Application Note: Discrete JFET versus JFET OP-Amp

A JFET, or Junction Field Effect Transistor, is a powerful engineering design solution almost always used in PIR sensors, Electret condenser microphones, Oscilloscope probes, and low noise operational amplifiers. The main reason for their use is because it is the lowest noise and highest input impedance transistor answer.

Advancements in the semiconductor industry have allowed smaller feature sizes, more robust designs, and integration of components. Sensor design engineers have the option to use a simple JFET-input op-amp rather than a separate JFET in conjunction with a discrete op-amp.

So . . . Why use a discrete JFET and not just a JFET-input Op Amp?

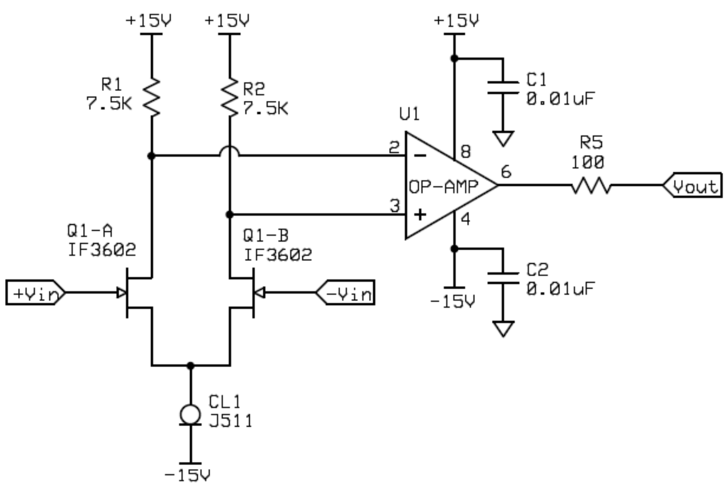
For several reasons:

1. Integrated op amps use different semiconductor processes that are un-optimized for JFETs.
2. Integrated op amps are on a monolithic die and have channel cross coupling.
3. Discrete JFETs can be selected, matched, and optimized to each application's specific parameters.

The main limitation of the integrated JFET-input op amp is due to the way the product is manufactured. The JFETs in the VLSI process are made using the same procedures and at the same time as the rest of the chip. This results in a less than optimal solution that may not be well matched to the sensor interface and cannot be individually tested or characterized. While JFET input op amps have improved over the years, designers achieve better results by selecting the individual JFETs that are best suited for their application. It may be tempting to drop a JFET-input op amp into the circuit to make it functional, but that does not ensure the sensor receives the best signal with the lowest noise. By matching impedances, voltage swings, and the frequency response of the JFET to the sensor, the result is a much cleaner signal sent to the digital part of the system.

While other JFET manufacturers produce monolithic dual JFETs on a single substrate, closely placed together for better temperature coefficients and matching, InterFET separates the JFETs by 0.56 millimeters; this creates adjacent die that are matched pairs. The benefit of this approach is lower crosstalk noise between the two monolithic JFETs. When both JFETs are on the same monolithic substrate, a parasitic bipolar transistor is created by the substrate which causes current to flow between the JFETs and appear as noise. InterFET matches adjacent die to stringent electrical characteristics to eliminate the parasitic transistor as a source of noise. By using adjacent die to match, the temperature coefficients and matching are still very well preserved.

Discrete JFETs can be selected, matched, and optimized to each application's specific parameters. All designs and components have performance trade-offs. Most integrated JFET op amps are designed for lower input capacitance at the trade-off of higher noise. If higher input capacitance is acceptable in the design, the noise can be reduced significantly with a discrete JFET front end. See figure 1 below:



IF3600 matched pair front end.
En = 0.5nV/√Hz @ 1KHz @ Gm = 20mS
In = 10fA/√Hz @ 1KHz

LT1115
En = 0.9nV/√Hz @ 1KHz
In = 1200fA/√Hz @ 1KHz

AD743
En = 3.2nV/√Hz @ 1KHz
In = 7fA/√Hz @ 1KHz

Figure 1 – Typical JFET difference amplifier input to Op-amp

If differential input is not needed, then a single ended solution will be lower noise. Figure 2 below is lower noise, and the miller capacitance is removed. This circuits is typically used to measure the noise of other devices and to measure the noise of device Q1, due to its extremely low input referred noise.

Circuit Noise Less JFET Contribution
En = 0.1nV/√Hz @ 1KHz @ Gm = 100mS

IF3601 JFET
En = 0.35nV/√Hz @ 1KHz

IF4500 JFET
En = 0.85nV/√Hz @ 1KHz

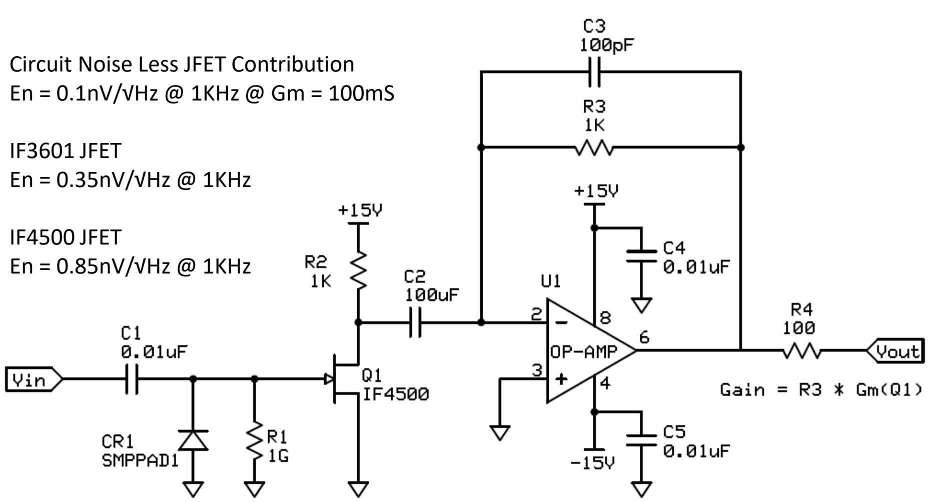


Figure 2 – Single ended low noise JFET input to Op-amp

One of the differences between a JFET and a bipolar transistor is that the JFET can shut current flow to practically zero whereas the bipolar transistor's base current is always greater than zero; this translates to noise injected to the signal. Another key difference of a JFET is that current flows through a single N or P type channel and does not cross a PN junction as it does with a bipolar transistor. Every time a PN junction is crossed noise is generated. This can be seen in figure 3 below:

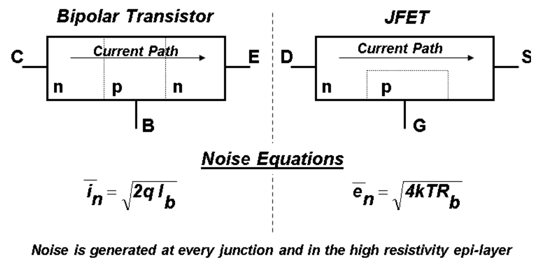


Figure 3 – The current path for the bipolar transistor must cross two PN junctions while the JFET current flow does not cross any PN junctions.

A JFET operates in four basic regions; The cutoff region, the linear region, the saturation region, and the breakdown region. Refer to graph in figure 4.

At the Gate-Source cut off voltage, the current flow through the channel is completely turned off. Since the Gate current (I_G) is near zero even when the voltage is fully cut off, the JFET makes an outstanding analog switch. For example, a 2N4117A operating at the gate-source cut off voltage will have a gate leakage current in the single digit femto-amps which translates into counting electrons as they pass. The gate leakage current is the current that escapes the gate to the source output and is a source of noise.

The output characteristics change at the Pinch-Off voltage (V_P). When the Source-Drain voltage is below the pinch off voltage region in Figure 4, the current-voltage characteristics are very linear. Allowing the JFET to function in this region enables the JFET to act as a voltage-controlled resistor. As the Source-Drain voltage increases or decreases, the Drain Current will correspondingly change in a linear fashion.

When Source-Drain voltage is above Pinch-Off voltage, in the Saturation region in Figure 4, the current is near constant over a wide range of Source-Drain voltages. This allows a JFET to function as a current regulator diode. For example, if the Source-Drain voltage is sufficiently greater than the Pinch-off voltage so that the noise component of the source-drain voltage does not approach the Pinch-Off voltage, then as the noise component of the source-drain voltage fluctuates, the Drain Current output will ideally remain constant. In the real world the Drain Current will not stay perfectly constant over a large Source-Drain voltage swing, but it will be very close to constant. This is an outstanding way to supply clean current from a noisy voltage supply to a sensor or an LED.

In the breakdown region of the JFET, the device acts like a PN junction diode. Current flows and the reverse breakdown voltage level is applied.

In Figure 4 you will see that as the Gate-Source voltage (V_{GS}) increases toward the gate-source cut off voltage ($V_{GS(off)}$) the amount of Drain current (I_D) that is able to flow through the channel decreases for all source-drain voltages.

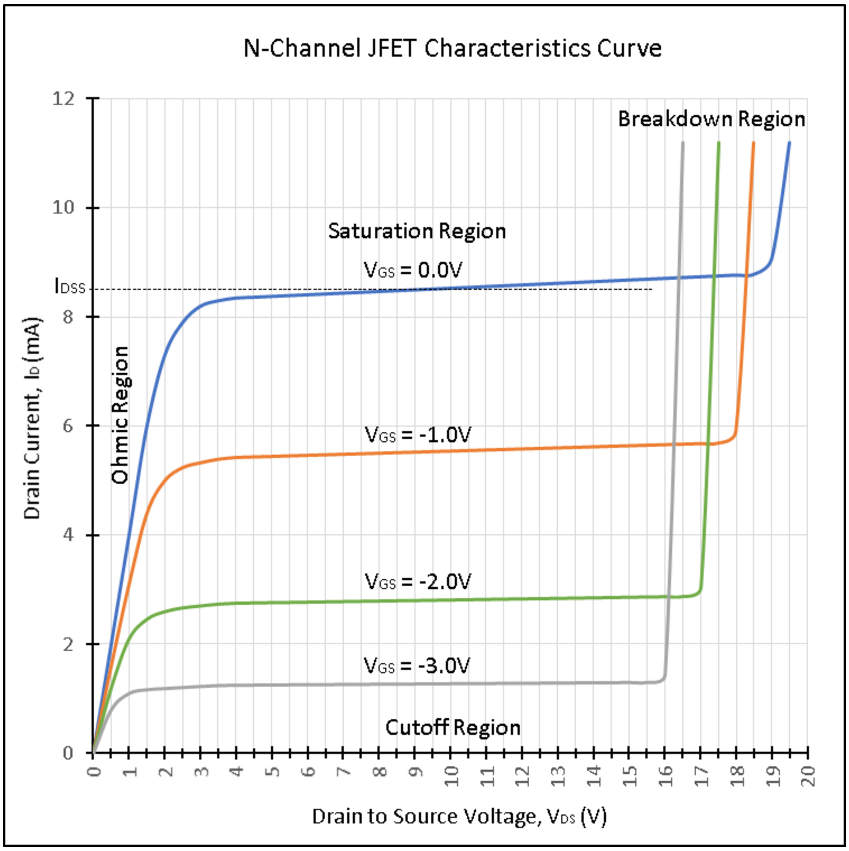
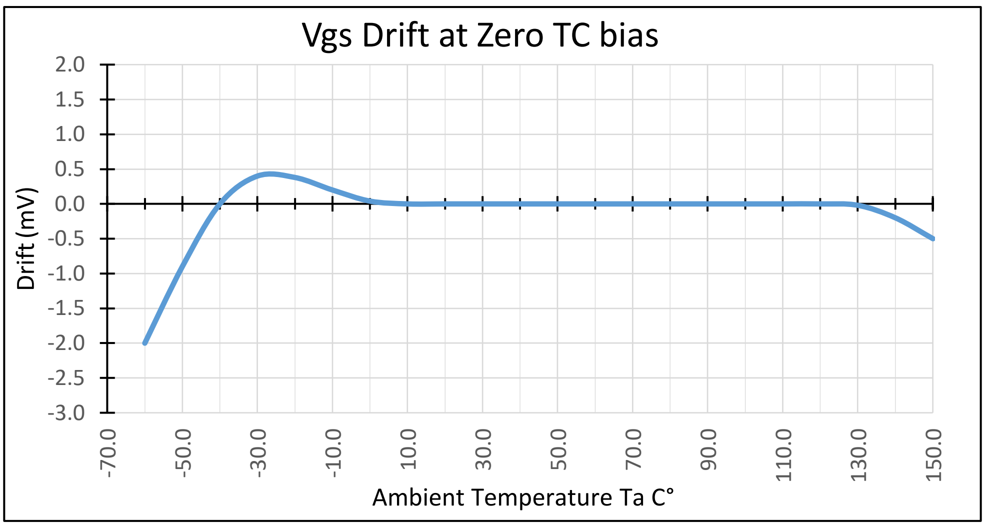


Figure 4 – Typical output characteristics for an N-type JFET

JFET's are very useful when interfacing a sensor with a small output current and/or high output impedance. The JFET Gate has a very high input impedance usually specified in terraOhms, which means that only a very small current is needed to open or close the Gate. As the Gate-Source voltage moves up or down with the sensor output, the drain current will increase or decrease. This characteristic can easily turn a sensor that is outputting a few electrons into a measurable current flow at the JFET output. This prevents the electronics from loading down the sensor and allows the JFET to act as an impedance translator from a high impedance sensor to relatively low impedance A/D.

Another interesting characteristic of JFETs is that they can be biased to achieve near zero temperature coefficient performance over a wide temperature range. As temperature increases, the mobility of the majority carriers within the channel is inhibited, about 0.8%/degree C. Any reverse biased PN junction in a JFET or bipolar transistor exhibits a barrier-potential depletion width that decreases with increased temperature, at about -2.2mV/deg C. For the JFET, this near zero coefficient can be realized if the channel conductance decreases cause the drain current to decrease, and the gate to channel barrier potential decreases causing the drain current to increase at the same rate to offset each other. Resulting in near zero temperature coefficient when the gate source voltage is equal to 0.63 V less than the gate source cut off voltage. $V_{GS} = V_{GS(off)} - 0.63V$. The resulting temperature compensated drift is shown in Figure 5 below.



* Reference Data: Lee Evans, Siliconix Inc. Biasing FET's for Zero DC Drift.

Figure 5. Near zero temperature coefficient

The JFET's unique characteristics make it ideal as an input stage or impedance translator for a sensor or microphone diaphragm. When there is a need for low noise, high gain amplifier such as a microphone output it can handle a wide frequency range without distortion or other injected noise. Some best-in-class part solutions are the following: IF140, IF1320, IF4500, and the IF3601. These parts start with the low capacitance, femtoAmp leakage IF140 to the lowest noise part on the market with the IF3601.

Just like the monolithic dual JFET, the JFET-input op amp has many unwanted paths to inject noise into the signal when the signal is the most vulnerable, at the sensor output. There are many examples where the design was outstanding, but the wrong JFET solution caused enough noise to overwhelm the sensor signal and result in poor performance at the system level. Many design engineers ignore or underestimate the importance of the analog front end and will decide that they can clean up the signal later with the DSP. All too often however, the noise injected into the sensor signal will be enough to mask small subtle changes in the sensor output that are important to the rest the system.

Consider designing with the discrete JFET the next time your sensor or microphone design needs a performance improvement. The discrete JFET will isolate your sensor from the rest of your circuit minimizing load on the sensor while increasing the volume of the output available to that other circuitry without adding injected noise, crosstalk, or mismatching errors.

The physical world is still analog and without a robust clean analog signal to the A/D converter, the rest of the system's great digital processing capabilities won't be realized.