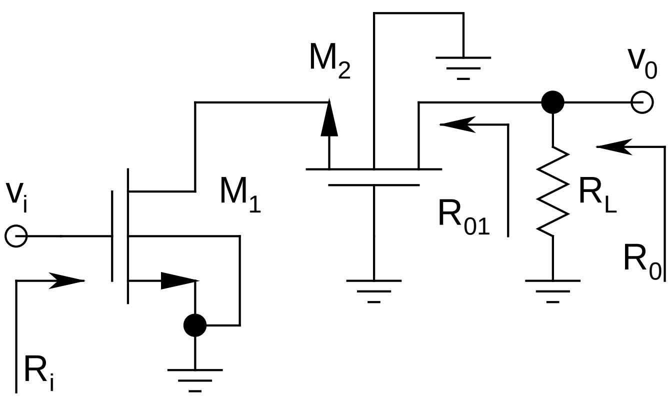
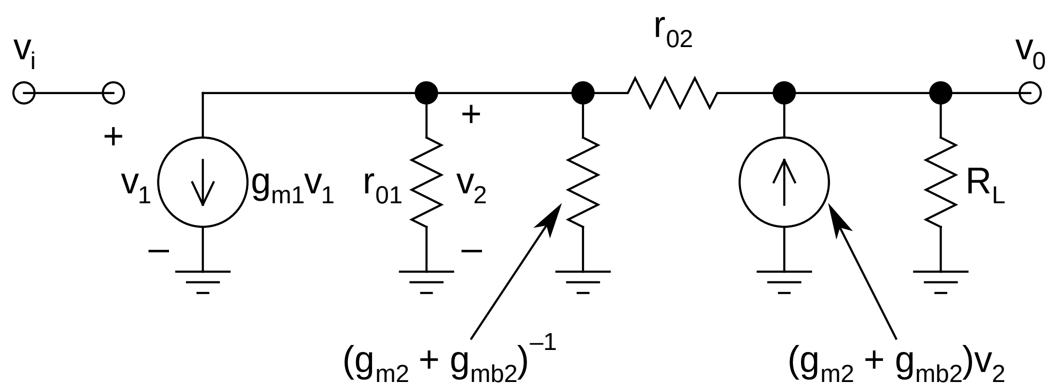
- ***NMOS Cascode***:



ac Schematic



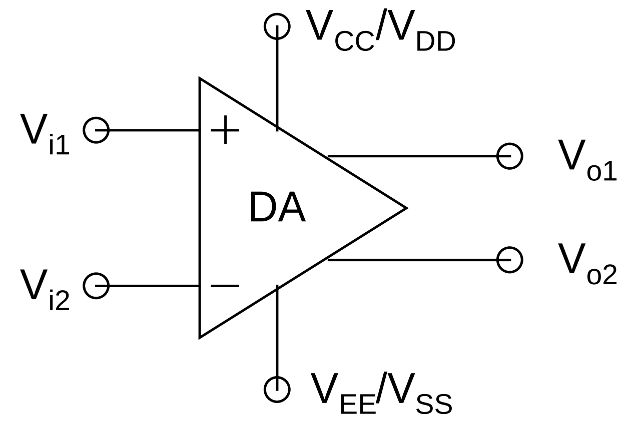
ac Midand Equivalent

- ***CS***, followed by ***CG***
- ***Generally, both M_1 and M_2 are biased with the same I_D***
- ***M_1 does not have body effect, but M_2 has***

- ***A_v gets affected a little if r_{01} and r_{02} were included***
- ***Since r_{01} comes in parallel with $(g_{m2} + g_{mb2})^{-1}$, its effect on A_v is less pronounced than that of r_{02}***
- ***By inspection***:

  $R_{01} \approx (g_{m2} + g_{mb2})r_{01}r_{02}$ (***Show***!)
- ***Note that if either of r_{01} or $r_{02} \to \infty$, $R_{01} \to \infty$*** (***Why***?)

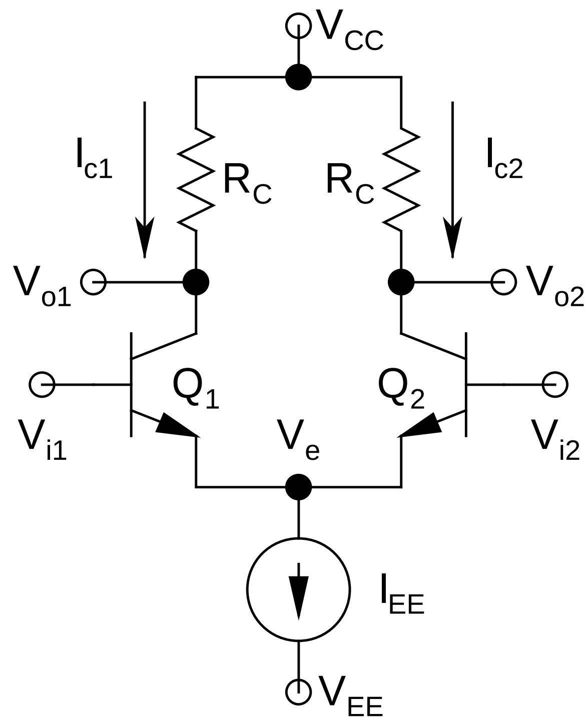
- ***Differential Amplifier (DA)/Differential Pair (DP)***:
  - ***Most versatile analog building block***
  - ***Immensely useful and widely used*** (particularly for ***sensing***/***telemetry***/ ***instrumentation*** applications)
  - ***Two inputs*** (V_{i1}, V_{i2})/***Two outputs*** (V_{o1}, V_{o2})
  - ***Dual Supply*** (V_{CC}/V_{DD}, V_{EE}/V_{SS})



Symbol for DA

- ***Unique Property***:
  - ***Amplifies the difference between V_{i1} and V_{i2}, while rejecting/suppressing signals common to both V_{i1} and V_{i2}***
  - ***Very efficient noise suppressor***
- ***The stage can be direct coupled to the next stage without the need for any coupling capacitor***
- In ***BJT technology***, known as ***Emitter-Coupled Pair*** (***ECP***)
- In ***MOS technology***, known as ***Source-Coupled Pair*** (***SCP***)

- ***npn DA (ECP)***:
  - Q_1-Q_2 constitute a a ***matched pair***, and have their ***emitters connected together***, hence, the name
  - I_{EE}: ***DC bias current source***
  - ***All voltages and currents*** (***apart from those used for biasing***) are ***instantaneous*** (***DC + ac***)



npn DA Topology

- $V_{be1} = V_{i1} - V_e$, and $V_{be2} = V_{i2} - V_e$
- ***KVL around Q_1-Q_2 BE loop***:

  $V_{i1} - V_{be1} + V_{be2} - V_{i2} = 0$

  $\Rightarrow V_{be1} - V_{be2} = V_{i1} - V_{i2} = V_{id}$

  V_{id}: ***Differential-Mode Input Voltage***
- ***Neglecting Early effect***:

  $V_{id} = V_T \ln(I_{c1}/I_{c2})$

  $\Rightarrow I_{c1}/I_{c2} = \exp(V_{id}/V_T)$ (1)
- ***Neglecting base currents***:

  $I_{c1} + I_{c2} = I_{EE}$ (***always***!) (2)

  This is because I_{EE} is an ideal current source

- ***Solving Eqs.(1) and (2)***:

  $I_{c1} = I_{EE}/[1 + \exp(-V_{id}/V_T)]$

  $I_{c2} = I_{EE}/[1 + \exp(V_{id}/V_T)]$

- ***Extremely interesting results***:
  - ***For $V_{id} = 0$, $I_{c1} = I_{c2} = I_{EE}/2$***

    I_{EE} shared equally between Q_1 and Q_2
  - ***For positive V_{id}, $I_{c1}\uparrow$ and $I_{c2}\downarrow$***

    For negative V_{id}, $I_{c1}\downarrow$ and $I_{c2}\uparrow$

    But for both cases, their sum is constant and equal to I_{EE}
  - ***For $V_{id} > 4V_T$, $I_{c1} \rightarrow I_{EE}$***

    For negative V_{id}, with $|V_{id}| > 4V_T$, $I_{c2} \rightarrow I_{EE}$