Super multi-channel recording systems with UWB wireless transmitter for BMI

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***Abstract*— In order to realize a low-invasive and high accuracy Brain-Machine Interface (BMI) system for clinical applications, a super multi-channel recording system was developed in which 4096 channels of Electrocorticogram (ECoG) signal can be amplified and transmitted to outside the body by using an Ultra Wide Band (UWB) wireless system. Also, a high density, flexible electrode array made by using a Parylene-C substrate was developed that is composed of units of 32-ch recording arrays. We have succeeded in an evaluation test of UWB wireless transmitting using a body phantom system.**

I. INTRODUCTION

As a source signal for clinical Brain-Machine Interface (BMI), the electrocorticogram (ECoG) has recently attracted attention in many research groups, because of its good balance of features. It is less invasive than penetrating electrode methods (for recording spikes or local field potentials (LFPs) for BMI decoding) and has a higher spatial resolution and richer information than does the normal EEG. The researches focusing on flexible electrode arrays for ECoG [1] and an implantable system for ECoG-BMI [2] have been started and reported. We have been developing a fully implantable human ECoG-BMI system for clinical BMI, which consists of ECoG neural electrode arrays made by using silicone sheet and platinum electrodes (64 - 128 channels), neural recording LSIs (Large-scale integrated circuits), a Wi-Fi based wireless data transmitter and a wireless power receiver with a rechargeable battery [3-6]. To achieve more precise control of a multi-joint prosthetic arm, it is necessary to increase the number of recording channels; however, there are several barriers, especially in the electrode array, amplifier, and wireless transmitting. In this paper, we report a novel super multi-channel recording system for low-invasive ECoG BMI in which 4096 channels of ECoG signals are recorded , amplified, and transmitted wirelessly by UWB (Ultra Wide Band). A future concept of the system (large-scale distributed ECoG recording system) is shown in Fig. 1.

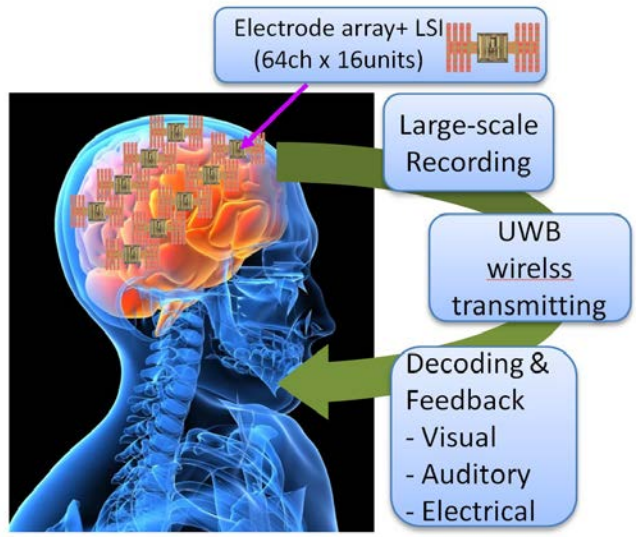

Fig.1 Concept of the Large-scale Distributed ECoG recording system

II. ELECTRODE ARRAY

We have been developing flexible electrode arrays using Parylene-C (Poly(chloro-para-xylylene)) as a substrate material [7,8]. Fig. 2 shows the fabrication process of our high density, flexible electrode array. A gold layer (200-250 nm in thickness) is sandwiched between two Parylene-C layers (10 μm thick × 2). The second Parylene-C layer was deposited after a treatment of an oxygen plasma etching for better adhesion. Electrode windows and outer shapes were patterned using an oxygen plasma etching machine with aluminum masks. Fig. 3(a) shows a unit electrode array of 32ch in which the inter-electrode distance is 1-2.5mm (the minimum is 20 μm). By combining these units together, a 32 - 4096-ch electrode array can be composed. Fig. 3(b) shows an example of the electrode array, which has 128-ch recording sites for use in monkey experiments. In the monkey experiment the ECoG

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signals are recorded stably for longer than 24 months (used with another wired system), and a part of the array can be inserted into the sulcus safely [7]. In order to achieve distributed 4096 ch system (Fig. 1), we are developing an integrated probe unit in which an LSI chip (64ch of amplifier and ADC) was connected directly to a flexible electrode array (Fig. 4). By using this integrated probe unit, the number of wiring cables between an electrode array and wireless transmitting module can be decreased.

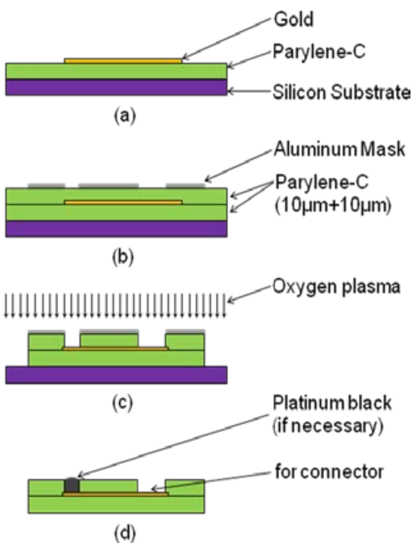
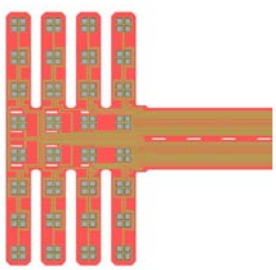
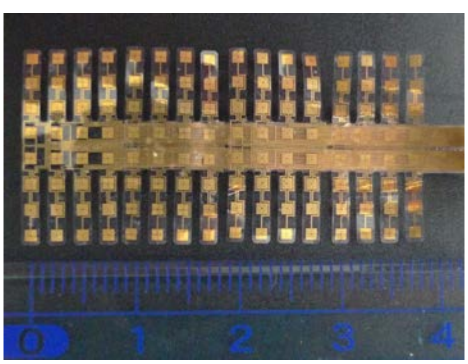


Fig. 2 Fabrication process of Parylene-C probe



(a) A unit electrode array of 32ch



(b) 128 ch electrode array
Fig. 3 High density flexible electrode array
(The scale is metric (cm))

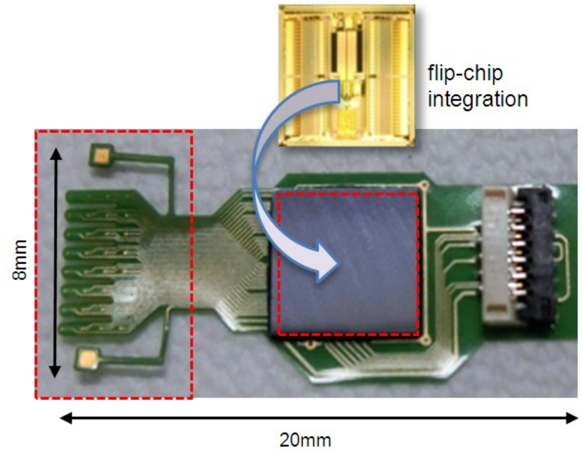


Fig. 4 An integrated probe unit for direct connection of a custom designed LSI (64ch amplifiers and ADC, 5mm by 5mm) and a flexible electrode array.

III. AMPLIFIER, ADC AND UWB

A schematic diagram of the system is shown in Fig. 5. A 512 channel recording units can be integrated by using eight neural recording LSIs [9] and one multiplexer (MUX-A).

The recorded ECoG signals (64ch 800-kbps) are converted into 512ch 6.4Mbps serial data by using 8:1 time division multiplexing. If more recording channels are needed, the system can be scaled up to a maximum 4096ch by connecting eight 512ch recording units with MUX-B. These ECoG electrodes, LSIs and MUX-A/B are implanted around the skull. The multiplexed recorded data are transmitted to a UWB transmitter through LVDS FPC cable subcutaneously, and the data is wirelessly transmitted outside of the body by UWB. The center frequency and bandwidth of the UWB are 7.9 GHz and 1.25 GHz, respectively, in order to meet international regulations. The UWB transmitter units including a Li polymer rechargeable 400 mAh battery and a ZigBee wireless transceiver are sealed in a waterproof package. ZigBee is used for wirelessly establishing the system operation settings and configuration.

IV. EVALUATION RESULT

We confirmed 4096ch UWB wireless communication (corresponds to 51.2Mbps data rate) in air at 5m distance. Preliminary inside to outside body wireless communication experiments are currently ongoing by using human body equivalent liquid phantoms specialized for UWB bandwidth, in which we have confirmed 4096ch UWB wireless communication from 20mm in depth and also basic operations have been confirmed (Fig. 6).

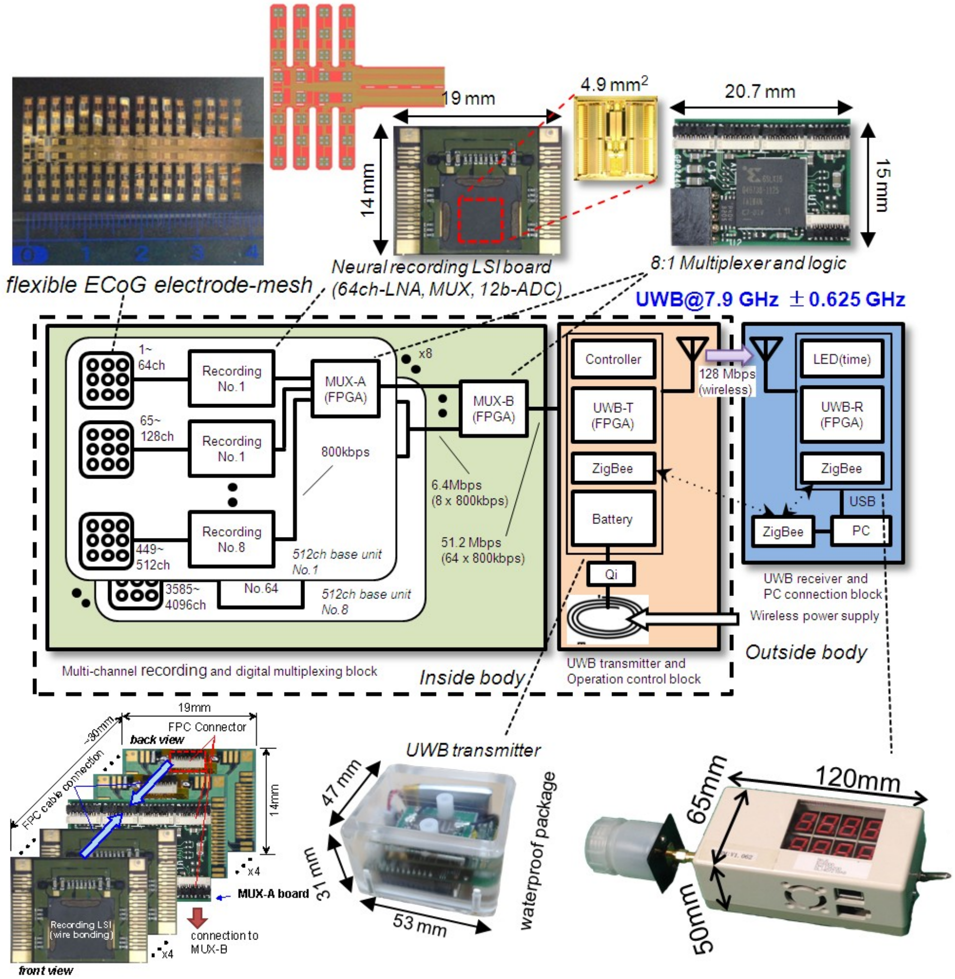


Fig. 5 Schematic diagram of the UWB recording system.

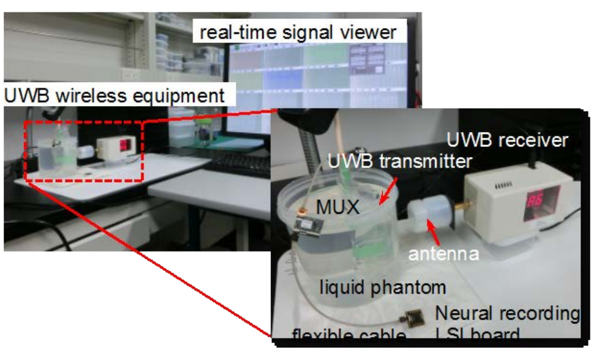


Fig. 6 UWB wireless communication experiment by using a liquid phantom.

Table 1: Specification of multi-channel BMI system

Number of channels	64~4096	ch	
Supply voltage	3.3	V	
UWB bandwidth	7.275 ~8.525	GHz	for internationally usage
UWB data rate	128	Mbps	
MUX-A and MUX-B (common hardware)			
Xilinx Spartan6 XC6SLX16, FPC connector (11pin)			
UWB transmitter (water proof casing)			
RF, BPF and ZigBee board			
LVDS receiver (51.2Mbps), Magnetic Power SW (20mm range) and rechargeable Li polymer battery (400mAh)			
UWB receiver			
RF board, base board (Xilinx vertex4, USB2.0) and Zigbee board			
PC			
Core i7 3820 Win7 (USB2.0, GUI application)			

V. Conclusion

To realize a low-invasive and high accuracy BMI system for clinical applications, we developed a super multi-channel recording system in which 4096 channels of ECoG signal can be amplified and transmitted to outside the body by using a UWB wireless system. Also, a high density and flexible Parylene-C electrode array was developed that is composed of units of 32-ch recording arrays. We have confirmed stable ECoG recording longer than 24 months from a monkey brain using a same type of electrode array (128ch). and also we have confirmed 4096ch UWB wireless communication (corresponds to 51.2Mbps data rate) in the air at 5m distance and from 20mm in depth using a liquid phantom model .

Acknowledgment

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