8-Channel Optical Stimulus & 16-Channel Chopper Technique Recording: A Dual-Module Neuromodulation Integrated System

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Introduction

- Precision in stimulation parameter control is fundamental for effective neuromodulation, where factors like charge balance, electrode stability, and electromagnetic compatibility directly determine stimulation efficacy and safety. While electrical stimulation faces these inherent challenges, emerging optical stimulation techniques offer superior artifact rejection and cell-type specificity, enabling cleaner signal acquisition during closed-loop neuromodulation.
- Faithful control of stimulation demands equally sensitive recording and amplification module, especially for low-frequency bioelectronic small signals typically in the range of several tens of microvolts. In practice, noises of the system, including flicker noise, thermal noise and the input offset voltage of the amplifier would be mixed with the input signal together to be amplified, which would dramatically decrease the signal-to-noise ratio (SNR) at the output.
- In this study, a neuromodulation integrated circuit (IC) system that includes an 8-channel optical stimulation module and a 16-channel recording module is proposed. The optical stimulation system is based on a switched current mode DAC, while the recording module utilizes a chopper amplifier. Simulation results demonstrate that the driving current can be adjusted from 14 µA to 29 mA for the stimulator, and the recording module achieves a 34 dB gain, 20 kHz bandwidth, and 6.951 µVrms input-referred noise.

Methodology

- The neuromodulation IC system, illustrated in Fig. 1, features an eight-channel LED stimulator and a sixteen-channel chopper amplifier. The stimulator module is based on a switched current mode digital-to-analog converter (DAC), capable of driving customized micro-LEDs for optical stimulation. To record very weak neural signals, the recording module adopts a chopper amplifier structure that offers lower noise compared to the normal amplifier structure. The entire IC system is designed using the TSMC 65 nm GP process.
- Input a 500K Hz sine wave with its amplitude equals to 100u V. Set the frequency of the chopper and LPF to be 0.1M and 1M Hz accordingly.

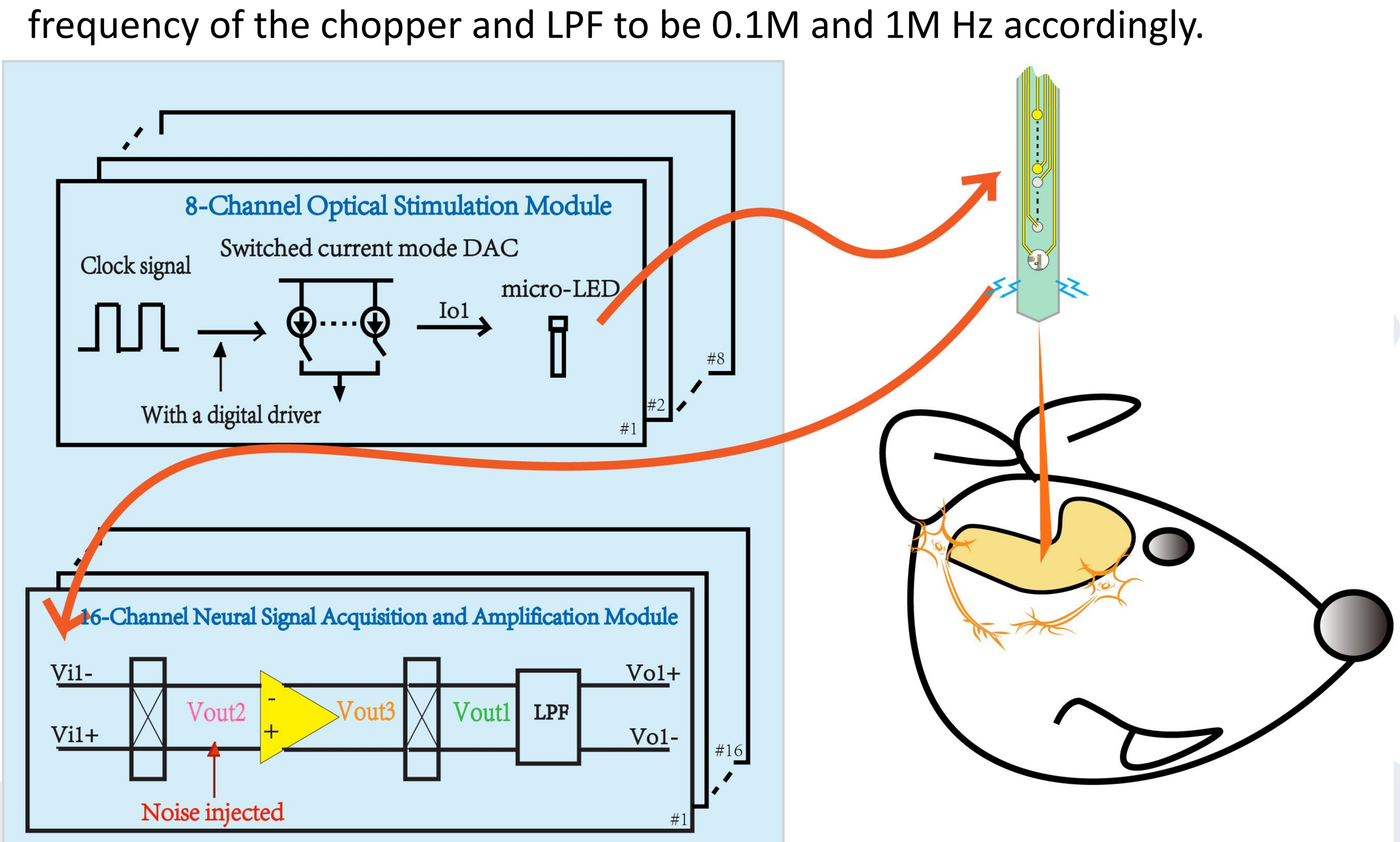

Fig. 1. Structure of the dual-module neuromodulation integrated system.

Conclusions

- This study introduces a multi-channel neuromodulation IC system based on a switched current mode DAC and chopper amplifier. By employing chopper techniques and gm/Id design methods, the recording module achieves lower input-referred noise and better noise-power efficiency.

Future Perspective:

- Stimulator: Transient currents may arise from photoelectric phenomena, these artifacts should be addressed.
- Recording: Compensation of two main leakage currents needed, reverse-biased diode leakage in Pseudo-R through a dummy deep N-well NMOS and the bulk leakage current of the chopper switches through a bias-adjusting amplifier.

References

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[2]Xia Y, Zheng R, Wang L, Zhang A, Li D, Wu Y, Gao Y, Xu Y, Zhang B, Li H, et al. A 4-Channel Optogenetic Stimulation, 16-Channel Recording Neuromodulation System with Real-Time Micro-LED Detection Function. Electronics. 2023; 12(23):4783.

Discussion & Results

Stimulator Circuit

- As shown in Fig.2, the customized blue light micro-LED was tested for its electrical characteristics, which has a turn-on voltage of 2.5V. Under the condition when the current is 10mA, the voltage between the cathode and anode of the LED is approximately 3V, and the optical power density shows 2.3mW/mm² .
- On the strength of a programmable 6-bit switched current mode DAC, the stimulator allows precise stimulation by adjusting the input clock signal, thereby controlling the micro-LEDs' output light intensity.

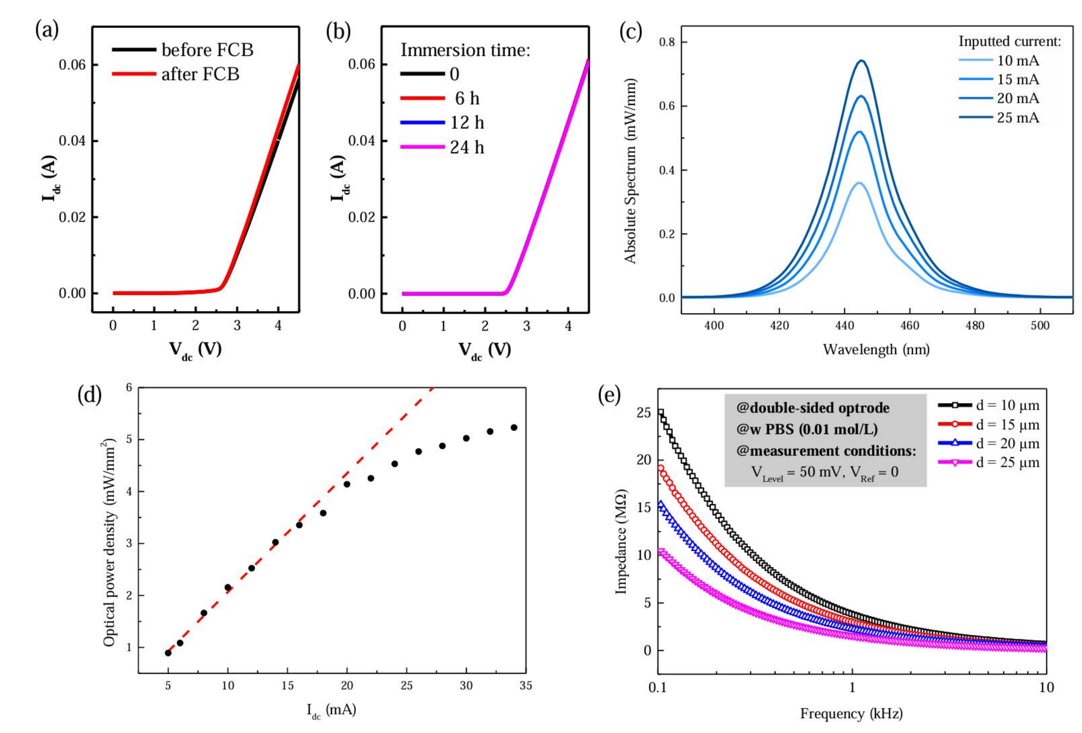

Fig. 2. Electrical characteristics of the customized blue light microLED.

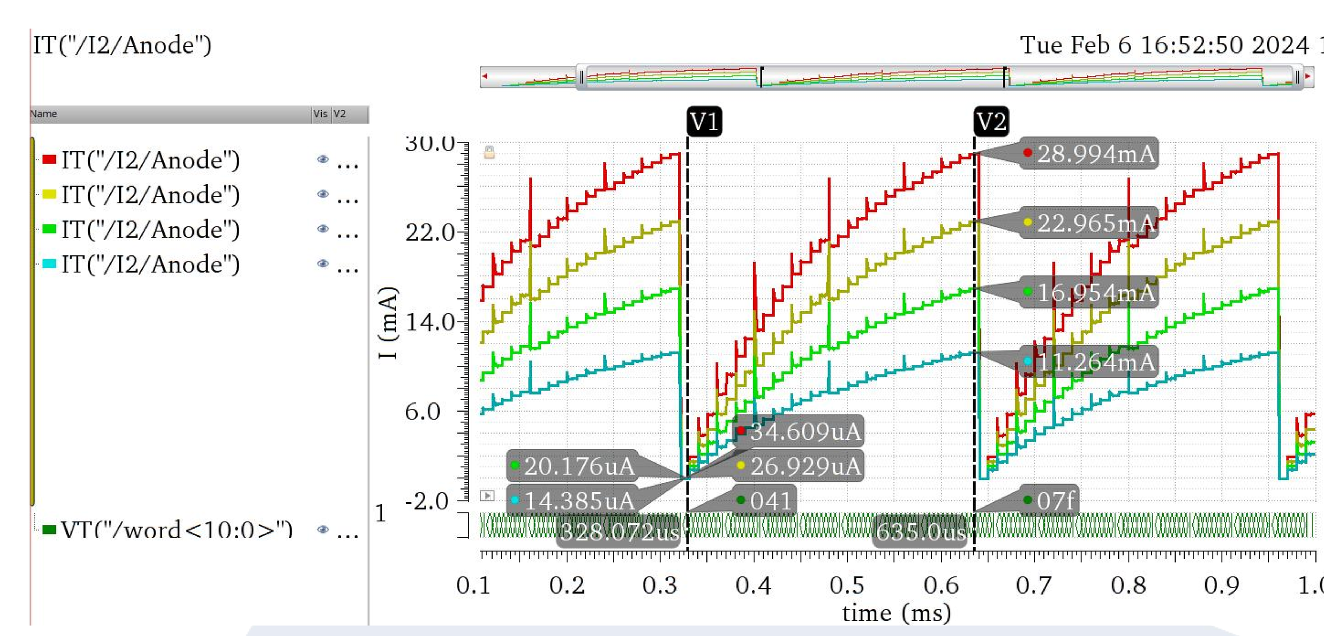

Fig. 3. The adjustable driving current of the stimulator.

Recording Circuit

- The system employs a chopper amplifier as a front-end amplifier, which separates circuit noise and neural signals into different frequencies, enhancing the signal-to-noise ratio (SNR).
- The input MOSFET of the amplifier is designed with a larger gm/Id to improve noise-power efficiency, while the current mirror MOSFET is designed with a lower gm/Id for precise current mimicry. Although the chopper amplifier reduces circuit noise, it introduces chopper glitches in the output signal. To mitigate these glitches, a switched capacitor-based filter is connected to the chopper amplifier.

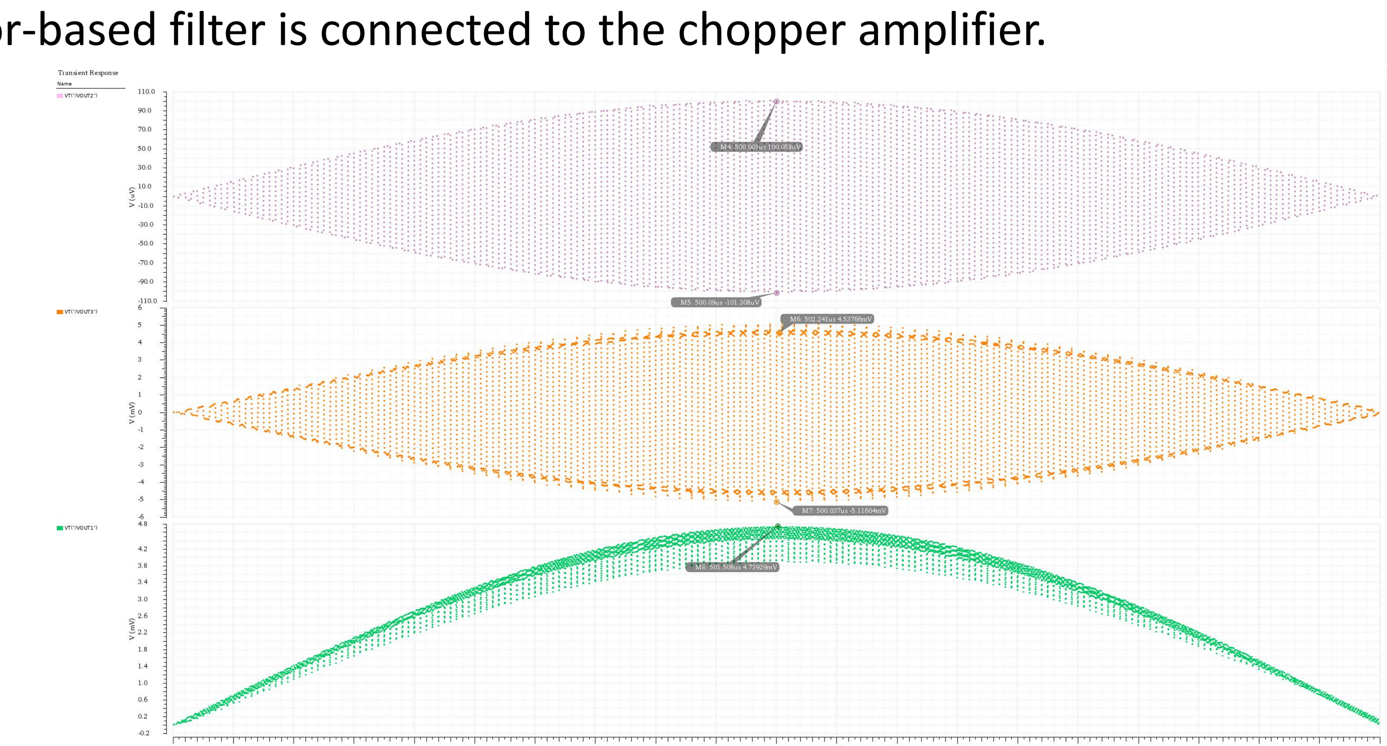

Fig. 4. The transient signals of 1ms in different stages.

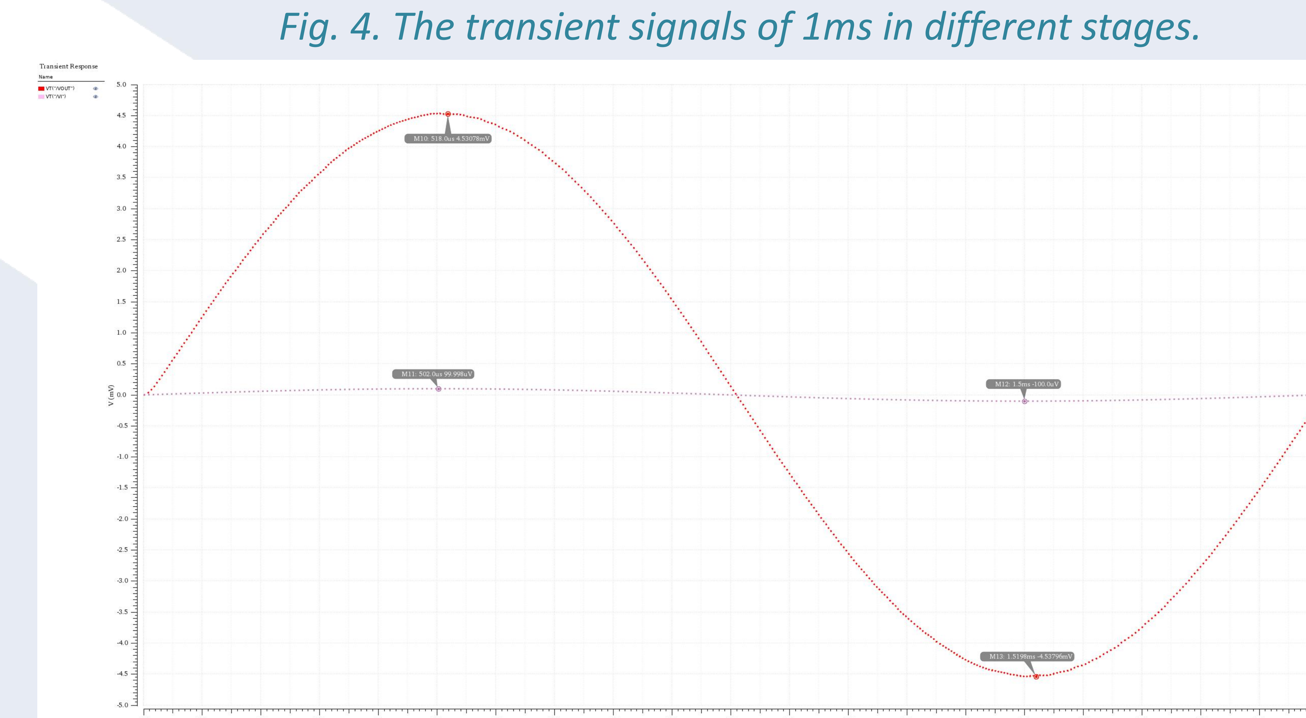

Fig. 5. The output/input signal with 34 dB gain.