Electronic Circuits

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FET Amplifiers

FETs provide:

- **Excellent voltage gain**
- **High input impedance**
- **Low-power consumption**
- **Good frequency range**

FET Small-Signal Model

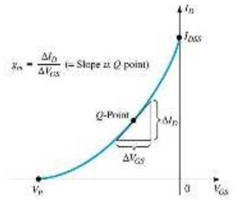
Transconductance

The relationship of a change in I_D to the corresponding change in V_{GS} is called transconductance

Transconductance is denoted g_m and given by:

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

Graphical Determination of g_m



Mathematical Definitions of g_m

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

$$g_m = \frac{2I_{DSS}}{|V_P|}\left[1 - \frac{V_{GS}}{V_P}\right]$$

Where V_{GS} =0V $$g_{m0} = \frac{2I_{DSS}}{|V_P|}$$

$$g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right]$$

Where $$1 - \frac{V_{GS}}{V_P} = \sqrt{\frac{I_D}{I_{DSS}}}$$

$$g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_P}\right) = g_{m0}\sqrt{\frac{I_D}{I_{DSS}}}$$

FET Impedance

Input impedance:

$$Z_i = \infty\Omega$$

Output Impedance:

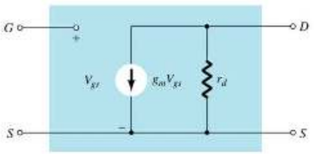
$$Z_o = r_d = \frac{1}{y_{os}}$$

where:

$$r_d = \frac{\Delta V_{DS}}{\Delta I_D}\bigg|_{V_{GS} = \text{constant}}$$

y_{os}= admittance parameter listed on FET specification sheets.

FET AC Equivalent Circuit



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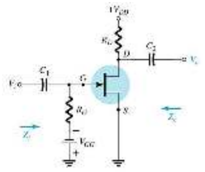
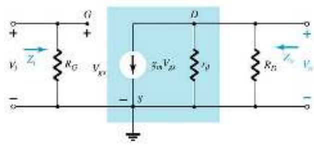
Common-Source (CS) Fixed-Bias Circuit

The input is on the gate and the output is on the drain

There is a 180° phase shift between input and output





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Calculations

Input impedance:

$Z_i = R_G$

Output impedance:

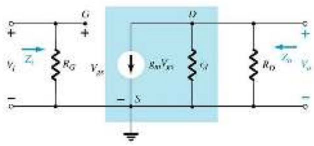
$Z_o = R_D \| r_d$

$Z_o \cong R_D \Big|_{r_d \geq 10 R_D}$

Voltage gain:

$A_v = \frac{V_o}{V_i} = -g_m (r_d \| R_D)$

$A_v = \frac{V_o}{V_i} = -g_m R_D \Big|_{r_d \geq 10 R_D}$



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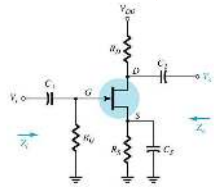
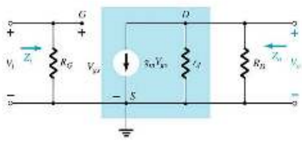
Common-Source (CS) Self-Bias Circuit

This is a common-source amplifier configuration, so the input is on the gate and the output is on the drain

There is a 180° phase shift between input and output





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Calculations

Input impedance:

$Z_i = R_G$

Output impedance:

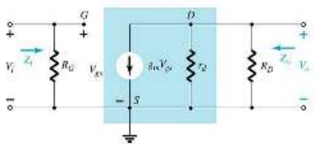
$Z_o = r_d \| R_D$

$Z_o \cong R_D \Big|_{r_d \geq 10 R_D}$

Voltage gain:

$A_v = -g_m (r_d \| R_D)$

$A_v = -g_m R_D \Big|_{r_d \geq 10 R_D}$



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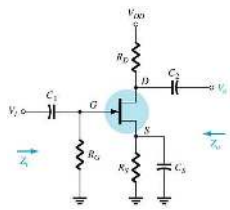
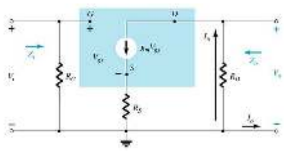
Common-Source (CS) Self-Bias Circuit

Removing C_s affects the gain of the circuit.





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Calculations

Input impedance:

$Z_i = R_G$

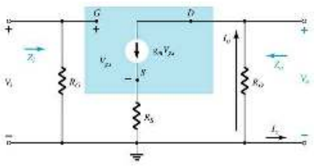
Output impedance:

$Z_o \cong R_D \Big|_{r_d \geq 10 R_D}$

Voltage gain:

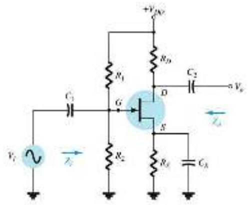
$$A_v = \frac{V_o}{V_i} = -\frac{g_m R_D}{1 + g_m R_S + \frac{R_D + R_S}{r_d}}$$

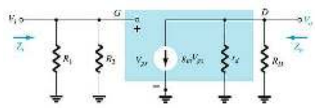
$$A_v = \frac{V_o}{V_i} = -\frac{g_m R_D}{1 + g_m R_S}\Big|_{r_d \geq 10(R_D + R_S)}$$



Common-Source (CS) Voltage-Divider Bias

This is a common-source amplifier configuration, so the input is on the gate and the output is on the drain.





Impedances

Input impedance:

$Z_i = R_1 \parallel R_2$

Output impedance:

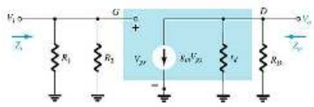
$Z_o = r_d \parallel R_D$

$Z_o \cong R_D \Big|_{r_d \geq 10 R_D}$

Voltage gain:

$A_v = -g_m (r_d \parallel R_D)$

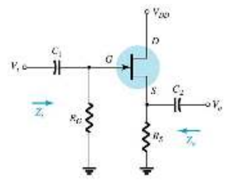
$A_v = -g_m R_D \Big|_{r_d \geq 10 R_D}$

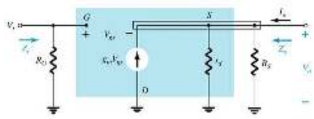


Source Follower (Common-Drain) Circuit

In a common-drain amplifier configuration, the input is on the gate, but the output is from the source.

There is no phase shift between input and output.





Impedances

Input impedance:

$Z_i = R_G$

Output impedance:

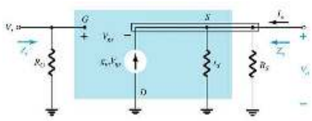
$Z_o = r_d \parallel R_S \parallel \frac{1}{g_m}$

$Z_o \cong R_S \parallel \frac{1}{g_m}\Big|_{r_d \geq 10 R_S}$

Voltage gain:

$$A_v = \frac{V_o}{V_i} = \frac{g_m (r_d \parallel R_S)}{1 + g_m (r_d \parallel R_S)}$$

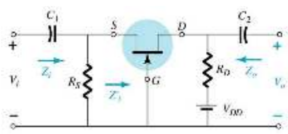
$$A_v = \frac{V_o}{V_i} = \frac{g_m R_S}{1 + g_m R_S}\Big|_{r_d \geq 10}$$

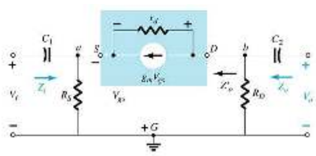


Common-Gate (CG) Circuit

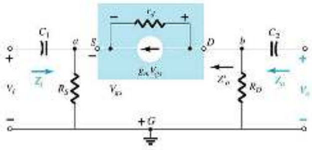
The input is on the source and the output is on the drain.

There is no phase shift between input and output.





Calculations



Input impedance:

$$Z_i = R_S \,\|\, \left[\frac{r_d + R_D}{1 + g_m r_d}\right]$$

$$Z_i \cong R_S \,\|\, \frac{1}{g_m}\bigg|_{r_d \geq 10R_D}$$

Output impedance:

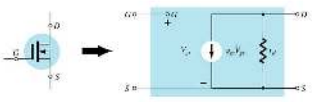
$$Z_o = R_D \,\|\, r_d$$

$$Z_o \cong R_D\big|_{r_d \geq 10}$$

Voltage gain:

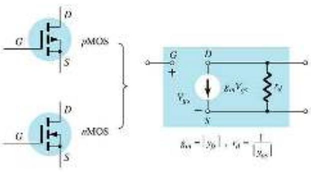
$$A_v = \frac{V_o}{V_i} = \frac{\left[g_m R_D + \frac{R_D}{r_d}\right]}{\left[1 + \frac{R_D}{r_d}\right]} \qquad A_v = g_m R_D\big|_{r_d \geq 10R_D}$$

D-Type MOSFET AC Equivalent



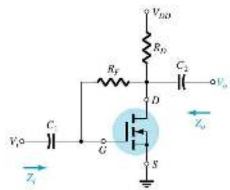
E-Type MOSFET AC Equivalent

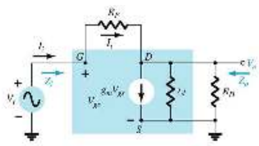
g_m and r_d can be found in the specification sheet for the FET.



Common-Source Drain-Feedback

There is a 180° phase shift between input and output.



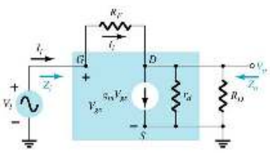


Calculations

Input impedance:

$$Z_i = \frac{R_F + r_d \,\|\, R_D}{1 + g_m (r_d \,\|\, R_D)}$$

$$Z_i \cong \frac{R_F}{1 + g_m R_D}\bigg|_{R_F \gg r_d \| R_D,\, r_d \geq 10R_D}$$



Output impedance:

$$Z_o = R_F \,\|\, r_d \,\|\, R_D$$

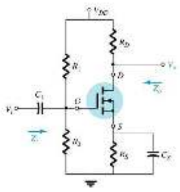
$$Z_o \cong R_D\big|_{R_F \gg r_d \| R_D,\, r_d \geq 10R_D}$$

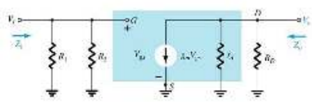
Voltage gain:

$$A_v = -g_m (R_F \,\|\, r_d \,\|\, R_D)$$

$$A_v \cong -g_m R_D\big|_{R_F \gg r_d \| R_D,\, r_d \geq 10R_D}$$

Common-Source Voltage-Divider Bias





Calculations

Input impedance:

$Z_i = R_1 \| R_2$

Output impedance:

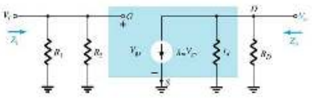
$Z_o = r_d \| R_D$

$Z_o \cong R_D \big|_{r_d \geq 10}$

Voltage gain:

$A_v = -g_m (r_d \| R_D)$

$A_v \cong -g_m R_D \big|_{r_d \geq 10 R_D}$



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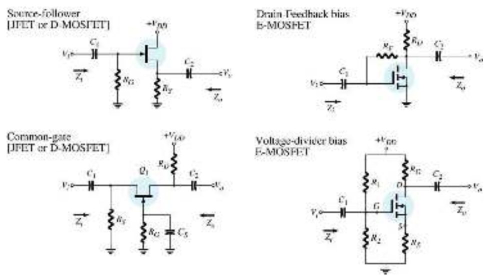
Summary Table



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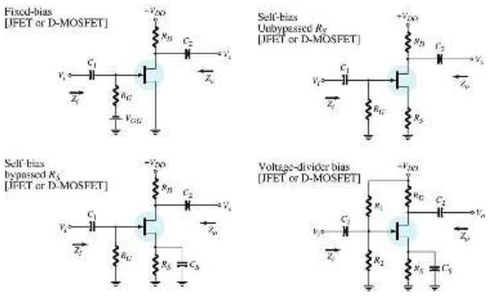
Summary Table



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Troubleshooting

Check the DC bias voltages:

If not correct check power supply, resistors, FET. Also check to ensure that the coupling capacitor between amplifier stages is OK.

Check the AC voltages:

If not correct check FET, capacitors and the loading effect of the next stage

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Practical Applications

Three-Channel Audio Mixer
Silent Switching
Phase Shift Networks
Motion Detection System

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