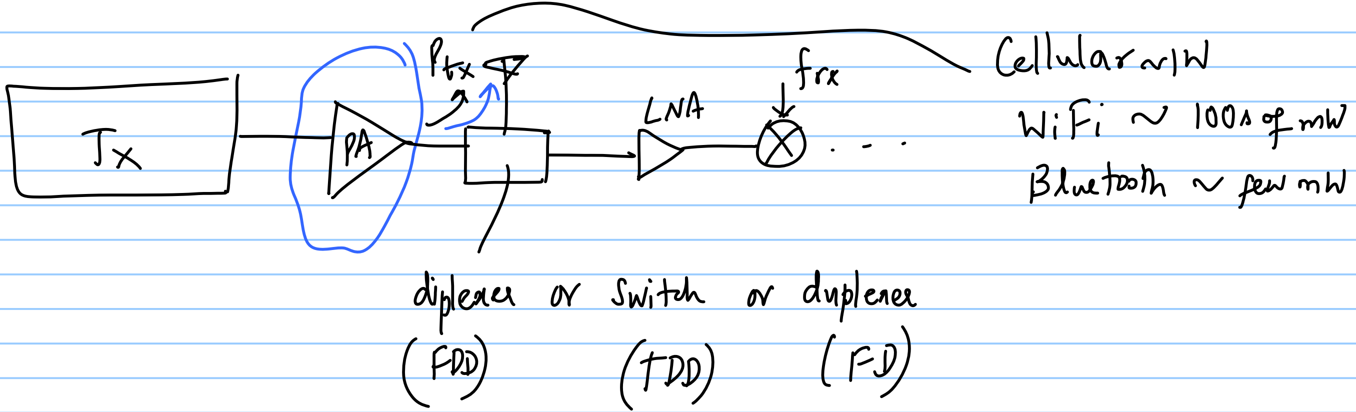
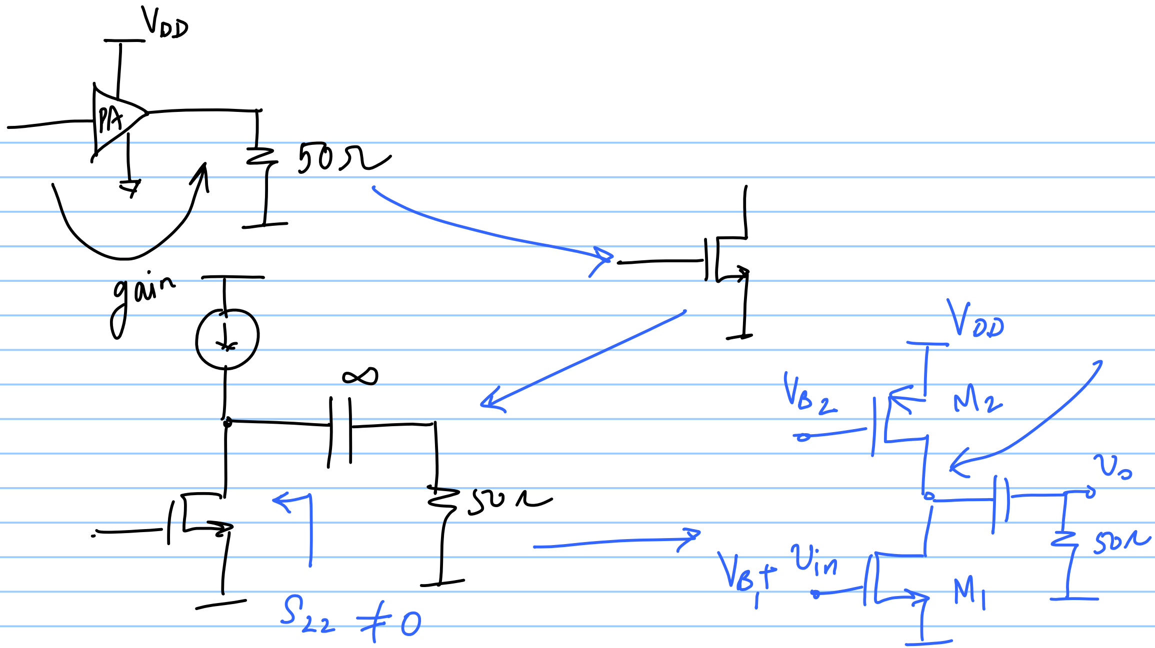
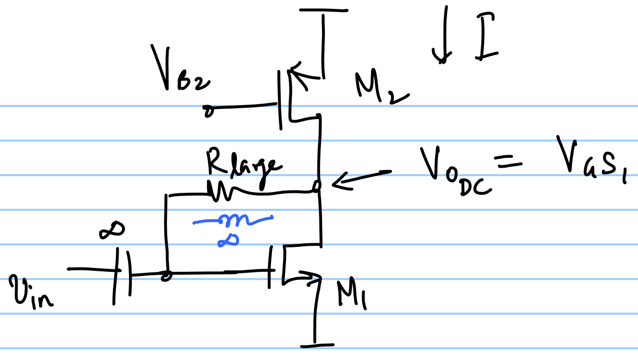
23/4/2019

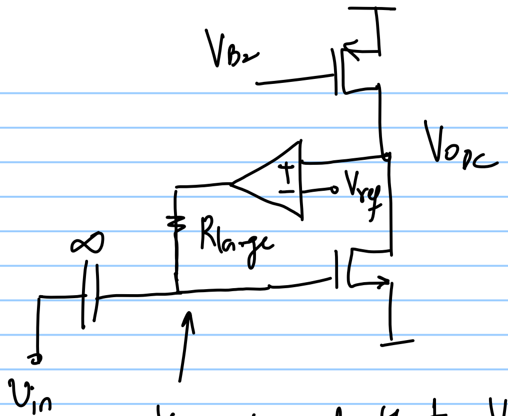
CMOS Power Amplifiers (RF PA)





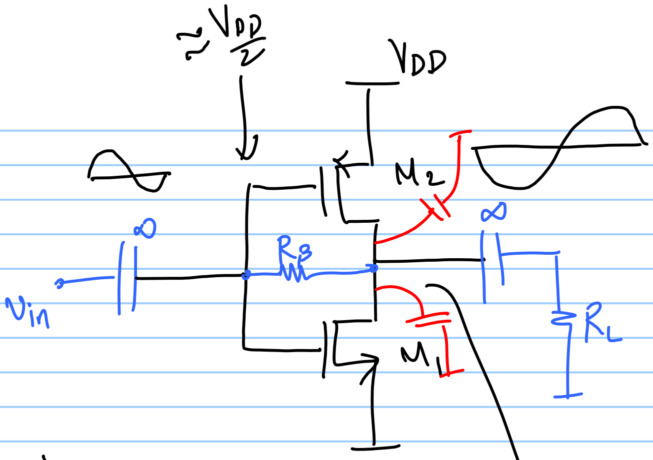
VDD
PA
50Ω
gain
∞
50Ω
S22 ≠ 0
VDD
VB2
M2
vo
50Ω
VB1 + vin
M1





V_{B_1} set such that $V_{O_{DC}} = V_{ref}$

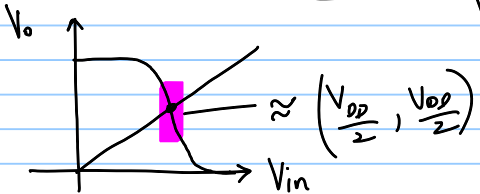
Best $V_{ref} \sim \frac{V_{DD}}{2}$



$g_{mp} \approx g_{mn}$ if $\frac{W_p}{W_n} \approx \frac{\mu_p}{\mu_n}$

low-freq.: max gain $= -\frac{g_{mn} + g_{mp}}{g_{dsn} + g_{dsp}}$

RF: gain $\approx -(g_{mn} + g_{mp}) \cdot R_L$



max amplitude $\approx V_T$ (linear operation)

p-p swing $= 2V_T$

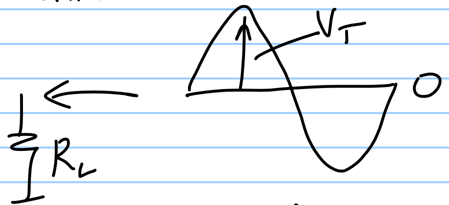
Limitations :

1) # of degrees of freedom in design $\{W_n\}$

2) BW : Parasitic capacitances @ output node $\{C_{db}\}$

limited to a few GHz

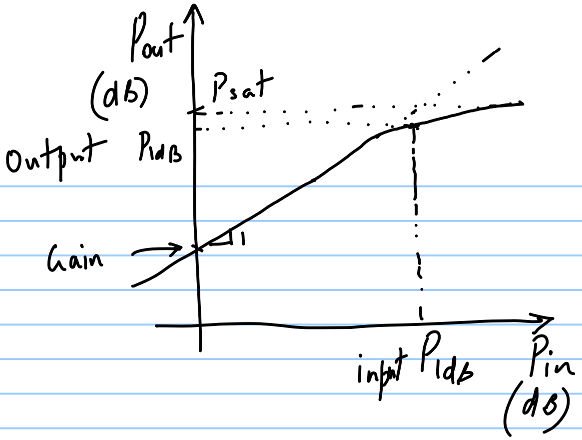
3) max $\underline{P_{out}}$: $\dfrac{V_T^2}{2R_L} = \dfrac{V_T^2}{100}$



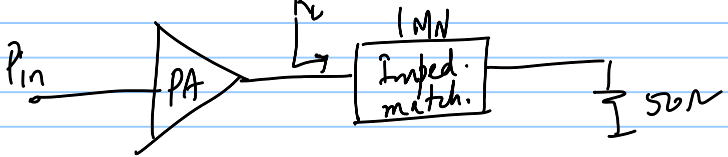
e.g. $V_T = 0.5V \Rightarrow P_{out}(max) = 2.5\,mW$

$$P_{sat} = \frac{V_{o_{max}}^2}{2R_L}$$

$$= \frac{(V_{DD}/2)^2}{2R_L}$$

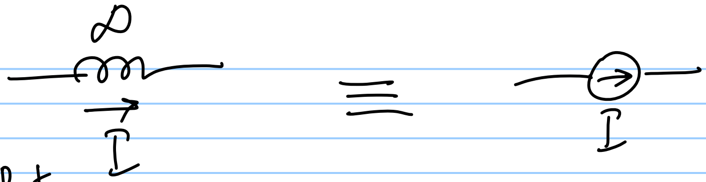


e.g. $V_{DD} = 1.8V \Rightarrow P_{sat} = 8.1mW$



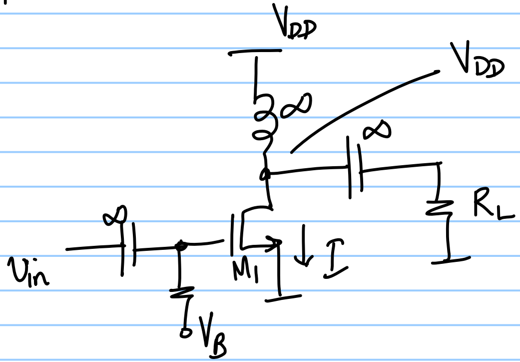
R_L can not be arbitrarily reduced

* Q of IMN
* layout parasitics



+ larger swing, P_{out}

+ wider BW



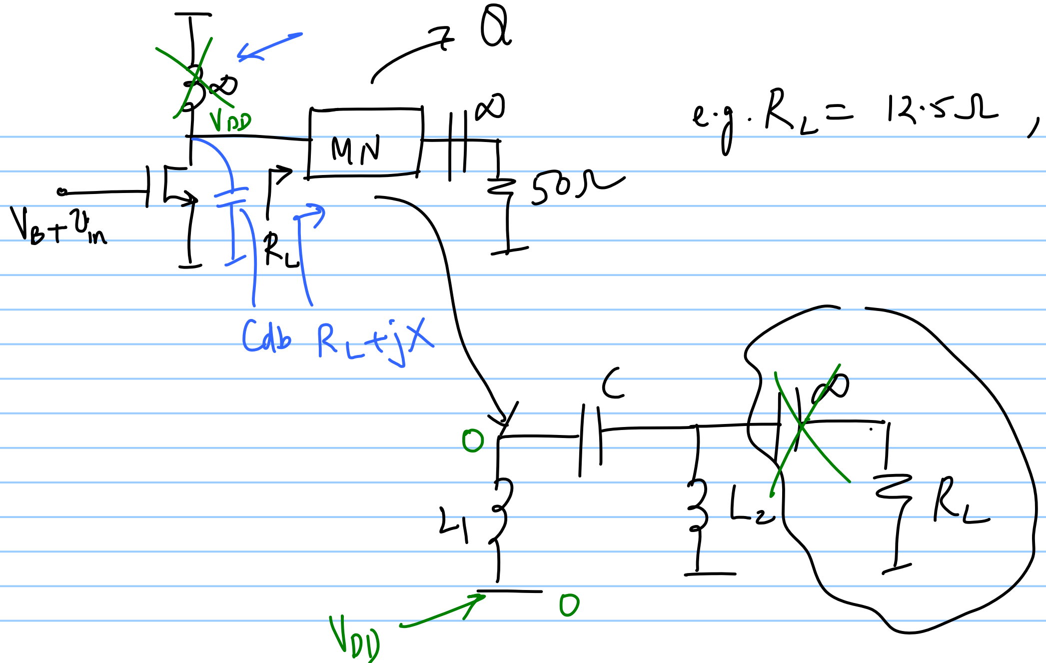
$V_{ODC} = V_{DD}$

$v_{omax} = V_{DD} - V_{Dsat,1}$

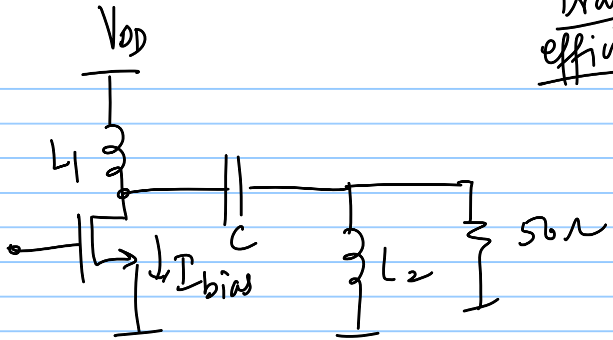
e.g. $v_{omax} = 1.8V - 0.2V$

$= 1.6V$

$P_{out\,max} = 40mW$



e.g. $R_L = 12.5\Omega$, $P_{out_{max}} = 100mW$



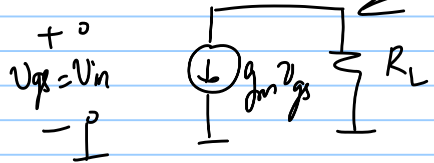
$$\text{Drain efficiency } \eta = \frac{P_{\text{delivered to load}}}{P_{\text{taken from } V_{DD}}} \times 100$$

$P_{\text{delivered to load}} \approx \frac{V_{out}^2}{2R_L}$

$P_{\text{taken from } V_{DD}} = V_{DD} I_{bias}$

$\eta_{max} := ?$

$I_{bias} = ?$

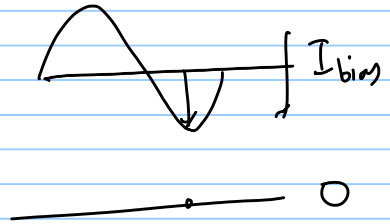


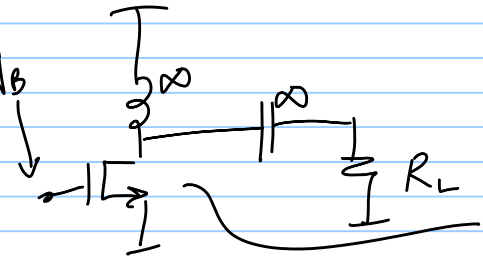
Cutoff condition for M_1

total $I_D > 0$ for no cutoff

$$= I_{bias} + g_m v_{in}$$

$$= I_{bias} + g_m V_{in} \sin \omega t$$





W, I_{bias}

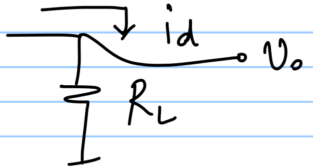
gain $= g_m R_L$

$P_{out} = i_{d_{rms}}^2 R_L$ → sets I_{bias}

Cut off when: $I_{bias} = g_m V_{in}$ ← input signal amplitude

$= i_d$

✓ * Set Cut off & Triode swing limits to be equal.



$i_d = \frac{V_o}{R_L}$ → set to triode limit

$I_{bias} = \frac{V_{o\,max}}{R_L} = \frac{V_{DD} - V_{Dsat}}{R_L}$

$P_{out\,max}$ sets V_{Dsat} → I_{bias} → W

* $P_{out_{max}} = P$
* $\eta_{max} = \eta$

$$P_{out} = i_{d_{rms}}^2 \cdot R_L$$

1) $$P = \frac{(V_{DD} - V_{Dsat})^2}{2R_L} \Rightarrow V_{Dsat} \text{ is set}$$

2) $$I_{bias} = \frac{V_{DD} - V_{Dsat}}{R_L} \Rightarrow I_{bias} \text{ is set}$$

(1) and (2) together $\Rightarrow$ W is set

neglect V_{Dsat}:

$$P_{O_{max}} = \frac{V_{DD}^2}{2R_L}$$

$$I_{bias} = \frac{V_{DD}}{R_L}$$

$$\eta_{max} = \frac{P_{O_{max}}}{V_{DD} \cdot I_{bias}}\Big|_{P_{O_{max}}} = \frac{V_{DD}^2 / 2R_L}{V_{DD} \cdot V_{DD}/R_L} = \frac{1}{2} = 50\%$$

Other 50% dissipated in M_1

$V_{D_{rms}} \cdot I_{D_{rms}}$

24/4/2019

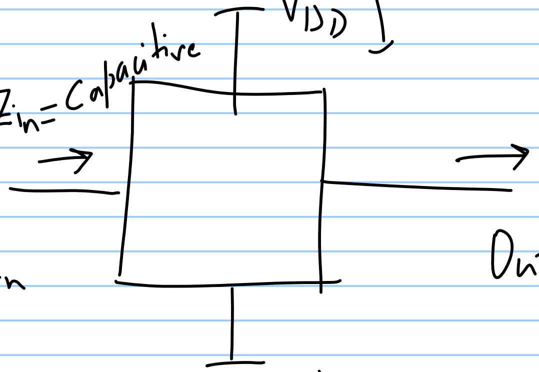
CMOS RF PAs — 2

$$V_{in_{max}} = \frac{V_{out_{max}}}{G}$$

$P_{in} = 0$ (real)

$Z_{in} =$ Capacitive

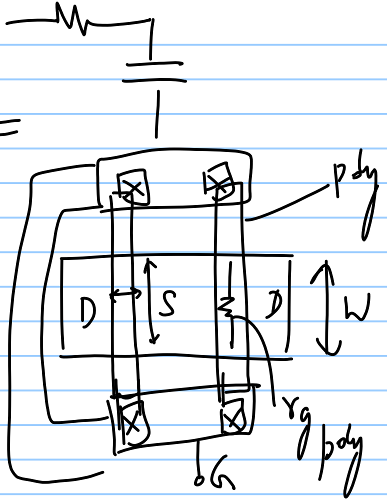
I_n



$$P_{in_{max}} = \left\{\frac{V_{in_{max}}}{|Z_{in}|}\right\}^2 \cdot \frac{R_g}{2}$$

$$Z_{in} = R_g + \frac{1}{j\omega C_{gs}}$$

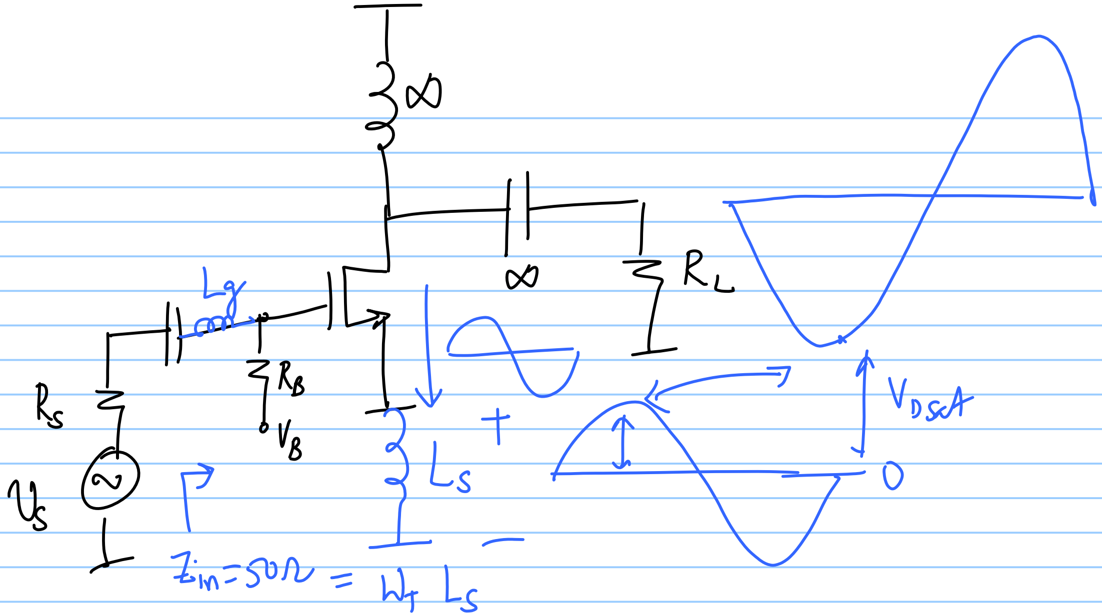
DE =



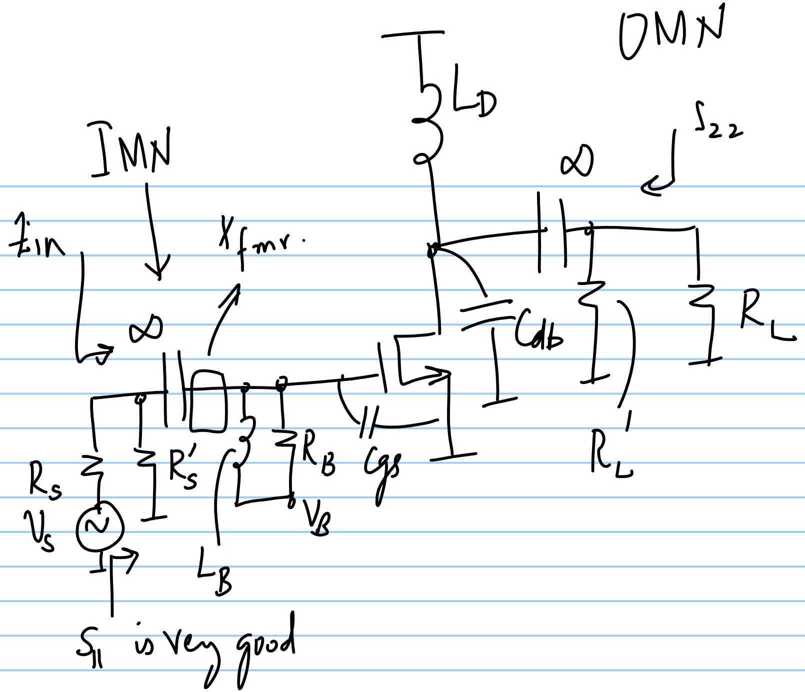
$$PAE = \frac{P_{out}}{P_{in} + P_{dc}} \times 100\%$$

power added efficiency

PA module: matched @ input & output to 50Ω



∞
∞
Lg
R_L
R_B
R_s
V_B
v_s
L_s
+
−
V_{DSsat}
0
$Z_{in} = 50\Omega = \omega_T L_s$



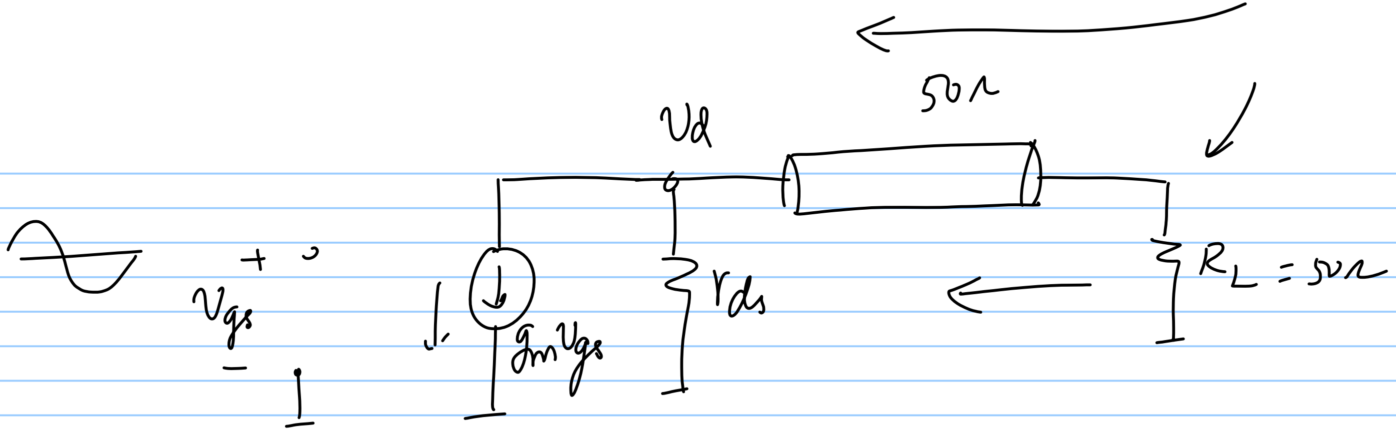
R_s' is chosen so that

$Re\{Z_{in}\} = 50\Omega = R_s$

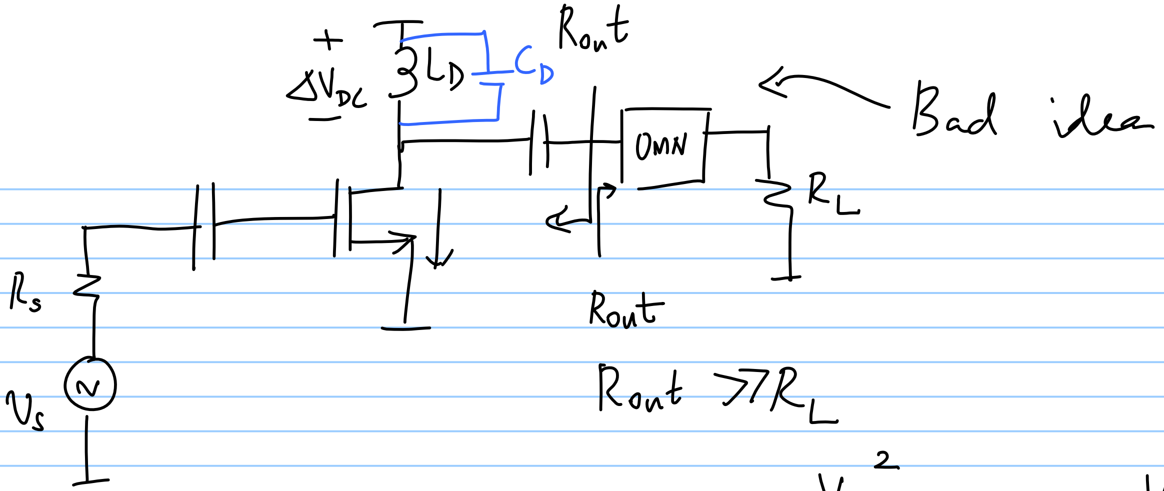
L_B : so that it resonates with C_{gs}

R_L' : So that S_{22} is low

L_D : So that it resonates with C_{db}

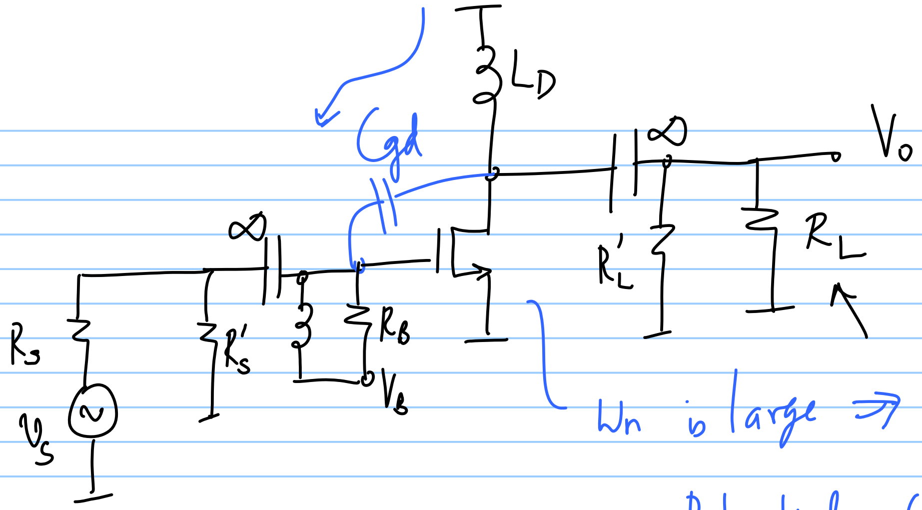


50Ω
Vd
v_{gs}
+
−
$g_m v_{gs}$
r_{ds}
$R_L = 50Ω$



$$R_{out} \gg R_L$$

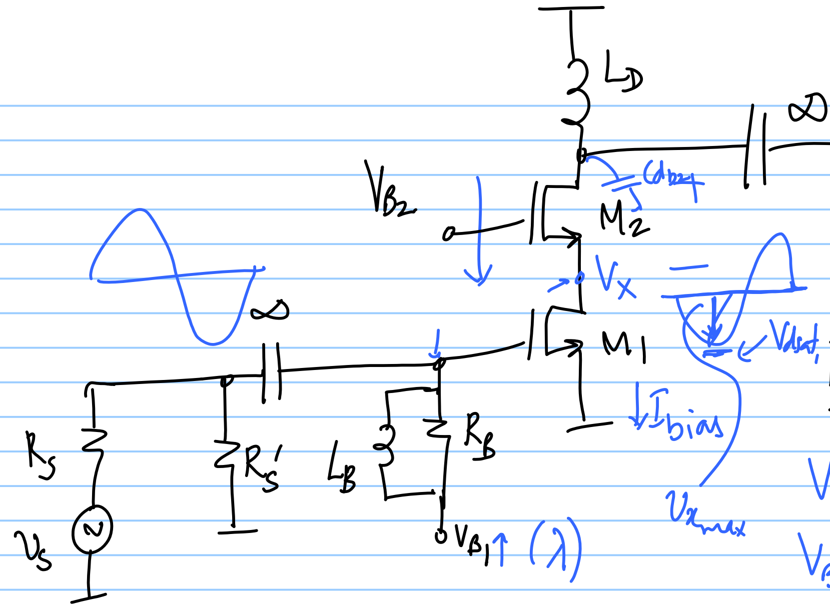
$$P_{out_{max}} = \frac{V_{DD}^2}{2R_{out}} \ll \frac{V_{DD}^2}{2R_L}$$

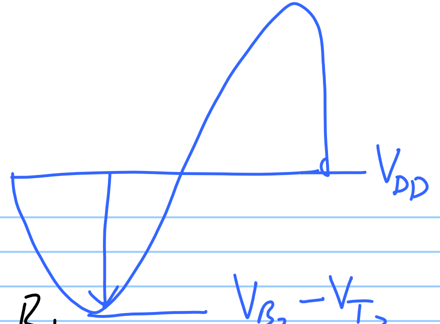


W_n is large ⇒ C_{gd} is large

⇒ Potential for instability

⇒ Add a cascode





$V_{B_2} - V_{T_2}$

$= V_{Dsat_1} + V_{Dsat_2}$

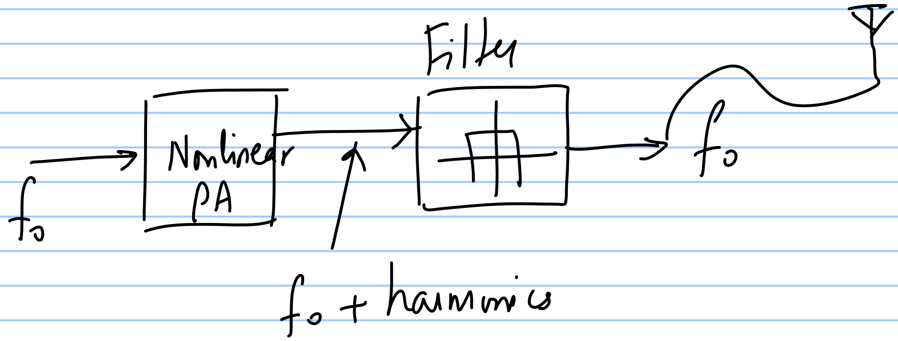
$+ v_{x\,max}$

1) $V_{B2} = V_{DD} \Rightarrow V_{o\,max} = V_{T_2}$

$V_X = V_{B_2} - V_{GS_2}$

$V_{B_2\,min} = V_{Dsat_1} + v_{X\,max} + V_{GS_2}$

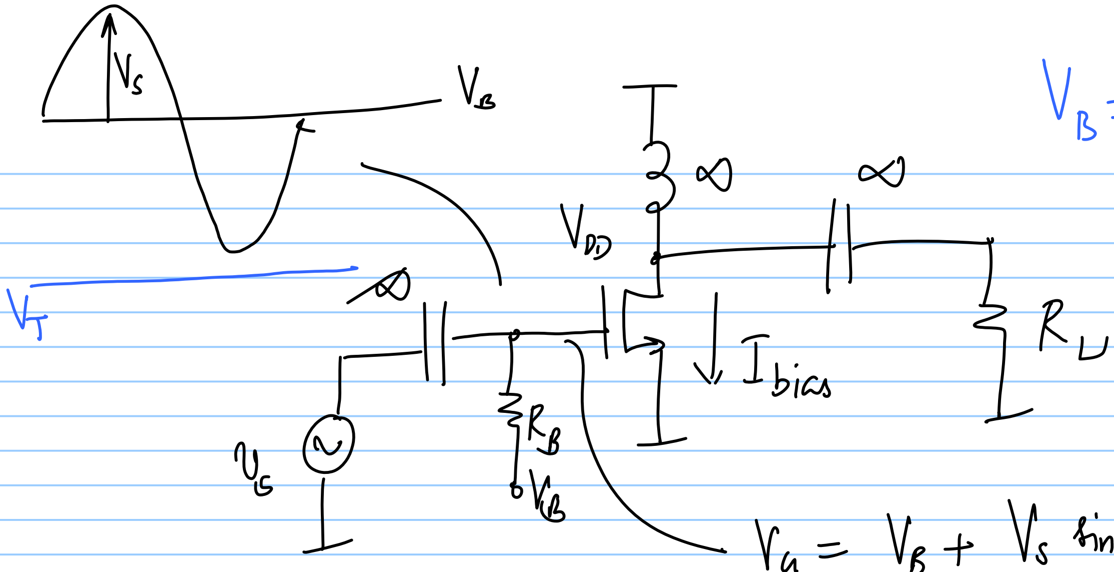
So far: Linear / Class A PAs $\theta_c = 360°$ "conduction angle"



$\theta_c = 180^\circ - 360^\circ \Rightarrow$ Class AB operation

$\theta_c = 180^\circ \Rightarrow$ Class B operation

$\theta_c < 180^\circ \Rightarrow$ class C operation



$V_B = V_T \Rightarrow$ class B operation

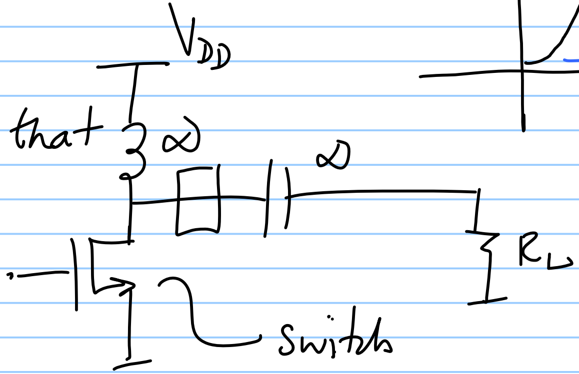
$V_B < V_T$: class C operation

$$V_G = V_B + V_s \sin \omega t$$

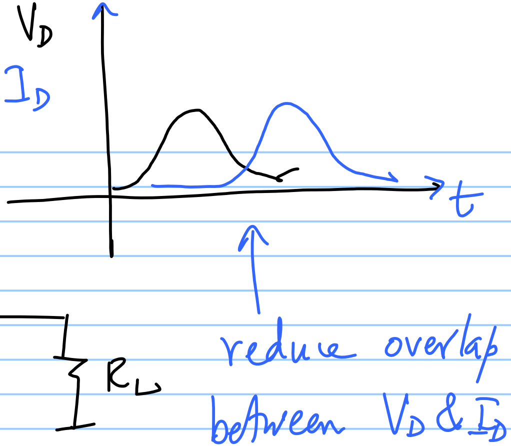
linear: $V_G > V_T$ for full cycle

class E

Add extra circuits {LC} so that



* when $V_{DS} > 0$, $I_D = 0$
* when $I_D > 0$, $V_{DS} = 0$



class D, class F, class G, class J ...