer of paste is essential to the long lifetime of the tag, thus in this paper a 600 μm thick layer of paste is employed.

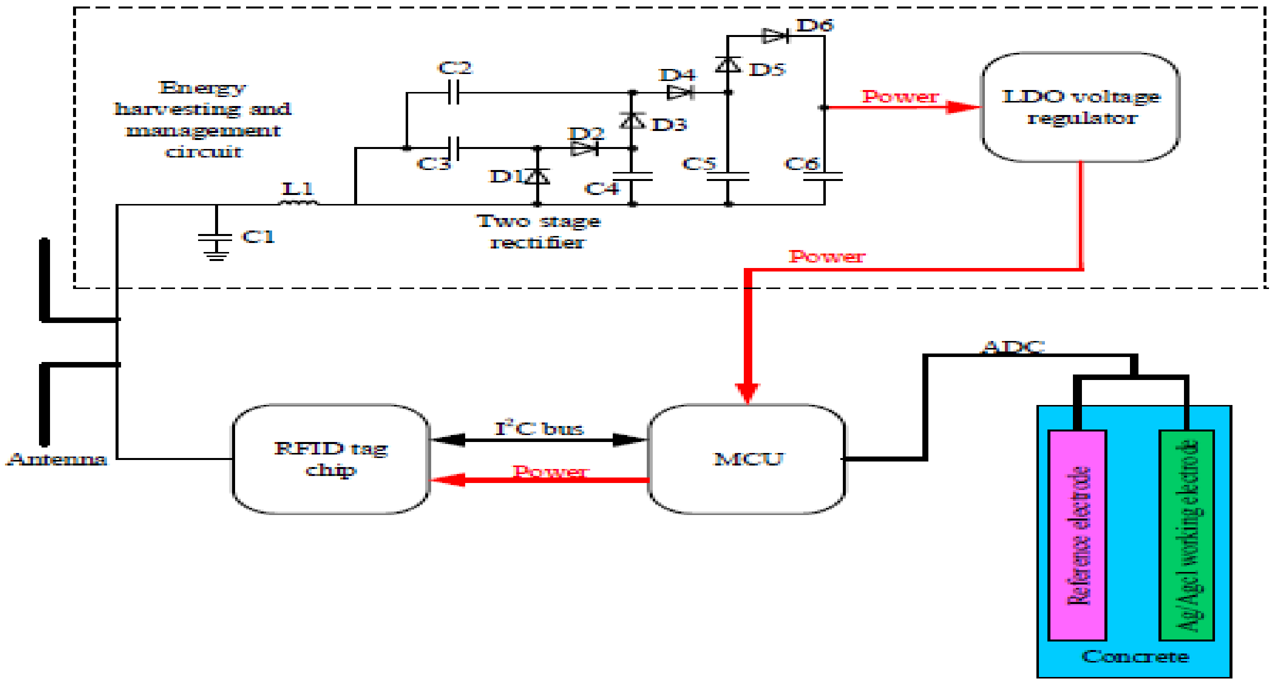


Figure 3. The block diagram of the proposed RFID sensor tag.

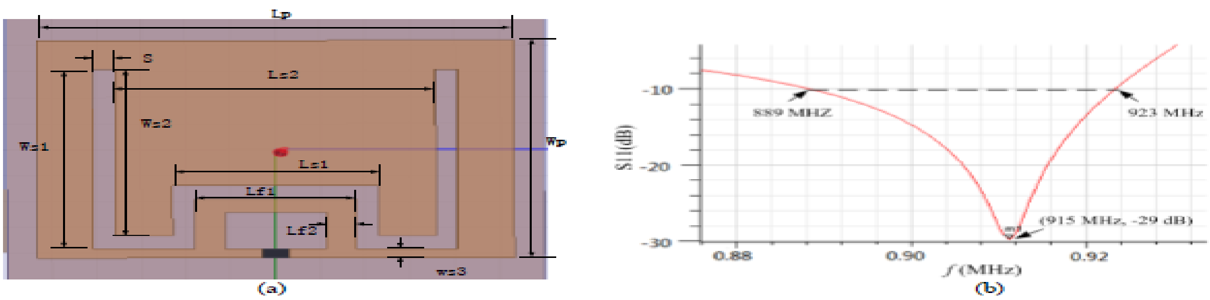


Figure 4. Proposed patch antenna: (a) antenna design; (b) return-loss in air.

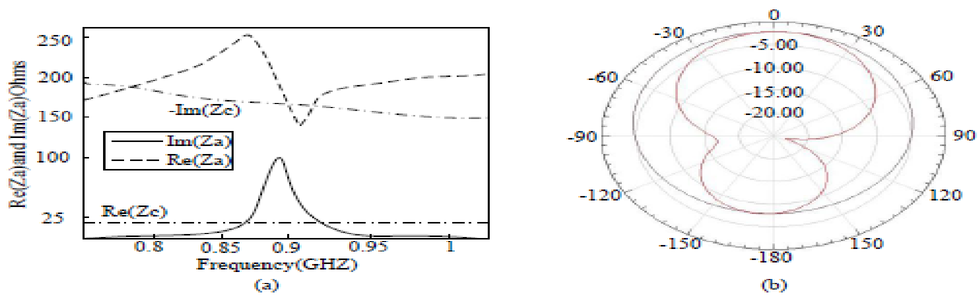


Figure 5. (**a**) Simulated impedance match between tag and antenna; (**b**) Simulated pattern radiation of the tag antenna.

Design of Chloride Ion Sensor

Ag/AgCl belongs to second-class electrode, which consists of metal and metal insoluble salt. Since argentic chloride has small solubility in solution, it can maintain its electrode potential in a long term. Moreover, it can decrease the possibility of solution being fouled. The corresponding electrode reaction is [7]

$$AgCl + e^- \rightarrow Ag + Cl^- \quad (1)$$

:

The potential of Ag/AgCl electrode (E) can be calculated by:

$$E = E^s - \frac{RT}{F} \ln a_{Cl^-} \quad (2)$$

where E^s is the standard potential of Ag/AgCl, R is ideal gas constant, T is the environmental emperature, F is the Faraday constant, and a_{Cl^-} is the activity quotient of Cl^- in the environment. Generally, the solution has low concentration, which means the activity quotient keeps almost constant, so the activity quotient can be replaced by concentration. In this way, Equation (2) can be simplified as:

$$E = E^s - 59.21 \lg [Cl^-] \quad (3)$$

From Equation (3) it can be seen that the electrode potential is linearly related to the negative logarithm of chloride concentration in the solution. Therefore, immersing the electrode into the concrete and then the corresponding potential can be obtained. According the potential value and calibration curve, the chloride concentration can be acquired. Figure 6 shows the principle of chloride concentration detection using Ag/AgCl electrode.

The Ag/AgCl electrode can be obtained by electrochemical deposition technique. The specific steps are as follows: firstly, the Ag wire is polished by water proof abrasive papers. Then, the polished Ag is cleaned using acetone, anhydrous ethanol, and distilled water respectively. Finally, the Ag is used as anode and Pt wire is employed as cathode and then the Ag wire is be coated by a layer of AgCl paste.

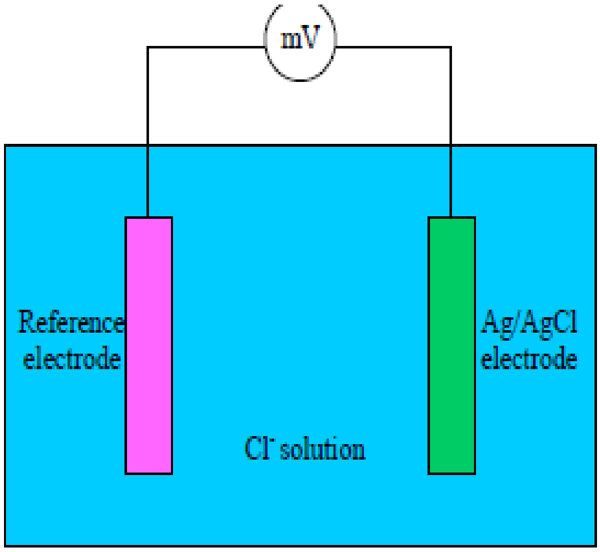
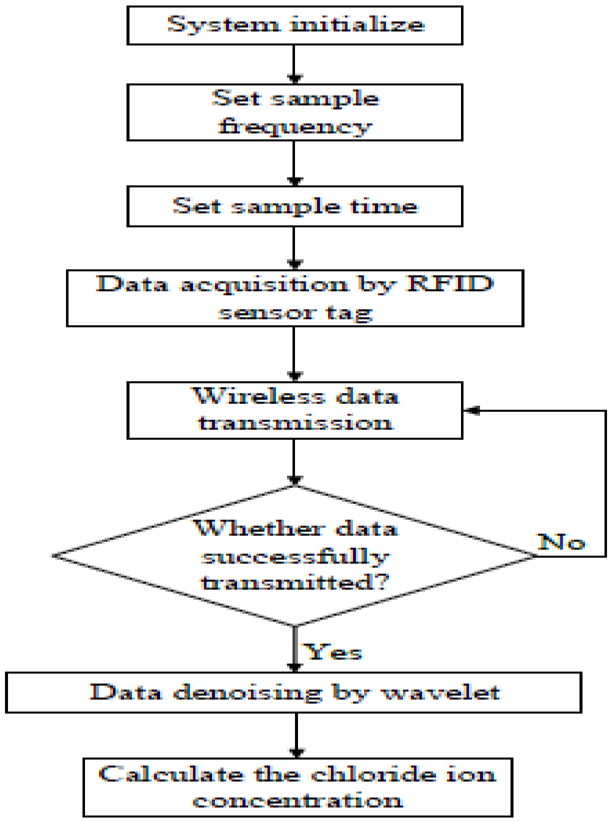


Figure 6. Principle of chloride concentration detection.

The whole measuring flow is shown in Figure 7. The sample frequency and sample time is pre-set, and the data is acquired by the proposed RFID sensor tag and then wirelessly transmitted.



1. Results and Discussion

The communication performance of the introduced tag should be firstly evaluated. The operating frequency of the tag is 915 MHz; the distance between the tag and the reader are 1.5 m, and the radiation power of the reader is 4 W. The measured communication flow is shown in Figure 8. Firstly, the tester sends Select command to the tag. After 5—6 Tari, the reader sends Query command to the tag and obtain a response of RN16. Next, the reader sends ACK command to obtain the tag's ID message as well as the measured data. Finally, the reader sends Req_RN command to acquire the Handle response. The digital data in the command are shown in Table2.

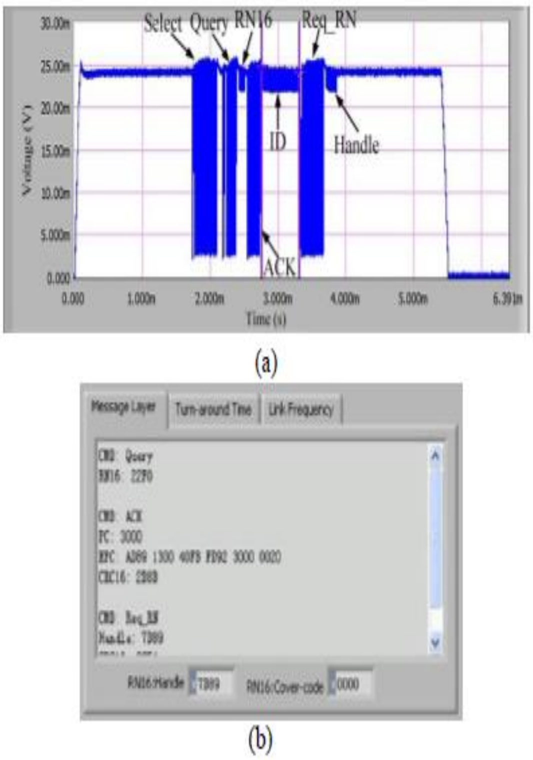


Figure 8. Overall communication flow: (**a**) corresponding waveform; (**b**) corresponding data.

The measured data are denoised twice by the wavelet denoising method with different thresholds. Firstly, they are processed by the wavelet denoising method with universal threshold, and then they are processed by the wavelet denoising method with minimax threshold. The raw data and denoised data are shown in Figure 11. It is obvious that the proposed denoised method can effectively remove all the noise.

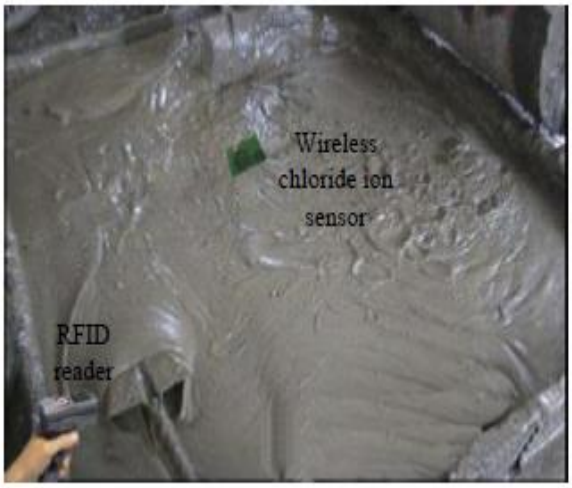


Figure 9. Test environment.

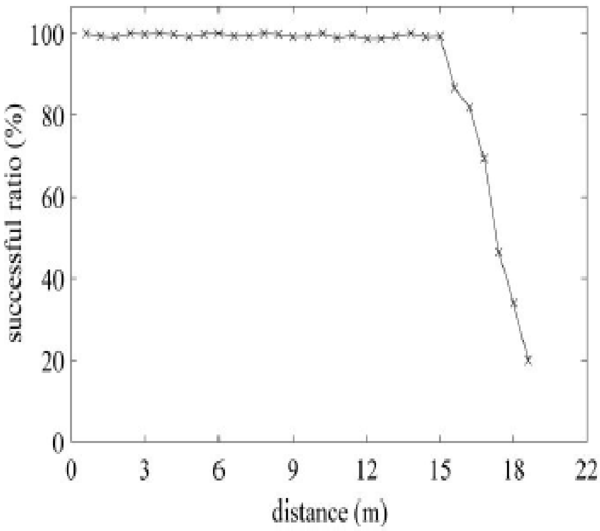


Figure 10. Measured successful ratio under different distance.

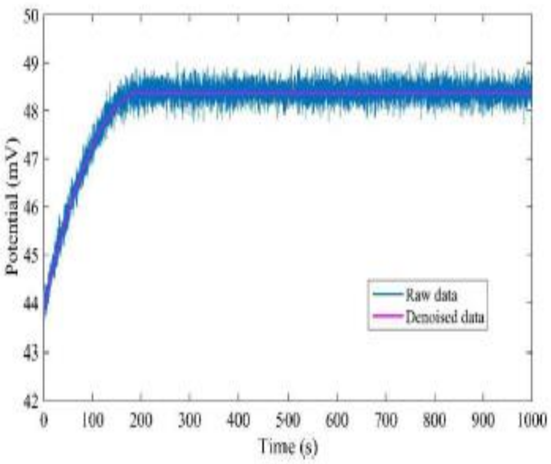


Figure 11. Comparison of raw data and denoised data.

The experiment is carried out in concrete mixed with NaCl solution in concentrations of 0.0001, 0.001, 0.01, 0.1, and 1.0 mol/L. Figure 12 shows the potential variation over 400 s. It can be seen that the response time is different in all of these five solutions, but they all achieve the stable value within 150 s. Moreover, the response time is longer in a dilute solution. The experimental results indicate that the Ag/AgCl electrode has high sensitivity to the chloride concentration and has a high response speed.

Table 3. Maximum relative potential shift of different reference electrodes.

Electrodes	Time (min)	Sodium Chloride Solution (mV)	Sodium Chloride Solution + Saturated Calcium Hydroxide Solution (mV)
Pt	0–2, 2–4, 4–6	2.7, 1.0, 0.6	2.1, 1.2, 0.2
Ag/AgCl	0–2, 2–4, 4–6	0.5, 0.6, 0.2	0.4, 0.5, 0.3
Calomel electrode	0–2, 2–4, 4–6	0.4, 0.2, 0.3	0.3, 0.4, 0.3

The selection of reference electrode is also significant to the performance of tag. The conventional reference electrode is calomel electrode, but it is inconvenient to be immersed in the concrete since it contains solution. Thus, in this paper the reference electrode is made of Pt wire, which has a simple structure and can be easily immersed in the concrete. To evaluate the performance of the adopted reference electrode, the Pt reference electrode couple, calomel reference electrode couple and Ag/AgC1 electrode couple are inserted into the Sodium Chloride Solution and saturated calcium hydroxide solution which is mixed with saturated sodium chloride solution, respectively. Then the relative potential shift of different reference electrodes can be obtained. The measured results are listed in Table 3. It is clear that the maximum relative potential shifts of Pt reference electrode in these two solutions are all smaller than 3 mV, which indicates acceptable stability.

Conclusions

A novel passive and wireless method to measure the chloride ion concentration in concrete is proposed in this paper. The proposed chloride ion sensor includes an energy harvesting and management circuit, a low dropout voltage regulator, a MCU, a RFID tag chip and a pair of electrodes operating in ultra-high frequency based on RFID technology. The proposed sensor utilizes RF power from the reader as power supply. A three-stage boost rectifier is customized to rectify the harvested power into dc power and step-up the voltage. The chloride ion concentration can be obtained from the potential difference between these two electrodes which are immersed in the concrete. Owing to the satisfactory performance in penetrating concrete, microstrip antenna is employed for both communication and energy harvesting. The wavelet denoising method is adopted to denoise the raw data since the measured data contains miscellaneous noises. Moreover, a monitoring software is developed to display the measurement results in real-time.

References

1. Abbas, Y.; de Graaf, D.B.; Olthuis, W.; van den Berg, A.

No more conventional reference electrode: Transition time for determining chloride ion concentration. *Anal. Chim. Acta* **2014**, *821*, 81–88. [CrossRef] [PubMed]

2. Meichers, R.E. Phenomenological Modeling of Reinforcement Corrosion in Marine Environments. *Mater. J.* **2006**, *103*, 25–32.
3. Zhao, J.; Cai, G.; Gao, D.; Zhao, S. Influences of freeze–thaw cycle and curing time on chloride ion penetration resistance of Sulphoaluminate cement concrete. *Constr. Build. Mater.* **2014**, *53*, 305–311. [CrossRef]
4. Muralidharan, S.; Vedalakshmi, R.; Saraswathi, V.; Joseph, J.; Palaniswamy, N. Studies on the aspects of chloride ion determination in different types of
8. Gao, X.J.; Zhang, J.; Yang, Y.Z.; Lu, S. Preparation of Chloride Ion Selective Electrode and its Potential Response to Different Chloride Solutions Representing Concrete Environments. *Mater. Sci. Forum* **2011**, *675*, 537–540. [CrossRef]
9. Femenias, Y.S.; Angst, U.; Caruso, F.; Elsener, B. Ag/AgCl ion-selective electrodes in neutral and alkaline environments containing interfering ions. *Mater. Struct.* **2016**, *49*, 2637–2651. [CrossRef]
10. Abbas, Y.; de Graaf, D.B.; Olthuis, W.; van den Berg, A. Dynamic Electrochemical Measurement of Chloride Ions. *J. Vis. Exp.* **2016**, *108*, e53312. [CrossRef] [PubMed]
11. Svegl, F.; Kalcher, K.; Grosse-Eschedor, Y.J.; Balonis, M.; Bobrowski, A. Detection of chlorides in pore water of cement based materials by potentiometric sensors. *Rare Met. Mater. Eng.* **2006**, *35*, 232–237.
12. Byun, J.; Jeon, B.; Noh, J.; Kim, Y.; Park, S. An intelligent self-adjusting sensor for smart home services based on ZigBee communications. *IEEE Trans. Consum. Electron.* **2012**, *58*, 794–802. [CrossRef]
13. Kumar, A.; Hancke, G.P. Energy efficient environment monitoring system based on the IEEE 802.15.4 standard for low cost requirements. *IEEE Sens. J.* **2014**, *14*, 2557–2566. [CrossRef]
14. Kovačić, M.; Vražić, M.; Gasparac, I. Bluetooth wireless communication and 1-wire digital temperature sensors in synchronous machine rotor temperature

concrete under macro-cell corrosion conditions. *Build. Environ.* **2005**, *40*, 1275–1281. [CrossRef]

5. Kassir, M.K.; Ghosn, M. Chloride-induced corrosion of Reinforced Concrete Bridge decks. *Cem. Concr. Res.* **2002**, *32*, 139–143. [CrossRef]
6. Abbas, Y.; Olthuis, W.; Berg, A.V.D. A chronopotentiometric approach for measuring chloride ion concentration. *Sens. Actuators B Chem.* **2013**, *188*, 433–439. [CrossRef]
7. Montemor, M.F.; Alves, J.H.; Simões, A.M.; Fernandes, J.C.S.; Lourenço, Z.; Costa, A.J.S.; Appleton, A.J.; Ferreira, M.G.S. Multiprobe chloride sensor for in situ monitoring of reinforced concrete structures. *Cem. Concr. Compos.* **2006**, *28*, 233–236. [CrossRef]

measurement. In Proceedings of the 14th International Power Electronics Motion Control Conference, Ohrid, Makedonija, 6–8 September 2010; pp. T7-25–T7-28.

15. Reinisch, H.; Wiessflecker, M.; Gruber, S.; Unterassinger, H.; Hofer, G.; Klamminger, M.; Pribyl, W.; Holweg, G. A multifrequency passive sensing tag with on-chip temperature sensor and off-chip sensor interface using EPC HF and UHF RFID technology. *IEEE J. Solid State Circuits* **2011**, *46*, 3075–3088. [CrossRef]
16. Liu, Y.; Deng, F.; He, Y.; Li, B.; Liang, Z.; Zhou, S. Novel Concrete Temperature Monitoring Method Based on an Embedded Passive RFID Sensor Tag. *Sensors* **2017**, *17*, 1463. [CrossRef] [PubMed]
17. Zhou, S.; Deng, F.; Yu, L.; Li, B.; Wu, X.; Yin, B. A Novel Passive Wireless Sensor for Concrete Humidity Monitoring. *Sensors* **2016**, *16*, 1535. [CrossRef] [PubMed]
18. Donno, D.D.; Catarinucci, L.; Tarricone, L. A Battery-Assisted Sensor-Enhanced RFID Tag Enabling Heterogeneous Wireless Sensor Networks. *IEEE Sens. J.* **2014**, *14*, 1048–1055. [CrossRef]
19. Abbas, Y.; ten Have, B.; Hoekstra, G.I.; Douma, A.; de Bruijn, D.; Olthuis, W.; van den Berg, A. Connecting to concrete: Wireless monitoring of chloride ions in concrete structures. *Procedia Eng.* **2015**, *120*, 965–968. [CrossRef]