Fully-differential amplifiers

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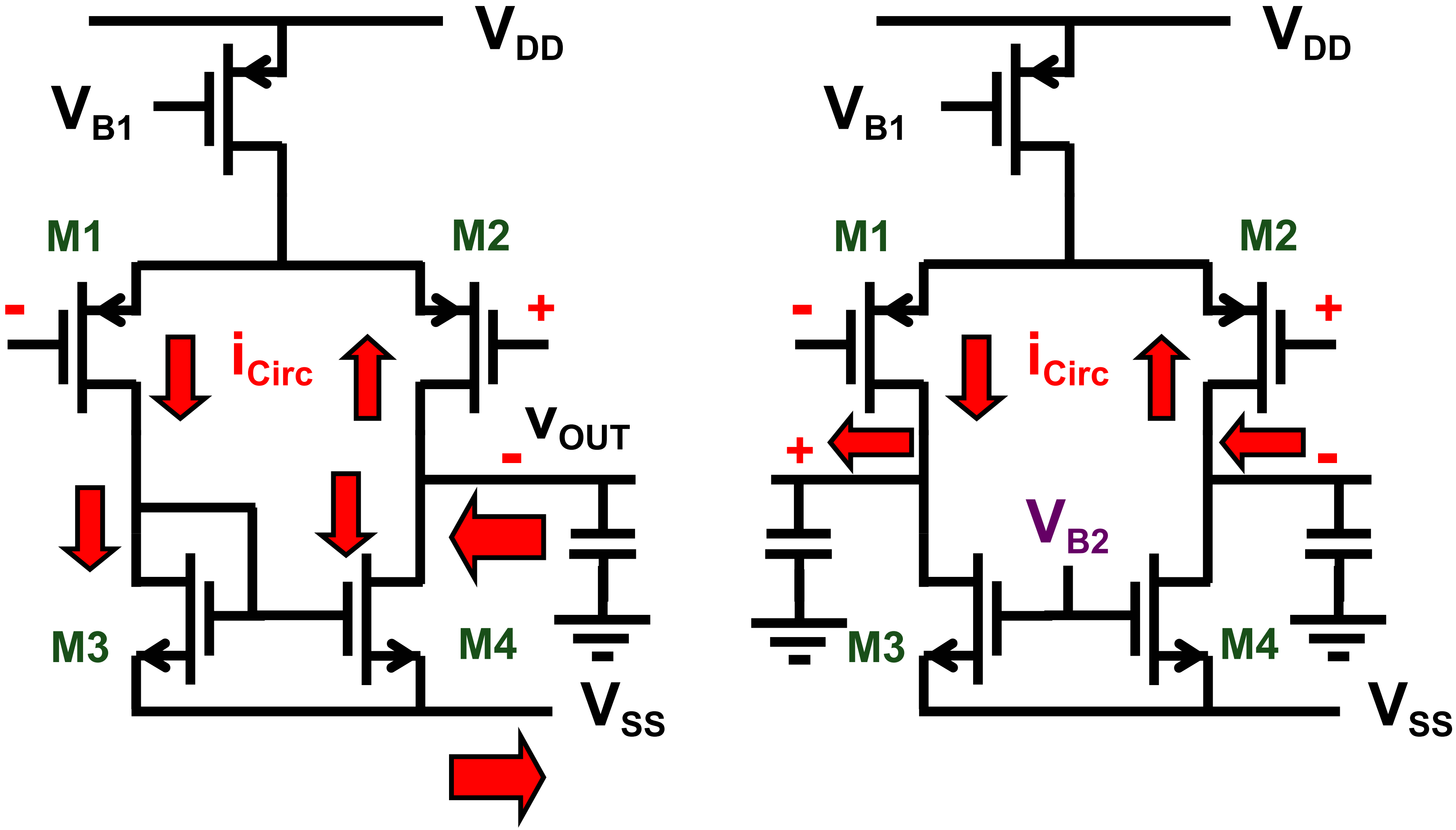
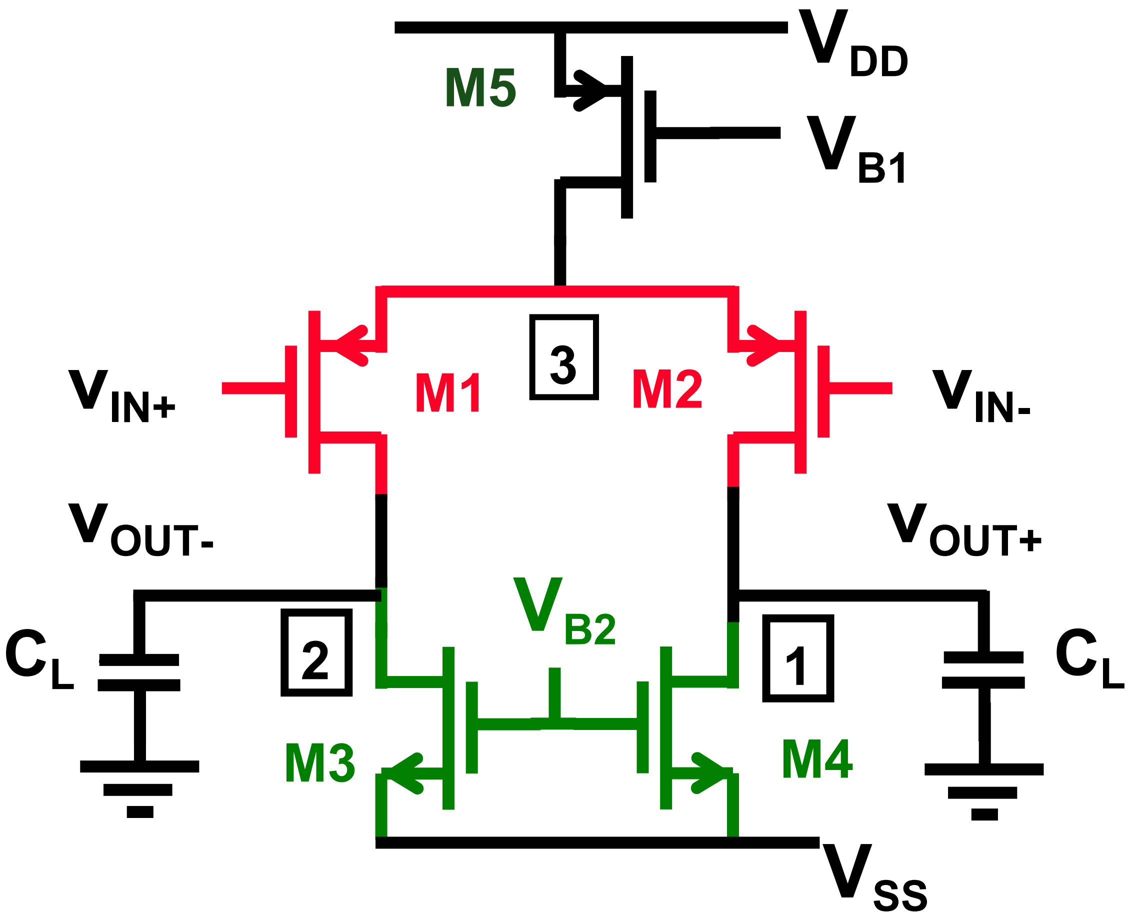
- Requirements
- Fully-diff. amps with linear MOSTs
- FDA's with error amp.& source followers
- Folded cascode OTA without SF's
- Other fully-differential amps
- Exercise

Single-stage OTA



Simple CMOS fully-differential OTA



Differential pair

No current mirror

$$GBW = \frac{g_{m1}}{2\pi C_L}$$

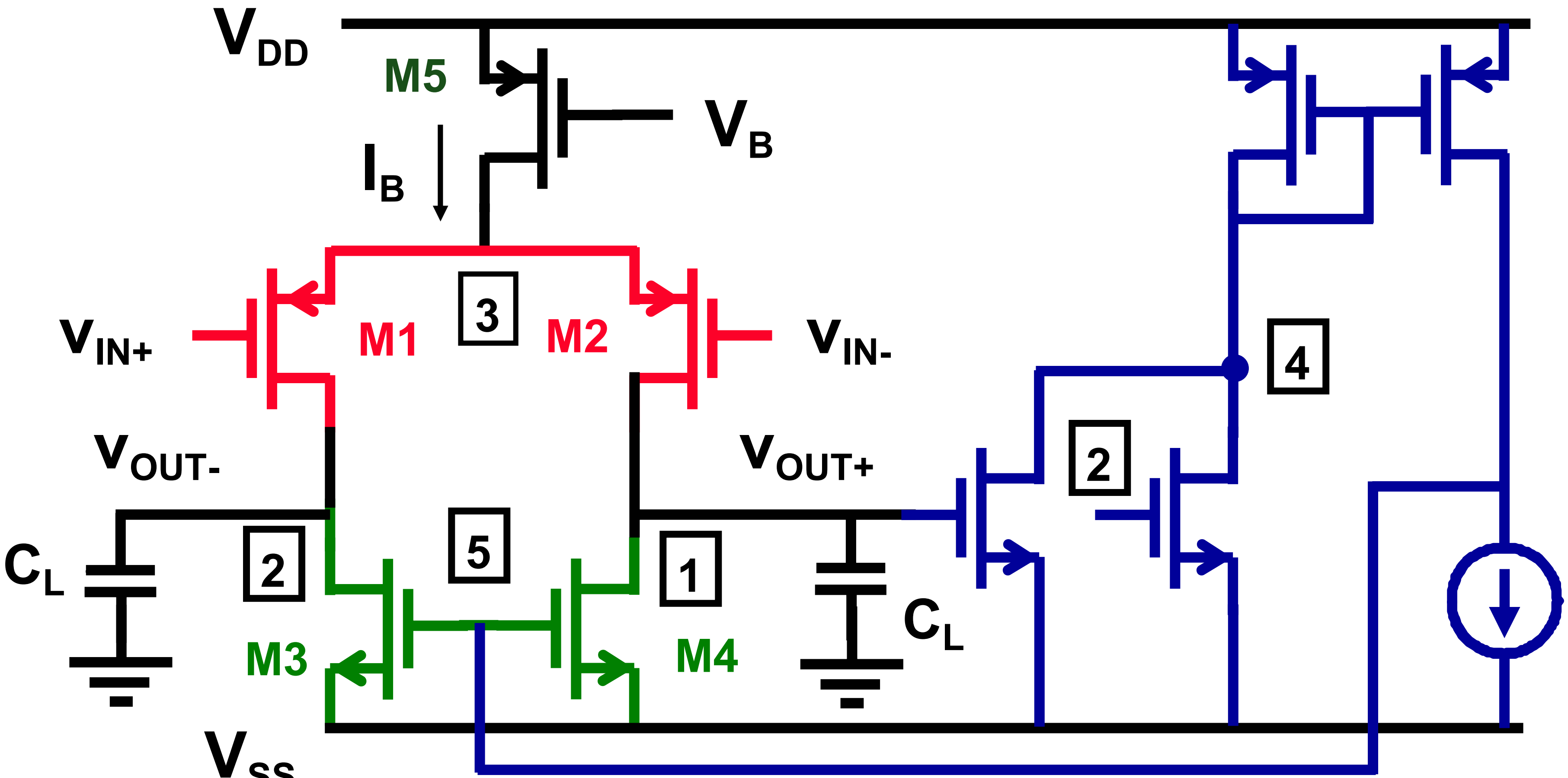
Problem:

keep M1-4 in saturation:

Control V_{OUTCOM}

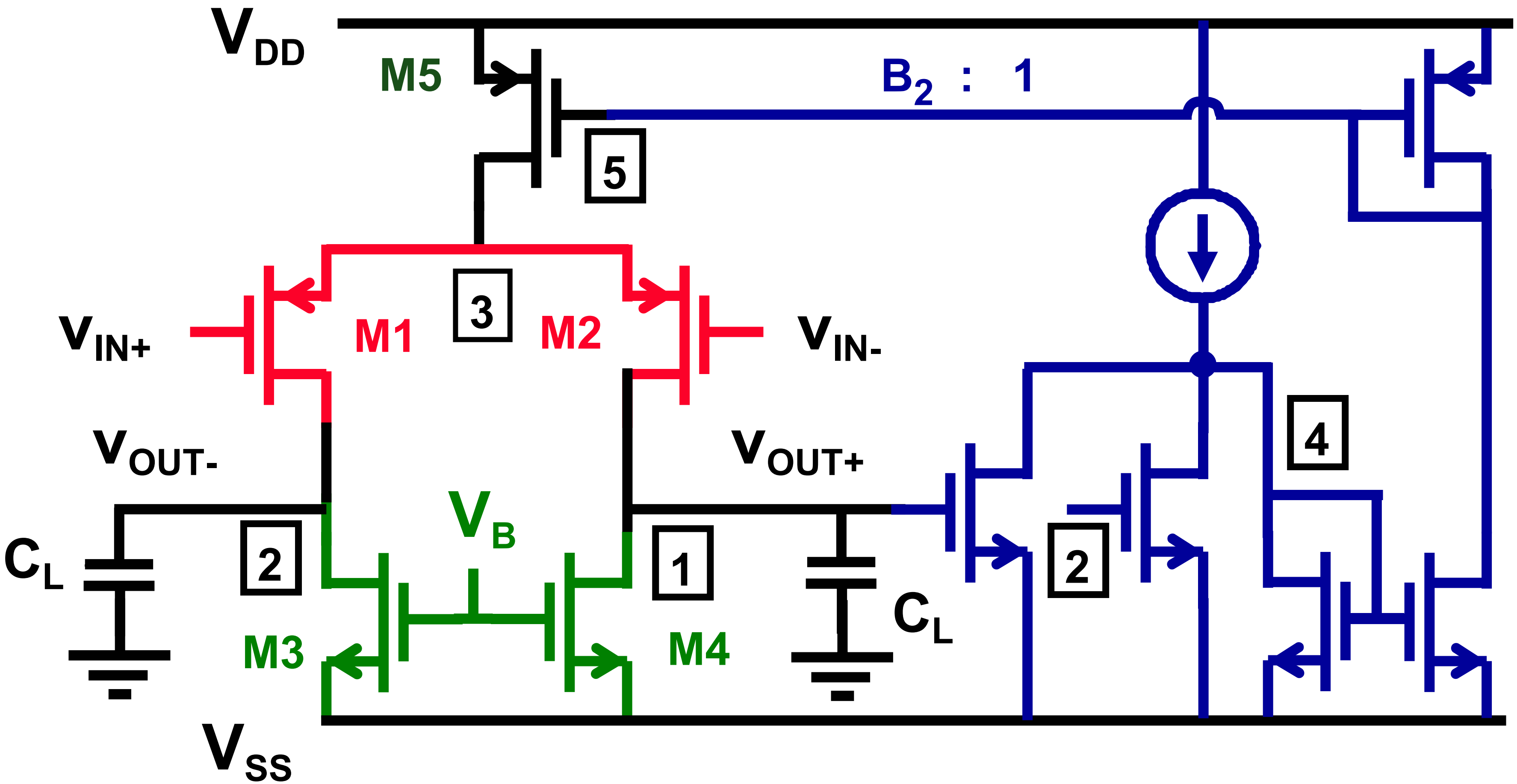
Control I_{DS5}

Simple CMOS fully-diff. OTA with CMFB - 1



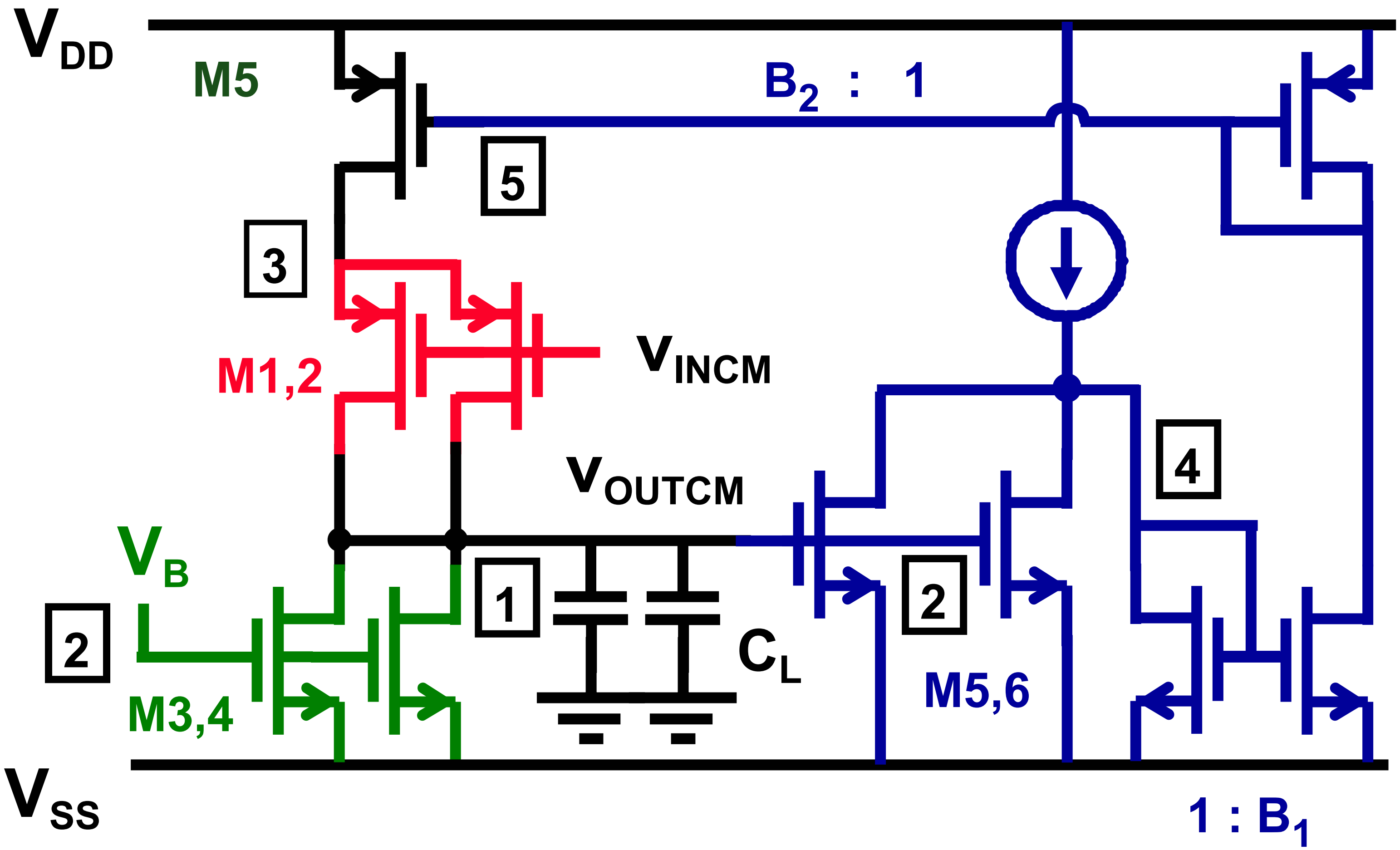
Control V_{OUTCOM}, I_{DS5}

Simple CMOS fully-diff. OTA withy CMFB - 2



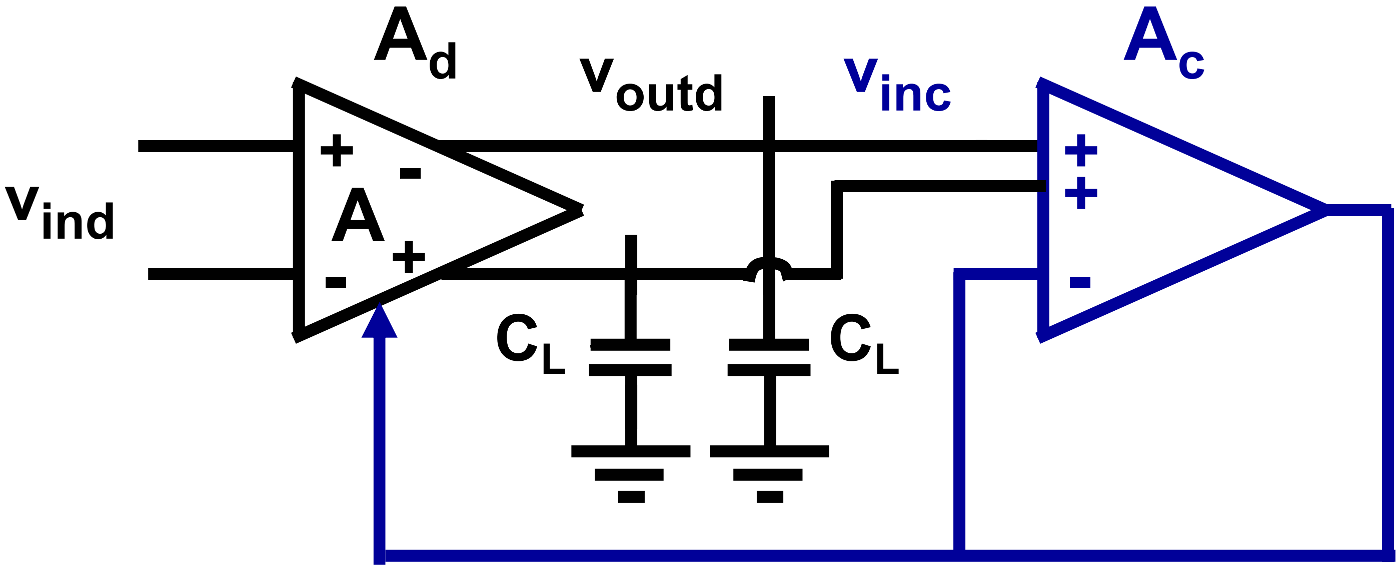
Control V_{OUTCOM}, I_{DS5}

Common-mode feedback equivalent circuit



Control V_{OUTCOM}, I_{DS5}

Common-mode feedback CMFB



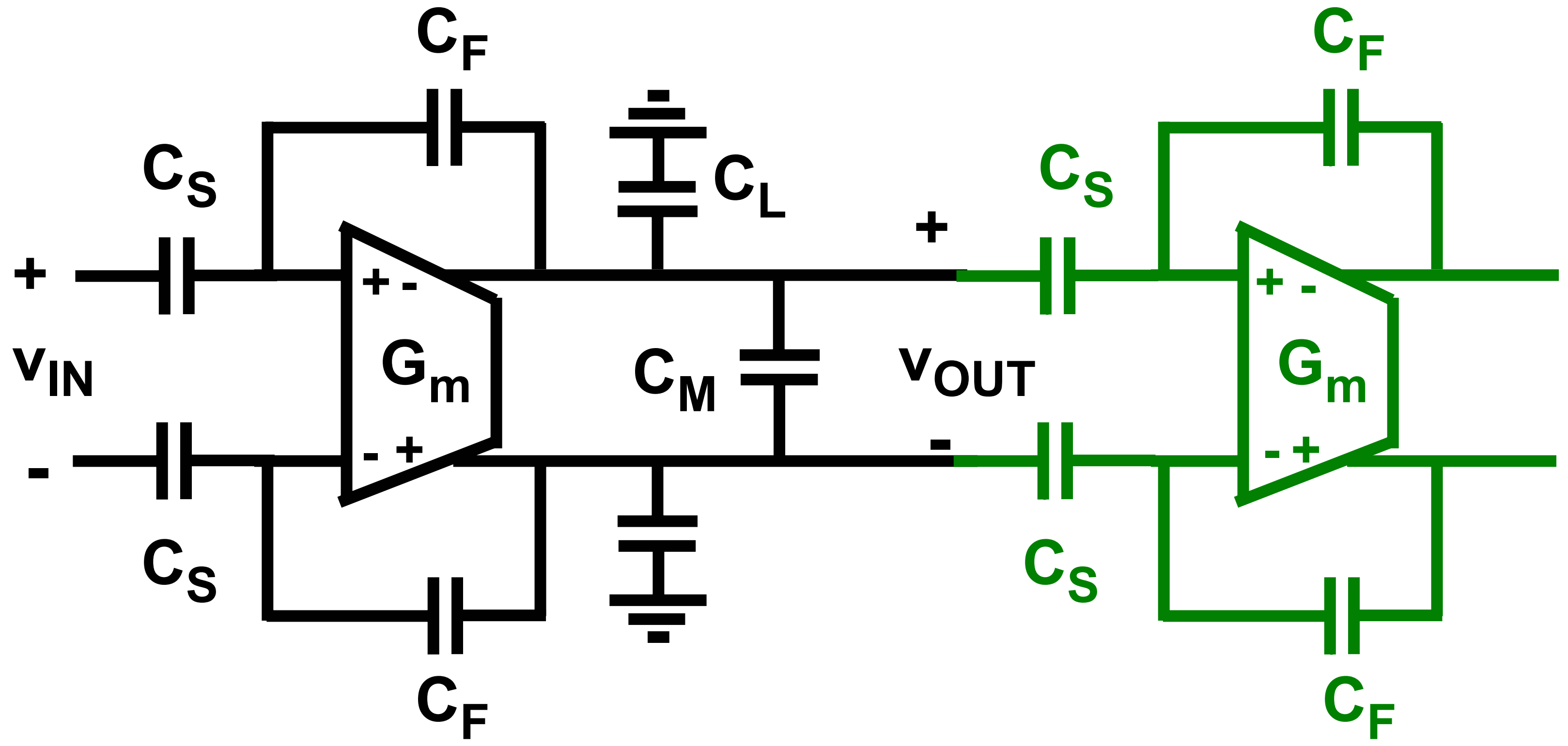
CMFB in unity gain : CMRR = A_{vCM}

Three tasks : 1. Measure the output voltages
2. Cancel out the differential signals
3. Close the CMFB loop

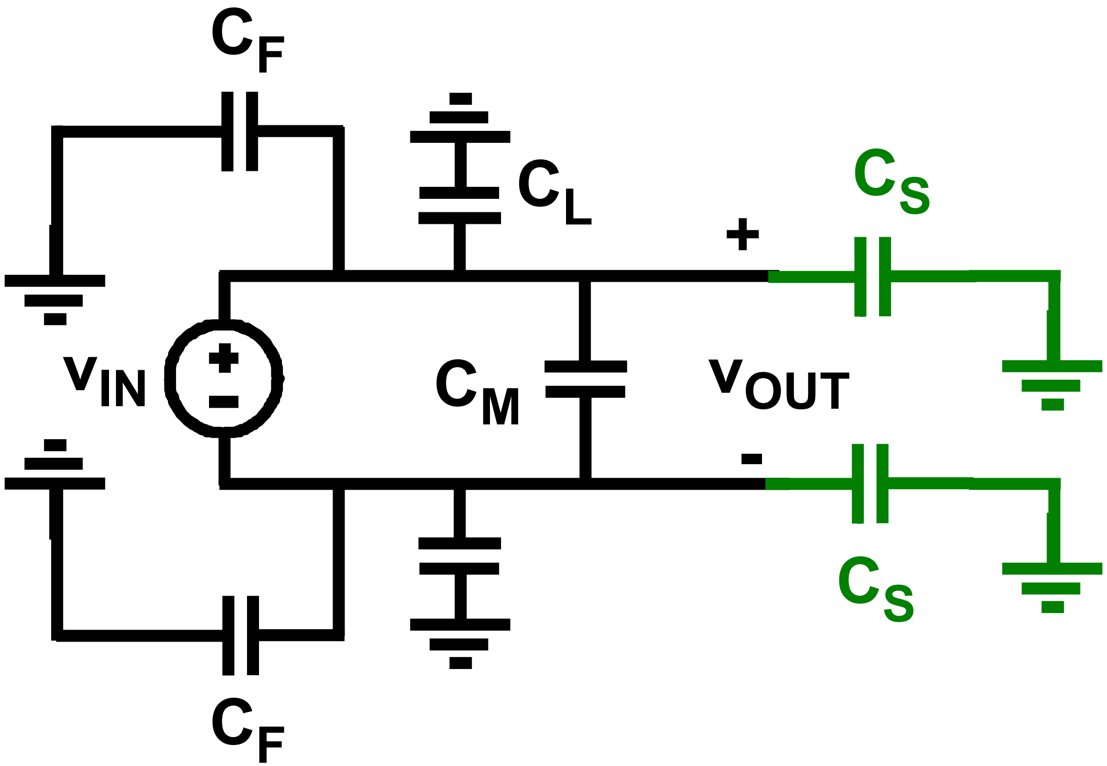
Requirements fully-differential amplifiers

- High speed : $GBW_{CM} > GBW_{DM}$
- Matching
- Output swing limited by :
  - Output swing of differential-mode amp
  - Input range of common-mode amp
- Low power $P_{CM} < P_{DM}$

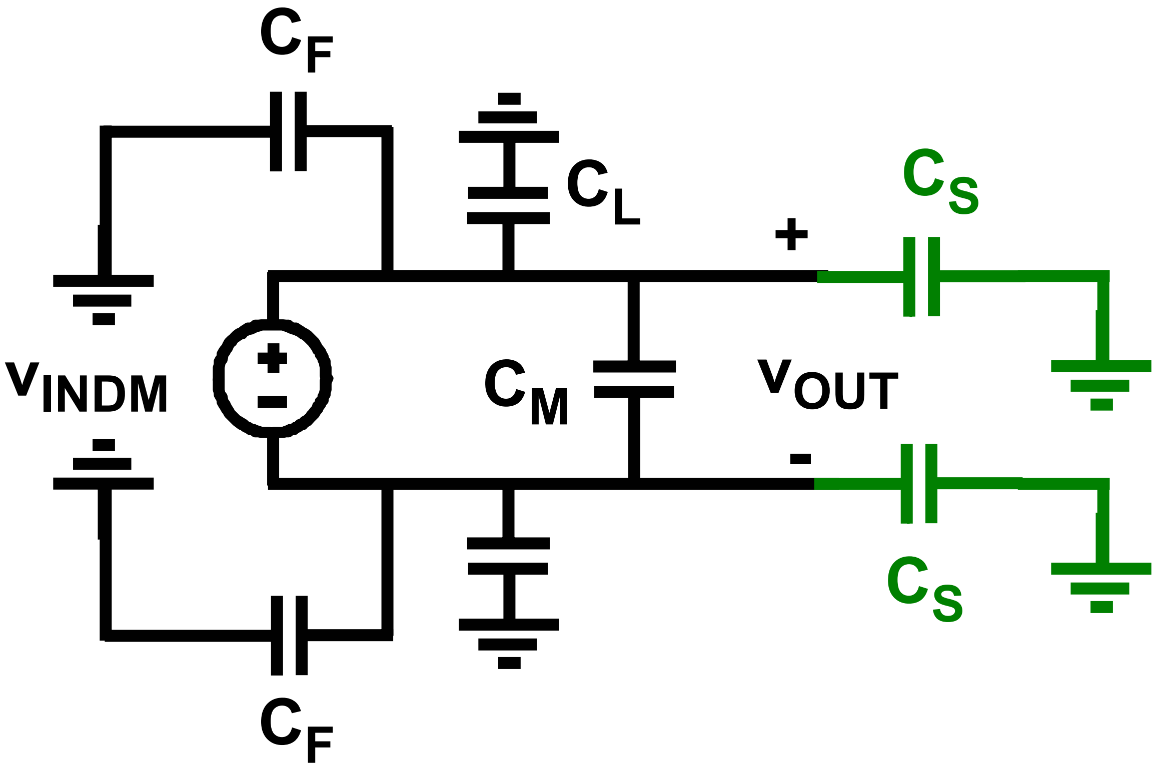
Load capacitance ?



Load capacitance C_{IN}

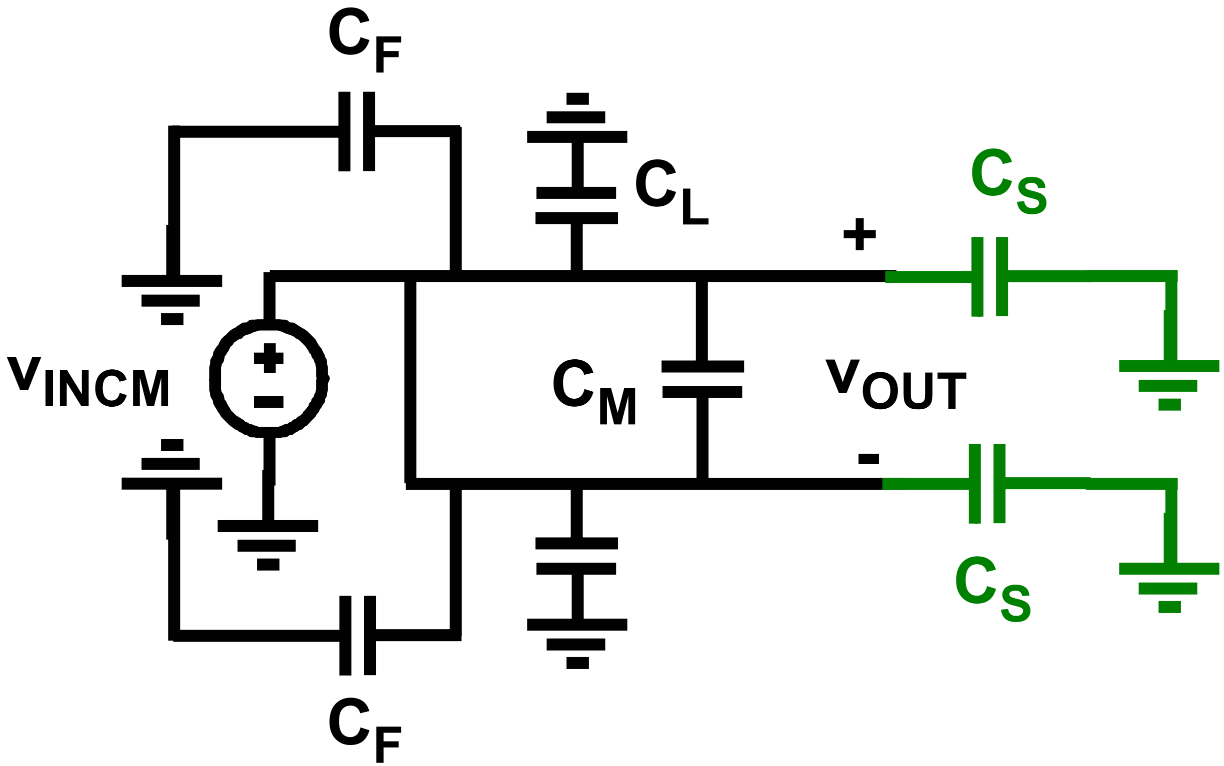


Load capacitance C_{INDM}



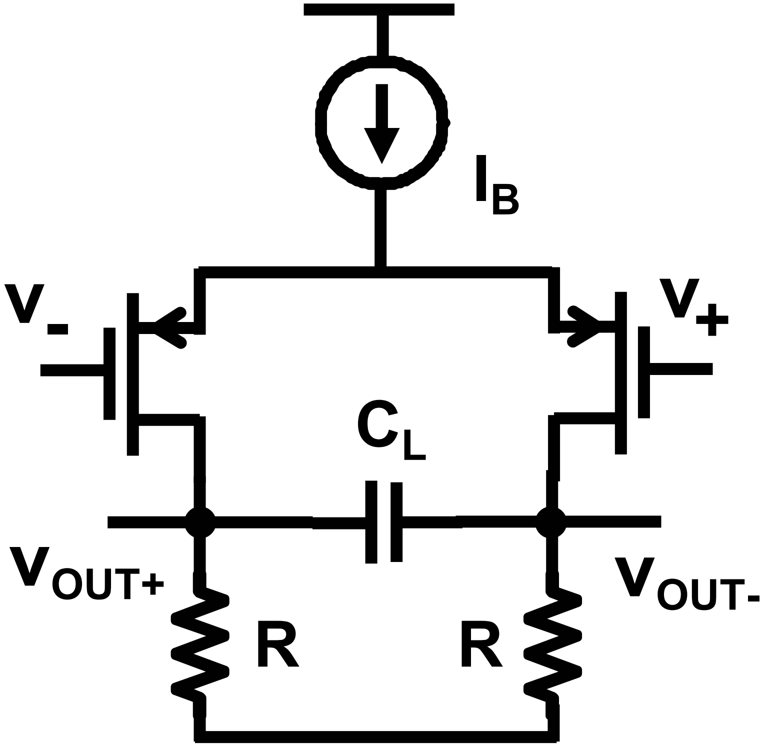
$$C_{INDM} = C_M + \frac{C_F + C_L + C_S}{2}$$

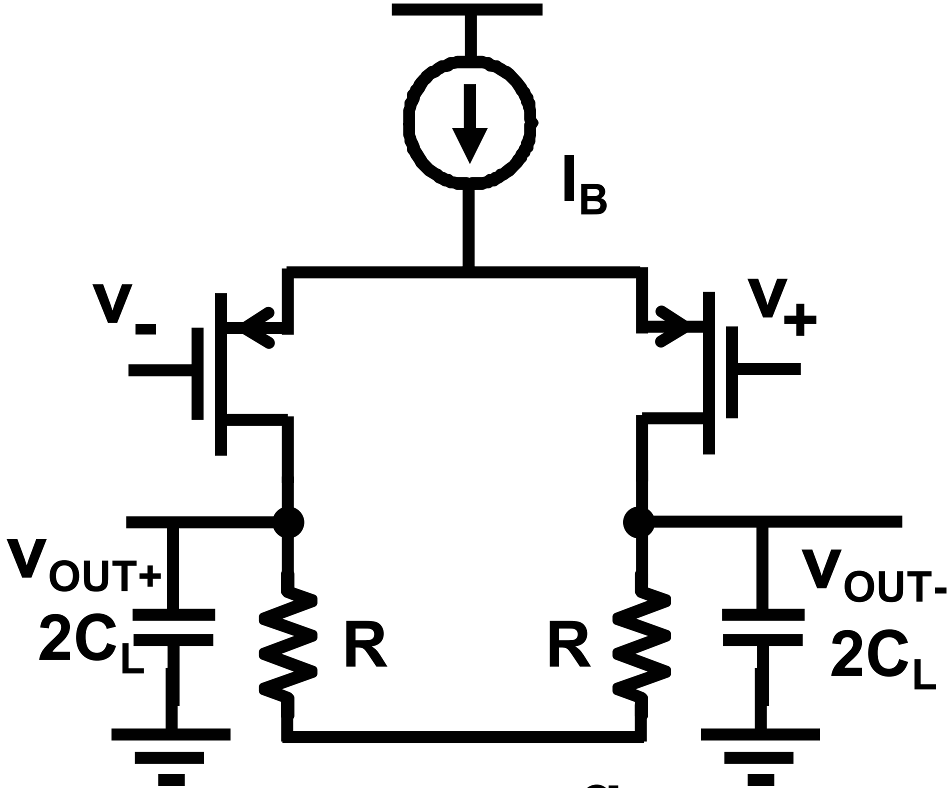
Load capacitance C_{INCM}



$$C_{INCM} = 2\,(C_F + C_L + C_S) \quad > C_{INDM}$$

GBW_{DM} & GBW_{CM}





$$GBW_{DM} = \frac{g_m}{2\pi\, 2C_L}$$

$$C_{LCM} = 0$$

$$GBW_{DM} = \frac{g_m}{2\pi\, 2C_L}$$

$$C_{LCM} = 4\, C_L$$

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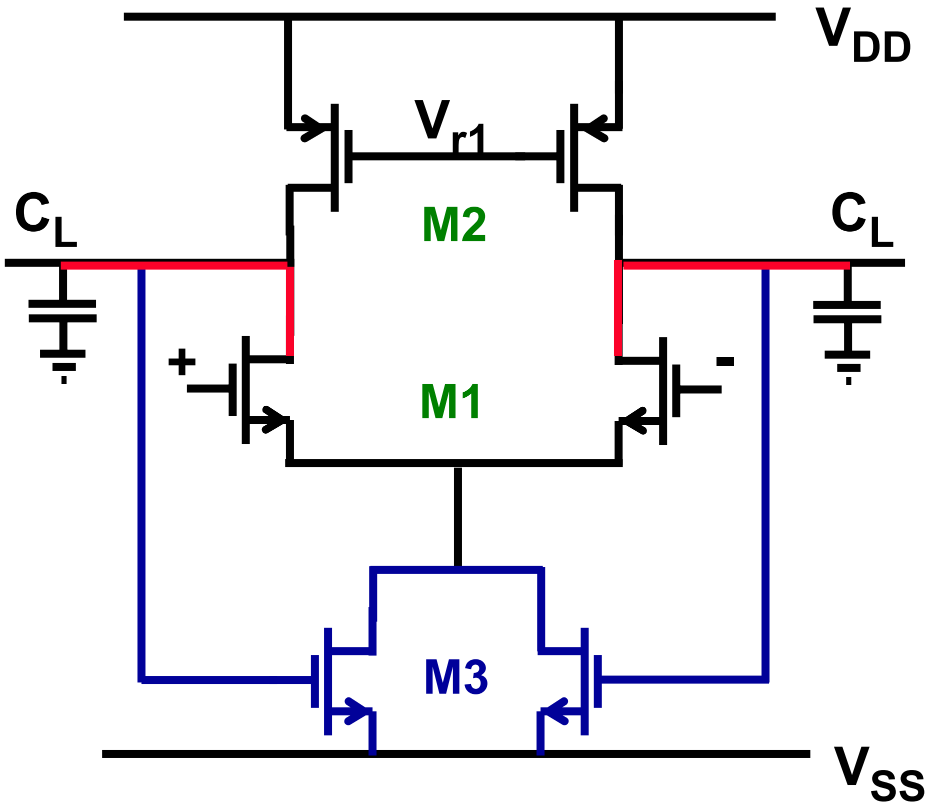
CMFB amplifier with linear MOSTs



Linear MOSTs:

$V_{DS3} \approx 200\ mV$

$I_{DS} = \beta V_{DS}(V_{GS}-V_T)$

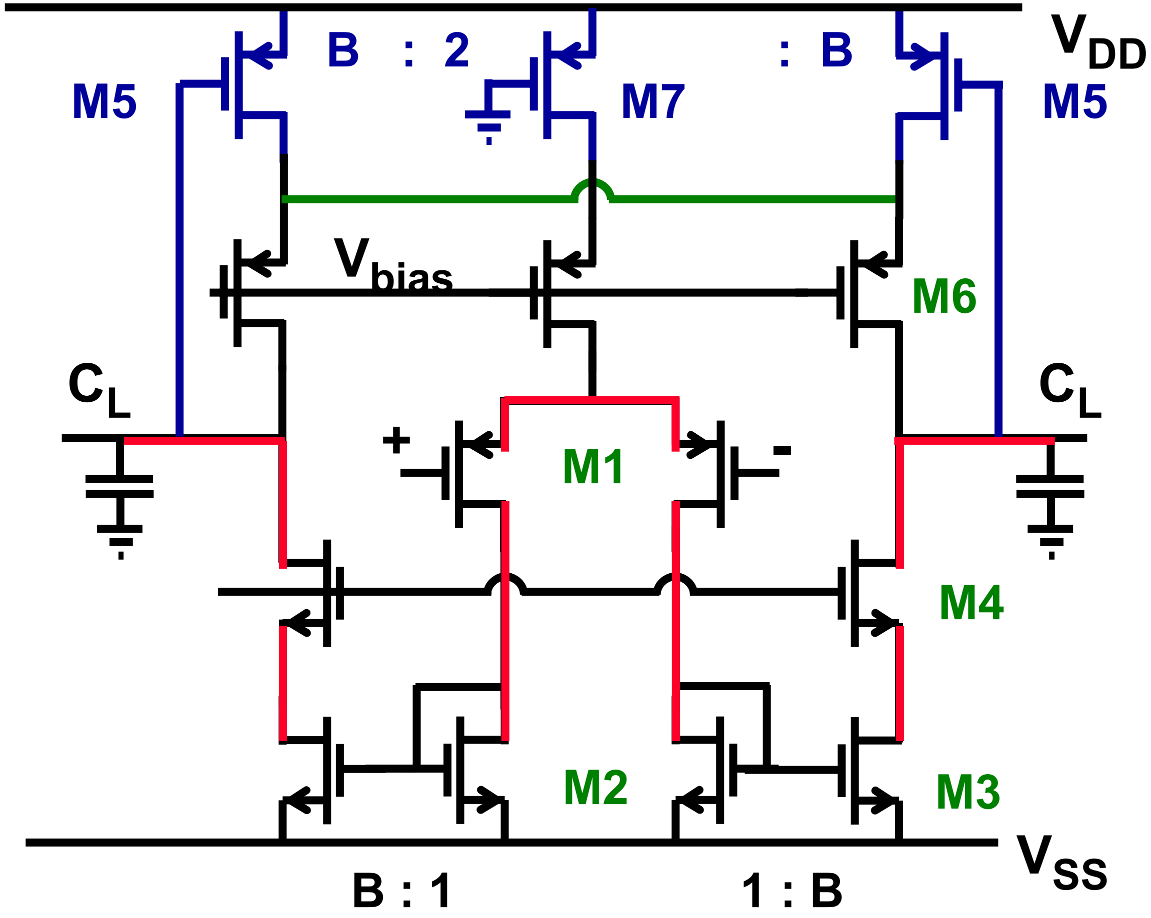
$g_{m3} = \beta V_{DS3}$

$$GBW_{DM} = \frac{g_{m1}}{2\pi C_L}$$

$$GBW_{CM} = \frac{g_{m3}}{2\pi C_L}$$

is always smaller !

Fully-differential amp. with linear MOSTs



Linear MOSTs:

$V_{DS5} \approx 200$ mV

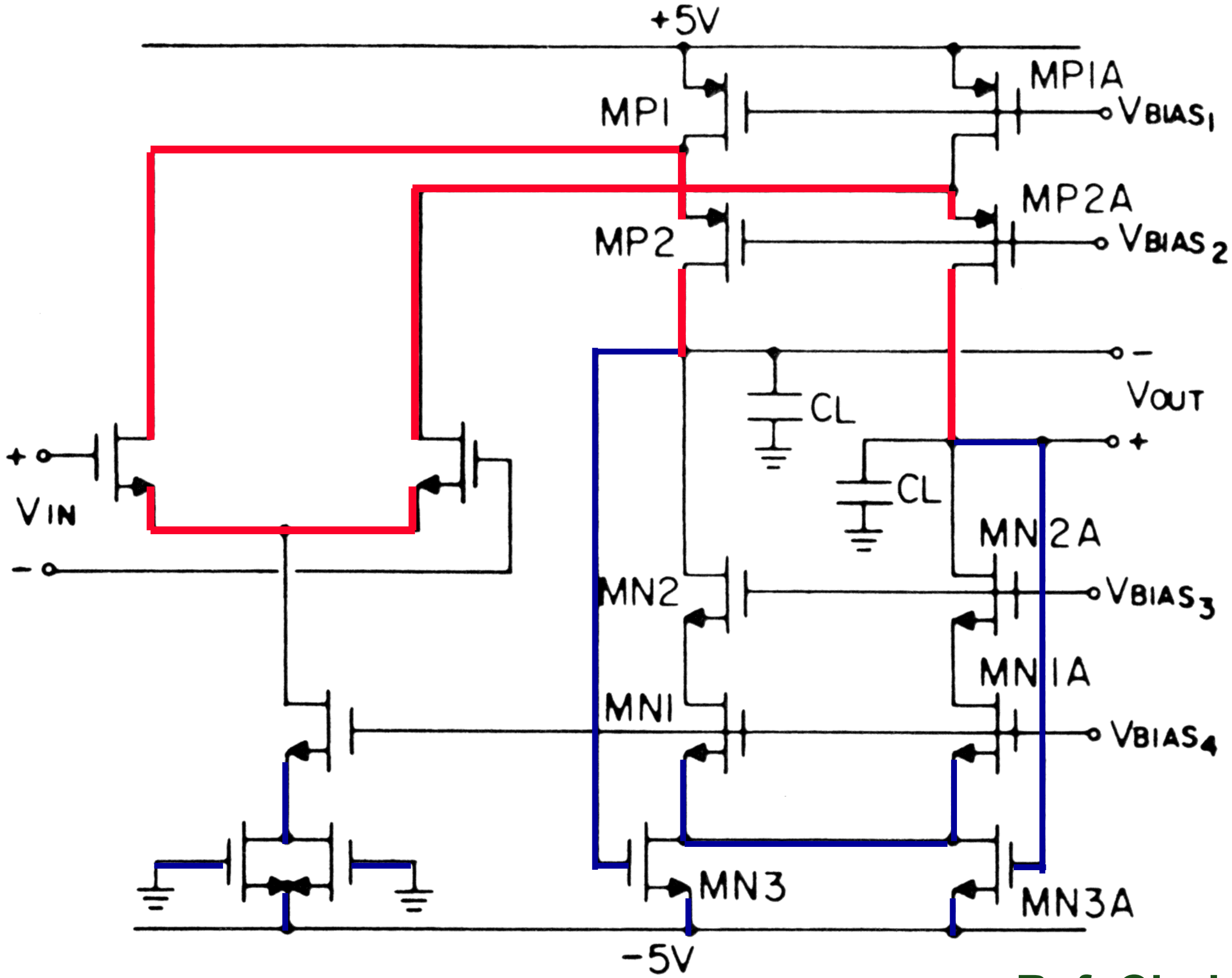
Cancel diff. signals

$$GBW_{DM} = B \frac{g_{m1}}{2\pi C_L}$$

$$GBW_{CM} = \frac{g_{m5}}{2\pi C_L}$$

is always smaller !
even with M5 in wi !

Fully-differential amp. with linear MOSTs

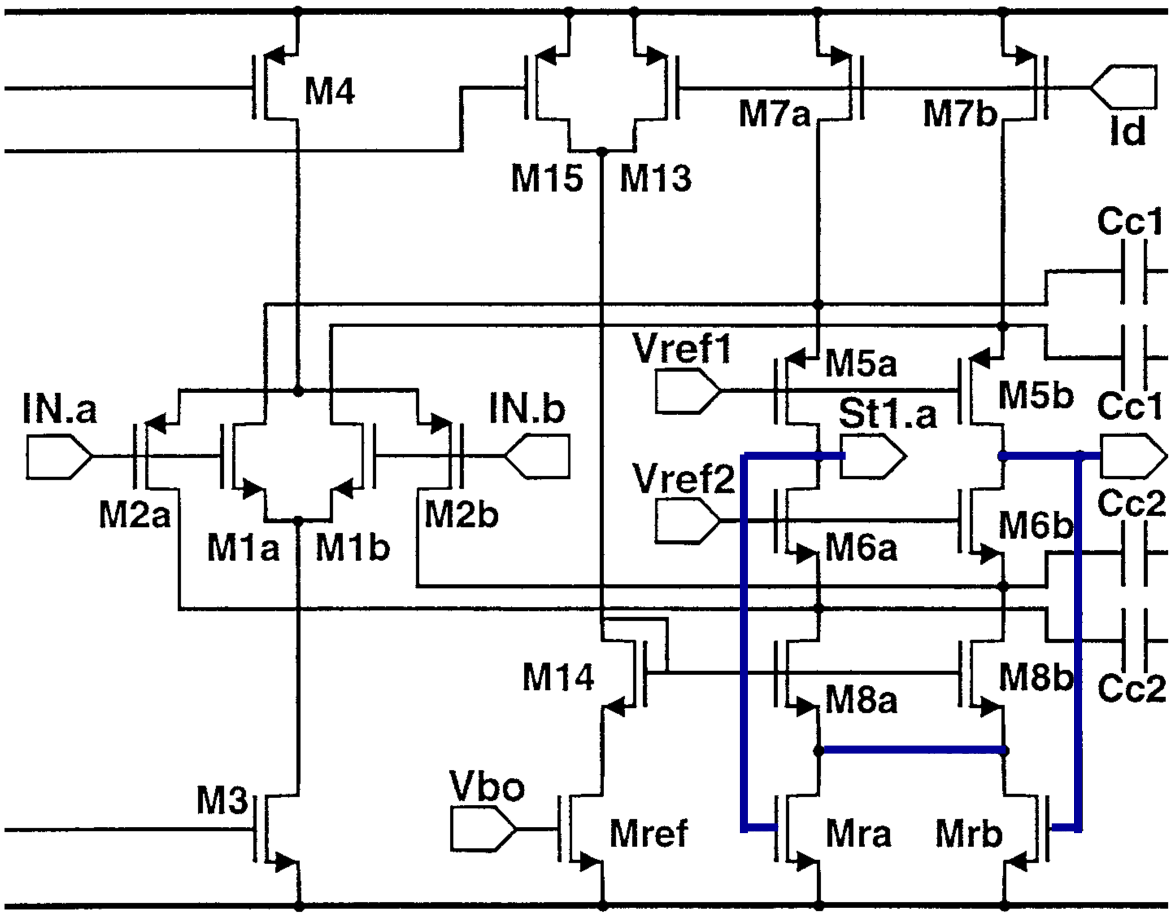


Linear MOSTs:

V_{DS3} ≈ 200 mV

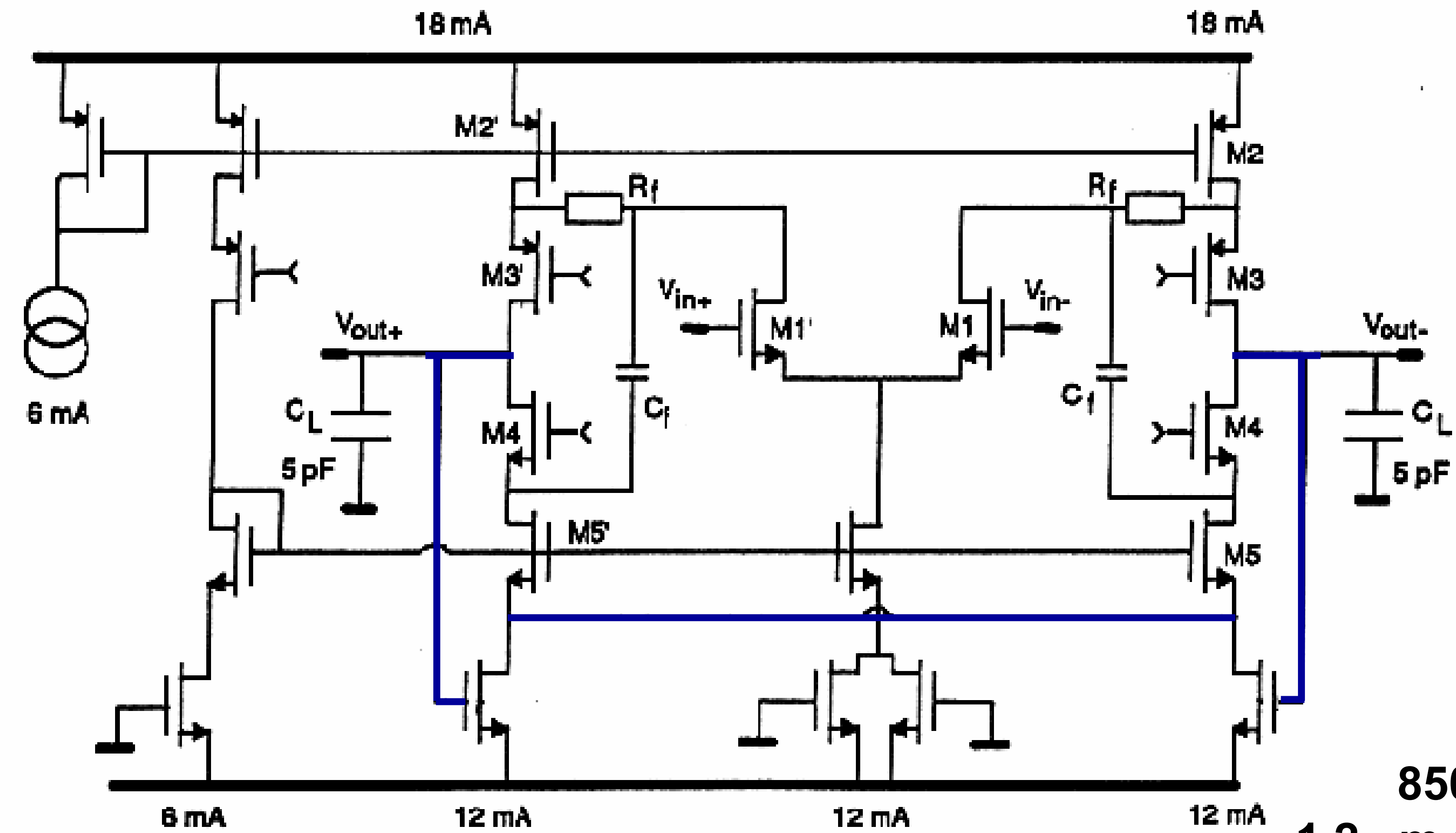
Ref. Choi, JSSC, Dec.83, 652-653

Total amplifier schematic



E.Peeters etal, CICC 1997

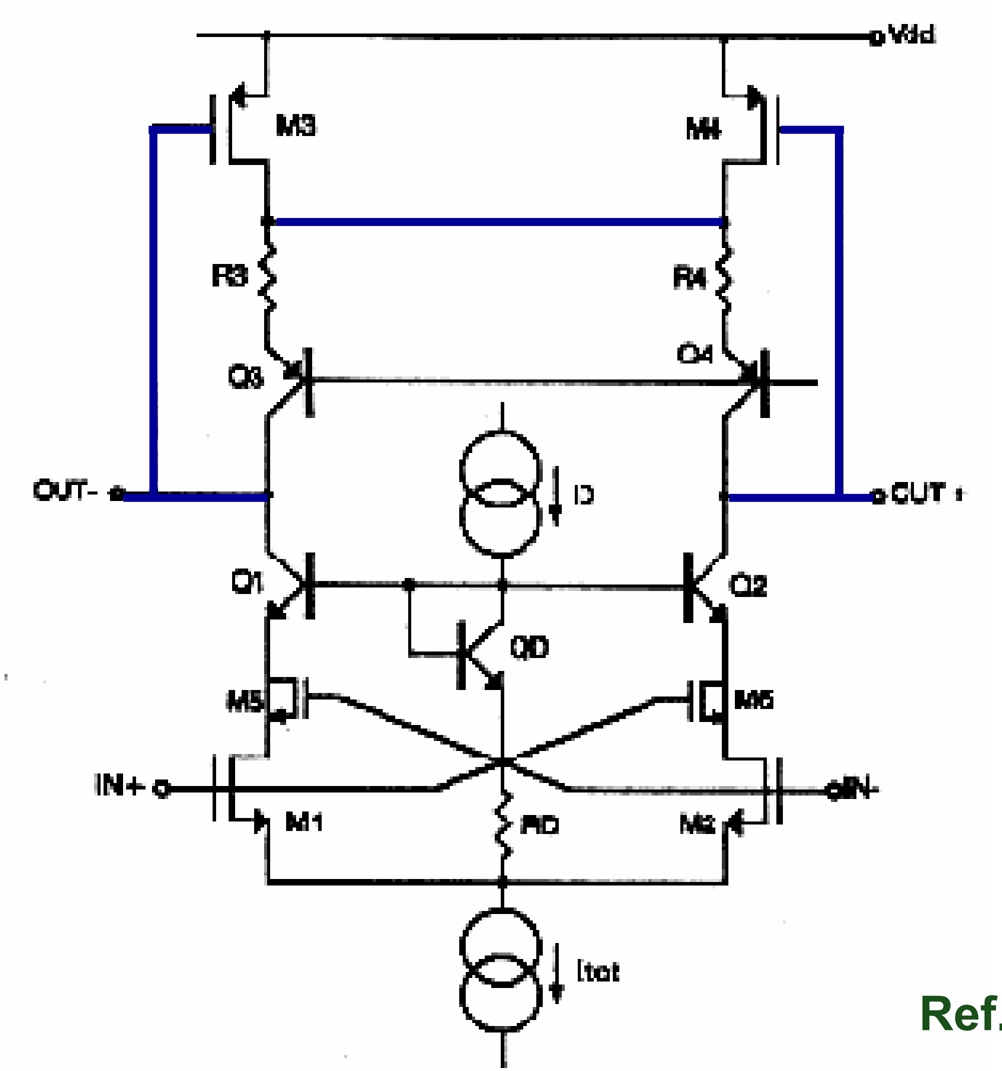
Fully-differential OTA with FF



850 MHz
1.2 μm CMOS

F. Op't Eynde, Kluwer Ac. 1993

Transconductor with C□$_{DG}$ compen.



$$V_{DS1} = R_D I_D \approx 0.2\ V$$

$$I_{DS1} = \beta_1 V_{DS1}(V_{GS1} - V_T)$$

$g_{m1} = \beta_1 V_{DS1}$ is constant

Ref. Alini, JSSC, Dec.92, pp.1905-1915

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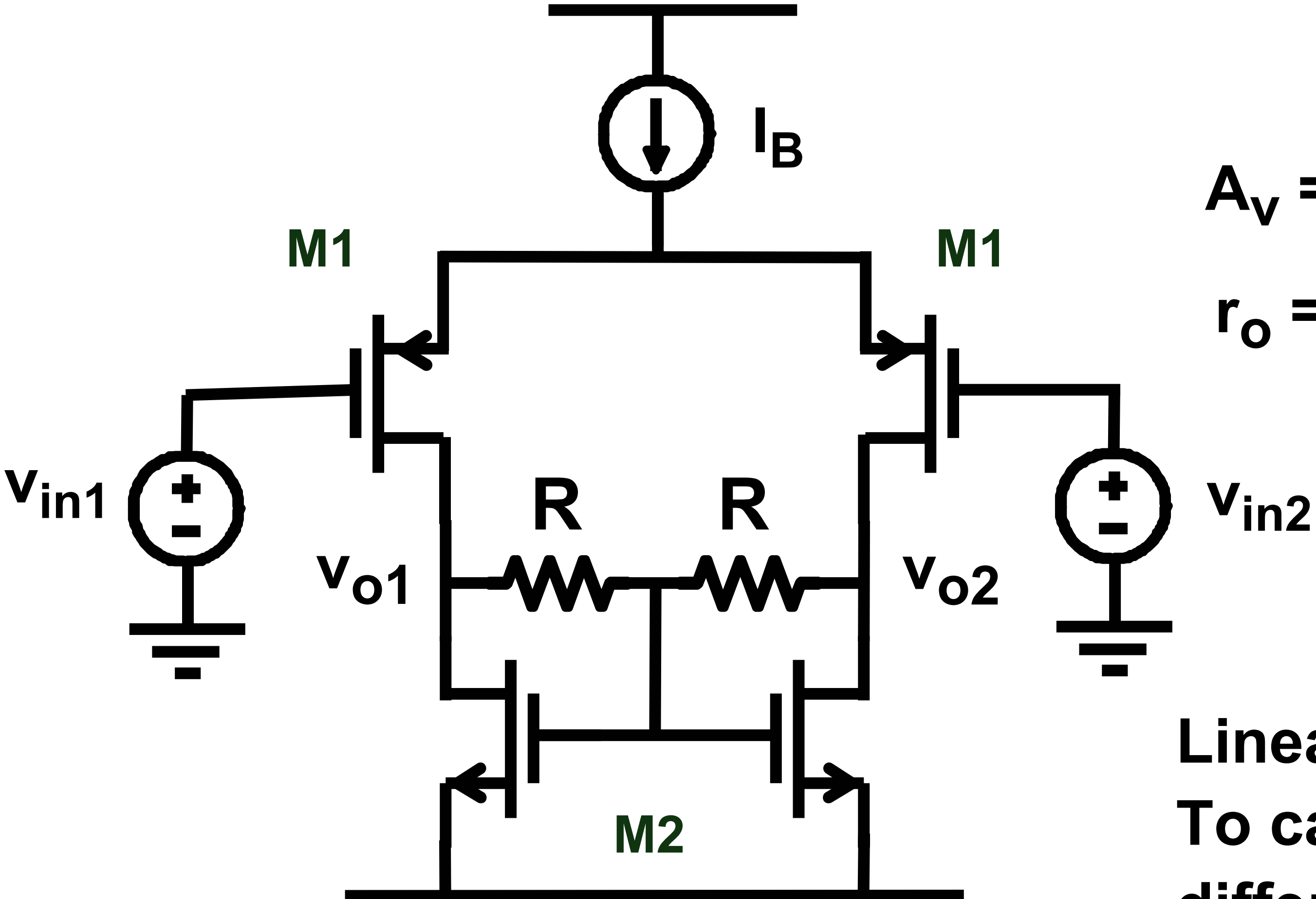
Fully-differential amplifier with resistive CMFB

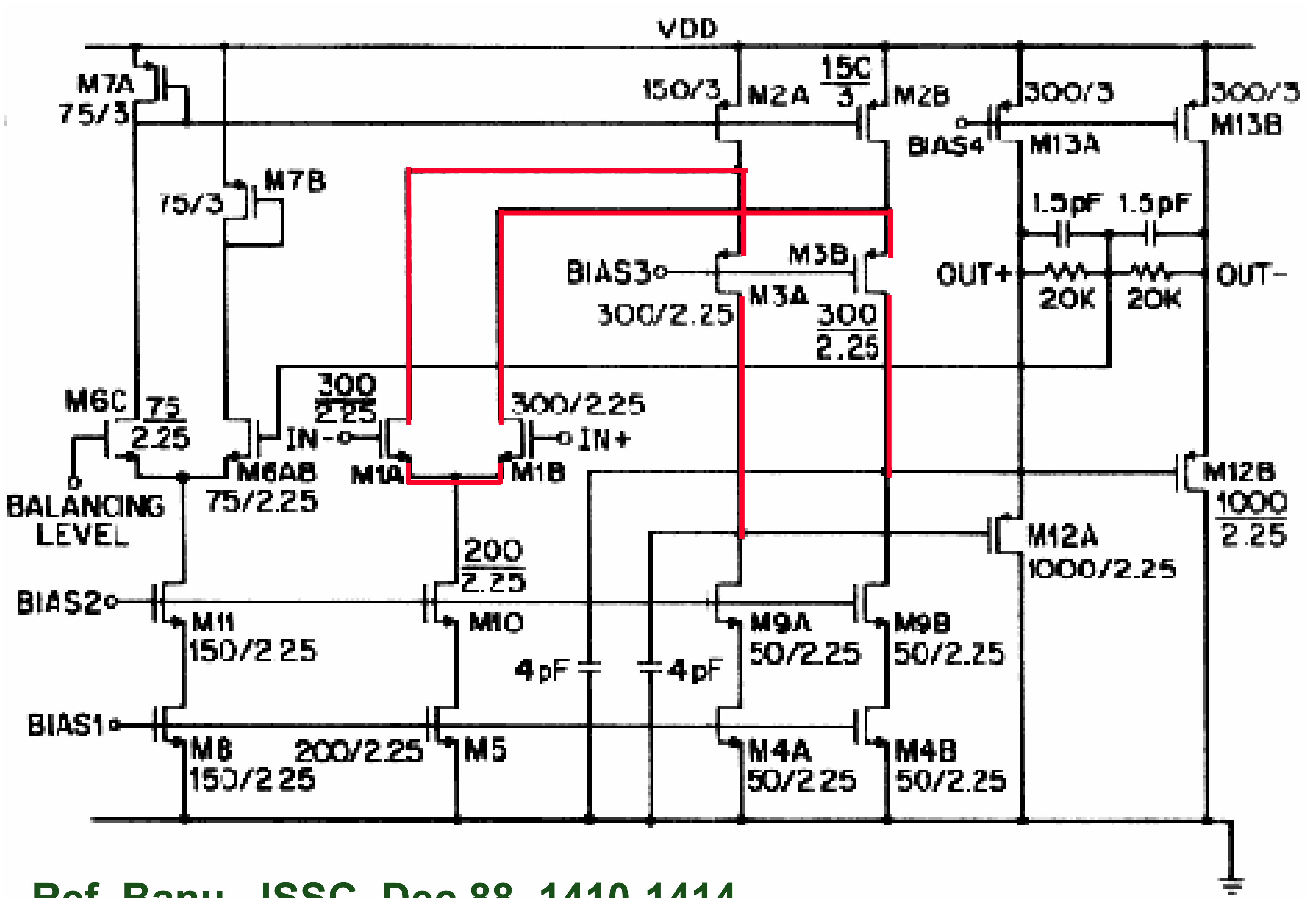


$A_v = g_{m1} (R \mathbin{//} r_o)$

$r_o = r_{o1} // r_{o2}$

Linear resistors R
To cancel
differential signals

Fully-diff. amp. with source followers: Diff. mode

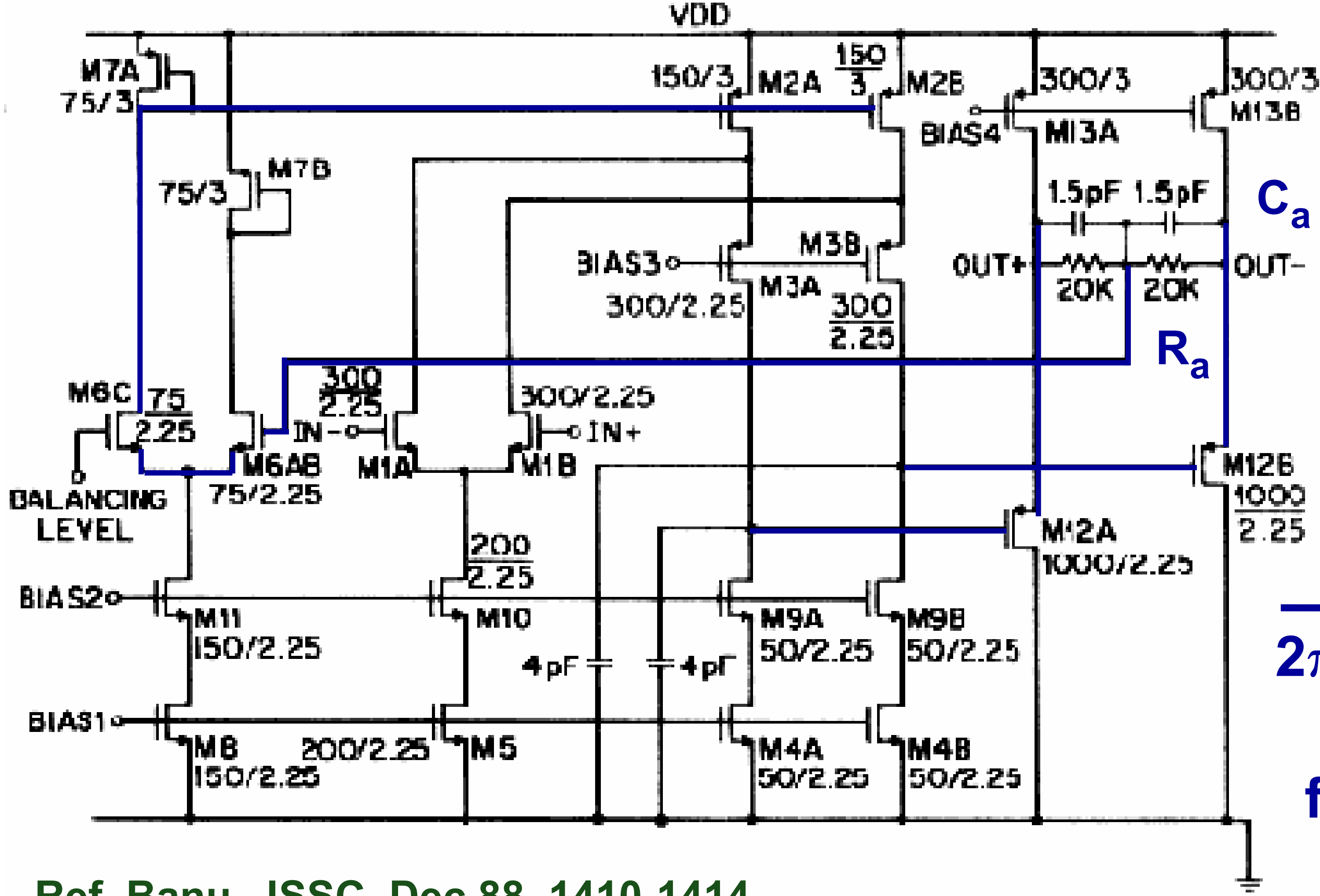


$$GBW_{DM} = \frac{g_{m1}}{2\pi C_L}$$

$$C_L = 4 \text{ pF}$$

Ref. Banu, JSSC, Dec.88, 1410-1414

Fully-diff. amp. with source followers: CM



$$GBW_{CM} = \frac{g_{m6}}{4\pi\, C_L}$$

$$f_{ndCM} = \frac{4}{2\pi R_a(C_{GS6}+C_a)}$$

$$f_z = \frac{1}{2\pi R_a C_a}$$

Ref. Banu, JSSC, Dec.88, 1410-1414

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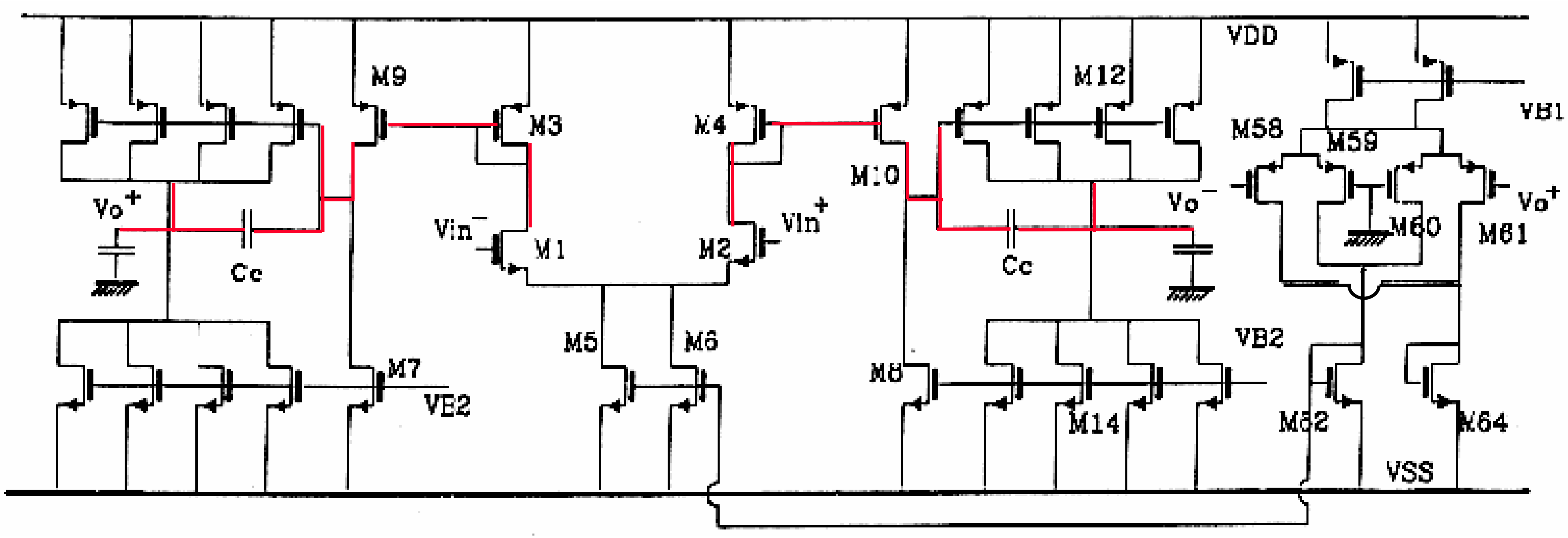
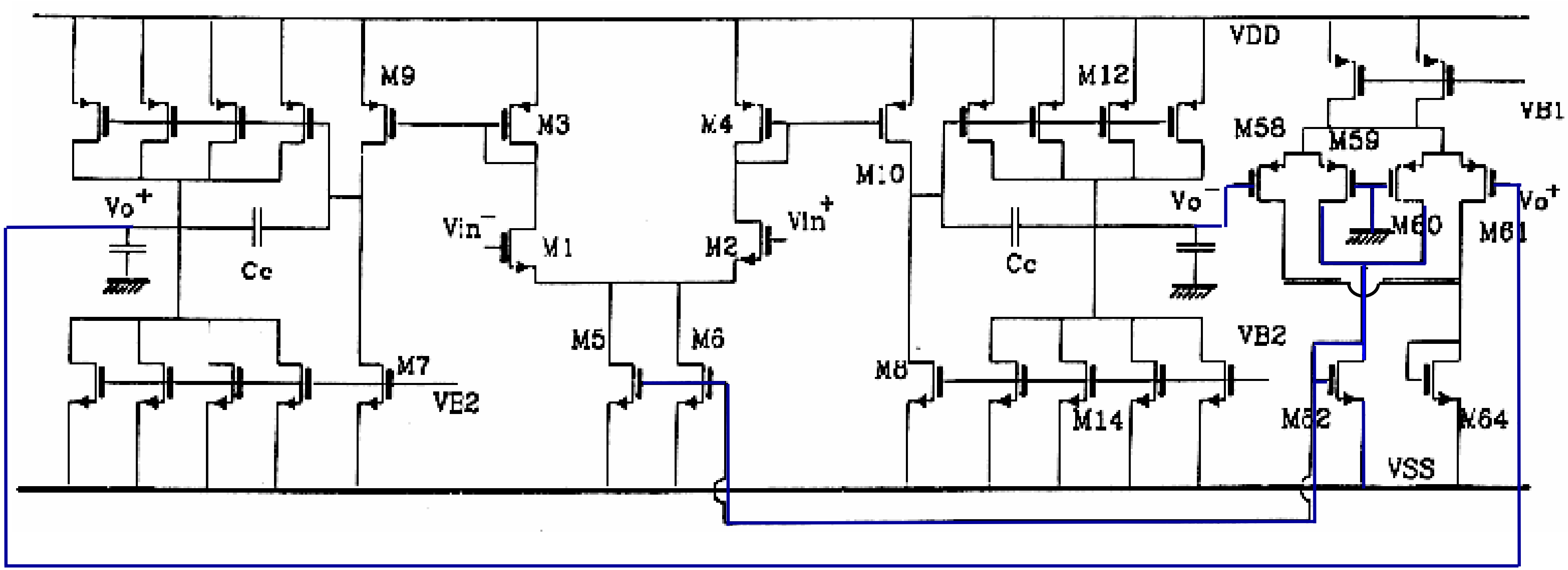
Fully-diff amp. with error amplifier: Diff. mode



$$GBW_{DM} = \frac{g_{m1}}{2\pi\, C_c}$$

Ref. Ribner, CICC 85; Haspeslagh, CICC 88

Fully-diff amp. with error amp. : Common mode

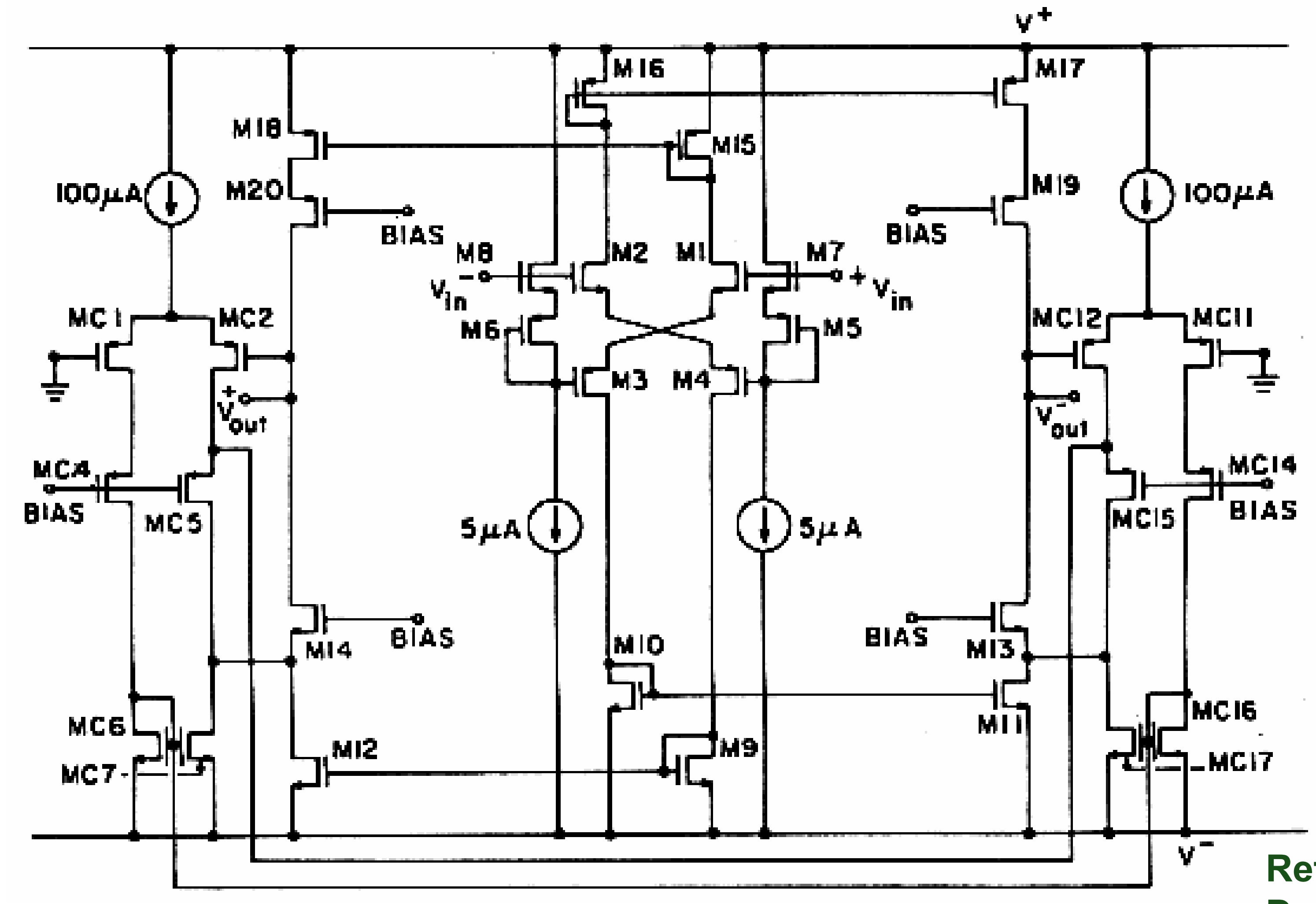


Nonlinear !

$$GBW_{CM} = \frac{g_{m58}}{4\pi\, C_c}$$

Ref. Ribner, CICC 85; Haspeslagh, CICC 88

Class AB fully-differential amplifier



Ref. Lee, JSSC
Dec.85, 1103-1113

Comparison

Criterion	Linear MOST	Error amp Source foll.	Error amp. Quad amp.
GBW_{CM}/GBW_{DM}	< 0.1	> 1	> 1
Required tol.	< 1 %	< 6 %	< 6 %
Diff.output swing Is limited by	$0.8\ V_{DDSS}$ cascodes	$0.4\ V_{DDSS}$ source foll.	$0.4\ V_{DDSS}$ cm input
Power dissipation	1 amp	3 amps	2 amps

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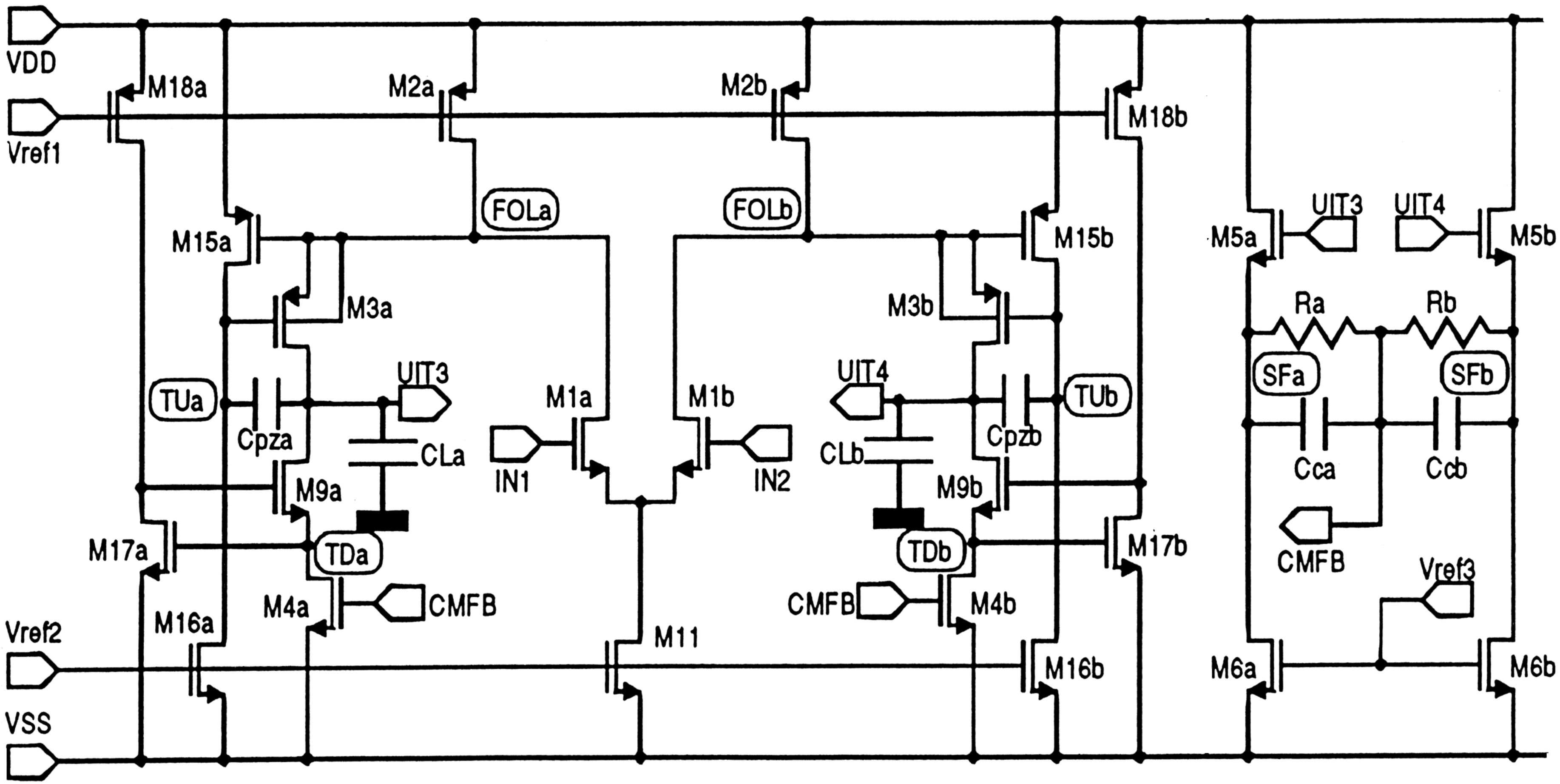
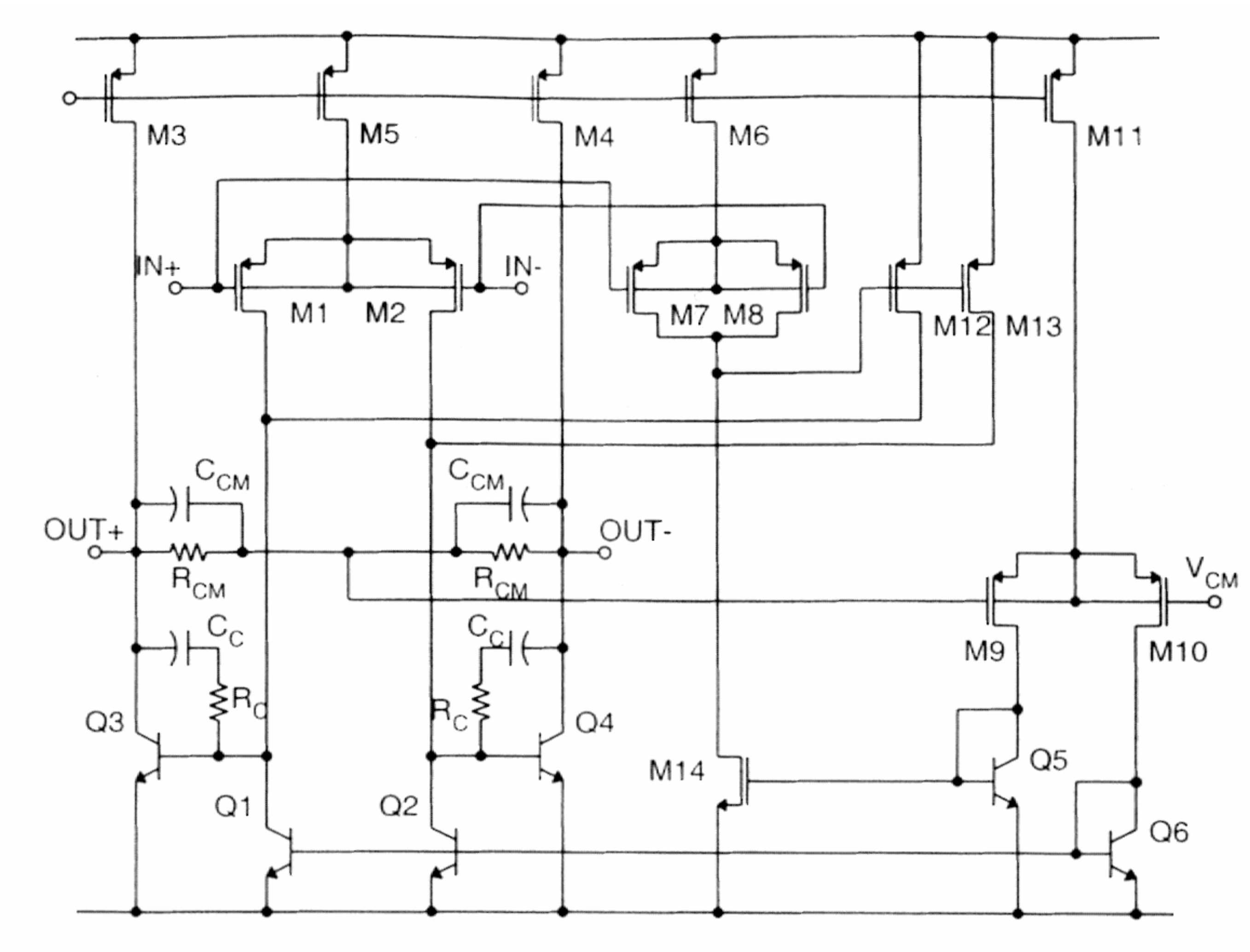
Fully-differential amplifier with gain boosting

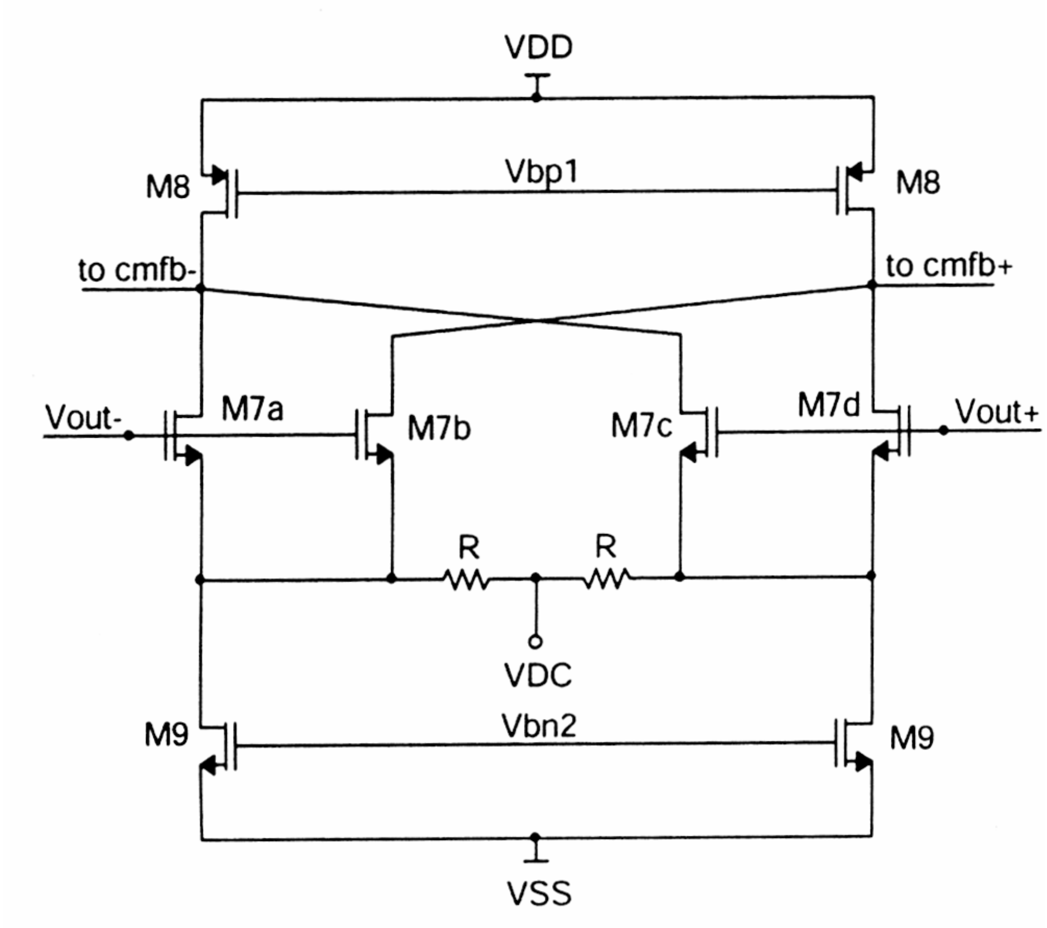


Low-voltage (1.1 V) DIDO



Gata, JSSC Dec.02
1670-1678

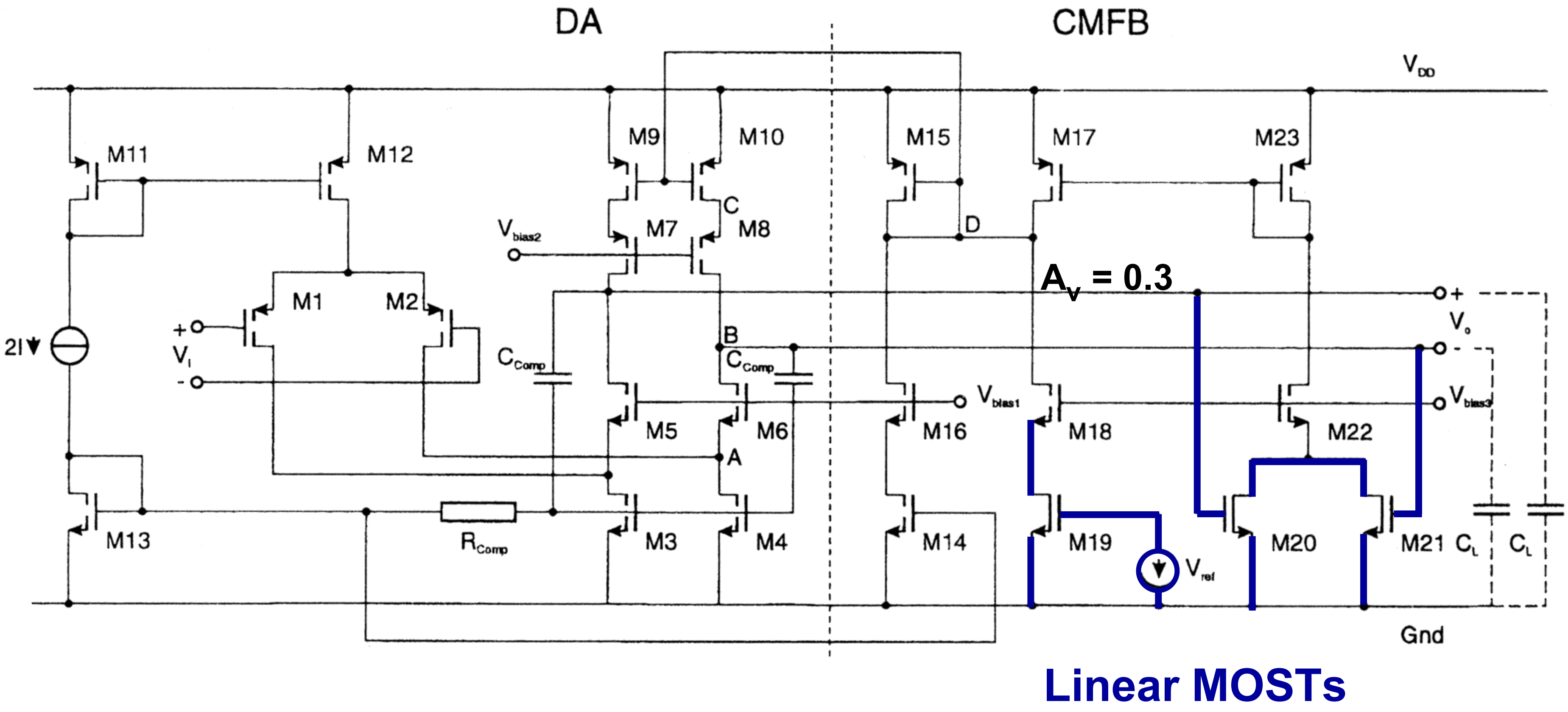
Linear CM amplifier



$$V_{outCM} = VDC + V_{GS7}$$

Ref. Hernandez, JSSC
Aug.05, 1610-1617

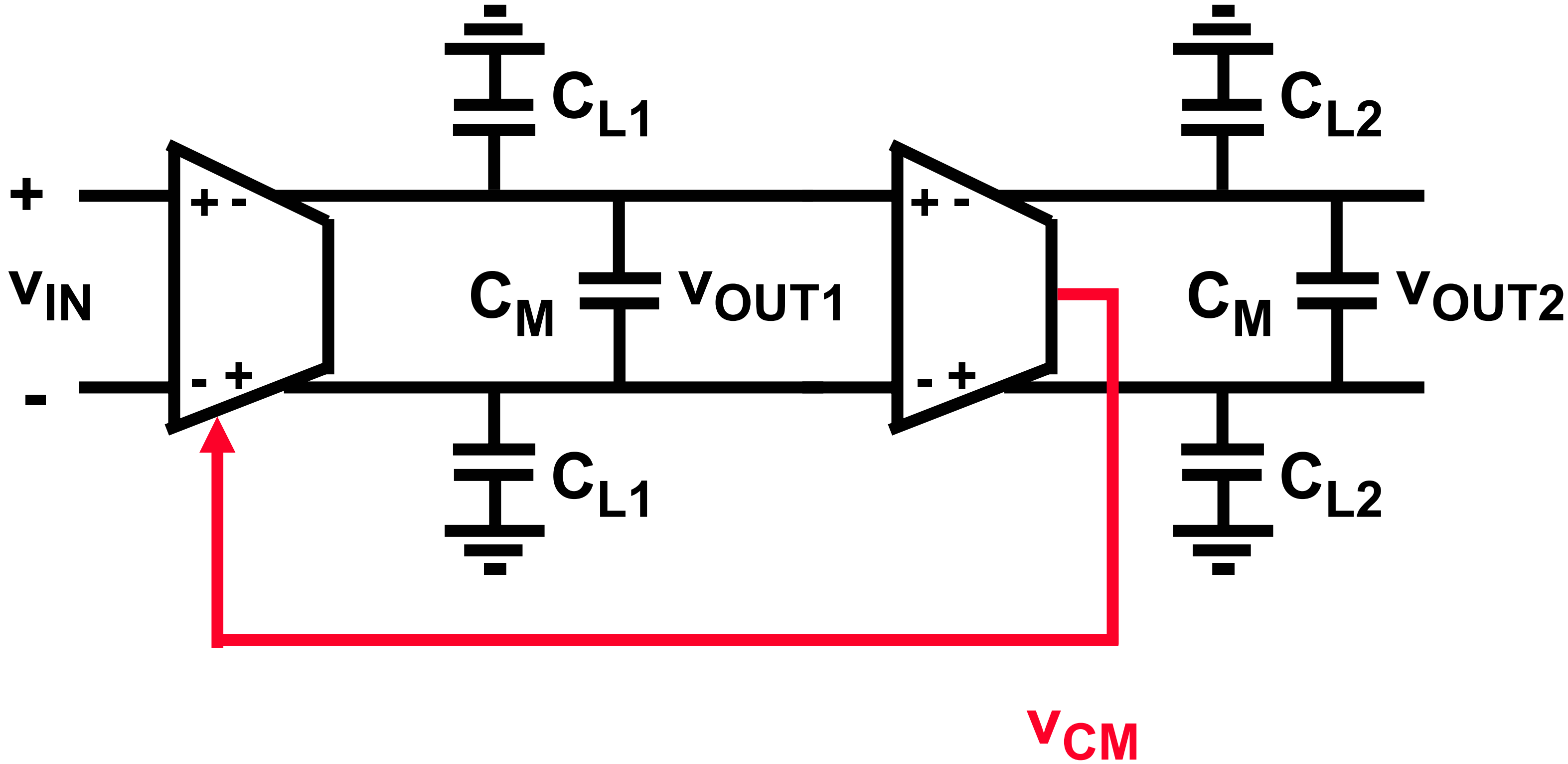
Fully-diff.amp. with separate linear trans.CMFB



24 MHz/ 3 pF 3 V/ 5 mA I_{DS1} = 0.25 mA Comp 4 kΩ/ 2 pF > 20 MHz

Ref. Pasch, AICSP, 2000

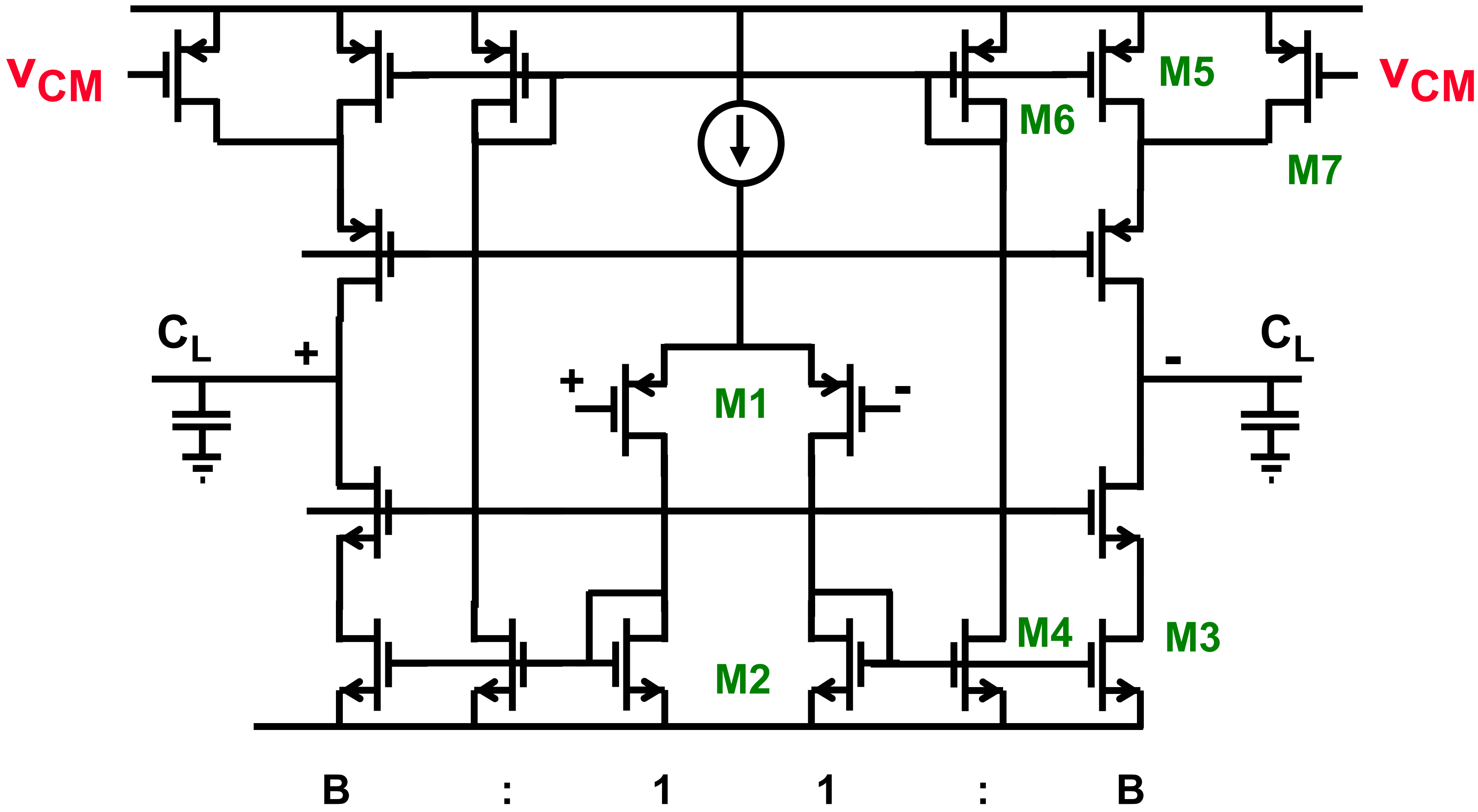
CMFB over 2 or more amplifiers



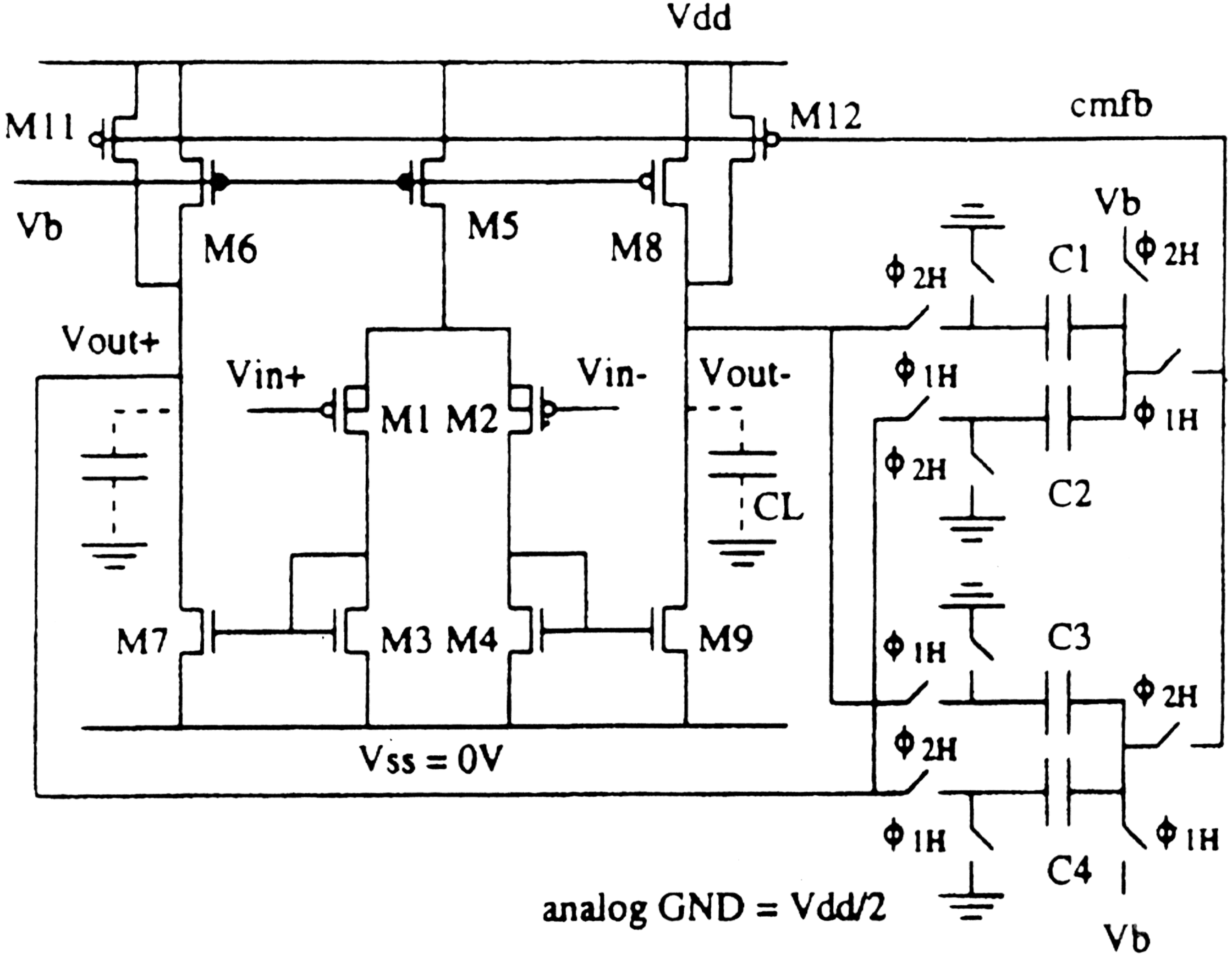
Efficient use of 2nd amplifier !

Ref. Mohieldin, JSSC April 2003, 663-668

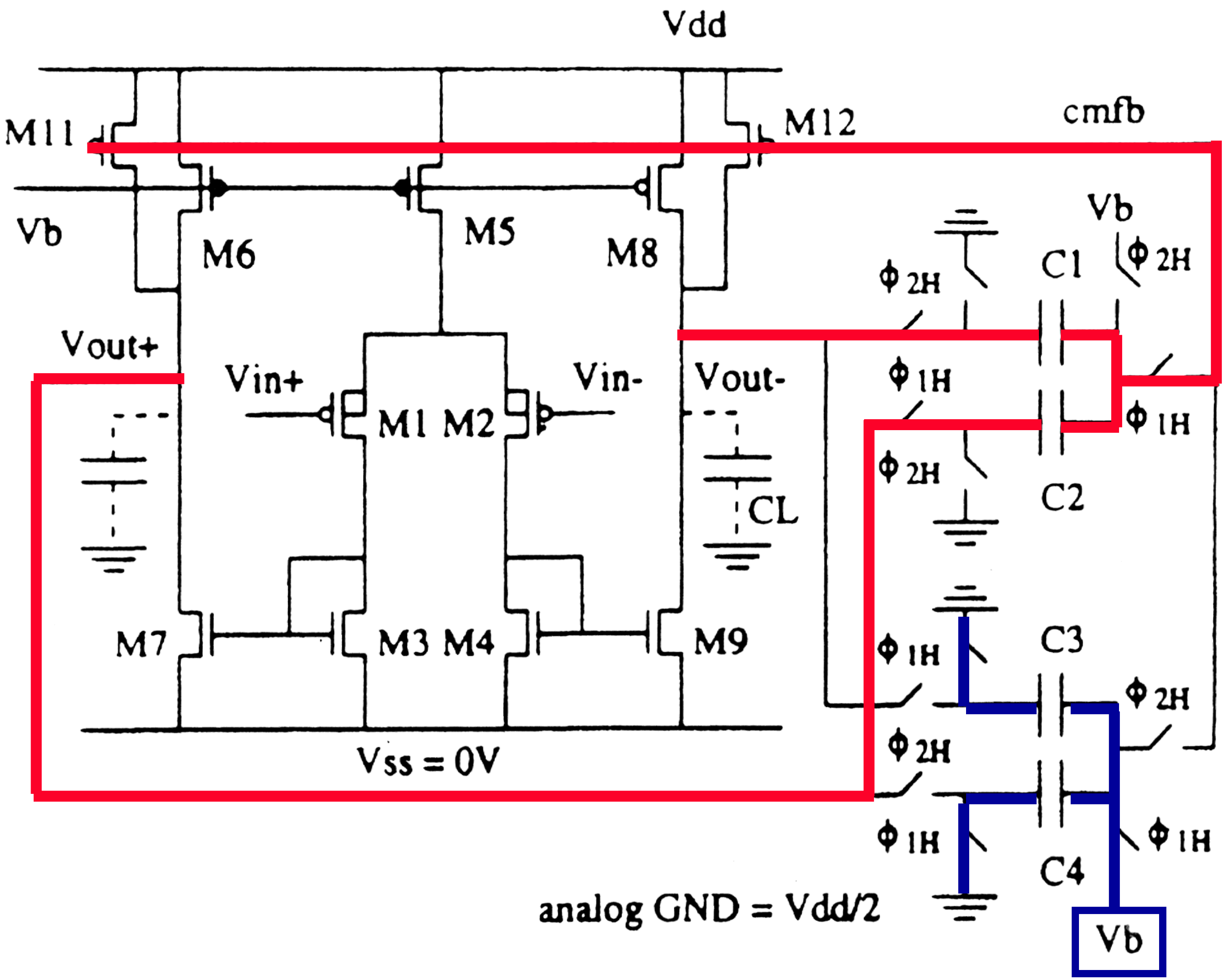
CMFB over 2 pseudo-differential amps



Fully-differential amplifier with SC CMFB

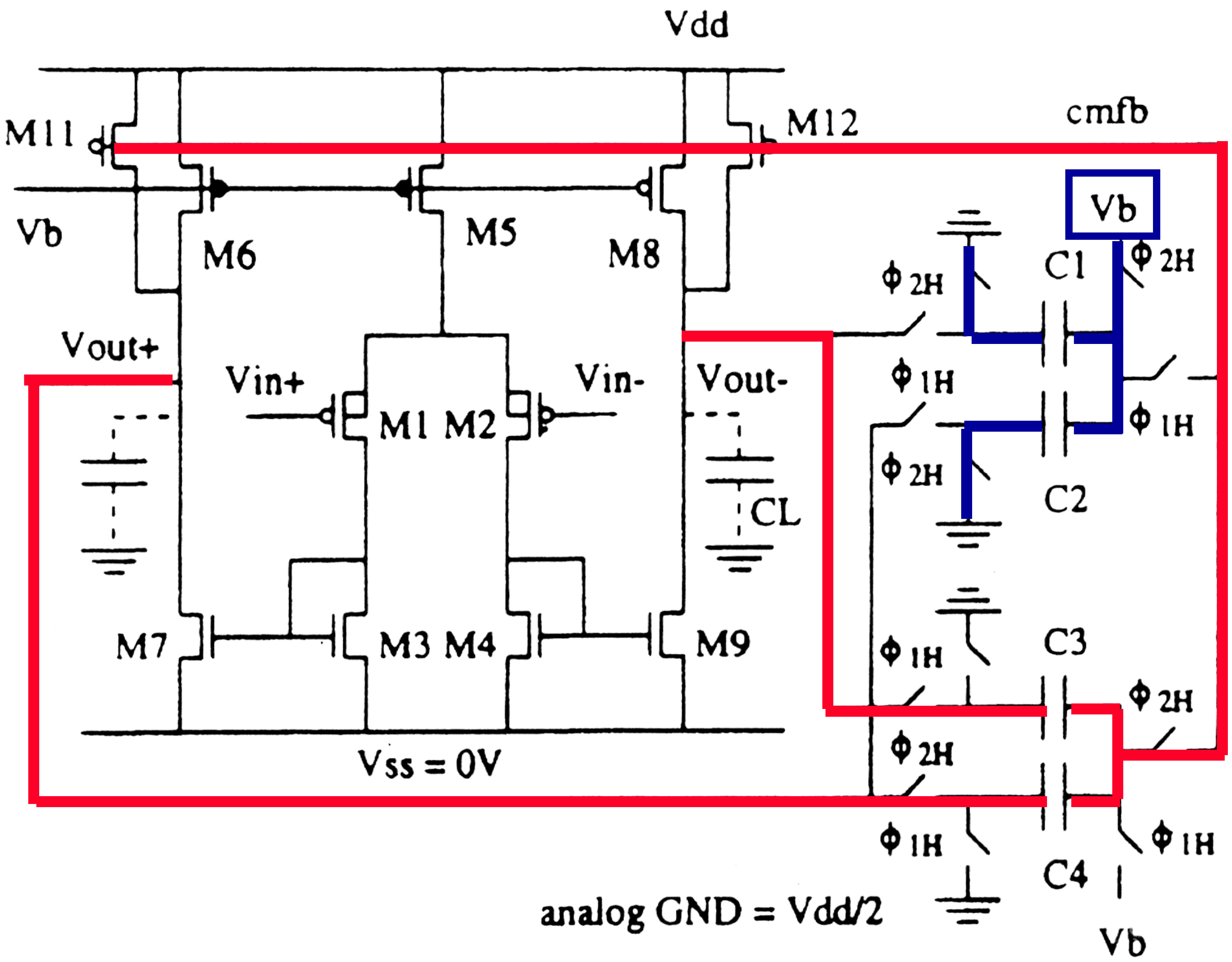


Fully-differential amp. with SC CMFB : Φ1



Switches ϕ_{1H} closed gives CMFB and precharge C

Fully-differential amp. with SC CMFB : Φ2



Switches ϕ_{2H} closed gives CMFB and precharge C

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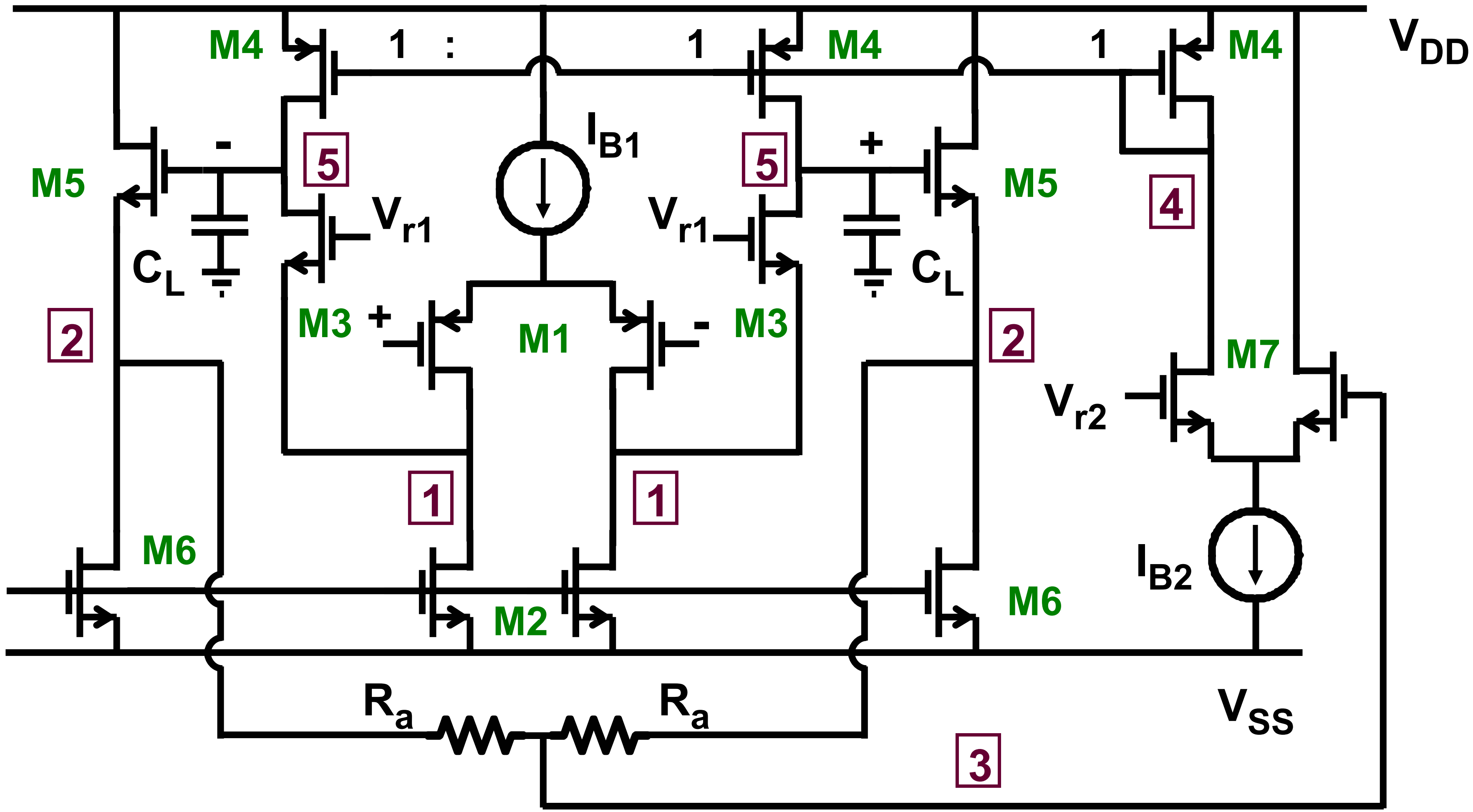
Fully-differential folded cascode with source foll.



Fully-diff. amp. : Specifications

Techn: CMOS $L_{min} = 0.8\ \mu m$; $V_T = 0.7$ V

$K'_n = 60\ \mu A/V^2$ & $K'_p = 30\ \mu A/V^2$

$V_{En} = 4$ V/µm & $V_{Ep} = 6$ V/µm

Specs: $GBW_{DM} = 10$ MHz $C_L = 3$ pF

$GBW_{CM} = 20$ MHz

all PM > 70°

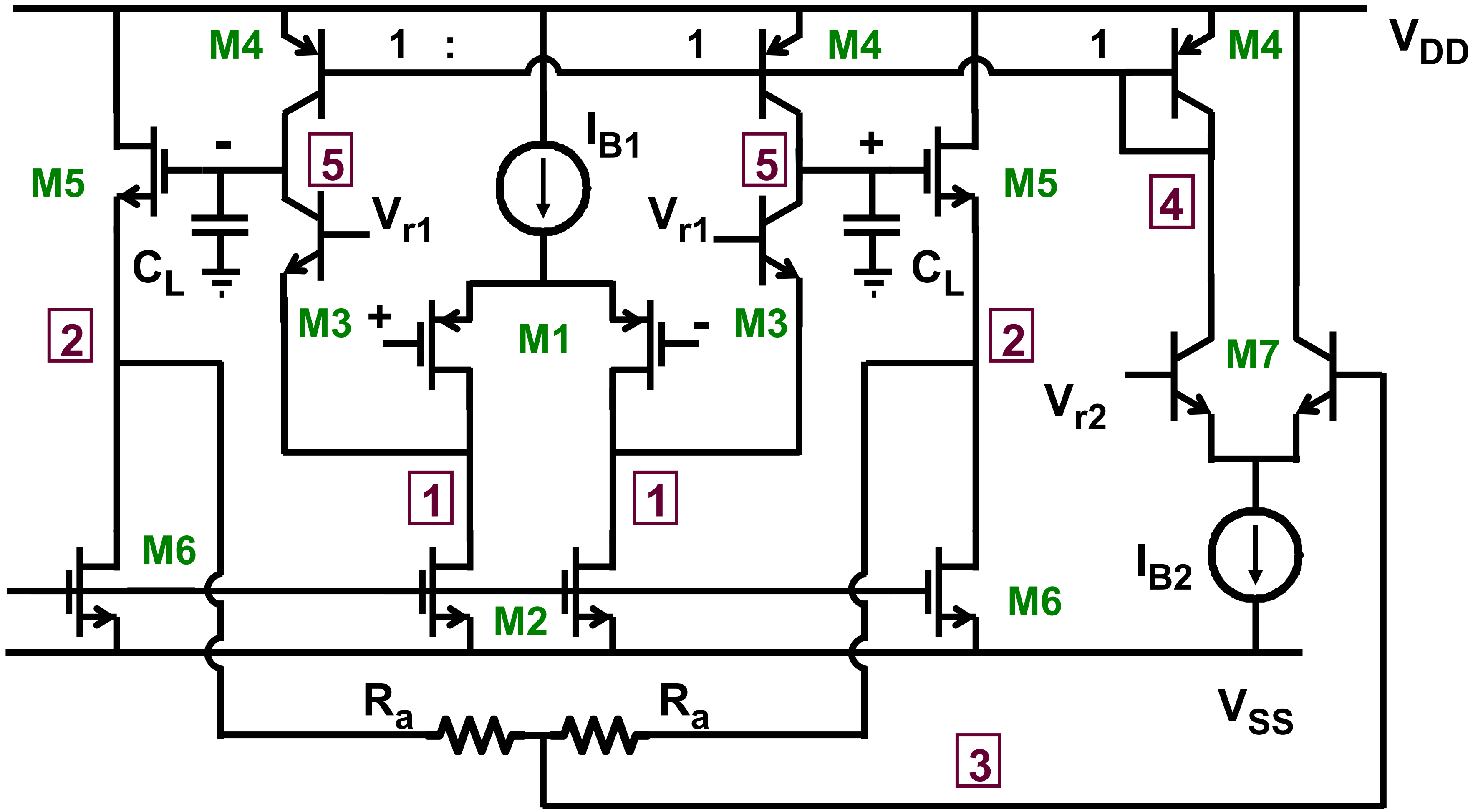
$V_{DD}/V_{SS} = \pm 1.5$ V

Maximum $V_{swingptp} = V_{outmax} - V_{outmin}$

Minimum I_{tot}

Verify: Slew Rate, Noise, ...

Fully-diff. folded cascode in BICMOS



Fully-diff. amp. : Specifications

Techn: **BICMOS**

$L_{min} = 0.8\ \mu m$; $V_T = 0.7\ V$

$K'_n = 60\ \mu A/V^2$ & $K'_p = 30\ \mu A/V^2$

$V_{En} = 4\ V/\mu m$ & $V_{Ep} = 6\ V/\mu m$

$f_{Tn} = 12\ GHz$ & $f_{Tp} = 4\ GHz$

Specs:

$GBW_{DM} = 10\ MHz$ $C_L = 3\ pF$

$GBW_{CM} = 20\ MHz$

all PM > 70^o

$V_{DD}/V_{SS} = \pm\ 1.5\ V$

Maximum $V_{swingptp} = V_{outmax} - V_{outmin}$

Minimum I_{tot}

Verify: Slew Rate, Noise, ...

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