Application Note : JFET Fundamentals

Introduction

The Junction Field Effect Transistor (JFET) exhibits characteristics which often make it more suited to an application than the bipolar transistor. Some of these applications are:

- High Input Impedance Amplifier
- Low-Noise Amplifier
- Differential Amplifier
- Constant Current Source
- Analog Switch or Gate
- Voltage Controlled Resistor

Basic JFET Amplifier Configuration

There are three basic JFET circuits: the common source, the common gate, and the common drain as shown in Figure 1.
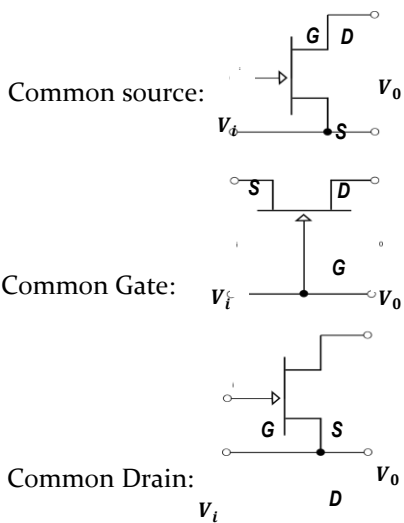
Common source:

Common Gate:

Common Drain:

Figure 1

Each circuit configuration describes a two-port network having an input and an output. The transfer function of each is also determined by the input and output voltages or currents of the circuit. The most common configuration for the JFET as an amplifier is the common source circuit. For an N- channel device the circuit would be biased as shown in Figure 2.
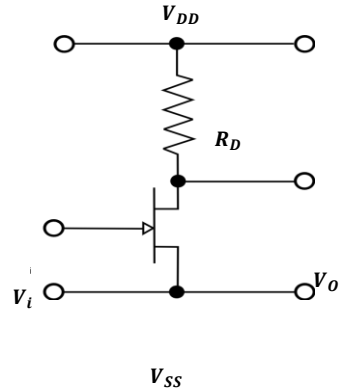
Figure 2

Since the N-channel JFET is a depletion mode device and is normally on, a gate voltage which has a negative polarity with respect to the source is required to modulate or control the drain current. This negative voltage can be provided by a single positive power supply using the self biasing method shown in Figure 3. This is accomplished by the voltage which is dropped across the source resistor, R_S, according to the current flowing through it. The gate-to-source voltage (V_{GS}) is then defined as:

(1) VGS = ID X RS

The circuit of Figure 3 also defines a basic single stage JFET amplifier. The source resistor value is determined by selecting the bias point for the circuit from the characteristic curves of the JFET being used. The value of the drain resistor is then chosen from the required gain of the amplifier and the value of the drain current which
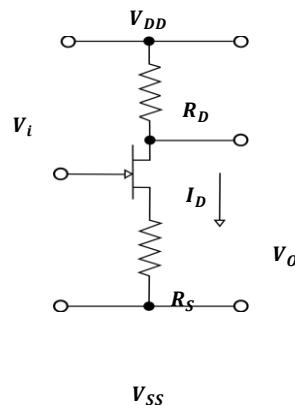
Figure 3

was previously selected in determining the gate voltage. The value of this resistor must also allow the circuit to have sufficient dynamic range, or voltage swing, required by the following stage. The following stage could be anything from another identical circuit to a loud speaker for an audio system. The voltage gain of this circuit is then defined as:

(2) $A_V = (g_m \times Z_L) / (1 + g_m \times R_S)$

Where:

- **A_V** = the voltage gain
- **g_m** = the forward transconductance or gain of the JFET
- **Z_L** = the equivalent load impedance
- **R_S** = the value of the source resistor

The effect of the source resistor on the gain of the circuit can be removed at higher frequencies by connecting a capacitor across the source resistor. This then results in an amplifier which has a gain of:

(3) $AV = gm \times ZL$

The source resistor can only be removed at frequencies above that defined by the resistor-capacitor network in the source circuit. This frequency is defined as:

(4) $f_{lo} = 1 / (2\pi \times R_S \times C_S)$

Where:

- **f_{lo}** = the low frequency corner
- **π** = the constant 3.1418
- **R_S** = the value of the source resistor
- **C_S** = the value of the source capacitor

The circuit also has a high input impedance, generally equal to the value of the input impedance of the JFET.

A Low-Noise Amplifier

A minor change to the circuit of Figure 3 describes a basic single stage low-noise JFET amplifier. Figure 4 shows that this change only incorporates a resistor from the gate to V_{SS}. This resistor supplies a path for the gate leakage current in an AC coupled circuit.

Its value is chosen by the required input impedance of the amplifier and its desired low-noise characteristics. The noise components of this amplifier are the thermal noise of the drain and gate resistors plus the noise component of the JFET. The noise contribution of the JFET is from the shot noise of the gate leakage current, the thermal noise of the channel resistance and the frequency noise of the
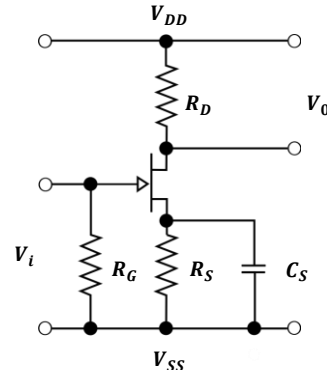

Figure 4

The JFET Differential Amplifier

Another application of the JFET is the differential amplifier. This configuration is shown in Figure 5. The differential amplifier requires that the two transistors be closely matched electrically and physically located near each other for thermal stability. Either input and either output can be used or both inputs and only one output can be used. For the configuration shown, the source resistor is chosen to determine the gate to source bias voltage, remembering that the current will be twice that of each of the JFET drain currents. The value of the drain resistor is chosen to provide a suitable dynamic range at the output. The gain of the circuit is defined by:
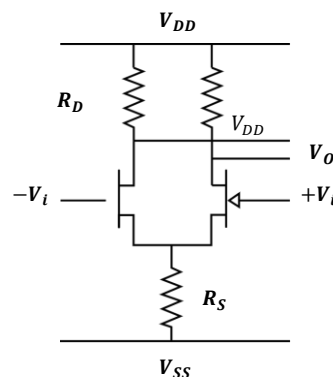

Figure 5

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This circuit configuration is very useful as a high input impedance stage to be connected to the input of a low cost operational amplifier

The JFET Constant Current Source

A constant current source using a JFET is shown in Figure 6. This circuit configuration has many useful applications ranging from sourcing and/or sinking current for a sensor to replacing the source resistor in the differential amplifier shown in Figure 5. The current provided by the constant current source of Figure 6 is defined by:

(6) $I_D = I_{DSS} [1 - (V_{GS} / V_P)]^2$

Where:
   I_D = the drain current or magnitude of current sourced
   I_{DSS} = the drain saturation current of the JFET
   V_{GS} = $I_D \times R_S$
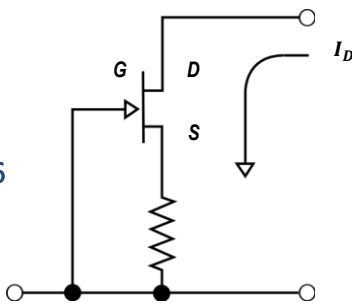 V_P = the JFET pinch-off voltage

Figure 6

It can be readily seen that the use of this circuit in the source circuit of the differential amplifier in Figure 5 would improve the circuit voltage gain as well as reduce the amplifier noise and enhance the CMRR of the amplifier.

The JFET Analog Switch

Figures 7, 8 & 9 show three different applications for the JFET to be used as an analog switch or gate. Figures 7 & 8 both demonstrate methods for realizing programmable gain amplifiers, while Figure 9 shows an analog multiplexer circuit using JFETs and a common op-amp integrated circuit.

It can be seen from Figure 7 that the gain of the stage can be changed by switching in any combination of feedback resistors R1 through Rn. The JFET in series with the input resistor should be of the same type as those in the feedback paths and is used for thermal stability of the circuit gain. The transfer function of the circuit of Figure 7 is approximated by:

(7) $Vo/Vi = 1 / [(1/R1) + (1/R2) +...+ (1/Rn)] / Ri$

Where:
   R1 through Rn = the feedback resistors
   Ri = the input resistor
   Vo = the output voltage
   Vi = the input voltage

Note that only those feedback resistors which are switched into the circuit are to be included in the transfer function equation.
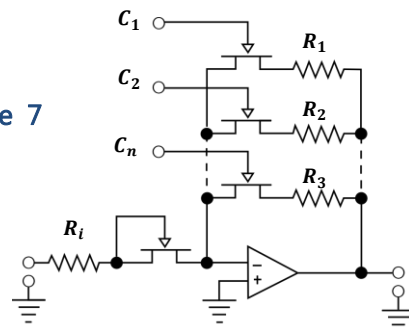

Figure 7

The circuit of Figure 8 shows another method to realize a programmable gain amplifier using a common op-amp, four resistors, and only two JFETs. The gain of this circuit can also be changed by switching in the desired resistors by turning off the appropriate JFET thus switching in the parallel resistor. The transfer function of this circuit is approximated by:
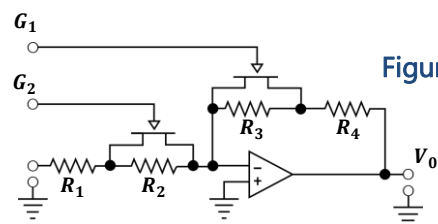(8) $Vo/Vi = (R3 + R4) / (R1 + R2)$

Figure 8

It should be noted that only those resistors which are switched into the circuit are to be included in the transfer function equation.

Figure 9 shows a circuit in which the JFETs are acting as analog switches to multiplex several input signal sources to a single output source. The transfer function of this circuit is then approximated by:

(9) Vo/Vi = Rf / Rn

Where:

Rf = the feedback resistor
Rn = any one of the input resistors

Further examination of this circuit shows that it can also be used as a programmable summing amplifier by switching in any combination of input signals. The transfer function is then approximated by:

(10) Vo/Vi = (Rf / R1) + (Rf / R2) +…+ (Rf / Rn)

Again in this application, only those resistors which are switched into the circuit are to be included in the transfer function equation.
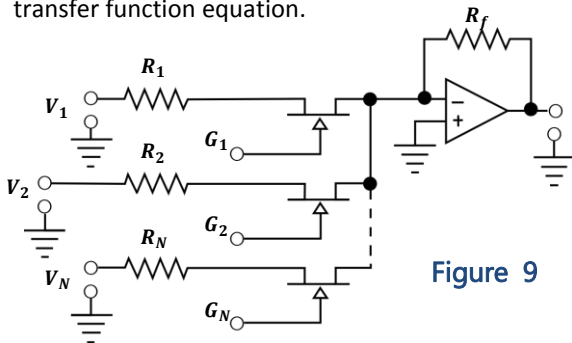
Figure 9

The JFET Voltage Controlled Resistor

Another common application for the JFET is as a voltage controlled resistor. The JFET action in normal operation simply changes the cross sectional dimensions of the channel. When the JFET is biased in the resistive or linear region as shown in Figure 10, a change in channel dimensions simply changes the drain to source resistance of the device.
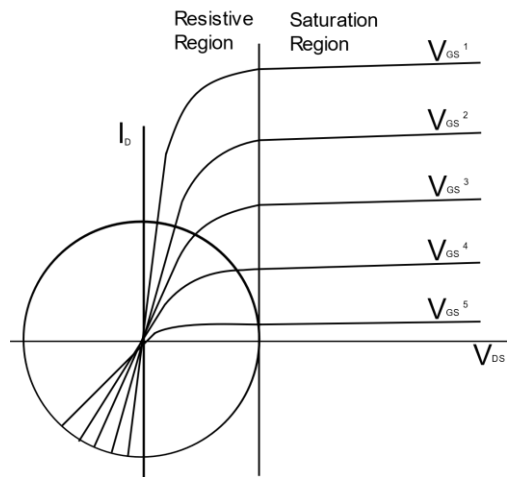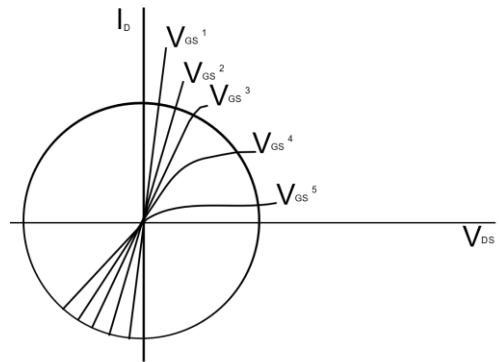
Figure 10

Figure 11 depicts a JFET being used as a voltage controlled resistor(VCR). The resistance is determined from the bias point conditions selected from the curves of Figure 10. The resistance is then defined as:

(11) RDS = VDS/IDS

Where:

RDS = the drain to source resistance
VDS = Vo or the output voltage
IDS = the drain current

It can readily be seen from the curves of Figure 10 that any change in the input voltage (Vi) or the gate to

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source voltage will cause a corresponding change in the drain current. Equation 11 indicates that there is a corresponding change in the drain to source resistance (RDS). Therefore, the resistance is controlled by the voltage applied to the gate, resulting in a voltage controlled resistor. Figure 11

Figure 11
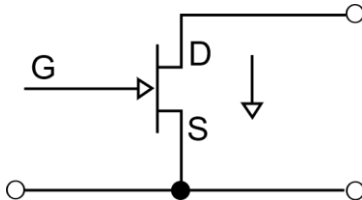
Conclusions

This application note describes several useful junction field effect transistor circuit configurations. The high input impedance and low-noise circuits are often used as input stages to voltage measurement instruments such as oscilloscopes and digital volt meters.

The differential amplifier is a very widely used circuit in applications where the difference between two voltages is to be measured, such as the input stage of an operational amplifier. The use of JFETs in this application provides high input impedance and low input leakage current. Constant current sources have many uses such as setting bias conditions for many other circuits in a system, sourcing and/or sinking current for a sensor and replacing the source resistor in a differential amplifier circuit. Voltage controlled resistors are normally found in automatic gain control circuits and voltage controlled tuning circuits.

Therefore, it is clearly seen that many applications for JFETs exist. Those discussed in this application note have many variations, refinements, and other uses. It should be noted that these applications were described in the simplest detail and additional study of the application should be considered before using any of the circuits presented.