PTAT Current Sink Driver

Cole Helms and Kevin Egedy

***Abstract*—Overview of the design decisions and challenges for a PTAT current source driver using 65nm TSMC PDK technology.**

I. Introduction

A challenging aspect of neural stimulation is accurately delivering charge to a cluster of nerves. Driver electronics must minimize loading effects due to the high-impedance of an implantable neural electrodes. This writeup discusses the method and implementation of a maximum output impedance source driver, on the order of Gigaohms (GΩ).

A. Objective

Design a PTAT current sink driver with largest output impedance possible. Assume I_{source} is an ideal current source.

Output Impedance	>	1GΩ
Bandwidth	>	1kHz
V_{DSat}	>	100mV
V_{DD}	=	2.5V

The accuracy of the current source is verified by integrating the positive and negative current pulses. A well-designed sink source will have approximately equivalent charge.

B. Problem Statement

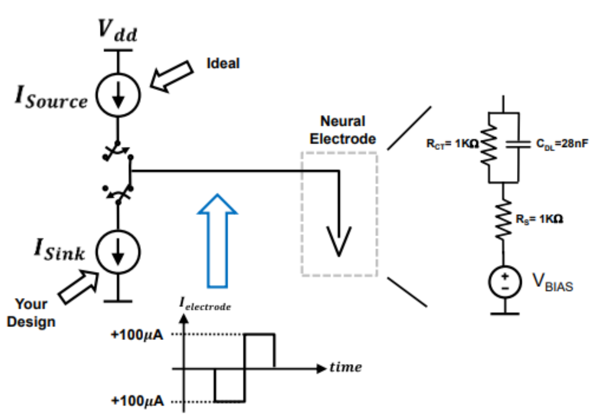

Fig. 1: Top Level Diagram

The sink and source currents are specified to 100μA. Additionally, the electrode equivalent circuit is provided in the top level diagram of figure 1. It is expressed as

$$R_{Electrode} = \left(R_1 // \frac{1}{j\omega C_1}\right) + R_2$$

$$R_{Electrode} = \frac{R_1 + R_2 + j\omega C_1 R_1 R_2}{1 + j\omega C_1 R_1}$$

The electrode exhibits a large resistance at low frequencies. However, it quickly diminishes and has magnitude of approximately 35KΩ at 1kHz.

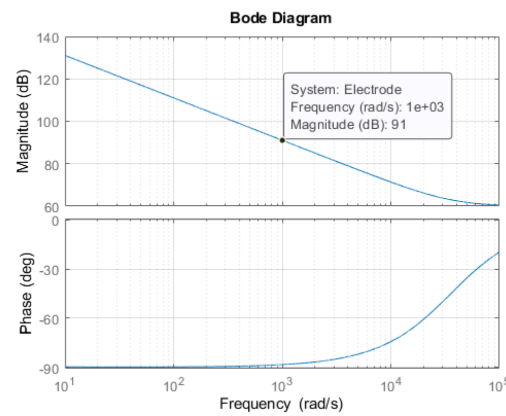

Fig. 2: Electrode Frequency Response

II. Design

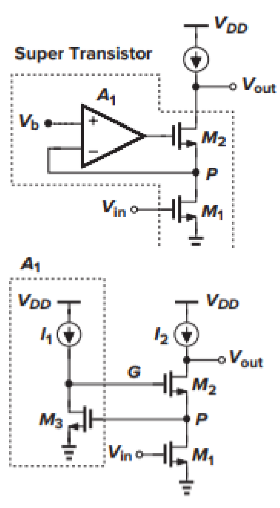

Fig. 3: Gain-Boosted Cascode

The gain boosted cascode is desirable for this application in order to achieve a very large output resistance. Given ideal current sources,

$$|A_V| = G_m R_{out}$$

$$|A_V| \approx g_{m1}\left[r_{02} + (A_1 + 1) g_{m2} r_{02} + r_{01}\right]$$

$$|A_V| \approx g_{m1}\left[g_{m2} r_{01} r_{02} A_1\right]$$

Thus the output resistance is seen as the cascode output resistance multiplied by the gain. The cascode amplifier and PTAT current source are investigated to determine how much gain needs to be designed around.

A. *PTAT Current Source (100μA)*

The PTAT current is defined as the current through R_1, $I_{bias} = \dfrac{V_T ln(n)}{R_1}$ where n is the number of devices.

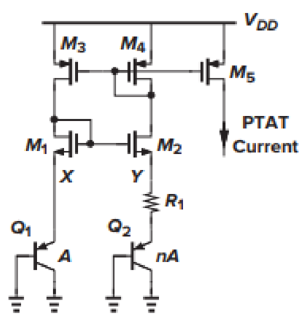

Fig. 4: PTAT Current Source

R_1 is swept to find desired current of $100\mu A$. In this implementation, n is chosen to be 2 and R_1 is determined to be 2.2 kΩ. The PTAT current is matched to the cascode output and shown in figure 5.

Name	Device	W	L
Q1	pnp	5u	5u
Q2	pnp	5u	5u
M0	nch	2u	1.4u
M1	nch	2u	1.4u
M2	pch	2u	1.4u
M3	pch	2u	1.4u
M4	pch	2u	1.4u
M5	pch	2u	1.4u

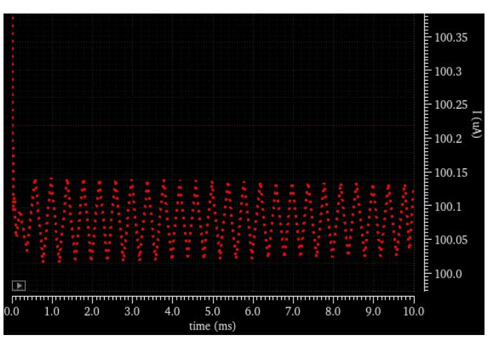

Fig. 5: Measured Cascode Current

B. *Telescopic Amplifier*

The ideal gain is defined as

$$A_v = g_{m1}(g_{m2}r_{04}r_{05}||g_{m6}r_{06}r_{07}) = 3778$$

The measured gain is 3557, which accounts for the losses due to the tail current source and non-ideality.

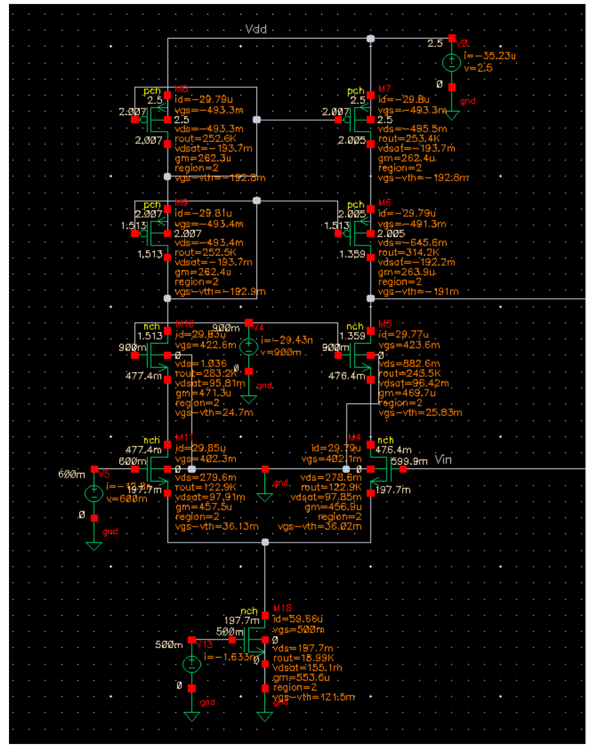

Fig. 6: Telescopic DC Operating Point

Name	Device	W	L	gm	rout
M4	nch	12u	750n	456.9u	122.9K
M5	nch	12u	750n	469.7u	243.5K
M6	pch	9u	750n	263.9u	314.2K
M7	pch	9u	750n	262.4u	253.4K
M8	pch	9u	750n	262.3u	252.6K
M9	pch	9u	750n	262.4u	252.5K
M10	nch	12u	750n	471.3u	283.2K
M11	nch	12u	750n	457.5u	122.9K
M18	nch	2u	200n	553.6u	18.99K

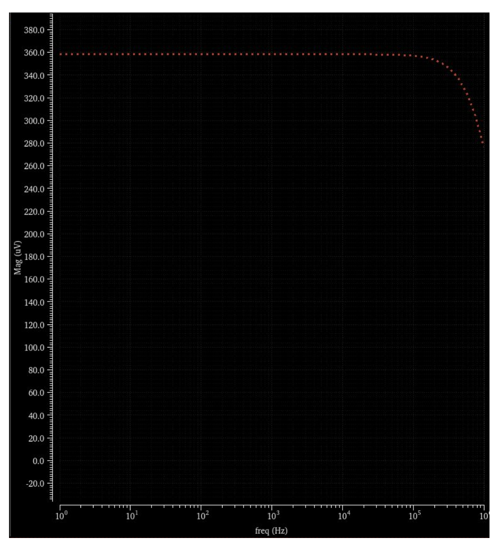

Fig. 7: Telescopic AC Response

Source	V_{Bias}
V4	900m
V5	600m
V13	500m

C. Gain-Boosted Cascode

The cascode is initially analyzed to provide a baseline output impedance. Different device sizes are tested to maximize the impedance while maintaining the PTAT current.

Name	Device	W	L	gm	rout
M19	nch	1.57u	600n	397.8u	65.78K
M20	nch	2u	1.4u	275.2u	50.03K

The output resistance is calculated to be

$$g_{m2}r_{01}r_{02} = 516u \cdot 85K \cdot 53K = 2.32M\Omega.$$

Adding the telescopic op amp, the expected resistance is

$$A_v g_{m2}r_{01}r_{02} = 3500 \cdot 516u \cdot 85K \cdot 53K = 8.14G\Omega.$$

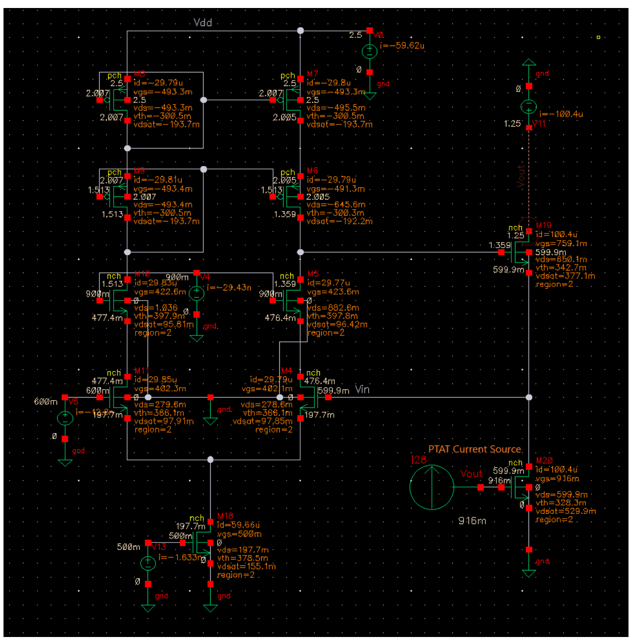

Fig. 8: Gain-Boosted Cascode Schematic

III. Results

The simulation of all the components discussed resulted in approximately 7 GΩ, as seen in figure 9.

Finding R_{out} took considerable fine tuning of the cascode parameters. Each stage required additional tuning as it was combined into the full circuit. The measured output resistance does not perfectly match the the calculations, however it is close and is easy to see where error may have occurred due to approximations.

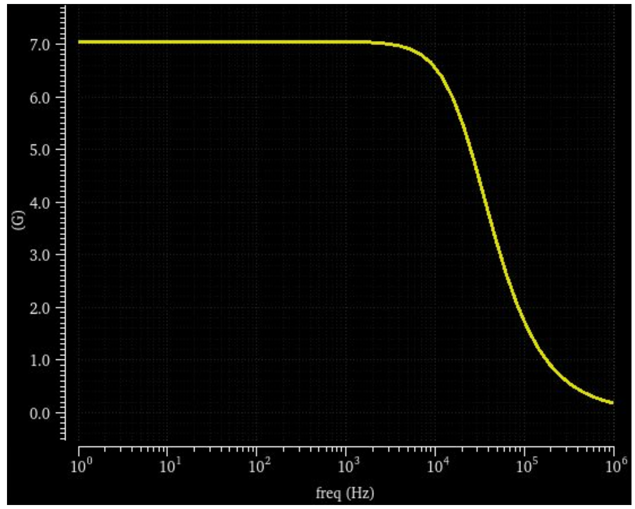

Fig. 9: Current Sink R_{out}

The electrode model is attached and tested for the complete functionality of the current sink driver. The transient simulation is analyzed to see how well the current source matches. This was challenging due to the trapezoidal ringing in the sink driver. It required long simulation times to compute the response and is visible at the end of the transient response.

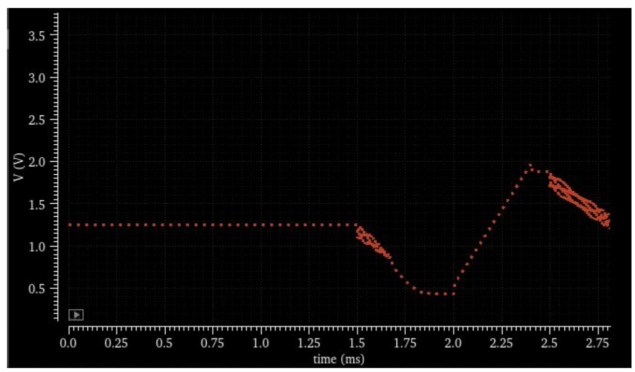

Fig. 10: Current Sink Transient Response

IV. Conclusion

This project required a great investment and resulted in a lot of lessons learned. Multiple iterations were performed in order to achieve an efficient design. We found bringing together different elements particularly challenging. Multiple variables required re-tuning due to mismatching. The transient response wasn't perfectly matched to the ideal current source, since the measured current into the electrode was not equivalent to the source driver. Ultimately, this results to increased voltage of the electrode.

In the next iteration, we'd like to further investigate the electrode model to understand the current sink circuit. We had a difficult time correctly simulating the sawtooth even with ideal current sources and switches. In order to achieve matched current, the PTAT current sources needs to be increased. In addition, we believe more gain can be extracted from the op amp by changing the device sizes drastically, but it would require a full redesign and re-biasing to achieve this and so was not possible for this project.