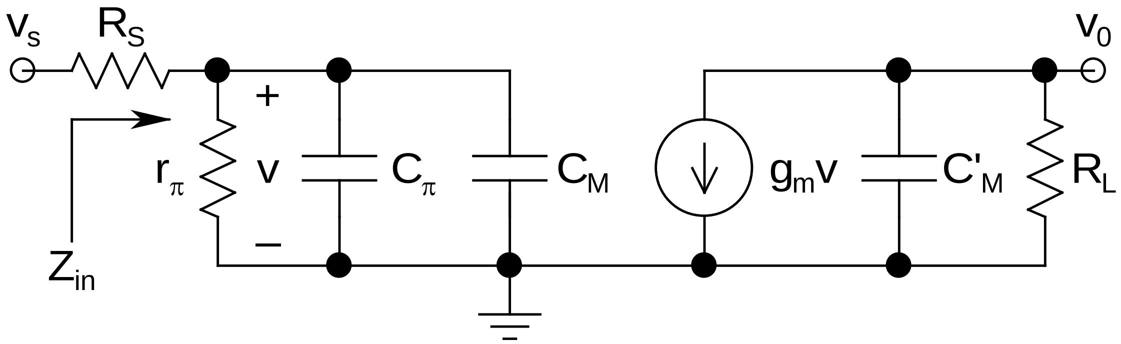
- C_μ can now be ***removed*** as the ***coupling element***, ***split into 2 parts*** C_M and C'_M, with C_M appearing in the ***input circuit*** and C'_M appearing in the ***output circuit***
- Now, ***include R_S*** - note that the circuit is ***completely decoupled*** now



Complete Circuit Including R_S

- $Z_{in} = r_\pi || [1/(sC_T) = r_\pi/(1 + sr_\pi C_T)$

$C_T = C_\pi + C_M$

$$\Rightarrow v = \frac{Z_{in}}{Z_{in} + R_S} v_s$$

$$= \frac{r_\pi}{(R_S + r_\pi)\left[1 + sr_\pi R_S C_T / (R_S + r_\pi)\right]} v_s$$

$$v_0 = -g_m\left(R_L \,||\, \frac{1}{sC'_M}\right)v = -\frac{g_m R_L}{1 + sR_L C'_M} v$$

- Thus:

$$A_v(s) = \frac{v_0}{v_s}$$

$$= -g_m R_L \frac{r_\pi}{R_S + r_\pi} \frac{1}{\left[1 + sR_S r_\pi C_T / (R_S + r_\pi)\right](1 + sR_L C'_M)}$$

- ***Comparing*** this expression with

$$A_v(s) = \frac{A_{v0}}{(1 - s/p_1)(1 - s/p_2)}$$

we note that the ***denominator*** is already in a ***factorized form***

- A_{v0} = ***midband gain*** = $-\, g_m R_L r_\pi /(R_S + r_\pi)$
- The ***transfer function*** shows that the system has ***two negative real poles*** and ***no zero***

  $\Rightarrow$ ***Information regarding the zero is suppressed by this technique***

- Also, the ***two poles*** obtained by ***this technique*** are ***not identical*** to those obtained from the ***exact analysis***

- Pole ***p_1*** (***p_2***) is referred to as the pole of the ***input*** (***output***) circuit
- Also, $|p_1| << |p_2|$

  $\Rightarrow$ ***p_1*** (***p_2***) is the ***DP*** (***NDP***) of the system
- ***Matching coefficients***:

$$p_1 = -\frac{R_S + r_\pi}{R_S r_\pi}\frac{1}{C_T} = -\frac{1}{(R_S \,||\, r_\pi)\left[C_\pi + (1 + g_m R_L)C_\mu\right]}$$

$$p_2 = -\frac{1}{R_L C'_M}$$

- Obviously, $|p_1| << |p_2|$

- Thus, ***using DPA***: $f_H = |p_1|/(2\pi)$
- Applying ***this technique*** to the ***previous example***, ***f_H = 3.9 MHz*** and ***NDP frequency = 156 MHz***
  - ***Error of only 2.6% in f_H***, but the ***ease of solution is much more***
- Thus, ***this technique*** is ***quite popular*** in getting a ***quick estimate*** of f_H, even though the ***solution*** may not be ***exact***
- ***Care***: ***The gain in the multiplicative factor is that between the input and output terminals of the capacitor***

- ***The Zero-Value Time Constant (ZVTC) Technique***:
  - ***Gives information only about the DP of the system***
  - ***Suppresses all information regarding other poles and zeros***
  - ***The ease of application of this technique is mind-boggling***

- ***Slightly less accurate***
- ***The maximum error can be as high as 22%*** (***under an extremely unusual situation, rarely encountered, if ever***)
- ***Underestimates f_H***
  - ***Far better than overestimation and eventually not achieving it***
- ***Applicable only for circuits that have a DP***
  - ***Fortunately, almost all analog circuits of interest do have a DP***

- ***The Algorithm***:
  - ***Null all independent sources to the circuit***
    - ***Short all independent voltage sources***
    - ***Open all independent current sources***
    - ***DO NOT TOUCH DEPENDENT SOURCES***
  - ***Name the capacitors C_i*** (***$i = 1$-n***)
  - ***Consider C_1 and assign zero values to all other capacitors*** (***thus the name***!)
    - Thus, ***except C_1***, ***all other capacitors will open out***
  - ***Determine the Thevenin Resistance*** $\left(R_1^0\right)$ ***across the two terminals of C_1***

- ***Find the time constant τ_1 associated with C_1*** $\left(\tau_1 = R_1^0 C_1\right)$
- ***Repeat for all other capacitors***, ***taking one at a time***, and ***find all the rest of the time constants*** $(\tau_2, \tau_3, \ldots, \tau_n)$
- Determine the ***net time constant*** τ_{net} by ***summing up*** all the ***individual time constants***

$$\Rightarrow \tau_{net} = \sum_{i=1}^{n} \tau_i$$

- Then the ***Upper Cutoff Frequency*** f_H is simply given by: $f_H = 1/(2\pi\tau_{net})$

- ***Note***: ***The capacitor contributing the largest time constant, in effect, determines f_H***
- ***The technique suppresses all information regarding other poles and zeros***
- Will present ***several examples*** to understand the ***application*** of this ***technique***
- Some ***topologies*** will be appearing ***frequently***, known as ***Standard Forms***, which can be treated as ***individual modules***, and the ***results can be used freely***

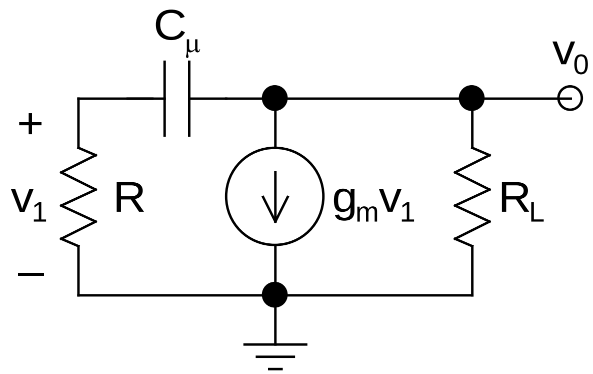
- ***CE***:
  - Refer to the ***high-frequency equivalent*** given in the ***exact analysis***
  - ***2 capacitors***: C_π and C_μ

    $\Rightarrow$ ***2 time constants***: τ_1 and τ_2
  - ***C_π***:
    - ***C_μ opens up***
    - ***By inspection***:

$$R_\pi^0 = R_S \,||\, r_\pi$$

$$\Rightarrow \tau_1 = R_\pi^0 C_\pi$$

- ***C_μ*** :
  - ***C_π opens up***
  - This is one ***Standard Form***, known as the ***Three-Legged Creature***
  - Show that:



$$R_\mu^0 = R + R_L + g_m R_L R \quad \left(R = R_S \parallel r_\pi\right)$$

$$\Rightarrow \tau_2 = R_\mu^0 C_\mu$$

- Thus, $\tau_{net} = \tau_1 + \tau_2$, and $f_H = 1/(2\pi\tau_{net})$
- Note the ***amazing simplicity*** of the analysis

- Putting ***values*** of our previous ***example***:

$$R_\pi^0 = 838.7\ \Omega,\ \ \tau_1 = 8.4\ \text{ns}$$

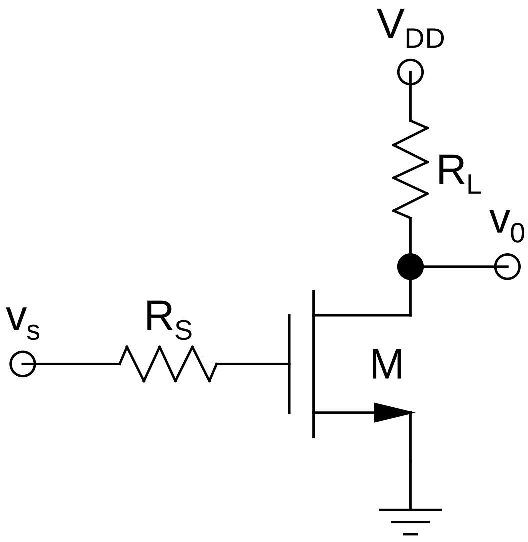
$$R_\mu^0 = 67.4\ \text{k}\Omega,\ \ \tau_2 = 33.7\ \text{ns}$$

$$\Rightarrow \tau_{net} = 42.1\ \text{ns}\ \ \text{and}\ \ f_H = 3.8\ \text{MHz}$$

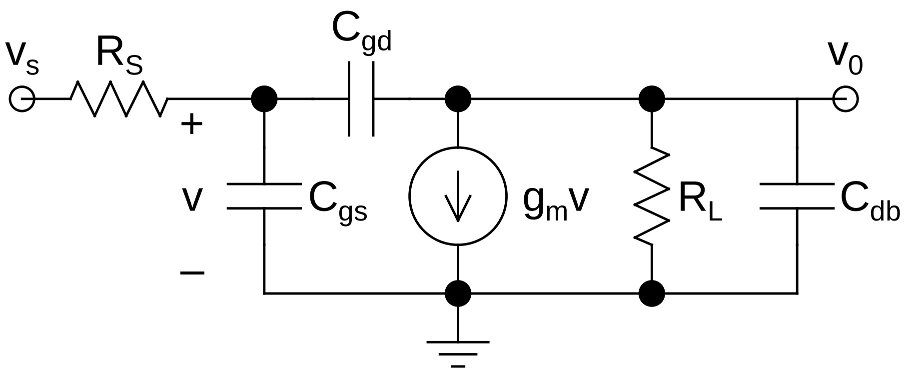
- This is ***identical*** to the ***result*** obtained from the ***exact analysis***, however, at a ***fraction*** of the ***effort***!
- Also, ***τ_2 is the dominant time constant***

  $\Rightarrow$ ***f_H is primarily dictated by C_μ***

- ***CS*** :



ac Schematic



High-Frequency Equivalent

➢ ***C_{sb} absent*** (***Why***?)

- ***3 capacitors***: C_{gs}, C_{gd}, and C_{db}

  $\Rightarrow$ ***3 time constants***: τ_1, τ_2, and τ_3
- ***C_{gs}*** :
  - ***C_{gd} and C_{db} open up***
  - ***By inspection***:

$$R_{gs}^{0} = R_S$$

$$\Rightarrow \tau_1 = R_{gs}^{0} C_{gs}$$

- ***C_{gd}*** :
  - ***C_{gs} and C_{db} open up***
  - ***By inspection***, it can be ***identified*** as a ***Three-Legged Creature***

- Thus:

$$R_{gd}^{0} = R_S + R_L + g_m R_S R_L$$

$$\Rightarrow \tau_2 = R_{gd}^{0} C_{gd}$$

- ***C_{db}*** :
  - ***C_{gs} and C_{gd} open up***
  - ***By inspection***:

$$R_{db}^{0} = R_L$$

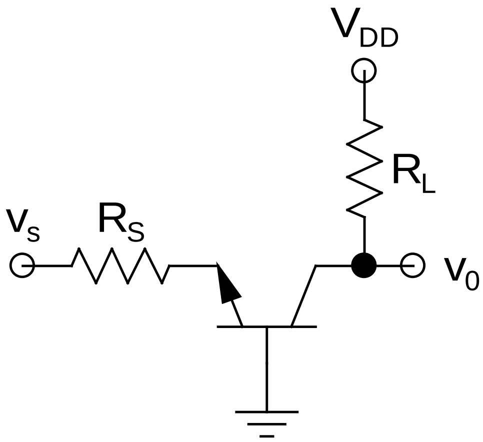
$$\Rightarrow \tau_3 = R_{db}^{0} C_{db}$$

- Thus:

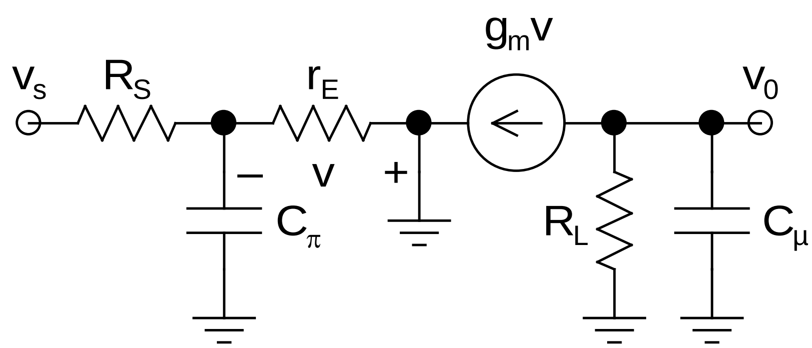
$\tau_{net} = \tau_1 + \tau_2 + \tau_3$, and $f_H = 1/(2\pi\tau_{net})$

- ***Mind-bogglingly simple*** - isn't it?

- ***CB*** :



ac Schematic



High-Frequency Equivalent

➢ ***Note that there is no input-output coupling capacitor present in this circuit***

$\Rightarrow$ ***Miller effect will be absent***, and the ***circuit will have very high f_H***