13.56 MHz-RFID Antenna Fabricated with Metal Layer of Standard CMOS Process for Biosensor Applications

#Boram Kim, Shigeyasu Uno, Kazuo Nakazato
Department of Electrical Engineering and Computer Science, Graduate School of Engineering, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan, r_kimu@nuee.nagoya-u.ac.jp

1. Introduction

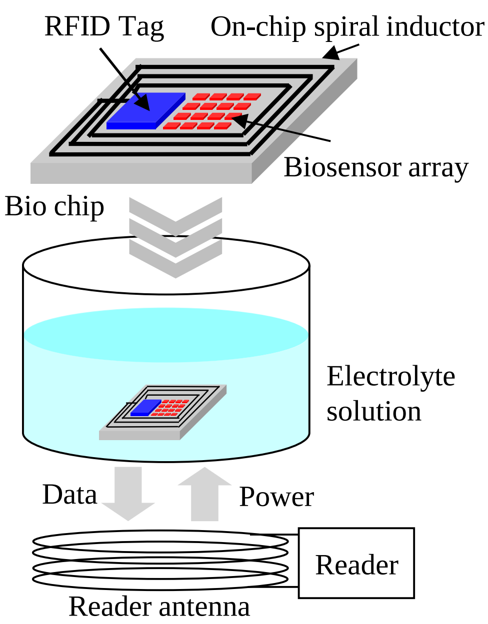

Fig. 1 RFID biosensor measuring system. The biosensor soaked in electrolyte solution is wireless measured by using RFID technology.

Radio frequency identification (RFID) technology is a generic term that is used to describe a system that transmits the information of a tag wirelessly, using electromagnetic wave or inductive coupling. Depending on integrated circuit and antenna technology development, RFID has been used in various applications; smart card, factory automation system, toll gates for motor vehicles and container control system. Recently, other application examples has reported that RFID biosensor chips integrates the RFID and biosensor for inexpensive, small and subaqueous sensing system [1]. In this case, integration of an on-chip antenna with RFID tags has significant advantages for small size and low cost tag fabrication. There have been several publications on RFID tags with an on-chip antenna [1-3]. However, many existing on-chip antenna implementations need post process in addition to the standard fabrication process, such as external chip-coil [1], gold plating [2] and thick oxide [3]. Therefore, the additional fabrication time and cost are required for the post process. In this paper, we simplify process and reduce cost by integrating chip and on-chip spiral inductor RFID tag antenna that is fabricated with metal interconnect layer of standard complementary metal oxide semiconductor (CMOS) process. First of all, we select the operating frequency 13.56 MHz that is suitable for the subaqueous measuring system (Fig. 1) and small area spiral inductor. Secondly, we analyse the on-chip spiral inductor by measurement and calculation. Thirdly, we propose the new modulation circuit for on-chip spiral inductor tag antenna and the load modulation is confirmed by measurement. Finally, the 212 kHz amplitude shift keying (ASK) transmission is shown in water by using on-chip spiral inductor RFID tag antenna and new modulation circuit. With such advances, low cost, small size and simple process on-chip tag antenna can be expected for the RFID biosensor applications.

2. On-chip Spiral Inductor

This section describes optimization method to realize an inductive coil with metal interconnect layer of standard CMOS process and evaluates the property. Figure 2 (a) shows micrograph of a chip fabricated by 1.2 μm standard CMOS process. Outermost diameter d_{out}, innermost diameter d_{in} and tag coil turns n were set to 6.3 mm, 3.0 mm, 8, respectively, based on a consideration of the chip size, internal circuit and resonance frequency. The thickness of metal layer is 1 μm. Modulation circuit, sensor circuit and signal processing circuit were located inside chip space of the on-chip spiral inductor. Figure 2 (b) shows the frequency dependence of on-chip spiral inductor impedance. The impedance was measured by using an impedance analyzer (Agilent 4294A) The solid line represents the measurement result of on-chip spiral inductor impedance that resonates around 13.56 MHz. The dotted line is calculated by Wolfram Mathematica8 based on the equivalent circuit (Fig.2 (c)). The parasitic elements C_{s2} and R_2 also exist in the equivalent circuit of on-chip spiral inductor in addition to inductive element L_2. A pattern ground shield is devised to eliminate the silicon parasitic elements of the on-chip spiral inductor [4]. However, C_{s2} can be used as a resonance adjustment capacitance in this RFID tag antenna. Figure 2 (b) indicates L_2 = 312 nH, C_{s2} = 269 pF and R_2 = 23 Ω.

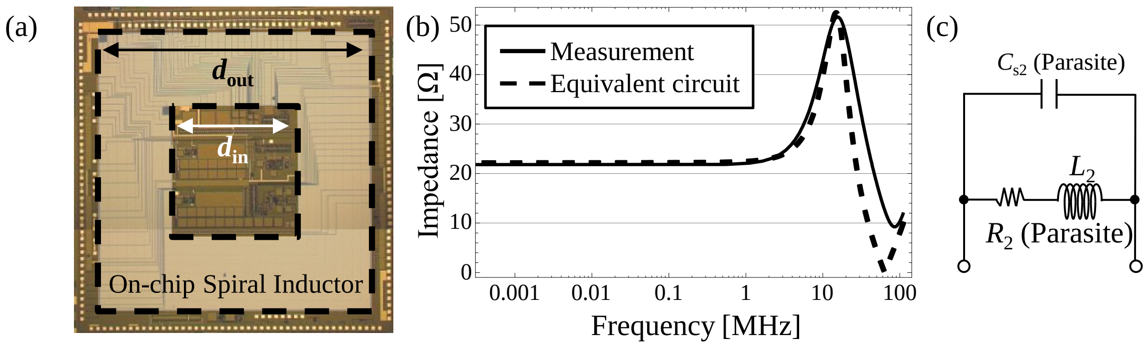

Fig. 2 On-chip spiral inductor (a) Micrograph of the chip fabricated in 1.2μm CMOS process. (d_{out} = 6.3 mm, d_{in} = 3.0 mm) (b) Impedance of on-chip spiral inductor. (c) Equivalent circuit

3. Modulation Circuit with AC Switch and Full Swing Inverter

The new modulation circuit proposed in this paper is shown in Fig. 3 (a). The variable capacitance C_1 and C_{m1} were used for impedance matching between power source V_1 and reader antenna. The capacitor C_2 (=52 pF) is the resonance adjustment capacitance for the 13.56 MHz resonant on-chip spiral inductor tag antenna. Due to the efficiency of the load modulation with small self inductance L_2, the AC switch (Fig. 3 (b)) is connected directly to the tag antenna before tag inductive sinusoidal wave is rectified. The AC switch is composed of two large size positive channel metal oxide semiconductor (PMOS) transistors. Due to either PMOS operates as a diode, AC signal can be switched. We selected the large size of AC switch PMOS transistor, because a large current can be switched by large width to length ratio (W/L) of the transistor. The load modulation (amplitude modulation) occurs when the digitalized biosensor signal enters to the AC switch input V_{swin}. To optimize efficiency of switching, input voltage V_{swin} need to swing up to the negative voltage. Figure 3 (c) shows the circuit diagram of full swing inverter. The digital data V_{data} that swings from 0 V to V_{dd} (supply voltage) is enlarged by full swing inverter to V_{swin} that swings from V_{inss} to V_{dd}. The V_{inss} is generated by charge pump negative stage. To obtain high modulation depth in the load modulation, we have done a theoretical analysis. Modulation depth m can be described by the following formula;

$$m = \frac{V_{out\text{-}ON} - V_{out\text{-}OFF}}{V_{out\text{-}ON} + V_{out\text{-}OFF}} \times 100, \quad (1)$$

where $V_{out\text{-}ON}$, $V_{out\text{-}OFF}$ are the output voltages at switch ON and OFF, respectively. Figure 4 shows the surface plot of modulation depth m as a function of number of turns (reader coil) N and load resistance R_d. This plot was calculated by Wolfram Mathematica8. It is evident that the modulation depth is high when R_d is small and N is large. Experimental result of load modulation at N = 20, R_d = 2.2 Ω and communication distance x = 1.5 mm is shown in Fig. 5. We measured two different size of AC switches (AC switch 1 : W/L = 1818.18 µm / 2.22 µm, AC SW2 : W/L = 3636.36 µm / 2.22 µm) as a function of V_{inss}. The measurement results show that m is high when V_{inss} is low. We also confirmed that m increases efficiently when the size of transistor is large. These results indicate the load modulation with the maximum modulation depth m = 3.5, which is smaller than the modulation depth m = 6.65 predicted by the theoretical analysis because impedance generated by packaging and AC switch loss.

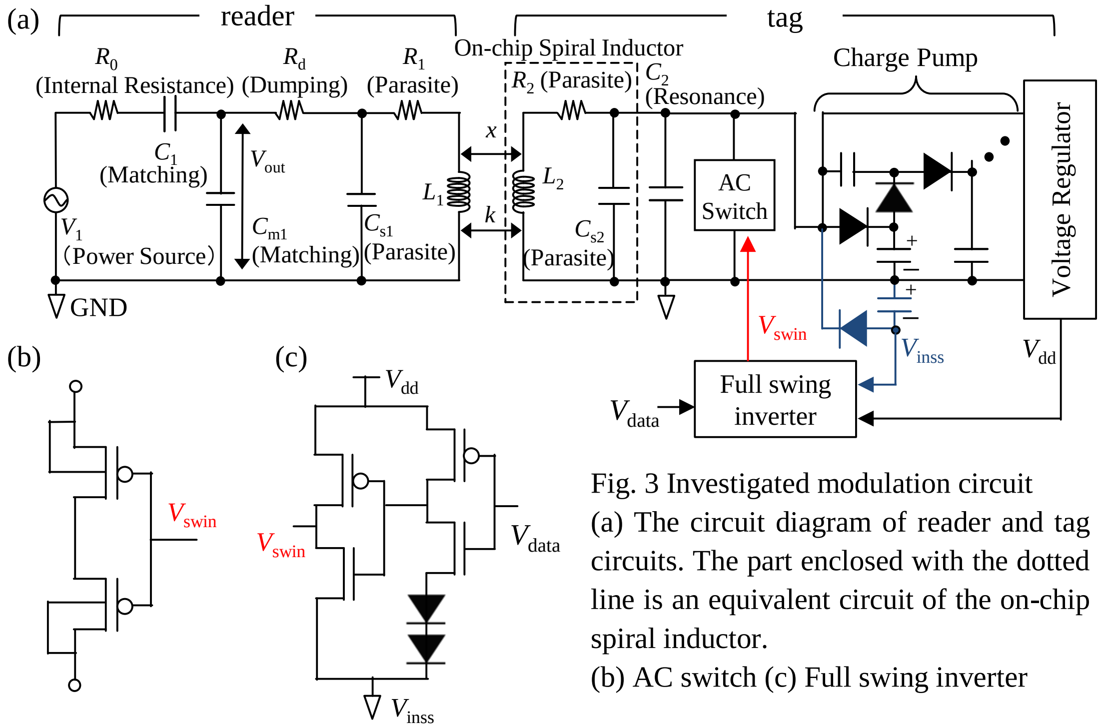

Fig. 3 Investigated modulation circuit
(a) The circuit diagram of reader and tag circuits. The part enclosed with the dotted line is an equivalent circuit of the on-chip spiral inductor.
(b) AC switch (c) Full swing inverter

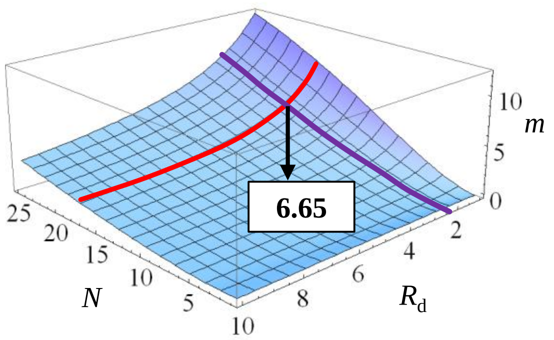

Fig. 4 Calculated modulation depth m to N and R_d.

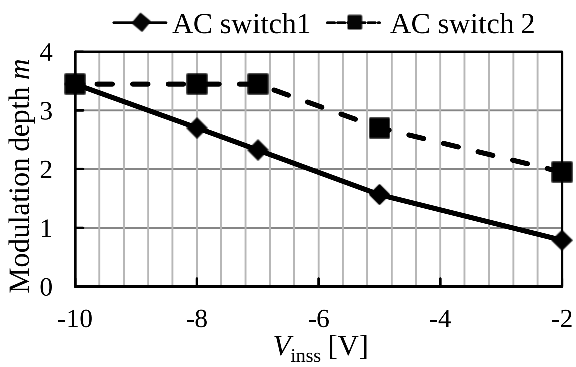

Fig. 5 Measured modulation depth with two AC switches.

4. ASK Transmission

In this section, we describe the experimental result of ASK transmission by using the proposed modulation circuit and on-chip spiral inductor tag antenna. We selected the 212 kHz (13.56 MHz / 64) as the baseband frequency due to this frequency is widely used as the subcarrier of the 13.56 MHz-RFID system. Figure 6 shows the result of ASK transmission experiment. The baseband signal V_{data} that swings from 0 V to 5 V is enlarged by full swing inverter to the AC switch input signal that swings from -5 V to 5 V when V_{inss} is set to -5 V. When the communication distance was set to x = 1.5 mm, the reader circuit output voltage V_{out} variation can be observed. The measured modulation depth m = 1.21 is almost equal to the result of Fig. 5. The ASK transmission is possible because the measured time constant (about 0.5 μs) is 10 times longer than the baseband wavelength (1 / 212 kHz = 4.72 μs). Also, we experimented with the subaqueous ASK transmission. Figure 7 (a) shows the photograph of measurement system that a beaker contained water and tag chip. (Side view and Bird eye view) The AC switch input signal supplied from external wiring. Experimental result of ASK transmission at x = 3 mm is shown in Fig. 7 (b). The water and glass of beaker were located between reader antenna and tag chip. As a result of the experiment, it is evident that the water do not affect this transmission system.

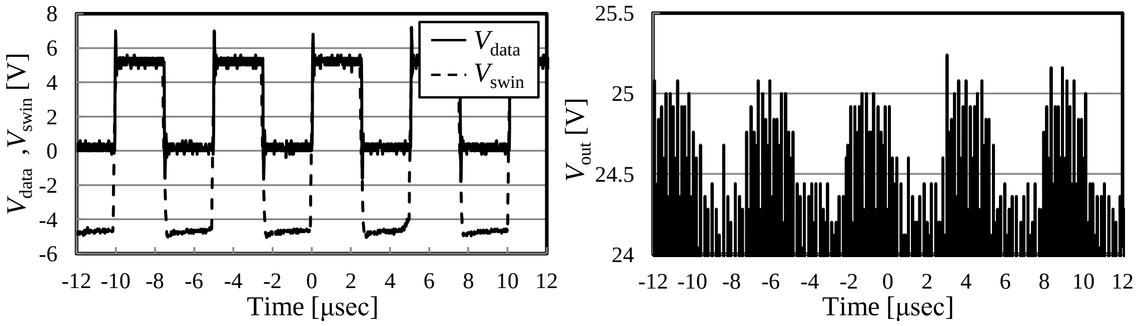

Fig. 6 Measured ASK transmission with AC switch and full swing inverter.

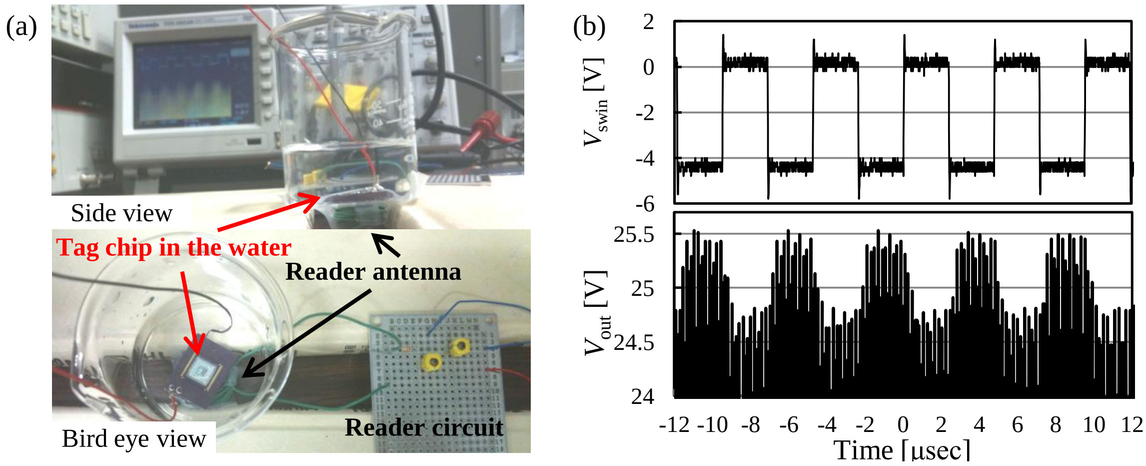

Fig. 7 ASK transmission in water.

(a) Photograph of measuring system. (b) Result of ASK transmission experiment

5. Conclusion

The presented work focuses on optimizing 13.56 MHz-RFID on-chip tag antenna with on-chip spiral inductor. On-chip spiral inductor and new modulation circuit are fabricated with standard CMOS process. As a result, the small size (7 mm × 7 mm), subaqueous operation, 212 kbps data rate, low cost and simple process (only standard CMOS process) RFID on-chip tag antenna can be fabricate. This on-chip tag antenna is expected to apply the RFID biosensor measuring system.

Reference

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