Sensor Review

Force sensor system for structural health monitoring using passive RFID tags

Yusuke Ikemoto
Research into Artifacts, Center for Engineering, University of Tokyo, Kashiwa-shi, Chiba, Japan

Shingo Suzuki
Denso Corporation, Showa-cho, Kariya-city, Japan

Hiroyuki Okamoto
Ritecs Co. Ltd, Tachikawa, Tokyo, Japan

Hiroki Murakami
IHI Corporation, Koto-ku, Tokyo, Japan

Hajime Asama
Research into Artifacts, Center for Engineering, University of Tokyo, Kashiwa-shi, Chiba, Japan

Soichiro Morishita
Research into Artifacts, Center for Engineering, University of Tokyo, Kashiwa-shi, Chiba, Japan

Taketoshi Mishima
Graduate School of Science and Engineering, Saitama University, Saitama, Japan

Xin Lin
National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan

Hideo Itoh
National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan
Research article

Force sensor system for structural health monitoring using passive RFID tags

Yusuke Ikemoto
Research into Artifacts, Center for Engineering, University of Tokyo, Kashiwa-shi, Chiba, Japan

Shingo Suzuki
Denso Corporation, Showa-cho, Kariya-city, Japan

Hiroyuki Okamoto
Ritecs Co. Ltd, Tachikawa, Tokyo, Japan

Hiroki Murakami
IHI Corporation, Koto-ku, Tokyo, Japan

Hajime Asama and Soichiro Morishita
Research into Artifacts, Center for Engineering, University of Tokyo, Kashiwa-shi, Chiba, Japan

Taketoshi Mishima
Graduate School of Science and Engineering, Saitama University, Saitama, Japan, and

Xin Lin and Hideo Itoh
National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan

Abstract
Purpose — The purpose of this paper is to describe the development of a contactless and batteryless loading sensor system that can measure the internal loading of an object structure through several covering materials for structural health monitoring.

Design/methodology/approach — The paper proposed an architecture by which two radio frequency identification (RFID) tags are used in the system. It has been difficult to realize sensing by RFID because of the low power supply. To solve the power supply problem, a method using functional distribution of RFID tags of two kinds of RFID for communication and power supply was proposed. One RFID tag is specialized as a power supply for communication of strain loading information through AD conversion. Another is specialized to supply power for driving the strain gauges bridge circuit.

Findings — By using developed system, the measurement of the structural internal loading with 20.0 mm depth was possible through covering materials such as concrete, but also plaster board, flexible boards, silicate calcium board, blockboard, and polystyrene with a resolution performance from $10 \times 10^{-6}$ to $40 \times 10^{-6}$.

Originality/value — A sensor system was developed using passive RFID, which enables measurement of load-deformation information inside a structural object. Moreover, the inexpensive wireless, batteryless devices used in this system require little maintenance, and applications for the user interface are also included in the developed system for uniform management of structural health monitoring. The developed system was evaluated in an actual situation using not only concrete but also other materials as covering materials on a structural object.

Keywords Structural analysis, Strain measurement, Loading (physics), Radio frequencies, Low voltage

Paper type Research paper

1. Introduction

Recently, demands for maintenance of structural objects such as buildings, bridges, and living spaces have been increasing.

It is important to detect the underlying danger of structures and to monitor the physical fatigue of materials. However, materials of living spaces are almost always covered with concrete. For that reason, it is difficult to measure the internal loadings and status of such structures.

Among existing methods for structural health monitoring, the interior structural state is estimated using surface measurement of changes of measurement objects. Direct monitoring is difficult because the measurement objects are generally covered with decorative laminate such as paint, veneer, plaster, siding, and concrete. Some studies have developed structural health monitoring systems using wireless
devices embedded into measurement objects. Such devices, however, require batteries or scheduled power supply maintenance, which requires removal of decorative laminate materials. To maintain the health and safety of the structural objects and to predict the destruction moment, time-series sensing of the internal loading monitoring, called structural health monitoring, is an important area of development (Doherty, 1987; Yuyin and Akira, 2007).

Structural objects in living spaces are damaged by natural hazards over a long-term and are affected by accumulation of damage. If the damage reaches the limit of the safety range or the demand standard, repairs or additional strength must be adequately performed (Figure 1). Therefore, rapid and easy scheduled maintenance are expected to be necessary. To enable convenient maintenance work, structural health monitoring systems should preferably have wireless and batteryless performance, which can be satisfied if passive radio frequency identification (RFID) tags are used because the user tries to sense the internal physical state of structures. However, it has been difficult to apply a passive RFID as a force sensor because RFID generally can drive only imperceptible electrical power devices such as temperature sensors (Nath et al., 2006). Power supply problems must be considered consistently if an any-band RFID is used. We developed a force sensor system using passive RFID tags by physically separating a power supply module and a communication module to address these problems. For this study, we developed loading monitoring of measurement objects using a passive RFID tag.

Two major contributions are provided by this study. First, we developed a sensor system using passive RFID, which enables measurement of load-deformation information inside a structural object. Moreover, the inexpensive wireless, batteryless devices used in this system require little maintenance, and applications for the user interface are also included in the developed system for uniform management of structural health monitoring. Second is evaluation of the developed system in an actual situation using not only concrete but also other materials as covering materials on a structural object. With those evaluations, the practical utility is indicated. In particular, the measurement of the structural internal loading with 20.0 mm depth through covering materials such as concrete, but also plaster board, flexible boards, silicate calcium board, blockboard, and polystyrene with a resolution performance from $10 \times 10^{-5}$ to $40 \times 10^{-5}$.

2. Approach

2.1 Related works and the proposed system

Passive RFID is used to achieve remote measurement of interior load-deformation information. Some studies have used optical fiber (Hocker, 1979; Kurashima et al., 1995; Kihara et al., 2001;

Figure 1 Experimental equipment with covering materials

Measurements, 2001), wireless LAN devices (Arai et al., 2007), crack sensors (Thiel et al., 2005), or ultrasound waves (Tan and Hirose, 2005) for maintenance of structures by placement in an iron frame, a concrete frame, a wall panel, or other material. In this study, passive RFID tags are examined (Marjonen et al., 2006a,b; Deng et al., 2006). They are expected to be used for structural health monitoring. Recently, studies using RFID tags for structural database management increases with RFID technology that sends and receives data without using physical contact with a wireless that uses electromagnetic fields, electric waves, etc., for communication. For instance, Yabuki described a system by which the construction process can be known immediately to users using the RFID tag for the checking and repairing structures (Yabuki et al., 2004). The YRP Ubiquitous Networking Laboratory (2006), developed a system that can support management of a structural database and construction processes by putting an RFID tag on a steel column or wall panel; they developed an RFID tag that can be implanted into concrete (www.ubin.jp/press/pdf/UNL061204-04.pdf, 2006). Therefore, research using RFID tags, implant inside structures for structural maintenance has been actively pursued. Passive RFID with a sensor function is attracted and studied in recent years (Opasjamurskit et al., 2006; Woochul et al., 2006; Philipose et al. 2005). To apply those technologies to structural health monitoring, it is required to design lower power consumption circuit because a strain gauge needs higher electrical power, comparing with thermistor and so on.

In this research, we develop the structural health monitoring system using passive RFID tags that can measure the strain loadings of structures (Figure 2) and evaluate the effectiveness using general covering materials. The developed system enables users to measure structural strain through the covering materials with no contact, and electrical wires in the signal for communication and a power supply is unnecessary. Especially, this study specifically addresses strain loading measurement using RFID, how to design the sensor circuits to reduce electrical power consumption, and evaluation in an actual environment with materials in popular use.

2.2 Problems and solution method

A strain gauge is used in the developed system to measure loading on the structure. The displacement range of a strain gauge is so minute that the sensor board consists of an amplifier circuit for detection of sensor output and a lowpass filter for high-frequency denoising, and a partial circuit to input to the lowpass filter and ADCIN terminal.

The strain gauges must be driven with a very small power supply from RFID tags. In addition to the power supply, this

Figure 2 Develop a structural health monitoring system using passive RFID tags
system needs a power supply to communicate: for transmission of the material's state data. The energy passed through an RFID decreases with the distance between the RFID reader/writer and the tags. It is, however, difficult to combine their power supply. Therefore, a contactless sensor system using RFID is limited to low power and responsible sensor devices such as a thermistor.

To solve the power supply problem and to realize stable communication using RFID, in the developed system, we propose a method using functional distribution of RFID tags of two kinds of RFID for communication and power supply. One RFID tag is specialized as a power supply for communication of strain loading information through A/D conversion. Another is specialized to supply power for driving the strain gauges bridge circuit. Herewith, using the separation of RFID functions, we develop structural health monitoring systems to realize contactless sensing with very small power.

3. Developed systems

3.1 System architecture

3.1.1 Overview of the architecture

Figure 3 shows architecture of the developed system, which consists of an RFID sensor module put into a structure inside of covering materials; it also shows the measurement module for data acquisition. In the RFID sensor module, the strain gauge data are converted to A/D through a sensor on the RFID tag. The data are transported to the measurement module through the covering materials with RFID reader/writer devices. From the data, information about deformation volume and loading are calculated without computers. Details of devices used in this system are described in the Appendix section. The RFID tag can passively operate with electromagnetic induction and the radio wave frequency is 13.56 MHz band. The degree of power supply depends on the size of on-board antenna in the tag, 56 mm high and 84 mm wide. The available voltage and electrical power are 2.2 V and 4.4 mW, respectively, on specifications. In fact, since the tag output 2.25 V, this voltage value is used in developed equipment.

3.1.2 RFID sensor module

Each RFID sensor module comprises strain gauge sensors, a sensor board, and RFID tags. A bridge circuit is configured with strain gauge sensors in the sensor board. The sensor board consists of an amplifier circuit for detection of sensor output and a lowpass filter for highfrequency denoising, in addition to a partial circuit to input to the lowpass filter and the ADCIN terminal.

The most important problem for designing the modules is how the strain gauges on a sensor board are driven with a small power supply from RFID tags. Both the ADC function of RFID and the communication process using RFID tags require high power consumption. Therefore, sensor systems using an RFID tag with ADC functions are limited to applications such as a thermistor, which has low power consumption, without an amplifier. To solve these problems, we developed an RFID sensor module consisting of two kinds of RFID tags, one for the power supply, another is for communications. To separate the functions is a utilitarian architecture because the electricity consumption is expected to be an important consideration when an RFID is used for sensing. This architecture realizes stable communication.

Figure 4 portrays the circuitry of the developed RFID sensor module. The voltages of a bridge circuit, an amplifier circuit, and a lowpass filter are supplied from the left side RFID tags of Figure 4. This circuit is driven by constant voltage, 2.25 V, between the VDD and GND terminal. The fixed resistance is inserted to input wiring to the bridge circuit to avoid carrying high level electric current. The drive current of the bridge circuit is set to 0.1 mA and the power consumption of the module is set to 2.5 mW. The offset calibration is carried out by adjusting RV in the figure. The operational amplifier (NJU7016D) is used for
the amplifier circuit and is driven with low voltage. To filter out
the noise from RFID electrical wave, three operational
amplifiers are used for common mode noise rejection between
both ends of a bridge circuit, as shown in Figure 5). The cutoff
frequency of the lowpass filter is set to \( f_c = 1.6 \text{ kHz} \).

The right side RFID tags of Figure 4 are for data
acquisition from a measurement module. The partial voltage
with three resistances \( Y_1 \), \( Y_2 \), and \( Y_3 \) from the amplifier
circuit is input to the ADCIN terminal.

In Figure 4, the input voltage to ADCIN terminal is
-described as below. In this regard, however, the effect of \( R_0 \)
that is the offset volume adjuster, is approximately negligible
because \( R_Y \ll R_0 \).

Let \( e \) be the strain of \( R_0 \) in Figure 4. The small resistance
changes \( \Delta R_0 \) occur and the relationship between the gauge
coefficient of the strain gauge is described as:

\[
\frac{\Delta R_0}{R_0} = Ke. \tag{1}
\]

Let \( V_{df} \) be the difference of voltages generated by the bridge
circuit. Before generating the difference of voltages, the bridge
circuit is in an equilibrium state. Let \( V_{app} \) be the applied
temperature to the bridge circuit; we have:

\[
V_{df} = \frac{R_0 R_Y}{(R_0 + R_Y)^2} Ke V_{app} = \frac{1}{4} Ke V_{app}. \tag{2}
\]

The output voltage from the amplifier circuit \( V_{AMP} \), as show
in Figure 5, is described as follows using amplifier gain \( A \):

\[
V_{AMP} = A \times V_{df}. \tag{3}
\]

The amplifier gain \( A \) is described as follows:

\[
A = \left(1 + \frac{2R_1}{R_5}\right) \frac{R_7}{R_6}. \tag{4}
\]

\( R_3, R_5, R_6 \), and \( R_7 \) are determined to satisfy amplifier gain \( A \) based
on strength of a measurement object. Let \( V_{ADClN} \) be the input
voltage from the ADCIN terminal and let \( Y_1 \), \( Y_2 \), and \( Y_3 \) be the
canotypes between \( V_{AMP} \)–ADCIN terminals, VDD–ADCIN

\[
V_{ADClN} = \frac{1}{Y_1 + Y_2 + Y_3} (V_{AMP} Y_1 + 2.25 Y_2)
\]

\[
= \frac{1}{Y_1 + Y_2 + Y_3} \left( \frac{1}{4} Ke V_{app} Y_1 + 2.25 Y_2 \right). \tag{5}
\]

The output of \( V_{AMP} \) can be input to ADCIN terminal if we set
\( Y_1 \gg Y_2 \). The developed system has 0.05 V 5\text{VAMP} \geq 2.20 \text{ V}
because the output amplifier range is set as 0.05 V to 2.20 V.
Figure 6 shows the developed RFID sensor module, which is
encapsulated in an acryllic package. The figure shows that they are
located parallel with 30 mm distance to avoid interference
between RFID tags. The component parts of the RFID sensor
module are presented in Table I.
Figure 6 Developed RFID sensor module

Table 1 Component parts of the RFID sensor module

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFID tag</td>
<td>2</td>
</tr>
<tr>
<td>Strain gauge</td>
<td>4</td>
</tr>
<tr>
<td>Operational amplifier (NUU7016D)</td>
<td>2</td>
</tr>
<tr>
<td>Fixed resistance (±0.1 percent)</td>
<td>12</td>
</tr>
<tr>
<td>Variable resistance</td>
<td>2</td>
</tr>
<tr>
<td>Multilayer ceramic capacitor</td>
<td>7</td>
</tr>
</tbody>
</table>

3.1.3 Measurement module
The developed measurement module consists of two RFID reader/writers and a computer for data processing and a user interface as Figure 3. One RFID reader/writer is for communication; another is for the power supply with an RFID sensor module. The measurement module obtains the value of $V_{\text{ACIN}}$ from the RFID module and the strain is calculated using the computer according to Equation (5). In the computer, the structure model, such as the parameters in Equation (5), is known for uniform management of structural health monitoring. The application for the user interface, which is one component of the developed system, is portrayed in Figure 7. Users can acquire the strain information of the target structure through covering materials. The application has materials parameters and transit from $V_{\text{ACIN}}$ to strain with (5).

3.1.4 Advantage of developed system
To drive both bridge circuit for sensing and communication circuit, large amount of power is needed, compared with the circuit without a sensor device. As a solution, with two RFID tags, we designed the circuit, that is physically separated to both functions. If above functions are forced in circuit with one RFID tag under conditions assumed in this developed system, the following problems are concerned. The RFID devices, that are equipped in developed system, carry out eight times of transmitting and receiving at one sensing process. When the communication circuit is driven, the voltage level of VDD terminal is forced to fluctuate according to communication status. During the communication, the available electrical power for driving bridge circuit is effected. When utilizing device specification electrical power to the full, both transmitting sensing data and driving bridge circuit cannot concurrently operate. Alternatively, if transmitting is achieved, it is expected that the data is partially reliable because sensing false positive is caused by lowering of electric power. The circuit design is complicated to realize stable voltage supply and it is difficult to exploit full electrical power of RFID.

In developed system, actually, the summation of the resistance in bridge circuit is 390.0. In the case of that current limiting resistor is $R_1 = 1\, \text{k}\Omega$ and available voltage supplied by a RFID tag is $2.2\, \text{V}$, that is the device specification, electrical power consumption is calculated as $3.6\,\text{mW}$. In this case, more than half of electrical power is used to drive bridge circuit because the electrical power supply of the RFID tag is $4.4\,\text{mW}$. In addition, the electrical power for driving amplifier circuit and voltage divider circuit is needed. Communication errors occur if the stable supply voltage $2.2\,\text{V}$ cannot be kept. The architecture, that is physically separating those functions by two kinds of RFID tags, is developed to solve the above problems. From another reasonable standpoint, the developed system enables to utilize full electrical power supplied from the RFID tags.

4. Experiments
4.1 Experiments for evaluation of basic properties
4.1.1 Experimental overview
In this developed system, concern exists that the power supply to a sensor module decreases when the distance separating the RFID sensor module and a reader module increases. Therefore, unstable operation of each circuit and communication might occur from a low power supply. First, in this section, the effective distances for measurement without covering materials are evaluated as basic properties of the proposed system.

4.1.2 Experimental equipment
Figure 8 shows the experimental equipment. In this experiment, cantilever examination is carried out using a general structural rolled steel (SS400). The vertical load is added gradually to the free end. The strain in the surface of the target member of framework is measured using the proposed system. Through this experiment, the effective distances without covering materials are demonstrated. In the fixed end, the member of the framework is fixed to the base with a precision vise. A digital force gauge (DS2-500N) is fixed to the same base to avoid momentum; it is used to measure the additional forces imparted to the free end.

In this experimental device, the strain $e$ is described as Equation (6) when $F$ is added to the free end, as shown in Figure 9:

$$ e = \frac{6x}{bh^2}E \left( F + \frac{w x}{2} \right). \quad (6) $$

In that equation, $w$ represents the distributed load under its own weight, and $E$, $b$, and $h$, respectively, signify the Young's modulus, width, and thickness of the member of the framework.

4.1.3 RFID module settings
In this experiment, the four strain gauges are set into an $x$ configuration in corners of the surface of the member of the framework so that all distance $x$ between the strain gauges' position and the free end are equal, as shown in Figure 10. Then, the output value of $V_{\text{diff}}$ in Equation (2) quadruples; we have:

$$ V_{\text{diff}} = KeV_{\text{app}}. \quad (7) $$

131
Figure 7 User interface for uniform management of structural health monitoring

Figure 8 Experimental equipment

Figure 9 Cantilever beam examination

Actually, considering the effect of the offset adjusting resistance $R_V$ of Figure 4, we have:

$$V_{\text{diff}} = \frac{R_1}{R_1 + R_2 + R_3 + R_4} K e V_{\text{app}},$$  \hspace{1cm} (8)

where it is approximated that $V_{\text{diff}} = 0$ because the differences between the resistances of strain gauges are very small. Table II shows the parameter value set in this experimental condition and equipment. Then, Equation (5) is described as:

$$V_{\text{ADCin}} = 2.35 \times 10^3 e + 0.35 \times 10^{-3}.$$  \hspace{1cm} (9)
The second terms of the right side of equation (9) are negligible because the resolution of ADC in a RFID tag is about 8.8 mV.

In addition, the strain gauge and gain $A$ is determined based on design strength $F_{\text{max}} = 235 \text{N/mm}^2 \times 80$ percent of SS400 of thickness 40 mm. In this measurement range, SS400 is within the elastic area.

4.1.4 Experimental methods
The sequence of experiments is explained as follows:
- The antenna of the reader module is moved close to the RFID tag antenna.
- The distance $L$ between each antenna is 5.0 mm from 2.5 mm as the origin.
- A load is added to the free end by 10 N steps from 0 N to 200 N at each antenna distance.
- The strain is measured using the developed system ten times for each distance and load.

4.1.5 Results
The experimental results of evaluations of basic properties are shown in Figure 11. The black line shows a realistic value predicted using Equation (9). The $m$ in the figure represents the mean squared error. When approaching $L = 32.5 \text{mm}$, $m$ increases because of the power supply reduction. The developed system enables measurement of the forces from $L = 2.5 \text{mm}$ to $L = 32.5 \text{mm}$.

Figure 11 Experiments with out covering materials at $L = 2.5 \text{mm}$, $L = 12.5 \text{mm}$, $L = 22.5 \text{mm}$, and $L = 32.5 \text{mm}$

To examine the relationship between the measured power reduces and distance $L$, the values of $V_{\text{ADCIN}}$ against $L$ increase are illustrated in Figure 12. Actually, $V_{\text{REF}}$ in Figure 5 was measured. Although the loading is fixed to $F = 50 \text{N}$, other cases give nearly same results because power reduces depends on only distance $L$. When approaching $L = 32.5 \text{mm}$, $m$ dramatically increases. Therefore, it is considered that the critical distance for power supply exists around over $L = 30 \text{mm}$. These results indicate the limitation of available measurement distance in developed system. If $L > 30 \text{mm}$, the developed system can operate because of stable voltage by both RFID tags for power supply and the amplifier circuit.

4.2 Experiments for evaluation in actual environmental conditions
4.2.1 Experimental overview
It is necessary to evaluate the possibility that the developed system can work stably in an actual environment, which includes measurement through the covered materials. The assuming situation is to hold the reader module over a typical wall; the RFID sensor modules are present inside the wall. In this section, we configure situations of several covering materials inserted between reader modules and RFID sensor modules, and perform experiments to evaluate the developed system's function.
4.2.2 Experimental equipment
The equipment for experiments is shown in Figure 13. The reader module is located in parallel opposite the RFID sensor module. The experiments are carried out in identical conditions (Figures 8-10). The loadings are added to the equipment by 10 N steps from 0 to 200 N.

4.2.3 Experimental methods
Various covering materials are used: concrete, plaster board, flexible, board, silicate calcium board, blockboard, and polystyrene. These materials are often present in typical walls. The materials' thicknesses are all set to 20 mm. Therefore, the distance between reader modules and sensor modules is fixed at 20 mm.

4.2.4 Results
The experimental results of using each covering material are portrayed in Figure 14. The theoretical values obtained by Equation (9) are shown as a continuous line on each figure. The $m$ represents the mean squared error, as in previous experiments.

4.3 Summary of results
In this section, the performance and stability of the developed system are evaluated. The system can measure the internal loadings of the structure by $L = 32.5$ mm without covering materials. When covering materials are inserted and $L = 20$ mm, the measurement can be carried out. For details, when $L$ increase from $L = 2.5$ mm to $L = 32.5$ mm. The measuring error also increased from 1 to 13 percent for the set measurement range. Within the range of $L < 30$ mm, it is possible to measure with strain resolution from $10 \times 10^{-6}$ to $40 \times 10^{-6}$. Although the ADC in the RFID sensor tag module has eight bit memory and 1/256 resolution performance of measurement range, the result of the range actually remains at a low level. It is considered that around over $L = 30$ mm is the limited for the power supply depending on the device specific characteristics. In addition, regarding the experiment with covering materials, the performance is evaluated toward use in an actual environment. The reason for differences of the mean squared error $m$ on each material is considered that the transmission factors and fluctuations of power supply are different.

5. Conclusion
For this study, we developed a force sensor system for structural health monitoring. Using an RFID, the system can measure the internal load of structural objects without contact. Additionally, we carried out an experiment through several covering materials that are assumed to be used in actual situations. To solve dissipation power problems, we proposed a simple idea: the separation of the RFID module to power supply and communications. Through circuit design for low electric power consumption, force sensing is realized on the conditions assumed for actual situations. The developed system can also be configured using commercially available and inexpensive devices. Regarding evaluations of developed system, it enables measurement of the forces with maximum distance of $L = 32.5$ mm In $L < 30.0$ mm. We confirmed the effectiveness of the proposed system, which enables measurement within $10 \times 10^{-6}$ to $40 \times 10^{-6}$ resolution performances, transmitting through covering materials that are used in actual building structures.
Figure 14 Experiments in actual environmental conditions

References
Further reading

Appendix: RFID devices used
The RFID tags and RFID reader/writer (RX5300; Yoshikawa RF Systems Co., Ltd. products) devices enable contactless communication with ADC function. The basic specifications are presented in Tables AI and AII.

Table AI Specifications of RFID tags

<table>
<thead>
<tr>
<th>Characteristics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiving</td>
<td></td>
</tr>
<tr>
<td>Center frequency</td>
<td>13.56 MHz</td>
</tr>
<tr>
<td>Modulation method</td>
<td>ASK</td>
</tr>
<tr>
<td>Coding method</td>
<td>PPM</td>
</tr>
<tr>
<td>Subcarrier</td>
<td>None</td>
</tr>
<tr>
<td>Communication rate</td>
<td>26.48 kbps</td>
</tr>
<tr>
<td>Transmitting</td>
<td></td>
</tr>
<tr>
<td>Center frequency</td>
<td>13.56 MHz</td>
</tr>
<tr>
<td>Modulation method</td>
<td>ASK of subcarrier</td>
</tr>
<tr>
<td>Coding method</td>
<td>Manchester</td>
</tr>
<tr>
<td>Subcarrier</td>
<td>423.75 kHz</td>
</tr>
<tr>
<td>Communication rate</td>
<td>26.48kbps</td>
</tr>
<tr>
<td>Available power</td>
<td></td>
</tr>
<tr>
<td>Supply</td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>2.2 V</td>
</tr>
<tr>
<td>Electrical power</td>
<td>4.4 mW</td>
</tr>
</tbody>
</table>

Table AII Specifications of RFID reader/writer

<table>
<thead>
<tr>
<th>Interface of computers</th>
<th>USB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna shapes</td>
<td></td>
</tr>
<tr>
<td>External diameter</td>
<td>40.0 × 70.0</td>
</tr>
<tr>
<td>Internal diameter</td>
<td>34.5 × 63.5</td>
</tr>
<tr>
<td>Antenna output</td>
<td></td>
</tr>
<tr>
<td>Number of turns</td>
<td>Four</td>
</tr>
<tr>
<td>Maximum</td>
<td>100 mW</td>
</tr>
</tbody>
</table>

Corresponding author
Yusuke Ikemoto can be contacted at: ikemoto@race.u-tokyo.ac.jp

To purchase reprints of this article please e-mail: reprints@emeraldinsight.com
Or visit our web site for further details: www.emeraldinsight.com/reprints
Author guidelines

Sensor Review

Copyright
Articles submitted to the journal should be original contributions and should not be under consideration for publication in any other periodical. At the same time, authors, submitting articles for publication warrant that the work is not an infringement of any copyright or other exclusive right. Authors must assign or transfer the copyright in their papers to the publisher against any breach of such warranty. For ease of dissemination and to ensure proper policing of use, papers and contributions become the legal copyright of the publisher unless otherwise agreed. Copyright is assigned through the use of a digital signature as part of the submission process in Manuscript Central.

The Editor
Dr. Clive Leigh, 52 Old Lane, Low Mill Village, Addingham, Ilkley, West Yorkshire LS29 5SA, UK.
Tel: +44 1932 873 350
Fax: +44 1932 873 866
E-mail: CliveLeigh91@ealingengineeringlist.com

Editorial objectives
Sensor Review provides up-to-date coverage of international articles that relate to the design and application of sensors and sensor systems. Coverage is essentially of a practical nature and designed to be of material benefit to those working in the field. Review papers are commissioned together with company news and new product information.

The journal also includes a substantial section reserved for "research articles". These will be selected by the Guest Solicitor who is an international authority on the theme for that issue and (s)he will commission typically four research articles from academic and commercial research centres. These articles will reflect the most interesting and strategically important research and development in this field.

Although typically academic in content than other articles in the journal, editorial considerations and academic standards in presentation and publication potential as rigorous academic analysis. This will ensure that the research articles remain accessible to all subscribers regardless of their particular areas of expertise.

The reviewing process
Each paper is reviewed by the Editors and, if it is judged suitable for this publication, it is then sent to two referees for double blind peer review. Based on their recommendations, the Editor then decides whether the paper should be accepted as is, accepted with revisions, or rejected. The Editor may make use of iThenticate software for checking the originality of submissions received.

Emerald Editorial Service
The Editorial Team can recommend the services of a number of freelance copy editors, all themselves experienced authors, to contributors who wish to improve the standard of English in their paper before submission. This is particularly useful for those whose first language is not English. Please see www.emeraldinsight.com/editorservice for further details.

Submissions process
Submissions to Sensor Review are made using Manuscript Central. Emerald’s online submission and peer review system. Registration and access is available at https://mc.manuscriptcentral.com/sr Full information and guidance on using Manuscript Central is available at the Emerald Manuscript Central Support Centre: http://msc.emeraldinsight.com

Registering on Manuscript Central
If you have not yet registered on Manuscript Central, please follow the instructions below:

- Please log on to http://mc.manuscriptcentral.com/sr
- Click on the Register button
- Follow the on-screen instructions, filling in the requested details before proceeding

Your username will be your e-mail address and you have to input a password of at least eight characters in length and containing two or more numbers

Click "Finish" and your account has been created.

Submitting an article to Sensor Review on Manuscript Central

- Please log on to Sensor Review at http://mc.manuscriptcentral.com/sr with your username and password. This will take you through to the Welcome page
- (To consult the Author Guidelines for this journal, click on the Home Page link in the Resources column)
- Click on the Author Centre button
- Click on the submit a manuscript link which will take you through to the Manuscript submission page
- Complete all fields and browse to upload your article
- When all required sections are completed, preview your pdf proof
- Submit your manuscript.

Manuscript requirements
The manuscript should be considered to be the definitive version of the article and should be in MS Word format, in single line spacing to conserve paper during the refereeing and layout phases. Good typographical layout and presentation of all figures and tables should be provided. All manuscripts should be run through a UK English spell checker prior to submission.

As a guideline, articles should be approximately 2,000 and 4,000 words in length. A title of not more than eight words should be provided. A brief autobiographical note should also be supplied including full name, affiliation, e-mail address and full international contact details. Authors must supply a structured abstract set out under the following headings: Purpose, Design/methodology/approach, Findings, Research limitations/implications (if applicable); Practical implications (if applicable); and Originality/value of the paper. Maximum is 250 words in total. In addition, authors should keep to six key points to illustrate the principal ideas of the paper and categorize your paper under one of these classifications: Research paper, Viewpoint, Technical paper, Conceptual paper, Case study, literature review or General review. For more information and guidance on structured abstracts visit: www.emeraldsight.com/structuredabstracts

Notes or Endnotes should be used if absolutely necessary but must be identified in the text by consecutive numbers, enclosed in square brackets and listed at the end of the article.

Figures should be supplied within the article itself. All figures (charts, diagrams, line drawings and photographic images) should be submitted in electronic form. Figure should be in clear quality and numbered consecutively with Arabic numerals. Graphics may be supplied in colour to facilitate their appearance in colour on the online database. Figures created to MS Word should be in black and white. An abstractor and Freehand should be saved in their native formats. Electronic figures created in other applications should be copied from the origination software and pasted into a blank MS Word document or saved and imported into an MS Word document by choosing "Insert" from the menu bar, "Picture" from the drop-down menu and selecting "From File..." to select the graphic to be imported. For figures which cannot be supplied in MS Word, acceptable standard image formats are: .pdf, .ai, .wmf and .eps. If you are unable to supply graphics in these formats then please ensure they are .tif, .jpeg, or .jpg at a resolution of at least 300dpi and at least 10cm wide.

To prepare screenshots, simultaneously press the "Alt" and "Print Screen" keys on the keyboard, open a blank Microsoft Word document and simultaneously press "Ctrl" and "V" to paste the image. (Capture all the contents/windows on the computer screen to paste into MS Word, by simultaneously pressing "Ctrl" and "Print Screen")

For photographic images good quality original photographs should be submitted. If supplied electronically they should be saved as .tif or .jpeg files at a resolution of at least 300dpi and at least 10cm wide. Digital camera settings should be set at the highest resolution/quality possible.

In the text of the paper the preferred position of all tables and figures should be indicated by typing on a separate line the words "Table 1 (Figure 1b)". Tables should be typed and included as part of the manuscript. They should not be submitted as graphic elements. Supply succinct and clear captions for all tables, figures and panels. Ensure that tables and figures (including in the text) include a reference to the figure/table superscripts shown, both next to the relevant items and with the corresponding explanations or levels of significance shown as superscripts to letter or number references. References to other publications must be in the Harvard style and carefully checked for completeness, accuracy and consistency. This is very important and necessary in an electronic environment because it enables your readers to exploit the Reference Linking facility on the database and link back to the works you have cited through CrossRef. You should give all author names and titles and give any journal title in full.

You should cite publications in the text as follows: using the author’s name, e.g. (Adams, 2006); citing both names if there are two authors, e.g. (Adams and Brown, 2006); or, if necessary (Adams et al., 2006) when there are three or more authors. At the end of the paper a reference list in alphabetical order should be supplied:

- For books: surname, initials (year), title of book, publisher, place of publication
- For book chapters: surname, initials (year), "chapter title" (writings), editor’s surname, editor’s initials (Ed.), title of book, publisher, place of publication
- For journal articles: surname, initials (year), "article title", journal name, volume, number, pages.
- For conferences: initials (year), "paper title", paper presented at conference, place of conference.

- For a published conference proceedings: initials (year), "paper title", in initials (Ed.), title of proceedings which probably published. The proceedings may be published out of date, in a conference or similar source.

- For working papers: surname, initials (year), "paper title", working paper number (if available), institution or organisation, place of organisation, date.

- For encyclopedia entries: (with no author or editor) title of encyclopedia (year), "title of entry", volume, title of encyclopedia, publisher, place of publication, pages.


- For web sites: surname, initials (year), "web page title", web page, organisation, date.

- For television program: surname, initials (year), "tv program title", organisation, date.

- For newspaper articles: surname, initials (year), "article title", newspaper, date, pages.

- For electronic sources: e.g. if available online the full URL should be supplied at the end of the reference, as well as a date that the website was accessed. E.g.iksby, h. (2005). "Introduction to web services for remote portlets", available at: www.123.fan.de/develop/workshops/library/ws-erw (accessed 12 November, 2007).

- For stand-alone software: i.e. on whom installed or should be installed within other software, would be supplied to illustrate the principal ideas of the paper and categorize your paper under one of these classifications: Research paper, Viewpoint, Technical paper, Conceptual paper, Case study, literature review or General review. For more information and guidance on structured abstracts visit: www.emeraldsight.com/structuredabstracts

Notes or Endnotes should be used if absolutely necessary but must be identified in the text by consecutive numbers, enclosed in square brackets and listed at the end of the article.
Authors’ Charter

This highlights some of the main points of our Authors’ Charter. For the full version visit:
www.emeraldinsight.com/charter

Your rights as an author

Emerald believes that as an author you have the right to expect your publisher to deliver:

• An efficient and courteous publishing service at all times
• Prompt acknowledgement of correspondence and manuscripts received at Emerald
• Prompt notification of publication details
• A high professional standard of accuracy and clarity of presentation
• A complimentary journal issue in which your article appeared
• Article reprints
• A premium service for permission and reprint requests
• Your moral rights as an author.

Emerald represents and protects moral rights as follows:

• To be acknowledged as the author of your work and receive due respect and credit for it
• To be able to object to derogatory treatment of your work
• Not to have your work plagiarized by others.

The Emerald Literati Network

The Emerald Literati Network is a unique service for authors which provides an international network of scholars and practitioners who write for our publications. Membership is a free and unique service for authors. It provides:

• A dedicated area of the Emerald web site for authors
• Resources and support in publishing your research
• Free registration of yourself and your work, and access to the details of potential research partners in Emerald Research Connections
• The opportunity to post and receive relevant Calls for Papers
• Information on publishing developments
• Awards for outstanding scholarship
• Usage information on authors, themes, titles and regions
• Access to tips and tools on how to further promote your work
• Awards for Excellence.

To discuss any aspect of this Charter please contact:

Emerald Literati Network, Emerald Group Publishing Limited, Howard House, Wagon Lane,
Bingley BD16 1WA, United Kingdom
Telephone +44 (0)1274 777700
E-mail: literatinetwork@emeraldinsight.com

The world's leading publisher of management journals and databases