FET Fundamental Amplifier Configurations

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Outline

- Small-signal middle-frequency equivalent circuits
- Common Source (CS)
- Common Gate (CG)
- Common Drain (CD)
- Source Degeneration (SD)
- Comparison between CS, CG, CD and SD
- Distortion limits (dynamic range)

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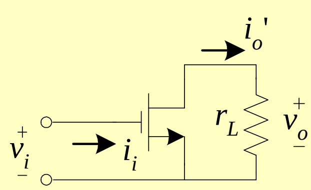
Small-Signal Mid-Frequency Equivalent Circuits

- To analyze an amplifier:

1. Calculate the DC operating point (bias circuit)
2. Obtain the small-signal equivalent circuit at medium frequencies
3. Identify the amplifier's configuration (CS, CG, etc.)
4. Analyze the small-signal equivalent circuit, either by using formulas or by deriving them

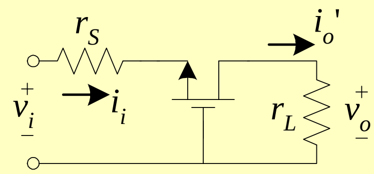
Common Source (CS)



$$A_v = -g_m(r_o \| r_L) \qquad R_i = \infty \qquad R_o = r_o \qquad A_i = \infty$$

If $r_L << r_o$, $\quad A_v = -g_m r_L$

Common Gate (CG)



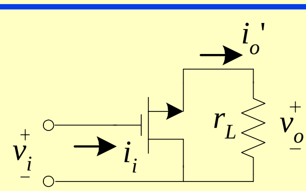
$$A_v = \frac{(1+g_m r_o) r_L}{r_o + r_S(1+g_m r_o) + r_L} \approx \frac{g_m r_L r_o}{r_L + r_o(1+g_m r_S)}$$

$$R_i = r_S + \frac{1}{g_m}\left(1+\frac{r_L}{r_o}\right) \qquad R_o = r_S + r_o(1+g_m r_S) \qquad A_i = 1$$

If $r_L << r_o$, $A_v = \dfrac{g_m r_L}{1+g_m r_S}$ $\quad R_i = r_S + \dfrac{1}{g_m}$

If $g_m r_S << 1$, $A_v \approx g_m (r_L \parallel r_o)$ $\quad R_o \approx r_o$

Common Drain (CD)

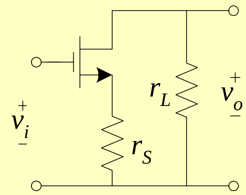


$$A_v = \frac{g_m (r_o \parallel r_L)}{1+g_m (r_o \parallel r_L)} \qquad R_i \approx \infty \qquad A_i = \infty$$

$$R_o = r_o \parallel \frac{1}{g_m} \approx \frac{1}{g_m}$$

If $r_L << r_o$, $A_v \approx \dfrac{g_m r_L}{1+g_m r_L}$ $\qquad$ If $g_m r_L >> 1$, $A_v \approx 1$

Source Degeneration (SD)



$$A_v = \frac{-g_m r_o r_L}{r_L + r_S(1+g_m r_o) + r_o} \qquad \text{If } g_m r_o >> 1,\quad A_v = \frac{-g_m r_o r_L}{r_L + r_o(1+g_m r_S)}$$

$$\text{If } r_o(1+g_m r_S) >> r_L,\quad A_v \approx \frac{-g_m r_L}{1+g_m r_S} \qquad \text{If } g_m r_S >> 1,\quad A_v \approx -r_L / r_S$$

$$R_o \approx r_S + r_o(1+g_m r_S) \approx r_o(1+g_m r_S)$$

$$R_i = \infty \qquad A_i \approx \infty$$

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Simplified Formulas – Comparison

	CS	CG	CD	SD
A_v	$-g_m(r_o \parallel r_L)$	$\frac{g_m r_L}{1+g_m r_S}$	$\frac{g_m r_L}{1+g_m r_L}$	$\frac{-g_m r_L}{1+g_m r_S}$
R_i	∞	$r_S + \frac{1}{g_m}\left(1+\frac{r_L}{r_o}\right)$	∞	∞
R_o	r_o	$r_o(1+g_m r_S)$	$r_o \parallel \frac{1}{g_m}$	$r_S + r_o(1+g_m r_S)$
A_i	∞	1	∞	∞

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Over Simplified Formulas – Summary

	CS	CG	CD	SD
A_v	$-g_m r_L$	$g_m r_L$	1	$\frac{-r_L}{r_S}$
R_i	∞	$r_S + \frac{1}{g_m}$	∞	∞
R_o	r_o	r_o	$\frac{1}{g_m}$	$r_o(1+g_m r_S)$
A_i	∞	1	∞	∞

Distortion Limits

- Distortion limits refer to the maximum output voltage swing for a linear operation (dynamic range)
- They depend on the amplifier configuration, the bias point, and the load line
- For CS amplifiers: $DL^+ = I_{DQ} r_L$ $\quad DL^- = V_{DSQ} - V_{OH}$
- For CD amplifiers: $DL^+ = V_{DSQ} - V_{OH}$ $\quad DL^- = I_{DQ} r_L$
- For CG amplifiers: $DL^+ = I_{DQ} r_L$ $\quad DL^- = V_{DGQ} - V_{OH} + V_{GS}$
- For SD amplifiers: $DL^+ = I_{DQ} r_L$ $\quad DL^- = \left(V_{DSQ} - V_{OH}\right)\frac{r_L}{r_L + r_S}$