EMG Sensor Array Integrated on a Flexible 2D Signal Transmission Sheet

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We have proposed a new man-machine interface that detects myoelectric signals on a forearm. In the system, we used “Two Dimensional Communication (2DC)” technology for integrating many electromyography (EMG) sensors on a flexible wristband. The sensors embedded in the 2D signal transmission (2DST) sheet could send their data and receive their electricity across the sheet using a microwave. One issue with our previous system is a standing wave in the 2DST sheet. When a connector is attached at a node of the electric field, our previous one, which detected electric field, could not receive any electricity. In this paper we propose a new connector that detects a magnetic field. Since the nodes of the electric field are the anti-nodes of the magnetic field, the receivable energy becomes uniform independent on a location when we use both electric and magnetic sensitive couplers together. We show our simulation and experimental results.

Keywords: Man-Machine Interface, Electromyography (EMG), Two−Dimensional Communication.

1. INTRODUCTION

We have proposed a new man-machine interface that detects myoelectric signals on a forearm [1]. Since the most muscles relating to finger motions exist on the forearm, we can know the motion of fingers when the high-density electromyography (EMG) sensors are arranged on it. This is useful for inputting data by natural motion without any constraints on fingers.

In order to integrate a large number of the sensors, we used “Two Dimensional Communication (2DC)” technology [2] instead of wires. The 2DC achieved with 3-layered thin sheet called “Two Dimensional Signal Transmission (2DST) sheet.” The sheet has two conductive layers that sandwich an insulator. When a microwave is supplied between the two conductive layers, it propagates two-dimensionally across it. Based on this microwave propagation, the sensors embedded in the sheet can receive their electricity and send their data across it. Since the sheet can be achieved with flexible materials including conductive fabrics, the technology allows us to integrate many sensors on a bendable and stretchable sheet as shown in Fig. 1. Our prototype system currently achieved 3-channels data acquisition through the wristband-shaped sheet.

One issue in our previous studies is an effect of a standing wave. When the microwave arrives to the boundary of the sheet, its energy reflects back to the sheet. This causes a standing wave inside it. Since our previous connector coupled to the electric field in the sheet, receivable electricity became low when it was attached at the node of the electric field of the standing wave. Connectable positions were limited due to this effect.

In order to solve this issue, we propose a new connector that couples to a magnetic field. Since nodes of the electric field is just anti-nodes of the magnetic field, the usage both electric and magnetic sensitive connectors together makes it possible to acquire electricity uniformly independent on their position.

In this paper, we show simulation and experimental results of magnetic sensitive connector. The result illustrates that the utilization of both types of connector is effective to receive electricity uniformly in the sheet.

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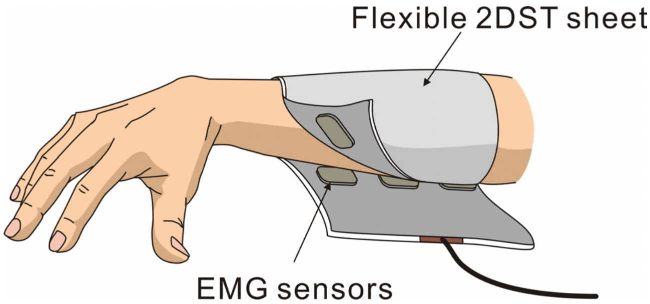


Fig. 1 Schematic diagram of the wristband-shaped electrode array for electromyography

2. PREVIOUS STUDIES

2.1 EMG Sensors on a Flexible Wristband In our previous study, we proposed an EMG-based interface [1]. A myoelectric signal is an electric impulse that produces muscle contractions. One remarkable aspect is that the signal can be detected before actual motions. Therefore, it is useful for estimating limbs movements. Since almost all of the muscles relating to finger motions exist under a forearm, a sensor array around the forearm can estimate finger motions before the real movement.

The idea that uses the myoelectric signals for man-machine interface already has been used in several systems including power assist suits [3]. In those studies, however, the myoelectric signals are obtained by a few sparse measurement points on the major muscles. They devoted most of their efforts to a pattern matching technique. Initial alignment of the electrodes is important for keeping the same measurement condition. There are several previous studies which measures dense 2D-EMG patterns [4] [5], however, the studies assumed some special situations that make wearing complex devices allowable. In both cases, the system is not feasible for daily use.

In order to achieve daily usable EMG device, we proposed a new approach that integrates many EMG-sensors on a stretchable wrist-band without any wires based on the 2DC technology. Figure 1 shows the schematic illustration. Many EMG sensors are arranged onto the flexible communication sheet. The EMG data is obtained as a two dimensional pattern. The system requires no specific alignment for measurement. Since the sheet is flexible and stretchable, we can wear the system comfortably. The stretchability also ensures the steady contact between the electrodes and the skin surface. The contact impedance between them can be decreased.

2.2 Two Dimensional Communication The 2DC is a new technology which allows a microwave propagating in a thin sheet. Figure 2 shows the basic configuration of the sheet. The two conductive layers sandwich an insulator. When a high frequency voltage is supplied between the conductors, microwave propagates two dimensionally across the sheet. This microwave enables a sensor, to send/receive data and to acquire electricity across the sheet. One remarkable aspect is that the sheet can be achieved with flexible and stretchable materials such as conductive fabrics.

We have proposed two types of the 2DST sheet. One is the sheet for surface connection [6]. In this case, the nodes touching to the sheet surface were connected each other. (We will not discuss this sheet in this paper.) The other one is the sheet for embedding type [7]. In this case, the nodes embedded in the sheet were coupled to it. Compared to the surface type, the size of the embedded-type connector can be reduced. Therefore this type is useful for a high-density sensor array.

In our previous study, we showed an effective coupler named "Resonant Proximity Connector (RPC)" [7] for the embedding type. When the electrode length is equal to $\lambda/4$ of a microwave, the RPC strongly couples to an electric field in the sheet.

2.3 Issues There are two issues, however, for usage of the RPC. One is the problem on a standing wave. When a microwave reaches to boundaries, its power mainly reflected back to the sheet. This causes a standing wave. Therefore RPC becomes useless when it is set around a node of the electric field. The other issue is absorption of the energy around the RPC. When we use omni-directional connector in the sheet, the diameter of its absorption area is theoretically estimated as

$$D = \lambda/2\pi \qquad (1)$$

Therefore, the intervals of each sensor must be larger than D so as to avoid interferences. For 2.4 GHz, D is about 2cm. This becomes a drawback for achieving high density sensor integration when we use the RPC.

In this paper, we show the solutions to the above issues. For eliminating the standing wave effect, we adopt a magnetic coupler as well as an electric one. One important feature of the standing wave is that a node of an electric field is an anti-node of a magnetic field. The sum of the both energies is constant independent on the location provided a microwave propagates uniformly inside the sheet. Thus if we use both types of the connector together, the magnetic coupler complements the electric one.

The solution for the second issue is that we do not use resonance for coupling. Of course the efficiency of the coupler becomes low compared with the RPC, however, we show that our non-resonant coupler gives sufficient electricity to our EMG sensor systems. Those connectors are expected to be useful for achieving high-density sensor array.

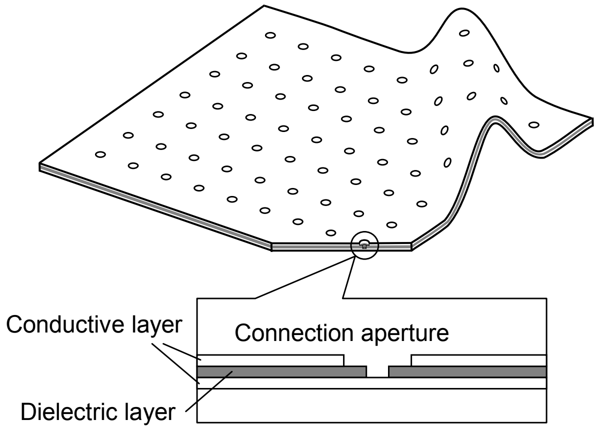


Fig. 2 Schematic illustration of the Two-Dimensional Communication described in [2]

3. SIMULATION RESULTS

3.1 Standing Wave in the 2DC Sheet We used an electromagnetic simulator, MW-STUDIO software (AET Japan Inc.), for confirming our principle. In order to make it simple, the sheet was modeled as 10 mm x 60 mm x 2 mm. Figure 3 shows the simulation model. A microwave was supplied from the right side to the sheet. It propagated as plane wave toward the left side. At the left side, there was coaxial cable that enables us to set a connector at the end of the sheet. The rest of the left side was covered with conductor for short-circuit. Thus the microwave completely reflected at the left-side when a coupler was not attached to the cable.

Figure 3 and 4 show average amplitudes of both electric and magnetic field in the sheet respectively without coupler. Both figures show a standing wave. One important feature is that the nodes of the electric field (both sides) are the anti-nodes of the magnetic field. Therefore, the electric-based coupler is considered to be useless at the left side. The magnetic-based coupler must be useful rather than electric one.

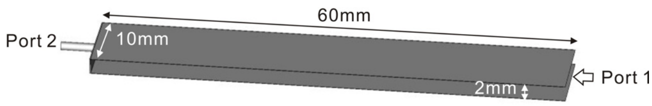


Fig.3 Simulation model of the sheet

Fig. 4 Average amplitude of the electric field in the sheet at 2.4 GHz. The sides are the node and the center is the anti-node for the electric field.

Fig. 5 Average amplitude of the magnetic field in the sheet at 2.4 GHz. The sides are the anti-node and the center is the node for the magnetic field.

3.2 Small Loop as the Magnetic Coupler Figure 6 shows the basic magnetic coupler in the simulation. We used a simple loop coil structure to couple to the magnetic field in the sheet. When a microwave propagates across the sheet as a plane wave, the magnetic field is emitted inside it whose direction is parallel to the conductive layers and perpendicular to the traveling direction of the microwave. Thus when we embed a single loop coil into the sheet whose orientation is shown in Fig.6, the current is induced due to the magnetic field penetrating in the loop. Since we simulated from 2GHz to 3GHz, the total length of the loop did not coincide with the target wavelength. Resonance does not occur.

For comparison, we also used capacitive coupler. That was simple conductive patches whose sizes were 5 mm x 5 mm respectively. The gaps to the conductive layers are 0.1mm.

Figure 7 and 8 show the S-parameter of the both couplers. S_{11} represents a reflection rate to the input microwave at the port 1. S_{21} shows a transmission rate between the port 1 and 2. Here, the port 1 is the right side of the sheet and the port 2 is the end of the coaxial cable as shown in Fig.3. Therefore, the S_{21} represents how much energy can be received around the short boundary (i.e. electric node of the standing wave).

It is clearly shown in the figures that the transmission rate for the magnetic coupler is higher than that of the capacitive coupler. The magnetic coupler simulated here could couple to the magnetic anti-node. Since the total length of the loop is quite short compared with the wave length, no resonant peak could be found in the graph. The S_{21} consequently becomes smaller than resonance-based connector, however, receivable energy is thought to be enough for our EMG sensor unit in practical. Theoretically, it will be about 400mW provided the 10 W of power is supplied.

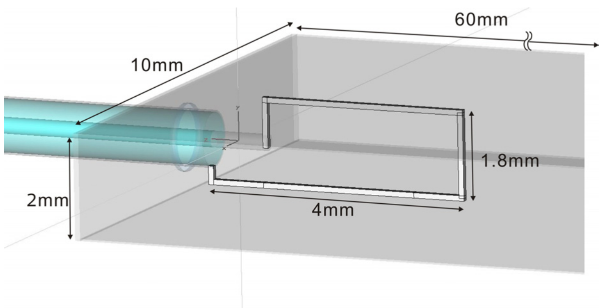


Fig. 6 The magnetic coupler at the left side.

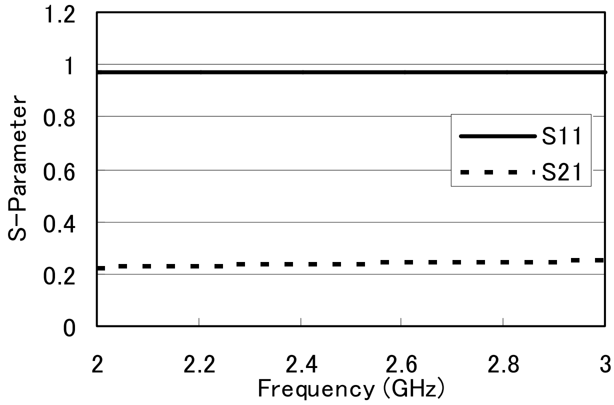


Fig. 7 S-parameter of the magnetic coupler.

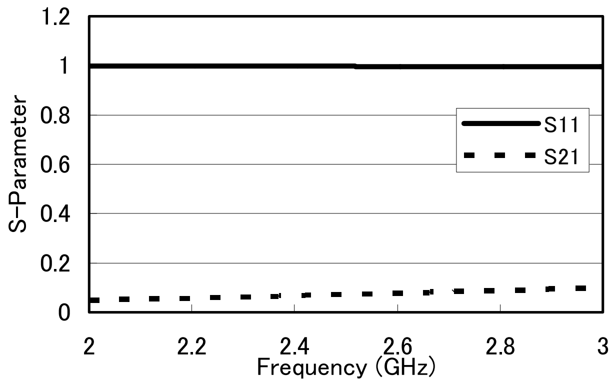


Fig. 8 S-parameter of the electric coupler.

4. EXPERIMENTAL RESULTS

We used simple model shown in Fig. 9 for a feasibility study. The both electric and magnetic non-resonant couplers were set at the left side of the sheet (this side corresponds to the port 2 in the simulation). From the other side, a microwave is supplied to the sheet through SMA connector (this side corresponds to the port 1). As shown in the figure, we changed its boundary condition at the left side of the sheet for achieving both open and short boundary.

For the inductive coupler we used a single loop whose cross-section area was 10 mm x 1.6 mm (Fig.10 (a)). Thus the total length of the loop is about 23 mm. The width of the loop was 1 mm. In contrast, for the capacitive coupler we used simple conductive patches whose size were 5 mm x 10 mm and whose interval was 1.6 mm (Fig.10 (b)). We put both couplers in the both open and short boundaries.

Figure 11 and 12 show the results. Each graph shows S_{21} (transmission rate) in the experimental system. For the magnetic coupler (Fig.11), it is clear that the transmission rate of the short boundary (Fig.11 (a): magnetic anti-node:) is 10 times larger than that of the open boundary (Fig.11 (b): magnetic node). While for the electric coupler (Fig. 12), the situation is opposite. The coupler at the open boundary (Fig.12 (a): electric anti-node) can receive larger energy than the one at the short boundary (Fig.12 (b): electric anti-node).

These results showed that our proposed principle can be applied to our system. If the two types of the coupler are used together, each sensor can receive its electricity independent on the standing wave in the sheet. Though the transmission rate of the magnetic coupler is smaller than that of electric, it is thought to be improved by changing its shape or materials.

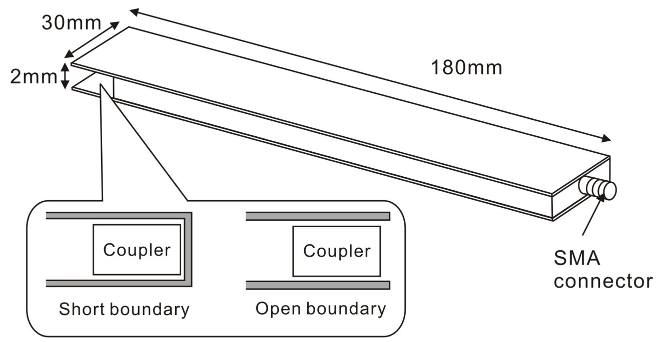
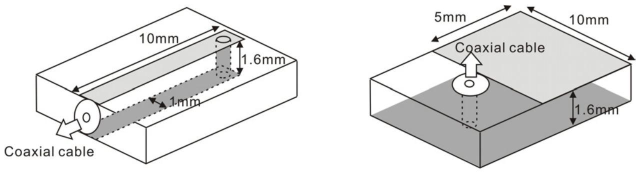
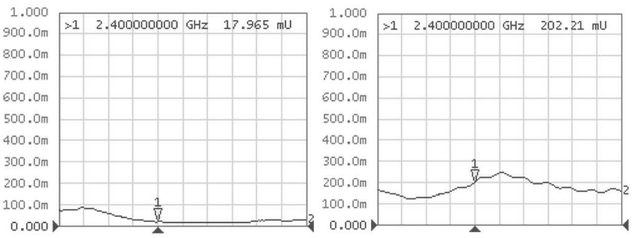


Fig. 9 Simple sheet used in the experiments.



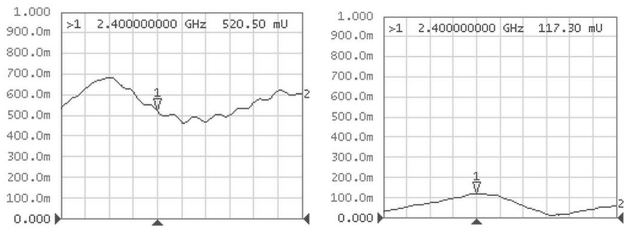
(a) magnetic (b) electric

Fig. 10 Connectors used in the experiment.



(a) open (b) short

Fig. 11 S_{21} of the magnetic coupler.



(a) open (b) short

Fig. 12 S_{21} of the electric coupler.

5. CONCLUSION

We have proposed a new man-machine interface that detects myoelectric signals on a forearm. For measuring high-density data, wires to sensors can be a big issue. In our proposed system, we used "Two Dimensional Communication (2DC)" technology for integrating many EMG sensors on a flexible wristband without wires. The sensors embedded in the 2DST sheet could send their data and receive their electricity across the sheet using a microwave.

One issue for our previous system is a standing wave in the 2DST sheet. Since our previous connector coupled to the electric field in the sheet, receivable electricity became low when it was attached at the node of the electric field of the standing wave. Connectable positions were limited due to this effect.

In this paper we propose a new connector that detects a magnetic field. Since the nodes of the electric field are the anti-nodes of the magnetic field, the receivable energy becomes uniform independent on a location when we use both electric and magnetic sensitive connectors together.

Based on the simulation and experimental results, we showed that the magnetic coupler could be used at the nodes of the electric field. If the two types of the coupler is used together, each sensor can receive its electricity independent on the standing wave in the sheet. Utilization of these couplers in a flexible sheet for integrating EMG sensors is our future work.

ACKNOWLEDGEMENT

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for JSPS Fellows, 18-11193, 2006-2008.

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