



NPTEL ONLINE CERTIFICATION COURSES

Course Name: *Analog Electronic Circuits*

Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

Topic:

Analysis of simple non-linear circuit containing a BJT

Flow of Discussion (Bottom-up) – *Building blocks*

- **System/ Sub-systems** (*for specific application*)
 - **Modules** (*performing specific tasks*)
 - **Building blocks** (*having specific characteristics*)
 - **Components** (*devices/circuit elements*)
- **Week 2:**
 - **Analysis of simple non-linear circuits (each containing one transistor)**
 - **Input-output transfer characteristic of a non-linear circuit.**
 - **Introducing the notion of signal amplification.**
 - **Linearization of input-output transfer characteristic of a non-linear circuit (w.r.t. an operation point) and, introducing the notion of small signal equivalent circuit.**
 - **Small signal models of transistors.**



CONCEPTS COVERED

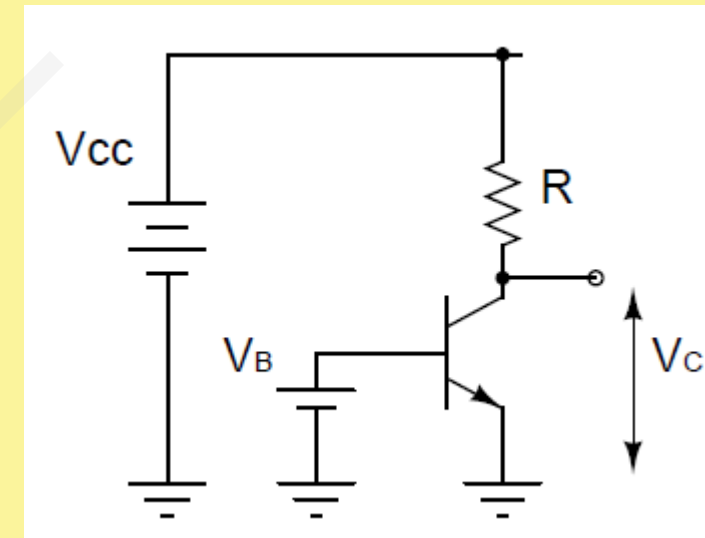
Concepts Covered:

- ☐ Analysis of non-linear circuit containing one BJT
- ☐ Common Emitter configuration
- ☐ Input-Output Characteristic of CE configuration
- ☐ Notion of signal amplification



Analysis of a circuit containing one BJT

- **Example circuit_1 (no resistor at base bias)**
- **Find operation condition of the transistor**
 - I_B , I_C and V_{CE}



- **Information known, in active region:**

$$I_C \approx I_s^{(C)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)} \times \left(1 + \frac{V_{CE}}{V_A}\right) \quad I_B \approx I_s^{(B)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)}$$

Analysis of a circuit containing BJT (Contd.)

• Example circuit_1 (contd..)

Steps to follow:

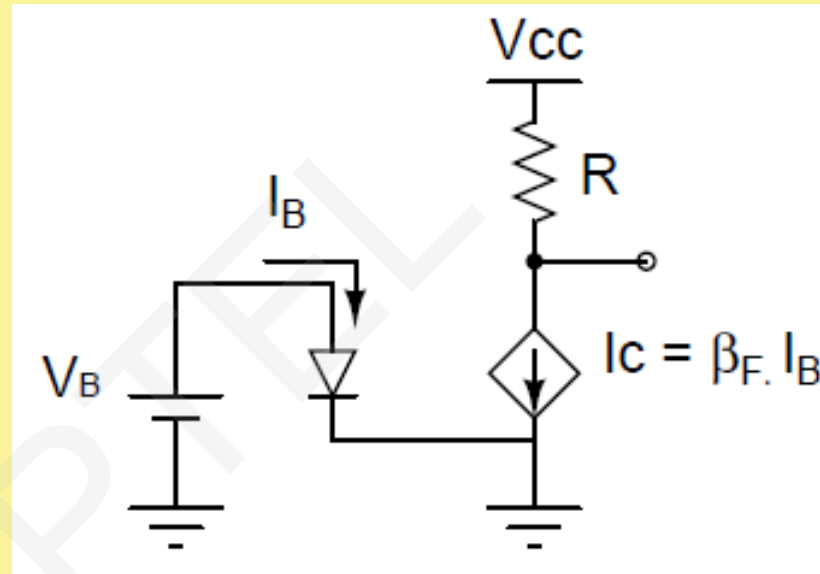
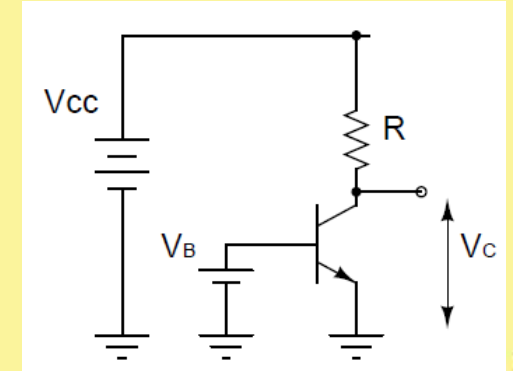
Find, I_B

$$I_B \approx I_s^{(B)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)}$$

Find, I_C

$$I_C \approx I_s^{(C)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)}$$

Find, V_{CE}

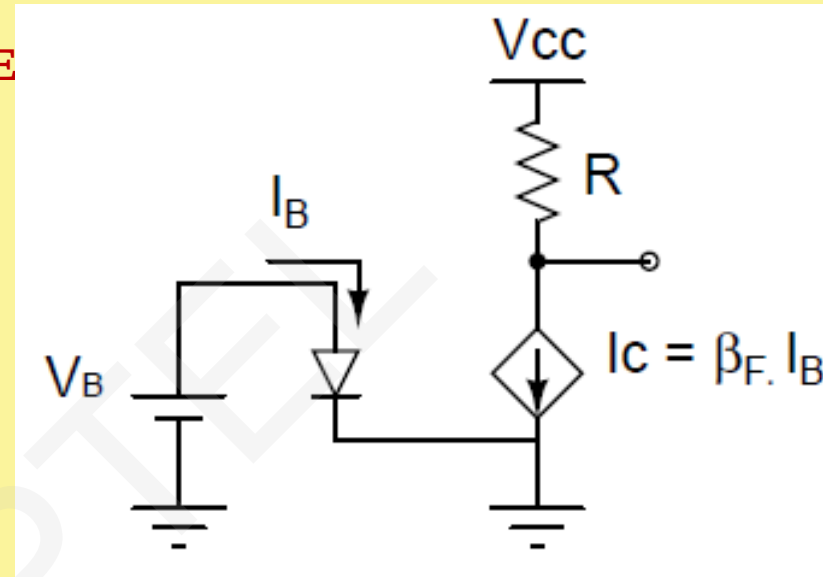
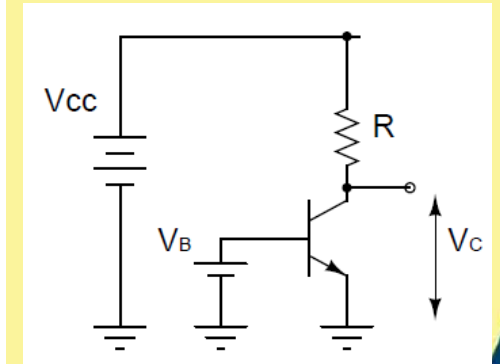


Analysis of a circuit containing BJT (Contd..)

- **Generalized method to find V_{CE}**

Steps to follow to :

1. Combining Pull-dn and pull-up chars
2. Rearrangement of pull-up char
3. Superposition of Pull-dn and rearranged pull-up chars .

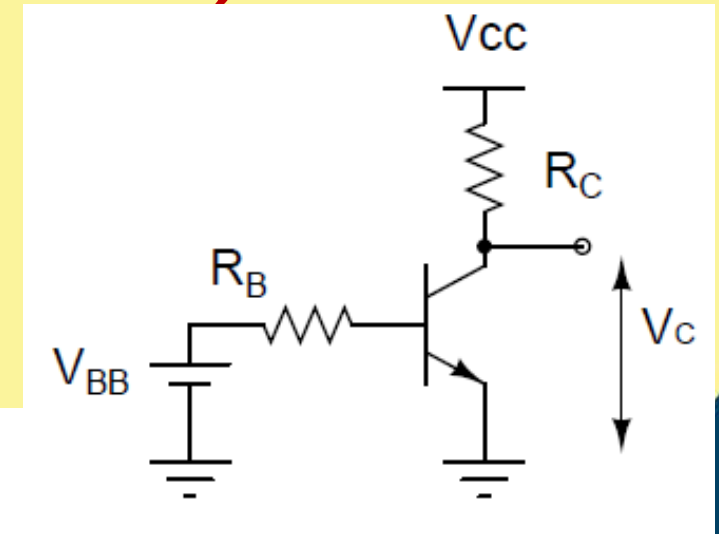
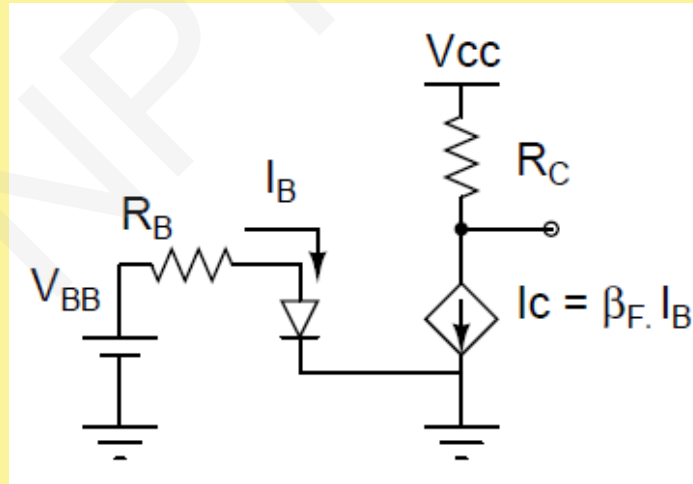


$$I_C \approx I_s^{(C)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)} \times \left(1 + \frac{V_{CE}}{V_A}\right)$$

$$I_B \approx I_s^{(B)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)}$$

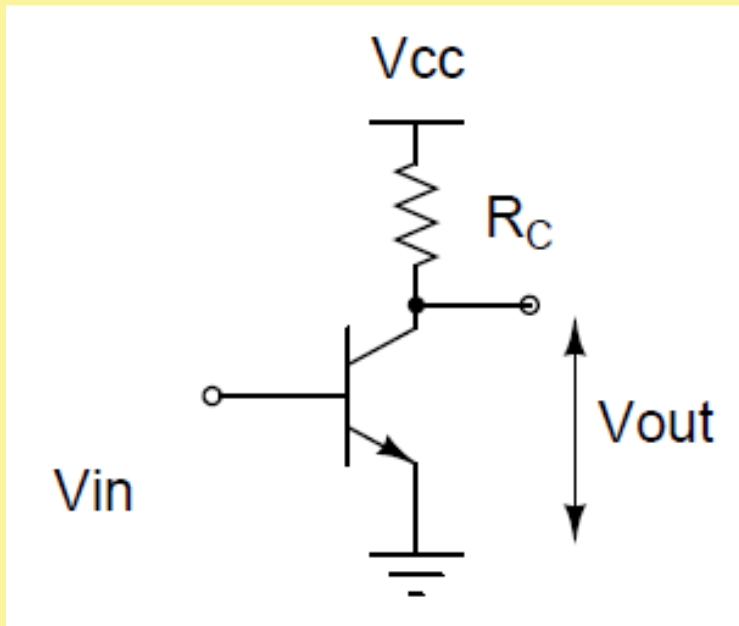
Analysis of a circuit containing BJT (Contd...)

- **Example circuit_2 (having resistor at base bias)**
- **Find operation condition of the transistor**
 - I_B , I_C and V_{CE}
- Needs additional sub-steps to find I_B



Analysis of a circuit containing BJT (*Contd....*)

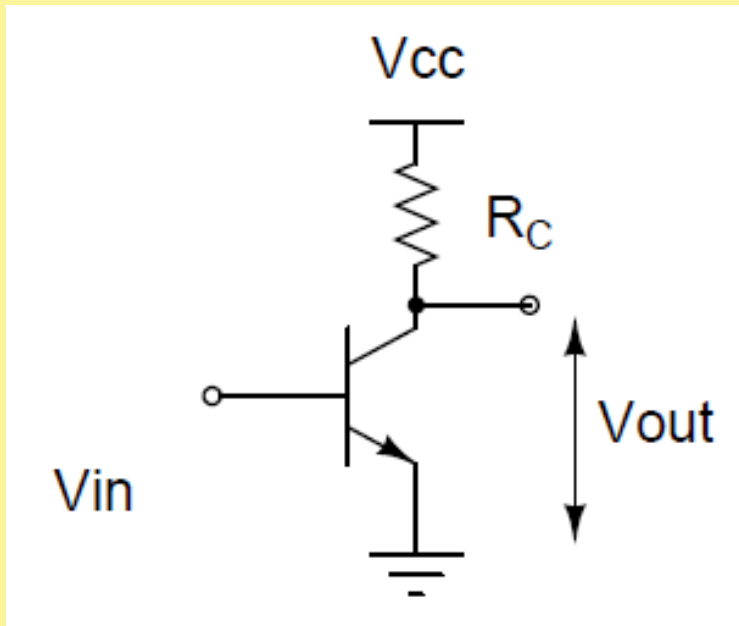
- **Common Emitter circuit**
with varying input



Analysis of a circuit containing BJT (Contd....)

- **Common Emitter circuit**

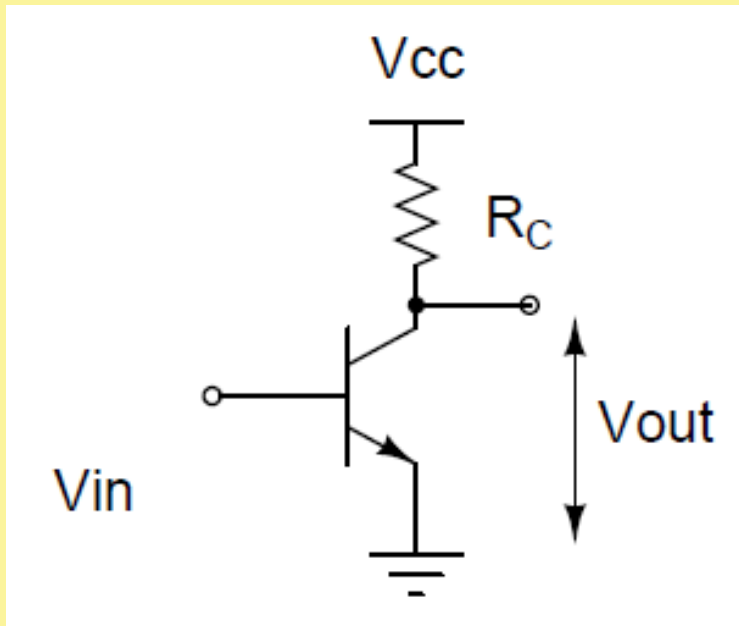
Input-Output Transfer characteristic



Analysis of a circuit containing BJT (Contd....)

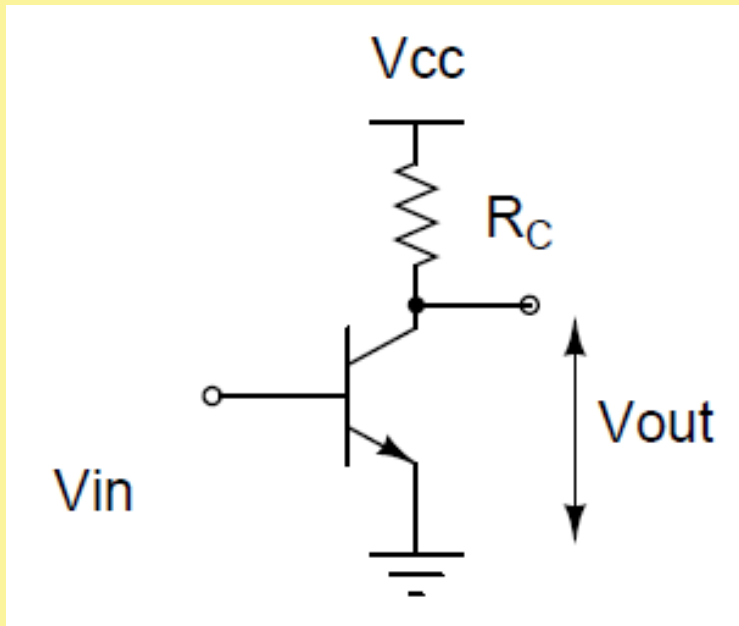
- **Common Emitter circuit**

Notion of signal amplification



Analysis of a circuit containing BJT (Contd....)

- **Common Emitter circuit**
Numerical example



Conclusion

Conclusion:

- ❑ Analyzed non-linear circuit containing BJT
- ❑ Two Example circuits
- ❑ Common Emitter configuration
- ❑ Input-Output Characteristic of CE configuration
- ❑ Notion of signal amplification





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*Thank
you*





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Course Name: *Analog Electronic Circuits*

Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

Topic:

Analysis of simple non-linear circuit containing a MOSFET

CONCEPTS COVERED

Concepts Covered:

- ☐ Analysis of non-linear circuit containing MOSFET
- ☐ Example circuits – how to find circuit solution ?
- ☐ Common Source configuration with varying inputs
- ☐ Input-Output Characteristic of CS configuration
- ☐ Notion of signal amplification
- ☐ Numerical examples



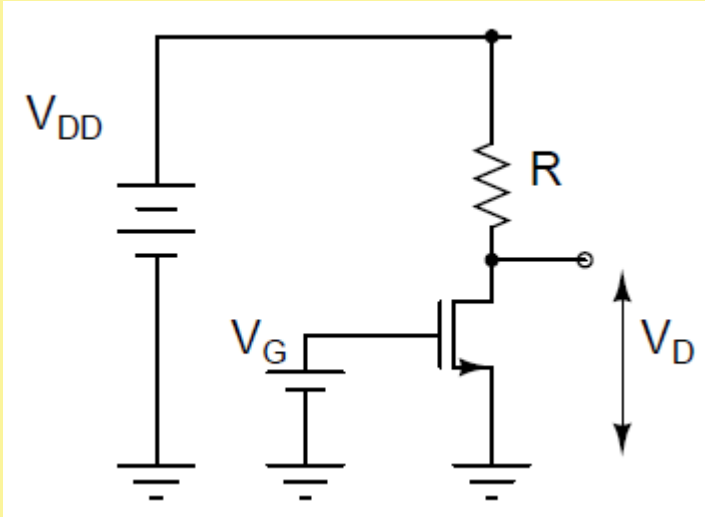
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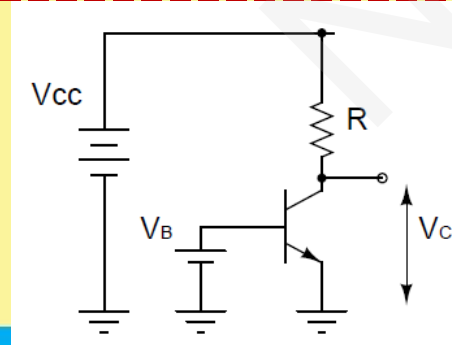
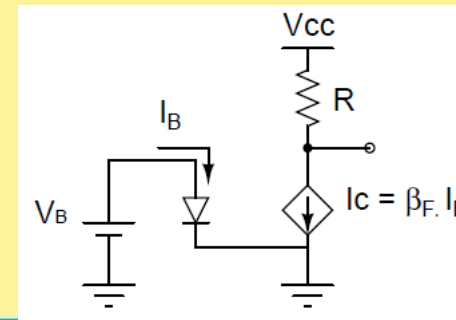
Analysis of a circuit containing MOSFET

• Example circuit_1



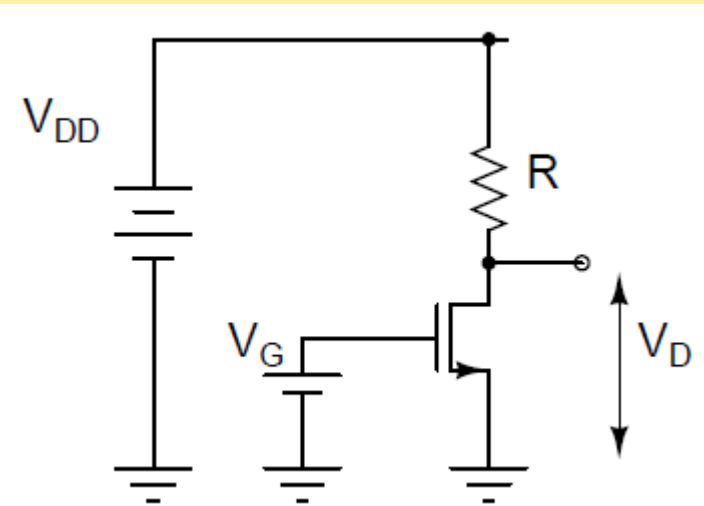
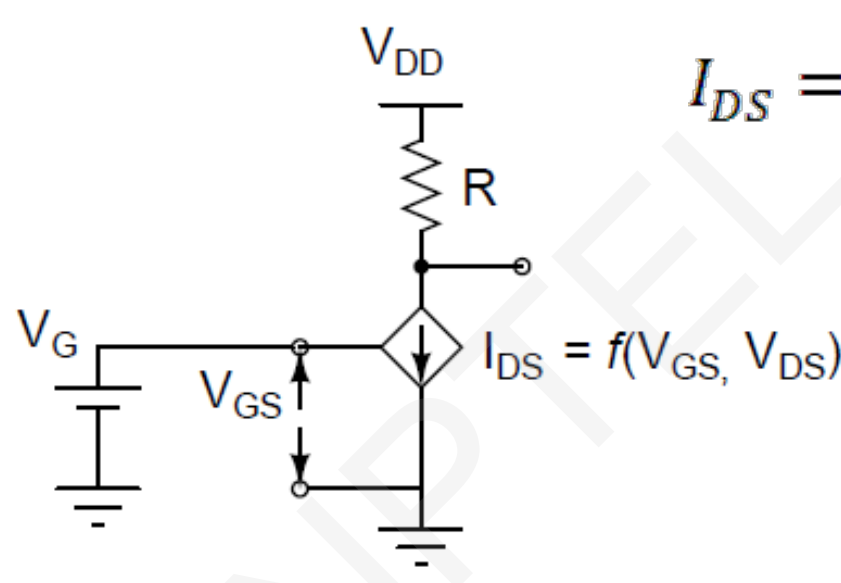
$$I_{DS} = \frac{\mu_n \epsilon_{ox}}{2t_{ox}} \frac{W}{L} (V_{GS} - V_{th})^2 (1 + \lambda_n V_{DS}) \quad V_{DS} \geq (V_{GS} - V_{th})$$

CE as reference:



Analysis of a circuit containing MOSFET (Contd.)

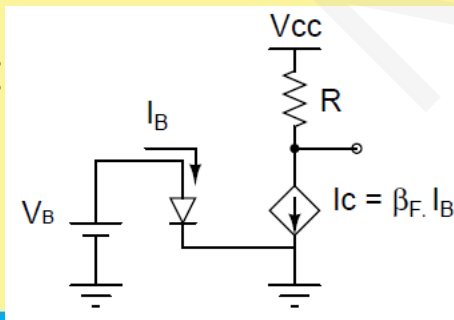
• Example circuit_1



$$I_{DS} = \frac{K W}{2 L} (V_{GS} - V_{th})^2 (1 + \lambda_n V_{DS})$$

$$V_{DS} \geq (V_{GS} - V_{th})$$

CE as reference:



Analysis of a circuit containing MOSFET (Contd..)

• Example circuit_1 (contd..)

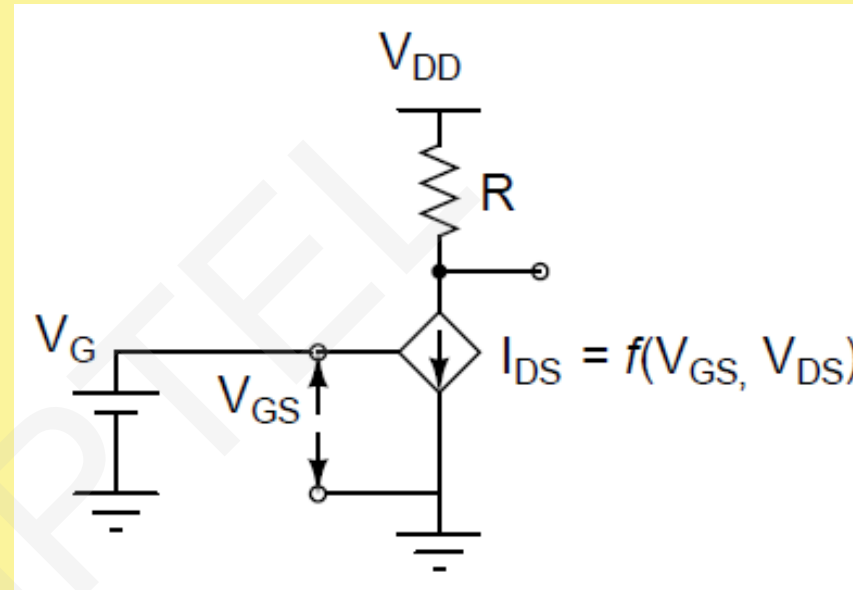
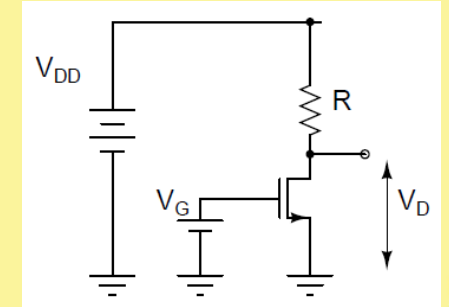
Steps to follow:

1. Find, I_{DS} :

$$I_{DS} = \frac{KW}{2L} (V_{GS} - V_{th})^2 (1 + \lambda_n V_{DS})$$

2. $V_R = R \cdot I_{DS}$

3. $V_{DS} = V_{DD} - V_R$

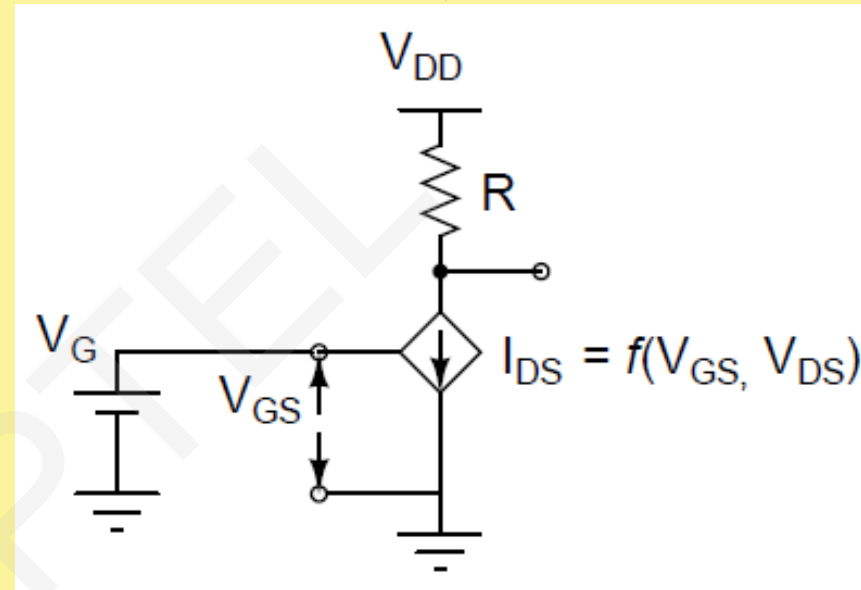
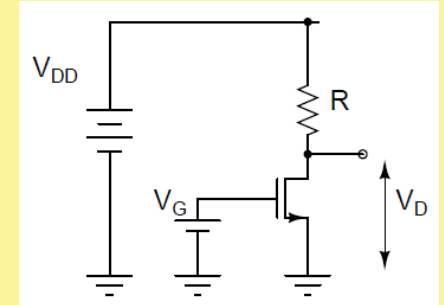


Analysis of a circuit containing MOSFET (Contd...)

- **Generalized method (graphical illustration)**

Steps to follow:

1. Combining Pull-dn and pull-up chars
2. Rearrangement of pull-up char
3. Superposition of Pull-dn and rearranged pull-up chars .

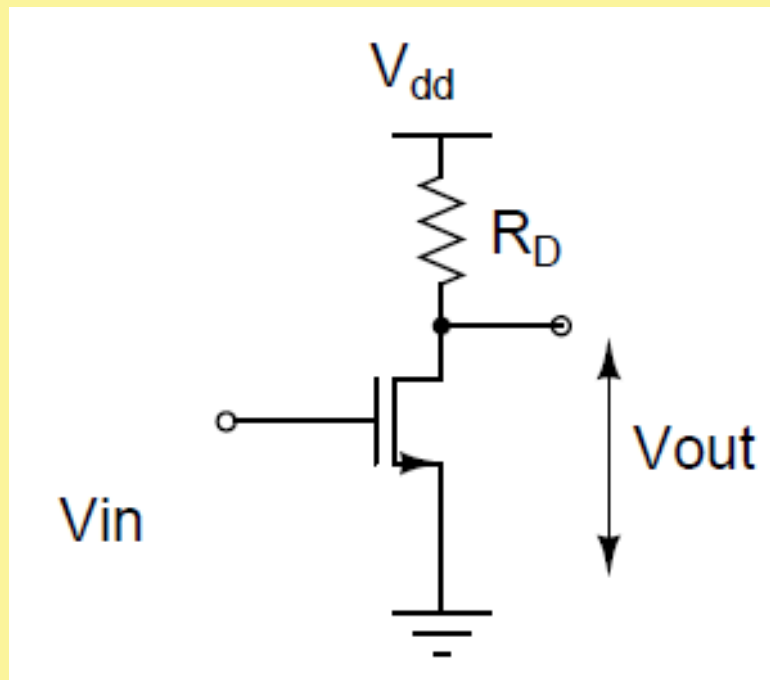


$$I_{DS} = \frac{K W}{2 L} (V_{GS} - V_{th})^2 (1 + \lambda_n V_{DS})$$

Analysis of a circuit containing MOSFET (Contd....)

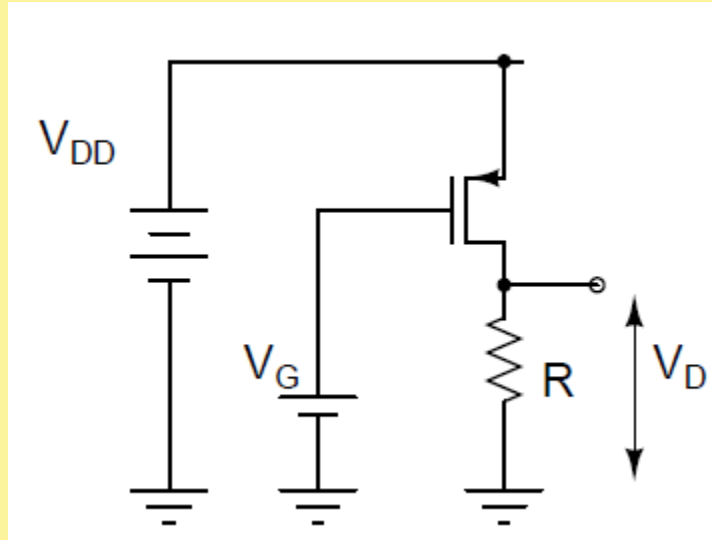
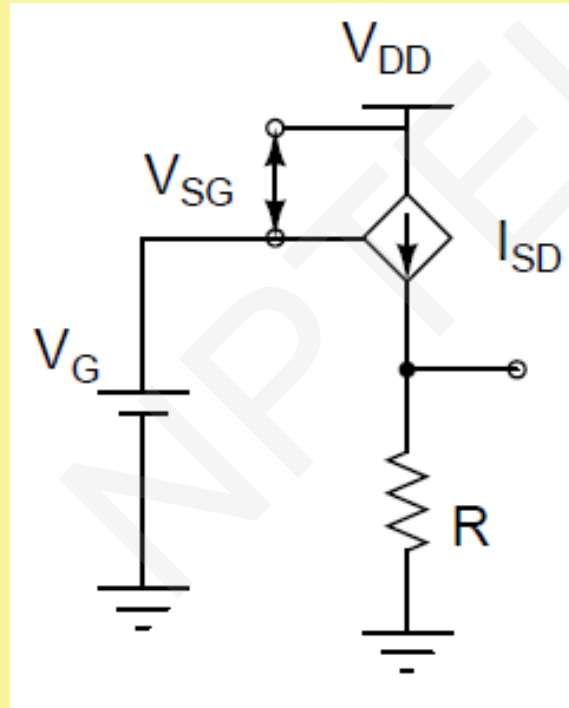
- **Common Source (CS) circuit**

Any change with resistance at the gate bias ?



Analysis of a circuit containing MOSFET (Contd.)

• Example circuit_2



$$I_{SD} = \frac{KW}{2L} (V_{SG} - |V_{th}|)^2 (1 + \lambda_p V_{SD})$$

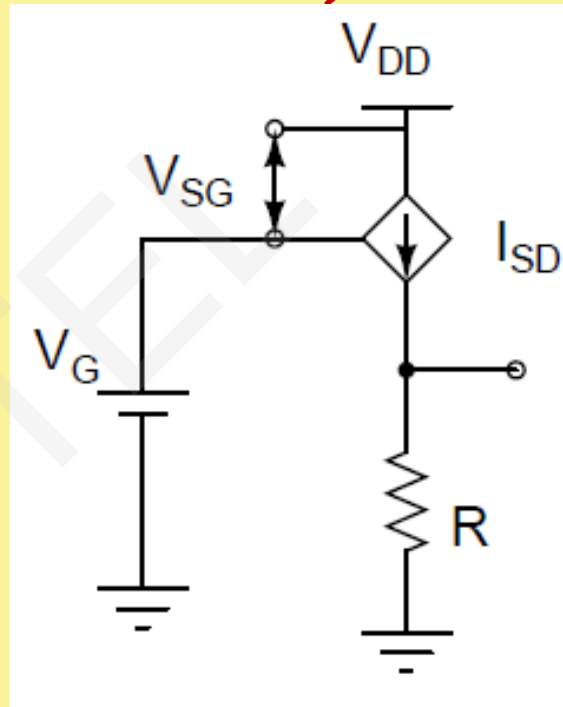
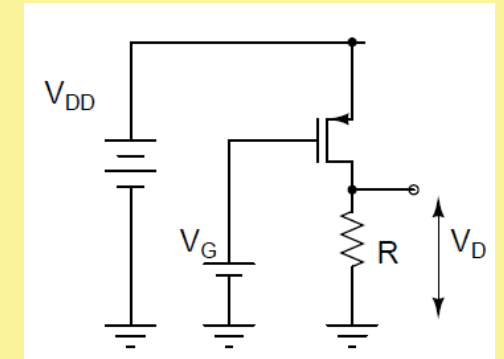
$$V_{SD} \geq (V_{SG} - |V_{th}|)$$

Analysis of a circuit containing MOSFET (Contd...)

- **Generalized method (graphical illustration)**

Steps to follow:

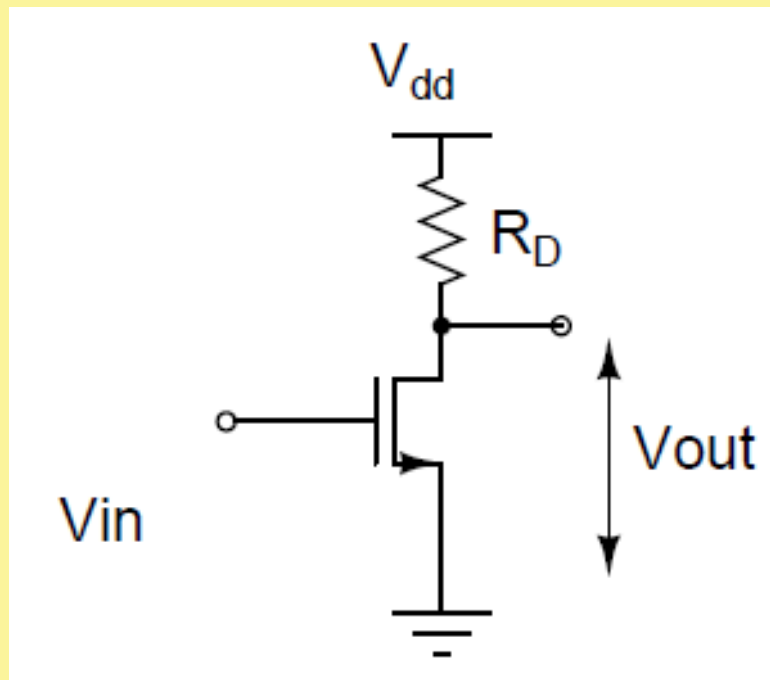
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$$I_{SD} = \frac{KW}{2L} (V_{SG} - |V_{th}|)^2 (1 + \lambda_p V_{SD})$$

Analysis of a circuit containing MOSFET (*Contd....*)

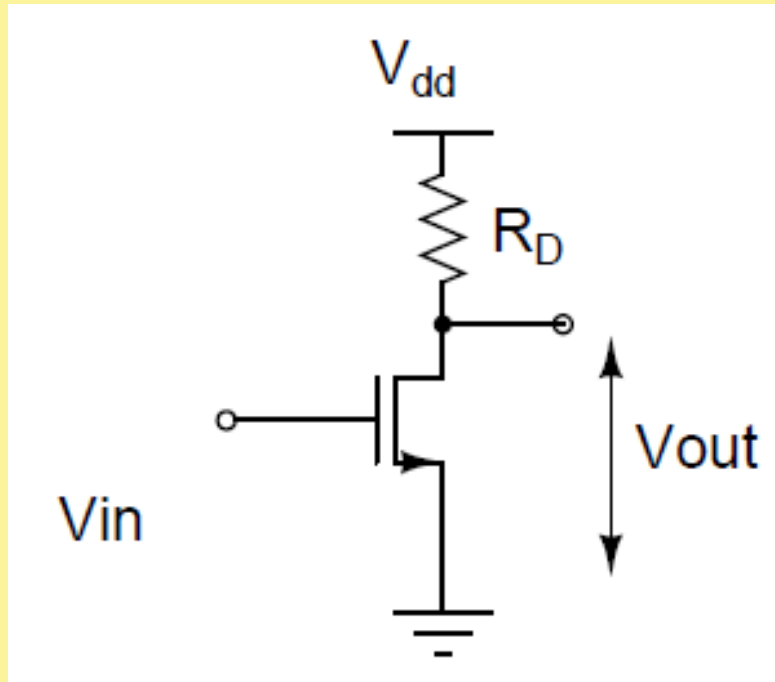
- **Common Source (CS) circuit**
with varying input



Analysis of a circuit containing MOSFET (*Contd....*)

- **Common Source circuit**

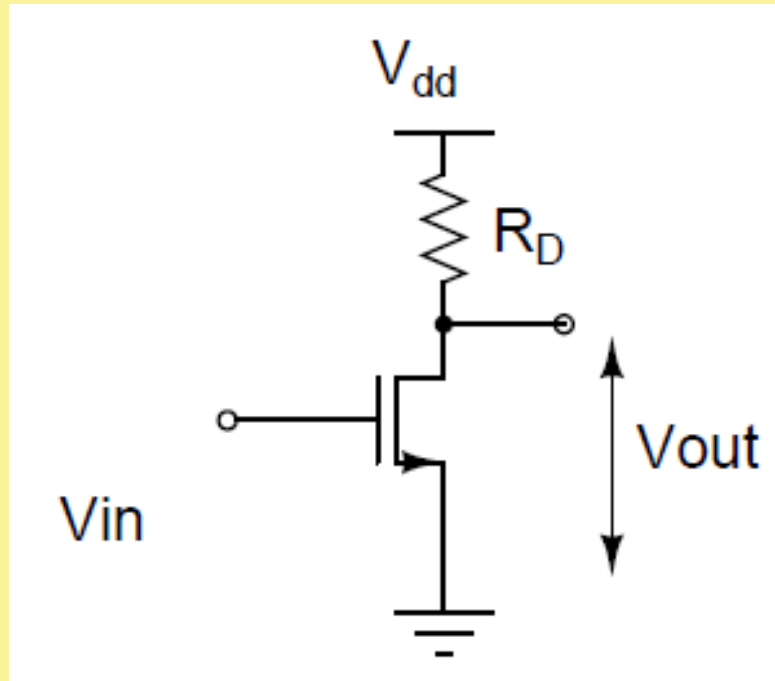
Input-Output Transfer characteristic



Analysis of a circuit containing MOSFET (*Contd....*)

- **Common Source circuit**

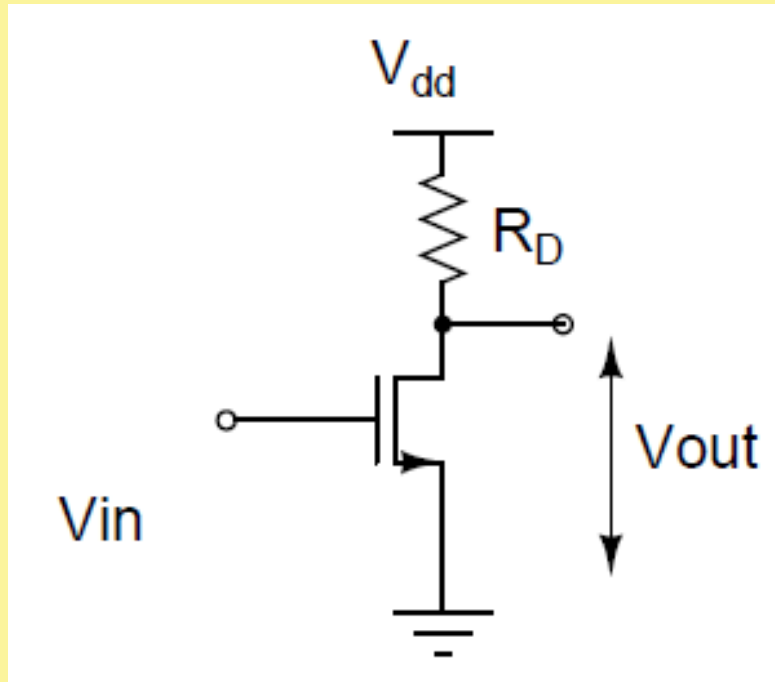
Numerical example to find operating point



Analysis of a circuit containing MOSFET (*Contd....*)

- **Common Source circuit**

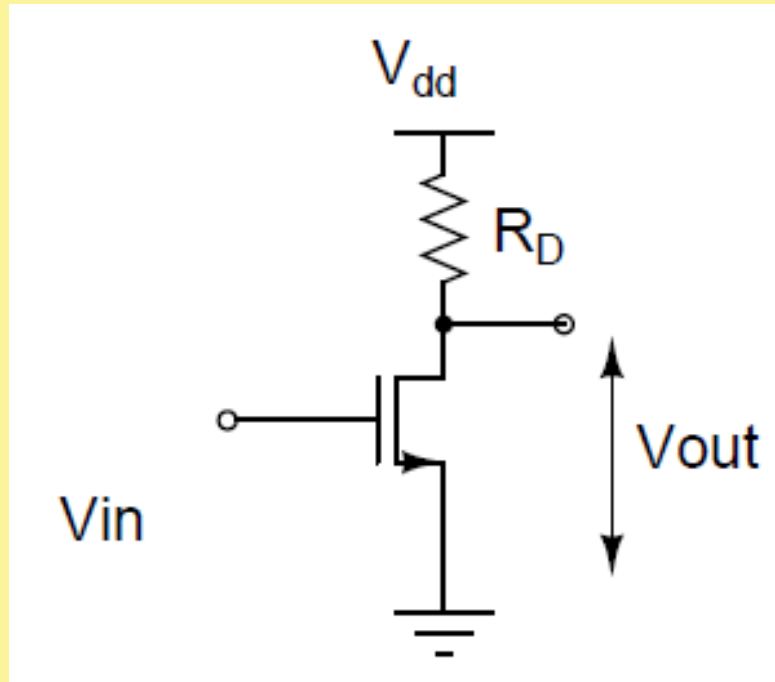
Notion of signal amplification



Analysis of a circuit containing MOSFET (*Contd....*)

- **Common Source circuit**

Numerical example to find its voltage gain



Conclusion:

- ❑ Analyzed non-linear circuit containing MOSFET
- ❑ Example circuits
- ❑ Common Source configuration
- ❑ Input-Output Characteristic of CS configuration
- ❑ Notion of signal amplification
- ❑ Numerical Examples

Conclusion





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Linearization of non-linear circuit containing BJT

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CONCEPTS COVERED

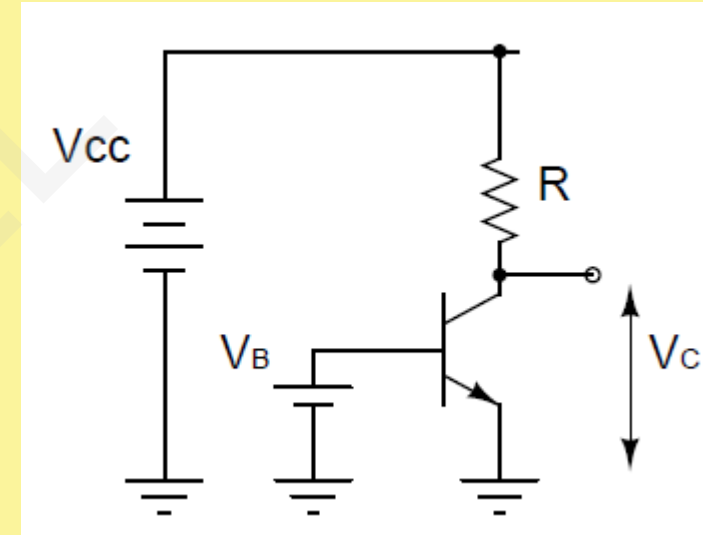
Concepts Covered:

- ☐ Linearization of non-linear circuit containing Transistor
- ☐ Notion of Small signal equivalent circuit
- ☐ Small signal models of BJT
- ☐ Usage of small signal models



Linearization of Input-Output Transfer Characteristic

- **Example circuit_1 (containing a BJT)**
- **Find effect of variation in V_{be} on**
 - I_b, I_c and V_{ce}

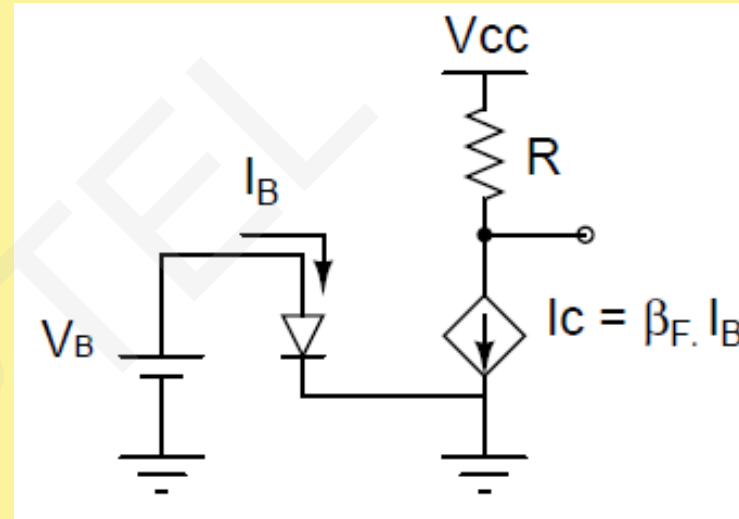
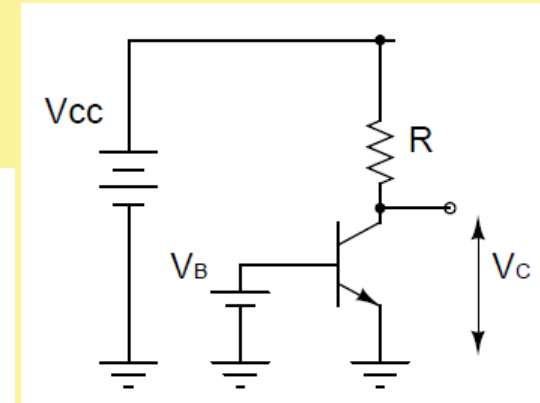


- **Information known, in active region:**

$$I_B \approx I_s^{(B)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)} \quad I_C \approx I_s^{(C)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)} \times \left(1 + \frac{V_{CE}}{V_A}\right)$$

Linearization of Input-Output Transfer Characteristic

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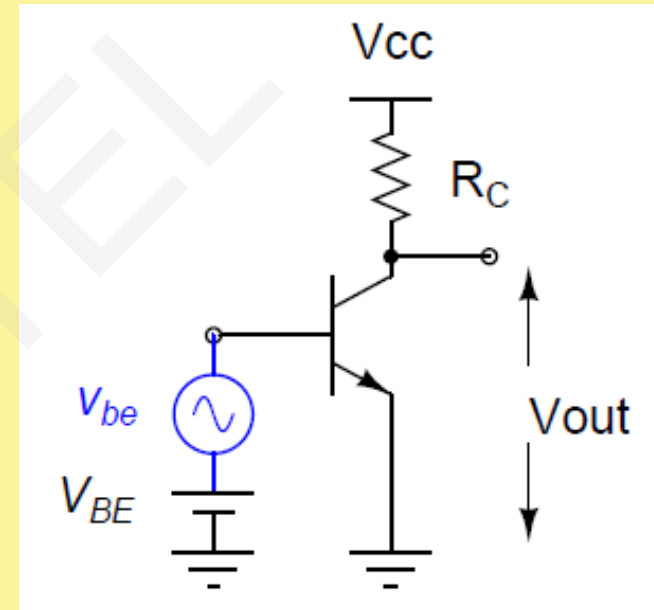
$$I_C \approx I_s^{(C)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)}$$

Linearization of Input-Output Transfer Characteristic

- **Example circuit_1 (Continued)**

- I_C :

$$I_C = I_C + i_c = I_s^{(C)} \cdot e^{\left(\frac{V_{BE} + v_{be}}{V_T}\right)}$$



- **So:**

$$i_c \approx \frac{I_C}{V_T} \cdot v_{be} \qquad I_C = I_s^{(C)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)}$$



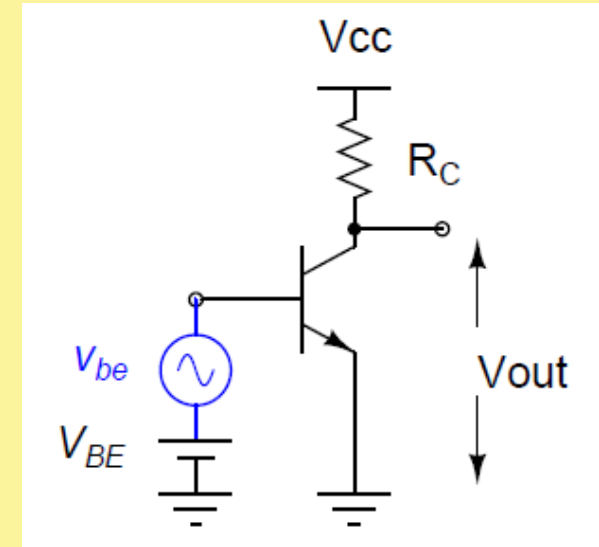
Linearization of Input-Output Transfer Characteristic

- **Example circuit_1 (Continued)**

- $V_{ce} = V_{out}$:

$$I_c = I_C + i_c = I_s^{(C)} \cdot e^{\left(\frac{V_{BE}}{V_T}\right)} + \frac{I_C}{V_T} \cdot v_{be}$$

$$V_{out} = V_{CC} - R_C \cdot (I_C + i_c)$$



- **So:**

$$v_{out} = -R_C \cdot \left\{ \frac{I_C}{V_T} \right\} \cdot v_{be}$$

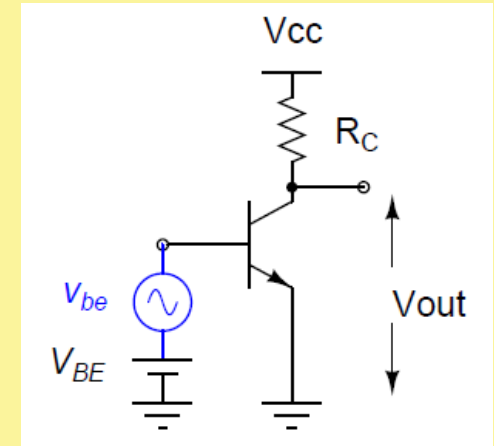
$$V_{OUT} = (V_{CC} - R_C \cdot I_C)$$



Linearization w.r.t. Q- pt.: *small signal transfer characteristic*

- **Example circuit_1 (Continued)**

i_c vs. V_{be} **and** V_{out} vs. V_{be}



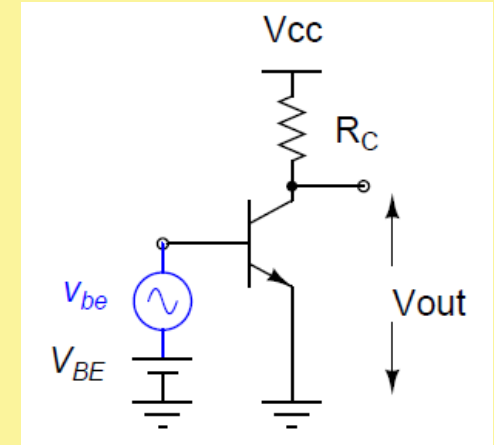
- **Notion of small signal equivalent circuit:**



Linearization w.r.t. Q- pt.: *small signal equivalent ckt.*

- **Example circuit_1 (Continued)**

- Drop out the d.c. parts
- Use new set of parameters:



Linearization w.r.t. Q- pt.: *small signal equivalent ckt.*

- **Example circuit_1 (Continued)**

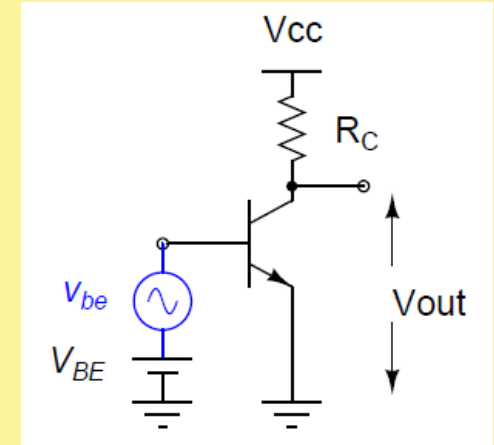
- Drop out the d.c. parts
- Use new set of parameters:

$$g_m = \frac{\partial I_c}{\partial V_{be}}$$

$$r_\pi = \left[\frac{\partial I_b}{\partial V_{be}} \right]^{-1}$$

$$\beta_o = \frac{\partial I_c}{\partial I_b}$$

$$g_o = \frac{1}{r_o} = \frac{\partial I_c}{\partial V_{ce}}$$



Small signal Model of BJT

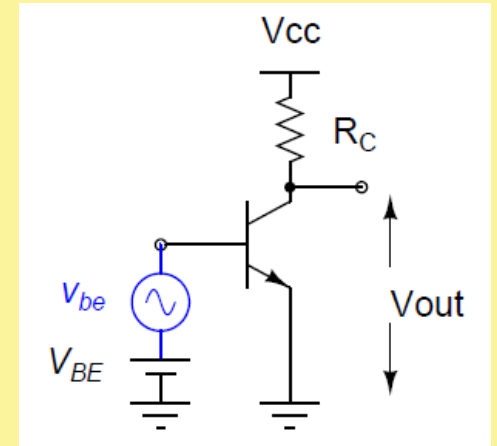
- **New set of device parameters**
 - Values depend on the Q-pt.

$$g_m = \frac{\partial I_c}{\partial V_{be}}$$

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Small signal Model of BJT (contd.)

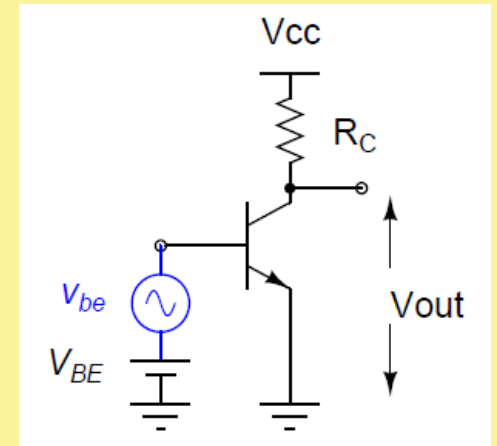
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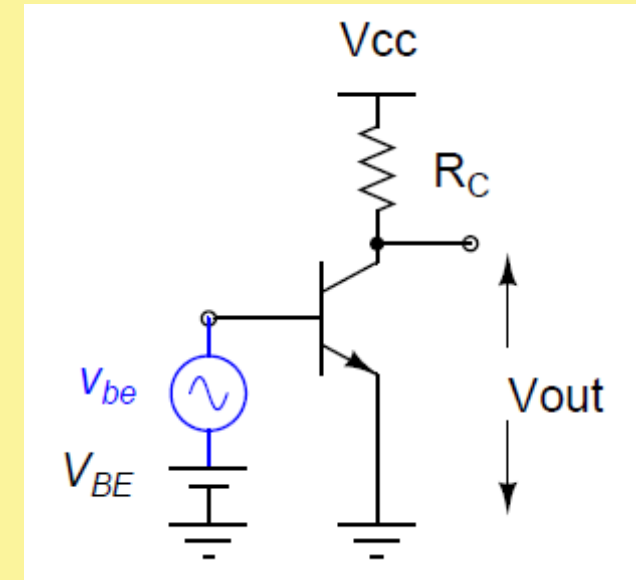
$$\beta_o = \frac{\partial I_c}{\partial I_b}$$

$$g_o = \frac{1}{r_o} = \frac{\partial I_c}{\partial V_{ce}}$$



Usage of Small signal Model of BJT

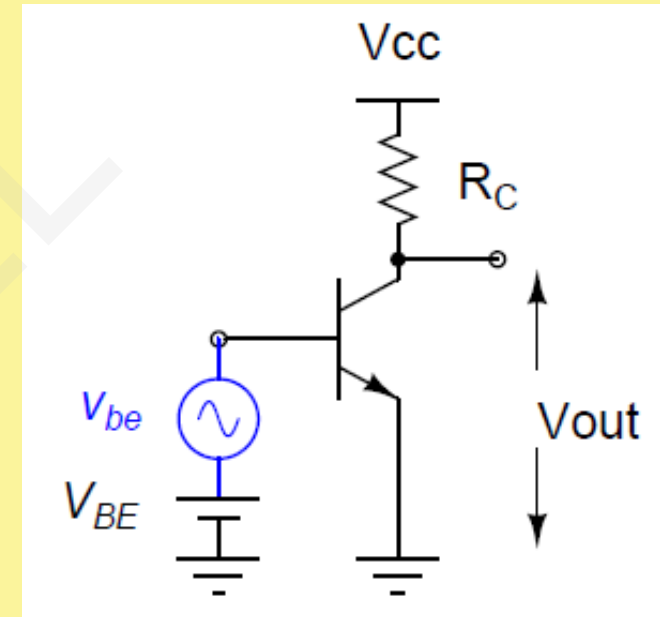
- **Numerical Problem (no resistor at base bias)**
 - Find the Operating point
 - Find the values of small signal parameters
 - Find the small signal voltage gain



Usage of Small signal Model of BJT

- **Numerical Problem_2 (with resistor at base bias)**

- Find the Operating point
- Find the values of small signal parameters
- Find the small signal voltage gain



Conclusion

Conclusion:

- ❑ Linearization of non-linear circuit containing Transistor
- ❑ Small signal equivalent circuit through linearization
- ❑ Small signal model of BJT having different set of parameters
- ❑ Small signal model is used to simplify analysis & calculation





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*Thank
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Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

Topic:

Linearization of non-linear circuit containing MOSFET

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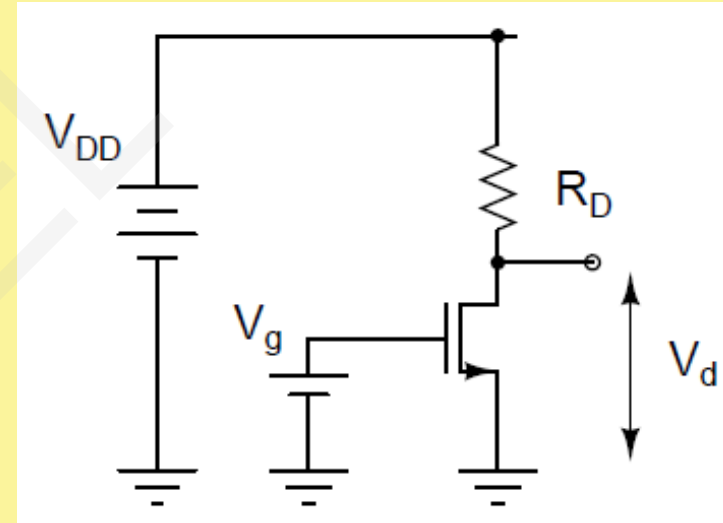
Concepts Covered:

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- ☐ Notion of Small signal equivalent circuit
- ☐ Small signal models of MOSFET
- ☐ Usage of small signal models of MOSFET



Linearization of Input-Output Transfer Characteristic

- **Example circuit_1 (containing a MOSFET)**
- **Find effect of variation in V_{gs} on**
 - I_{ds} and V_{ds}

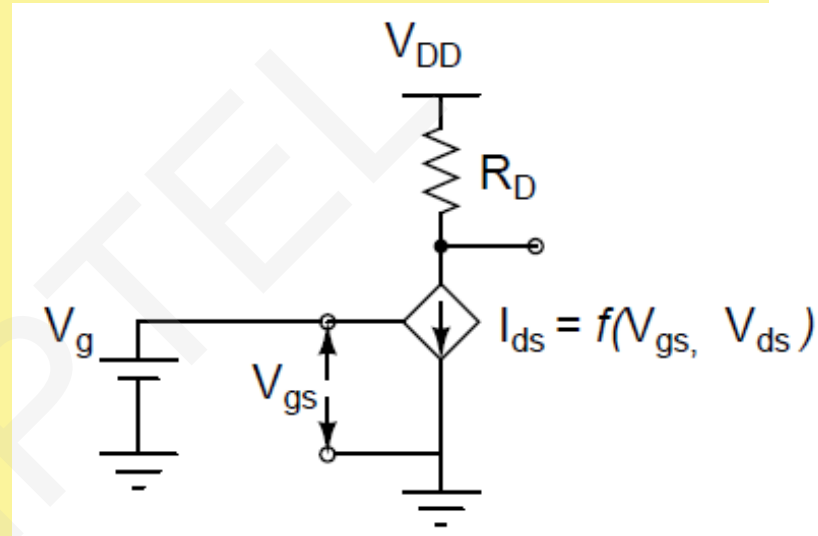
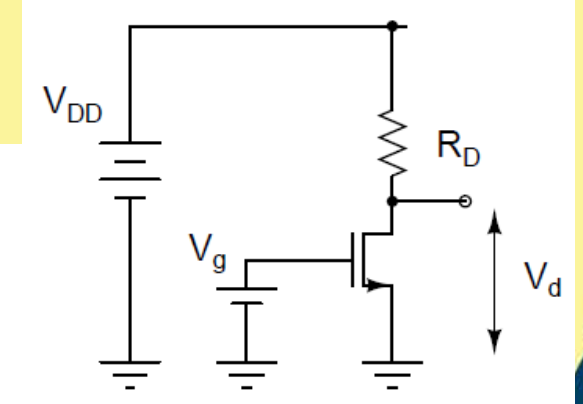


- **Information known, in saturation region:**

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Linearization of Input-Output Transfer Characteristic

- **Example circuit_1 (containing a MOSFET)**
- **Find effect of variation in V_{gs} on**
 - I_{ds} and V_{ds}



- **Information known, in saturation region:**

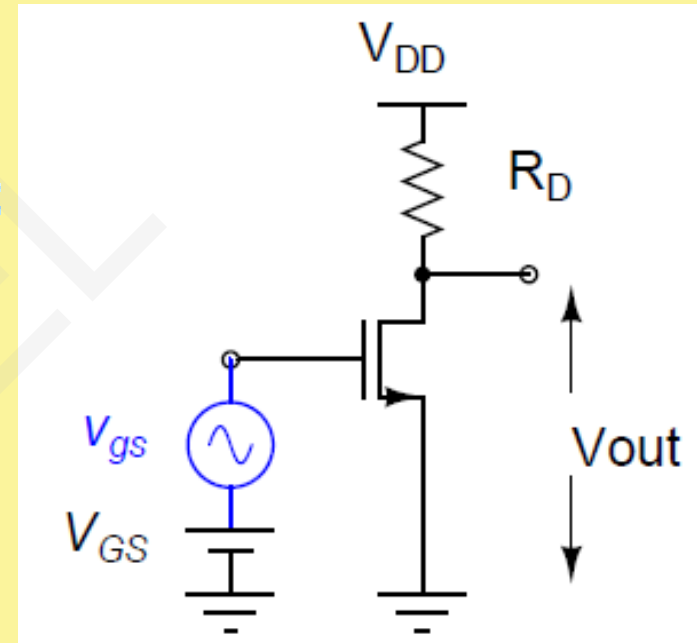
$$I_{ds} = \frac{K W}{2 L} (V_{gs} - V_{th})^2 (1 + \lambda_n V_{ds}) \approx \frac{K W}{2 L} (V_{gs} - V_{th})^2$$

Linearization of Input-Output Transfer Characteristic

• Example circuit_1 (Continued)

• I_{ds} :

$$I_{ds} = I_{DS} + i_{ds} = \frac{K W}{2 L} (V_{GS} + v_{gs} - V_{th})^2$$



So:

$$i_{ds} = \frac{K \cdot W}{L} (V_{GS} - V_{th}) \cdot v_{gs} = \frac{2 \cdot I_{DS}}{(V_{GS} - V_{th})} \cdot v_{gs} = \sqrt{\frac{2 \cdot I_{DS} K \cdot W}{L}} \cdot v_{gs}$$

Linearization of Input-Output Transfer Characteristic

• Example circuit_1 (Continued)

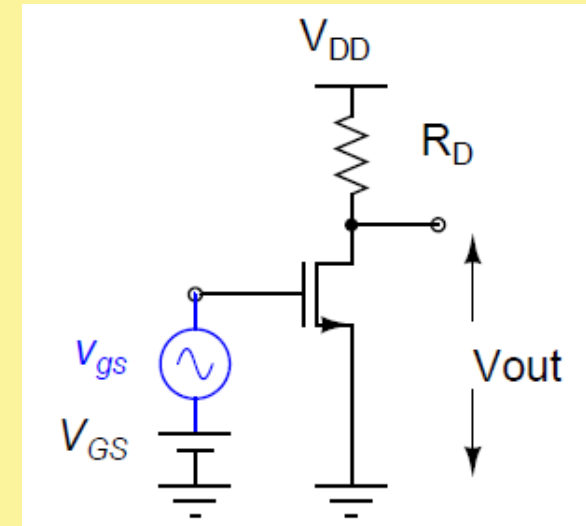
• $V_{ds} = V_{out}$:

$$I_{ds} = I_{DS} + i_{ds}$$
$$= \frac{K W}{2 L} (V_{GS} - V_{th})^2 + \sqrt{\frac{2 \cdot I_{DS} K \cdot W}{L}} \cdot v_{gs}$$

$$V_{out} = V_{DD} - R_D \cdot (I_{DS} + i_{ds})$$

• So:

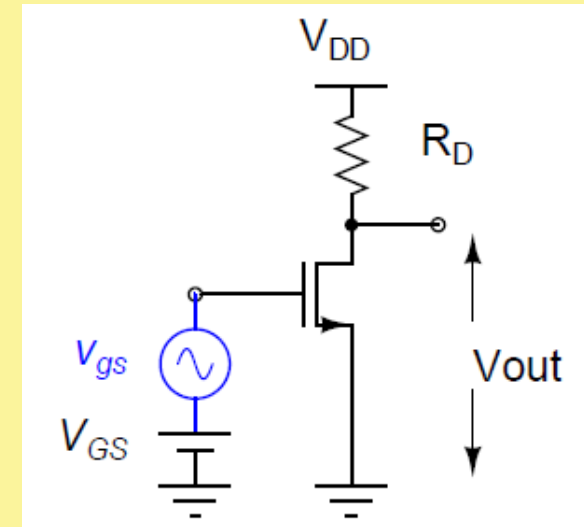
$$v_{out} = -R_D \cdot \sqrt{\frac{2 \cdot I_{DS} K \cdot W}{L}} \cdot v_{gs} \quad V_{OUT} = V_{DD} - R_D \cdot I_{DS}$$



Linearization w.r.t. Q- pt.: *small signal transfer characteristic*

- **Example circuit_1 (Continued)**

i_{ds} vs. V_{gs} **and** V_{out} vs. V_{gs}

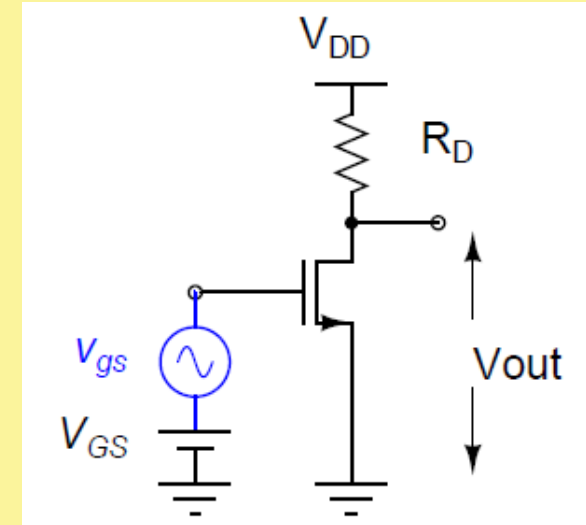


- **Notion of small signal equivalent circuit:**

Linearization w.r.t. Q- pt.: *small signal equivalent ckt.*

- **Example circuit_1 (Continued)**

- Drop out the d.c. parts
- Use new set of parameters:



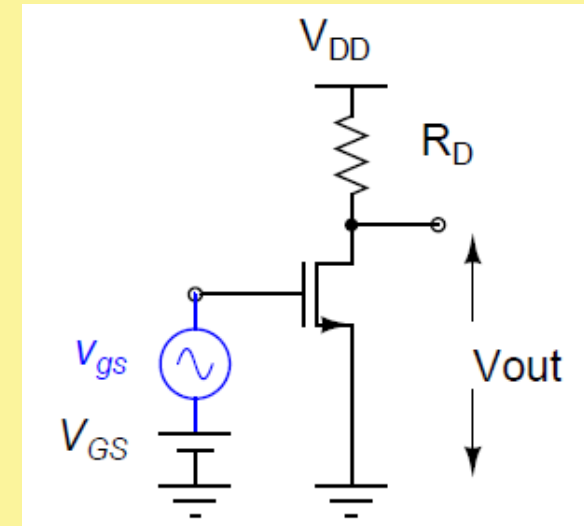
Linearization w.r.t. Q- pt.: *small signal equivalent ckt.*

- **Example circuit_1 (Continued)**

- Drop out the d.c. parts
- Use new set of parameters:

$$g_m = \frac{\partial I_{ds}}{\partial V_{gs}}$$

$$g_d = \frac{1}{r_d} = \frac{\partial I_{ds}}{\partial V_{ds}}$$

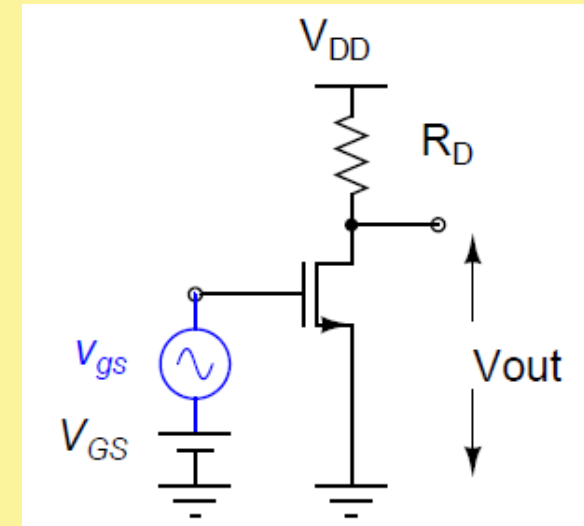


Small signal Model of MOSFET

- **New set of device parameters**
 - Values depend on the Q-pt.

$$g_m = \frac{\partial I_{ds}}{\partial V_{gs}}$$

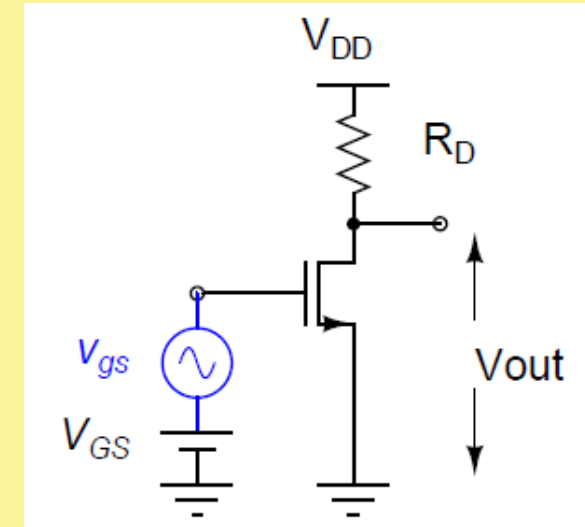
$$g_d = \frac{1}{r_d} = \frac{\partial I_{ds}}{\partial V_{ds}}$$



Usage of Small signal Model of MOSFET

- Numerical Problem**

- Find the Operating point
- Find the values of small signal parameters
- Find the small signal voltage gain



Conclusion:

- ❑ Linearization of non-linear circuit containing Transistor
- ❑ Small signal equivalent circuit through linearization
- ❑ Small signal model of MOSFET having different set of pars.
- ❑ Small signal model is used to simplify analysis & calculation

Conclusion





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*Thank
you*

