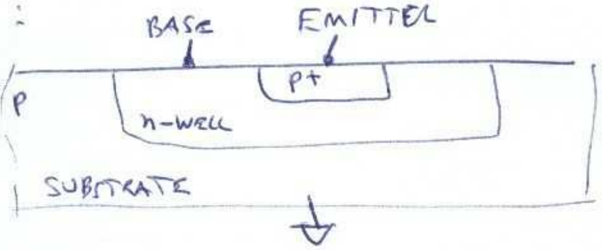
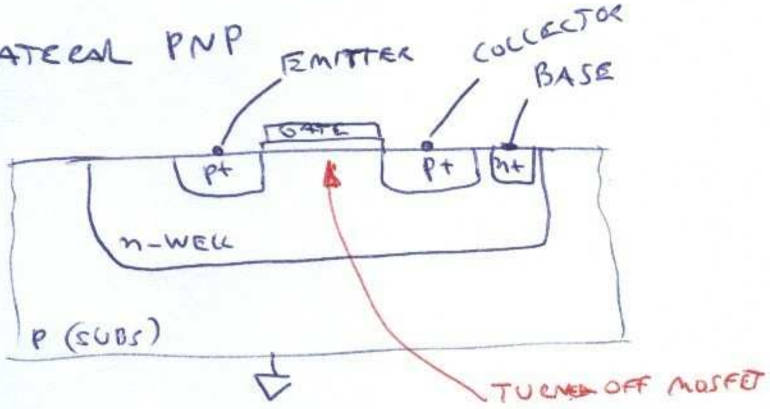
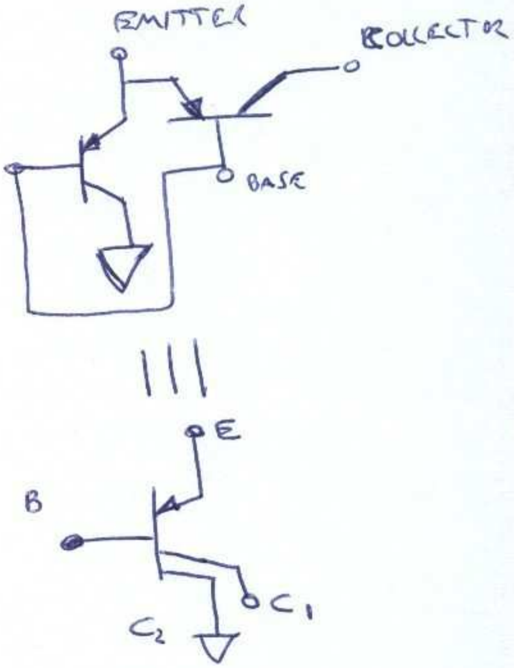
BIPOLAR TRANSISTORS

- LOWER $\frac{1}{f}$ NOISE THAN MOSFETS
- BETTER MATCHING
- BANDGAP REFERENCES
- VERTICAL PNP :

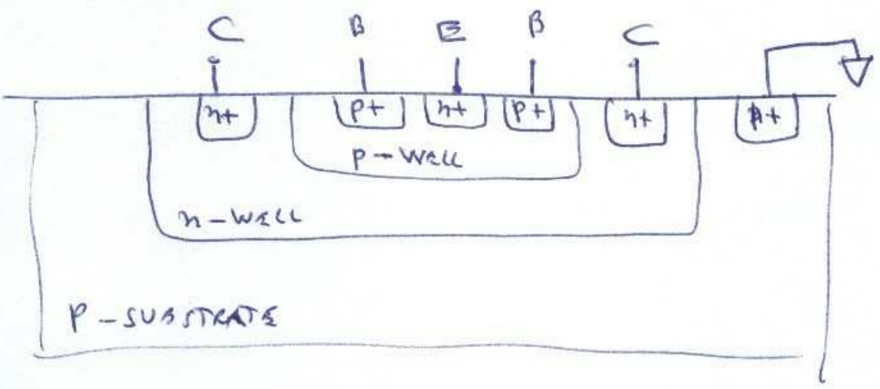


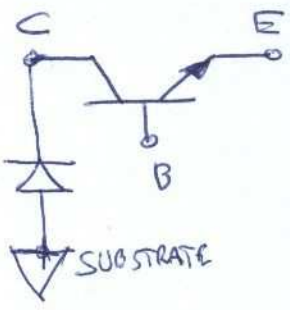
- LATERAL PNP





- VERTICAL NPN IN TRIPLE-WELL CMOS:



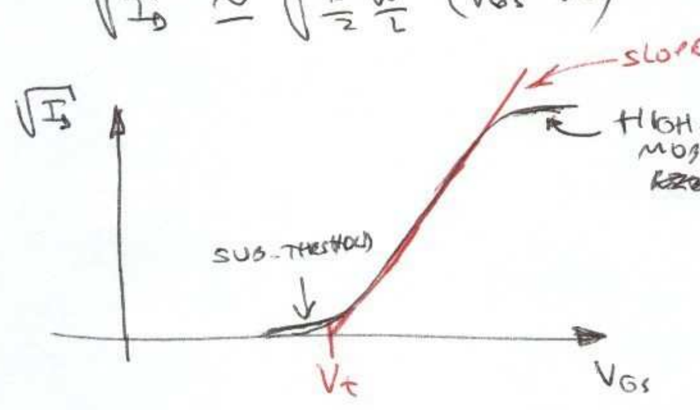


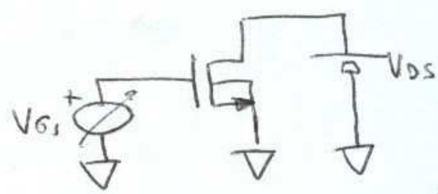
METHODS TO DETERMINE DESIGN PARAMETERS OF CMOS T. ⑦

DETERMINATION OF k', V_t

$$I_D \simeq \frac{k'}{2}\frac{W}{L}\left(V_{GS}-V_t\right)^2$$

$$\sqrt{I_D} \simeq \sqrt{\frac{k'}{2}\frac{W}{L}}\left(V_{GS}-V_t\right)$$





3.3V NMOS:

$L = 1\mu m$
$W = 1.5\mu m$
$V_{DS} = 1V$
$L_d = 20nm$

$\text{SLOPE} = \frac{4.3\times10^{-3}}{415.9\times10^{-3}} = 10.3\times10^{-3}$

$L_{eff} = 0.96\mu m$

$k' = 137\ \frac{\mu A}{V^2}$

$V_t = 0.73\ V$

$\boxed{L_d = 20nm}$

$gds = 181.4n \Rightarrow \lambda = 0.0075\ V^{-1}$

$I_D = 24.2\mu A$

$\left|\frac{\partial x_d}{\partial V_{DS}}\right| = L_{eff}\,\lambda = 0.072\ V^{-1}\times\mu m$

$\boxed{\left|\frac{\partial x_d}{V_{ds}}\right| = 0.072\ \frac{\mu m}{V}}$

DETERMINATION of λ

RUN DC OP. POINT ⟶ PRINT PARAMETERS. ⟶ $gds = \frac{1}{r_o}$

$L = 10\mu m$, $I_D = 10.7\mu A$ $\rightarrow gds = 51.69n \rightarrow \lambda_1 = 0.0048\ V^{-1}$

$L = 1\mu m$, $I_D = 7.38\mu m$ $\rightarrow gds = 126.8n \rightarrow \lambda_2 = 0.0172\ V^{-1}$

$$\lambda = \frac{\left|\frac{\partial x_d}{\partial V_{DS}}\right|}{L_{eff}} \Rightarrow \lambda_1 \simeq \frac{\lambda_2}{10}$$ → NOTICE THAT DOES NOT HAPPEN.

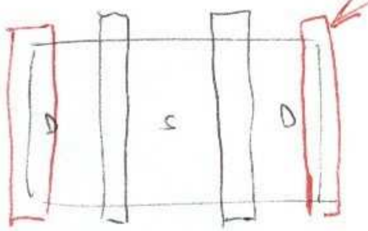
OBSERVATION: gm, gmb AND CAPACITANCES CAN ALSO BE OBTAINED FROM DC. OP. POINT.

(SHOW ALSO HOW TO DETERMINE GAIN FROM DC SWEEP)

LAYOUT CONSIDERATIONS

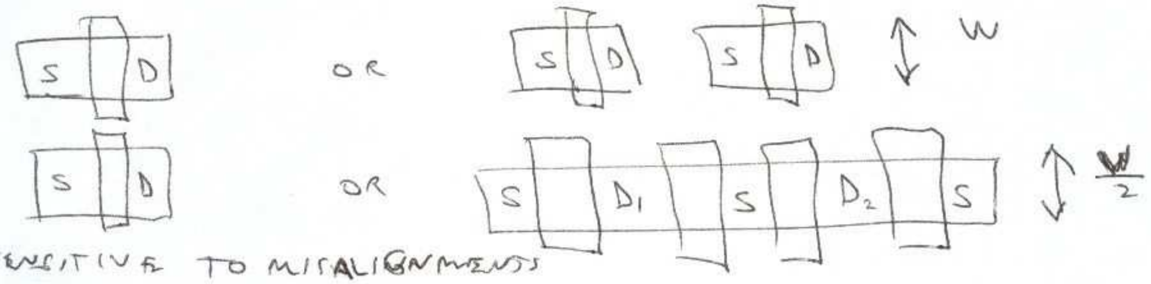
- EXPLAIN MASK ALIGNMENT

CAN HAVE DUMMY GATES HERE



DIFFERENTIAL PAIR
(COMMENT THIS ARRANGEMENT IS ALSO USED FOR TRANSISTORS IN SERIES)

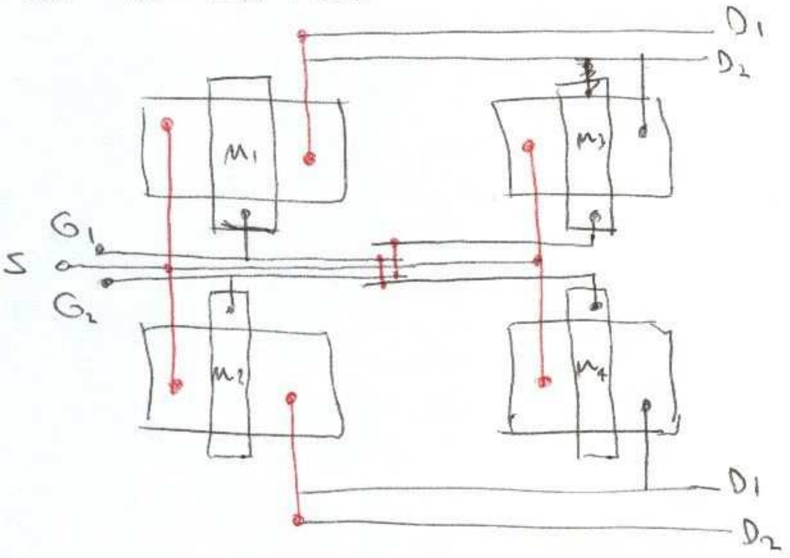
NOT SO GOOD FOR MATCHING DUE TO MASK MISALIGNMENTS.
(DRAIN CAPACITANCES BECOME DIFFERENT)



INSENSITIVE TO MISALIGNMENTS
BUT SENSITIVE TO PROCESS GRADIENTS.

OP-AMP INPUTS ARE THE MOST SENSITIVE NODES → MUST BALANCE PARASITIC CAPACITANCES ~~B~~ CAREFULLY

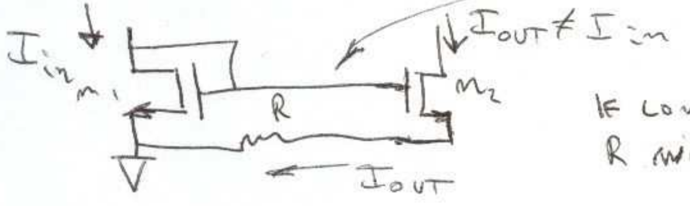
COMMON-CENTROID



- NOTE ONLY G-S LINES CROSS OVER (OK SINCE C_{gs} IS QUITE IMPORTANT ALREADY)
- DISADVANTAGE: MORE SEPARATION BETWEEN TRANSISTORS → MAY NOT BE CONVENIENT IF GRADIENTS ARE NOT TOO STRONG.

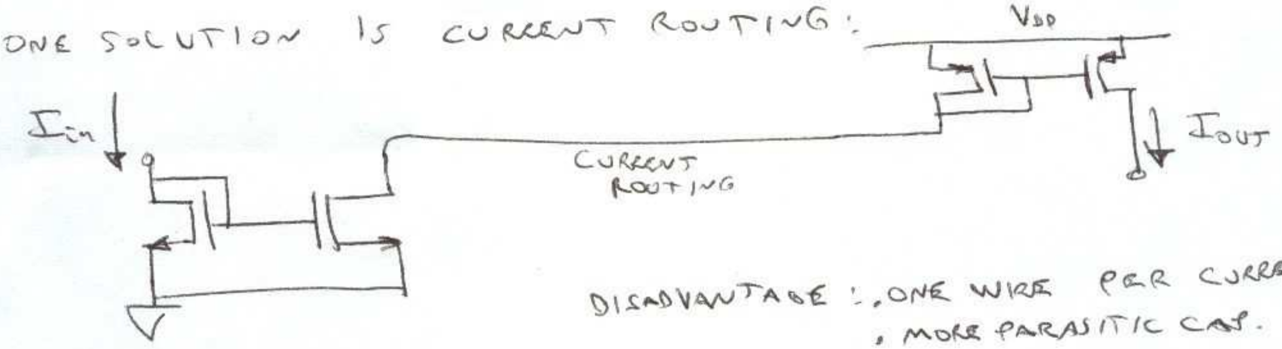
VOLTAGE ROUTING / CURRENT ROUTING IN MIRRORS

VOLTAGE ROUTING



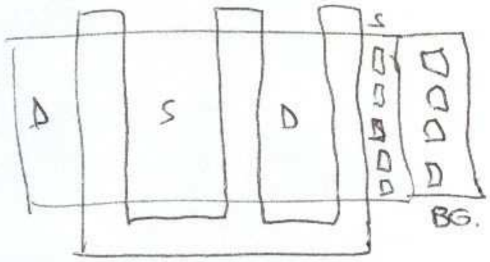
IF LONG DISTANCE M₁ ≠ M₂ AND R MIGHT HAVE AN EFFECT.

- ONE SOLUTION IS CURRENT ROUTING:



DISADVANTAGE : • ONE WIRE PER CURRENT.
• MORE PARASITIC CAP.

~~LONG~~ WIDE TRANSISTORS : USE MULTI-FINGERS



- FOR GOOD MATCHING (GATE AREA) :

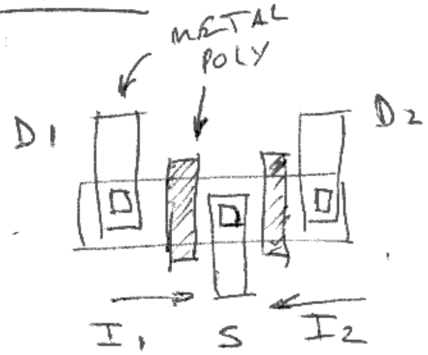
$$\left\{ \begin{array}{ll} \text{MINIMAL} & \\ \text{MODERATE} & > 100 (\mu m)^2 \\ \text{PRECISE} & > 1000 (\mu m)^2 \end{array} \right.$$

- AVOID $L < 1 \mu m$ IN MATCHING TRANSISTORS

SUMMARY OF E. VITTOZ NOTES ON DEVICE MATCHING (ALSO SEE § 3.4.3 SCHNEIDER/ GALUP-MONTORO)

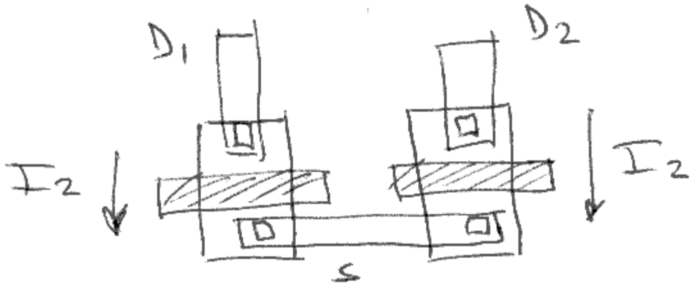
1. SAME STRUCTURE (OF COURSE)
2. SAME TEMPERATURE (ISOTERMS)
3. SAME SHAPE AND SIZE
4. MINIMUM DISTANCE
5. COMMON CENTROID (IF NEEDED)
6. SAME ORIENTATION
7. SAME SURROUNDINGS (DUMMY DEVICES)
8. NON-MINIMUM SIZE (RULE OF THUMB ≥1 μm)

EXAMPLE: DIFFERENTIAL PAIR



BAD

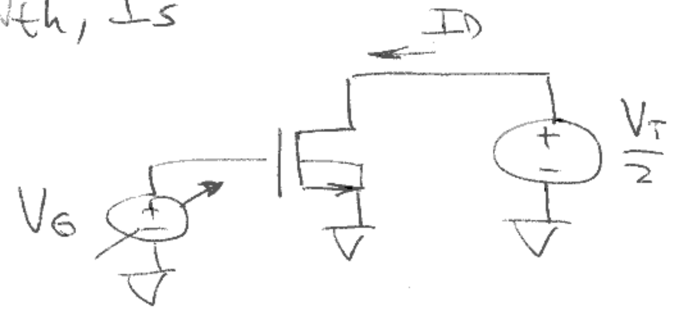
NOT SAME ORIENTATION



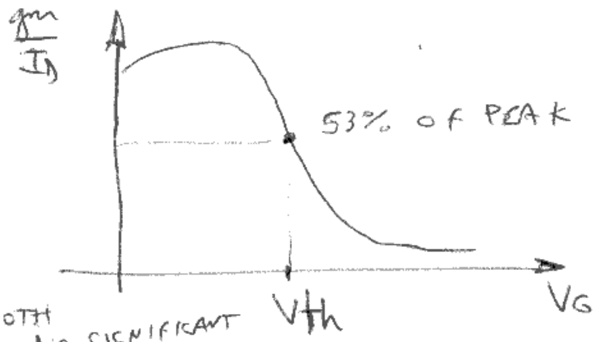
GOOD

EXTRACTION OF ACM PARAMETERS FROM SIMULATIONS

1) V_{th}, I_S



PLOT $\frac{g_m}{I_D}$



$\frac{g_m}{I_D} = \frac{\partial \log I_D}{\partial V_G}$

SINCE BOTH i_f, i_r SIGNIFICANT

$$\frac{g_m}{I_D} = \frac{g_{mg}}{I_D} = \frac{g_{ms} - g_{md}}{n I_D} = \frac{2 I_S}{n V_T I_D}\left(\sqrt{1+i_f} - \sqrt{1+i_r}\right)$$

$$I_D = \left(i_f - i_r\right) I_S$$

WHEN $V_G = V_{th} \Rightarrow i_f = 3$

$i_r \cong i_f$ SINCE $V_G >> V_D$

$$\frac{g_m}{I_D} \simeq \frac{1}{n V_T} \frac{1}{\sqrt{1+i_f}} = \frac{1}{2 n V_T} \text{ IF } i_f = 3$$

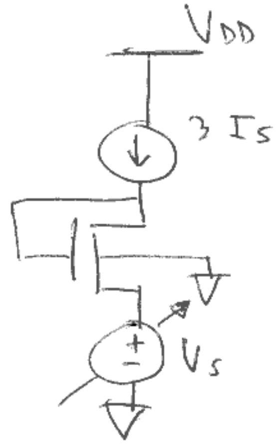
$$\frac{\sqrt{1+i_f} - \sqrt{1+i_r}}{i_f - i_r} \; \frac{\sqrt{1+i_f} + \sqrt{1+i_r}}{\sqrt{} + \sqrt{}} = \frac{1 + i_f - 1 - i_r}{i_f - i_r} \; \frac{1}{\sqrt{1+i_f} + \sqrt{1+i_r}}$$

$$i_f \approx i_r \Rightarrow \frac{g_m}{I_D} = \frac{2 \cancel{I_S}}{n V_T \cancel{I_S}} \cdot \frac{1}{2\sqrt{1+i_f}} \longrightarrow \text{MORE ACCURATE 53\%}$$

$$I_D \approx \frac{2 V_{DS}}{V_T} I_S \quad \text{IF } V_{DS} < V_T$$

$$\therefore \boxed{I_S = I_D \Big|_{V_G = V_{th}}} \longrightarrow \text{BUT MORE ACCURATE } I_S = 1.13 I_D \Big|_{V_G = V_{th}}$$

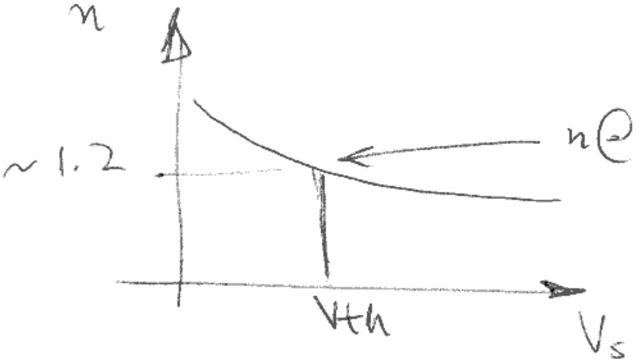
2) n



$$\frac{V_P - V_S}{V_T} = \mathcal{F}(i_f)$$

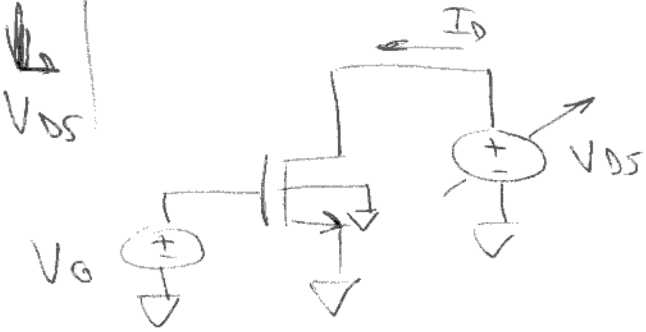
$$i_f = 3 \Rightarrow V_P = V_S = \frac{V_G - V_{th}}{n} \Rightarrow V_G = V_{th} + nV_S$$

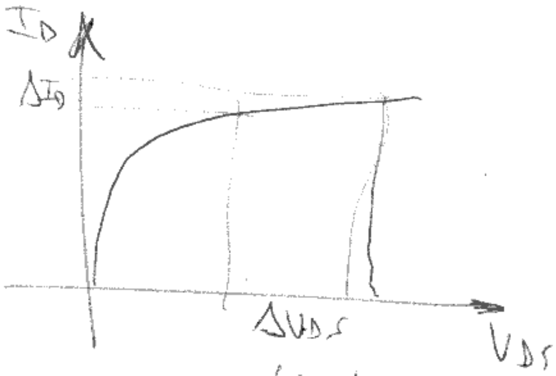
$$\boxed{n = \frac{\partial V_G}{\partial V_S}}$$



n @ V_{th} IS A GOOD APPROXIMATION FOR MODERATE INVERSION AND NOT TOO BAD FOR STRONG/WEAK.

3) $\left|\frac{\partial L}{\partial V_{DS}}\right|$





$$\frac{\Delta V_{DS}}{\Delta I_D} = r_o = \frac{1}{\lambda I_D} = \frac{L}{\left|\frac{\partial L}{\partial V_{DS}}\right| I_D} \longrightarrow \text{SOLVE FOR } \left|\frac{\partial L}{\partial V_{DS}}\right| = \frac{L_{eff}}{\frac{\Delta V_{DS}}{\Delta I_D} I_D}$$