Evolution of a Folded Floating-Gate Differential Pair

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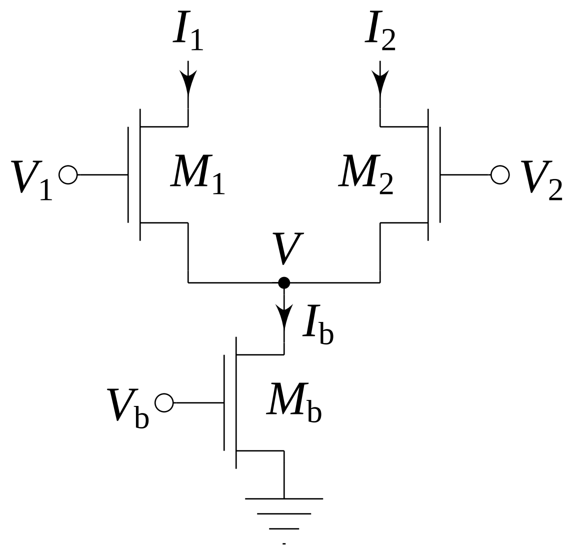
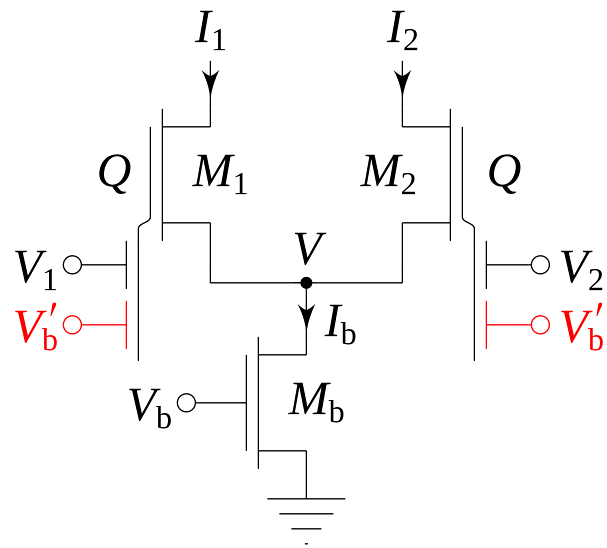
Conventional Differential Pairs

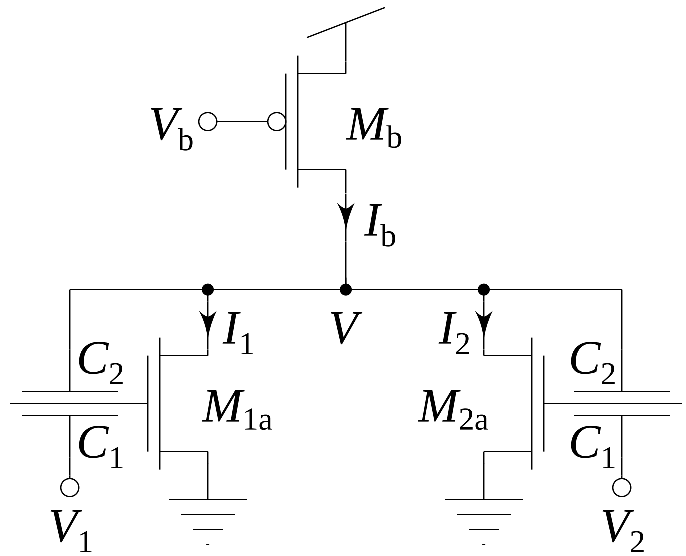




Differential-pair intuition:

- $I_1 = f(V_1, \text{-}V)$ and $I_2 = f(V_2, \text{-}V)$, where f is expansive.
- V adjusts itself so that $I_1 + I_2 \rightarrow I_b$.

A Folded Floating-Gate Differential Pair



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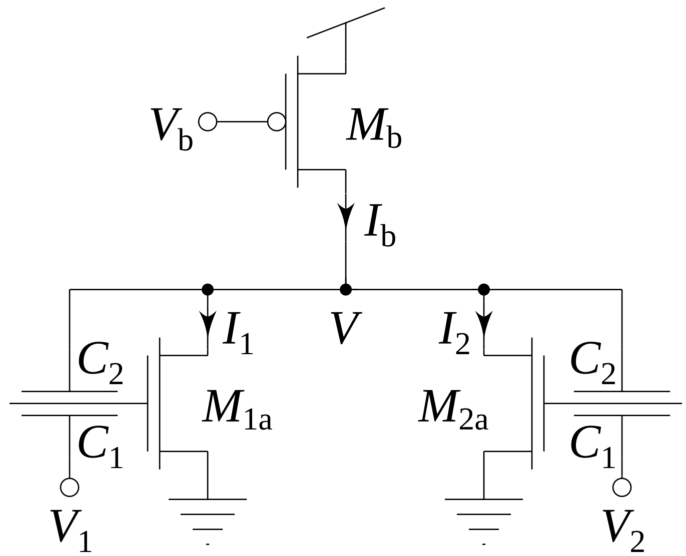

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Sign difference permits us to *fold* M_b relative to M_1 and M_2.

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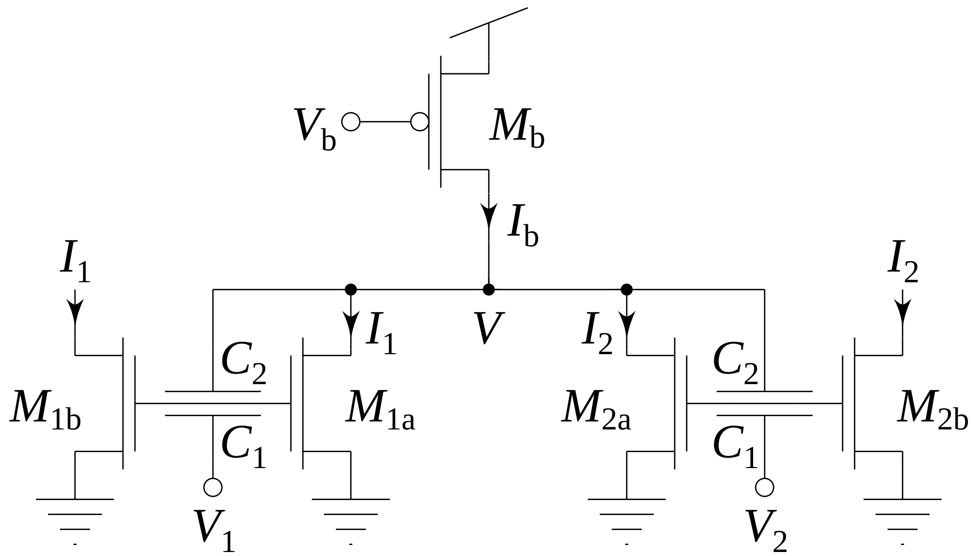

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M_{1b} and M_{2b} provide mirror copies of I_1 and I_2.

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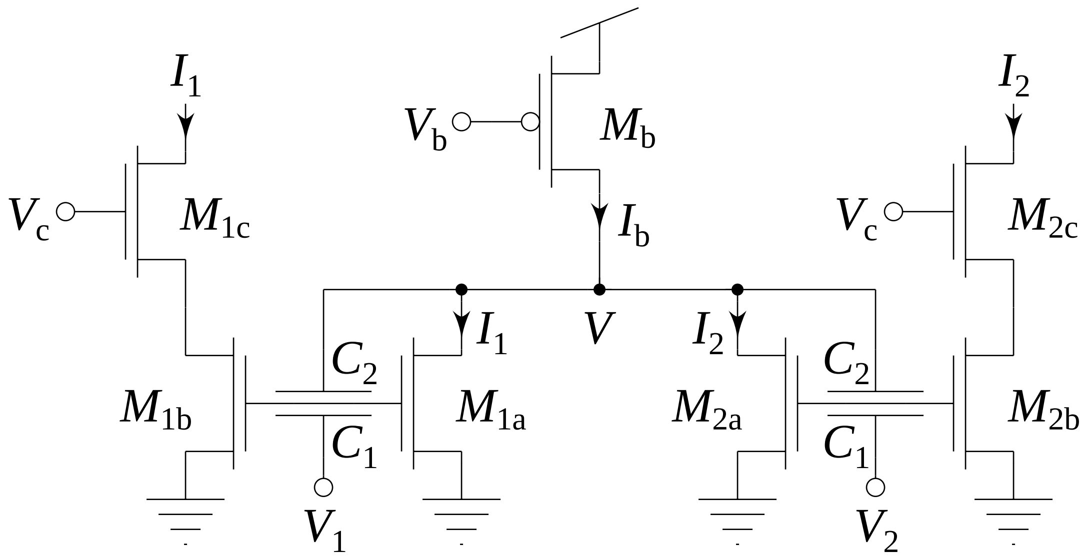

Differential-pair intuition:

- $I_1 = f(V_1, V)$ and $I_2 = f(V_2, V)$, where f is expansive.
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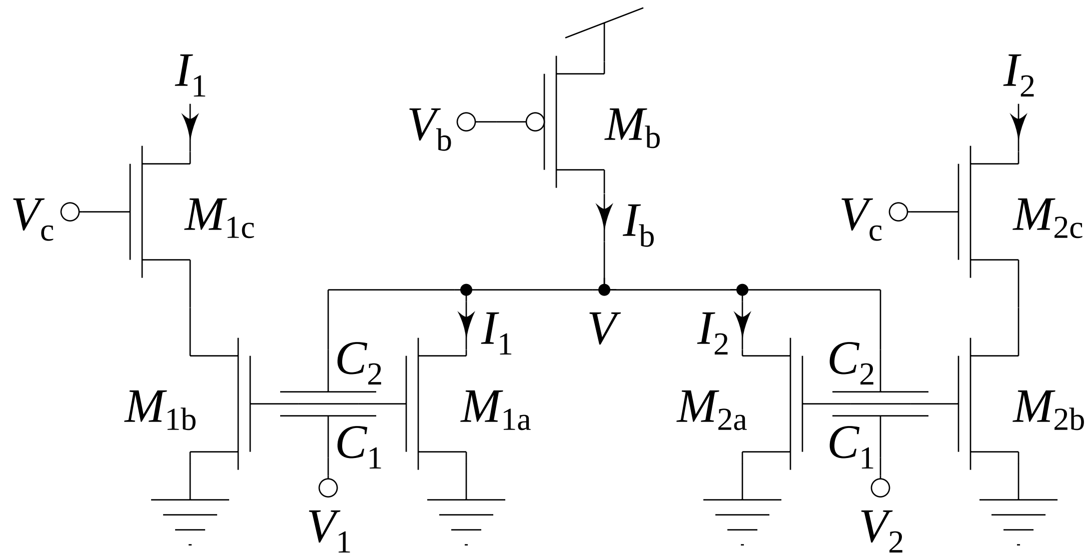
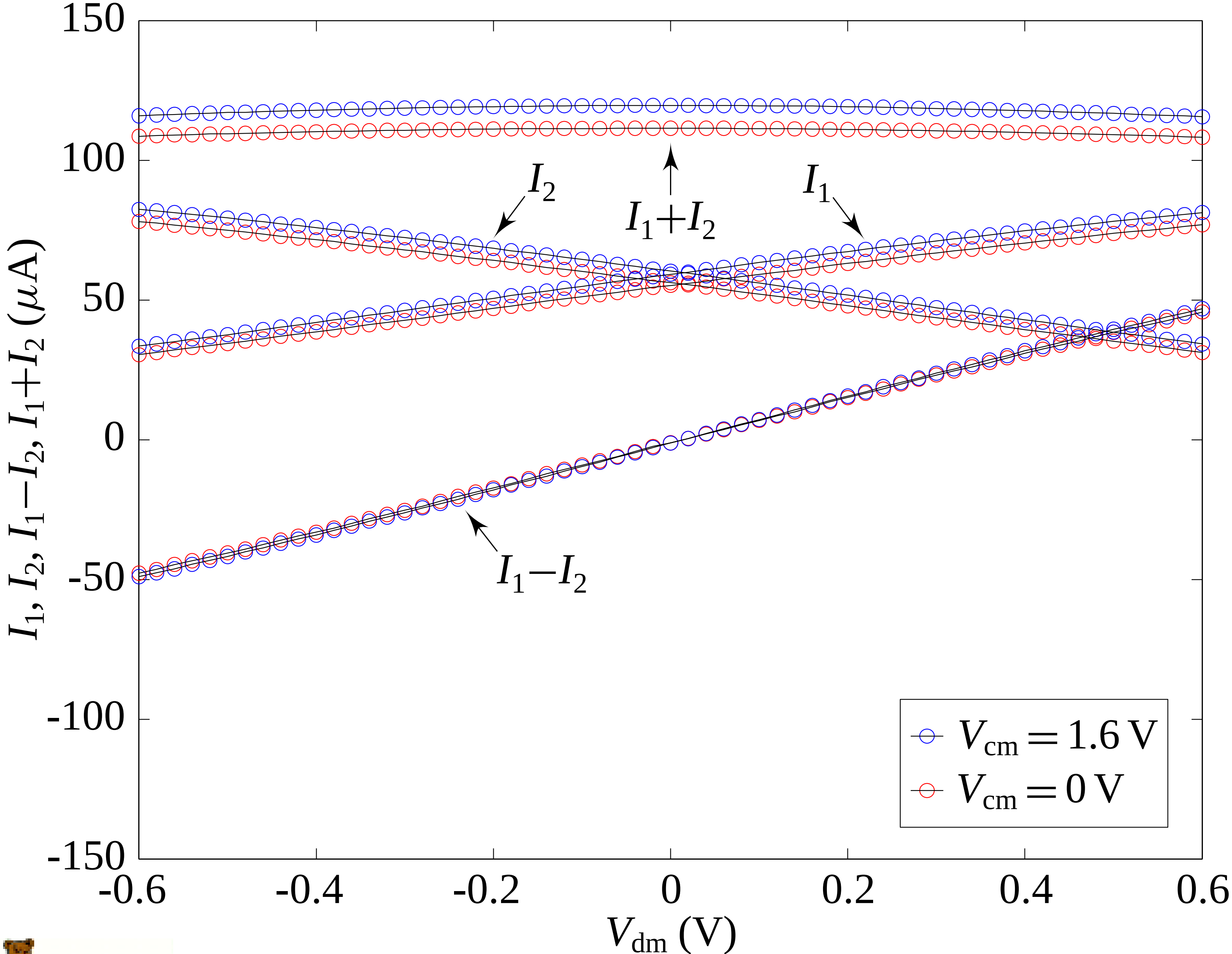
M_{1c} and M_{2c} mitigate the C_{gd}'s of transistors M_{1b} and M_{2b}.

A Folded Floating-Gate Differential Pair



- C_1 sets the linear range and transconductance gain.
- C_2 controls by how much V changes in response to changes in either V_{cm} or I_b.
- Input and output voltage ranges are from rail-to-rail.
- Transconductance gain nearly constant with V_{cm}.

Output Currents vs. V_{dm} ($I_b = 116\,\mu A$)



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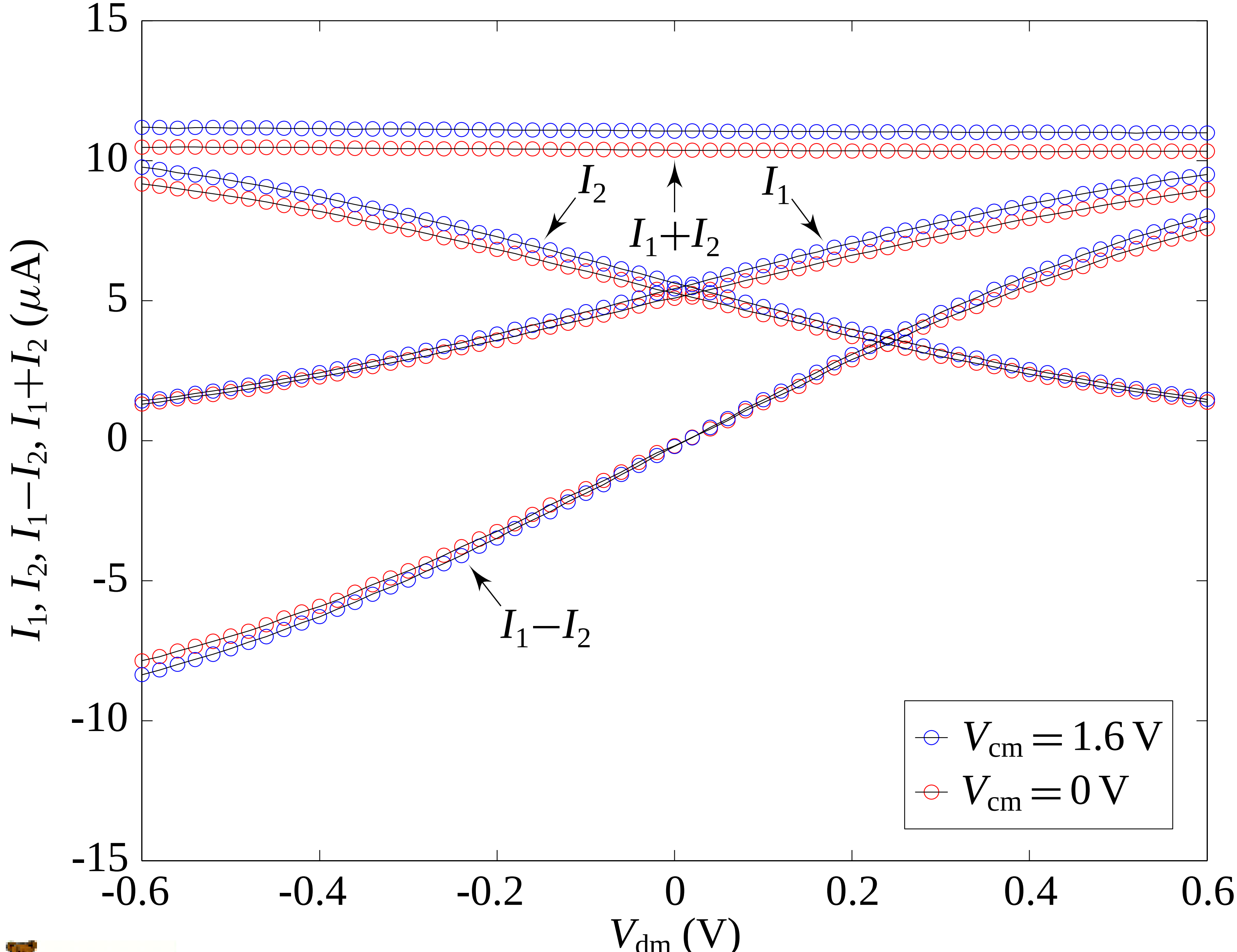
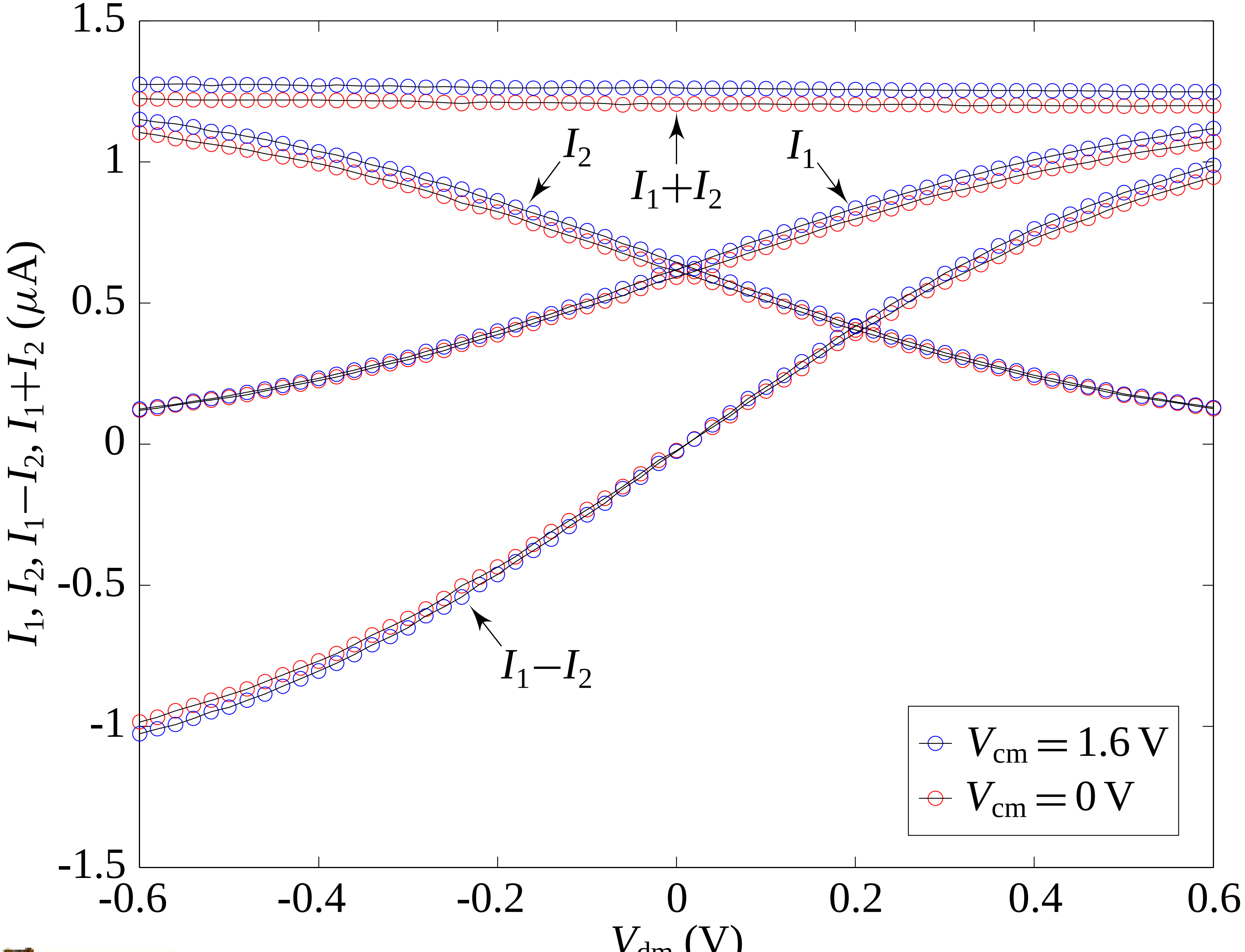
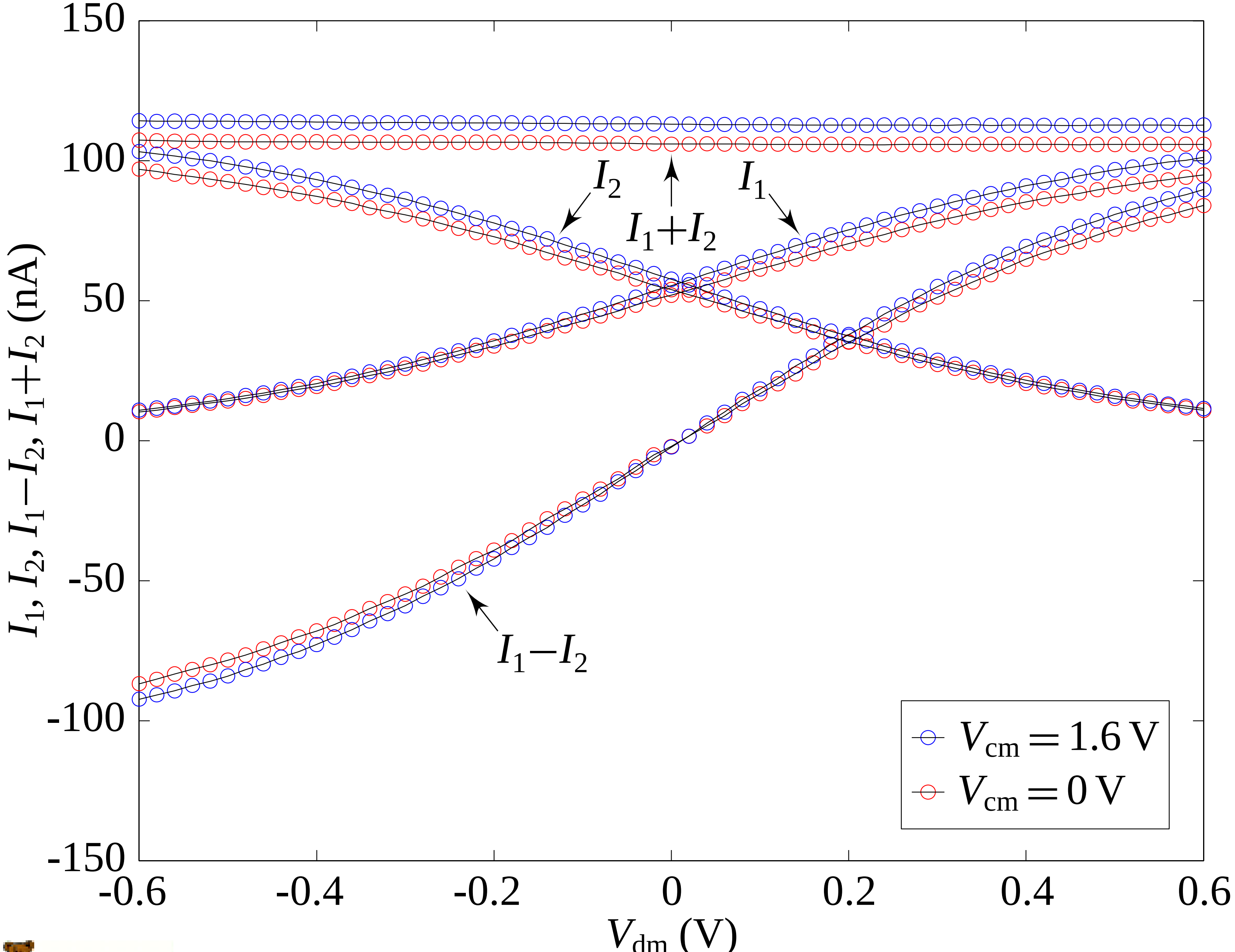
Output Currents vs. V_{dm} ($I_b = 10.7\,\mu A$)



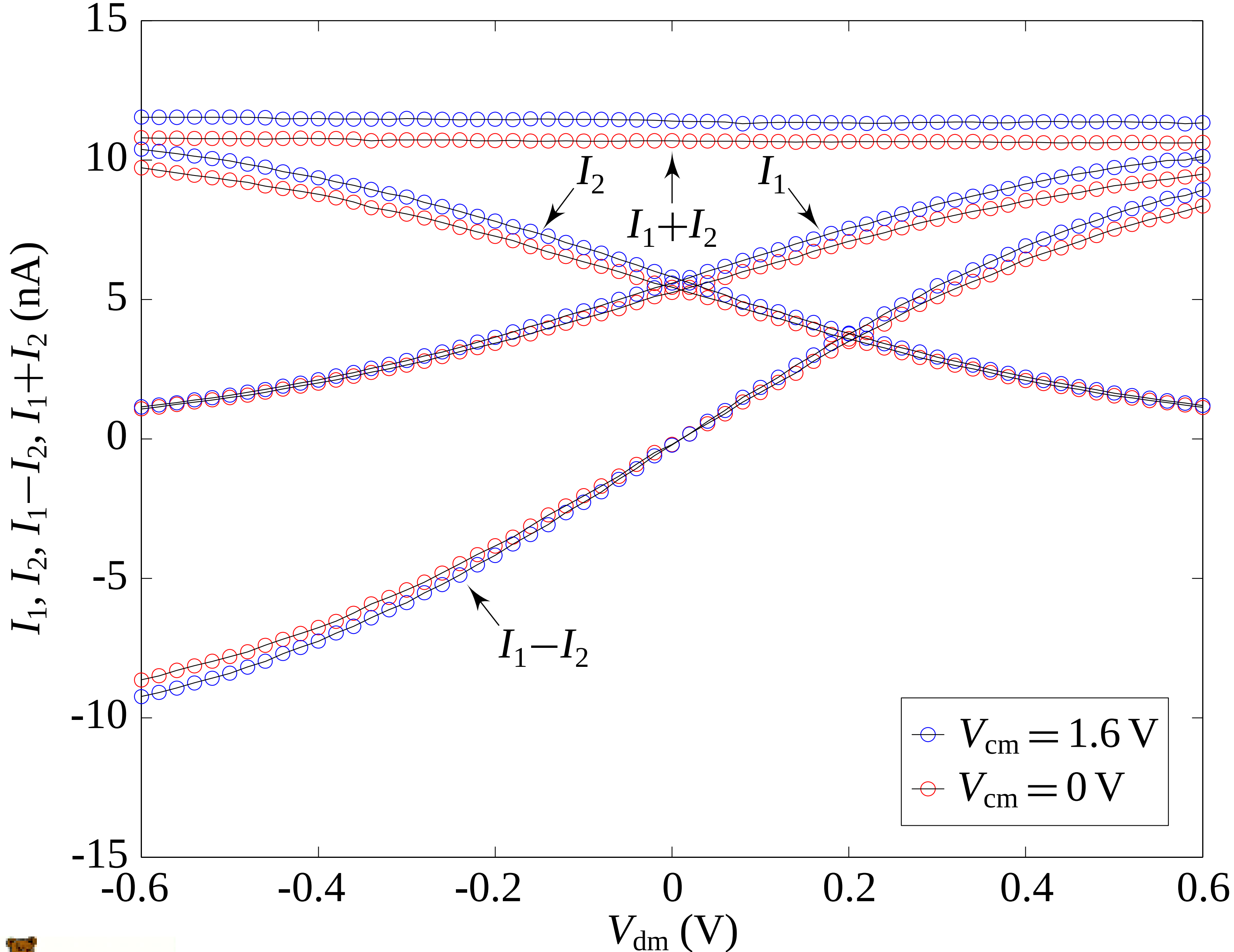
Output Currents vs. V_{dm} ($I_b = 1.23\,\mu A$)



Output Currents vs. V_{dm} ($I_b = 110\,nA$)



Output Currents vs. V_{dm} ($I_{\mathrm{b}} = 11.1\,\mathrm{nA}$)



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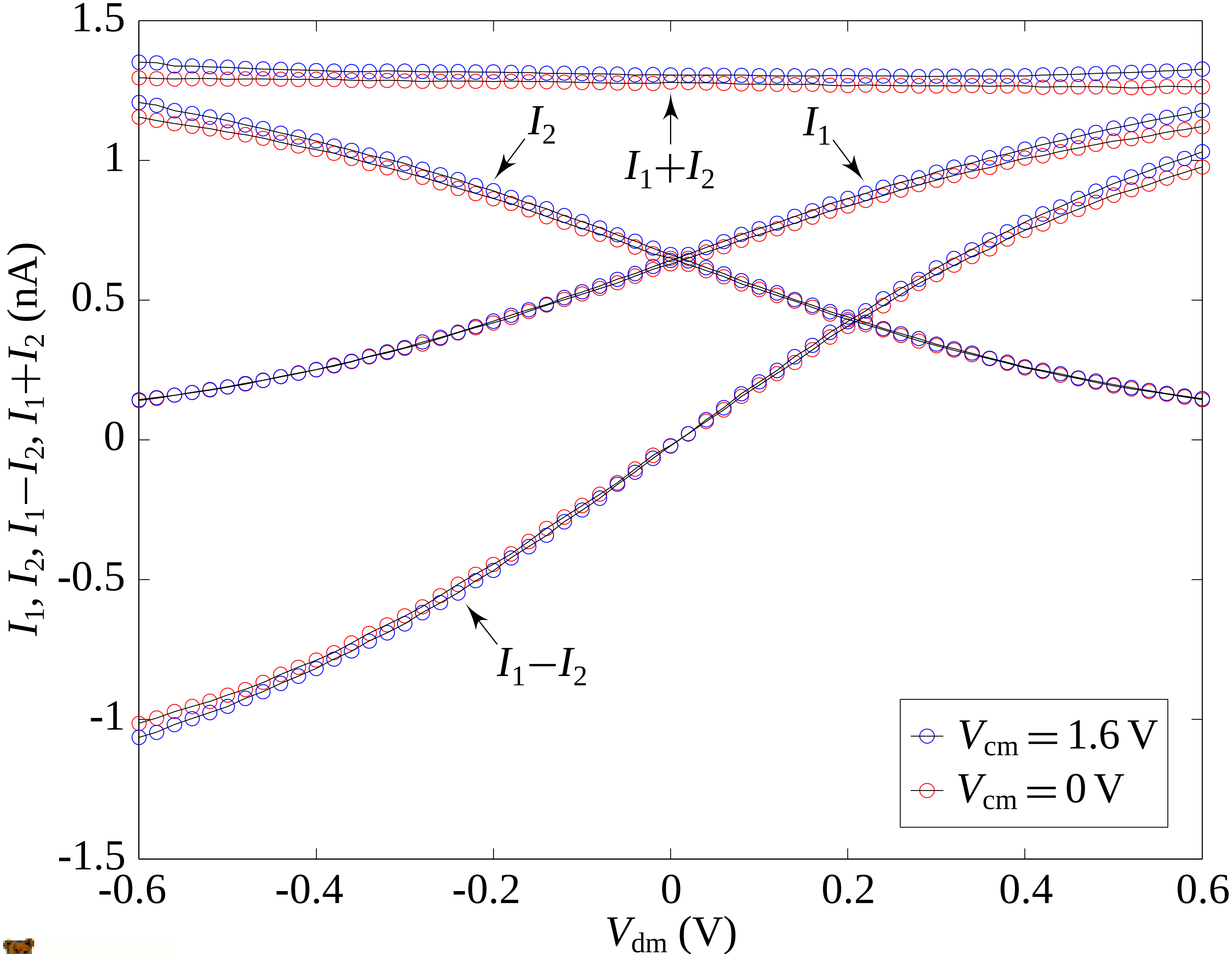
Output Currents vs. V_{dm} ($I_b = 1.28\,nA$)



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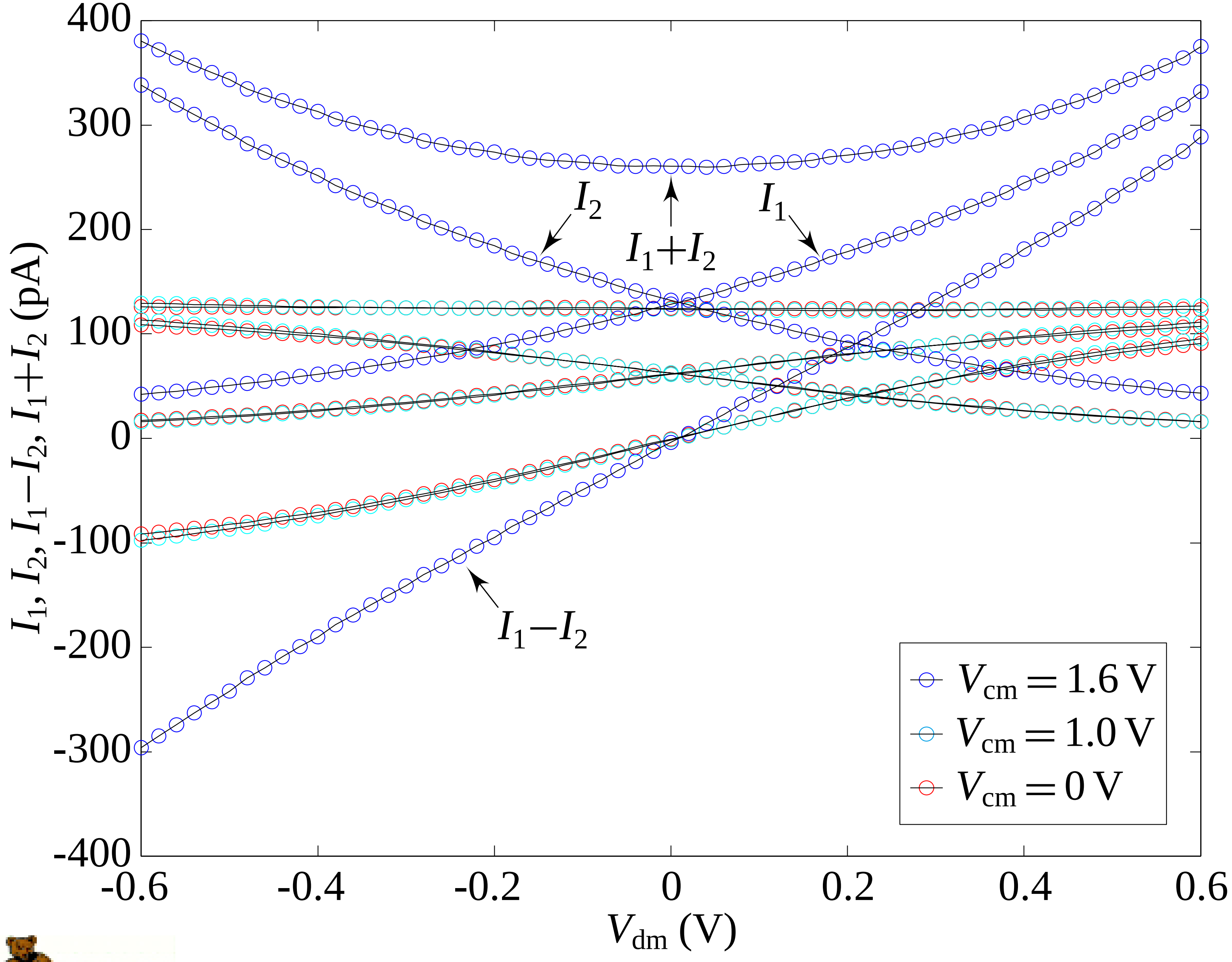
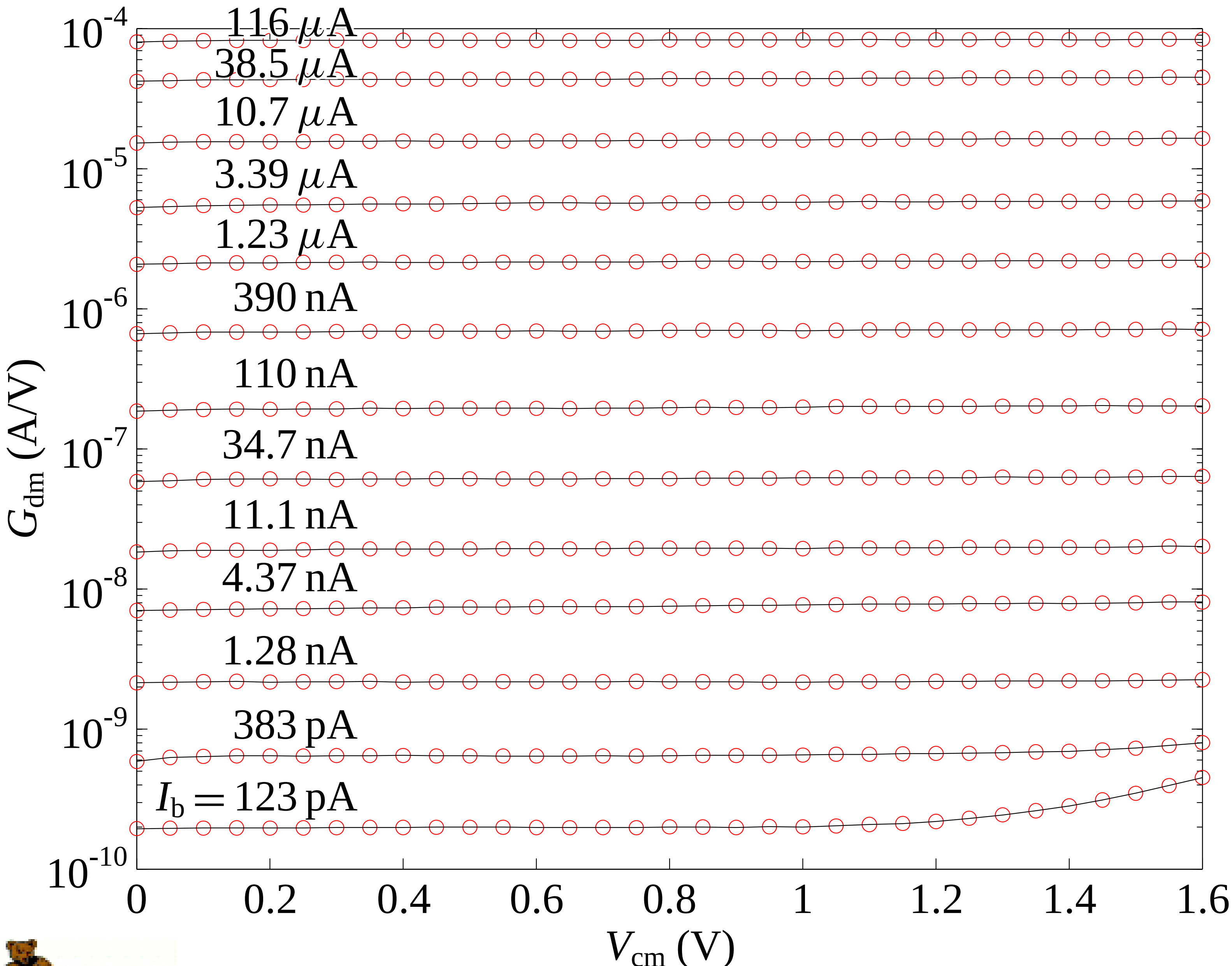
Output Currents vs. V_{dm} ($I_b = 123\,\mathrm{pA}$)



Transconductance Gain vs. V_{cm}



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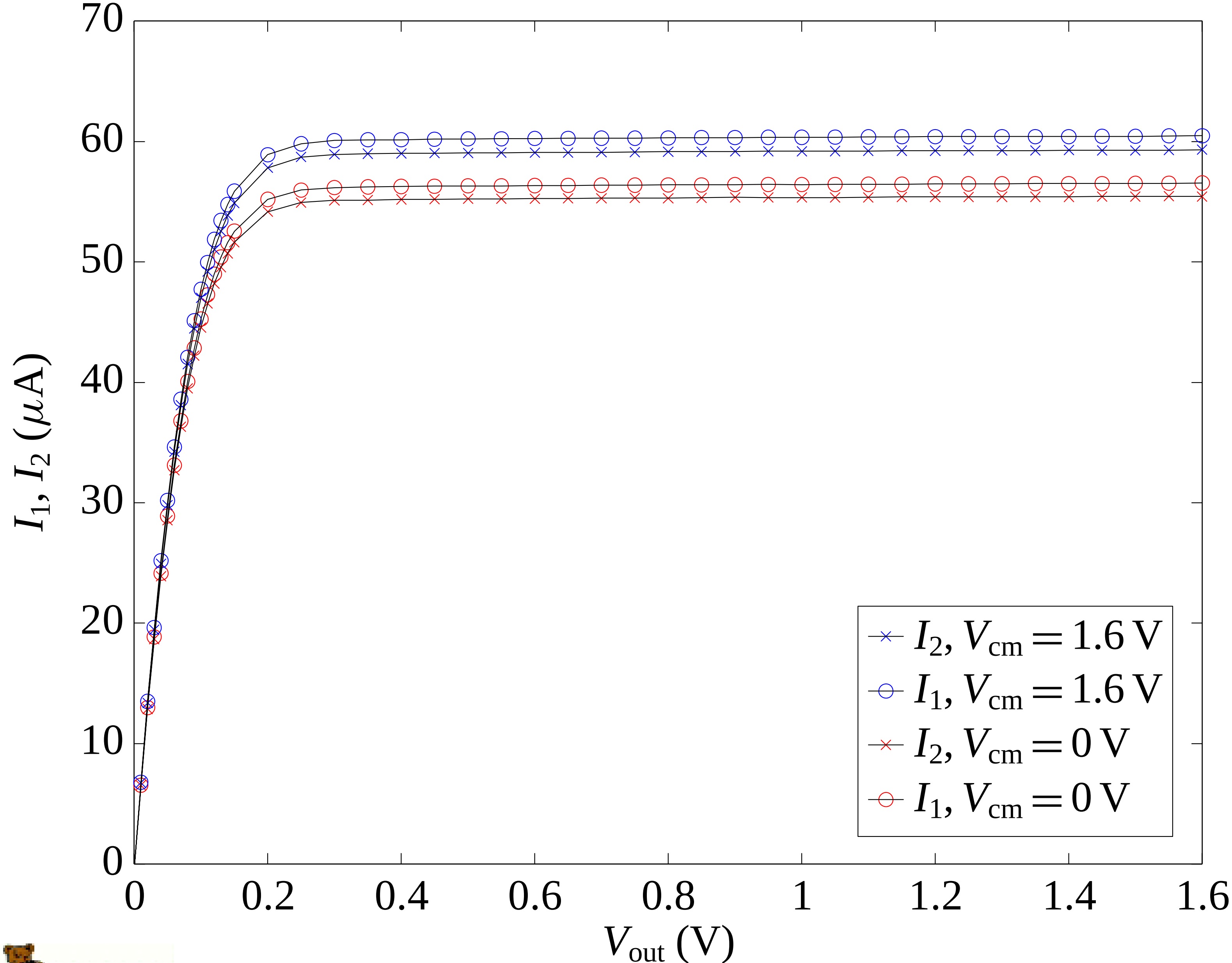
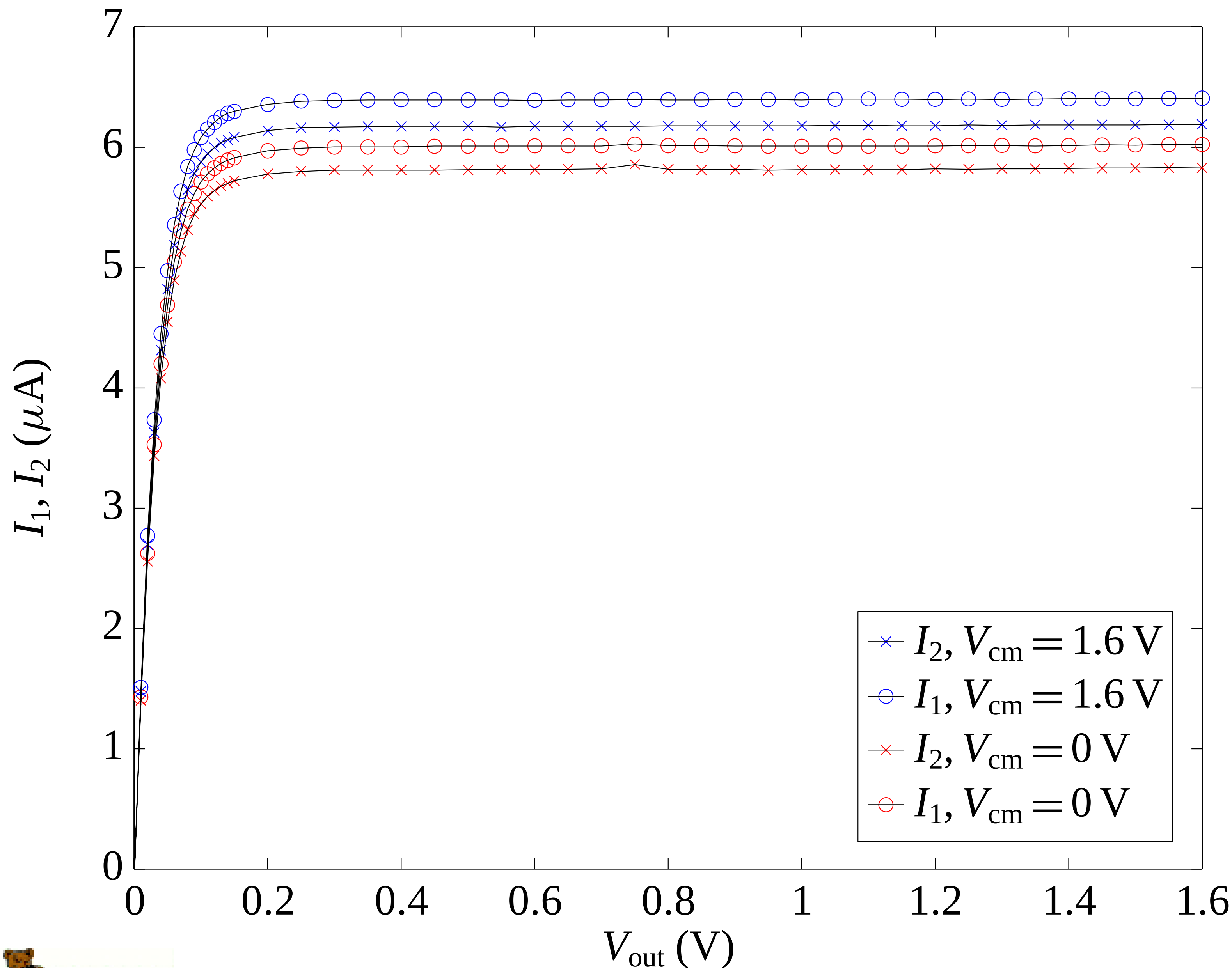
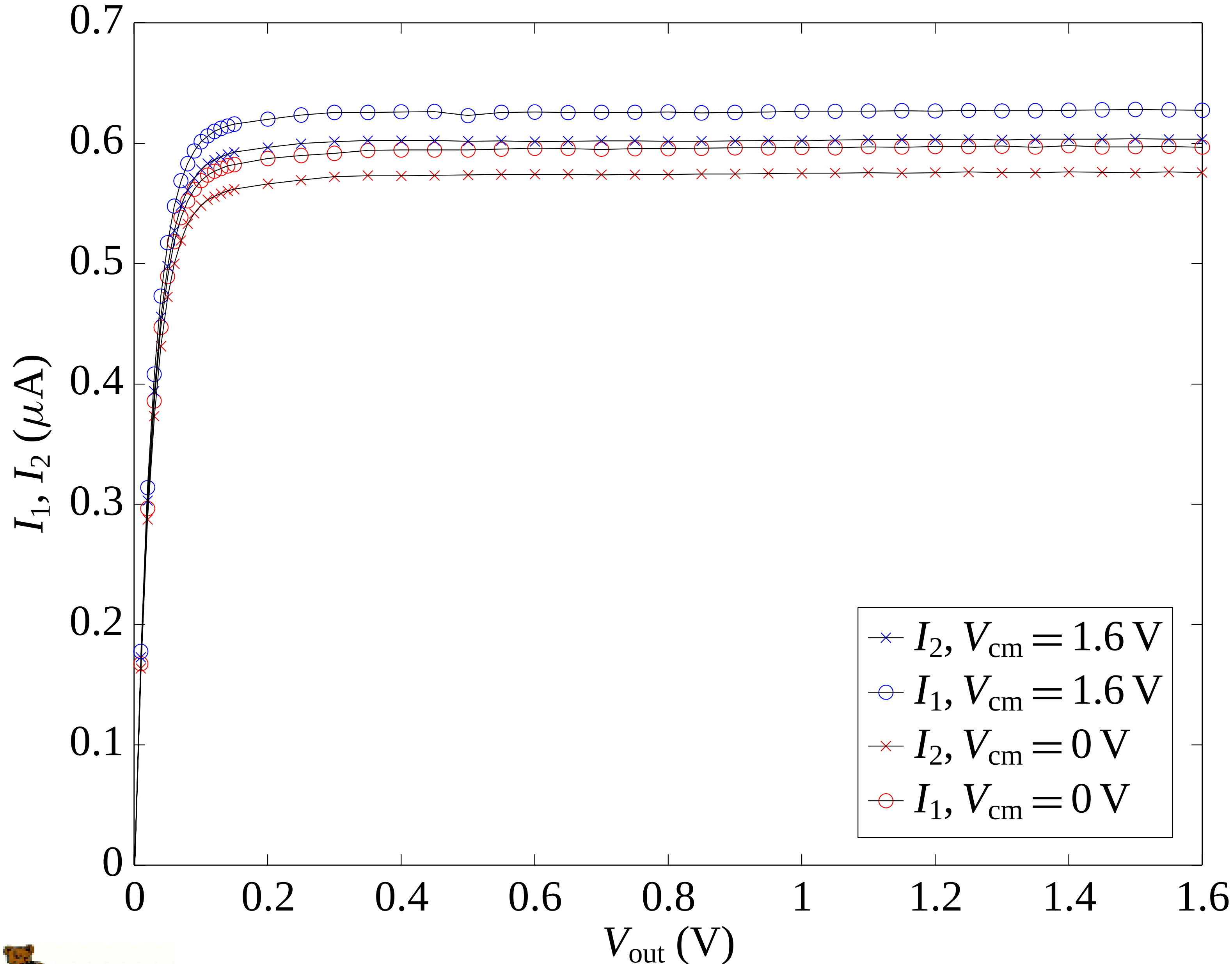
Output Currents vs. V_{out} ($I_b = 116\,\mu A$)



Output Currents vs. V_{out} ($I_b = 10.7\,\mu A$)



Output Currents vs. V_{out} ($I_b = 1.23\,\mu A$)



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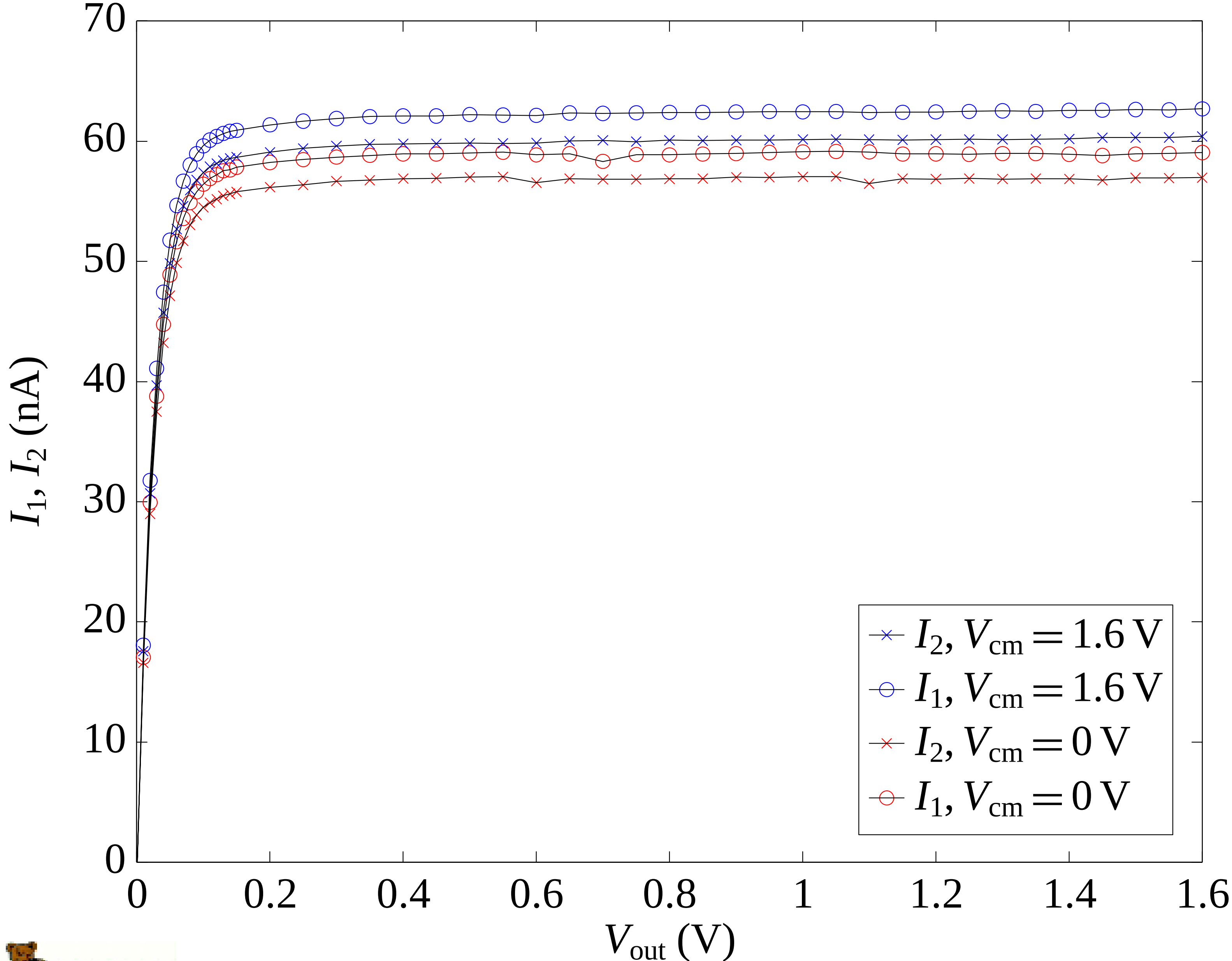

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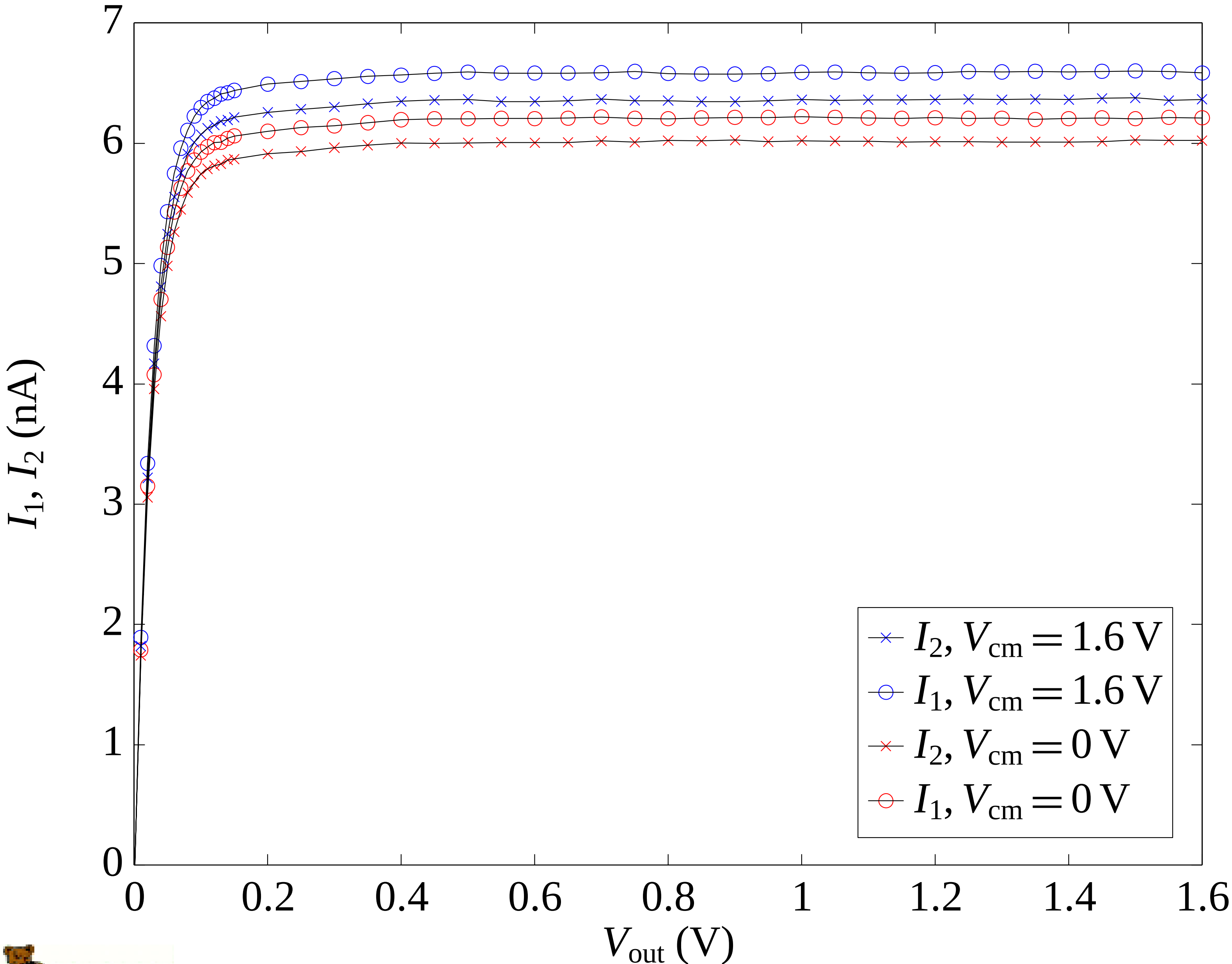
Output Currents vs. V_{out} ($I_b = 11.1\,nA$)



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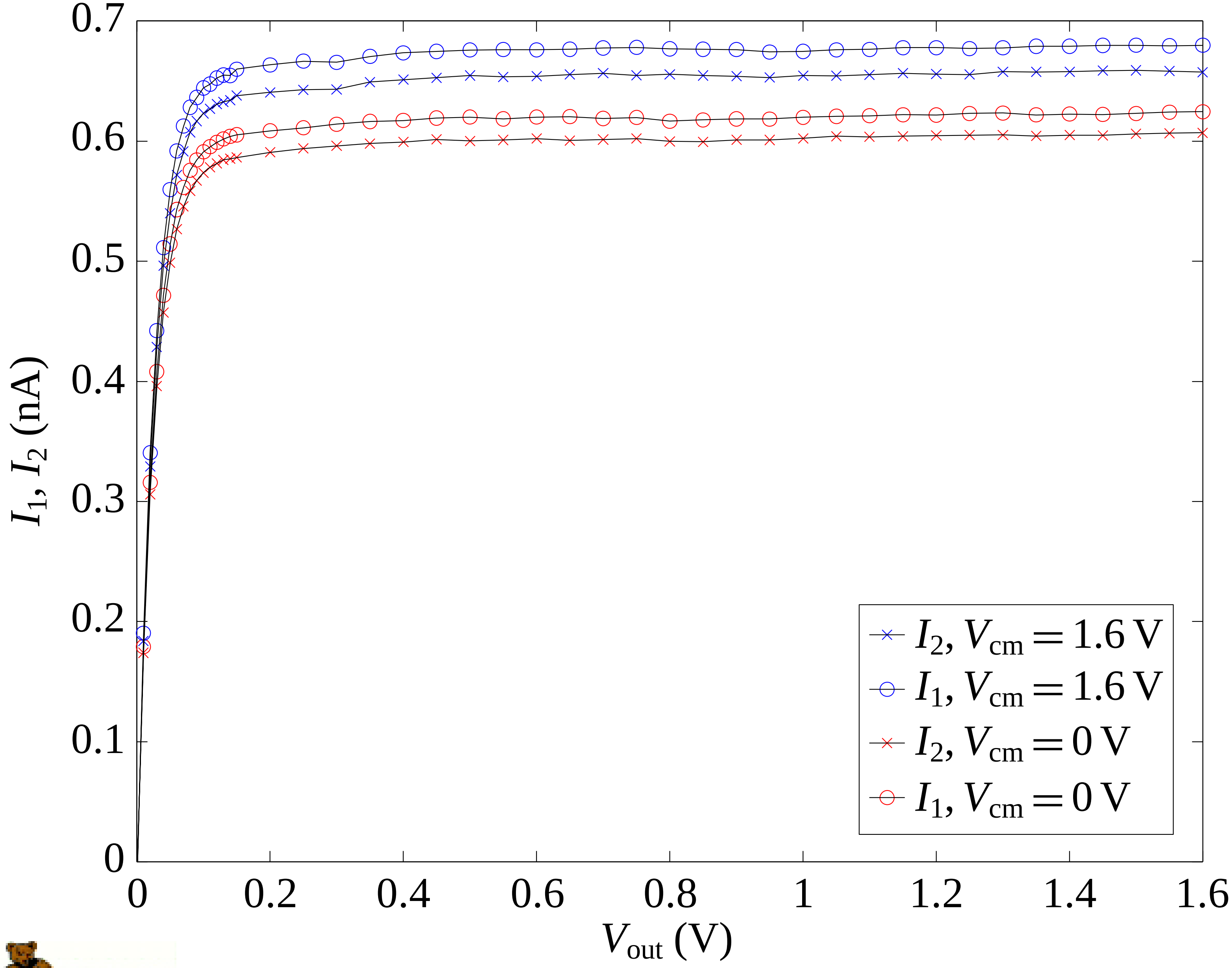
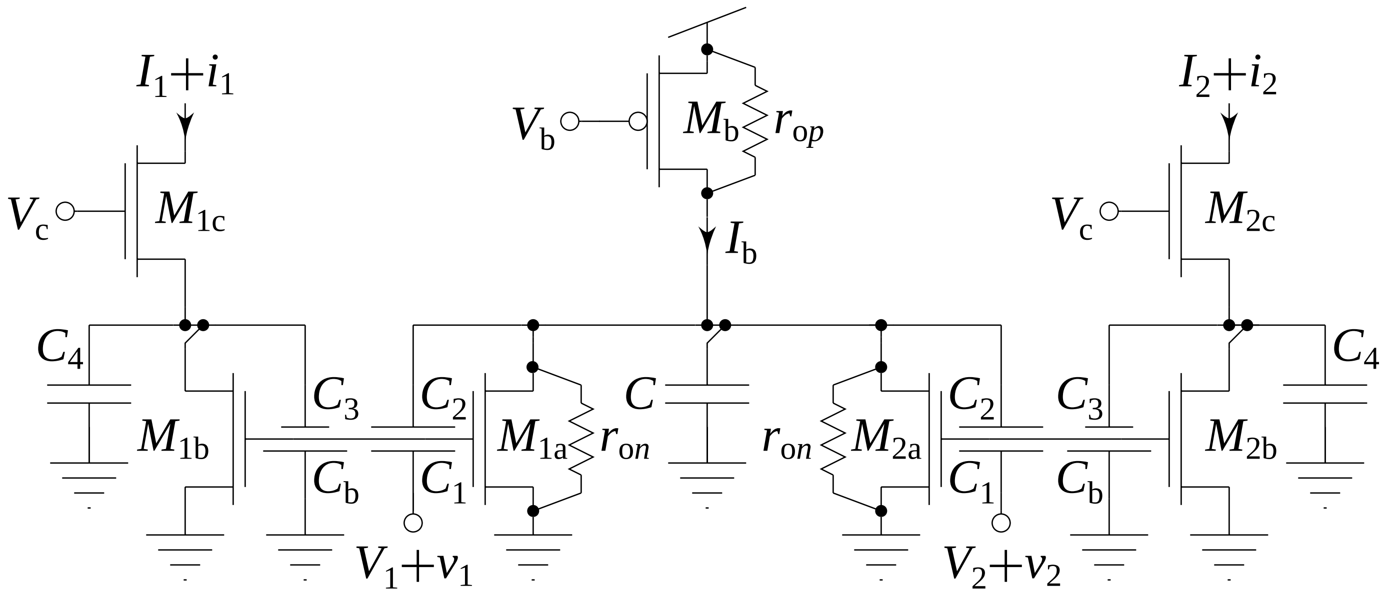
Output Currents vs. V_{out} ($I_b = 1.28\,\mathrm{nA}$)



Incremental High-Frequency Analysis



- Given that $g_m\left(r_{on} \| 2r_{op}\right) \gg 1$ and $C_3 \ll C_2$, we can show that

$$i_{dm} \equiv i_1 - i_2 = g_m \frac{C_1}{C_T} \frac{1 - sC_3/g_m}{1 + s(C_3 + C_4)/g_s} v_{dm}$$

where $C_T \equiv C_1 + C_2 + C_3 + C_b$.

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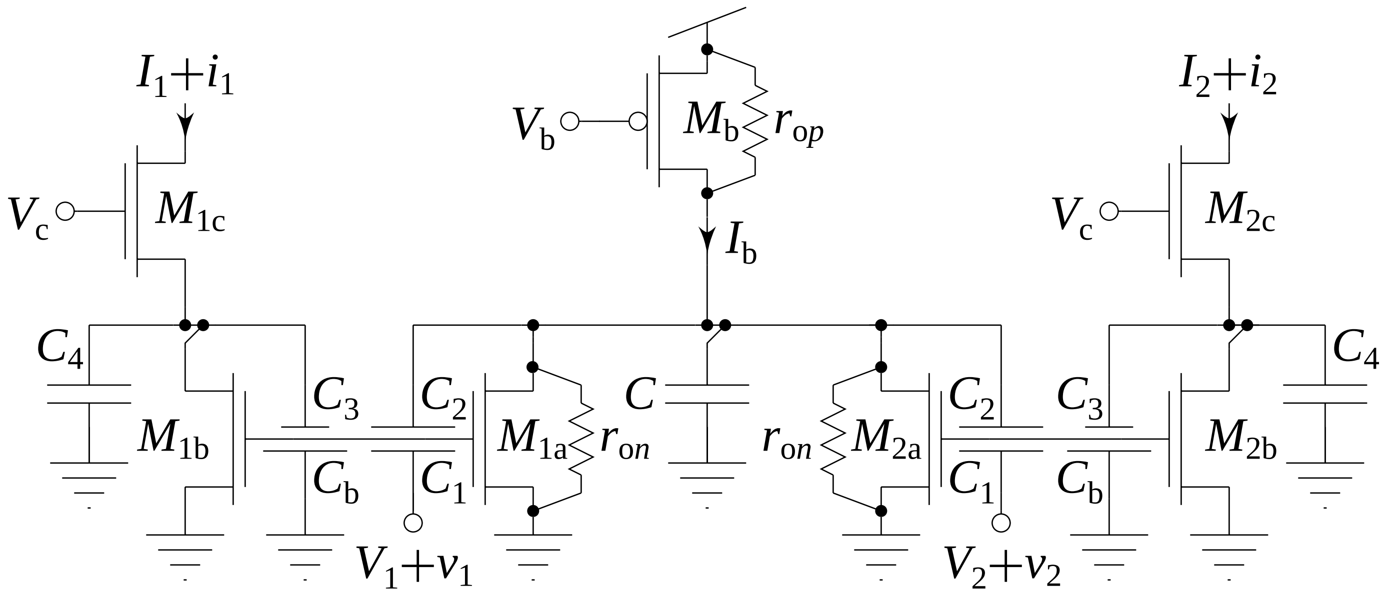

...and that

$$i_{\mathrm{cm}} \equiv \frac{i_1 + i_2}{2}$$

$$= \frac{C_1/C_2}{r_{\mathrm{on}} \| 2r_{op}} \frac{(1 - sC_3/g_{\mathrm{m}})\left(1 + s\left(r_{\mathrm{on}} \| 2r_{op}\right)(C_2 + C/2)\right)}{(1 + s(C_3 + C_4)/g_{\mathrm{s}})\left(1 + s\left(C_2 \| (C_1 + C_3 + C_{\mathrm{b}})\right)/(g_{\mathrm{m}} C_2/C_{\mathrm{T}})\right)} v_{\mathrm{cm}}$$

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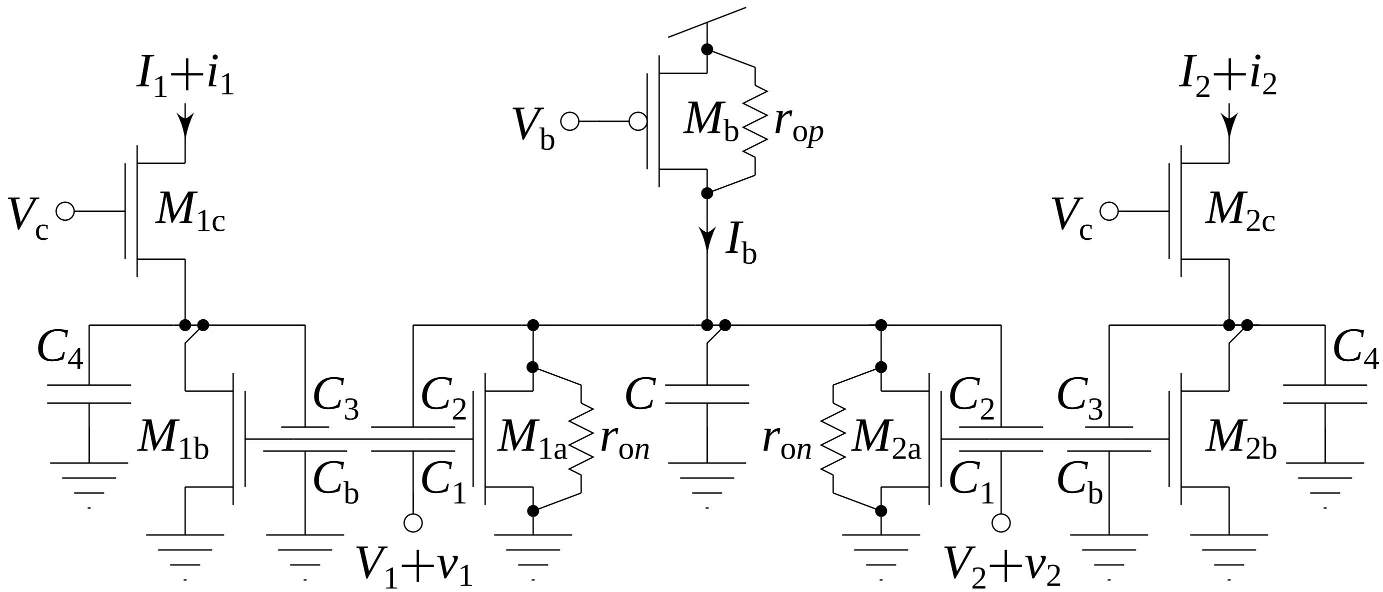

...and so

$$\text{CMRR} \equiv \frac{i_{\text{dm}}/v_{\text{dm}}}{i_{\text{cm}}/v_{\text{cm}}} = g_{\text{m}}\left(r_{on} \| 2r_{op}\right)\frac{C_2}{C_{\text{T}}}\frac{\left(1+s\left(C_2 \|(C_1+C_3+C_{\text{b}})\right)/(g_{\text{m}}C_2/C_{\text{T}})\right)}{\left(1+s\left(r_{on} \| 2r_{op}\right)(C_2+C/2)\right)}$$