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An Optical Microsystem for Wireless Neural Recording

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Abstract—**In this paper, we describe an optical microsystem for wireless neural recording. The system incorporated recording electrodes, integrated electronics, surface-mount LEDs, and a CCD camera. The components were mounted on a PCB platform having a total dimension of 2.2X2.2cm^2 , 4 integrated biopotential amplifiers (IBA) and 16 LEDs. The IBAs having a bandwidth of 0.1-93.5Hz with the midband gain of 38 dB were fabricated using AMI 1.6µm technology. The simulated local field potentials (LFP) were amplified and used to drive the LEDs. A CCD camera with a temporal resolution of 30FPS was used to capture the image and retrieve the signal.**

I. INTRODUCTION

PARRALEL single-unit extracellular recording continues to be the dominant mode of interface with complex neural systems [1]. This is in part due to its superior spatial/temporal resolution compared to other methods such as fMRI and PET. Multi-unit extracellular recording, however, suffers from cabling/bandwidth bottleneck whenever one needs to send tens/hundreds of channels of data to the recording system (which is a must in state of the art neural interface systems). Extensive cabling requires miniature low-profile percutaneous connectors [2], whereas, wireless transmission can easily become bandwidth/power limited [3-6]. In this paper, we discuss a new scheme for transmitting parallel neural data using a free space optical link. Although, we present the proof of concept using a limited number of channels; in principal, this method can handle massively parallel transmissions if combined with a dense array of light emitting diodes (LEDs) which has recently been demonstrated using self-assembly methods [7].

II. OPTICAL RECORDING MICROSYSTEM

The wireless recording system includes silicon or metallic microelectrodes, integrated circuit interface circuit, surface mount LEDs, and a CCD camera, Figure 1. Each LED represents a pixel element that corresponds to a single recording site. A custom-made PCB houses the components and is used to connect the electrodes located on the bottom side of the PCB. Wire bonding of thin gold wire (100µm in diameter) is used to connect IC chips to the PCB, while the LEDs are surface mounted using conductive epoxy. The first prototype recording system reported here contains an array of 16 electrodes that is connected to 16 LEDs acting as individual pixel elements. The PCB interface can be fixed to the skull of a rat and a total of 16 channels can be recorded simultaneously using a CCD camera that is connected to a computer.

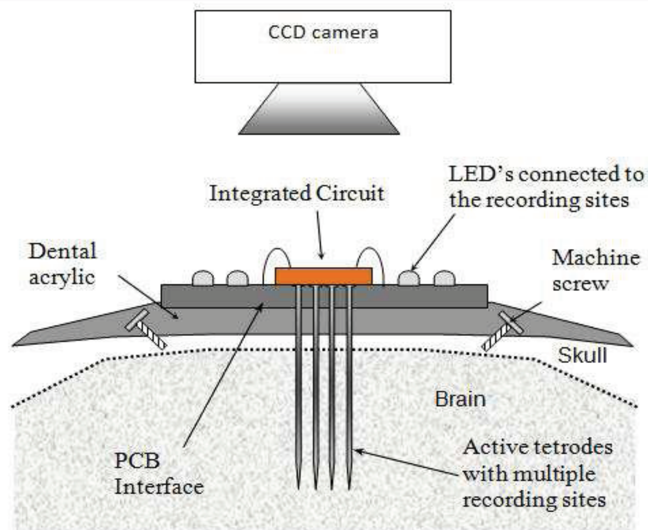

Figure 1. Schematic of the optical recording microsystem

Figure 2 shows a block diagram which explains how the neural signals can be recorded, amplified, and processed. The wireless neural recording microsystem contains three essential stages – neural/biological interface, electronic system, and optical recording stage.

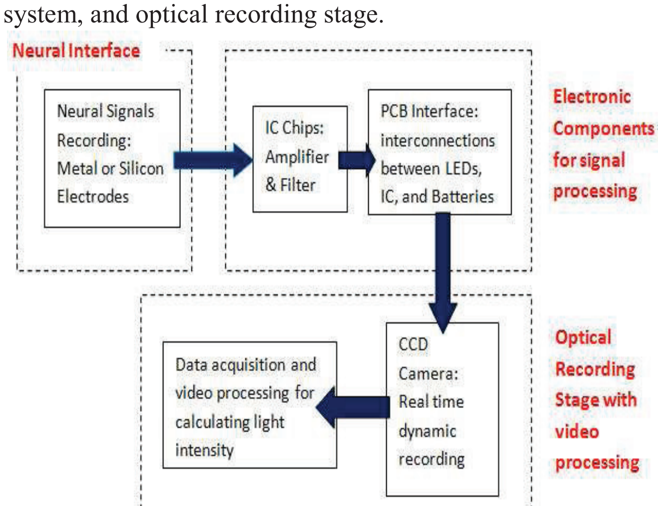

Figure 2. Block diagram of the microsystem.

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III. MICROSYSTEM MODULES

A. *Interface Integrated Circuit*

Multiunit extracellular recording mostly involves measuring Local Field Potential (LFP) which is generated by a group of neurons. LFPs are typically 10 mV (pp) in amplitude and have a bandwidth of 0.1 ~ 100Hz riding on a large DC offset (hundreds on mV) created by electrodes. Therefore an integrated biopotential amplifier (IBA) is essential for recording and observing the signal [8]. Although IBAs have been designed by various groups, none was optimized to record LFPs and drive an LED. We developed an IBA to record LFPs and drive an LED.

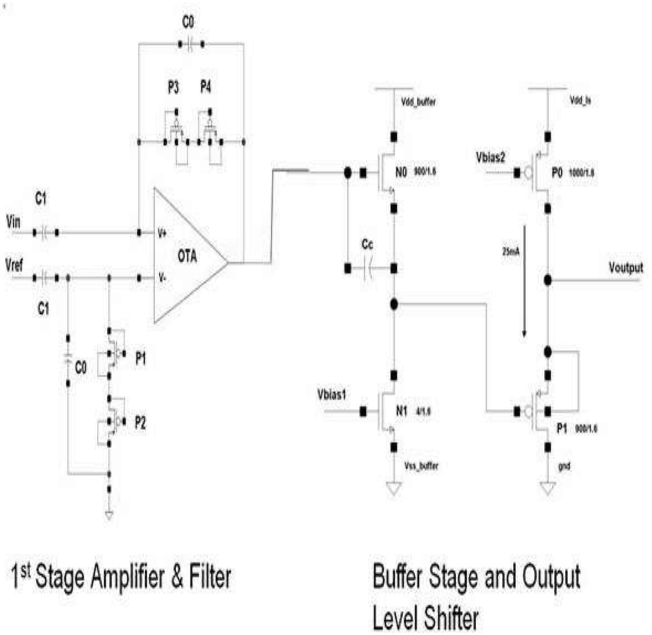

Figure 3. Integrated biopotential amplifier.

The amplified LFPs have to be able to drive LED loads operating at 1.6~2.4V with 20mA DC current. Figure 3 shows the schematic circuit diagram of the designed chip. It consists of a first stage amplifier that would amplify the input signal and filter out the large DC offset from the electrodes. The cascaded MOS–bipolar devices (P1, P2, P3, P4) are used as large resistors to create a low pole at mHz range and filter out the DC offsets. The mid-band gain of the amplifier is set by the ratio of C_1/C_0 = 30pF/0.2pF= 43.5 dB. The amplifier is followed by a source follower buffer and level shifter to create low output impedance from the first stage amplifier. The width of transistor N_0 (900/1.6) is designed to be large in order to reduce the output impedance seen by the level shifter. Capacitor Cc = 60pF is used for a OTA compensation. The DC operating point at output node is 1.96V with a DC current drive capability of 25mA. The two transistors P_0 (1000/1.6) and P_1 (900/1.6) again have large W/L ratio to create a low impedance at output to drive resistive LED load. The simulated circuit shows a bandwidth of 0.1-93.5Hz and a mid-band gain of 38 dB. The input impedance of the IBA was measured to be 5.3MΩ at 1kHz. The integrated circuit was fabricated through MOSIS (AMI 1.6μm). Figure 4 shows a micrograph of the fabricated chip with 4 amplifiers.

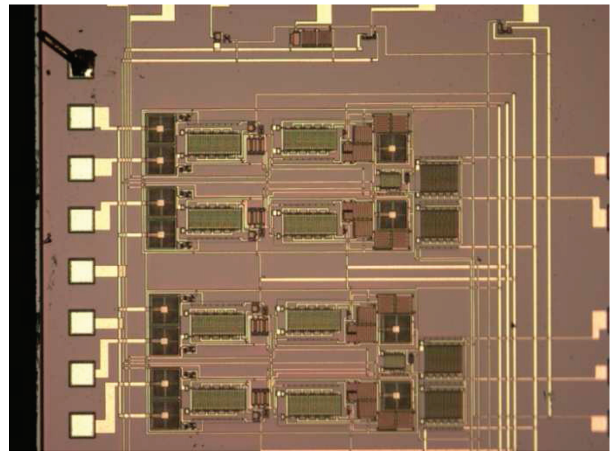

Figure 4. A micrograph of the fabricated chip (die size is 2.2x2.2 mm^2)

B. *Platform Design and Assembly*

A four layer printed circuit board (PCB) was designed and populated by 16 surface mounted LEDs (distance between the LEDs is 2mm) and four integrated chip (each containing 4 amplifiers) achieving a small foot print area of 2x2 cm^2. Figure 5 shows the LEDs and amplifiers connected to the PCB using silver epoxy and wire bonds, respectively.

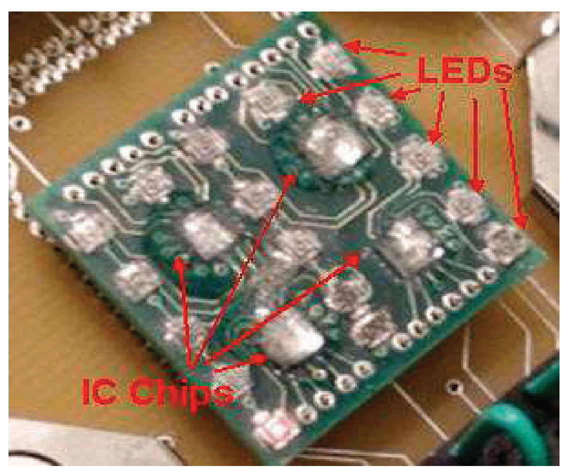

Figure 5. Platform Assembly.

IV. RESULTS AND DISCUSSION

After assembly, the system was mounted onto an interface board for *in-vitro* tests, Figure 6. DC power was supplied by four 3V batteries and two voltage regulators (LM2937, National Semiconductor). Neutrik Minirator MR1 was used to provide simulated neural signals (10mV peak-to-peak, 2Hz, sine wave) used as the input.

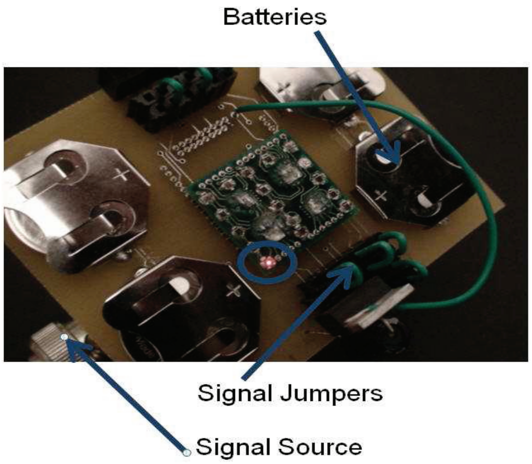

Figure 6. Testing board with illuminated LED

The illuminations of the LEDs were recorded with a CCD camera and stored as a video file with temporal resolution of 30 frames per second. Each frame was then extracted from the video for calculating the variations of light intensity. The light intensity of each LED driven by the neural signal was calculated with respect to a reference LED drive by a DC source. As can been seen, the variation of the light intensity represents a waveform of 2Hz sine wave, which corresponds to the input signal.

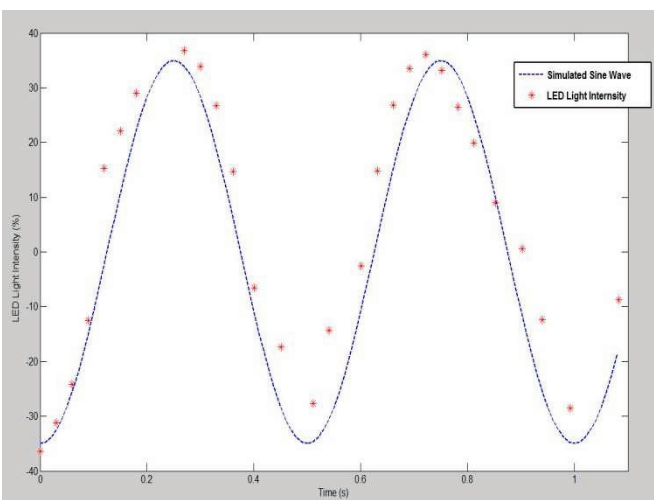

Figure 7. Variation of LED light intensity over one second (red dots: LED light intensity; blue line: simulated 2Hz sine wave)

V. CONCLUSIONS

In this paper, we successfully designed, fabricated, and tested an optical microsystem for wireless neural recording. The designed platform contained 4 biopotential amplifiers capable of driving 16 LEDs whose output were captured by a CCD camera. Through in-vitro experimental results, we demonstrated the capability of the system to faithfully record simulated local filed potentials.

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