Development of a Data Transmission Method using a Hybrid Signal Generated by Analog and Digital Signals

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The IC card is widely used in various public systems such as in credit cards, electronic wallet systems, and card locking systems. Therefore, an integrated card (multifunction card) adapted to various utilization scenarios has been developed. The numerically functionalized device requires a large data capacity and large-volume data communication. Enhancement of the numerical functionalization may lead to an increase in the data transmission time, inconveniencing users in the near future. In this paper, we propose a data transmission method using both analog and digital signals. This method utilizes a synthesis signal called a Hybrid-signal generated electrically from an analog and digital signal, using a signal addition circuit. We have developed a prototype system using the Hybrid-signal and performed data communication experiments. The experimental results of the prototype system suggest that the Hybrid-signal can simultaneously transmit both analog and digital information.

Key Words: IC card, Hybrid-signal, synthesizing information, analog waveform, digital signal

1. INTRODUCTION

The IC card system is widely used in various aspects of our life, for example, in credit card systems, electronic wallet systems for various stores such as Edy or QUICPay [1, 2], card locking systems such as smart keys for automobiles, and many other public systems. Therefore, an integrated card (multifunction card) adapted for each utility is developed. SUICA [3] was developed for the electronic passenger-ticket settlement system. However, it was also used as an electronic wallet card. The numerically functionalized device requires a large data capacity and large-volume data communication. The enhancement of numerical functionalization may lead to an increase in the data transmission time and inconvenience the users. Generally, the data transmission system in IC cards uses a digital transmission protocol determined by the IC card communication standard [4, 5]. The protocol is enabled to adapt to a request for high-speed communication to a certain extent, within the IC card communication standard [4, 5]. However, sufficient capacity may not be available in the near future.

On the other hand, in other fields, two-dimensional bar codes “QR codes” [6, 7] have large data volumes compared to the conventional bar codes. Further, QR codes have many other advantages. They need less recorded area than the conventional bar codes, have a good readability, and can correct a read error. Besides realizing large capacities, they have useful additional functions. The development of a new type of transmission protocol for the IC card system can be highly beneficial for many users.

Currently, the analog data communication method is not widely used because the analog system is easily influenced by external noise and attenuation compared to the digital communication method. The analog signal is continuous and the information to be transmitted is the existing analog waveform. Therefore, the analog signal can transmit a high density of information. Several types of microprocessors with both analog and digital circuits have been developed because information is analog by nature. Based on the above, if a new type of transmission protocol using both analog and digital signals can be developed, it can solve the problems of data capacity and can enhance the IC card system. Additionally, the enhanced system can also promote the usage of the IC card system in various other social fields and products.

In this paper, we propose a data transmission method using both analog and digital signals. Figure 1 shows an outline of the proposed method. This method uses a synthesis signal (hereafter, called as Hybrid-signal) for the data communication system. The Hybrid-signal is electrically generated from an analog and digital signal by using a signal addition circuit. Each signal (analog and digital) contains the respective information. Therefore, this method can simultaneously transmit analog and digital information. Additional information utilizing signal combinations can also be included in the hybrid-signal. The Power Line Communication (PLC [8]) system is as example of the application of synthetic signal communication. The aim of the PLC is to use common lines for power supply and data communication. Therefore, the PLC system is technically different from our method.

This paper consists of five sections. The background and purpose of this study are described in Section 1. Section 2 explains the definition and utilization methods of the Hybrid-signal. Section 3 elucidates the details of the prototype device that transmits and receives the hybrid-signal. Section 4 describes the two types of data communication experiments, and evaluation of the communication
quality in consideration of general knowledge regarding digital communication methods. Section 5 summarizes the results of this study.

2 HYBRID-SIGNAL

2.1 Definition of Hybrid-signal

In this paper, Hybrid-signal refers to a mixed signal that consists of a digital and an analog signal generated using a signal addition circuit as shown in Figure 1. The analog and the digital signals are generated from optional information sources. The Hybrid-signal contains the information of both the analog and the digital signals. The advantage of using the hybrid-signal is in the variety of combinations of the source signals that can be used. Additional information utilizing signal combinations can also be added to the Hybrid-signal. The details regarding the method for including additional information to the Hybrid-signals is described in the following section.

2.2 Utilization method for Hybrid-signals

Figure 2 shows the usage model of the Hybrid-signal. The analog signal is partially added onto the digital signal as shown in Figure 1. On the transmitter side, analog and digital signals are modulated by the composite information as listed in the look-up table, and both the signals are mixed by an addition circuit. We named the look-up table that defined the composite conditions of both the signals required to generate the Hybrid-signal as "composite table," displayed in Figure 3. Two kinds of parameters are required to generate the information added to the selectable Hybrid-signal. The composite range CR indicates the synthesizing part of the analog and the digital signals. The phase of the analog signal PD indicates the modulation pattern of the analog source. These two parameters are set in the composite table. The variables $i$ and $j$ represent the number of the CR and the PD. $A_{ij}$ is the additional information obtained by signal composition. Transceiver devices share the common table, and it can be used as transmit information other than that of the analog and the digital signals. Figure 4 displays an example of the result of simulating a Hybrid-signal generation circuit using the composite table. Bit converting operation is set to $A_{ij}$ as the additional information. A two bit invert operation is performed for input digital data in this simulation (see Figure 4 (b) and (c)). For this simulation, we used a Cadence design systems Inc. OrCAD Unison EE circuit simulator. The main components of the circuit model were a digital signal generator, an analog signal generator, an add circuit and a level converter. The digital signal was a 5 Vp-p, 9.6 kbps, 13 bit NRZ signal including the start and end bits. The analog signal was a sine wave cycle. The voltage of the sine wave was set to 0.4 Vp-p and the frequency was set to 4.8 kHz. The composite table was developed and four composite positions different from each other by $\pi/2$ and four composite positions different from each other by 2 bits. The composite table was set to a 4 x 4 size and it can be used to add 16 types of additional information to the Hybrid-signal. The additional information specified two invert bits for modulating the input digital data in this simulation.

3. DEVELOPMENT OF THE PROTOTYPE SYSTEM

3.1 System structure and specification

Figure 5 shows the outline of the prototype system. The prototype system consists of two pairs of transceivers and laptop computers as shown in Figure 5 (b). The two white boxes are the Hybrid-signal transceivers. The transceivers were connected by
The communication format of the digital signal was a thirteen bit NRZ (Non Return to Zero) signal that consists of one start bit (high level), eight data bits, and four end bits (low level). The communication speed of the digital signal was set to 19200 bps. The amplitude of the high level was set to 4.0 V in the prototype device. The analog signal was a sine wave that had a fixed amplitude and a fixed period. The amplitude of the sine signal was set to 1.0 Vp-p, and frequency of the sine wave was set to 4.8 kHz. One cycle of the analog signal has the same length as to two bits of the composite digital signal. One cycle of a low amplitude sine wave was synthesized on a part of the digital signal in an addition process similar to the one used in the simulation in Figure 4 (see section 2.2). The composite position \( C_{R_i} \) and the phase of analog signal \( P_{D_j} \) are determined on the basis of the additional information \( A_{i,j} \) in the composite table. The details of the composite table and the selection process of the \( A_{i,j} \) are described in section 3.3.

### 3.2 Details of the transceiver device

Figure 6 shows the internal components of the Hybrid-signal transceiver. The main components are a one-chip micro controller: Renesas electronics Corp. M30291 [9], a direct digital synthesizer IC: Analog devices Inc. AD9833 [10], an adding circuit, and a filter circuit. AD9833 was connected to M30291 through a SPI (Serial Communication Interface) bus and received information for generating the analog waveform. The addition circuit was constructed using Texas Instruments Inc. LMC 660 and LMC 662 [11, 12] operation amplifiers. The data receiver interface was composed of a noise filter circuit and 1-channel A/D converter built in the M30291. The sampling frequency of the A/D port was set to a maximum speed of 153.6 kHz in order to receive the Hybrid-signal waveforms as clear as possible.

### 3.3 Composite table for the prototype system

Figure 7 shows the 4×4 sized composite table that was generated for the prototype device. The 4×4 size composite table has sixteen types of \( A_{i,j} \) similar to the circuit simulation in section 2.2. The composite table for the prototype device also has the same parameters as that of table used for the simulation in section 2.2: four phases different from each other by \( \pi/2 \) and four composite positions different from each other by two bits. The additional information specifies sixteen types of two-bit invert operations for the digital data before performing the composite process: invert the two bits of the transmitting digital data as listed in Figure 7. The control information was input by the laptop computer with an input interface function. \( A_{i,j} \) could be chosen randomly or optimally.

### 4 EXPERIMENT AND RESULT

#### 4.1 Data communication experiment

In order to confirm the propriety of the prototype system, we performed a communication experiment using the Hybrid-signal. Figure 8 depicts the flow of the experiment and the communication process used in the experiment. Experiment 1 was performed for confirming the proposed method with the process shown in Figure 8 (a). The transmission data consisted of fifty-two alphabetical characters (i.e., twenty-six uppercase characters, A–Z and twenty-six lowercase characters, a–z) represented in ASCII code. We transmitted the fifty-two character ASCII data one character at a time and the number of the times of one character was transmitted was 10 times per \( A_{i,j} \). Therefore, the total of transmitted data was 8320 (52 types of characters × 10 times × 16 composite patterns = 8320). We evaluated the success or failure of the Hybrid-signal...
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communication from the received data observations. When the transmitted character and analog waveform were received correctly, it was judged that the Hybrid-signal communication has succeeded. Further, we observed the Hybrid-signals on the transmission line to investigate the cause of the communication failure. We checked the noise and distortion of the transmitted waveform for both the successful as well as the failed case.

Figure 8 (b) shows the flow of experiment 2. In this experiment, we transmitted the same character (‘s’) 100 times, continuously. We checked the received data logs to confirm the generation and recognition of the sixteen types of Hybrid-signals. The composite pattern was selected using the random function “rand ()” built in the C programing language. The Hybrid-signal waveforms were observed for investigating the cause of the communication failures in experiment 1.

In this paper, we did not include a retransmission request function in our prototype system to check the cause of the communication failure mentioned above.

4.2 Experimental results

Table 1 summarizes the result of experiment 1. The experimental results established that the prototype system can communicate using the Hybrid-signal and the error rate was 0.9% in total. All the transmitted codes for thirteen patterns of composite table were received successfully. The other three patterns AI32, AI33, and AI34 had failed in several communications. The success rate was over 93% in these three patterns. The communication accuracy of the prototype system was low in comparison with the BER (Bit Error Rate) of general knowledge regarding digital communication methods [13]. However, bit errors in the digital signal did not occur and all the Hybrid-signal communication errors were detected in this experiment. Therefore, the prototype system has a good communication accuracy considering that it did not have the retransition and error correction functions. The proposed prototype system demonstrated the applicability of Hybrid-signals in communication.

We investigated the occurrence factor of the communication
failure and checked the operating states of the prototype system. The prototype system worked normally throughout this experiment. We also checked the communication log of the receiving terminal and the waveform of the failed signals. Figure 9 shows the waveforms of both the successful and the failed cases, observed at the receiver device. It was found that the waveform distortion occurred at the analog part of the Hybrid-signal in the failed cases as shown in Figure 9 (b). As already mentioned, the transmitter side worked normally throughout this experiment. The cause of the distortion was considered to be external noise. Hence, the sine wave that was modulated based on the composite table could not be recognized.

Figure 10 shows the distribution of the generation result of the Hybrid-signal communication in experiment 2. The Hybrid-signal waveforms of all the patterns selectable from the composite table was observed, and character ‘s’ was received correctly all 100 times. Waveform distortion did not occur in this experiment, even when the A13, A13, and A14 patterns of the Hybrid-signal were generated. The result shows that it is possible to receive the original information of the analog and digital signals accurately from the Hybrid-signals. The proposed method can generate different Hybrid-signal waveforms from the same analog and digital signals containing the same information. In contrast, the proposed method can also generate the same waveform from different original signals. Thus, this method can increase the confidentiality of the transmitted data by controlling the composite table.

5 CONCLUSION

In this paper, a data transmission method using a synthesis signal generated from analog and digital signals was proposed. Further, a prototype of the Hybrid-signal communication terminal was developed and two types of data communication experiments were performed to investigate the possibility and utility of the proposed method. The results obtained are as follows:

1. The experimental results demonstrated that the prototype system can communicate using the Hybrid-signal and it had an error rate of 0.9% in total.
2. The proposed prototype system illustrated the applicability of the Hybrid-signal for communication.
3. The proposed method can communicate the original information of the analog and digital signals through different Hybrid-signal waveforms controlled by the composite table, accurately.

In the future, we will develop a system that is more practical and continue to investigate useful synthesis methods and composite tables.

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