JFETs are commonly used to amplify small ac signals. One reason for using a JFET instead of a bipolar transistor is that very high input impedance, $Z_{\text{in}}$, can be obtained. A big disadvantage, however, is that the voltage gain, $A_V$, obtainable with a JFET is much smaller.

JFET amplifier configurations are as follows:
- Common-source (CS)
- Common-gate (CG)
- Common-drain (CD)
The circuit shows a **common-source** amplifier. For a common-source amplifier, the input voltage is applied to the gate and the output is taken at the drain.
- The **ac** equivalent circuit is shown in the following.
- On the input side, \( R_G = Z_{in} \), which is 1 M\( \Omega \).
- This occurs because with practically zero gate current, the gate-source resistance, designated \( R_{GS} \), approaches infinity.
FET AC Equivalent Circuit
To do the AC analysis, remember these 4 STEPs:

1) Set all the DC sources to zero and replace them by a short circuit equivalent.
2) Replace all capacitors by a short circuit equivalent.
3) Remove all elements bypassed by the short circuit equivalents as introduced by Step 1 and Step 2.
4) Redraw the network in a more convenient and logical form.
JFET CS Fixed-Bias

\[ X_{C1} \approx 0 \Omega \]

\[ X_{C2} \approx 0 \Omega \]

\[ g_m V_{gs} \]

\[ r_d \]

\[ R_G \]

\[ R_D \]

\[ Z_i \]

\[ Z_o \]

\[ V_{GG} \]

\[ V_{DD} \]

\[ V_i \]

\[ G \]

\[ D \]

\[ V_o \]
JFET Common Source AC Equivalent Circuit

\[ Z_i = R_G \quad Z_O = R_D \parallel r_d \quad Z_O \approx R_D \quad r_d \geq 10R_D \]
Voltage Gain

\[ A_v = \frac{V_o}{V_i} = -g_m R_D \quad \text{if} \quad r_d \geq 10R_D \]

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

Phase Relationship

A CS amplifier configuration has a 180-degree phase shift between input and output.
Example:

Fixed-bias configuration has an operating point defined by VGSQ = -2V and IDQ = 5.625 mA, with IDSS = 10mA and VP = -8V. The value of gm0 is provided as 2.5 mS.

Determine:

- gm
- Zi
- Zo
- AV
- AV ignoring the effects of rd

Determine DC bias:

1. VGS = _____ VDC
2. ID = _____ milliA
3. VD = _____ VDC
4. VDS = _____ VDC
Solution:

(a) \[ g_{m0} = \frac{2I_{DSS}}{|V_P|} = \frac{2(10 \text{ mA})}{8 \text{ V}} = 2.5 \text{ mS} \]

\[ g_m = g_{m0} \left( 1 - \frac{V_{GSQ}}{V_P} \right) = 2.5 \text{ mS} \left( 1 - \frac{(-2 \text{ V})}{(-8 \text{ V})} \right) = 1.88 \text{ mS} \]

(b) \[ r_d = \frac{1}{y_{os}} = \frac{1}{40 \mu \text{S}} = 25 \text{ k}\Omega \]

(c) \[ Z_i = R_G = 1 \text{ M}\Omega \]

(d) \[ Z_o = R_D \parallel r_d = 2 \text{ k}\Omega \parallel 25 \text{ k}\Omega = 1.85 \text{ k}\Omega \]

(e) \[ A_v = -g_m(R_D \parallel r_d) = -(1.88 \text{ mS})(1.85 \text{ k}\Omega) \]
\[ = -3.48 \]

(f) \[ A_v = -g_mR_D = -(1.88 \text{ mS})(2 \text{ k}\Omega) = -3.76 \]

As demonstrated in part (f), a ratio of 25 k\Omega : 2 k\Omega = 12.5 : 1 between \( r_d \) and \( R_D \) resulted in a difference of 8% in solution.
JFET Source Follower
(Common-Drain) Configuration

In a CD amplifier configuration the input is on the gate, but the output is from the source.
AC Equivalent Circuit

A **Common Drain** amplifier configuration has no phase shift between input and output.

\[
Z_i = R_G \\
Z_o = r_d || R_s || \frac{1}{g_m} \\
Z_o \geq R_s || \frac{1}{g_m} / r_d \geq 10R_s
\]

\[
A_v = \frac{V_o}{V_i} = \frac{g_m(r_d || R_s)}{1 + g_m(r_d || R_s)} \\
A_v = \frac{V_o}{V_i} = \frac{g_mR_s}{1 + g_mR_s} / r_d \geq 10R_s
\]
JFET Common Gate Configuration

The input is on source and the output is on the drain.
AC Equivalent Circuit

\[ A_v = \frac{V_o}{V_i} = \frac{g_m R_D + \frac{R_D}{r_d}}{1 + \frac{R_D}{r_d}} \]

Input Impedance:
\[ Z_i = R_s || \left( \frac{r_d + R_D}{1 + g_m r_d} \right) \]
\[ Z_i \approx R_s \left( \frac{1}{g_m} \right) \quad r_d \geq 10R_D \]

Output Impedance:
\[ Z_o = R_D || r_d \]
\[ Z_o \approx R_D \quad r_d \geq 10R_D \]

A CG amplifier configuration has no phase shift between input and output.
- The circuit below shows a **common-drain** amplifier, usually referred to as a source follower.
- A source follower has a high input impedance, low output impedance, and a voltage gain of less than one, or unity.

![Diagram of a common-drain amplifier](image)
THE METAL OXIDE SEMICONDUCTOR FET (MOSFET)

- The D-MOSFET can be operated in two modes:
  1. The depletion mode
  2. The enhancement mode

Sometimes called Depletion enhancement MOSFET

- Either positive or negative Gate voltage can be applied
- Depletion mode: when negative gate-to-source voltage is applied.
- Enhancement mode: when positive gate-to-source voltage is applied.
- Generally operate in the depletion mode
Enhancement MOSFET (E-MOSFET)

- Operates only in the enhancement mode

Schematic symbols: (a) n-channel; (b) p-channel.

- N-channel required positive gate-to-source voltage
- P-channel required negative gate-to-source voltage
- Equation transfer characteristic curve differs from that of JFET and D-MOSFET
D-MOSFET transfer characteristic curves.
E-MOSFET transfer characteristic curves.
Enhancement MOSFET (E-MOSFET) continue

• The equation for the E-MOSFET transfer characteristic is:
  \[ I_D = K ( V_{GS} - V_{GS(th)} )^2 \]
• the constant K depends on the particular MOSFET
• Can be determined from data sheet by taking the specified value of ID, called ID(ON) at the given value of VGS

HANDLING Precautions:

• All MOS devices are subject to damage from electrostatic discharge (ESD)
• MOS devices should be shipped and stored in conductive foam
• All instruments and metal benches used in assembly or test should be connected to earth GND.
• The assembler’s or handler’s wrist should be connected to earth GND with the length of wire and a high value series resistor.
• Never remove an MOS device from the circuit while power is ON
• Do not apply signals while the DC power is OFF