Circuits Final Project: Adaptive Biasing Differential Amplifier

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Background information

In the final lab of Intro to Microelectronic Circuits we built a differential amplifier. This amplifier had a constant bias current, I_b which limited the speed at which the amplifier could respond to large changes in input (its slew rate). For our final project, we decided to build a similar circuit with an increased slew rate by adding a method of adjusting bias current to the original circuit. This is done by adding two current subtractors to the previously built circuit. A subtractor has two inputs, I_1 and I_2, with output $A(I_1 - I_2)$, where A is a variable known as the current feedback factor. A is determined by the characteristics of the transistors used in the circuit. By using two current subtractors (one for $I_1 - I_2$ and one for $I_2 - I_1$) the outputs from the two subtractors are added to the current I_b, therefore adjusting the bias current when necessary.

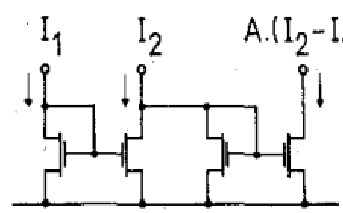

Figure 1: Current subtractor (1)

Schematic

We built the adaptive biasing CMOS amplifier on bread boards and did simulation work in LTSpice to specifically examine the current subtractors in more depth. Figure 2 on the following page is the schematic of the circuit we built. Figure 3 on the next page is the schematic we used for simulations. We added a capacitor of 10pF and changed V^- to V_{out} to have unity gain for those.

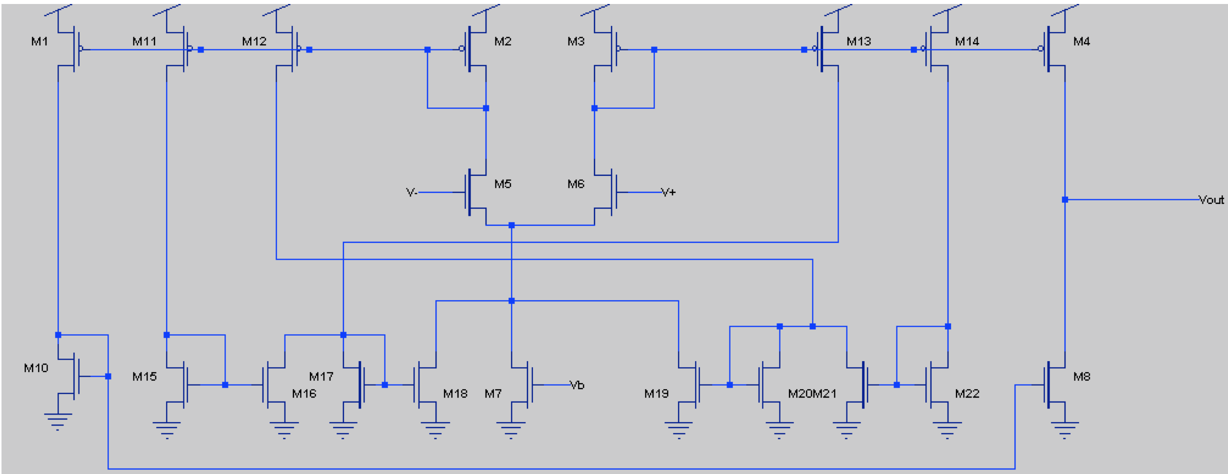

Figure 2: Schematic for the Adaptive biasing CMOS Amplifier

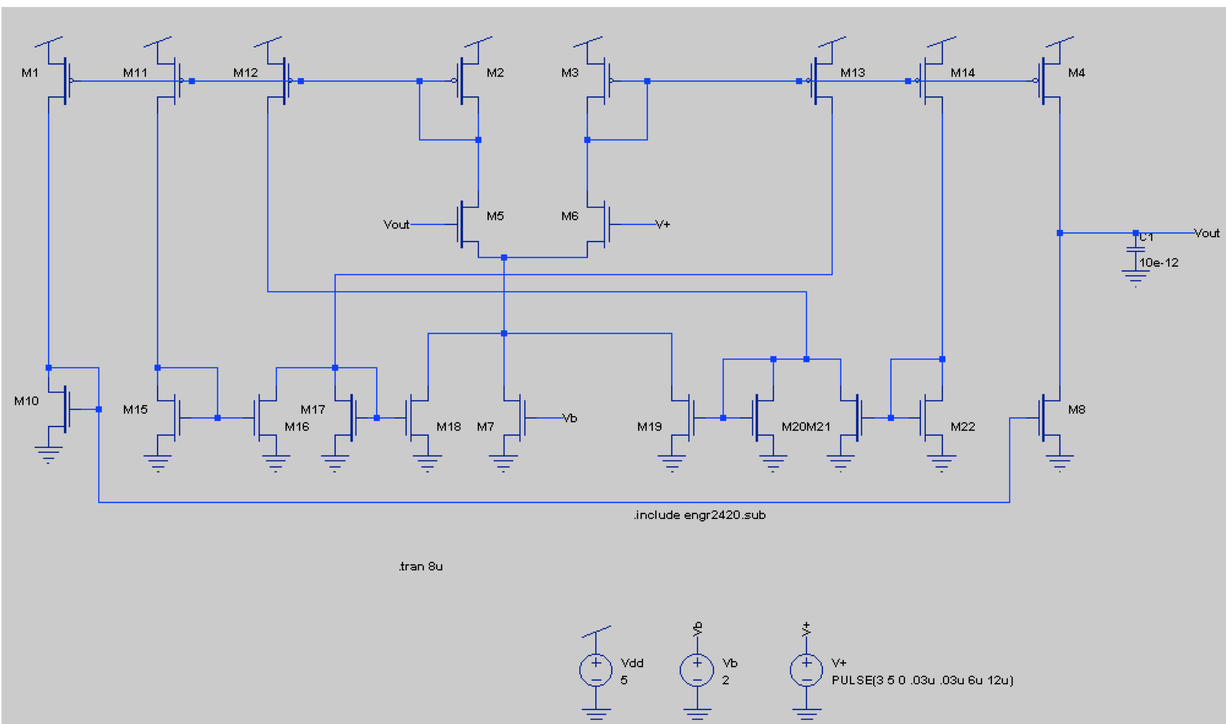

Figure 3: Schematic for the Adaptive biasing CMOS Amplifier used for LTSpice simulation

Results

Figure 4 on the following page shows the voltage transfer characteristics that we measured for our circuit with and without adaptive biasing. We observed rail to rail behavior for both circuits, with a sharp increase at 2.5 V as predicted since we set V^- to 2.5 V. With the addition of adaptive biasing, the VTC displayed a linear region between $V^+ = 1.5V$ and $V^+ = 2.4V$. This could be due to some of the transistors falling into the Ohmic region.

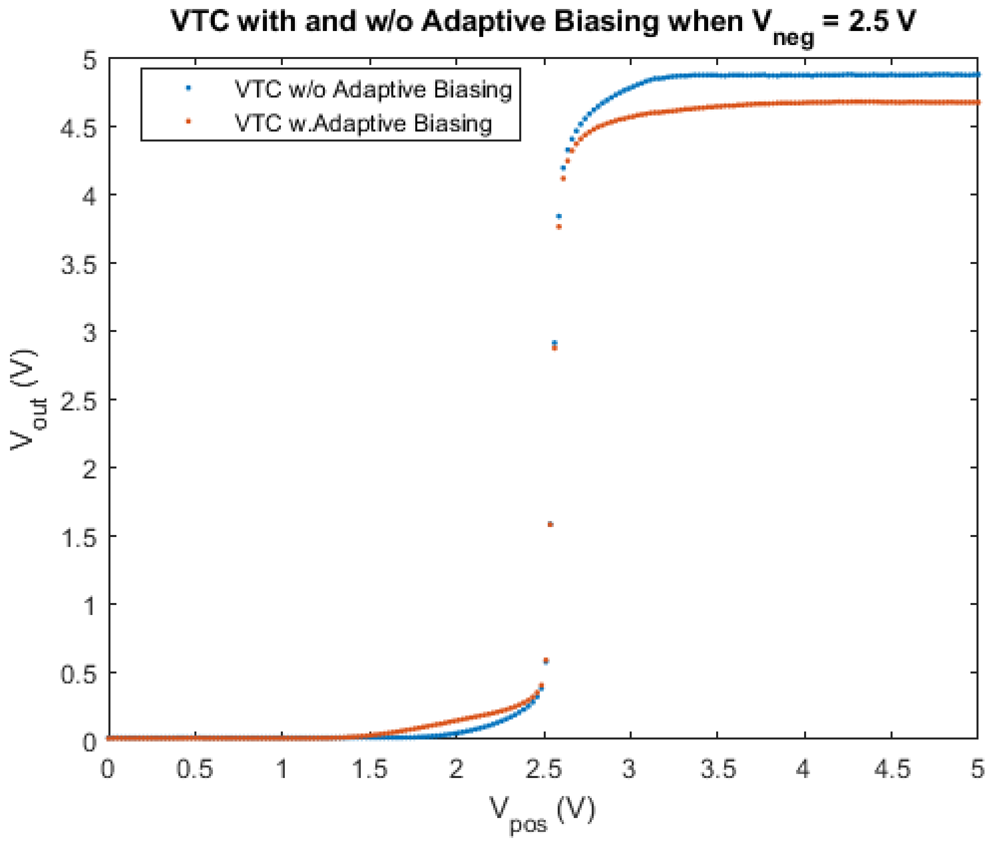

Figure 4: Voltage Transfer Characteristics of circuit with and without adaptive biasing when V^- is set to 2.5 V

In Figure 5 on the next page, the behavior of the circuit with and without the subtractors can be seen. In lab 9 we determined that when V_{out} is fixed in the middle of the rails, I_{out}, ignoring the Early Effect, can be approximated as $I_{out} = -I_b$ when $V^+ << V^-$ and that $I_{out} = I_b$ when $V^+ >> V^-$. The range of I_{out} is significantly increased with the addition of adaptive biasing due to increase in I_b the biasing provides. Because V^- goes through two mirror stages, it has a systematic current gain of slightly more than 1 due to the Early effect. This means the negative current asymptote ($V^+ << V^-$) is somewhat larger than the positive current asymptote. This behavior is exaggerated with the addition of the current subtractors.

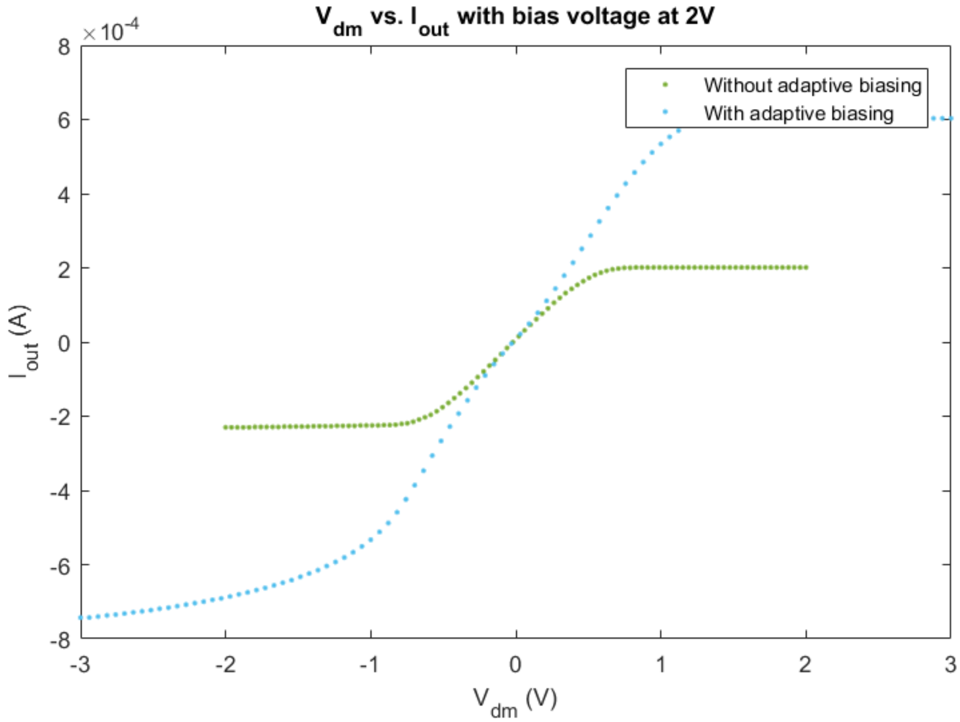

Figure 5: With V^- and V_{out} set to 2.5 V, this graph shows I_{out} as a function of V_{dm}.

To examine the effect of our current subtractors on slew rate we tied V^- to V_{out} to make a unity gain amplifier. We input a square wave at $5kHz$ to V^+ and examined the response of V_{out}. This is shown in Figure 6 on the following page.

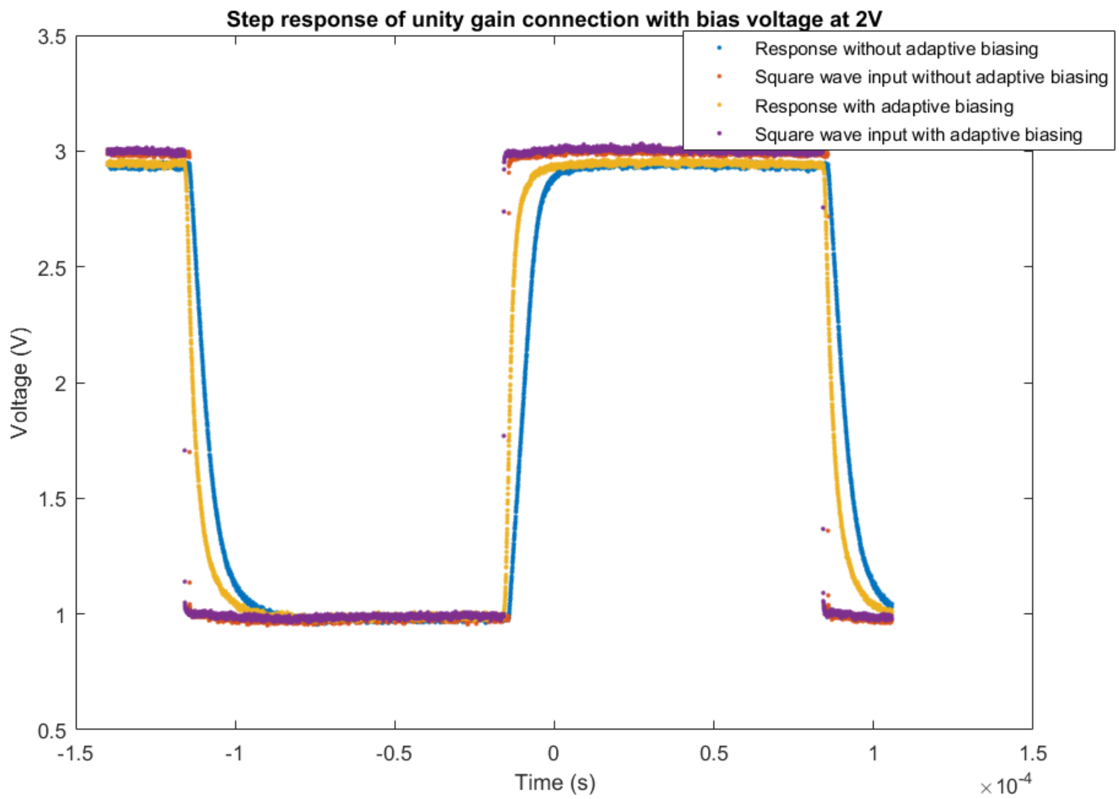

Figure 6: With the differential amplifier connected in unity gain (V^- tied to V_{out} this graph shows the response V_{out} to a square wave input to V^+.

The result of adaptive biasing was a considerable improvement in time for the output to reach steady state:

	Time to reach steady state. (s)	Slew rate ($\frac{V}{s}$)
Without adaptive biasing	1.40e-05	1.99e5
With adaptive biasing	9.63e-06	5.93e5

These values showed addition of the current subtractors decreased the time to reach steady state by a percent difference of 37.1% and increased the slew rate by a percent difference of 99.4%.

Learnings

A significant part of this project was learning about current subtractors, and how they can be used in circuits to calculate the difference between two currents and manipulate other currents in the system based off of that. We simulated the adaptive biasing differential amplifier circuit in LTSpice to observe current subtractor characteristics. Figure 7 on the next page shows the square wave input and step response that we simulated. Figure 8 on the following page shows the result of the current subtractor formed by transistors M15 - M18.

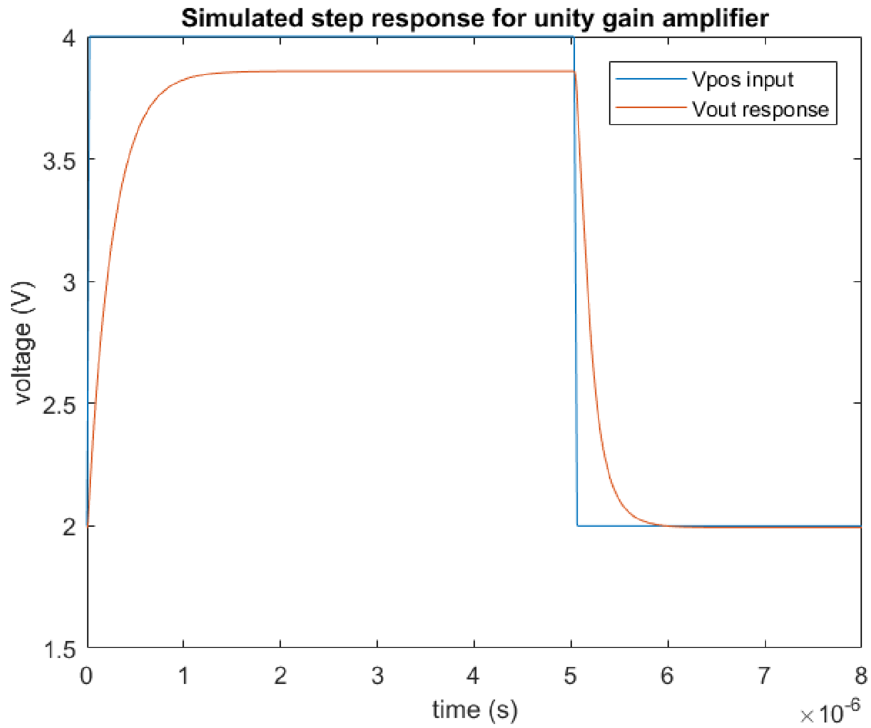

Figure 7

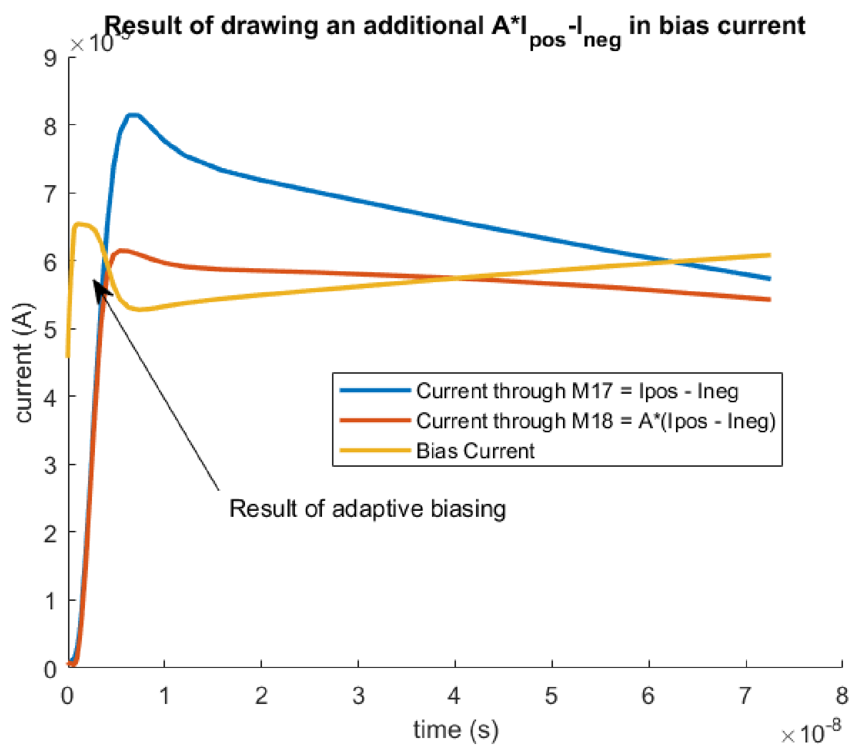

Figure 8

The result of this simulation revealed that A is less than 1 which means the slew rate change we calculated in the previous section is valid. Having an A of greater than 1 would mean the maximum bias current would be unlimited and the differential amplifier would never slew (theoretically).

A eulogy to the differential difference amplifier

Forgotten but not gone.

DDA was the light of our lives.

The differential amplifier was first born in 1934 to British neurologist Bryan Matthews and has only grown since then.

Its love for life, much like its input resistance, was theoretically infinite.

But DDA had a lot to deal with- both differential and common large signals. DDA was always so great with the high voltage technologies...

But DDA was steadfast through it all.

Even as a little freshman, I remember it making me laugh so much I would nearly cry and making me cry so much I would nearly laugh. It had a wicked sense of humor that rubbed off on anyone that was near it and would surprise us with its behavior all the time.

No one was upset around DDA for too long—although it did have its serious side, too, of course.

There are so many great memories with DDA and it saddens me that my close friends and relatives may never get the chance to meet DDA. They would have loved it.

Goodbye, DDA. You will always live on in our hearts.

References

1. M. G. Degrauwe, J. Rijmenants, E. A. Vittoz and H. J. De Man, "Adaptive biasing CMOS amplifiers," in IEEE Journal of Solid-State Circuits, vol. 17, no. 3, pp. 522-528, June 1982.