Towards A Button-Sized 1024-Site Wireless Cortical Microstimulating Array

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Abstract **- Design and development of a micromachined 16-site wireless addressable active stimulating microprobe, called Interestim-3, based on the University of Michigan MEMS 3-D microelectrode-array technology have been discussed. Up to 64 Interestim-3 probes can be used in parallel with only 2 connections to a mutual hybrid coil in order to achieve a 1024-site intracortical microstimulating system with no trans or sub-cutaneous wires. 3-D microassembly of Interestim-3 probes, which is facilitated by small number of interconnects (2/probe) that also gives way to a high yield has been shown. Interestim-3 has been fabricated in the UM 3-µm 1M/2P BiCMOS process. It has four 60µm × 3.1mm shanks with 250µm spacing, each having four 181µm^2 sites. Interestim-3 circuitry has about 4200 transistors that occupy 21.2 mm^2 of 32.5 mm^2 probe back-end.**

Keywords **- Microelectrode, wireless, implant, stimulator, cortex**

I. INTRODUCTION

Neuroscientists have shown that there is a topographic representation of each sensory modality over the appropriate region of sensory cortex. This suggests that by implanting an array of electrodes in an individual with a sensory deficit and stimulating specific sites on sensory cortex we can restore a limited sensation [1]. However, a cortical neural prosthesis must apply electrical stimulations in a well controlled temporal-spatial pattern similar to the natural cognitive neural activity in order to be effective [2]. This approach has been highly successful in auditory cortex with tens of sites; nevertheless it is significantly more challenging in visual restoration and needs hundreds of stimulating sites at least, to afford a minimum functional resolution [3][4].

The University of Michigan micromachined silicon micro-probes, developed during the past two decades with more than 50 passive and active recording and stimulating designs, can provide the fundamental tools by taking advantage of the features available from thin-film IC technology on silicon wafers such as precise definition of probe shanks and site geometries as well as integration of active circuitry on the probes [5]. These probes are now being widely distributed throughout the world to the medical community and are being used by neuroscientists to advance the clinical and experimental aspects of this promising technology [6].

Research on developing a wireless intracortical probe started by designing a wireless interface chip, called Interestim-1 [7], a chip for STIM-2, an active 64-site multi-shank stimulator probe [8], and gained experience from several peripheral-nerve wireless stimulators [9]. Interestim-1 mounts on a flat micromachined platform that supports the receiver coil and vertical STIM-2 probes as shown in Fig. 1. It is designed to generate dual regulated ±5V supplies capable of providing up to 50mW. It also regenerates a 4 MHz internal clock and extracts data bit-stream of up to 100 Kbps from the ASK-modulated 4 MHz radio-frequency (RF) carrier. The internal clock is stepped down by a user selectable ratio to be synchronized with the recovered data and sent to the STIM-2 probes along with synchronizing strobe pulses.

Interestim-2, a 4-channel stand-alone wireless stimulating chip, was designed by transferring all active circuitry, including stimulation and site selection circuits from the UM-probe to the wireless chip while still using the same microassembly structure of Fig. 1 [10]. This new allocation has two advantages. First, the wireless chip can stimulate tissue through passive UM-probes which are more prevalent and have simpler and lower cost processing. Second, the back-end height of the cortical-implant can be reduced, which is critical in some applications. However, when the number of stimulating sites increases, integration of some sort of site selection circuitry on the probe in order to reduce the number of interconnections is inevitable [11].

Reducing the number of interconnects becomes even more crucial when the goal is a 1024-site stimulating system because it has been shown that interconnects are the major cause of failure in cortical implants with large number of stimulating or recording sites [4][11][14]. The first step was elimination of transcutaneous wires by making all these stimulating systems wireless. Furthermore, in design of Interestim-3, we tried to make every probe as self-sufficient as possible up to the level that each probe only needs a pair of connections to a receiver coil, which is the only hybrid component of the Interestim-3 cortical implant.

The following sections describe the electrical and micro-mechanical architecture of Interestim-3 probes that qualify them as building blocks for a 1024-site wireless micro-stimulating array.

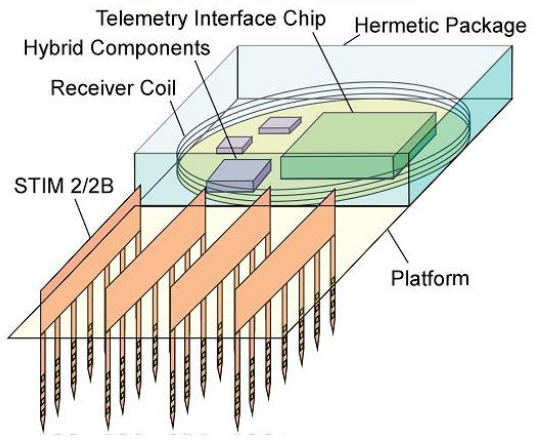

Fig. 1: A wireless microstimulator array with hybrid-coil and interface chip mounted on a micromachined platform [7].

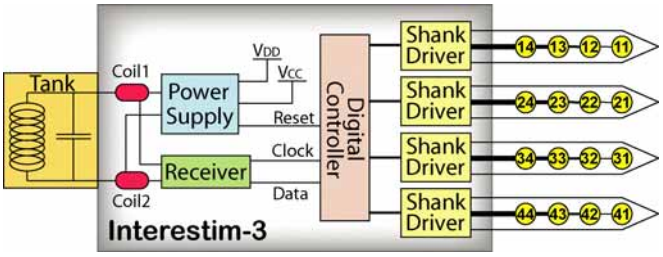

Fig. 2: The overall block diagram of Interestim-3.

II. System Overview

The overall block diagram of Interestim-3 is shown in Fig. 2. Each individual probe has all the necessary components to operate as a 16-site stand-alone wireless microstimulator such as RF power conditioning, receiver, digital controller, and site manipulating blocks. The only inputs of this probe, called Coil1 and Coil2, are the nodes of implantable hybrid tank circuit, which are shared between all probes that are connected in parallel to form a 3-D stimulating array.

Each Interestim-3 probe has 4 shanks and each shank has 4 stimulating sites on it, which are controlled by an individual shank driver block. A more detailed diagram of the shank driver block is shown in Fig. 3. There are two 8-bit registers in every shank driver. One is the command register that keeps configuration of the sites by assigning two bits to each site, defining whether they are involved in a biphasic-bipolar stimulation, at high impedance, or connected to the common analog line, which passes through all of the site driver blocks for charge balancing. Every stimulating site has an individual site-driver circuit, which is shown in Fig. 4 and has a single NMOS nonlinear current-sink similar to Interestim-2 [10]. The stimulation current amplitude information is stored in data register, which controls the gate voltage of the NMOS current sink through a 7-bit current steering DAC circuit.

The digital controller block is shown in Fig. 5. Serial data bit-stream out of the receiver block is initially converted to a parallel data-frame by an 18-bit shift-register. The shift-register content is latched once it is filled by a data-frame and then a parity checking circuit is activated to look for an even parity. In case of a wrong parity, reset line is activated and resets the entire probe without taking any further steps.

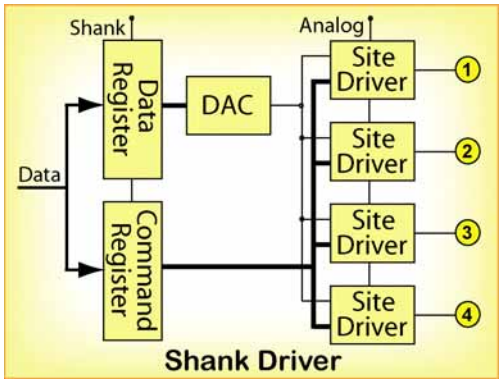

Fig. 3: The shank driver block diagram.

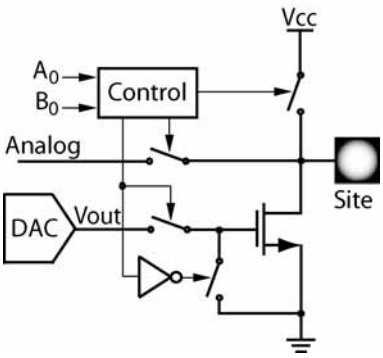

Fig. 4: The site driver simplified schematic [10].

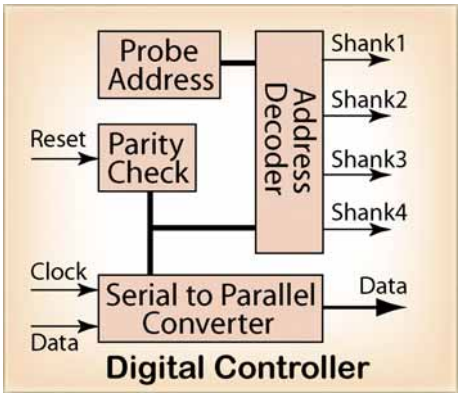

Fig. 5: The digital controller block diagram.

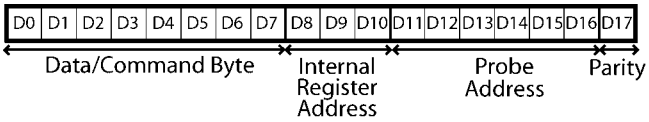

Fig. 6: Interestim-3 data-frame protocol.

Each Interestim-3 data-frame, shown in Fig. 6, has 1-byte of stimulation amplitude data or site configuration command (D0~D7), 3-bits for internal register address (D8~D10), 6-bits for the probe address (D11~D16), and 1-bit for parity checking (D17). Each Interestim-3 probe has a 6-bit hard-wired address, which is initially set to '0' when all of the links are shorted to ground. Cutting each link with laser changes the associated address bit from 0 to 1. Therefore, up to 64 probes can be addressed in order to achieve a 1024-site 3-D stimulator array. If data-frame address matches the probe address then 3-bit internal register address is decoded to send the configuration command or amplitude data byte to one of the 8 internal registers in each probe (two in every shank driver as shown in Fig. 3). Addressing data and command registers separately can save the amount of data that is needed to be transmitted across the limited-bandwidth wireless link in those circumstances where stimulation amplitude is constant and only active sites configuration or timing of stimulation pulses change.

The receiver consists of data-recovery, clock-recovery, and synchronization blocks as shown in Fig. 7. It receives the sinusoidal carrier across the tank circuit and recovers

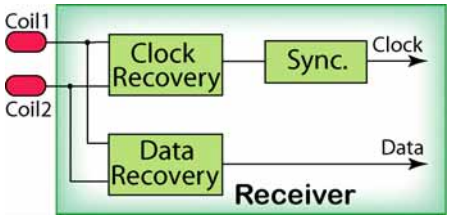

Fig. 7: The receiver block diagram [12].

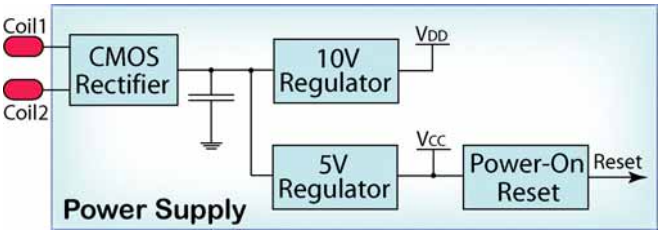

Fig. 8: The power supply block diagram [13].

clock and data bit-stream for the rest of the chip. High data-rate is one of the key requirements of a 1024-site stimulating system. In order to achieve data-rates above 1 Mbps while keeping the carrier frequency below 10 MHz, frequency shift keying (FSK) modulation was utilized for data transfer with a novel demodulator circuit that is described in [12].

Supplying a 1024-site stimulator in an efficient way is another challenge in this design, which has been addressed by employing simple and low power circuits, reducing supply voltage, and eliminating leakage current to substrate [7][13]. Fig. 8 shows the Interestim-3 power supply block, which generates regulated 5V and 10V supplies for probe internal circuitry and stimulating site-drivers respectively. The power supply block also includes a CMOS full-wave rectifier, a low-pass 400 pF capacitive filter, and a power-on reset block, which activates the reset line at startup and releases it after 15µs when all transient voltages have passed.

The distributed power supply scheme which is adopted here by including a complete integrated power supply block on every probe has several advantages over a central power supply for the entire 1024-site wireless stimulator system:

1) Each Interestim-3 probe is a self sufficient 2-D stimulating array and can be used either individually or in parallel with other similar probes in a 3-D array.

2) The power supply output current capacity of the 3-D stimulating system scales by the number of probes that are used in parallel without any unutilized capacity.

3) Less leakage current into the substrate due to lower current levels through each power supply rectifier block.

4) Better heat dissipation by distributing the high current components such as rectifiers and regulators across all probes in a larger area.

III. 3-Dimensional Array Microassembly

Interestim-3 planar probe has been designed with all the features required for typical microassembly of UM-probes on a platform as shown in Fig. 9 and described in [14]. Two wide electroplated gold-beams, each with seven 100 µm × 300µm fingers, have been added to each side of the probe to provide probe-platform interconnects. All of the gold-beams on each side of the probe are electrically shorted to a big pad on that side. These two pads, shown in Fig. 9, represent Coil1 and Coil2 input nodes in Interestim-3 circuit of Fig. 2.

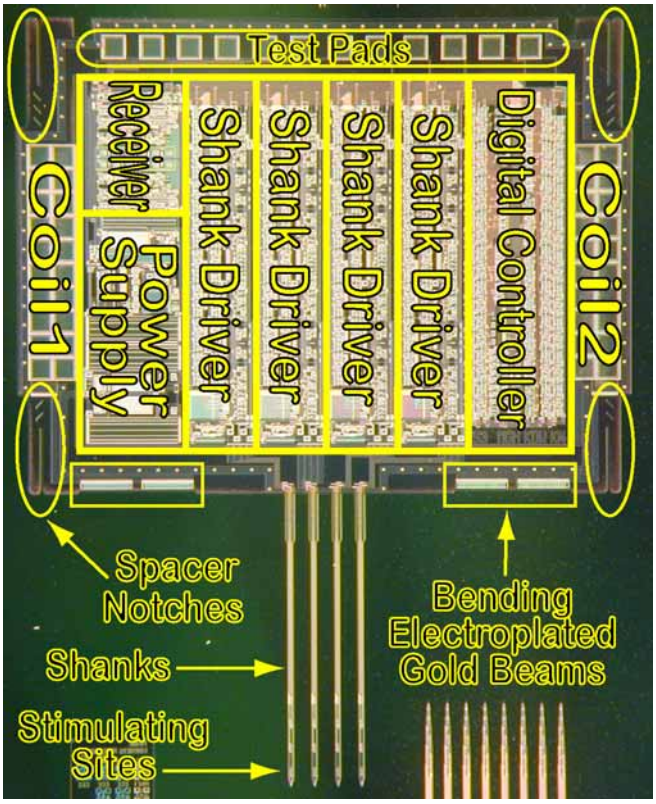

Fig. 9: Floor-plan of Interestim-3 (under processing), the 16-site wireless addressable stimulating active microprobe with micromachining features for 3-D microassembly [14].

Bai mentions in [14] that, "The most time consuming step in the 3-D microassembly process is that of placing spacers. The greater the number of probes the more difficult this is because the probes inserted into the platform are not initially parallel to each other and tend to stick back to back before the spacer is put in." In order to solve this problem, two new sets of spacer notches were added to lower edges of probe back-end (Fig. 9) to insert probes after the two spacers have been installed on the platform. This procedure is easier than keeping 16 or more probes in parallel and orthogonal to the platform while inserting two vertical spacers in, because when spacers are installed first, each probe should be only placed between two vertical spacers and it will be kept upright parallel to previously installed probes by the spacers. After insertion and ultrasonic bonding of the last probe, a cylindrical coil, which is the only hybrid component of this structure, is mounted on the platform while encompassing the entire back-end volume of the 3-D array. Finally the coil and the entire back-end will be potted by epoxy or silicone to fix all components before implantation. A conceptual drawing of a microassembled Interestim-3 probe along with its building blocks has been shown in Fig. 10.

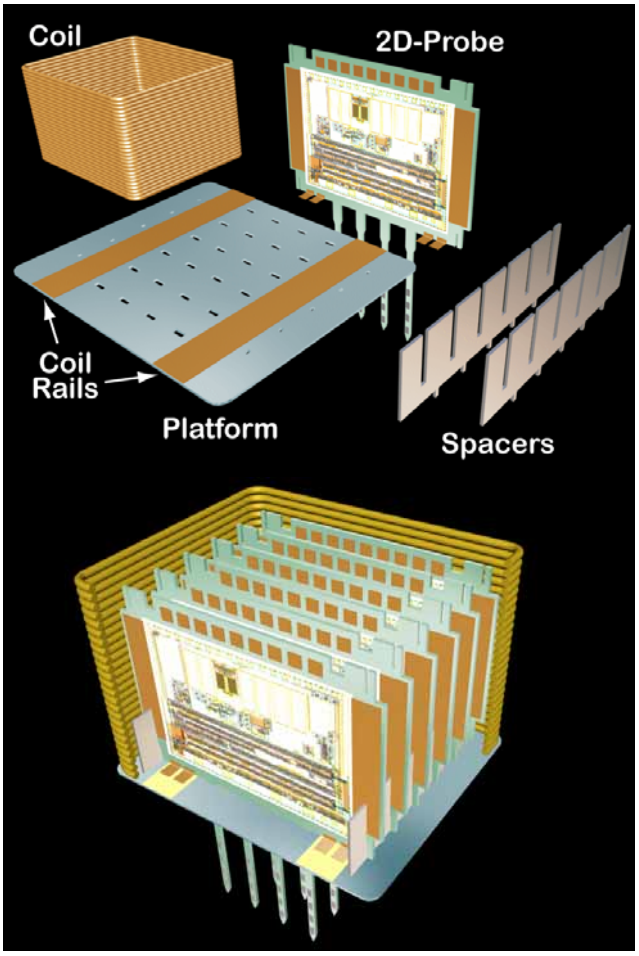

Fig. 10: Interestim-3 microassembly components with an assembled probe.

IV. Conclusion

Our goal is to develop a 1024-site intracortical wireless stimulating 3-D array for visual or auditory prosthesis based on UM micromachined silicon microprobe technology. We started with a wireless interface chip for the existing hardwired stimulating probes (Interestim-1 [7]) and carried on by a 4-channel stand-alone wireless stimulator chip (Interestim-2 [10]). Interestim-3 is a self-sufficient 16-site wireless active stimulating probe with a 6-bit internal address, which allows us to use up to 64 probes in parallel in a 3-D microstructure to achieve the above goal.

Table 1
INTERESTIM-3 PHYSICAL SPECIFICATIONS

Parameter	Value
Circuit size	5.3mm × 4.0mm
Back-end size	6.5mm × 5.0mm
Shank size	3.1mm × 60µm
Shank spacing	250 µm
Site area	181 μm^2
Number of sites	16
Transistors	4200
Estimated Power	15 mW

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