JFET Applications in today's Analog World

Understand how this basic device fills a vital circuit function

By Don Schuyler, Vice President of Engineering, InterFET Corporation

The semiconductor marketplace has evolved and grown by being focused on the next smaller, faster, lower- power technology or widget that improves or enhances its customer's end application. Similarly, as new markets develop, the demand for new customer applications can promote the next generation of semiconductor technology, and as next generations of technology appear, more new applications can be developed and/or improved. This seemingly never-ending cycle continues to evolve as an underlying foundation, and has been instrumental in establishing the industry as we know it today.

However, there are customer applications in both the commercial and military market segments that even the newest technologies do not address. We should not lose sight of the decades-old products and technologies that continue to solve critical customer-design requirements. One such technology in the analog circuit area is the Junction Field-Effect Transistor (JFET). This technology, over 40 years old, is still solving real-world, small-signal-chain problems typically requiring low power, high impedance, and low noise.

JFETs also offer excellent radiation and temperature tolerance (typically -60°C to +150°C), which is required in many military/high-reliability applications. In fact, when properly biased, JFETs may have a zero temperature-compensation parameter, where their performance remains virtually unaffected over a wide temperature range.

You will find examples in both the commercial and military market segments, and they include consumer as well as industrial/OEM applications and end equipments. A few examples of products still using JFETs today include:

- Microphones (miniature to high-end professional)
- Sensors and detectors
- Electronic measurement instrumentation (oscilloscopes, analyzers, and others)

- Medical imaging and blood-analysis instrumentation

Let's look at various applications which take advantage of the key features of JFETs such as low noise, low voltage, low leakage current, and high impedance.

JFET elements can be used in a variety of ways to include diodes (pico amp, constant current), VCRs (voltage-controlled resistors), and switches, but there is no doubt that the amplifier is the most common JFET application. However, to look at specific JFET uses, it is important first to cover some of the basic electrical and thermal characteristics of the JFET.

General Characteristics–Electrical

There are some basic characteristics of JFETs to be understood before considering them for an application. A primary one is that the JFET is a normally "ON" device. **Figure 1** shows the typical power connections to the N-Channel and P-Channel devices.

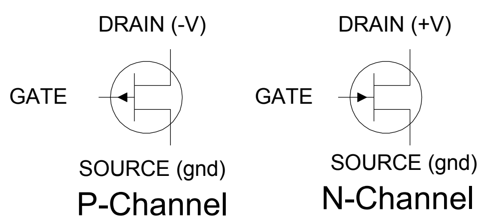

Figure 1

Control of the N-Channel device is achieved by taking the Gate voltage more negative than the Source. This action constricts the Drain/Source channel and reduces the device current flow; continuing in the negative direction will achieve the complete turn-off of the device. The same action is achieved with the P-Channel device by taking the Gate voltage more positive than the Source. (It is possible that the actual circuit usage may require additional bias circuitry.)

As noted earlier, JFETs exhibit some unique thermal characteristics. As a rule of thumb, designers should be aware of the following temperature considerations:

- $V_{gs(off)}$ changes by approximately -2.2 mV/°C with increasing temperature.
- I_{GSS} doubles with every 10 to 12°C increase in temperature.
- I_{DSS} will approximately double when cooled to –55° and will decrease by a half when heated to +125°C; typically, for devices with a V_P near 0.6 volts, these variations are greatly reduced.
- B_{VGSS} will increase with increasing temperature ≈5 volts at +125°C and decrease ≈5 volts at -55°C

- $R_{DS\ (on)}$ may change at a rate of approximately +0.7%/°C, increasing temperature.

The amplifier is the most-common JFET application, and there are three fundamental types: the common-source amplifier, the source-follower amplifier, and the common-gate amplifier. Each has its own purpose, design rules, and unique characteristics.

The common-source amplifier is capable of high voltage gain, and simultaneously may offer high input impedance. The common-source configuration is especially popular in low-frequency, RC-coupled designs.

The common-source amplifier is called that because the JFET's Source is common to both the input and output circuitry (**Figure 2**):

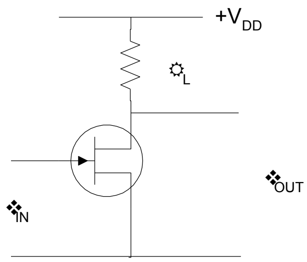

Figure 2: Common Source

The source follower (common drain) is where the Drain is common to both the input and output (**Figure 3**). However, unlike the common-source amplifier, the Drain is heavily bypassed so commingling of signals does not affect performance.

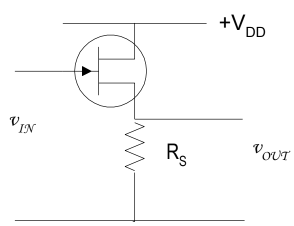

Figure 3: Source Follower (Common Drain)

The source follower (common drain) amplifier offers high input impedance but low output impedance, by sacrificing a voltage gains less than unity. Despite this sacrifice, the source-follower amplifier is the design of choice for impedance transformations. The input impedance of some JFETs can reach in the range of 100 GΩ, while the output impedance is set by the source resistor. For example, how would you couple an electret microphone to a bipolar amplifier? The electret microphone's output impedance is at least 50 MΩ, while the bipolar amplifier's input impedance may be as low as 200 Ω.

The common-gate amplifier exhibits low input impedance, moderate gain and extremely low feedback capacitance. Consequently, it is more widely used in high-frequency applications, **Figure 4**.

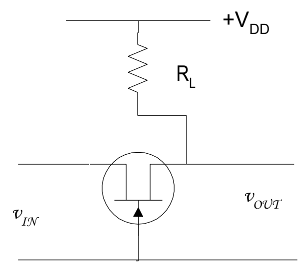

Figure 4: Common-Gate Amplifier

The above amplifier examples describe the basic JFET capabilities and characteristics.

To primarily address both sensor and audio applications, InterFET recently introduced a JFET device with integrated input diodes. It is designated the IFND89 and the circuit schematic is shown in **Figure 5** with the standard package configuration (SC-70), **Figure 6**.

DEVICE SCHEMATIC:

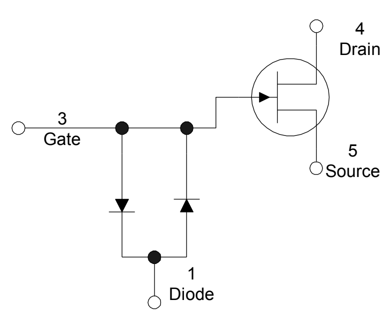

Figure 5

Package Lead Configuration:

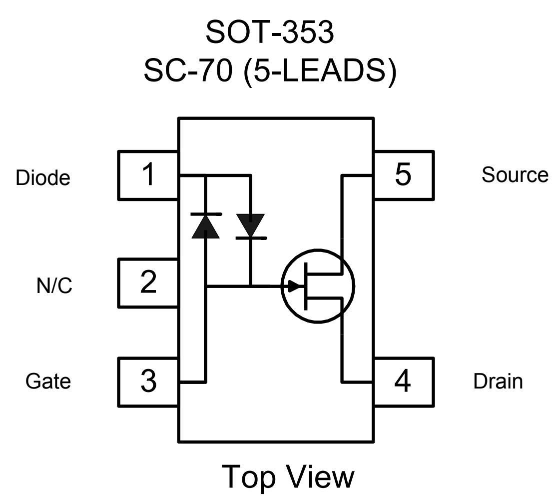

Figure 6

Features:
High Gain
Built-In Diodes
$V_{GS(off)}$ Max –2.5 V (Selectable)

Benefits:
Full Performance from Low Voltage
Power Supply: As Low As 0.9 V
Low Signal Loss/System Error
High Quality, Low Level Signal Amplification

Applications:
Hearing Aids, Mini Microphones
High-Gain/Low-Noise Amplifiers
Low-Current/Low-Voltage Battery Powered Amplifiers
Infrared Detector Amplifiers
Ultra-High Input Impedance Pre-Amplifiers

The device offers high gain, low noise, and low leakage, and offers distinct advantages over discrete amplifiers, including improvements in both circuit operation and ease of implementation through the reduction of additional circuit elements, as follows:

- A low-noise and low-leakage combination is effective in providing an extremely high input impedance and low 1oading. These characteristics allow connection to the outputs of high impedance transducers with minimal signal loss and signal noise injection.
- The diodes provide overvoltage protection for later stages. If voltage-sensitive circuits follow the IFND89 device, the maximum output swing of the IFND89 source follower-amplifier will be less than a diode forward-voltage drop above or below ground. depending on the ground connection for the device.
- Monolithic design reduces space requirements to a minimum, allowing circuit placement in location that are often impossible for discrete amplifiers. This is very attractive for use in hybrid circuits such as hearing aids, where minimizing space is a critical design factor.
- Low-current and low-voltage capability make the amplifier well-suited for battery operation.
- The most common application of the IFND89 is in impedance matching for high impedance sources (such as transducers) to low impedance loads (such as transmission lines).

It is important designers have access to and use models, such as Spice models, in their initial design stage. The following is PSPICE model listing for the IFND89, when as a source follower:

```
IFND89
.OPTIONS NOPAGE NOECHO
*OPERATING TEMPERATURE 25 C
* JFET CIRCUIT: SOURCE FOLLOWER
VD 5 0 DC 1.2V
VIN 1 0 AC 1.0E-3V
R1 1 2 50
D1 0 2 DIODE1
D2 2 0 DIODE2
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```
J1 3 2 4 IFND89
R2 4 0 22K
*DUMMY VOLTAGE SOURCE MEASURED JFET CURRENT
VX 5 3 DC 0V
* DIODE MODELS DEFINED
.MODEL DIODE1 D (IS=1E-16 RS=23 BV=40 IBV=1E-16 CJO=0.43P VJ=0.6
+N=1.15 EG=1.11)
.MODEL DIODE2 D (IS=2E-17 RS=10 BV=40 IBV=1E-16 CJO=0.43P VJ=0.6
+N=1.1 EG=1.11)
*JFET MODEL DEFINED
.MODEL IFND89 (IS=5P RS=43 VTO=-0.746 BETA=2.126M
+LAMBDA=9.71M CGS=1.6P CGD=0.3P)
*DC SWEEP FROM 0 TO 1.2V @ 0.05 INCREMENTS
.DC VD 0 1.2 0.05
* PLOT JFET CURRENT
.PLOT DC I(VX)
*AC ANALYSIS @ 100 HZ TO 100KHZ
.AC DEC 10 10HZ 100KHZ
.PLOT AC VM(4) VP(4)
.PROBE
.END
```

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