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EMG Sensor Integration Based on Two-Dimensional Communication

Yasutoshi Makino, Shuhei Ogawa and Hiroyuki Shinoda

***Abstract*—We have proposed a new communication technology called "Two-Dimensional Communication (2DC)" in our previous studies. The technology enables one to integrate sensor units on a flexible and stretchable sheet without individual wires. Electrical power is also supplied through the sheet to the sensor nodes in contact with it. This technology considered to be useful for room-size sensor network, wearable computing and so on. Last year, we proposed an electromyography-based man machine interface as a possible application of the 2DC. A myoelectric signal is the signal that can be detected when the muscle contraction occurs. One feature is that the myoelectric signals can be obtained before actual motions. Thus the system can predict motions of the fingers when the myoelectric signal pattern is measured on forearm. It is considered that a high-density electrode array is required for improving the accuracy of the motion estimation. Therefore, the 2DC technology is useful for integrating such a large number of the EMG sensor units without complicated wires. In this paper, we show how to connect sensors to the sheet efficiently without electrical contact. We also demonstrate how to send data and how to receive electricity with the single 2DC sheet. We adopt a time division multiplexing (TDM) method for reducing interferences. We show an electrical circuit for achieving TDM with low power consumption.**

***Index terms*- Electromyography (EMG), Man-Machine Interface, Two-Dimensional Communication.**

I. Introduction

MANY small sensors including accelerometers, magnetic sensors and strain gauges are recently available owing to the development of the MEMS and other relating technologies. There is no doubt that distributing such small sensors and gathering their data through a network gives a new function to conventional sensing techniques.

One of the important issues for integrating a large number of sensors is how to physically connect those sensors to a host machine. A most simple way for connecting them is to use cables such like USB or Ethernet. Or they can be connected with a wireless communication. In our previous works, we proposed another type of communication technology named "Two-Dimensional Communication (2DC)" [11]. In the 2DC system, signal energy propagates in a two dimensional medium named 2DC sheet. The sheet enables one to achieve both signal transmission to a host machine and power supply to the sensor nodes touching to it with microwave. Details are shown in Appendix A.

We have also proposed a new man-machine interface as a possible application of the 2DC [1]. The system was based on electromyography (EMG) as shown in Fig. 1. The sensor units that detect myoelectric signals are arrayed on the sheet surface. Measured EMG data is converted into high frequency signal which is sent to the host machine through the sheet. When the sheet is fabricated like a wrist-band shape as shown in the figure, the EMG data is obtained as two dimensional patterns. Therefore, the system requires no specific alignment for measurement. Since flexible and stretchable materials can be used for fabricating the 2DC sheet, we can wear the measurement system comfortably. The stretchability also ensures the steady contact between the electrodes and the skin surface. The contact impedance between them can be reduced. The system is useful not only for special situations such as medical fields but for our daily lives.

Because of the features mentioned above, following two practical advantages are expected.

1) Intuitive data input by natural finger motions is possible.
2) Response delays are reduced.

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Thus, the following applications are possible.

- An input interface for small devices such as mobile phones or PDAs.
- Operating artificial limbs.
- Inputting commands by one's behaviors for video games and etc.
- Recording behaviors of athletes by the myoelectric signals. The stored data are useful to know the motions and to teach the motions.

In our previous paper [6], we theoretically and experimentally showed that our sensing system could reduce common mode noises. Since the sensor units need no electrical contact for connecting with the 2DC sheet, they can be driven being isolated from ground potential. You can see brief summary in Appendix B.

In this paper, we show an efficient connector for the 2DC sheet. In our previous paper [12], we also reported that impedance between the sheet and the connector can be minimized using resonance without any electrical contact. The connector was designed so as to lessen the effects of sheet deformations, however, its performance was considerably influenced by them. An efficient connector independent on the sheet deformation is required. In this research, we show a configuration of connector that can receive electricity about ten times larger than our previous one. The connector couples with the directional mode of the microwave as well as the isotropic mode. Since the resonance for the directional mode is almost independent on the sheet deformation, the connector can receive practically enough electricity.

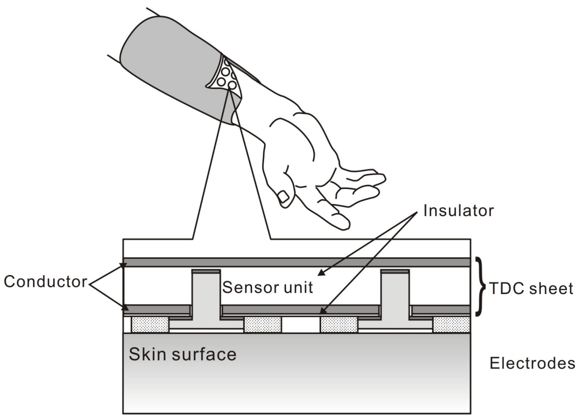


Fig. 1 Schematic diagram of the wristband-shaped electrode array for electromyography [1].

We also demonstrate how to send data to a host machine in the 2DC sheet. We adopt a time division multiplexing (TDM) method for reducing interferences among the sensor units. In our method, there are two stages. One is for power supply to every sensor on the sheet; the other is the stage for sequential signal transmission. Measured data is transmitted by PWM method with low power consuming electric circuit. We demonstrate that the PWM can be achieved by our proposed circuit and that the signals can be received at the side of the sheet.

II. Resonant Proximity Connector

A. Principle

In our previous studies, we reported "Resonant Proximity Connector (RPC)" for effective coupling between a sensor and the 2DC sheet [12]. When the total length of the electrode is designed to be $\lambda/4$ of the microwave, the connection can be seen as a short owing to its resonance. The resonance condition of the connector has weak dependence on the gap distance between the electrode and the conductive layers of the 2DC sheet. A notable characteristic is that it requires no electrical contact between them. The conductive layers can be covered with a thin insulating material so as to prevent them from oxidization.

Although the connector was designed for reducing the effect of the sheet deformation, the performance of the connector actually depended on it. The allowed deformation of the thickness for our previous system was practically smaller than 1 mm. When the deformation was larger than the limit, the reactance component of radiation impedance varied considerably. This made both communication and power supply difficult.

In this paper, we propose a new connector for efficient electricity reception. Figure 2 shows the connector with the four thin electrodes whose lengths are equal to $\lambda/4$ of the microwave respectively. The connector is used as shown in Fig.3 though the other two electrodes which are set perpendicular to the paper are not shown in the figure.

In order to illustrate the principle simply, we use the two-electrodes-based (I-shaped) model as shown in Fig.4. Here, we assume that only the two thin electrodes are set along x-direction. The difference from the previous connector is that the thin electrodes are straighten and arranged in opposite direction. In this case, the connector can couple with two different types of the resonant modes.

The one mode is shown in Fig.5 (a) that is the same one to the former connector used. The connector is seen as if it connects directly to the sheet near the base of the electrode. In this case, the connector can couple with the two-dimensionally isotropic mode of the microwave due to its symmetric property. We call this symmetric mode “mode A”.

The other mode is a directional mode (Fig 5 (b)). When a microwave propagates along x-direction, the resonance occurs as shown in the figure provided the total length of the two electrodes is equal to the half wavelength. While the resonance does not occur when a microwave comes along y-direction. This means the connector has the directivity. We call this directional mode “mode B”. One remarkable aspect is that the resonant frequency of mode B is almost independent on the sheet thickness. Even when the receivable energy relating to the mode A is lessened due to the sheet deformation, the coupling condition to the mode B suffers less change. The total directivity of the new connector is given as the superposition of the two modes. In our previous RPC, the energy relating to the mode B was not used.

When the two connectors are arranged so as to be orthogonal and their rectified electric power is connected serially, we can get electricity omnidirectionally. We fabricated four-electrodes type of the connector as shown in Fig.2.

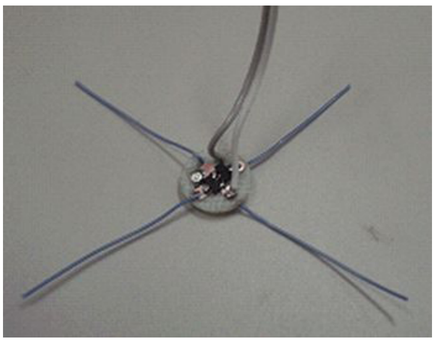


Fig. 2 . The new connector having four thin electrodes.

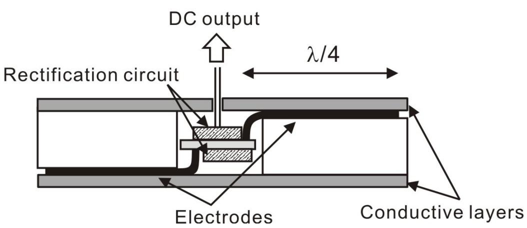


Fig. 3 . Cross section of the new connector.

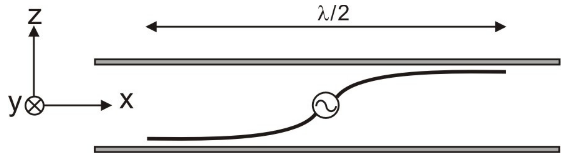


Fig. 4 Two-electrodes-based (I-shaped) model of the new connector

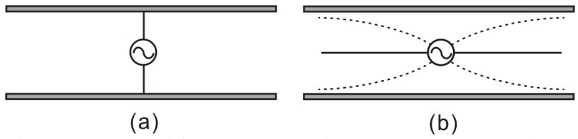


Fig.5 Two modes of the resonance on the connector. (a): Isotropic mode, (b): Directional mode.

B. Simulation

Figure 6 shows the simulation result of the new connector. In order to confirm the directivity of the connector, we modeled one directional (I-shaped) connector. The figure illustrates the electric field between two conductive layers. A microwave is supplied from the connector to the sheet. It shows that the microwave propagates two dimensionally in the sheet. Figure 7 (a) shows the averaged electric field and Fig.7 (b) plots the numerical data on the circle shown in Fig.7 (a). The directivity of the connector can be seen as is theoretically expected.

C. Experiments

We experimentally evaluated the principle. Figure 8 shows the flexible 2DC sheet whose conductive layers were composed of a conductive fabric. They were covered with a non-conductive cloth. There were nine connection apertures on the surface of the sheet. We measured the received electricity at each point with the new connector (X-shaped connector), the one directional connector (I-shaped connector) and our previously proposed connector.

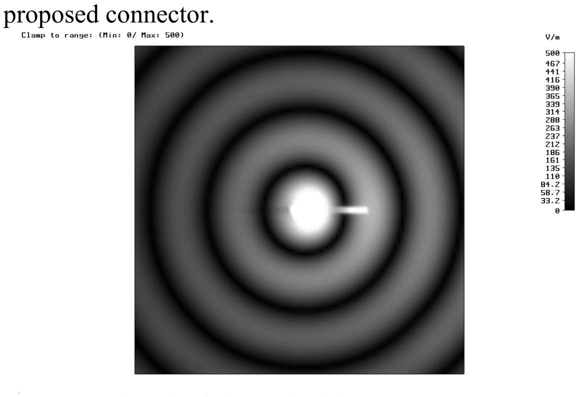
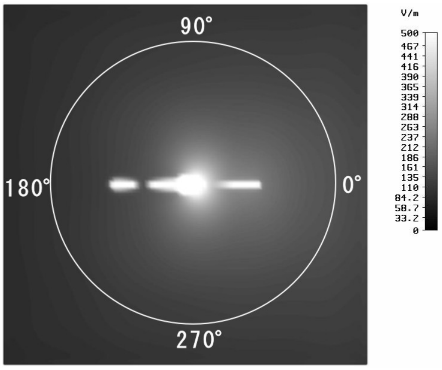
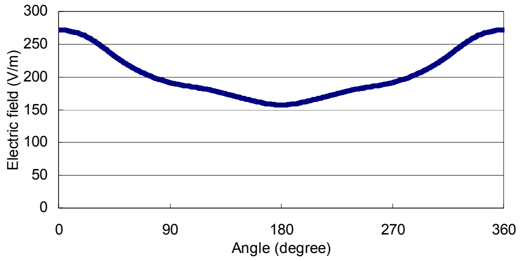


Fig.6 Simulation result of the new connector.



(a)



(b)

Fig.7 (a): Averaged electric field of Fig. 6. (b): the numerical data on the circle in (a)

Figure 9 shows the result. The horizontal axis shows the position number of the sheet (given in Fig.8) and the vertical axis represents the electricity on a logarithmic scale. We supplied 10 W of electric power of a microwave to the sheet. It is obvious that the received electricity with the new X-shaped connector is larger than the other two except the position 6. The averaged receivable electric power was 577 mW with the X-shaped connector, while it was 243 mW with the I-shaped connector and it was 8 mW with our previous one. This shows the coupling to the directional mode is effective for efficient power reception.

Figure 10 shows the variation of the received electricity depending on the sheet deformation. We pressed the sheet above the connector with a flat surface. The horizontal axis shows the compressed distance from the stationary position and the vertical axis indicates the received electricity on a logarithmic scale. The averaged received electricity with the new connector was 256 mW, while it was 23.6 mW with the previous one. Regarding the ratio R of the variance to the received power, R of the X-shaped connector is smaller than that of the previous one.

Fig.8 Textile 2DC sheet. Each number denotes the position.

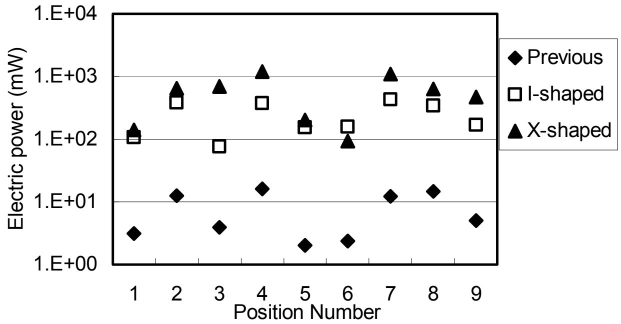


Fig.9 Received electric power with three types of connectors.

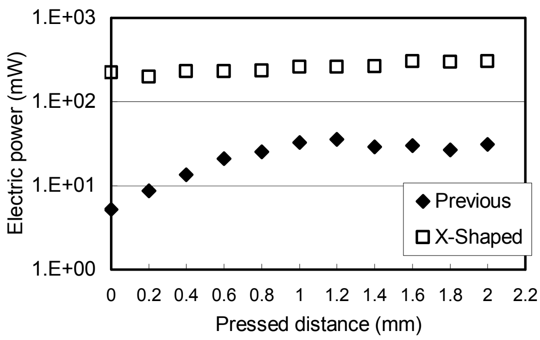


Fig.10 Received electric power depending on the sheet deformation.

III. Multi-channel Data Transmission and Power Supply

A. *Time division multiplexing circuit*

In our former researches, we used the single sensor unit and we confirmed that the signal transmission could be possible. In this paper, we adopt time division multiplexing (TDM) method for achieving multi channel data transmission and power supply alternately in the same sheet. Although there are many protocols that assure multi channel communication such as the frequency division multiplexing (FDM), the code division multiple access (CDMA) and etc., we adopted TDM from the easiness of implementation.

There are two stages in our TDM method. One is for power supply to each sensor unit and the other is for data transmission. Figure 11 shows the time chart of our proposed method. After the power supply stage, each sensor sends data sequentially with PWM. The graph shows the envelope of the burst wave whose carrier frequency is supposed to be 2.4 GHz.

Figure 12 shows the one configuration for achieving the TDM. The circuit is composed of the passive components, the logic circuits and the analog switch. Therefore the circuit can be driven with low power consumption.

The behavior of the circuit is understood by Fig. 13 which shows the voltages at the points a~e in Fig. 12. (We use description V_i (i = a~e) as the voltage to the common potential at the point i.) When the power signal ends, the V_a also becomes low with a time delay t_1. The delay t_1 is determined by the product of the resistance R_1 and capacitance C_1. Thus the rising edge of the V_b occurs t_1 second later than the falling edge of the power signal. The V_b is used to switch the state of the analog switch S. The switch S is connected to the EMG circuit during the V_b is low. On the other hand when the V_b becomes high, the point c is connected to the common potential through the resistance R_2. Then the V_c decreases with its time constant R_2C_2. The decay time t_2 is determined by the momentary voltage of the V_c at the exact moment when the V_b returns to high level. As a result, we obtain the PWM signal V_e. This signal is used as an "enable signal" of the 2.4 GHz oscillator. It is important that the time delay t_1 can readily be designed with different pairs of R_1 and C_1 so that the delays are different among multiple sensor chips.

The relationship between the voltage of the measurement circuit V_c and the pulse width t_2 can be calculated by this eqation.

$$t_2 = R_2C_2(\log V_{\mathrm{init}} - \log V_{\mathrm{th}}) \qquad (1)$$

Here V_{init} is the momentary voltage of the V_c at the exact moment when the switch S was connected. V_{th} is the low level threshold of the logic circuit.

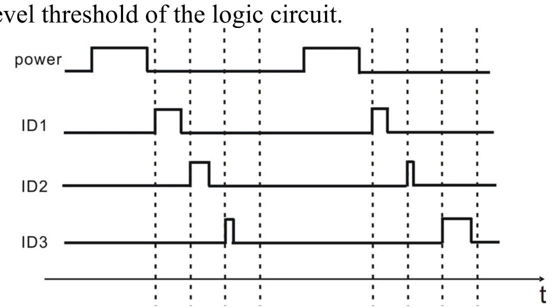


Fig. 11 Time diagram of the time division multiplexing method. The lateral axis indicates the time. Each sensor has a different delay to the falling edge of the power signal.

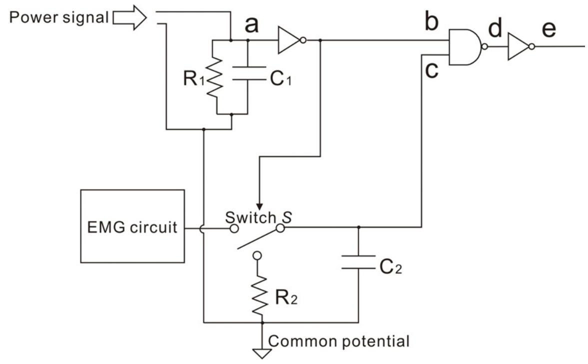


Fig. 12 Electric circuit that achieves the TDM method with low power consumption.

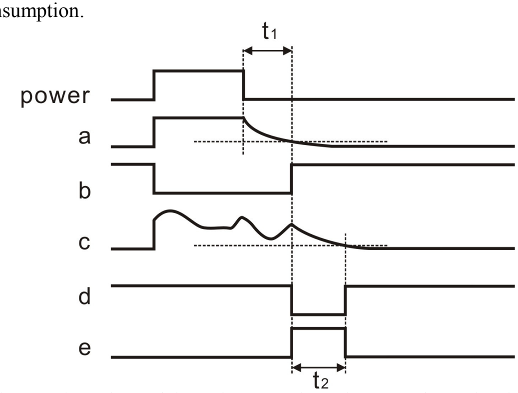


Fig. 13 Time chart of the voltages at the points a~e shown in Fig. 9.

B. Prototype

Figure 14 plots the experimental results of the relationship between the voltage V_{init} and the pulse width t_2. Here, R_2=300Ω and C_2=0.1μF. A designed differential voltage was supplied to the electrodes with stabilized voltage source. The dashed line indicates the theoretical curve. Though there is constant difference (about 10 μs) between the experimental results and the theoretical values, a tendency of the curve is similar to each other. The difference is considered to be caused by the variation in V_{th} of the used IC. This result indicates that the PWM is apparently possible by our proposed circuit. Power consumption of the all the circuit was less than 10 mW which could be supplied through the sheet with microwave.

Figure 15 shows the demodulated data of two channels EMG signals. One channel was set on a "flexor carpi radialis muscle" which relates to the bending motion of a wrist (Channel A). While the other one was set on an "extensor digitorum muscle" which relates to the extension of the wrist (Channel B). We measured the data when one subject bends and extends his wrist alternately in 5 seconds. The graphs show that the EMG signals occur alternately corresponding to the wrist motion.

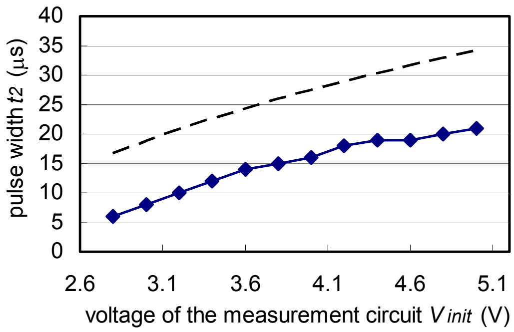


Fig. 14 The relationship between the voltage of the EMG measurement circuit and the pulse width.

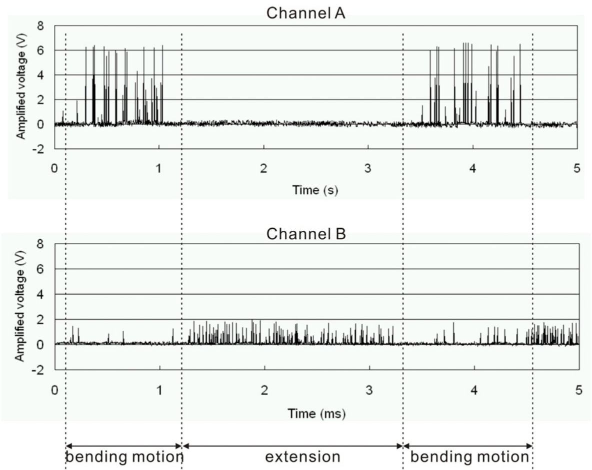


Fig. 15 Demodulated EMG signals. The upper graph shows the result relating to bending motions of the wrist. The lower graph shows the result relating to extensions of the wrist.

IV. Conclusion

In our previous studies, we proposed a new communication technology called "Two-Dimensional Communication (2DC)". The technology enables one to integrate sensor units on a flexible and stretchable sheet without individual wires. Electrical power is also supplied through the sheet to the sensor nodes touching it. This technology is useful for room-size sensor network, wearable computing and so on.

Last year, we proposed a new man-machine interface which detects a myoelectric signal. A myoelectric signal can be detected when the muscle contraction occurs. Since the myoelectric signals are obtained before actual motions, the system can predict finger motion when the myoelectric signal patterns are measured on the forearm. In order to improve the accuracy of the motion estimation, it is considered that a high-density electrode array is required. The 2DC technology is appropriate method for integrating such a large number of the EMG sensor units without complicated and annoying wires.

In this paper, we show how to connect sensors to the sheet efficiently without electrical contact. We proposed a resonant-based connector for this requirement. Based on our experimental results, the connector can receive around 500 mW of electric power in average when 10 W of a microwave is supplied. It is sufficient for activating our EMG sensor unit.

We also showed how to transmit data through the 2DC sheet. We adopted a time division multiplexing (TDM) method. The signal transmissions and the power transfer were achieved with the same frequency in our system. There are two phases in our scheme. One is the term for the power supply and the other is for the signal transmissions. In the signal transmission phase, measured data is transferred by Pulse Width Modulation (PWM) method. We showed two channel data transmission of EMG signals. The signals corresponding to wrist motions were measured.

Appendix

A. Two Dimensional Communication

The idea of communication using two dimensional medium was originally proposed by some research groups [8], [9], [10] including us [7] at the early 2000s. In the researches [8], [9] and [10], however, high speed communication through the medium was out of consideration. In addition, mechanical and electrical contacts of elements to the conductive layers were necessary.

"Two Dimensional Communication (2DC)" was reported by Makino et al. in [11] as a substitution for the wires. Basic configuration of the communication sheet is quite simple. The sheet consists of three layers. Two conductive layers sandwich a dielectric layer. We theoretically showed that a propagation mode exists in the sheet when a high frequency alternate voltage is supplied between the two conductive layers. The theory shows that the frequency must be high enough so that the corresponding wave length λ is smaller than the sheet size. For example, 2.4 GHz microwave, whose wavelength λ is about 10 cm, (which is usually used in the wireless communication protocols) propagates within the dielectric layer if the sheet size is assumed to be 30 cm x 30 cm. In this propagation mode, the energy is confined within the sheet. It does not interfere with outside devices. Since a higher power microwave can be applied without worrying about interferences, we can supply enough electric power to the sensor units with microwave as well as a signal transmission.

We can list the following advantages of the 2DC.

1) 2DC sheet can be fabricated by various conductive materials such as conductive films, foils, and fabrics. Therefore stretchable and foldaway communication sheet is possible. They can be buried into floors, walls, desks, curtains or cloths at low costs.
2) The waste of energy for communication is small compared with the case of wireless communication since the electromagnetic energy is confined in the 2DC sheet.
3) A 2DC sheet does not leak the electromagnetic radiation outside of the sheet. This is useful to construct secure communication environment. It is also available where the electromagnetic radiation is harmful such as in a hospital.
4) Electrical power is also transmitted to the sensor nodes touching the sheet by microwaves safely since the wave does not reach people being outside of the sheet. Efficiency of the electrical power transmission is practically acceptable in many cases.
5) Wide frequency band is available. In the 2DC sheet, we can use wide band of electromagnetic wave since the communication in it is free from Radio Law.
6) This technology corresponds to the physical layer of the OSI reference model. Any communication protocols such as IEEE802.11a/b/g, Bluetooth and etc. are available for high speed communication.

Two types of the communication sheets were proposed previously. One is surface connection type (we do not treat this type of sheet in this paper). This type of the communication sheet enables one to connect devices anywhere on the sheet without electrical contact [13]. To achieve this performance, upwards-facing side of the conductive layer has lattice structure. The connector size for the surface connection is about 6 cm in diameter at 2.4 GHz.

On the other hand, the other type of the sheet is embedding type of the communication sheet. Figure A-1 shows the basic configuration of the embedding type of the 2DC sheet. There are connection apertures on the sheet surface. The devices can be coupled with the sheet through the connection aperture. Though the connecting point is restricted in this type of connection, the size of the connector can be reduced than that of the surface type.

For effective coupling between the sensor and the embedding type of the sheet, we proposed a connector named "Resonant Proximity Connector (RPC)" [12]. When the total length of the electrode is designed to be $\lambda/4$ of the microwave, the connection can be seen as a short owing to its resonance. A notable characteristic is that it requires no electrical contact between them. The connection apertures can be covered with a thin insulating material so as to prevent the conductive materials from oxidization. We also confirmed that the size of the RPC could be reduced down to about 3 mm in diameter by curling its shape. This connector is suitable for achieving a high density sensor array. Since the connector requires no rigid connection to the sheet, the system is durable and stretchable even when a large number of the sensor units are arranged. Moreover, when the electric power is supplied through the RPC, the common potential of the sensor unit can be isolated to ground potential. This advantage is useful for reducing common mode noises as shown in next section.

Any materials with high conductivity are available for the conductive layers like conductive fabrics and conductive rubbers. The sheet is feasible for the comfortably wearable wristband shaped man-machine interface.

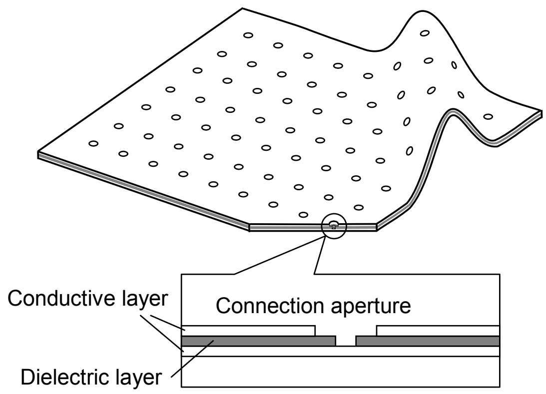


Fig. A-1 Schematic illustration of the of the Two-Dimensional Communication descrived in [11]

B. Myoelectric potential measurement using isolated sensing units

A myoelectric signal is the signal that produces muscle contraction. The signal is observed by electrodes in contact with a skin surface with its voltage is order of several mV. As a result, reducing a common mode noise is one of important issues for the EMG. However, if the measurement circuit is isolated from the ground potential, we are released from consideration about the common mode noise. In our 2DC system, the sensor unit is connected to the sheet through a small capacitor (RPC) whose capacitance is as small as 1 pF. Thus, the connection to the ground potential is negligible.

Figure A-2 shows an equivalent circuit of our proposed method [6]. The point of the circuit is that the common potential of the measurement circuit $V_{a.}$ is isolated from the ground potential (weakly connected through the 1 pF capacitor). This makes the all the potential on the circuit float. The common mode noise can be reduced by instrumentation amplifier.

In our former paper, we demonstrated that the myoelectric signals could be detected by these two-electrodes based measurement system. Figure A-3 shows the myoelectric signal when the noise source (handy-size drill) touched on the skin. The signal can be seen with sufficient SN ratio. We confirmed that our proposed method is useful for reducing the common mode noise.

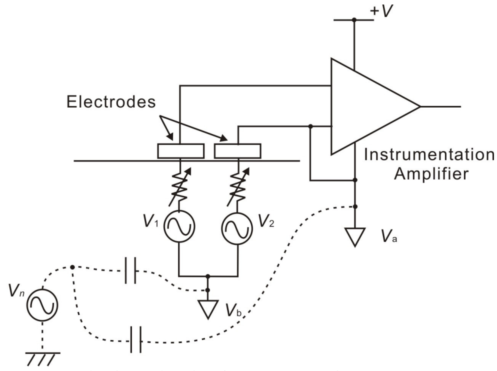


Fig. A-2 Equivalent circuit of our proposed measurement system.

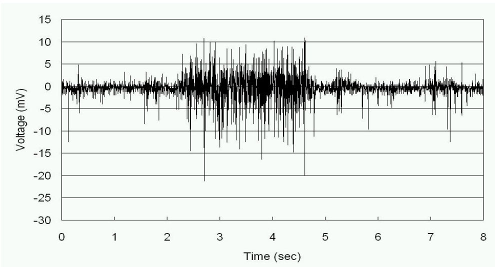


Fig. A-3 Measured myoelectric signal under noisy condition [6].

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REFERENCES

[1] Y. Makino, A. Okada, and H. Shinoda: "Measuring Myoelectric Potential Patterns Based on Two-Dimensional Signal Transmission Technology," Proc. SICE Annual Conference 2006, pp.2005-2009 (2006)

[2] J. H. Blok, J. P. van Dijk, G. Drost, M. J. Zwarts, and D. F. Stegeman : "A high-density multichannel surface electromyography system for the characterization of single motor units," Review of Scientific Instruments, Vol. 73, No. 4, pp. 1887-1897 (2002)

[3] B. G. Lapatki, J. P. van Dijk, I. E. Jonas, M. J. Zwarts and D. F. Stegeman: A thin, flexible multielectrode grid for high-density surface EMG," Journal of Applied Physiology, Vol. 96, pp.327-336 (2004)

[4] H. Kawamoto, S. Kanbe, Y. Sankai: "Power Assist Method for HAL-3 Estimating Operator's Intention Based on Motion Information," Proc. 2003 IEEE International Workshop on Robot and Human Interactive Communication, pp.67-72 (2003)

[5] L. Pelland and P. Mckinley: "A pattern recognition technique to characterize the differential modulation of co-activating muscles at the performer/environment interface," Journal of Electromyography and Kinesiology, Vol. 14, pp.539-554 (2004)

[6] Yasutoshi Makino and Hiroyuki Shinoda: "Comfortable Wristband Interface Measuring Myoelectric Pattern," Proc. World Haptics 2007, pp. 433-438 (2007)

[7] M. Hakozaki and H. Shinoda: "Digital Tactile Sensing Elements Communicating through Conductive Skin Layers," Proc. 2002 IEEE Int. Conf. on Robotics & Automation, pp.3813-3817 (2002)

[8] K. V. Laerhoven, N. Villar, A. Schmidt, and H.W. Gellersen: "Pin & Play: The Surface as Network Medium," IEEE Communication Magazine, pp. 90-95 (2003)

[9] J. Lifton and J. Paradiso: "Pushpin Computing System Overview: A Platform for Distributed, Embedded, Ubiquitous Sensor Networks," Proc. Perv. Comp., LNCS 2414, pp. 139-151 (2002)

[10] J. Scott, F. Hoffmann, M. Addleseet, G. Mappt and A. Hopper: "Networked Surfaces: A New Concept in Mobile Networking," ACM Mobile Networks and Applications, Vol. 7, No. 5, pp. 353-364 (2002)

[11] Y. Makino, K. Minamizawa and H. Shinoda: "Two Dimensional Communication Technology for Networked Sensing System," Proc. International Workshop on Networked Sensing Systems (INSS) 2005, pp. 168-173 (2005)

[12] Y. Makino, H. Chigusa and H. Shinoda, "Two-Dimensional Sensor Integration Using Resonant Proximity Connector –Basic Technology and Application to Elastic Interface Device," International Workshop on Networked Sensing Systems (INSS) 2006, pp. 196-202 (2006)

[13] Y. Makino N. Yamahira and H. Shinoda: "Proximity Connector for Two-Dimensional Electromagnetic Wave Communication," Proc. IEEJ 23nd Sensor Symposium, pp. 397-402 (2006)