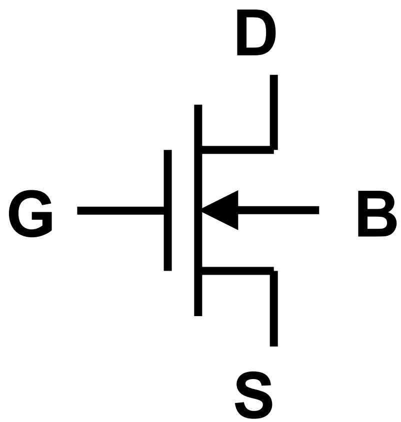
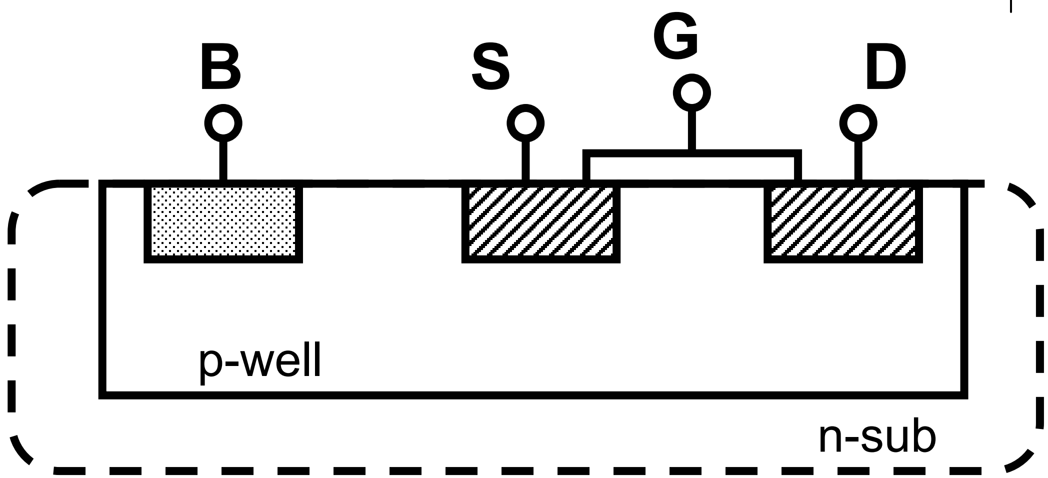
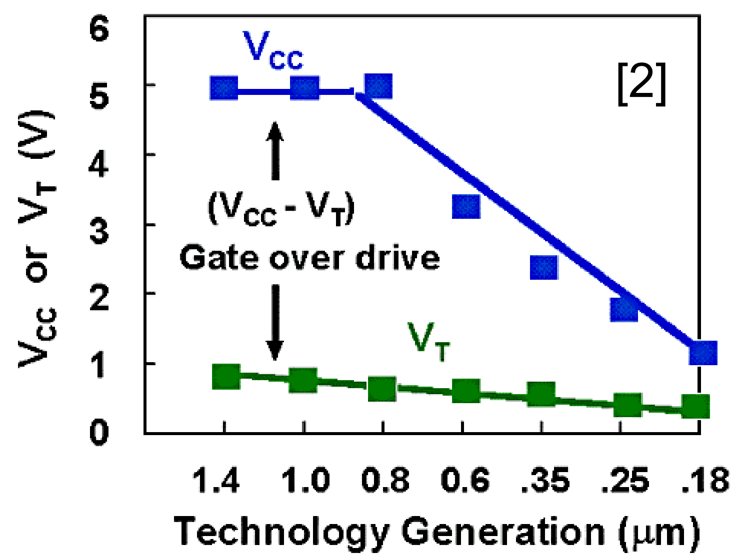
MOSFET as a 4-terminal device





- Bulk node gives the designer an extra degree of freedom
- But designers don't use the bulk node

- **V_T does not scale with V_{DD} in new submicron processes!**



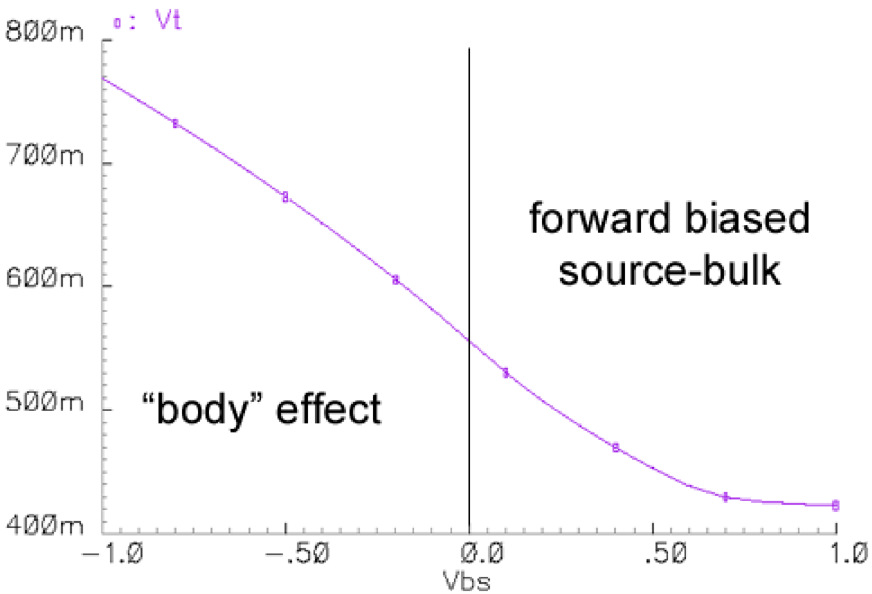
The Body Effect

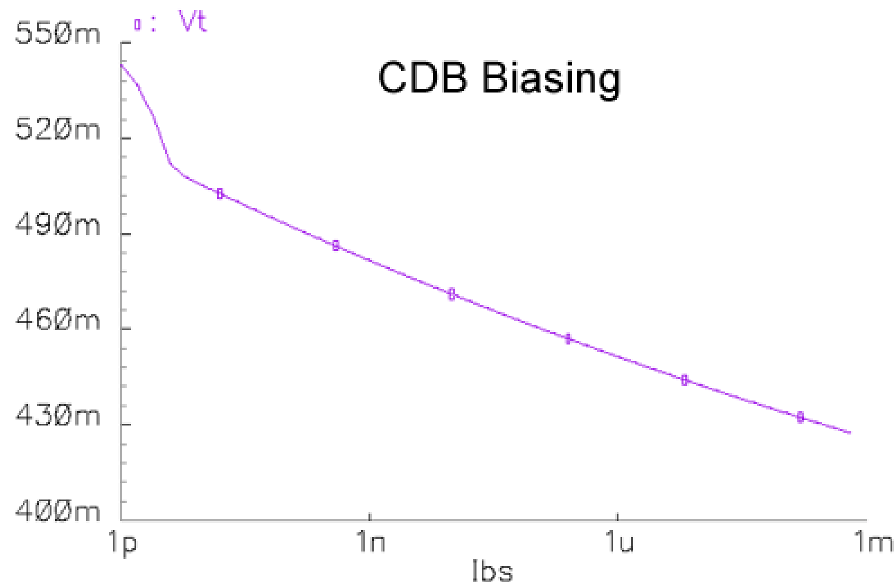
- Common bulk effects: “Body Effect”
  - Considered as a “bad” side-effect when $V_b \neq V_s$
  - Increases V_T and lowers voltage headroom

$$V_T = V_{T0} \pm \gamma\left(\sqrt{2|\phi_F| - V_{BS}} - \sqrt{2|\phi_F|}\right)$$

- What if $V_{BS} > 0$? ← **Reduce V_T**
  - Use as a low-voltage technique
  - Might forward bias B-S diode
- Current Driven Bulk (CDB) technique

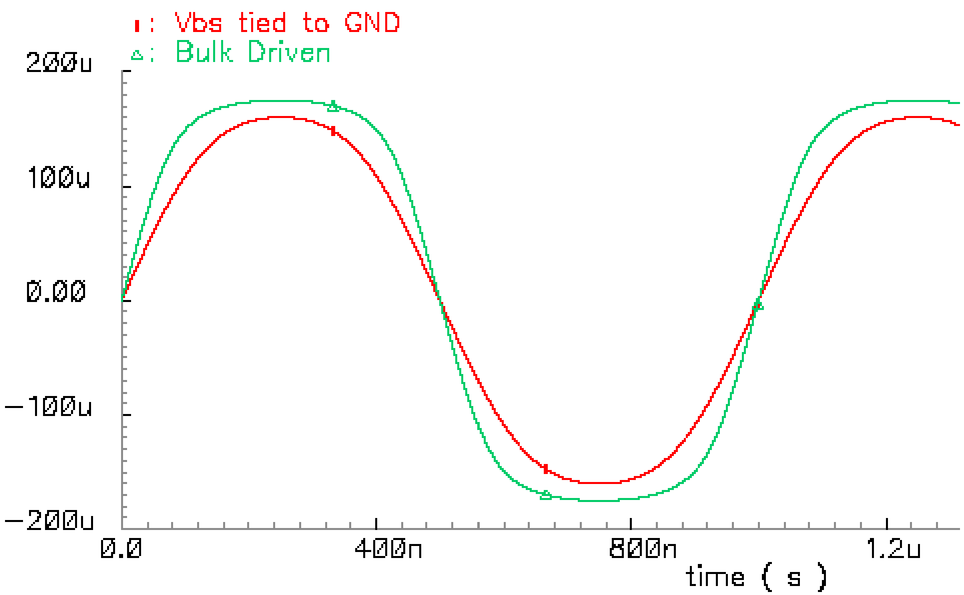
Threshold Adjust

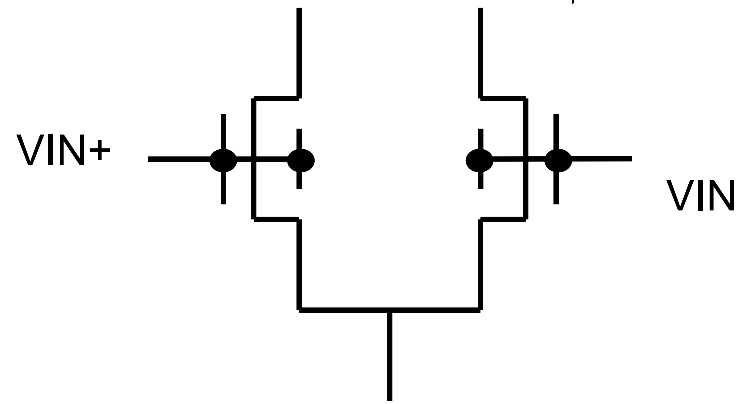


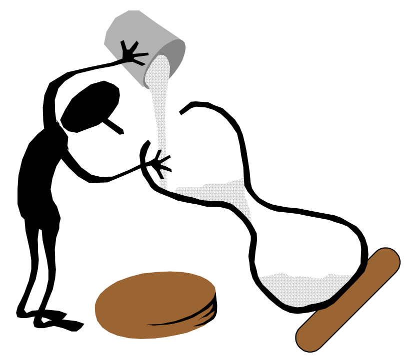


- V_T reduced from 0.55V to 0.45V
- CDB intentionally turns on the BS diode
  - Achieves maximum $V_{BS} = V_{DIODE} \approx 0.7V$
- Can **AC** signals be applied to the bulk?

Faster Switching







- Connect VIN to gate AND bulk
  - VIN ↑, V_{BS} ↑, V_T ↓, Turn on faster
  - VIN ↓, V_{BS} ↓, V_T ↑, Turn off faster
- **Faster switching**: Digital gates, Mixers, etc.

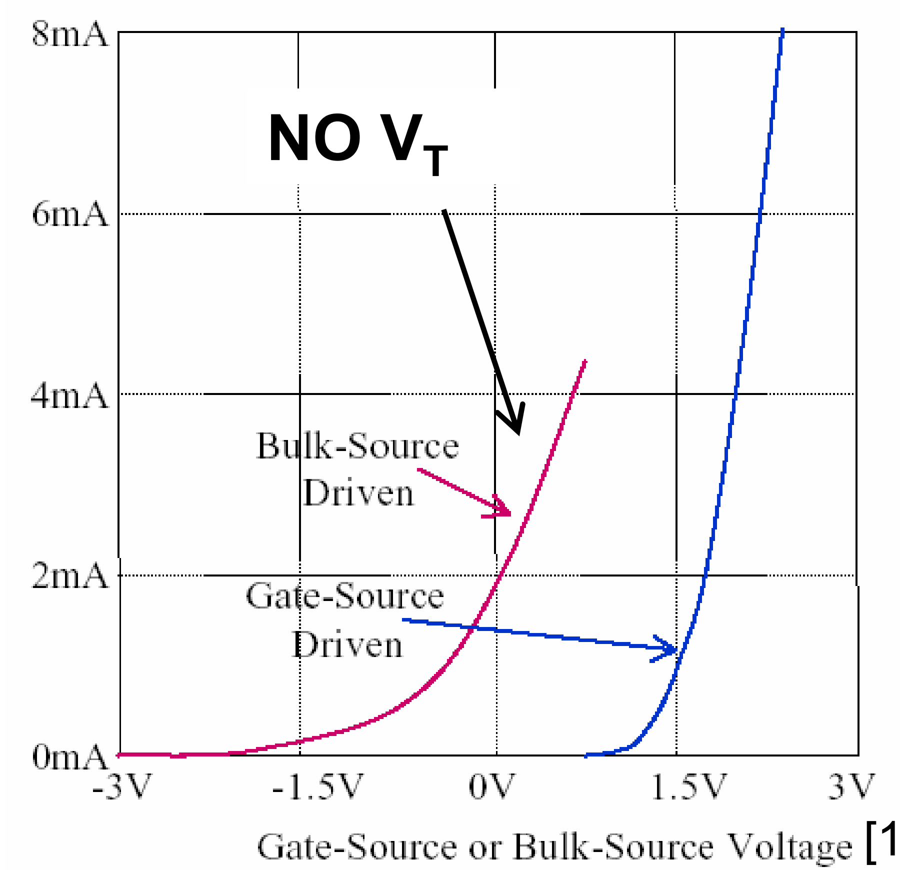
Bulk Node as AC Input?

- So far used bulk to adjust V_T, but can we drive actual signals through it?
- We reduced V_T, but can we get rid of it?

- Gate driven: $g_m V_{gs}$
- Bulk driven: $g_{mb} V_{bs}$

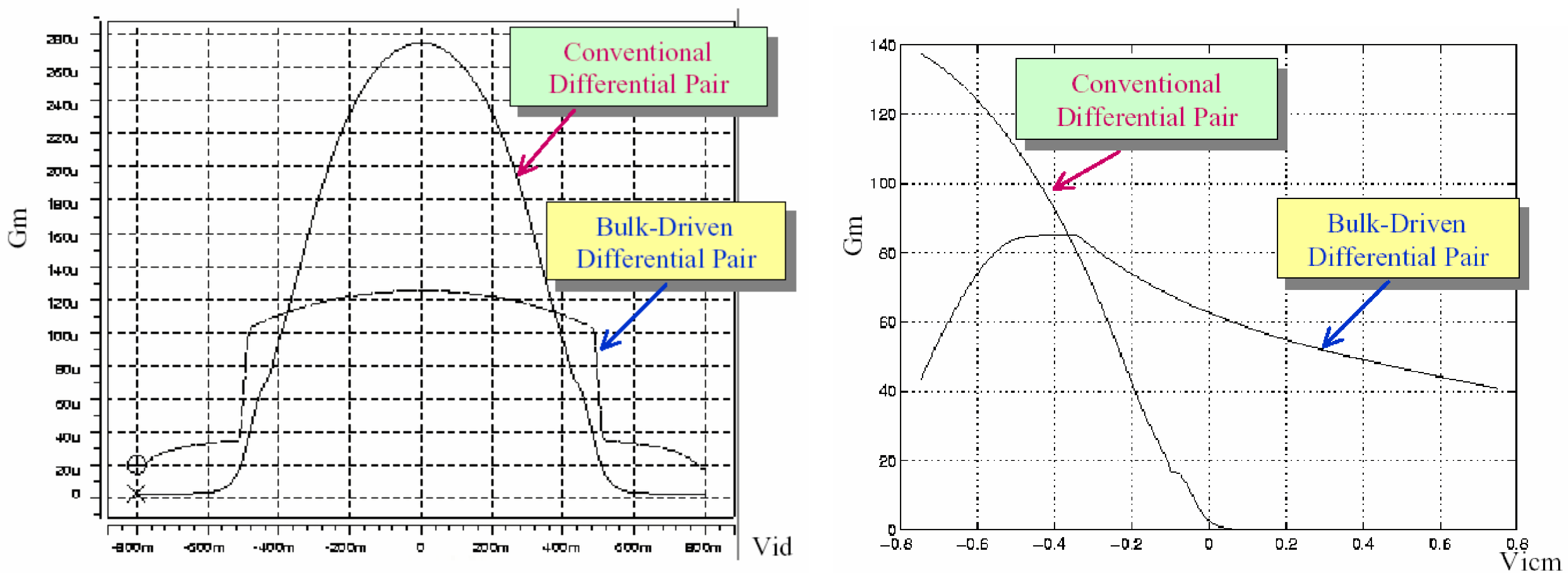
$$g_{mb} = \eta g_m$$

$$\eta = \frac{\gamma}{2\sqrt{2\phi_F - V_{BS}}}$$ ~ **0.2 .. 0.4**



[1]

Linearization



Simulation of a differential pair (bulk-input vs. gate-input) [1]

Main benefits: Linear Gm, Rail-to-Rail Input, Constant Gm

Perfect for building Rail-to-Rail OPAMPs !!! [6,7]

The small print

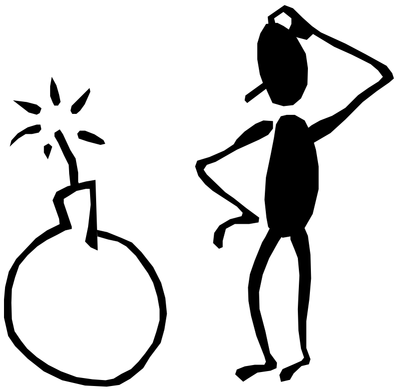
- Gain is reduced $g_{mb} = \eta g_m$ **η ~ 0.2 .. 0.4**
- Bandwidth is reduced [3]

$$f_{T,bulk\text{-}driven} \approx \frac{\eta}{3.8} f_{T,gate\text{-}driven}$$

- Higher noise figure (because of lower gm)

$$Noise_{bulk-driven} = \frac{Noise_{gate-driven}}{\eta^2}$$

- Need separate wells (dual well process)
  - More expensive process
  - Bigger chip area
  - Worst matching

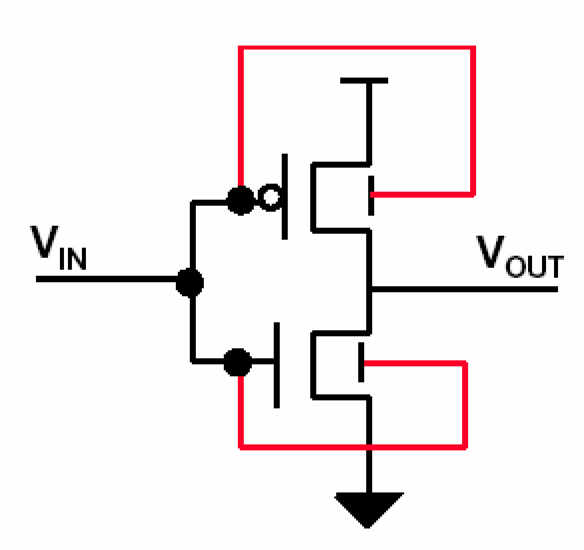


Latest trends from Intel

"Current performance scaling trends will not continue past the 0.13 - 0.10mm device technologies by using traditional scaling methods." [2]

"Fundamental limits in $Si0_2$ … are currently being reached" [2]

- DTMOS switches faster by lowering V_T during switching
- Circuit topologies are being developed for <0.6V supply



Proposed DTMOS – Dynamic V_T MOS Inverter

A lot of research in bulk-driven circuits is needed, but very few publications exist

Summary

- Consider the Bulk node as another parameter
  - Static Bulk Voltage – Reduce V_T
  - Dynamic Bulk Voltage – Dynamically Reduce V_T
  - Bulk-Driven Signals – Ignore V_T completely

References

[1] E.S. Sinencio, “Bulk Driven Transistors”, ELEN-607 Course notes, Texas A&M University, 2003

[2] S. Thompson et al, “MOS Scaling: Transistor Challenges for the 21st Century”, Intel Technology Journal, 3rd quarter, 1998

[3] L. Yong, “Complementary Body-driving - A Low-voltage Analog Circuit Technique Realized In 0.35um SOI Process”, M. Sc. Thesis, University of Tennessee, Knoxville, August 2002

[4] T. Lehmann, M. Cassia, “1-V Power Supply CMOS Cascode Amplifier”, Solid-State Circuits Journal, July 2001

[5] R. Friend, C.C. Enz, “Bulk driven MOST transconductor with extended linear range”, Electronics Letters, 28 March 1996

[6] T. Stockstad, H. Yoshizawa, “0.9V, 0.5uA Rail-to-Rail Opamp”, Custom Integrated Circuits Conference, May 2001

[7] B.J. Blalock et al, “Designing 1-V Op Amps Using Standard Digital CMOS Technology”, Circuits and Systems II: Analog and Digital Signal Processing, July 1998

[8] H. Huang, J. Lin, “CMOS Bulk Input Technique”, ISCAS, May 2002

[9] B.J. Blalock, P.E. Allen, “A Low-Voltage, Bulk-Driven MOSFET Current Mirror for CMOS Technology”, ISCAS, May 1995