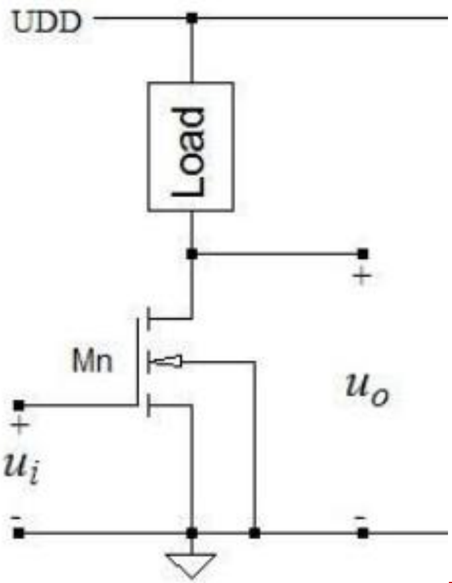
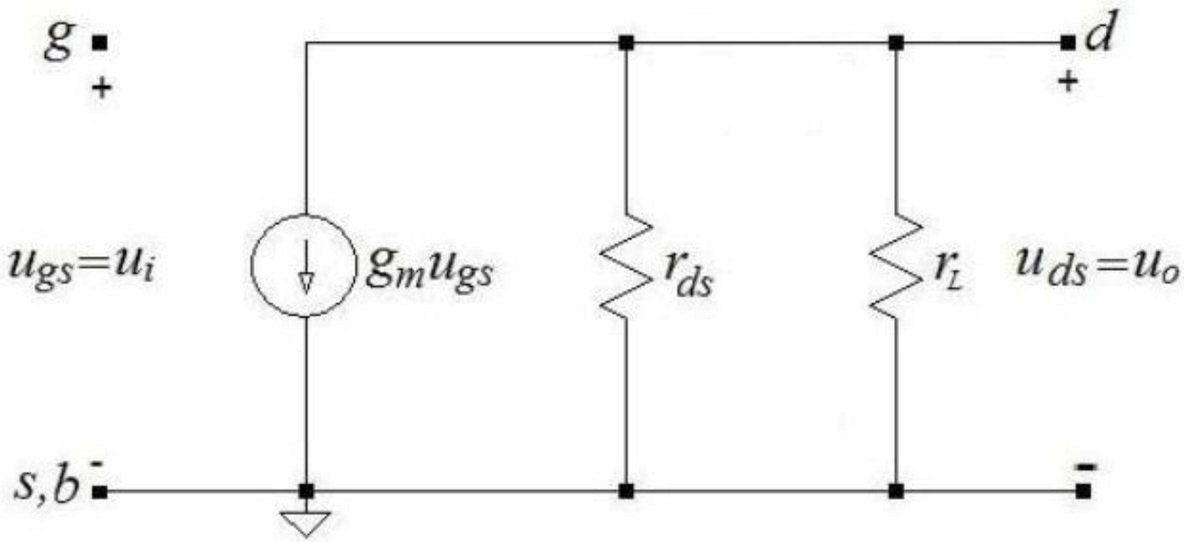
CMOS едностъпални усилватели

Усилвателни стъпала с общ сорс





$$r_o = r_{ds} \| r_L = \frac{1}{g_{ds} + g_L}$$

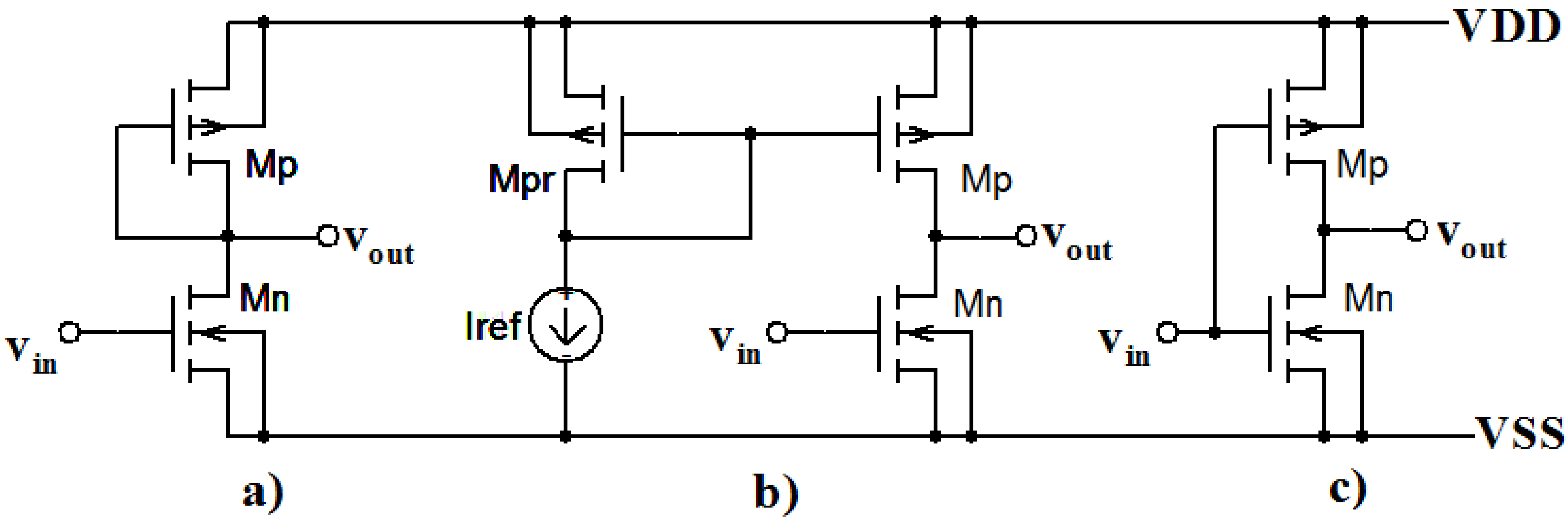
$$u_o = -g_m u_{gs} \left(r_{ds} \| r_L \right) = -\frac{g_m u_i}{g_{ds} + g_L}$$

$$A_u = \frac{u_o}{u_i} = -g_m r_o$$

$$A_u = \frac{u_o}{u_i} = -\frac{g_m}{g_{ds} + g_L}$$

!!!

Варианти на усилватели с общ сорс

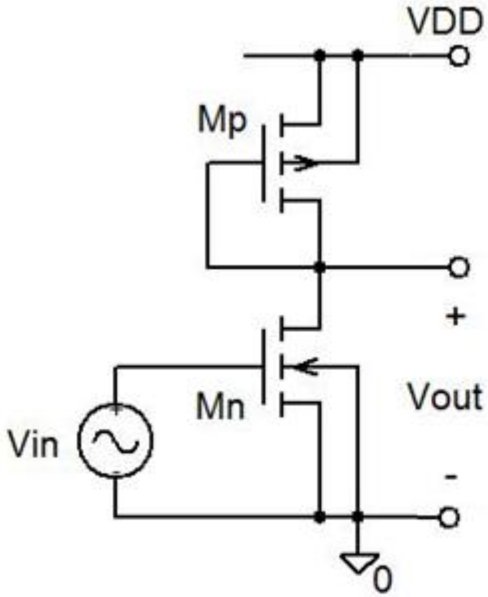


a) Усилвател с динамичен товар с активен резистор;

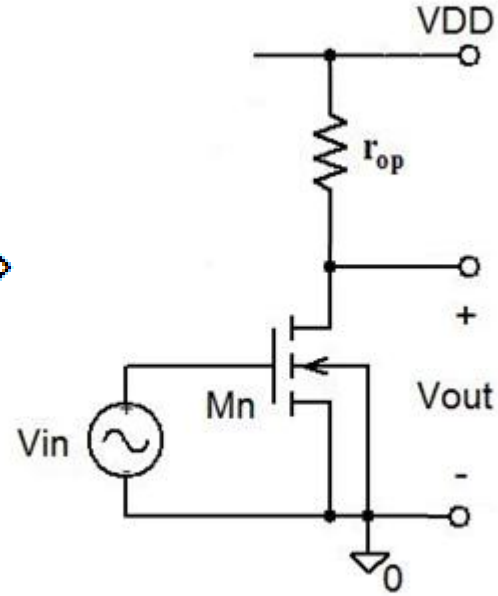
b) Усилвател с динамичен товар с източник на ток;

c) Противотактно усилвателно стъпало “push-pull”

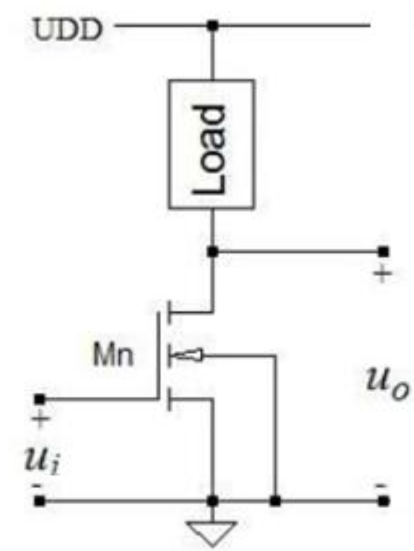
Усилвател с динамичен товар с активен резистор



⇒



⇒



$$A_u = ?$$

⇒

$$r_{op} = \frac{1}{g_{mp}}$$

⇒

$$A_u = \frac{u_o}{u_i} = -\frac{g_m}{g_{ds} + g_L}$$

⇓ ⇐

$$g_L = \frac{1}{r_{op}} = g_{mp}$$

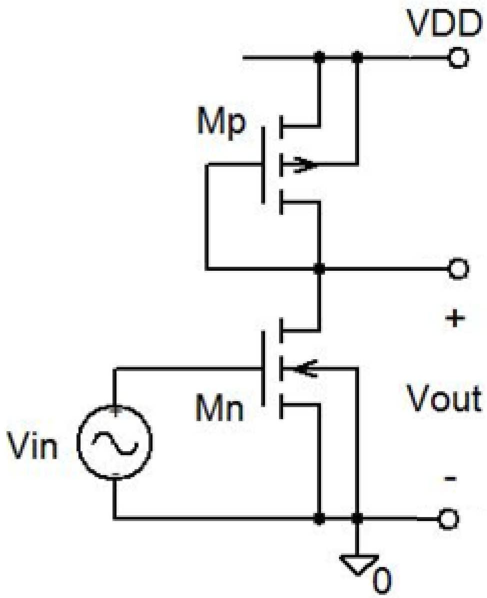
$$g_m = g_{mn}$$

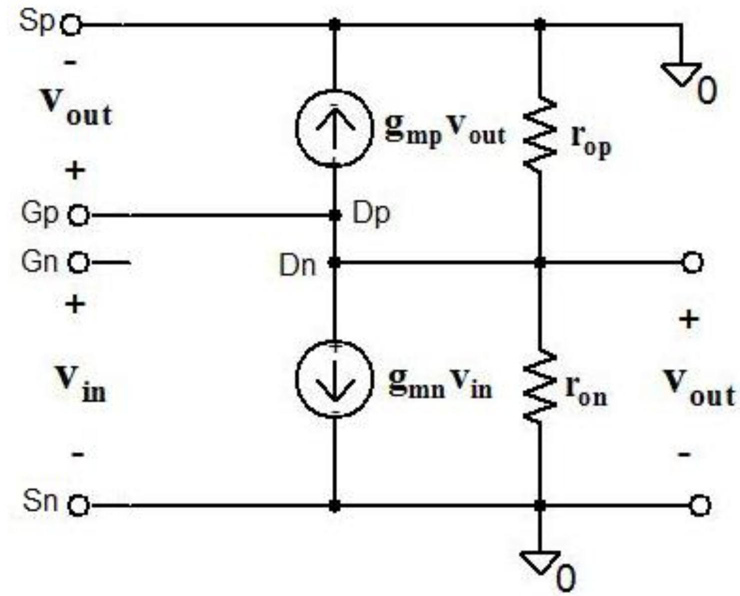
$$g_{ds} = g_{dsn} \ll g_{mp}$$

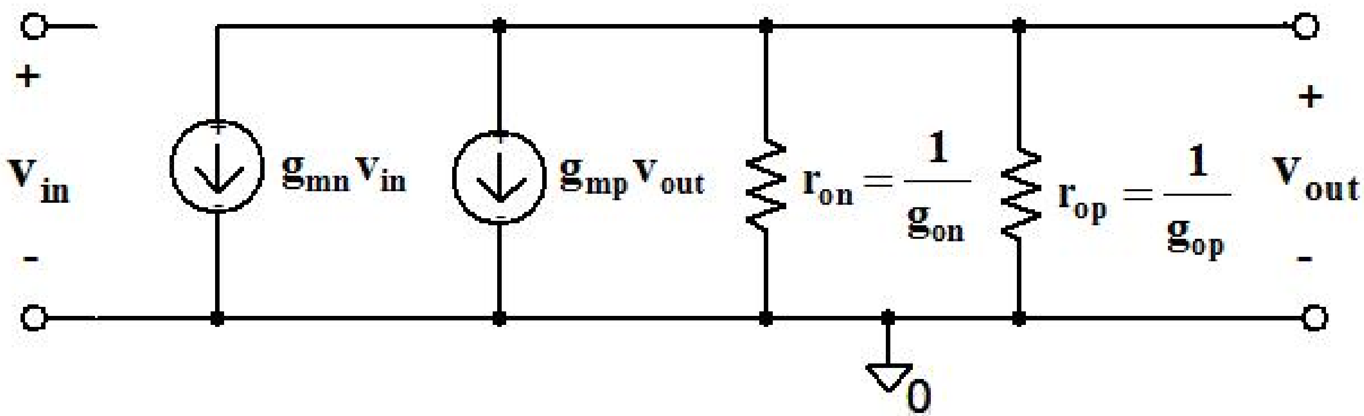
⇐

$$A_u = -\frac{g_{mn}}{g_{dsn} + g_{mp}} = -\frac{g_{mn}}{g_{mp}}$$

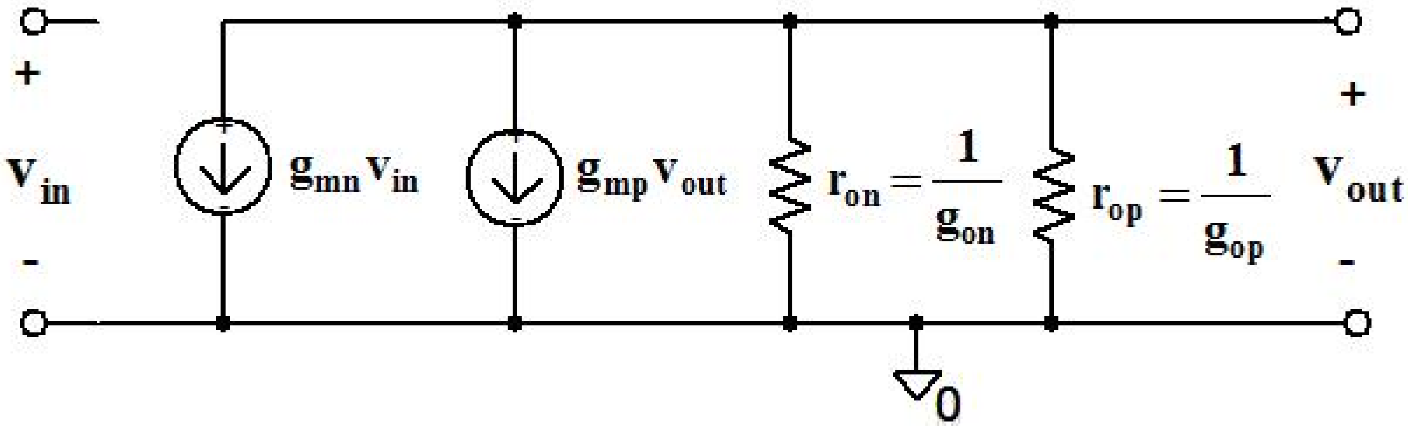
Усилвател с динамичен товар с активен резистор







Усилвател с динамичен товар с активен резистор



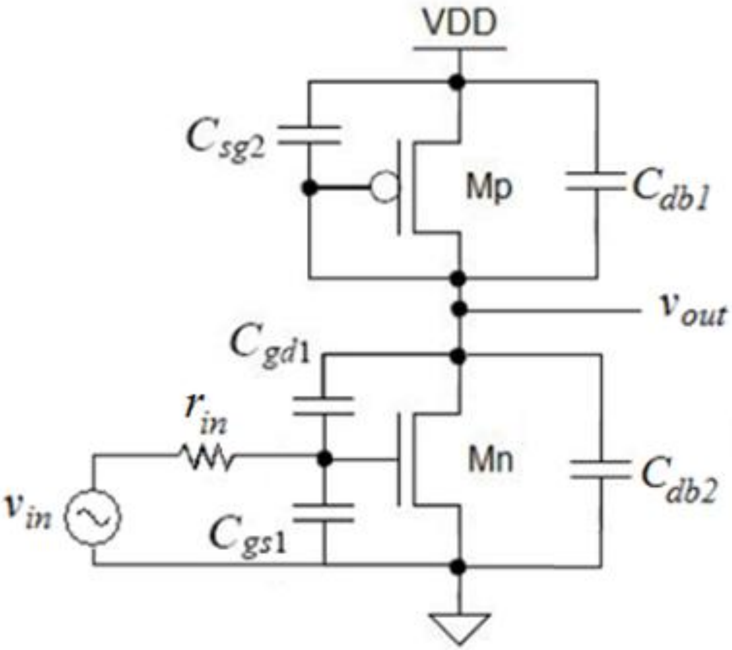
$$u_{out} = -(i_{dn} + i_{dp})(r_{on} \parallel r_{op}) = -\frac{g_{mn}u_{in} + g_{mp}u_{out}}{g_{on} + g_{op}}$$

$$u_{out}(g_{on} + g_{op} + g_{mp}) = -g_{mn}u_{in}$$

$$A_{u0} = \frac{u_{out}}{u_{in}} = -\frac{g_{mn}}{g_{on} + g_{op} + g_{mp}} \approx -\frac{g_{mn}}{g_{mp}} = -\sqrt{\frac{2K_n(W_n/L_n)I_D}{2K_p(W_p/L_p)I_D}} = -\sqrt{\frac{K_n(W_n/L_n)}{K_p(W_p/L_p)}}$$

$$r_{out} = \left.\frac{u_{out}}{i_{out}}\right|_{uin=0} = \frac{u_{out}}{u_{out}(g_{on} + g_{op} + g_{mp})} = \frac{1}{g_{on} + g_{op} + g_{mp}} \approx \frac{1}{g_{mp}}$$

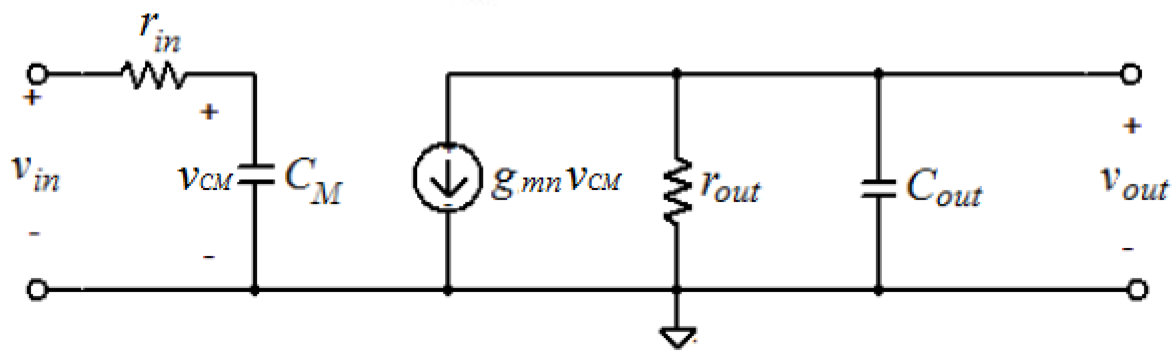
Усилвател с динамичен товар с активен резистор – честотни зависимости



$$u_{out} = -\frac{g_{mn}}{\frac{1}{r_{out}} + j\omega C_{out}} u_{CM} = -\frac{g_{mn} r_{out}}{1 + j\omega C_{out} r_{out}} u_{CM}$$

$$u_{CM} = \frac{\frac{1}{j\omega C_M}}{r_{in} + \frac{1}{j\omega C_M}} u_{in} = \frac{u_{in}}{1 + j\omega C_M r_{in}}$$

$$u_{out} = -\frac{g_{mn}/g_{mp}}{(1 + j\omega C_M r_{in})(1 + j\omega C_{out} r_{out})} u_{in}$$



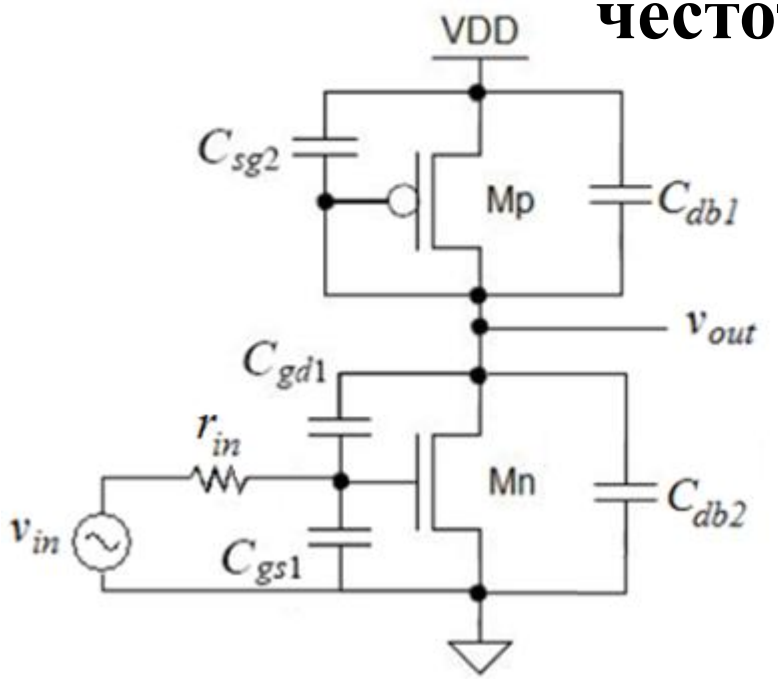
$$C_M = C_{gd1}(1 + |Au|) + C_{gs1}$$

$$r_{out} \approx \frac{1}{g_{mp}}$$

$$C_{out} = C_{sg2} + C_{db1} + C_{db2} + C_{gd1}\left(1 + \frac{1}{|Au|}\right)$$

$\mathbf{r_{in}}$ - серийно съпротивление на източника

Усилвател с динамичен товар с активен резистор – честотни зависимости

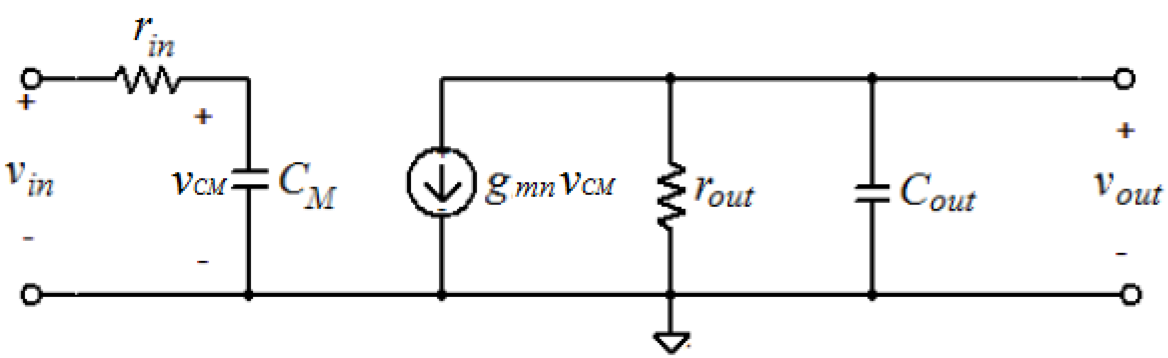


$$u_{out} = -\frac{g_{mn}/g_{mp}}{(1+j\omega C_M r_{in})(1+j\omega C_{out} r_{out})} u_{in}$$

$$A_u = \frac{A_{u0}}{(1+j\omega C_M r_{in})(1+j\omega C_{out} r_{out})}$$

$$f_{in} = \frac{1}{2\pi C_M r_{in}} \qquad f_{out} = \frac{1}{2\pi C_{out} r_{out}}$$

$$A_u = \frac{A_{u0}}{[1+j(f/f_{in})][1+j(f/f_{out})]}$$



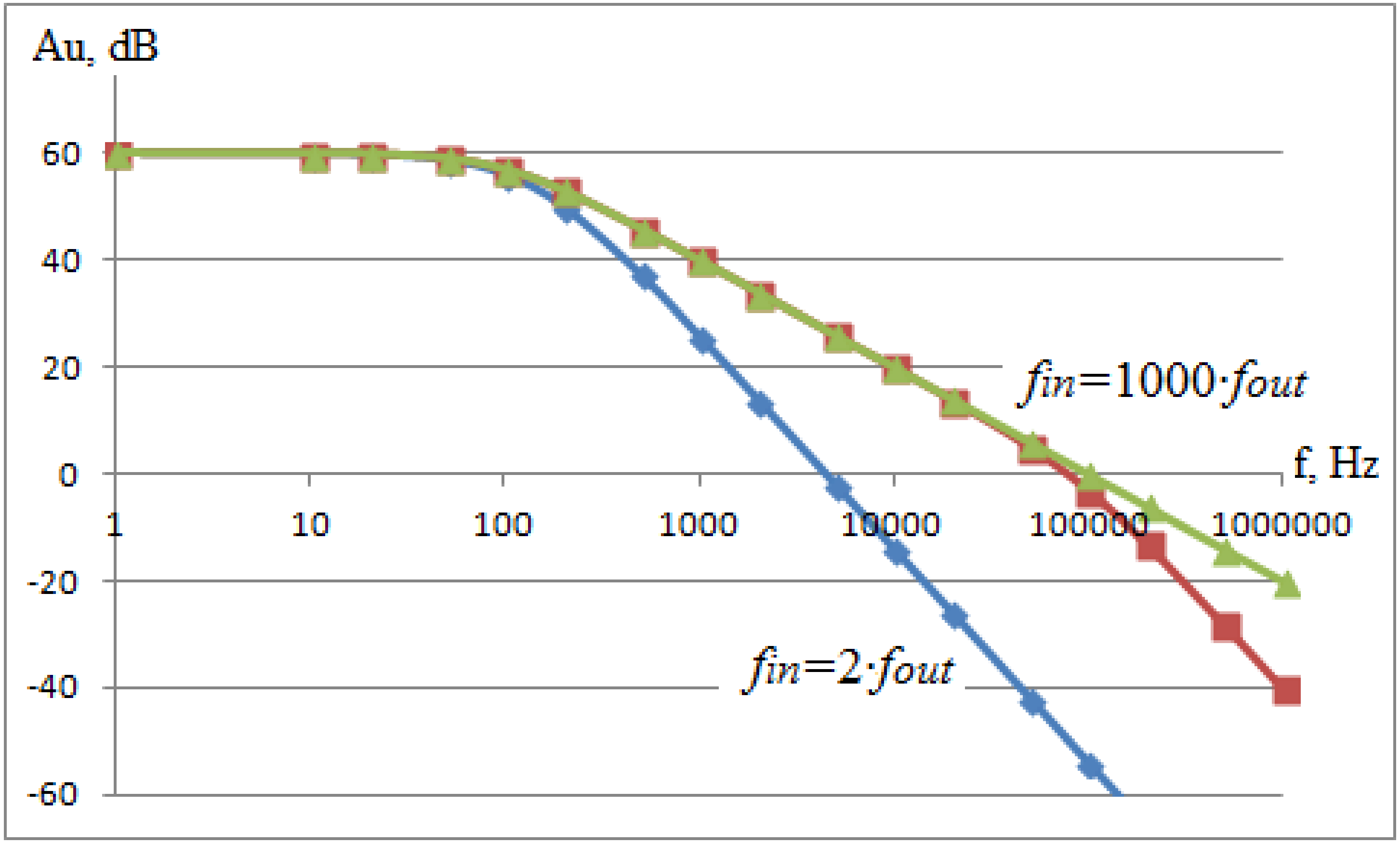
$$C_M = C_{gd1}(1+|Au|)+C_{gs1}$$

$$r_{out} \approx \frac{1}{g_{mp}}$$

r_{in} - серийно съпротивление на източника

$$C_{out} = C_{sg2} + C_{db1} + C_{db2} + C_{gd1}\left(1+\frac{1}{|Au|}\right)$$

Усилвател с динамичен товар с активен резистор – честотни зависимости



$$A_u = \frac{A_{u0}}{(1 + j\omega C_M r_{in})(1 + j\omega C_{out} r_{out})}$$

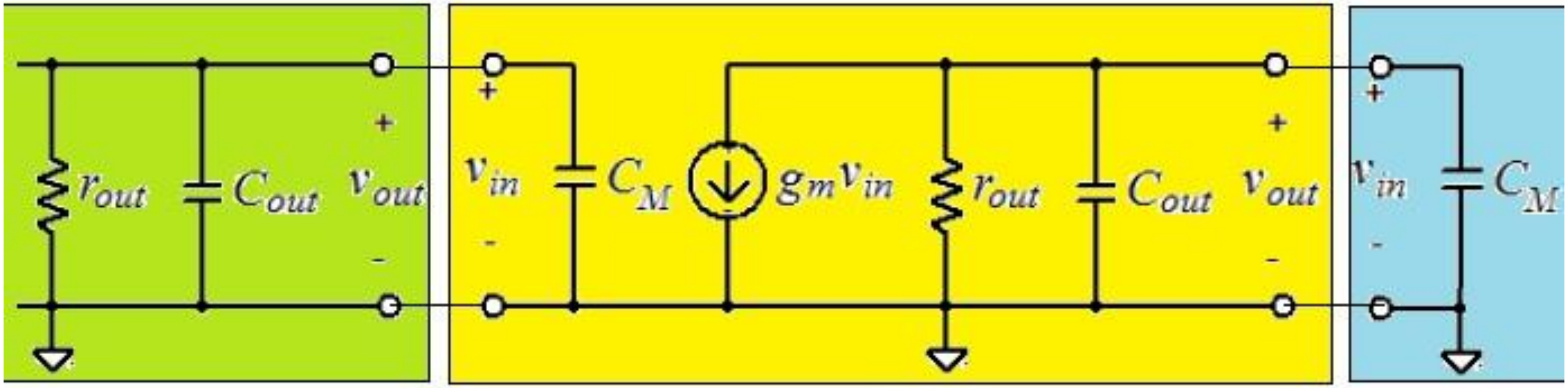
$$f_{in} = \frac{1}{2\pi C_M r_{in}}$$

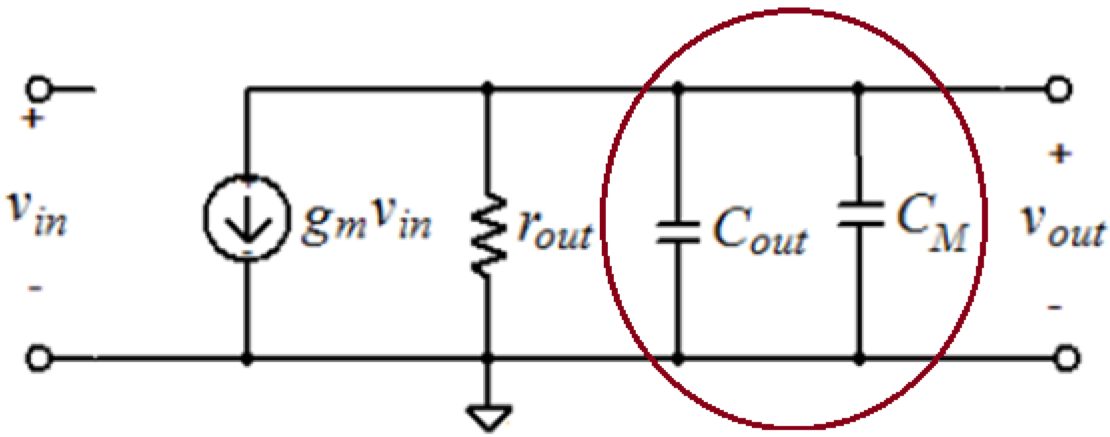
$$f_{out} = \frac{1}{2\pi C_{out} r_{out}}$$

$$|A_u| = \frac{A_{u0}}{\sqrt{1 + (f/f_{in})^2}\sqrt{1 + (f/f_{out})^2}}$$

$$|A_u| = \frac{A_{u0}}{\sqrt{1 + (f/f_{out})^2}}$$

Честотни зависимости при многостъпален усилвател





$C_L = C_{out} + C_M$

$$A_u = \frac{A_{u0}}{1 + j\omega C_L r_{out}}$$

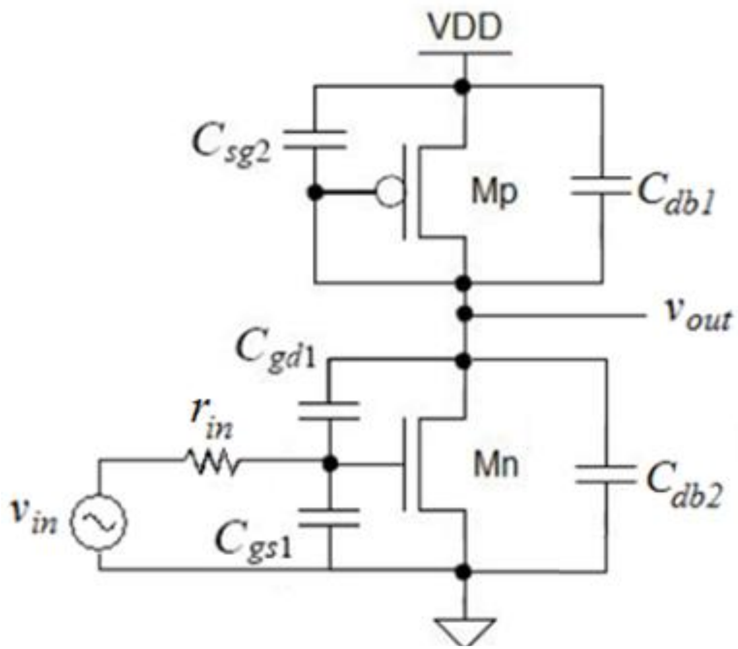
$$BW \Rightarrow \quad \omega C_L r_{out} = 1; \quad 2\pi f_{-3dB} C_L r_{out} = 1;$$

$$f_{-3dB} = \frac{1}{2\pi C_L r_{out}} = BW$$

$$GBW = |A_{u0}| BW$$

Усилвател с динамичен товар с активен резистор –

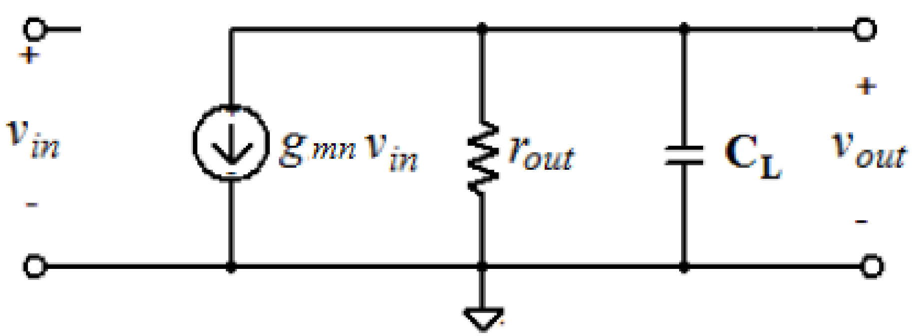
честотни зависимости като елемент на многостъпален усилвател



$$A_u = \frac{A_{u0}}{1 + j\omega C_L r_{out}}$$

$$BW = f_{-3dB} = \frac{1}{2\pi C_L r_{out}} = \frac{g_{mp}}{2\pi C_L}$$

$$GBW = |A_{u0}|BW = \frac{g_{mn}}{g_{mp}}\frac{g_{mp}}{2\pi C_L} = \frac{g_{mn}}{2\pi C_L}$$



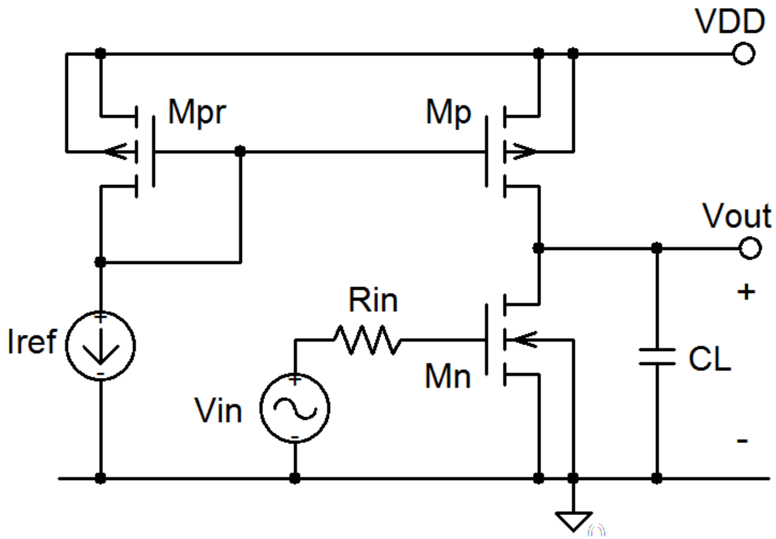
$$r_{out} \approx \frac{1}{g_{mp}}$$

$$C_M = C_{gd1}(1 + |Au|) + C_{gs1}$$

$$C_{out} = C_{sg2} + C_{db1} + C_{db2} + C_{gd1}\left(1 + \frac{1}{|Au|}\right)$$

$$C_L = C_{out} + C_M = C_{sg2} + C_{db1} + C_{db2} + C_{gd1}\left(1 + \frac{1}{|Au|}\right) + C_M$$

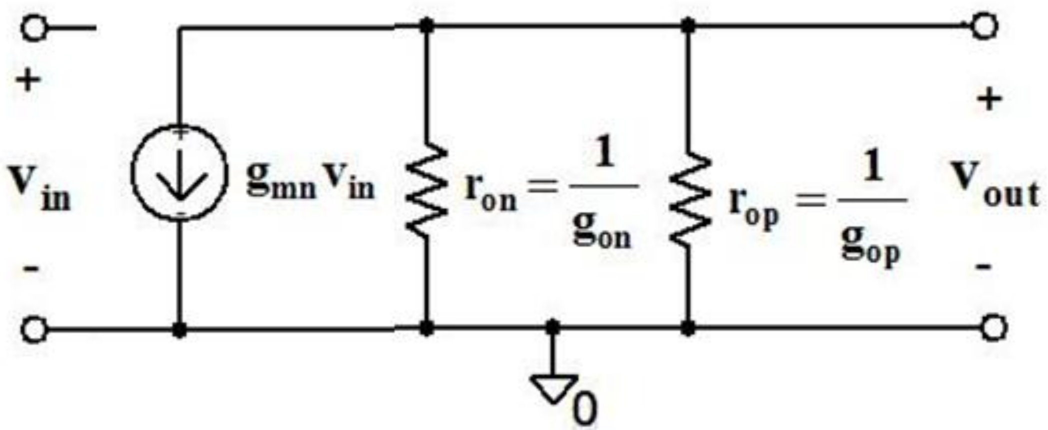
Стъпало с динамичен товар



$$A_{uo} = -\frac{g_{mn}}{g_{on} + g_{op}} \qquad r_{out} = \frac{1}{g_{on} + g_{op}}$$

$$BW = f_{(-3dB)} = \frac{1}{2\pi C_L r_{out}} = \frac{g_{on} + g_{op}}{2\pi C_L}$$

$$GBW = A_{uo} BW = \frac{g_{mn}}{2\pi C_L}$$



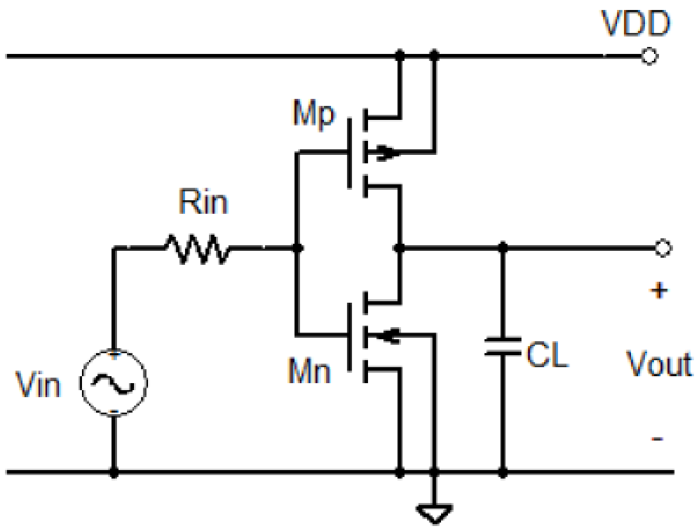
$$u_{out} = -g_{mn} u_{in} r_{out}$$

$$r_{out} = (r_{on} \| r_{op}) = \frac{1}{g_{on} + g_{op}}$$

$$u_{out} = -\frac{g_{mn}}{g_{on} + g_{op}} u_{in}$$

$$A_{uo} = -\frac{g_{mn}}{g_{on} + g_{op}}$$

Противотактно инвертиращо стъпало

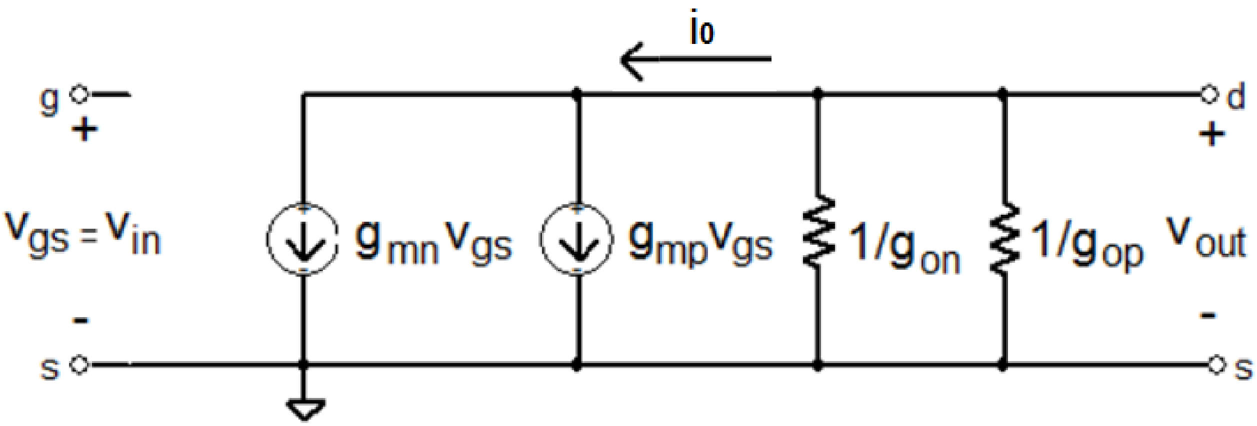


$$A_{uo} = -\frac{g_{mn} + g_{mp}}{g_{on} + g_{op}}$$

$$r_{out} = \frac{1}{g_{on} + g_{op}}$$

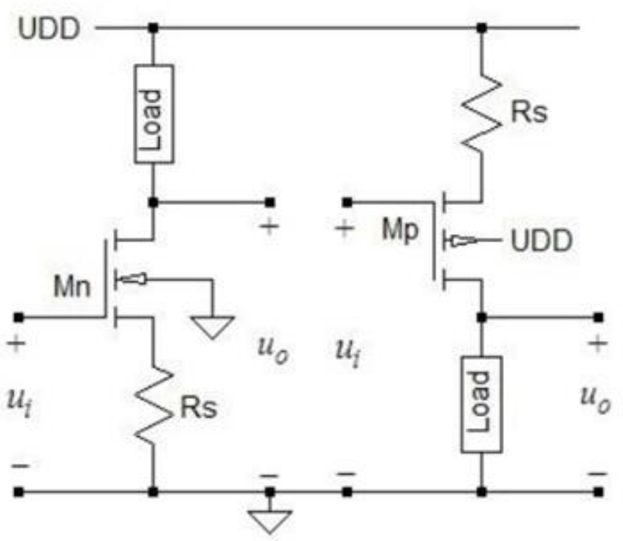
$$BW = f_{(-3dB)} = \frac{1}{2\pi C_L r_{out}} = \frac{g_{on} + g_{op}}{2\pi C_L}$$

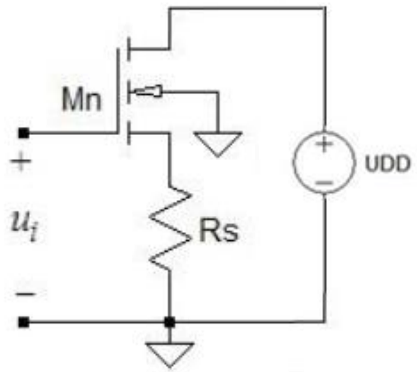
$$GBW = A_{uo} BW = \frac{g_{mn} + g_{mp}}{2\pi C_L}$$

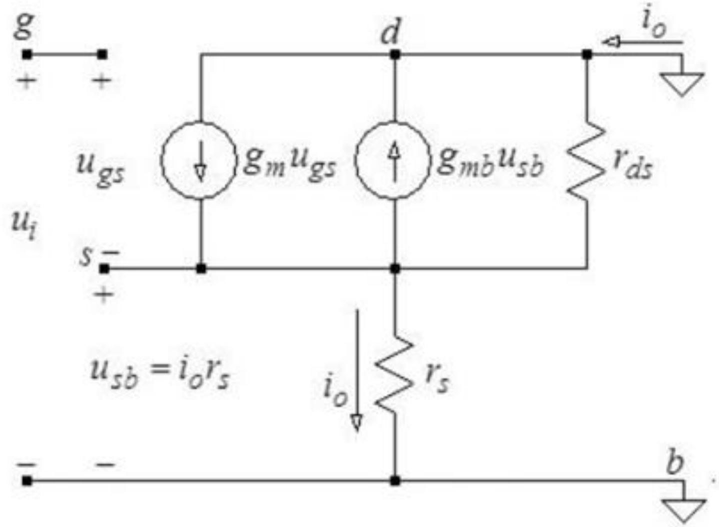


$$A_{uo} = \frac{u_{out}}{u_{in}} = -\frac{i_o r_{out}}{u_{in}} = -\frac{(g_{mn} + g_{mp})u_{in}}{(g_{on} + g_{op})u_{in}} = -\frac{g_{mn} + g_{mp}}{g_{on} + g_{op}}$$

Усилвателно стъпало с резистор в сорса







Определяне на еквивалентната стръмност $g_{m(eff)}$ на транзистор с резистор в сорса

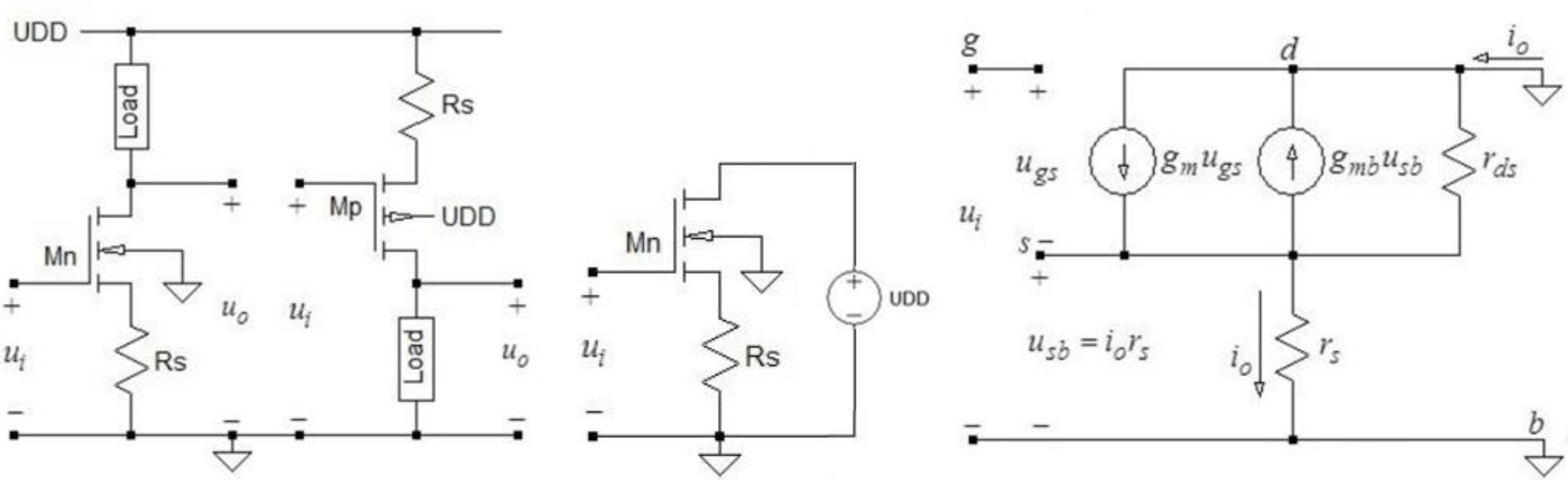
$$g_m = \left.\frac{dI_D}{dU_{GS}}\right|_{U_{DD} = const.} \quad \Rightarrow \quad g_{m(eff)} = \left.\frac{i_o}{u_i}\right|_{u_{dd} = 0}$$

$$i_o = g_m u_{gs} - g_{mb} u_{sb} + g_{ds}(-u_{sb})$$

$$u_{sb} = i_o r_s\,; \qquad u_{gs} = u_i - u_{sb} = u_i - i_o r_s$$

$$\boxed{i_o = g_m(u_i - i_o r_s) - g_{mb} i_o r_s - g_{ds} i_o r_s}$$

Усилвателно стъпало с резистор в сорса



Определяне на еквивалентната стръмност $g_{m(eff)}$ на транзистор с резистор в сорса

$$i_o = g_m(u_i - i_o r_s) - g_{mb} i_o r_s - g_{ds} i_o r_s$$

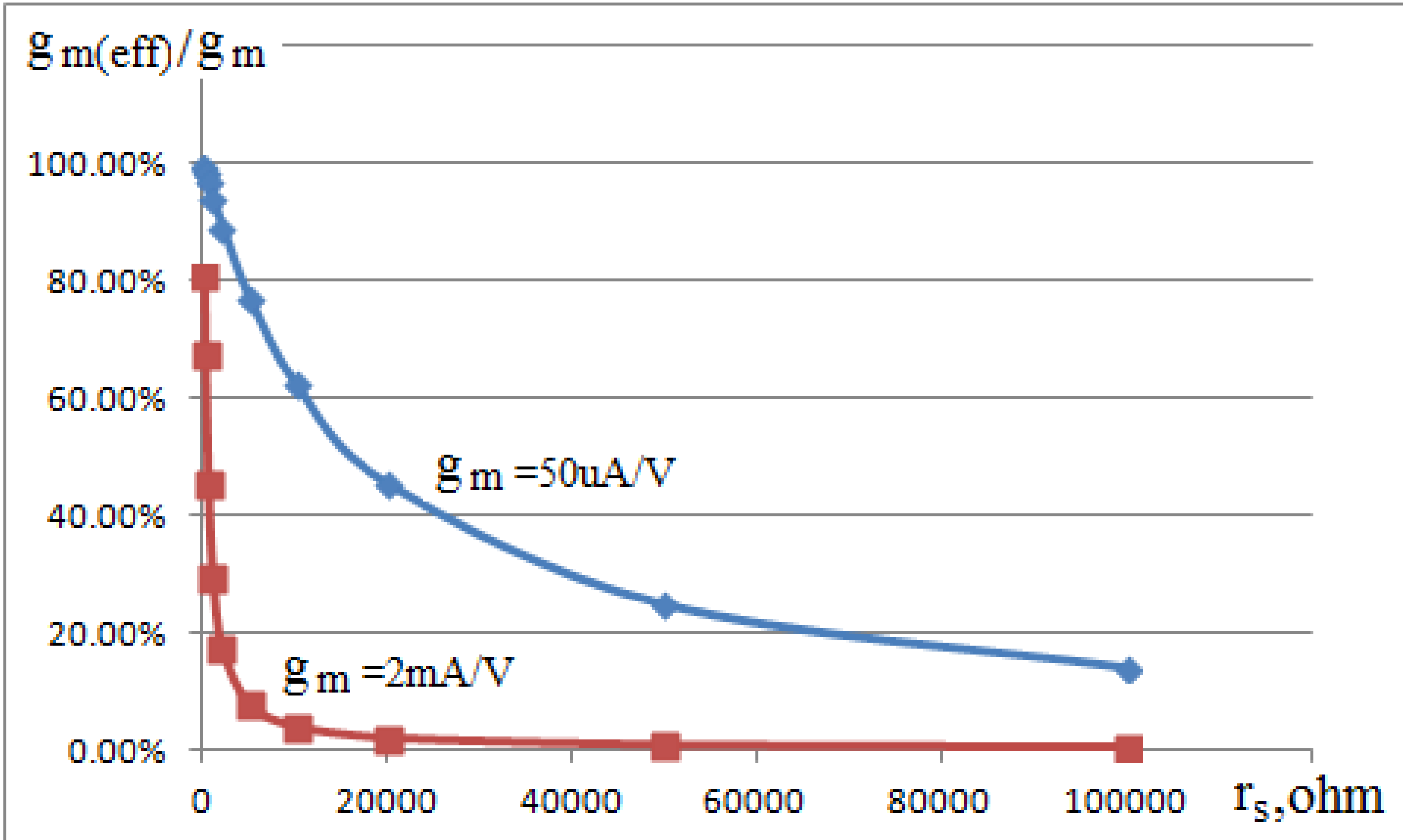
$$i_o = \frac{g_m u_i}{1 + (g_m + g_{mb} + g_{ds})r_s} \approx \frac{g_m u_i}{1 + (g_m + g_{mb})r_s}$$

$$g_{m(eff)} = \frac{i_o}{u_i} \approx \frac{g_m}{1 + (g_m + g_{mb})r_s}$$

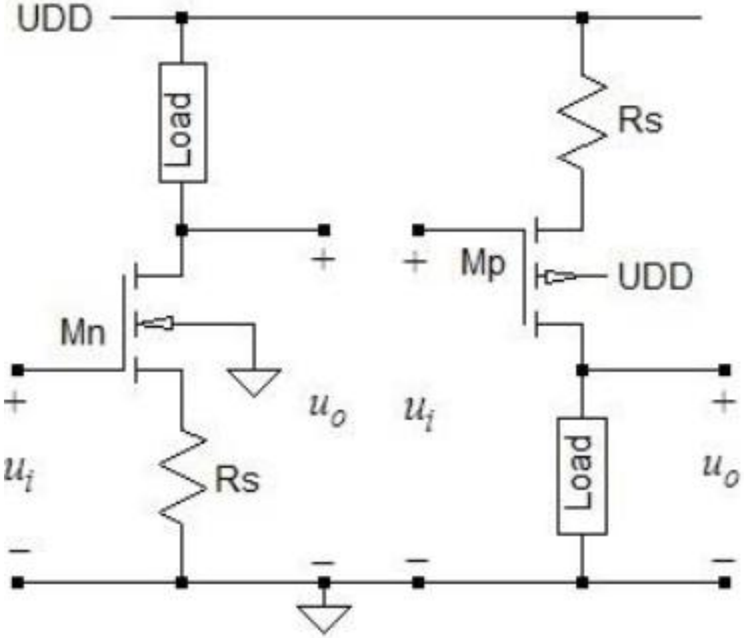
Усилвателно стъпало с резистор в сорса

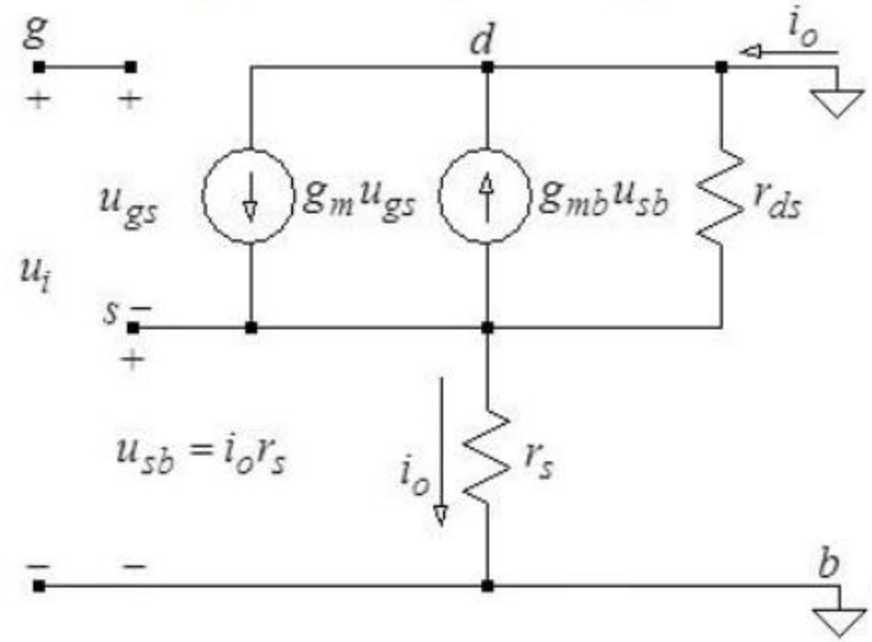
Анализ на резултата

$$g_{m(eff)} = \frac{i_o}{u_i} \approx \frac{g_m}{1 + (g_m + g_{mb})r_s}$$



Усилвателно стъпало с резистор в сорса





Определяне на диференциалното изходно съпротивление r_o

$$r_o = r_{ds-s} \| r_L = \frac{1}{g_{ds-s} + g_L} \approx \frac{1}{\dfrac{1}{g_m r_{ds} r_s} + \dfrac{1}{r_L}} = \frac{g_m r_{ds} r_s r_L}{g_m r_{ds} r_s + r_L}$$

Определяне на коефициента на усилване входното напрежение A_u

$$A_u = \frac{u_o}{u_i} = -\frac{i_o r_o}{u_i} = -\frac{g_{m(eff)} u_i r_o}{u_i} = -g_{m(eff)} r_o \approx -\frac{g_m}{1 + (g_m + g_{mb}) r_s} \frac{g_m r_{ds} r_s r_L}{g_m r_{ds} r_s + r_L}$$

Усилвателно стъпало с резистор в сорса

Анализ на резултата

$$A_u = -\frac{g_m}{1+(g_m+g_{mb})r_s}\frac{g_m r_{ds} r_s r_L}{g_m r_{ds} r_s + r_L}$$

$$g_{m(eff)} = \frac{g_m}{1+(g_m+g_{mb})r_s}$$

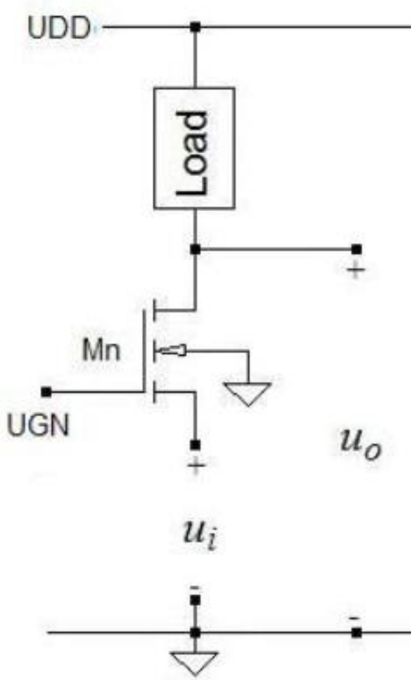
$$r_o = r_{ds-s} \| r_L = \frac{1}{g_{ds-s}+g_L} \approx \frac{1}{\frac{1}{g_m r_{ds} r_s}+\frac{1}{r_L}} = \frac{g_m r_{ds} r_s r_L}{g_m r_{ds} r_s + r_L}$$

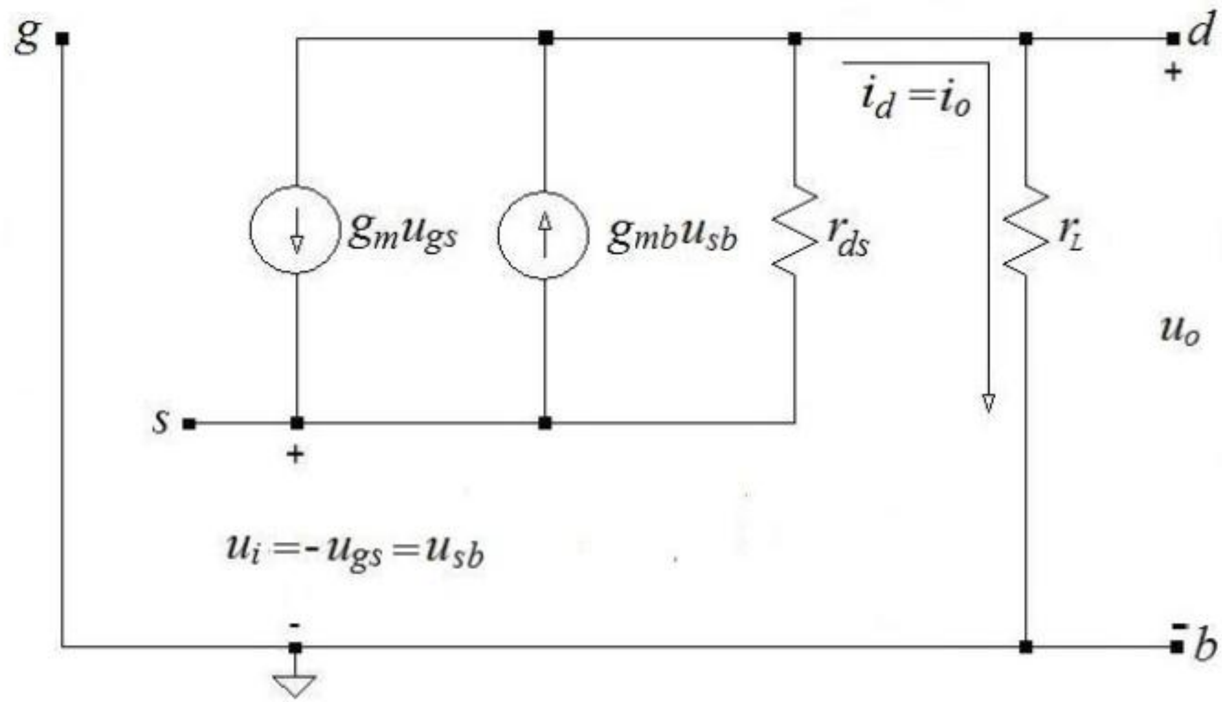
Обикновено $g_m r_{ds} r_s \gg r_L \quad \Rightarrow \quad r_o \approx r_L$

$$A_u = -g_{m(eff)} r_o \approx -\frac{g_m r_L}{1+(g_m+g_{mb})r_s}$$

Ако $(g_m+g_{mb})r_s \gg 1$, т.е. $r_s \gg \frac{1}{g_m} \quad \Rightarrow \quad A_u \approx -\frac{r_L}{r_s}$

Усилвателно стъпало с общ гейт





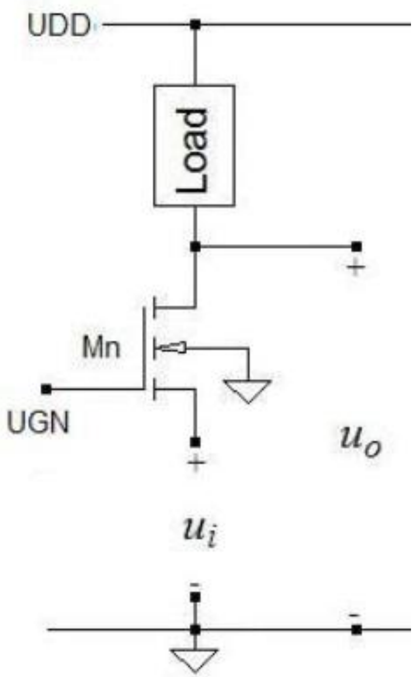
Определяне на коефициента на усилване на входното напрежение A_u

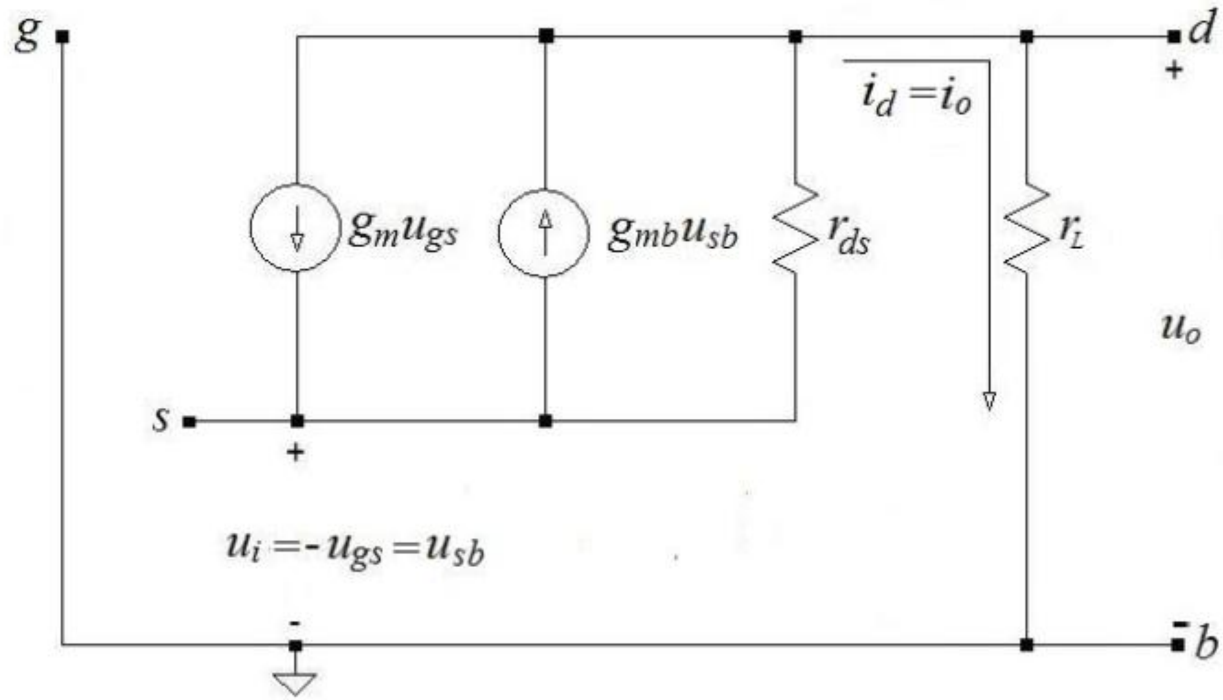
$$u_o = i_o r_L = \frac{i_o}{g_L}$$

$$i_o = i_d = -g_m u_{gs} + g_{mb} u_{sb} + (u_i - u_o) g_{ds} = g_m u_i + g_{mb} u_i + g_{ds} u_i - g_{ds} u_o$$

$$u_o = i_o r_L = \frac{i_o}{g_L} = \frac{g_m u_i + g_{mb} u_i + g_{ds} u_i - g_{ds} u_o}{g_L}$$

Усилвателно стъпало с общ гейт





Определяне на коефициента на усилване на входното напрежение A_u

$$u_o = i_o r_L = \frac{i_o}{g_L} = \frac{g_m u_i + g_{mb} u_i + g_{ds} u_i - g_{ds} u_o}{g_L}$$

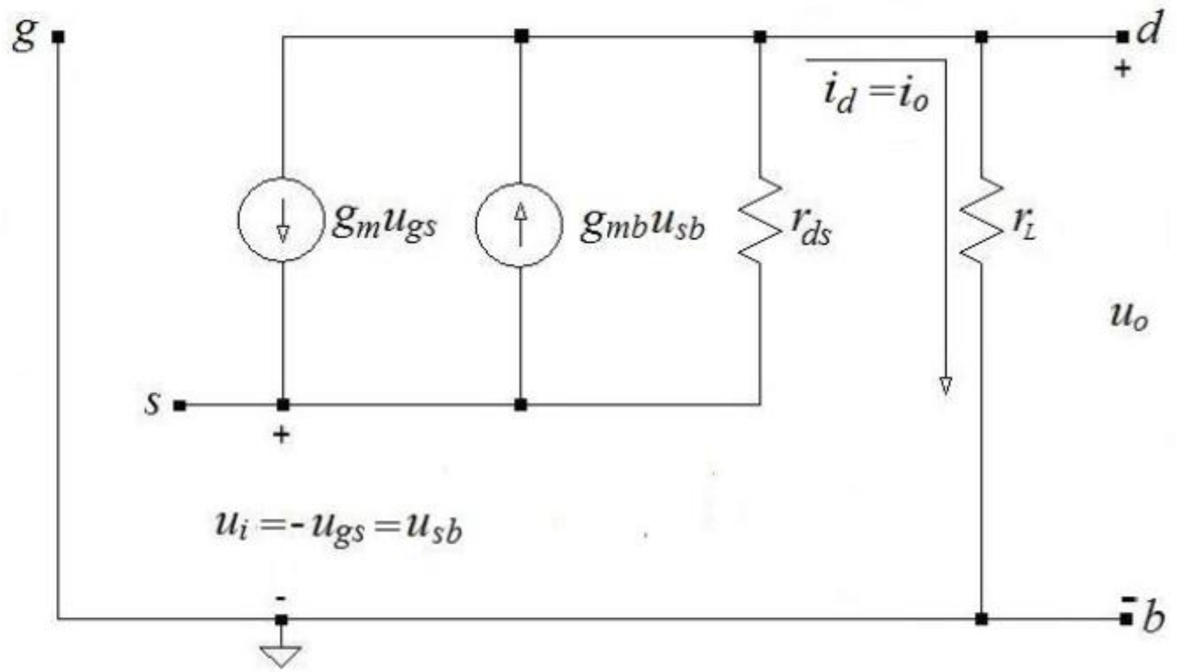
$$(g_{ds} + g_L) u_o = (g_m + g_{mb} + g_{ds}) u_i$$

$$A_u = \frac{u_o}{u_i} = \frac{g_m + g_{mb} + g_{ds}}{g_{ds} + g_L}$$

$$A_u \approx \frac{g_m + g_{mb}}{g_{ds} + g_L} \approx \frac{g_m}{g_{ds} + g_L}$$

Усилвателно стъпало с общ гейт

$$r_i \approx \frac{1}{g_m + g_{mb}}$$



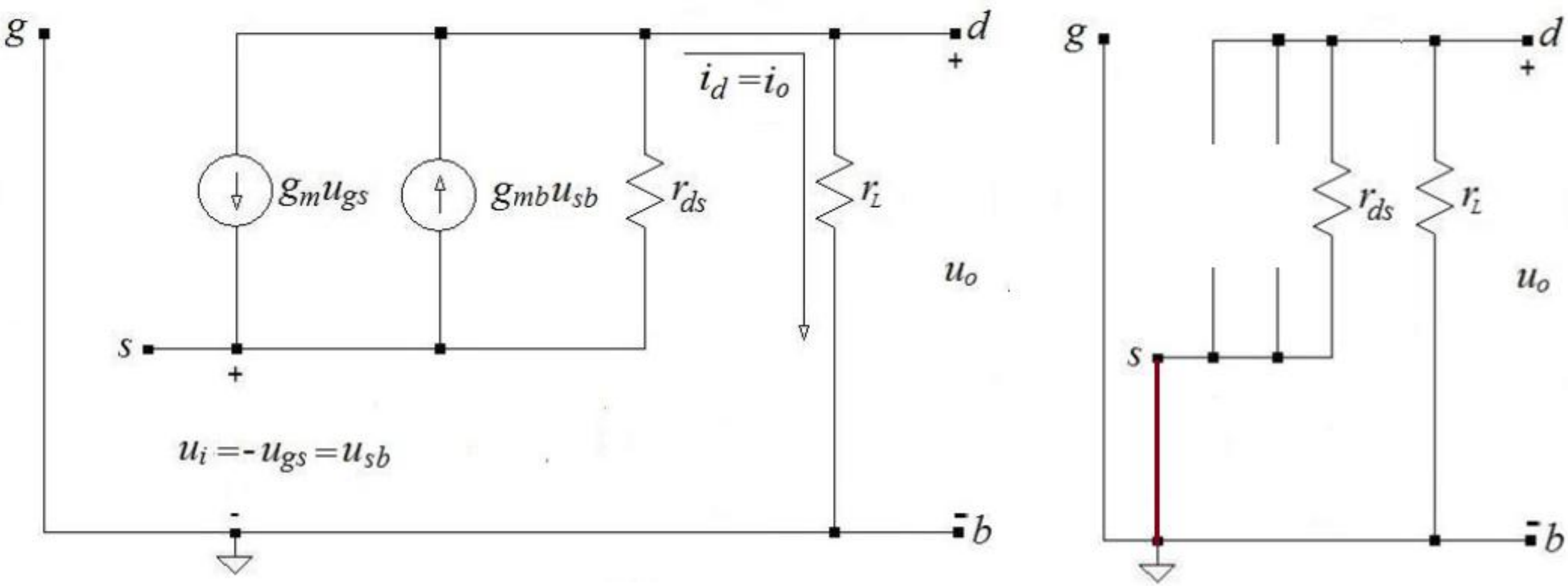
Определяне на входното съпротивление r_i

$$i_i = i_s = i_d = i_o = -g_m u_{gs} + g_{mb} u_{sb} + (u_i - u_o) g_{ds} \qquad u_o = i_o r_L = \frac{i_i}{g_L}$$

$$i_i = g_m u_i + g_{mb} u_i + g_{ds} u_i - g_{ds}\frac{i_i}{g_L} \qquad \left(1 + \frac{g_{ds}}{g_L}\right) i_i = g_m u_i + g_{mb} u_i + g_{ds} u_i$$

$$r_i = \frac{u_i}{i_i} = \frac{1}{g_m + g_{mb} + g_{ds}}\left(1 + \frac{g_{ds}}{g_L}\right) \approx \frac{1}{g_m + g_{mb}}\left(1 + \frac{g_{ds}}{g_L}\right) \qquad r_i \approx \frac{1}{g_m + g_{mb}}$$

Усилвателно стъпало с общ гейт



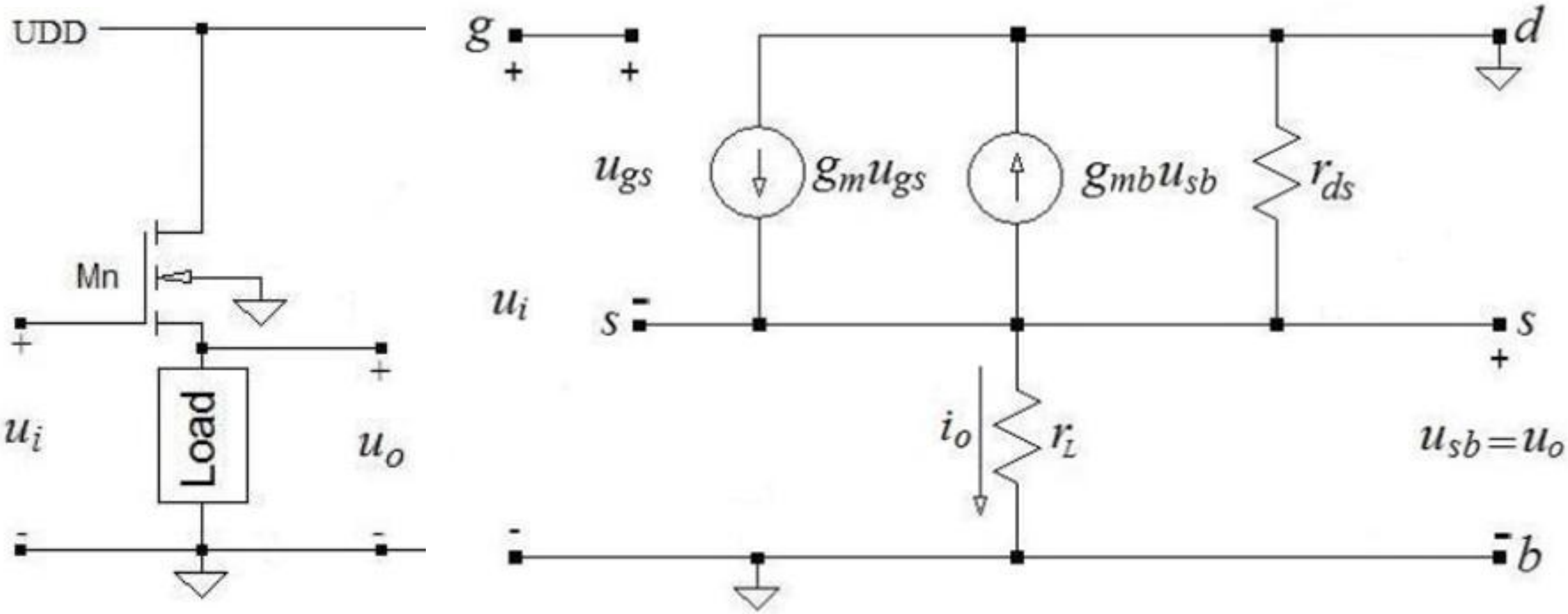
Определяне на изходното съпротивление r_o

$$u_i = 0$$

$$g_m u_{gs} = g_{mb} u_{sb} = 0$$

$$r_o = r_{ds} \| r_L = \frac{1}{g_{ds} + g_L}$$

Усилвателно стъпало с общ дрейн



Определяне на коефициента на предаване на входното напрежение A_u

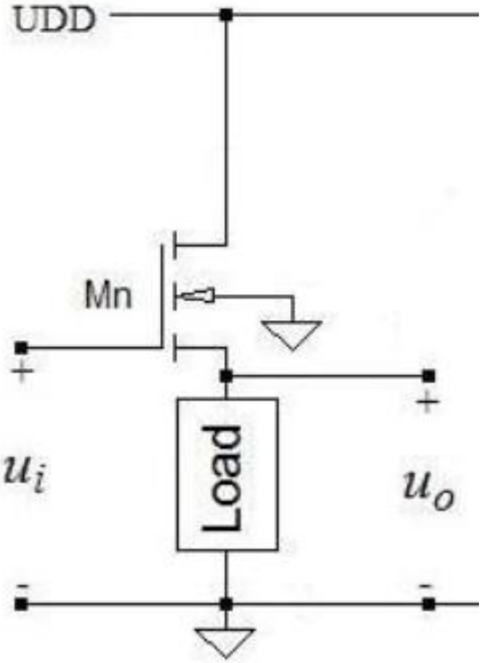
$$u_o = i_o r_L = i_o / g_L \,;$$

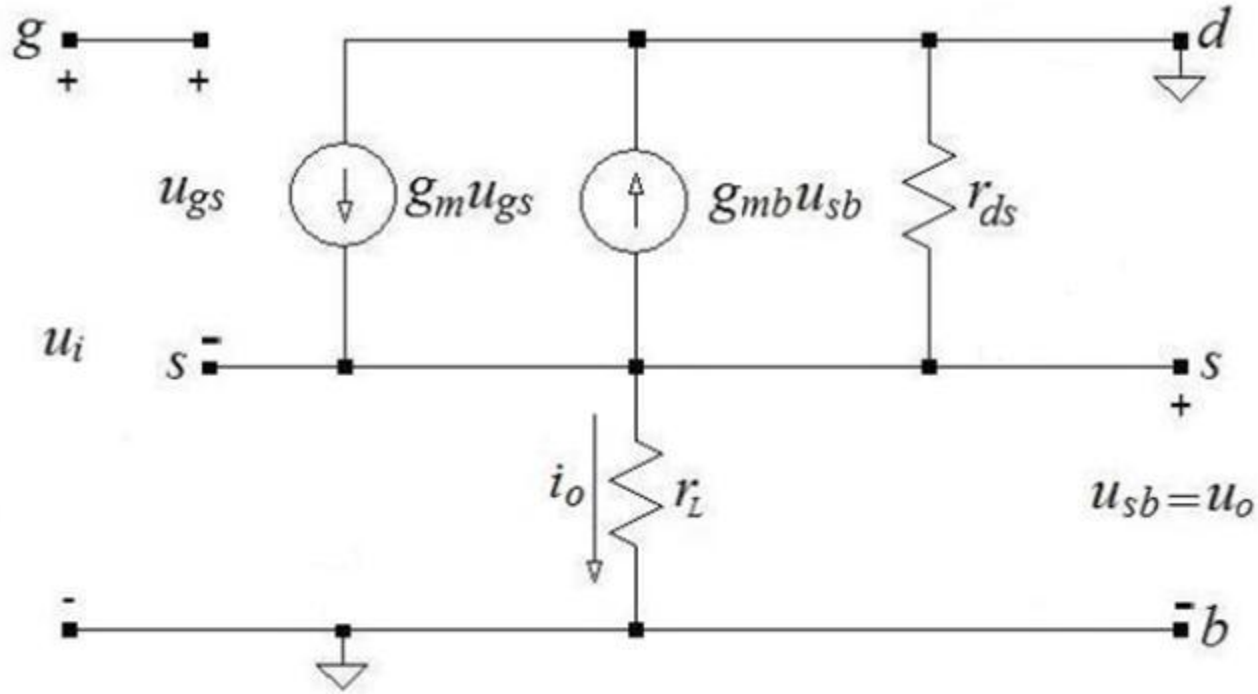
$$i_o = g_m u_{gs} - g_{mb} u_{sb} - g_{ds} u_o \,;$$

$$u_{gs} = u_i - u_o \,; \qquad u_{sb} = u_o \,;$$

$$g_L u_o = g_m (u_i - u_o) - g_{mb} u_o - g_{ds} u_o$$

Усилвателно стъпало с общ дрейн





Определяне на коефициента на предаване на входното напрежение A_u

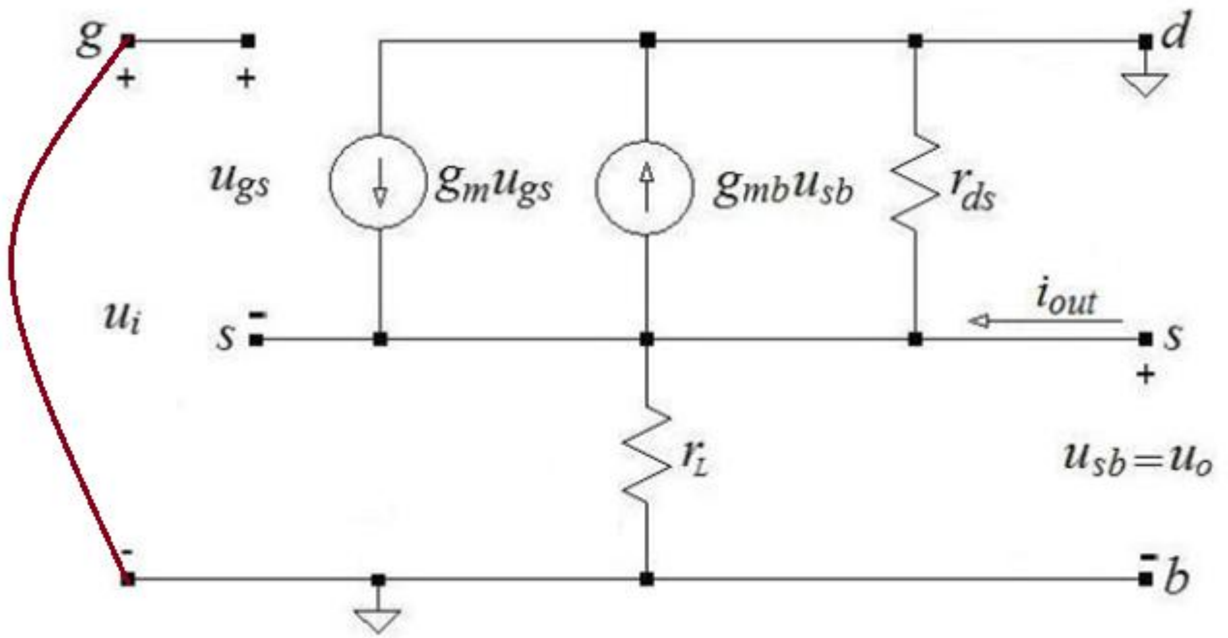
$$g_L u_o = g_m (u_i - u_o) - g_{mb} u_o - g_{ds} u_o$$

$$(g_m + g_{mb} + g_{ds} + g_L) u_o = g_m u_i$$

$$A_u = \frac{g_m}{g_m + g_{mb} + g_{ds} + g_L}$$

$$A_u \approx \frac{g_m}{g_m + g_{mb}}$$

Усилвателно стъпало с общ дрейн



$$r_o = \frac{u_o}{i_{out}}$$

Определяне на изходното съпротивление r_o

$$i_{out} = g_L u_o + g_{ds} u_o - g_m u_{gs} + g_{mb} u_{sb}$$

При стойност на входното напрежение $u_i = 0$, $\quad u_{gs} = -u_o = -u_{sb}$

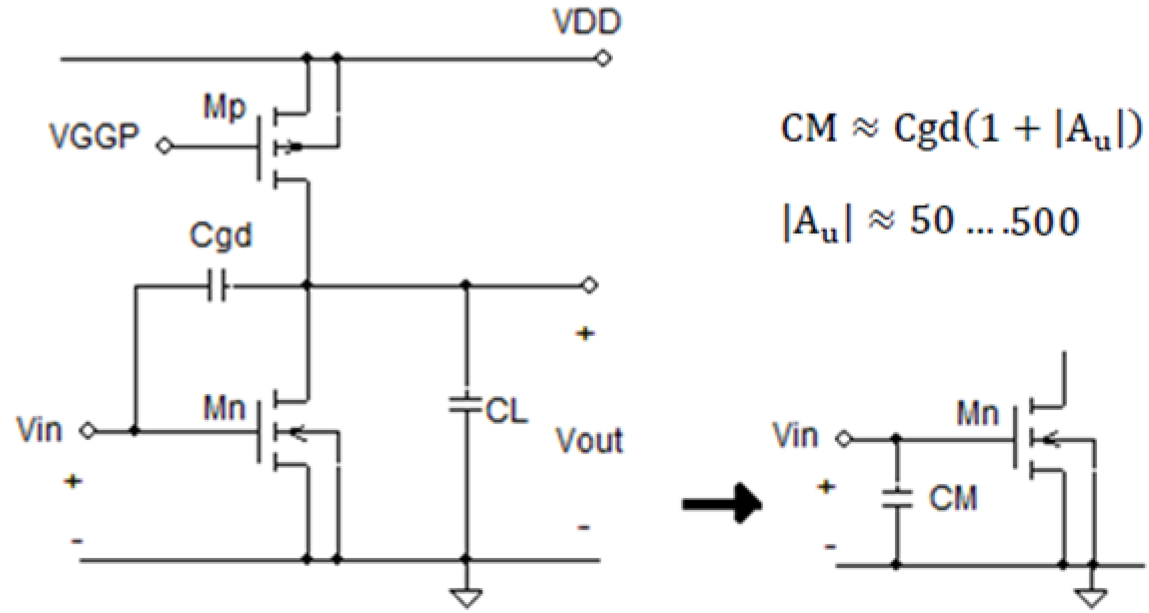
$$i_{out} = g_L u_o + g_{ds} u_o + g_m u_o + g_{mb} u_o$$

$$r_o = \frac{u_o}{i_{out}} = \frac{1}{g_m + g_{mb} + g_{ds} + g_L}$$

$$r_o \approx \frac{1}{g_m + g_{mb}}$$

Каскоден усилвател

недостатък на класическото усилвателно стъпало



$$CM \approx Cgd(1 + |A_u|)$$

$$|A_u| \approx 50 \dots .500$$

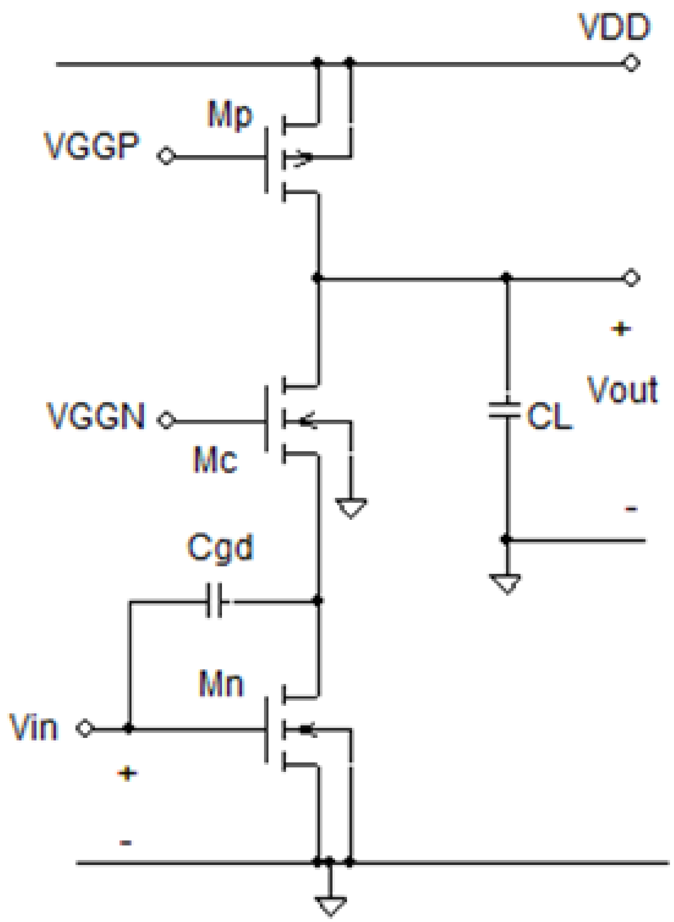
$$A_u = -\frac{g_{mn}}{g_{dsn} + g_{dsp}} = -\frac{2I_D/U_{effn}}{(\lambda_n + \lambda_p)I_D} = -\frac{2}{(\lambda_n + \lambda_p)U_{effn}}$$

При $U_{effn} = 0{,}2V = const.$,

за увеличение на A_{umax} е необходимо $(\lambda_n + \lambda_p) \downarrow$ (т. е. L_n $(L_p) \uparrow$),

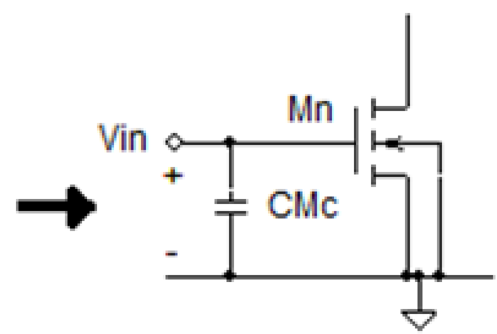
което води до нарастване на паразитните капацитети и стесняване на BW

Каскоден усилвател



$$CMc \approx Cgd(1 + |A_u|)$$

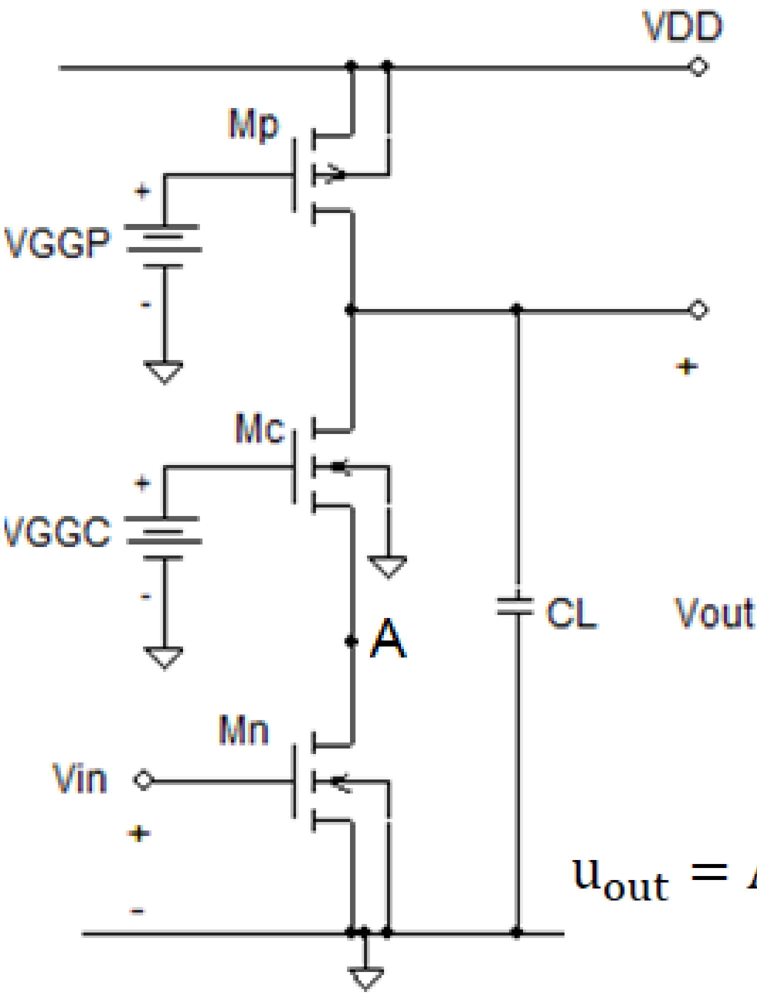
$$|A_u| \approx 1$$



Принципна схема на каскоден усилвател общ сорс (Mn) – общ гейт (Mc).

Каскоден усилвател

Анализ – вариант 1



$$A_{u(Mn)} = -\frac{g_{mn}}{g_{dsn} + g_{ic}}$$

$$g_{ic} = g_{mc} + g_{mbc}$$

$$A_{u(Mn)} = -\frac{g_{mn}}{g_{dsn} + g_{mc} + g_{mbc}}$$

$$A_{u(Mn)} \approx -\frac{g_{mn}}{g_{mc} + g_{mbc}} \approx -1$$

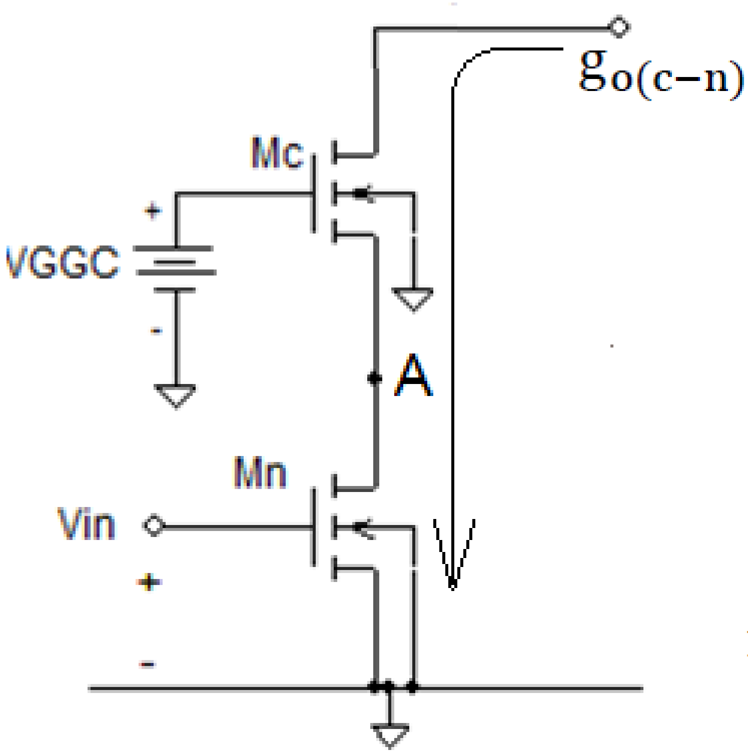
$$u_A = A_{u(Mn)} u_{in} \approx -\frac{g_{mn}}{g_{mc} + g_{mbc}} u_{in}$$

$$u_{out} = A_{u(Mc)} u_A = -\frac{g_{mc} + g_{mbc}}{g_{o(c-n)} + g_{dsp}} \frac{g_{mn}}{g_{mc} + g_{mbc}} u_{in}$$

$$A_u = \frac{u_{out}}{u_{in}} = -\frac{g_{mn}}{g_{o(c-n)} + g_{dsp}}$$

Каскоден усилвател

Анализ – вариант 1



$$A_u = \frac{u_{out}}{u_{in}} = -\frac{g_{mn}}{g_{o(c-n)} + g_{dsp}}$$

$$r_{o(c-n)} = g_{mc} r_{dsc} r_{dsn} = \frac{g_{mc}}{g_{dsc} g_{dsn}}$$

$$g_{o(c-n)} = \frac{1}{g_{mc} r_{dsc} r_{dsn}} = \frac{g_{dsc} g_{dsn}}{g_{mc}}$$

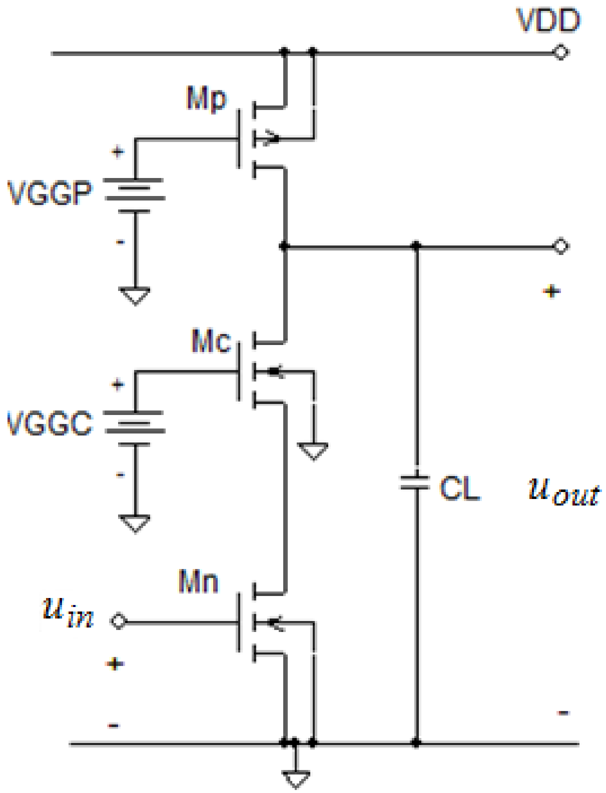
$$r_{out} = \frac{1}{g_{o(c-n)} + g_{dsp}} = \frac{g_{mc}}{g_{dsc} g_{dsn} + g_{mc} g_{dsp}}$$

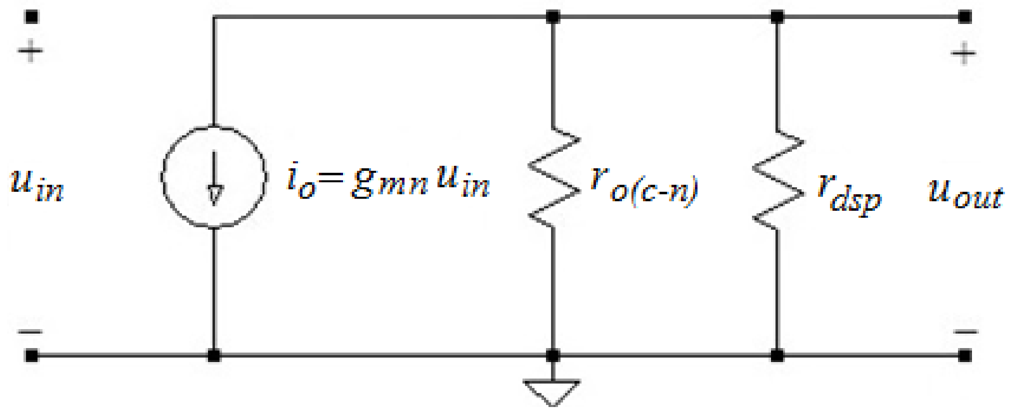
$$A_u = -\frac{g_{mn} g_{mc}}{g_{dsc} g_{dsn} + g_{mc} g_{dsp}}$$

Обикновено $g_{o(c-n)} \ll g_{dsp} \implies A_u = -\frac{g_{mn}}{g_{dsp}}$

Каскоден усилвател

Анализ – вариант 2





$$i_o = i_{dn} = i_{sc} = i_{dc} = g_{mn} u_{in}$$

$$r_{o(c-n)} = g_{mc} r_{dsc} r_{dsn} = \frac{g_{mc}}{g_{dsc} g_{dsn}} \gg r_{dsp}$$

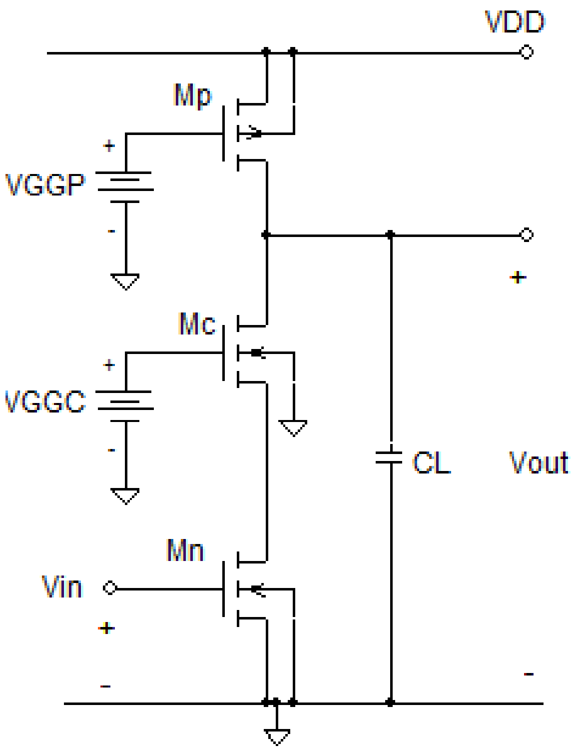
$$r_{out} = r_{o(c-n)} \| r_{dsp} \approx r_{dsp}$$

$$u_{out} = -i_o r_{out} = -g_{mn} u_{in} r_{dsp} = -\frac{g_{mn}}{g_{dsp}} u_{in}$$

$$A_u = \frac{u_{out}}{u_{in}} = -g_{mn} r_{dsp} = -\frac{g_{mn}}{g_{dsp}}$$

Каскоден усилвател

Анализ – вариант 3



$$u_{gsc} = -\frac{g_{mn} u_{in}}{g_{dsn} + g_{mc} + g_{mbc}} \approx -\frac{g_{mn}}{g_{mc} + g_{mbc}} u_{in}$$

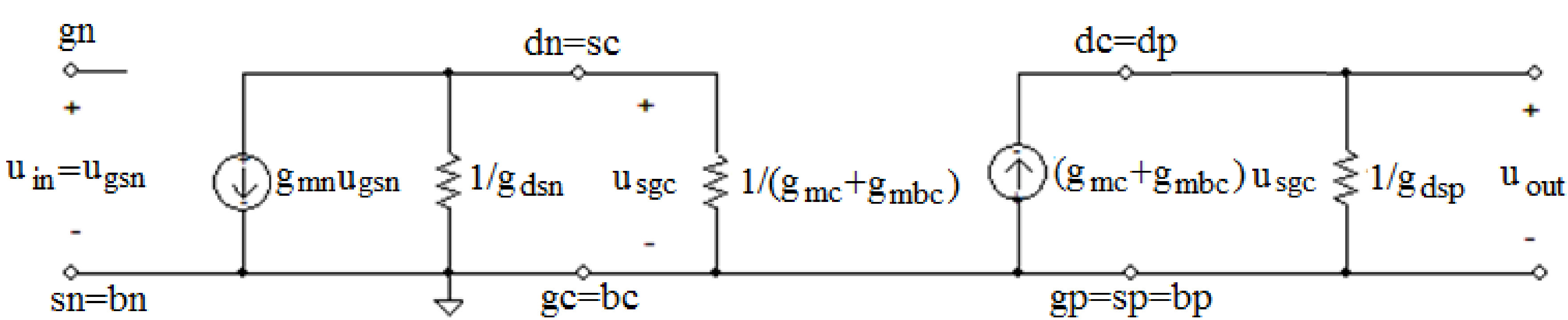
$$u_{out} = \frac{g_{mc} + g_{mbc}}{g_{dsp}} u_{sgc} = -\frac{g_{mn}}{g_{dsp}} u_{in}$$

$$A_u = \frac{u_{out}}{u_{in}} = -\frac{g_{mn}}{g_{dsp}}$$

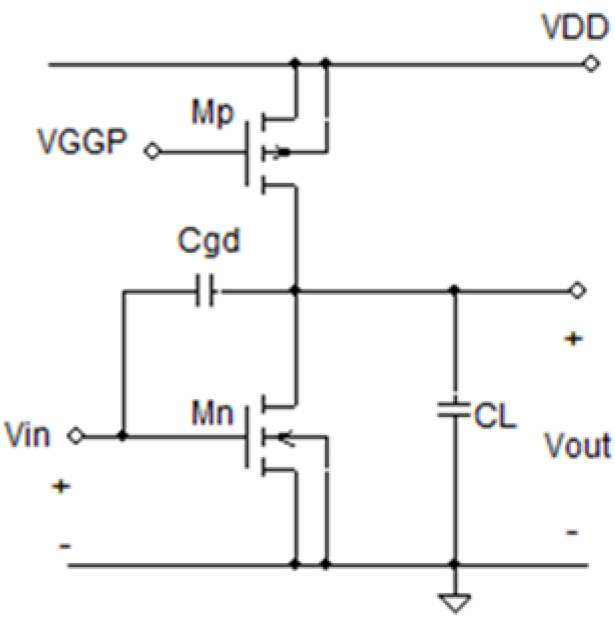
$$r_{out} = \frac{1}{g_{dsp}} = r_{dsp}$$

$$BW = \frac{1}{2\pi r_{out} C_L} = \frac{g_{dsp}}{2\pi C_L} = f_{(-3dB)}$$

$$GBW = |A_u| BW = \frac{g_{mn}}{g_{dsp}} \frac{g_{dsp}}{2\pi C_L} = \frac{g_{mn}}{2\pi C_L} = f_u = f_T$$



Сравнение между едностъпален и каскоден усилвател

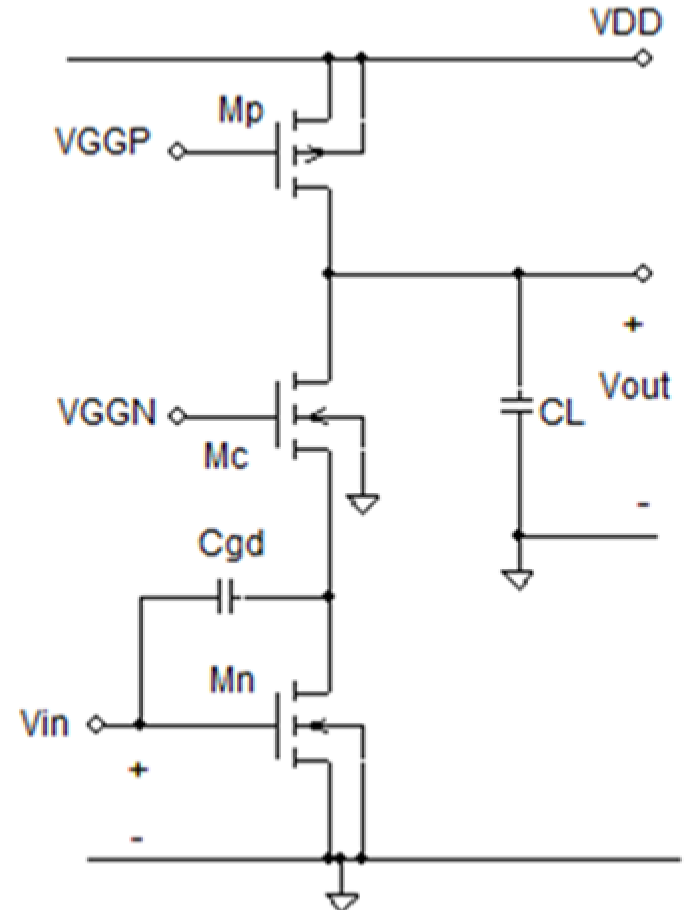


$$A_u = -\frac{g_{mn}}{g_{dsn} + g_{dsp}} = -\frac{2}{(\lambda_n + \lambda_p)U_{effn}} \approx -300$$

$$BW = \frac{g_{dsn} + g_{dsp}}{2\pi C_L}$$

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

$$C_{in} \approx |A_u| C_{gd} \approx 300 C_{gd}$$

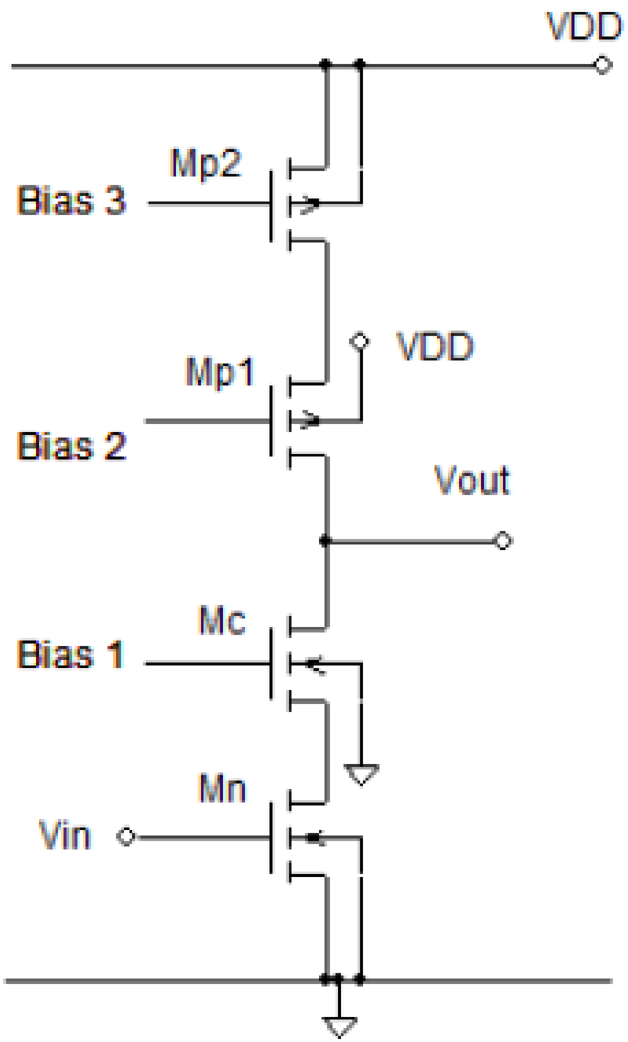


$$A_u = -\frac{g_{mn}}{g_{dsp}} = -\frac{2}{\lambda_p U_{effn}} \approx -550$$

$$BW = \frac{g_{dsp}}{2\pi C_L} \qquad GBW = \frac{g_{mn}}{2\pi C_L}$$

$$C_{in} \approx C_{gd}$$

Каскодни усилватели с подобрени показатели /телескопичен каскод/



$$A_u = -g_{mn} r_{out} = -g_{mn}\left(r_{o(c-n)} \| r_{o(1-2)}\right) \approx$$

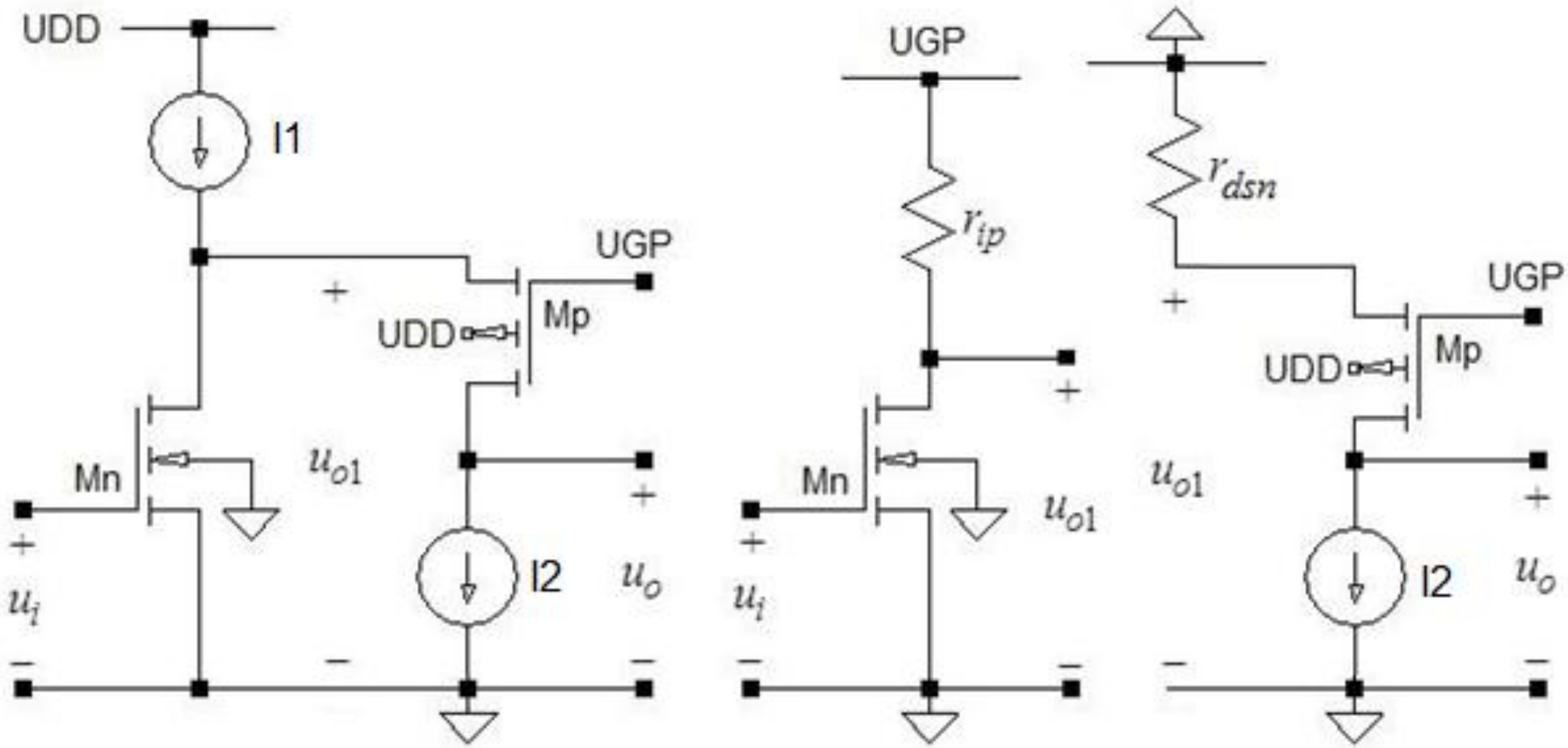
$$\approx -g_{mn}\frac{r_{o(c-n)}}{2} = -\frac{g_{mn} g_{mc}}{2 g_{dsn} g_{dsc}} = -\frac{1}{2}\frac{\frac{2I_D}{U_{effn}}}{\lambda_n I_D}\frac{\frac{2I_D}{U_{effc}}}{\lambda_n I_D}$$

$$A_u \approx -\frac{1}{2}\left(\frac{2}{\lambda_n U_{effn}}\right)^2 \approx -250000$$

$$BW = \frac{1}{2\pi r_{out} C_L} \approx \frac{1}{2\pi \frac{r_{o(c-n)}}{2} C_L} = \frac{g_{dsn} g_{dsc}}{\pi g_{mc} C_L}$$

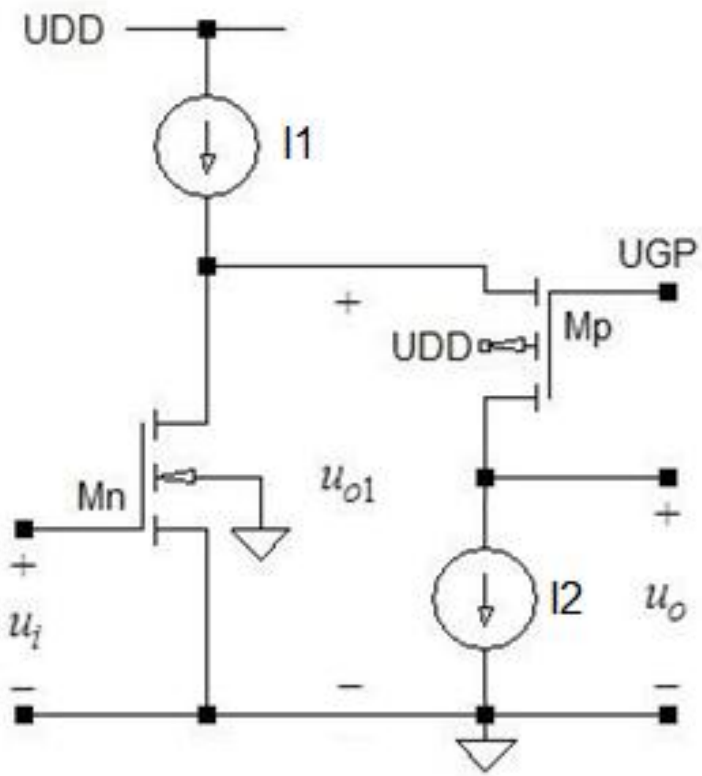
$$GBW = |A_u| BW = \frac{g_{mn} g_{mc}}{2 g_{dsn} g_{dsc}} \frac{g_{dsn} g_{dsc}}{\pi g_{mc} C_L} = \frac{g_{mn}}{2\pi C_L}$$

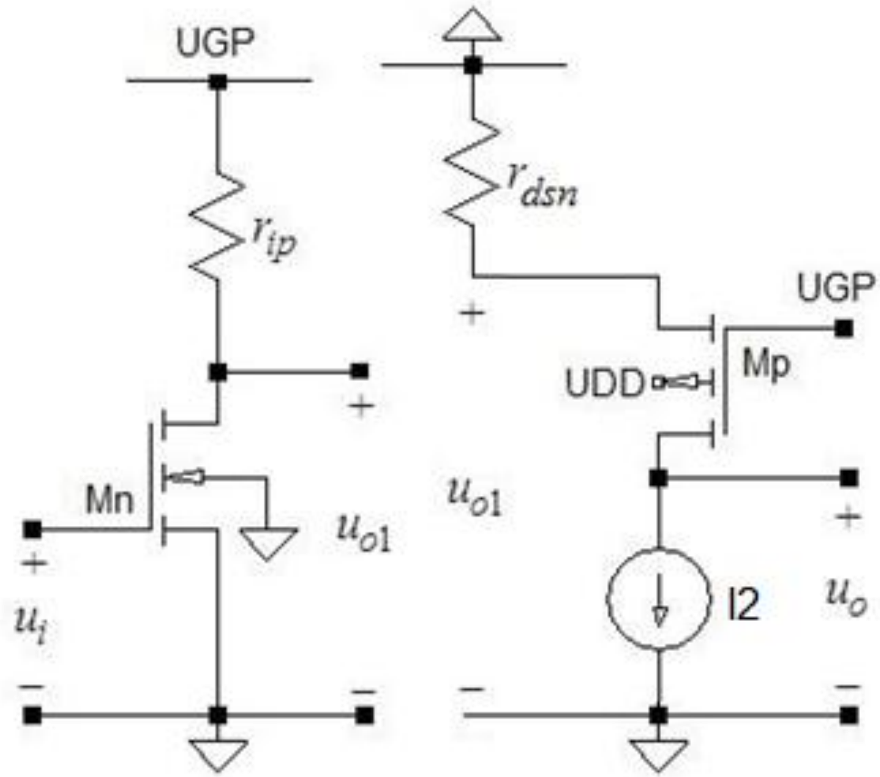
Каскодни усилватели с подобрени показатели /прегънат каскод/



Основно приложение – в диференциални схеми (ще ги разгледаме по-късно).
Обикновено I1=2·I2 (два пъти по-висока консумация от класическата структура).

Каскодни усилватели с подобрени показатели /прегънат каскод/

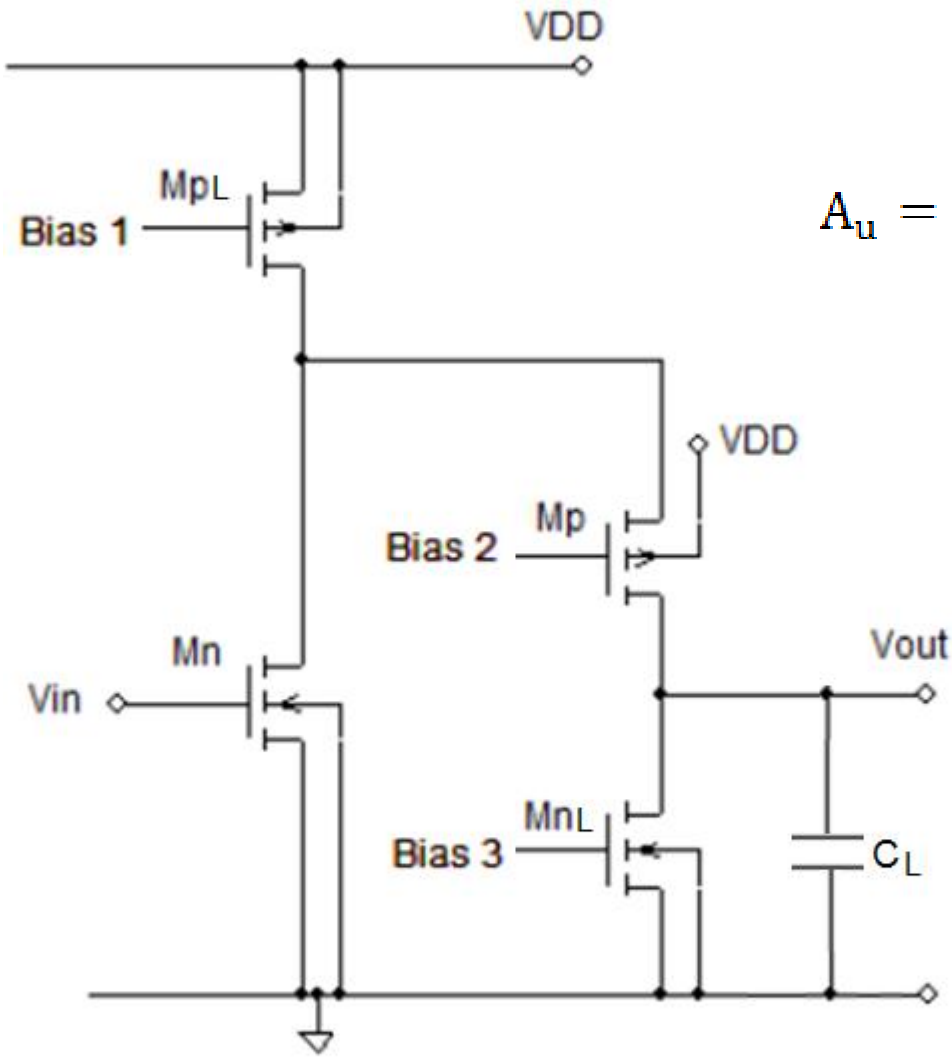




$$A_{u1} \approx -\frac{g_{mn}}{g_{ip}} = -\frac{g_{mn}}{g_{mp} + g_{mbp}} \qquad A_{u2} \approx \frac{g_{mp} + g_{mbp}}{g_{o(p-n)} + g_L} \qquad g_{o(p-n)} \approx \frac{g_{mp}}{g_{dsp} g_{dsn}}$$

$$A_u = A_{u1} A_{u1} = -\frac{g_{mn}}{g_{mp} + g_{mbp}} \frac{g_{mp} + g_{mbp}}{g_{o(p-n)} + g_L} = -\frac{g_{mn}}{g_{o(p-n)} + g_L} = -\frac{g_{mn} g_{mp}}{g_{dsp} g_{dsn} + g_{mp} g_L}$$

Каскодни усилватели с подобрени показатели /прегънат каскод/



$$g_L = g_{dsnL}$$

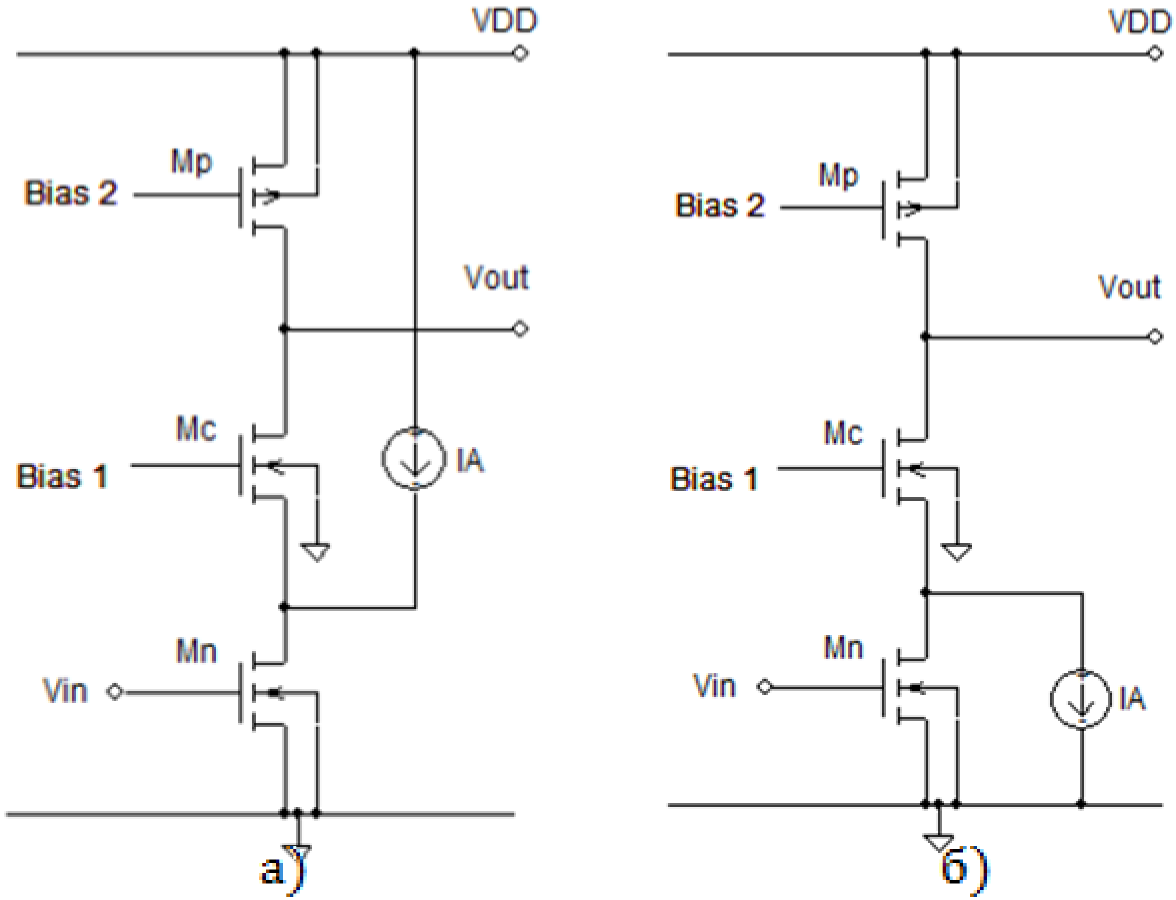
$$A_u = -\frac{g_{mn} g_{mp}}{g_{dsp} g_{dsn} + g_{mp} g_{dsnL}} \approx -\frac{g_{mn}}{g_{dsnL}}$$

$$r_{out} = \frac{1}{g_{dsnL}}$$

$$BW = \frac{1}{2\pi r_{out} C_L} = \frac{g_{dsnL}}{2\pi C_L}$$

$$GBW = |A_u| BW = \frac{g_{mn}}{2\pi C_L}$$

Каскодни усилватели с подобрени показатели



$$A_u = -\frac{g_{mn}}{g_{dsp}}$$

$$r_{out} = r_{dsp}$$

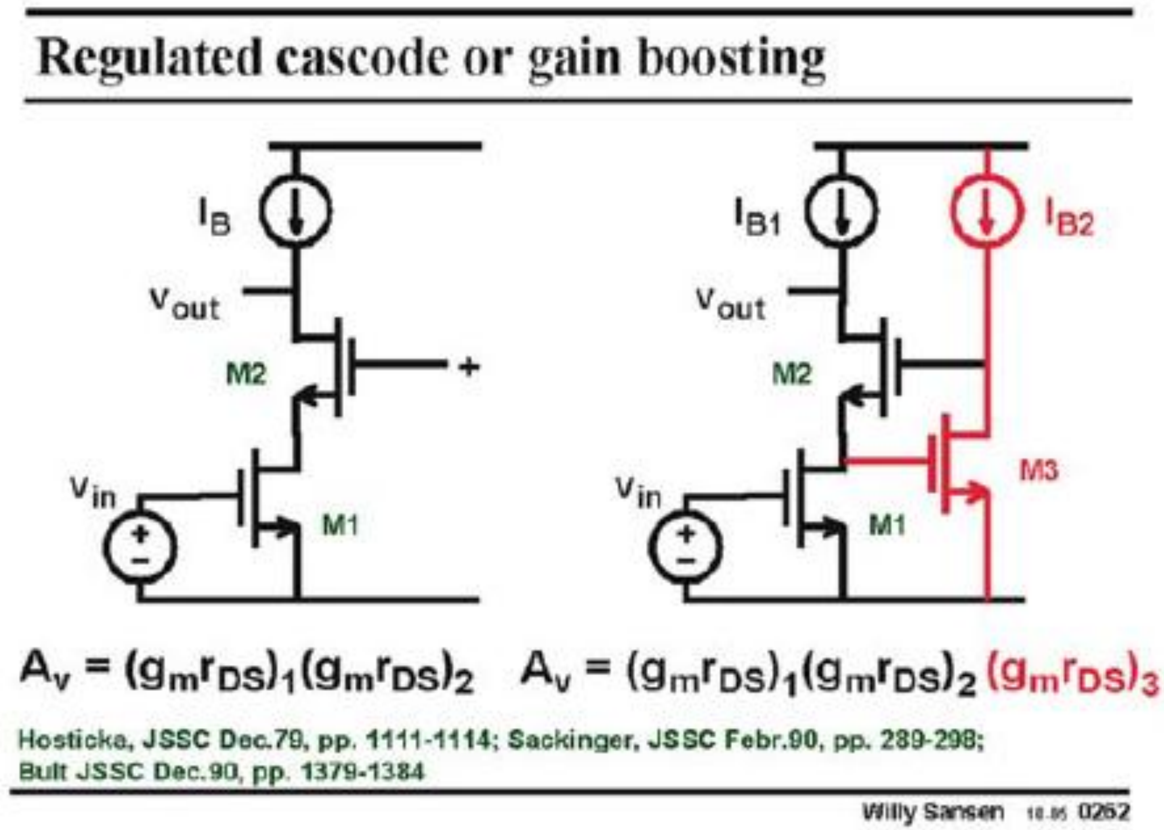
$$BW = \frac{1}{2\pi r_{dsp} C_L}$$

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

а) Стъпало с повишено усилване – увеличение на g_{mn} при запазване на стойността на r_{dsp} и BW (Au↑, GBW↑, BW=const.).

б) Стъпало с понижено усилване – намаление на g_{mn} при запазване на стойността на r_{dsp} и BW (Au↓, GBW↓, BW=const.).

Регулиран каскод

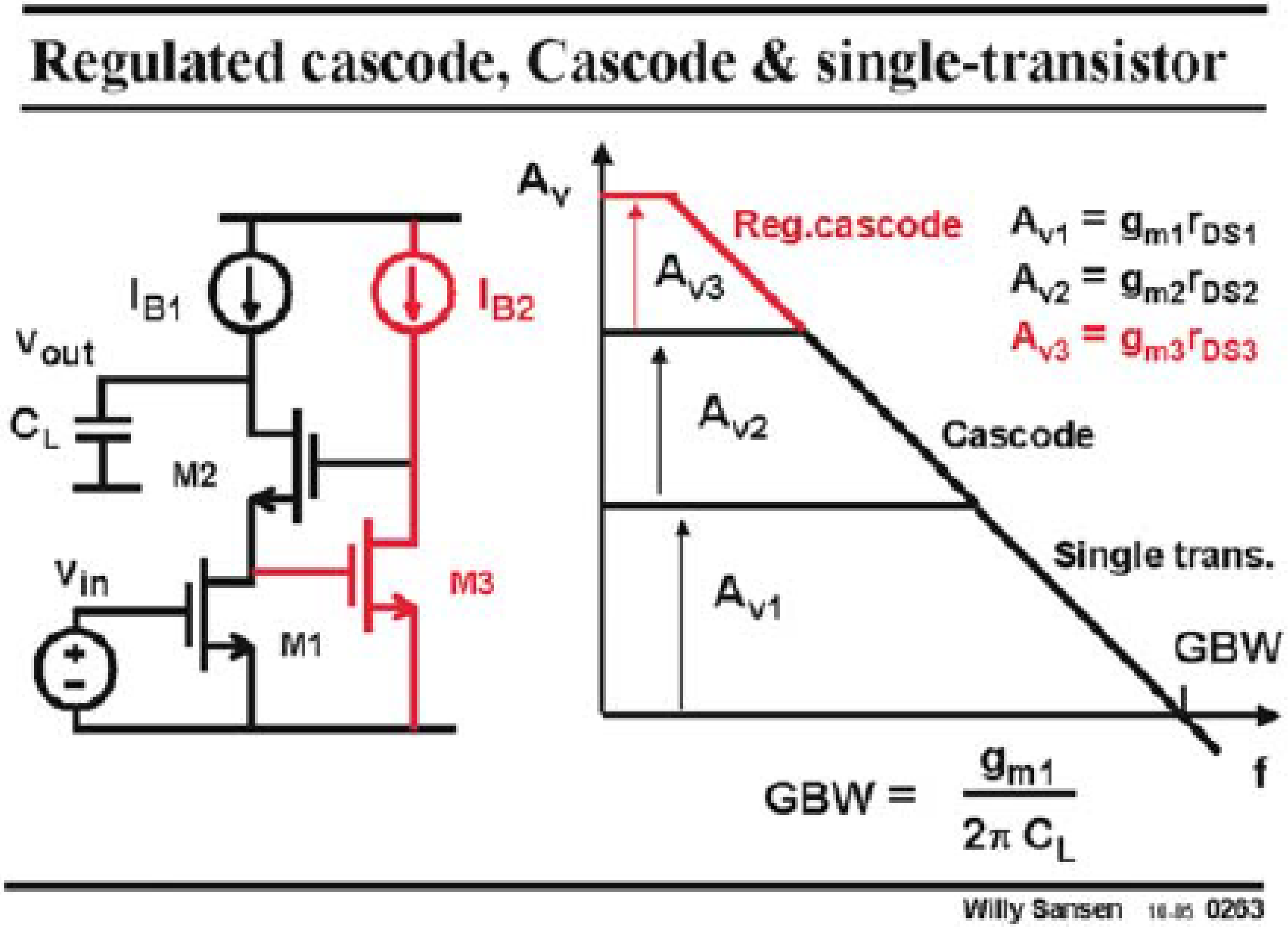


Формулите са в сила при идеални източници на ток IB, IB1 и IB2.

$$A_{uc} = -\frac{g_{m1} g_{m2}}{g_{ds1} g_{ds2} + g_{m2} g_L} = -\frac{g_{m1} g_{m2}}{g_{ds1} g_{ds2}} = -(g_{m1} r_{ds1})(g_{m2} r_{ds2})$$

$$A_{urc} = -\frac{g_{m1} g_{m2} g_{m3}}{g_{ds1} g_{ds2} g_{ds3}} = -(g_{m1} r_{ds1})(g_{m2} r_{ds2})(g_{m3} r_{ds3})$$

Регулиран каскод, каскод и еднотранзисторен усилвател



БЛАГОДАРЯ ЗА ВНИМАНИЕТО