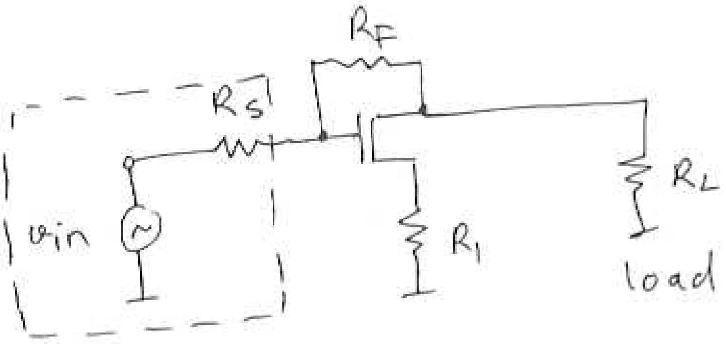
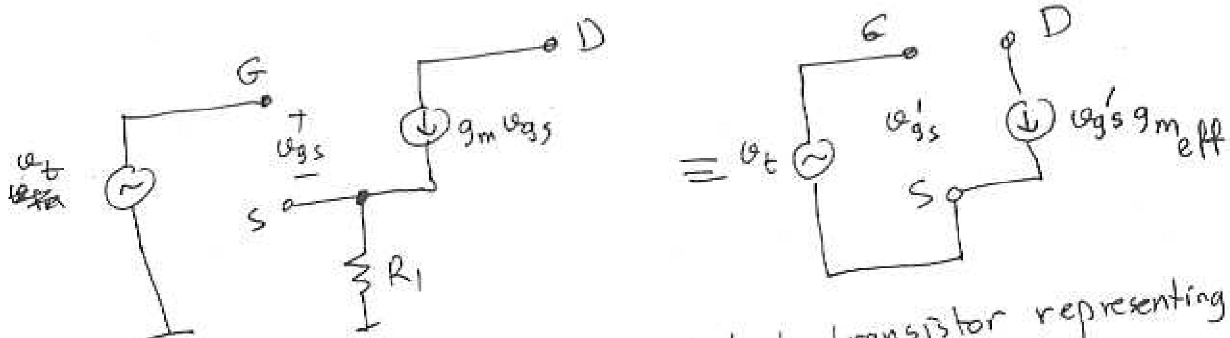
The Shunt-Series Amplifier



This is an amplifier which has controlled gain and input and output impedances. At low enough frequencies and if the effect of R_F is neglected then

$$A_v \cong -\frac{R_L}{R_1} \quad \text{(open-loop gain)}$$

But for a more precise calculation of the gain, let us first find the equivalent circuit for the source degeneration.



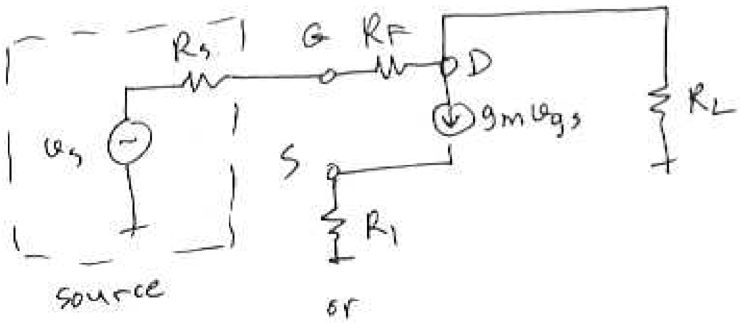
Can we define an equivalent transistor representing the R_1 and transistor combination.

$$v_{gs} = v_t - v_s = v_t - g_m v_{gs} R_1$$

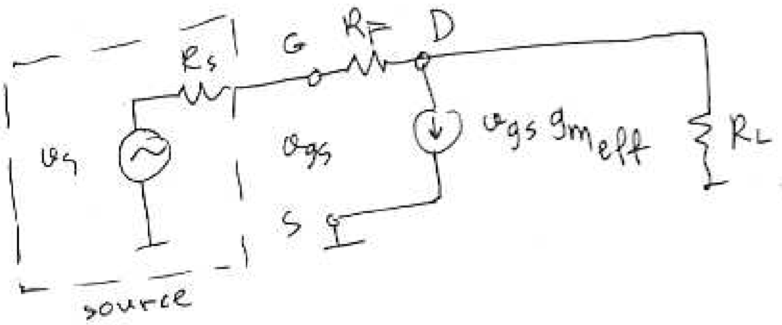
$$\Rightarrow v_{gs}(1+g_m R_1) = v_t \Rightarrow \quad i_o = g_m v_{gs} = v_t \frac{g_m}{1+g_m R_1}$$

Therefore we can replace the transistor with an source degeneration resistor R_1 by another transistor with transconductance equal to $\boxed{\frac{g_m}{g_m R_1 + 1} = g_{m_{eff}}}$

The small signal equivalent circuit of the shunt-series amplifier is:

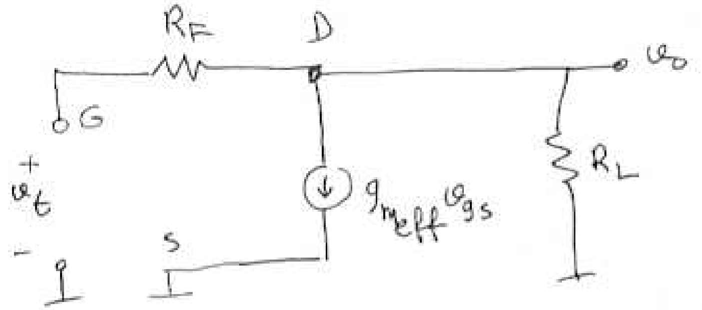


or



where $g_{m_{eff}} = \frac{g_m}{1+g_m R_1}$

If we define the gain of the amplifier as $\frac{v_D}{v_G}$, then we can draw the equivalent circuit as:



By superposition

$$v_o = v_t \frac{R_L}{R_F + R_L} - \underbrace{v_t g_{m_{eff}} \cdot \frac{R_F}{R_F + R_L}}_{\substack{\text{load current} \\ \text{contribution from} \\ \text{the current source}}} \cdot R_L$$

$$A_v = \frac{v_o}{v_t} = \frac{R_L}{R_F + R_L}\left[1 - \underbrace{\frac{g_m}{1 + g_m R_1}}_{g_{m_{eff}}} \cdot R_F\right]$$

If we continue rearranging A_v as below: to express A_v in terms of $-\frac{R_L}{R_1}$ times modifying factors

24.10.2003
4 (20.10.2005)

$$A_v = \frac{R_L}{R_F+R_L}\left[1-\frac{g_m}{1+g_mR_1}R_F\right]$$

$$= -\frac{R_L}{R_F+R_L}\left[\frac{g_mR_F-1-g_mR_1}{1+g_mR_1}\right]$$

$$= -\frac{R_L}{R_1}\cdot\left[\frac{g_mR_F-1-g_mR_1}{g_m+\frac{1}{R_1}}\right]\cdot\frac{1}{R_F+R_L}$$

$$= -\frac{R_L}{R_1}\left[\frac{R_F-\frac{1}{g_m}-R_1}{1+\frac{1}{g_mR_1}}\right]\frac{1}{R_F\left(1+\frac{R_L}{R_F}\right)}$$

$$= -\frac{R_L}{R_1}\cdot\frac{1}{1+\frac{1}{g_mR_1}}\cdot\frac{1}{1+\frac{R_L}{R_F}}\cdot\left[1-\frac{1}{g_mR_F}-\frac{R_1}{R_F}\right]$$

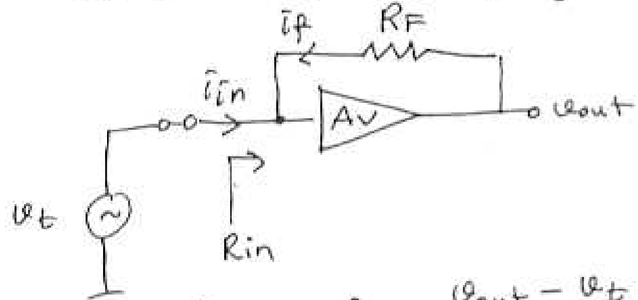
$$= -\frac{R_L}{R_1}\frac{1}{1+\frac{1}{g_mR_1}}\cdot\frac{1}{1+\frac{R_L}{R_F}}\cdot\left[1-\frac{1+R_1g_m}{g_mR_F}\right]$$

$$= -\frac{R_L}{R_1}\left[\frac{1}{1+\frac{1}{g_mR_1}}\right]\cdot\left[\frac{1}{1+\frac{R_L}{R_F}}\right]\cdot\left[1-\frac{1}{g_{meff}R_F}\right]$$

all of the expressions inside the pharantesis are less than one. If $\frac{1}{g_mR}$, $\frac{R_L}{R_F}$ and $\frac{1}{g_{meff}R_L}$ are much less than one, then the gain approaches $-\frac{R_L}{R_1}$

24-10.2003

In order to calculate the i/p impedance of the shunt-series amplifier, we can make use of the formula giving the input impedance of the h ∞ input impedance amplifier with the feedback resistance R_F and the gain A_v.



$$i_{in} = -i_f = -\frac{v_{out} - v_t}{R_F} = -\frac{v_t A_v - v_t}{R_F} = v_t\left(\frac{1-A_v}{R_F}\right)$$

$$\overrightarrow{R_{in}} = \frac{v_t}{i_{in}} = \frac{R_F}{1-A_v}$$

Substituting the expression for A_v into the equ. above:

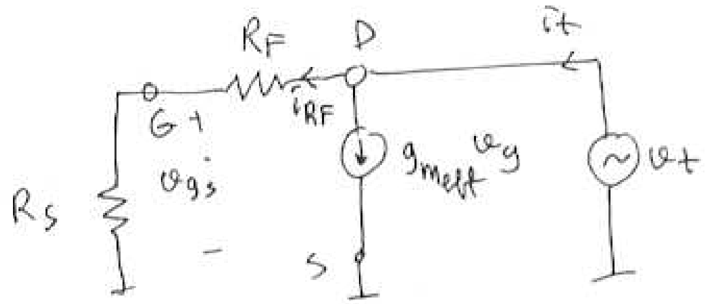
$$R_{in} = \frac{R_F}{1 - \frac{R_L}{R_F+R_L}\left[1 - R_F g_{m_{eff}}\right]} \quad \text{letting } R_E = \frac{1}{g_{m_{eff}}}$$

$$R_{in} = \frac{R_F}{1 + \frac{R_L}{R_F+R_L}\left[\frac{R_F}{R_E} - 1\right]} = \frac{R_F}{1 + \frac{R_L\left[R_F - R_E\right]}{R_E\left[R_F+R_L\right]}}$$

$$= \frac{R_F R_E\left[R_F+R_L\right]}{R_E\left[R_F+R_L\right] + R_L\left[R_F - R_E\right]} = \frac{R_F \cdot R_E\left[R_F+R_L\right]}{R_E R_F + \cancel{R_E R_L} + R_L R_F - \cancel{R_L R_E}}$$

$$R_{in} = \frac{\cancel{R_F} \cdot R_E\left[R_F+R_L\right]}{\cancel{R_F}\left[R_E+R_L\right]} = R_E\,\frac{\left[R_F+R_L\right]}{\left[R_E+R_L\right]}$$

In order to find the o/p impedance of the shunt-series amplifier, we connect a test source to the output



By adding i_{RF} and the current source

$$i_t = \frac{v_t}{R_F + R_S} + g_{meff}\, v_t \frac{R_S}{R_S + R_F} = v_t \cdot \frac{1}{R_S + R_F}\left[1 + R_S g_{meff}\right]$$

$$= v_t \frac{1 + g_{meff} R_S}{R_S + R_F} \Rightarrow$$

$$\frac{v_t}{i_t} = \frac{R_S + R_F}{1 + \frac{R_S}{R_E}} \qquad \text{by } R_E = \frac{1}{g_{meff}}$$

$$= R_E \frac{R_S + R_F}{R_E + R_S}$$

$$R_{in} = R_E \frac{R_F + R_L}{R_E + R_L} \quad \text{and} \quad R_{out} = R_E \frac{R_F + R_S}{R_E + R_S}$$

if R_S is chosen as equal to R_L, then R_{in} becomes equal to R_O and

$$R_{in} = R_{out} = R_E \frac{R_F + R}{R_E + R} \quad \text{where } R_S = R_L = R$$

For designing a shunt-series amplifier the following equations are useful:

If we would like to have $R = R_S = R_L$, then:

$$R = R_E \frac{R_F + R}{R_E + R} \Rightarrow R R_E + R^2 = R_E (R_F + R)$$

$$\Rightarrow R_E (R_F + \cancel{R} - \cancel{R}) = R^2 \Rightarrow \boxed{R_E = \frac{R^2}{R_F}}$$

$$\boxed{R_E = \frac{R^{\cancel{2}}}{\cancel{R}(1 - A_v)} = \frac{R}{1 - A_v}} \quad \text{and} \quad \boxed{R = \frac{R_F}{1 - A_v}}$$

and

$$R_E = \frac{g_m R_1 + 1}{g_m} \Rightarrow R_E g_m = g_m R_1 + 1$$

$$\Rightarrow \boxed{R_1 = \frac{g_m R_E - 1}{g_m} = R_E - \frac{1}{g_m}}$$

24-10-2003

7-A

Explanation of equal input & output impedances at a shunt-series amplifier.

$$R_{in} = R_E \frac{R_F + R_L}{R_E + R_L} = R_o = R_E \frac{R_F + R_S}{R_E + R_S} = R = R_L = R_S$$

is there a such solution?

$$R = R_E \frac{R_F + R}{R_E + R} = R_E \frac{R_F + R}{R_E + R}$$

Obviously the quotients are equal. The only requirement is to find pairs of R_E & R_F to satisfy the condition on the left.

$$\cancel{RR_E} + R^2 = R_E R_F + \cancel{R_E R} \Rightarrow \boxed{R_E R_F = R^2}$$

is the condition defining the pairs of R_E & R_F.

24-10-2003

(8)

Design example: (Shunt-series amp)

Design and amplifier with input & output impedances equal to 600Ω. The gain of the amplifier when driven by a 600Ω source and being loaded by 600Ω ohms must be 10 dB. The transconductance of the transistor to be used is 12 mS.

$$10\,db \rightarrow A_v = -10^{1/2} = -3.1622$$

$$R_1 = R_E - \frac{1}{g_m} = \frac{600}{1-A_v} - \frac{1}{g_m} = \frac{600}{4.1622} - \frac{1}{12\times10^{-3}}$$

$$= 144.1518 - 83.3\overline{3} = 60.818\,\Omega$$

$$R_1 = R_E - \frac{1}{g_m} = 60.818\,\Omega$$

Here R_1 must be a positive reasonabe resistor. Therefore from this equation, it can be seen if the values of R, A_v and g_m are compatible or not.

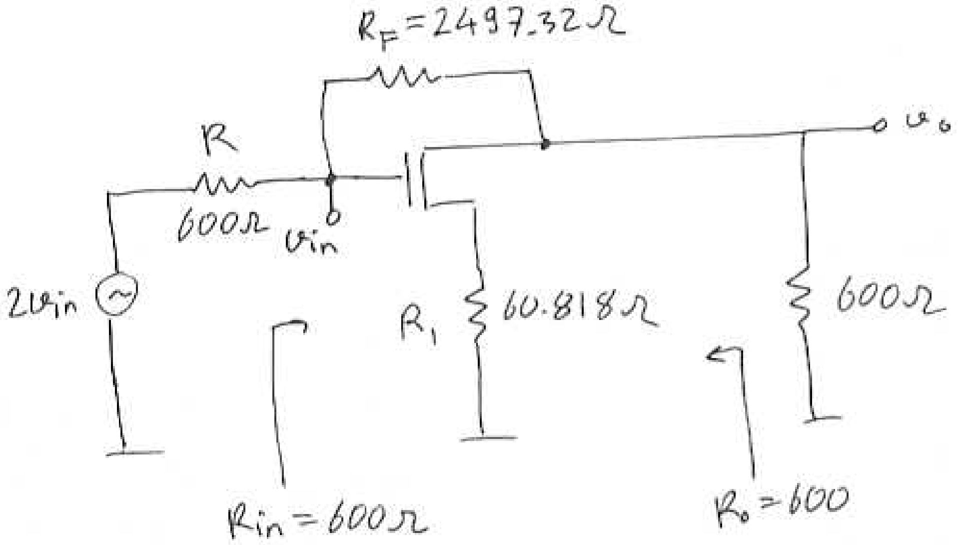
As the last step R_F can be found from

$$R_F = R(1-A_v) = 2497.32\,\Omega$$

as a check R_1 can be calculated from

$$R_E = \frac{R}{1-A_v} = 144.1545 \text{ (a slight calculation error)}$$

The amplifier becomes:



$$\frac{v_o}{v_{in}} = -3.1622 \Rightarrow 10\,dB$$

$$R_E = \frac{g_m R_1 + 1}{g_m} = 144.1518\,\Omega$$

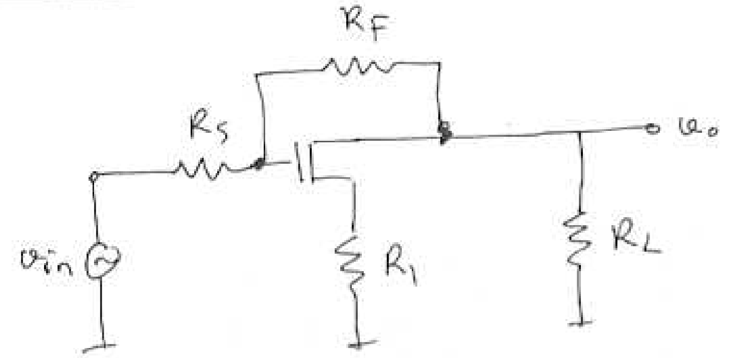
$$R_{in} = R_E \frac{R_F + R}{R_E + R} = 144.1518 \frac{2497.32 + 600}{144.1518 + 600} = 600\,\Omega$$

$$R_{out} = R_{in}$$

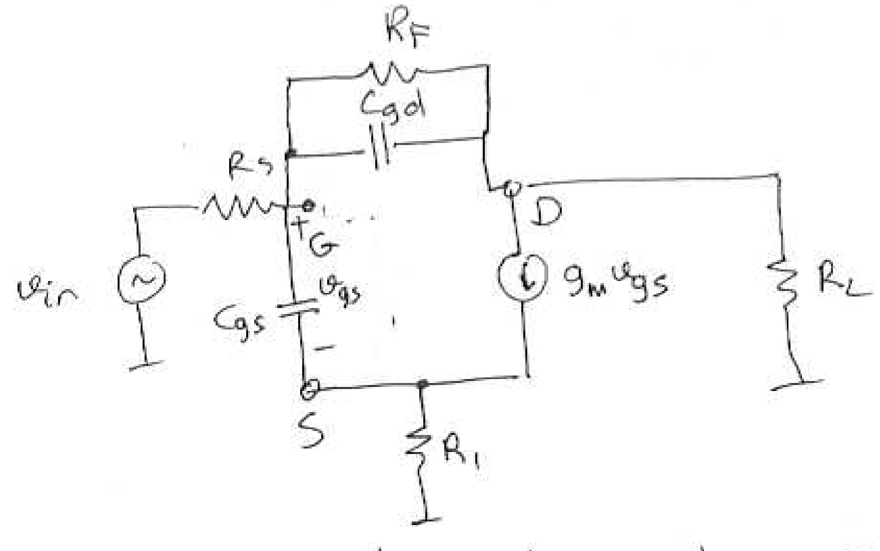
$$A_v = + \frac{R}{R_F + R}\left[1 - \frac{R_F}{R_E}\right] = -3.1622$$

$g_m R_1 = 0.72 \qquad A_v = 3.16$

Bandwidth, input-output impedances as a function of frequency



The high frequency equivalent circuit of the shunt-series amplifier, if C_{gs}, C_{gd} and g_m only taken into the model, becomes:



Since this is a low order system, ⇒ open circuit time constants is a good estimate of the BW.
Assume $R_S = R_L = R$ as it is the usual application.

31.10.2003

2

The resistance facing C_{gd} is

$$R_{gd} = R_F // R_{eq}. \quad \text{where}$$

$$R_{eq} = r_{left} + r_{right} + g_{m_{eff}} r_{left} r_{right} \quad \text{where } g_{m_{eff}} = \frac{g_m}{1+R_1 g_m}$$

$$R_{eq} = R + R + g_{m_{eff}} R^2 \Rightarrow$$

$$R_{gd} = R_F // R[2 + g_{m_{eff}} R]$$

but $R_F = R_{in}(1 - A_v) = R(1 - A_v)$

$\Rightarrow$

$$R_{gd} = R(1-A_v) // R[2 + R g_{m_{eff}}]$$

$$= R\left[(1-A_v) // \left[2 + R \frac{g_m}{1+g_m R_1}\right]\right]$$

let $g_m R_1 >> 1$

$$R_{gd} = R\left[(1-A_v) // \left(2 + \frac{R}{R_1}\right)\right] = R\left[(1-A_v) // (2-A_v)\right]$$

let $|A_v| >> 1$ and $|A_v| >> 2$

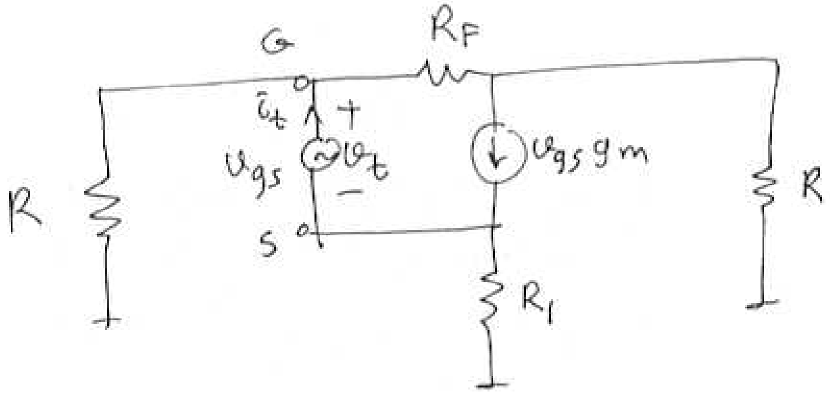
$$R_{gd} = -R[+A_v // A_v] = -R \frac{+A_v \times A_v}{A_v + A_v} = -R\frac{A_v^2}{2A_v}$$

$$R_{gd} \cong -R\frac{A_v}{2}$$

$$R_{gd} \approx R \frac{|A_v|}{2}$$

$$\Rightarrow \boxed{\tau_{gd} = C_{gd} \times R \frac{|A_v|}{2}}$$

In order to find R_{gs}, the circuit becomes:



we can connect a test source v_t and calculate i_t, the current passing through the source and then calculate R_{in} by

$$R_{in} = \frac{v_t}{i_t}$$

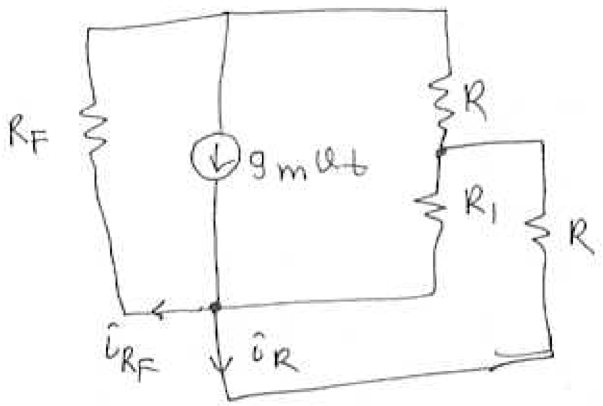
In order to find i_t we can use superposition to find the effects of v_t and $v_{gs} g_m = v_t g_m$

The contribution by v_t is given by

$$i_{g_t} = v_t \times \frac{1}{\left[(R_F + R) /\!/ R\right] + R_1} = v_t \frac{1}{\frac{(R_F + R) R}{R_F + R + R} + R_1}$$

$$= v_t \frac{R_F + 2R}{R_F R + R^2 + R_1 R_F + 2 R R_1}$$

The contribution by $g_m v_t$ can be calculated from the redrawn circuit:



$$i_{g_c} = i_{R_F} + i_R$$

$$i_{R_F} = g_m v_t \cdot \frac{(R_1 // R) + R}{(R_1 // R) + R + R_F}$$

$$i_R = g_m v_t \frac{R_F}{(R_1 // R) + R + R_F} \cdot \frac{R_1}{R_1 + R}$$

$$i_{g_c} = i_{R_F} + i_R = g_m v_t \frac{(R_1 // R) + R + \frac{R_F R_1}{R_1 + R}}{(R_1 // R) + R + R_F}$$

$$= \frac{\frac{R_1 R}{R_1 + R} + \frac{R_F R_1}{R_1 + R} + \frac{R(R_1 + R)}{R_1 + R}}{\frac{R_1 R}{R_1 + R} + \frac{R(R_1 + R)}{R_1 + R} + \frac{R_F (R_1 + R)}{R_1 + R}} g_m v_t$$

$$i_{g_c} = g_m v_t \frac{R R_1 + R_1 R_F + R R_1 + R^2}{R R_1 + R R_1 + R^2 + R_F R_1 + R_F R}$$

31-10-2003

5

$$i_t = i_{gt} + i_{ct} = v_t \frac{R_F + 2R}{RR_F + R^2 + R_1 R_F + 2RR_1}$$

$$+ v_t g_m \frac{RR_1 + R_1 R_F + RR_1 + R^2}{2RR_1 + R^2 + R_F R_1 + R_F R}$$

$$i_t = v_t \frac{R_F + 2R + g_m (2RR_1 + R_1 R_F + R^2)}{R(2R_1 + R + R_F) + R_F R_1}$$

$$R_{eq} = \frac{v_t}{i_t} = \frac{R(2R_1 + R + R_F) + R_F R_1}{(R_F + 2R)(g_m R_1 + 1) + g_m R^2}$$

If component values are given R_{eq} can easily be calculated. But to get a general feeling about the BW of the amplifier R_{eq} can be simplified at large A_v to:

31.10.2003

(5A)

$$R_{eq} = \frac{R\left(2R_1\frac{R_F}{R_F} + \frac{R_F}{1-A_v} + R_F\right) + R_F R_1}{\left(R_F + \frac{2R_F}{1-A_v}\right) g_m R_E + g_m R^2}$$

because $R = \frac{R_F}{1-A_v}$ and $g_m R_E = 1 + g_m R_1$

$$R_{eq} = \frac{\cancel{R_F}\left[R\left(\frac{2R_1}{\cancel{R_F}} + \cancel{\frac{1}{1-A_v}} + 1\right) + R_1\right]}{\cancel{R_F}\, g_m\left[\left(1 + \cancel{\frac{2}{1-A_v}}\right)R_E + \frac{R^2}{R_F}\right]}$$

but $R_F = \frac{R^2}{R_E}$

or $R_E = \frac{R^2}{R_F}$

for large A_v $\frac{1}{1-A_v} \ll 1$

$R_1 < R_E \ll R \ll R_F$

$$R_{eq} = \frac{R + \cancel{R_1}}{g_m(R_E + R_E)} \approx \frac{R}{2g_m R_E}$$

$$R_{eq} = \frac{\cancel{R}\,(1-A_v)}{2g_m \cancel{R}} \simeq \frac{|A_v|}{2g_m}$$

$$\tau_{gs} = C_{gs} \times R_{gs} = C_{gs} \cdot \frac{R}{2R_E} \frac{1}{g_m} \approx C_{gs} \frac{-A_v}{2g_m}$$

Therefore the BW becomes

$$BW \cong \frac{1}{\tau_{gs} + \tau_{gd}} = \frac{1}{C_{gd} R \frac{|A_v|}{2} + C_{gs} \frac{|A_v|}{2g_m}}$$

$$BW \approx \left[|A_v| \left(\frac{C_{gs}}{2g_m} + \frac{R C_{gd}}{2} \right) \right]^{-1}$$

$$BW = \frac{1}{|A_v|} \frac{1}{\frac{C_{gs}}{2g_m} + \frac{R C_{gd}}{2}} \Rightarrow$$

$$BW \times |A_v| = \frac{1}{\frac{C_{gs}}{2g_m} + \frac{C_{gd} R}{2}}$$

different from the book

$\Rightarrow$ The gain-bandwidth product of the amplifier is constant. And in practical cases C_{gd} dominates the bandwidth.

For a typical small signal transistor which we are using at the examples,

$$\left.\begin{aligned} \frac{C_{gs}}{2g_m} &= 9.16 \times 10^{-12} \\ \frac{C_{gd} R}{2} &= 13.5 \times 10^{-12} \end{aligned}\right\} \Rightarrow C_{gs} \text{ is not negligable and}$$

$$BW \times |A_v| = 4.41 \times 10^{10}$$

Assuming that the BW is mainly limited by one dominant pole at the input (remember the case at experiment II), i.e.

$$w_o = \frac{1}{\tau} = \frac{1}{R\ C_{in}} = \frac{1}{|A_v|\dfrac{C_{gs}}{2g_m} + |A_v|\dfrac{R C_{gd}}{2}}$$

$= R_s$

$$\cancel{R} C_{in} = \frac{\cancel{R}}{R_1}\frac{C_{gs}}{2g_m} + \frac{\cancel{R} C_{gd}}{2}|A_v|$$

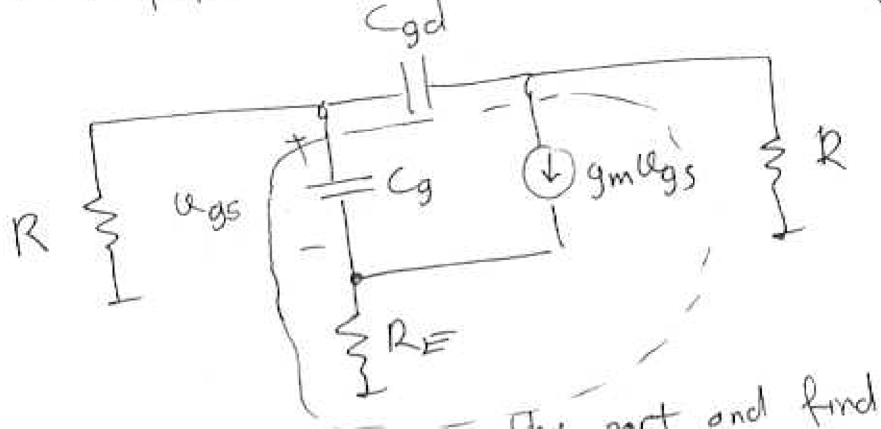
$$C_{in} \approx \frac{C_{gs}}{2R_1 g_m} + C_{gd}\frac{|A_v|}{2}$$

in practical cases $C_{gd}\frac{|A_v|}{2}$ dominates the input impedance

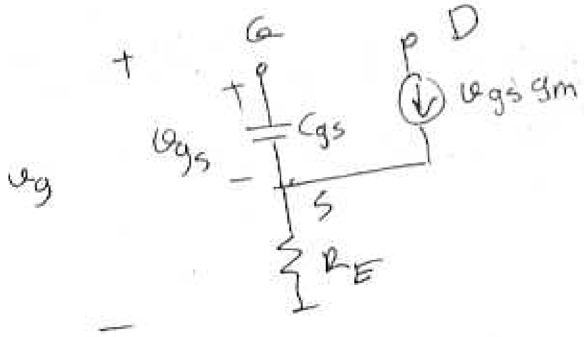
Formulation to find out the exact expression of R_o of the shunt-series amplifier

24-10-2003

1



isolate this part and find an equivalent



writing the node equation at the source

$$v_s G_E = (v_g - v_s) sC_{gs} + (v_g - v_s) g_m$$

$$v_s G_E = v_g (sC_{gs} + g_m) - v_s (sC_{gs} + g_m)$$

$$v_s [G_E + g_m + sC_{gs}] = v_g [sC_{gs} + g_m]$$

$$\Rightarrow \quad v_s = v_g \frac{[sC_{gs} + g_m]}{G_E + g_m + sC_{gs}}$$

$$i_g = sC_{gs}[v_g - v_s] \quad \Rightarrow$$

$$z_{in} = \frac{v_g}{i_g} = \frac{\cancel{v_g}}{sC_{gs}\left[\cancel{v_g} - \cancel{v_g}\frac{sC_{gs}\, g_m}{G_E + g_m + sC_{gs}}\right]}$$

$$i_g = sC_{gs}[v_g - v_s]$$

24.10.2003

2

$$Z_{in} = \frac{1}{sC_{gs}\left[1 - \frac{g_m + sC_{gs}}{G_E + sC_{gs} + g_m}\right]}$$

$$= \frac{1}{sC_{gs}\left[\frac{G_E + \cancel{sC_{gs}} + \cancel{g_m} - \cancel{g_m} - \cancel{sC_{gs}}}{G_E + sC_{gs} + g_m}\right]}$$

$$= \frac{G_E + g_m + sC_{gs}}{sC_{gs}G_E} = \frac{G_E + g_m}{sC_{gs}G_E} + \frac{1}{G_E}$$

$$Z_{in} = \frac{1 + \frac{g_m}{G_E}}{sC_{gs}} + R_E = \underbrace{\frac{1 + g_m R_E}{C_{gs}}}_{C_{eq}.} \cdot \frac{1}{s} + \underbrace{R_E}_{R_E}$$

$$Z_{in} = \frac{1}{sC_{eq}} + R_E \quad \text{whe} \quad C_{eq} = \frac{C_{gs}}{1 + g_m R_E}$$

$$i_d = v_{gs} g_m = g_m (v_g - v_s) = g_m v_g \left[1 - \frac{sC_{gs} + g_m}{G_E + g_m + sC_{gs}}\right]$$

$$i_d = v_g g_m \frac{G_E + \cancel{g_m} + \cancel{sC_{gs}} - \cancel{sC_{gs}} - \cancel{g_m}}{G_E + g_m + sC_{gs}}$$

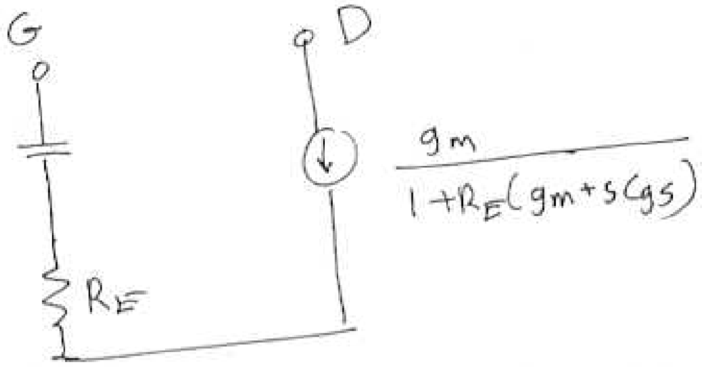
$$i_g = v_g \frac{g_m G_E}{G_E + g_m + sC_{gs}} = v_g g_m \frac{1}{1 + g_m R_E + sC_{gs} R_E}$$

$$i_g = v_g \frac{g_m}{1 + R_E(g_m + sC_{gs})}$$

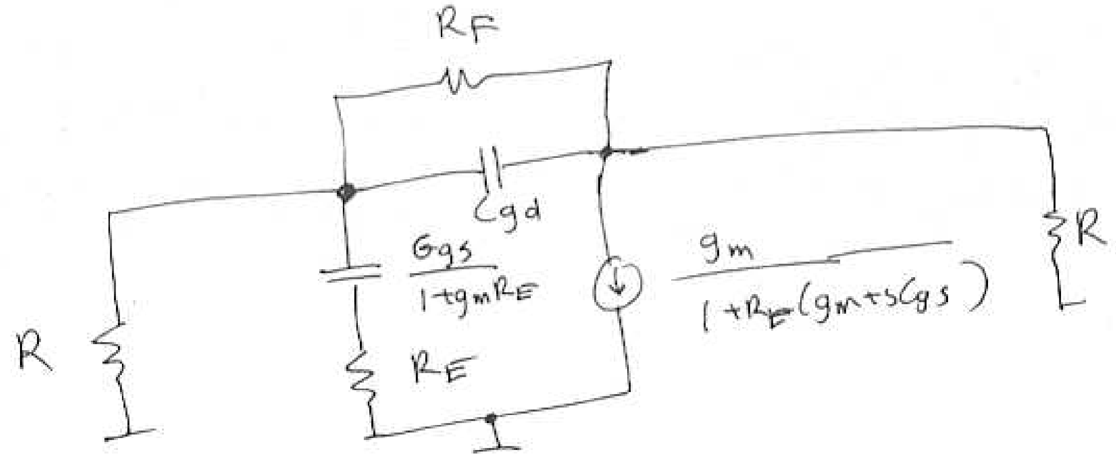
24-10-2003

3

$$C_{eq} = \frac{C_{gs}}{1 + g_m R_E}$$



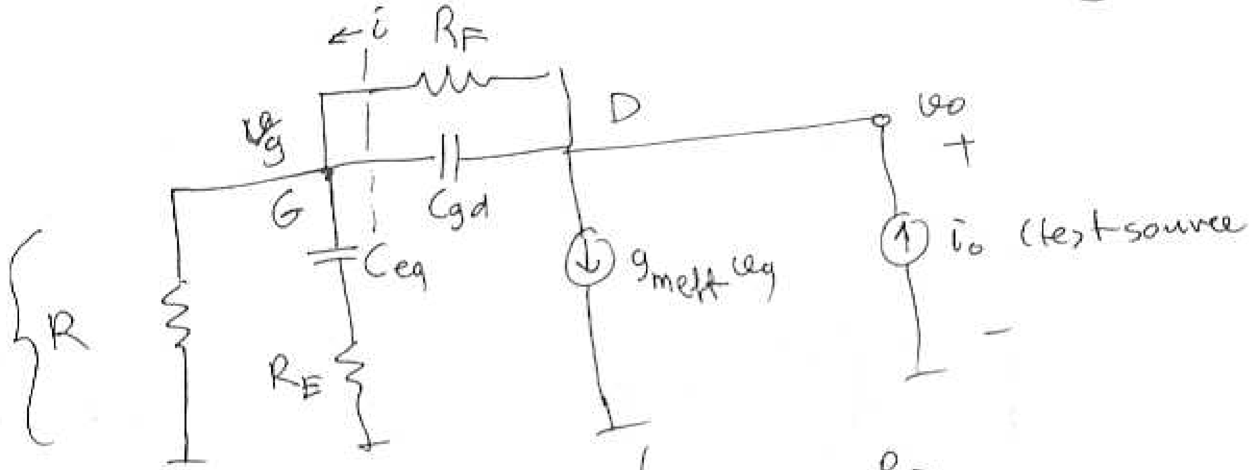
subsituting into the original diagram



24.10.2003

(4)

Z_b



$$Z_b = R_F // \frac{1}{sC_{gd}} = \frac{R_F \cdot \frac{1}{sC_{gd}}}{R_F + \frac{1}{sC_{gd}}} = \frac{R_F}{1 + R_F s C_{gd}}$$

$$Z_a = R // \left(R_E + \frac{1}{sC_{eq}}\right) = \frac{R\left(R_E + \frac{1}{sC_{eq}}\right)}{R + R_E + \frac{1}{sC_{eq}}} = R\frac{[sC_{eq}R_E + 1]}{(R+R_E)sC_{eq} + 1}$$

$$Z_a = R$$

$$i = i_o - v_g g_{meff}$$

$$i Z_a = v_g = Z_a(i_o - v_g g_{meff})$$

$$v_g = Z_a i_o - Z_a v_g g_{meff}$$

$$v_g(1 + Z_a g_{mef}) = Z_a i_o \Rightarrow \boxed{v_g = i_o \frac{Z_a}{1 + Z_a g_{meff}}}$$

24-10-2003

5

$$i\,[Z_a + Z_b] = v_o$$

$$v_o = [Z_a + Z_b]\,[i_o - v_g\, g_{meff}]$$

$$v_o = [Z_a + Z_b]\left[i_o - i_o g_{meff} \cdot \frac{Z_a}{1 + Z_a g_{meff}}\right]$$

$$R_o = \frac{v_o}{i_o} = [Z_a + Z_b]\left[1 - g_{meff}\frac{Z_a}{1 + Z_a g_{meff}}\right]$$

$$= [Z_a + Z_b]\left[\frac{1 + \cancel{Z_a g_{meff}} - \cancel{Z_a g_{meff}}}{1 + Z_a g_{meff}}\right]$$

$$= [Z_a + Z_b]\,\frac{1}{1 + Z_a g_{meff}}$$

$$R_o = \frac{Z_a + Z_b}{1 + Z_a g_{m\,eff}}$$

$$= \frac{Z_a + Z_b}{1 + Z_a \dfrac{g_m}{1 + R_E(g_m + sC_{gs})}}$$

$$Z_a = R \frac{\dfrac{sC_{gs}R_E}{1+g_mR_E}+1}{(R+R_E)\dfrac{sC_{gs}}{1+g_mR_E}+1}$$

$$= R \frac{\dfrac{R_EsC_{gs}+1+g_mR_E}{\cancel{1+g_mR_E}}}{\dfrac{(R+R_E)sC_{gs}+1+g_mR_E}{\cancel{1+g_mR_E}}}$$

$$= R \frac{R_EsC_{gs}+1+g_mR_E}{(R+R_E)sC_{gs}+1+g_mR_E} = RR_E \frac{sC_{gs}+G_E+g_m}{\frac{R+R_E}{R_E}sC_{gs}+G_E+g_m}$$

$$Z_a = R \frac{sC_{gs}+G_E+g_m}{\left(1+\frac{R}{R_E}\right)sC_{gs}+G_E+g_m}$$

$$R_o = (Z_a + Z_b) \frac{1}{\dfrac{1 + R_E(g_m + sC_{gs}) + Z_a g_m}{1 + R_E(g_m + sC_{gs})}}$$

$$R_o = \frac{(Z_a + Z_b)(1 + R_E(g_m + sC_{gs}))}{1 + R_E(g_m + sC_{gs}) + Z_a g_m}$$

$$R_o = \frac{\left[R \dfrac{[sC_{eq} R_E + 1]}{(R + R_E)sC_{eq} + 1} + \dfrac{R_F}{1 + R_F sC_{gd}} \right]}{1 + R_E(g_m + sC_{gs}) + g_m R \dfrac{[sC_{eq} R_E + 1}{(R + R_E)sC_{eq} + 1}}$$

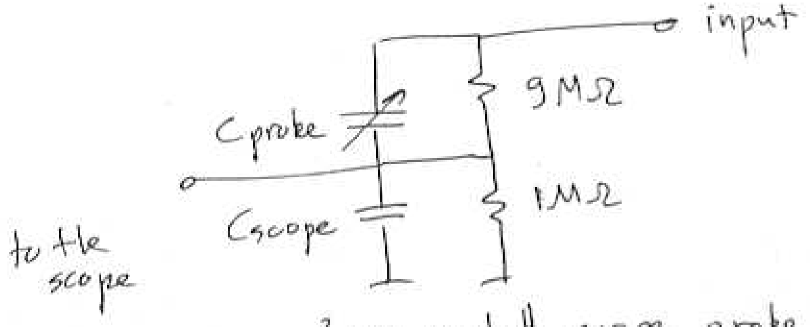
$$Z_o = \frac{R \left[\dfrac{s \dfrac{C_{gs} R_E}{1 + g_m R_E} + 1}{(R + R_E) s \dfrac{C_{gs}}{1 + g_m R_E} + 1} + \dfrac{R_F}{1 + R_F sC_{gd}} \right]}{1 + R_E(g_m + sC_{gs}) + g_m R \left[\dfrac{s \dfrac{C_{gs} R_E}{1 + g_m R_E}}{(R + R_E) s \dfrac{C_{gs}}{1 + g_m R_E} + 1} \right]}$$

$$R_o = \frac{R \dfrac{sC_{gs} + G_E + g_m}{\left(1 + \frac{R}{R_E}\right) sC_{gs} + G_E + g_m} + R_F \dfrac{1}{G_F + sC_{gd}}}{1 + R_E(g_m + sC_{gs}) + g_m R \dfrac{sC_{gs} + G_E + g_m}{\left(1 + \frac{R}{R_E}\right) sC_{gs} + G_E + g_m}}$$

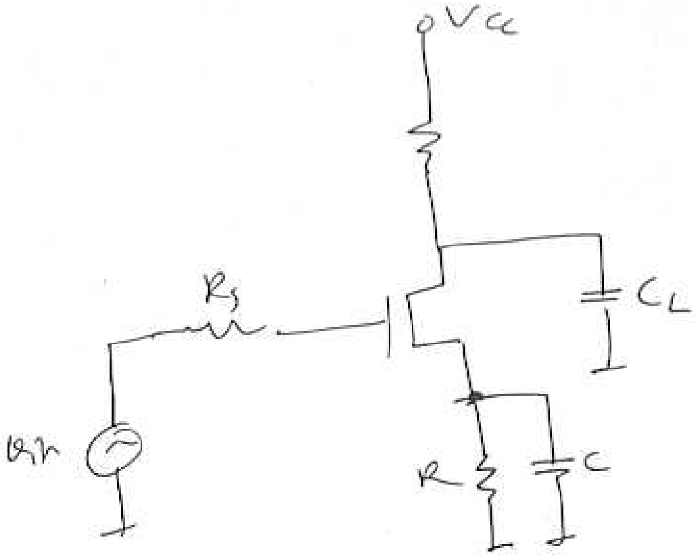
18.10.2005

2

Talk about scope probe



Zero peaked scope probe



Zero-peaked common source amplifier.