# Wireless Link Design for Contactless Smart Cards

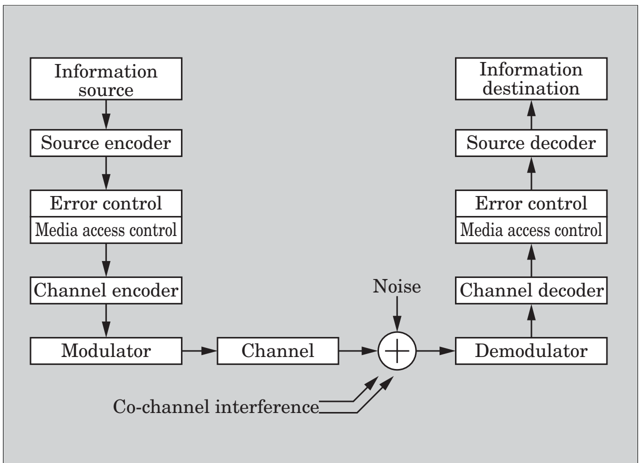
**Shiro Kondo**
**Tatsuyuki Shikura**

## 1. Introduction

Fuji Electric has a history of working to develop short-range wireless communications which can operate with relatively low power such as specified low power radios and high-frequency equipment. Although these wireless devices are convenient because wireless licenses are not required, their use often leads to problems since adequate link quality is not guaranteed. In response to this problem, through research into the concept of a wireless system that takes into consideration the characteristics of wireless channels and information, Fuji Electric has succeeded in the practical use of wireless devices. Contactless smart cards have experienced an especially dramatic increase in wireless applications in recent years, and various reader-writer (RW) devices have been commercialized for use with Sony Corporation's FeliCa card which exhibits the excellent characteristics of high speed and high security.

This paper focuses on the wireless communications technologies of contactless smart cards and describes relevant technical points and Fuji Electric's activities in this field.

Fig.1 Wireless link model




## 2. Wireless Link Design for Contactless Smart Card Systems

### 2.1 Wireless link model

The portion of a wireless system that transmits digitized information from an information source to an information destination can generally be modeled as shown in Fig. 1. Many various methods have been proposed for the modulator, encoder and other systems of Fig. 1, and this is a consequence of supporting the many various properties of information to be transmit and characteristics of the communication channels.

A contactless smart card system handles information in the form of digital data, typically electronic money information, and the handling of this information must be totally error-free. Moreover, the communication range $d$ is on the order of ten and several of centimeters, the carrier frequency wavelength is approximately 2.2 m (frequency of 13.56 MHz) and the relationship of $d < \lambda / 2\pi$ must be maintained. This is

Fig.2 Operating principles

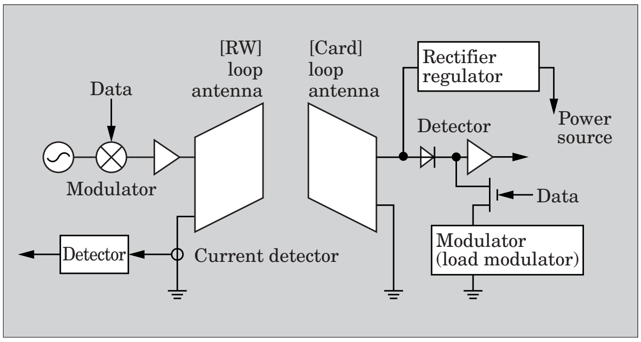



Table 1 Specification of physical and data link layers

| Item | | Specification |
|---|---|---|
| Carrier frequency | | 13.56 MHz |
| Modulation method | RW → card | ASK (approx. 10 % modulation) |
| | Card → RW | LM (load modulation) |
| Data rate | | 211.875 kbits/s |
| Bit coding | | Manchester |
| Error control | | FCS-based error detection + ARQ (auto repeat request) |

because the communication uses induction coupling, and due to various factors, fluctuation in one characteristic (for example, antenna impedance), will affect the performance of the system.

### 2.2 Principles of RW operation

Figure 2 shows principles of RW device operation. First of all, since the smart card does not have its own power supply, the RW supplies power to the card while communicating with it. While the RW and card loop antenna (card antenna) are in an inductively coupled state, the RW supplies power to the card via a 13.56 MHz carrier wave. At the same time, in the case where data is to be transmitted from the RW to the card, the RW transmits approximately 10 % modulated ASK (amplitude shift keying) signal. The card detects that signal and converts it into data. Conversely, in the case where data is to be transmitted from the card to the RW, while the card is receiving continuous wave signals from the RW, the card switches its own impedance of the antenna in accordance with data stream to be transmitted. The RW detects this load switching as fluctuations in the voltage and current of its own loop antenna (RW antenna), and then demodulates the data.

Main specifications of the FeliCa physical layer and data link layer are listed in Table 1.

## 3. Challenges for Contactless Smart Card Communications

### 3.1 Required link quality and error control

The link quality and error control to realize error-free operation are described below. Strong error correcting techniques have been commonly applied in recent years in order to achieve error-free operation, however, since a contactless smart card system has a packet length of several hundred bits, the effectiveness of error correction is thought to be rather limited when there are only random errors.

Therefore, if a relatively good bit error rate can be guaranteed, a method that combines a low redundancy error correcting code with an auto-repeat request (ARQ) function is believed to be more suitable than the use of an error correcting code having poor encoding efficiency. In accordance with this belief, FeliCa uses ARQs to remedy errors.

With this method, however, it is known that if the bit error rate of the link deteriorates, then the number of ARQs will increase and the packet success rate will suddenly drop. In the case where the packet length is 256 bits and ARQs are implemented twice, a link is required to have a bit error rate of approximately $10^{-5}$ or better in order to achieve a packet error rate of $10^{-8}$. On the other hand, in order to obtain a bit error rate of $10^{-5}$ with ASK asynchronous detection, a SN ratio of approximately 15 dB is required, and the RW should be able to guarantee these target values.

### 3.2 Challenges

The key to realizing the targeted bit error rates as described above is the response to fluctuations in impedance and other characteristics that have been mentioned in section 2, and specifically the response to fluctuations in card characteristics and suitability to the RW installation environment. Although called a "contactless smart card," its shape leverages advantages not necessarily associated with cards and some commercialized devices feature a chip embedded in a wristband or watch. Moreover, the embedding of chips into cell phones is about to come into widespread practice. Because there are various media characteristics, Fuji Electric's RW devices are targeting general-purpose applications and the guarantee of interconnectivity is extremely important.

In an actual system, the design challenge is to provide the capabilities to simultaneously distinguish multiple cards and to suppress co-channel interference from multiple RW devices. The abovementioned challenges are summarized below.

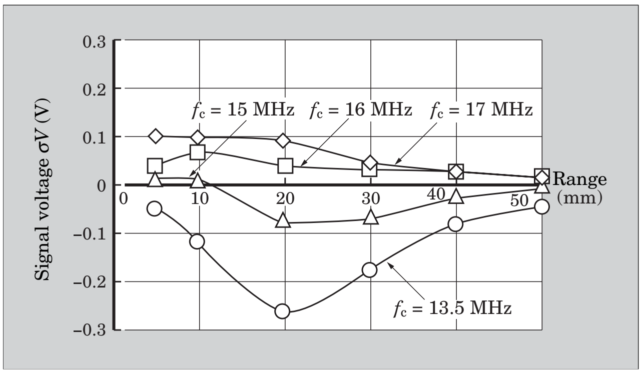
(1) Support of various types of media and suitability with the surrounding environment
(2) Simultaneous recognition of multiple cards (anti-collision mechanism)
(3) Suppression of co-channel interference from multiple RW devices

Efforts to overcome these challenges are described in detail below.

## 4. Technologies for Supporting Various Types of Media and Maintaining Suitability with the Surrounding Environment

Figure 3 shows one example of the influence of media characteristics on communications. The relationship between the card-to-RW distance and the strength of the signal voltage from the card to the RW device is shown with card resonant frequency $f_c$ varied as a parameter. Several different card resonant frequencies are shown, and as can be seen, the characteristics differ dramatically when $f_c$ is different.

Fig.3 Relation between communication range and signal voltage



Moreover, in examining the characteristics for the case where $f_c$ = 15 MHz, it can be seen that the signal voltage crosses zero at a distance of approximately 10 mm. This is a dead point (null point) and indicates that communication is not possible even though the card is within the communication range of the RW device.

Figure 4 is an analysis of the effect on the impedance of the RW antenna when that antenna is installed in close proximity to a metal plate. It is understood that the flow of eddy currents in the metal plate cause the self-inductance component to decrease and the resonant frequency to shift toward a higher frequency.

Fig.4 Influence of a metal plate

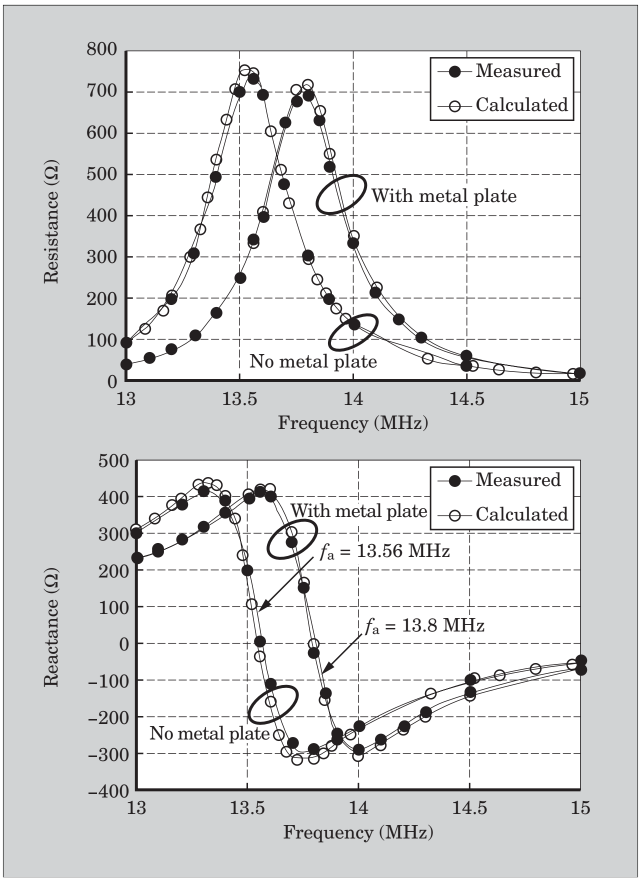
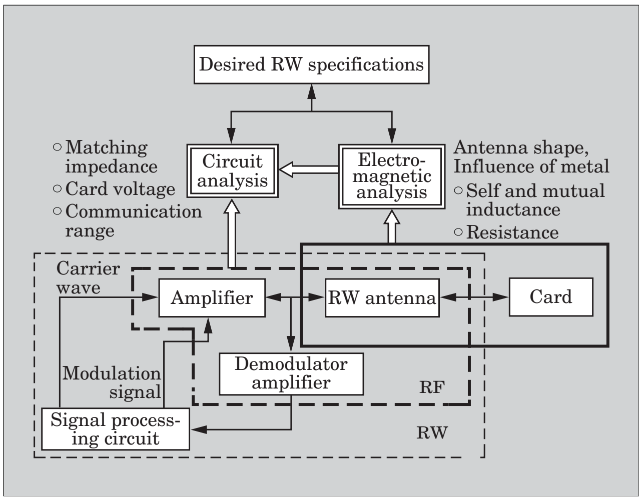



Fig.5 Hybrid analysis technique




As described above, media characteristics in the surrounding environment have a large effect on the communication performance. Therefore, when installing a RW device on the front of an automated vending machine, for example, the parameters must be optimized for those installation conditions. To increase the efficiency of the development and design work, Fuji Electric has developed a hybrid analysis technique as shown in Fig. 5 that combines electromagnetic analysis and circuit analysis. Specifically, a high frequency electromagnetic analysis program capable of analyzing both wire antennas and planar antennas is used to analyze the self and mutual inductance, resistance and other constants of the RW device and card antenna with consideration of the effects from metal and the like. Meanwhile, the abovementioned constants are imported into a circuit analysis where RW characteristics such as the communication range and matching impedance are analyzed. As a result, the characteristics can be predicted and the shape of the RW antenna can be optimized prior to building a prototype.

These technologies have been applied to develop the RW device shown in external view in Fig. 6. Figure 7 shows the relationship between the communication range and card frequency for this RW device. The prototype card shown in the figure is for evalua-

Fig.6 External view of RW device

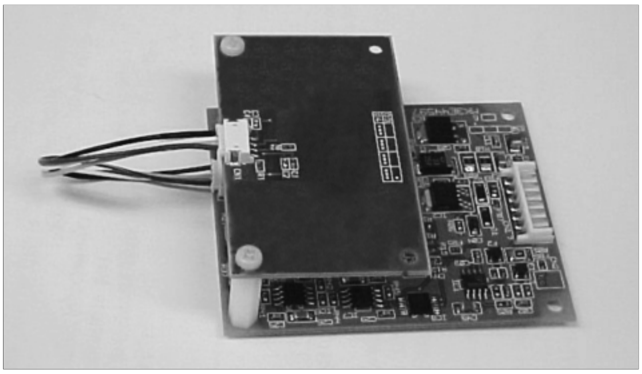
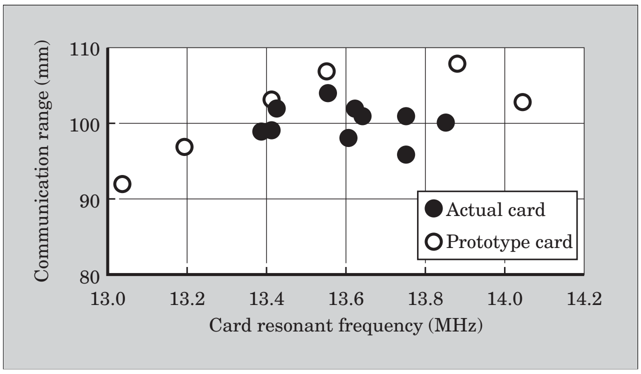


Fig.7 RW communication range



tion purposes and is configured from a card antenna and chip that enable the card frequency to be varied. A communication range of 90 mm or more was realized over a wide range of card frequencies. In addition, constants were optimized to achieve communication without any dead points and the design has minimized the number of locations for adjustment so that when installed in another machine, adjustments may be performed easily according to that installation environment.

## 5. Simultaneous Recognition of Multiple Cards

In contactless smart card communication, the capability to simultaneously recognize multiple cards is essential and there are basically two techniques which provide this capability.

The first solution is an anti-collision technique in which the card ID is acquired by a slotted ALOHA procedure.

The second technique solves the problem of the large fluctuation in characteristics caused by mutual coupling that occurs when there is overlap from multiple cards. Accordingly, schemes have been proposed for $f_c$ and the antenna known as an anti-collision card, and the optimal RW design that supports these characteristics can be realized by applying the analysis techniques described in section 4.

## 6. Inter-RW Interference

Figure 8 shows an example of a practical application in which a contactless wristband is used to control the opening and closing of locks on locker doors. Because a lot of RW devices are installed in close proximity to one another, there is the possibility that the electromagnetic field generated by one RW device may effect to other RW devices.

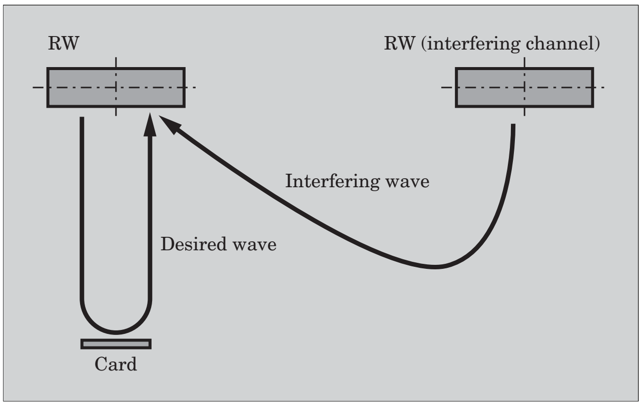
Figure 9 shows a model of the interference between RW devices. Here, the effect of inter-RW interference is greatest when one RW device is receiving a signal from a card while adjacent RWs are simultaneously generating downlink signals. The downlink signals from an RW device are either unmodulated or ASK modulated.

In the case of an unmodulated signal, if the desired channel and interference channel have different carrier frequencies, cross modulation will occur at the detector circuit and the phenomenon of beating will appear. In an actual RW device, however, the carrier frequency tolerance is suppressed to approximately 50 ppm and therefore the beat frequency will only be several hundred Hz at most. Moreover, by encoding the bits in a Manchester encoding scheme, the receiver will cut low frequencies and unmodulated signals will not actually be a significant problem.

On the other hand, in the case of ASK modulated signals, the overlap between the frequency bandwidth

Fig.8 Locker system

Fig.9 Inter-RW interference model




of the interference signal and the frequency bandwidth of the desired wave is potentially troublesome. In this case, no matter how much the signal output level is raised to improve its SN ratio, the bit error rate will show almost no improvement and therefore it will be necessary to implement such measures as redesigning the RW device in order to lower the interference power, employing controls to avoid the simultaneous operation of adjacent RW devices and so on. However, these measures will have the undesirable effect of degrading the responsiveness to cards, and therefore in the above example, the design has optimized to meet these challenges.

## 7. Conclusion

Focusing on the wireless communication of contactless smart cards which are soon be put into practical applications, this paper has presented key technologies for the interconnectivity of cards and RW devices and for application to systems. Fuji Electric will continue to improve these RW technologies and to promote further development of contactless smart cards.

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