Application Note

JFETs: An Ideal Choice for Audio Applications

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Introduction

Despite the widespread use of MOSFETs in integrated circuits and the popularity of BJTs in analog circuits, JFETs still find much use in audio processing due to the capacity for low-noise amplification. Considering the three major types of noise experienced in amplification (thermal, shot, 1/f), a JFET often produces the least of each when compared to a similar MOSFET or BJT. However, a low voltage gain may prevent JFETs from wider use.

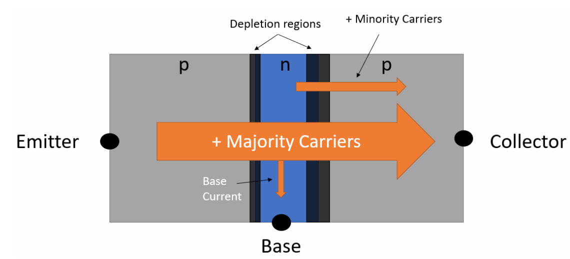

Figure 1:
PNP BJT

JFET Operation and Superior Thermal Performance

The most important JFET parameter is its pinch-off voltage, called V_P or $V_{GS(OFF)}$. Drain-to-source current (I_D) is established by a positive drain-source potential (V_{DS}), and I_D increases nearly linearly with V_{DS} until $V_{DS} > V_P$, when I_D saturates at a fixed value. Maximum saturation current, called I_{DSS}, occurs when $V_{GS} = 0V$. As V_{DS} grows, the depletion regions around the p-type material increase in size, reducing the channel width. At $V_{DS} = V_P$, the depletion regions nearly touch, or "pinch off" the channel, causing the saturation. V_{GS} dipping below 0V (for an n-channel) causes saturation at a lower V_{DS} value, but saturation current is lower in return. Once $V_{GS} < -V_P$, I_D drops to 0mA. JFETs operate in depletion mode as they can conduct without a gate voltage, unlike enhancement mode MOSFETs that cannot.

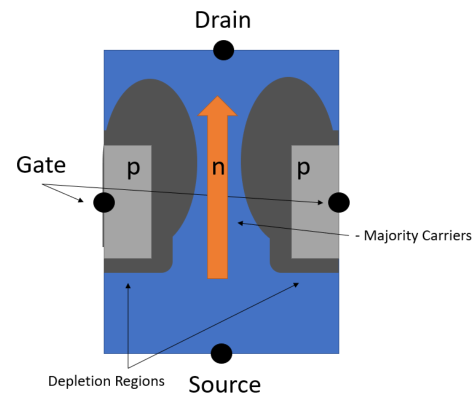

Figure 2:
N-Channel JFET

Both JFETs and MOSFETs are set apart from BJTs by operating as unipolar devices, rather than bipolar. This difference has to do with the charge carriers being used in the device. All transistors contain p-type (rich in positive holes) and n-type (rich in negative electrons) silicon. When biased, both types will contain a minority of the opposing charge carrier as well. While BJT's use the flow of both majority and minority carriers to conduct, JFETs and MOSFETs use only majority carriers when passing through current. As seen at right, the minority carriers in a BJT come from the charge having to cross two depletion regions, while both types of FETs do not experience this.

Crossing a depletion region makes the charge carriers work harder than passing through a clear channel. In addition, when minority and majority carriers are moving together, there's the chance that they collide and recombine, which essentially removes them from the current being carried, wasting energy. For these reasons, BJTs typically operate at a higher temperature than FETs. Higher temperature increases the collisions of charge carriers while navigating the silicon crystal lattice - the source of thermal noise, commonly called white noise.

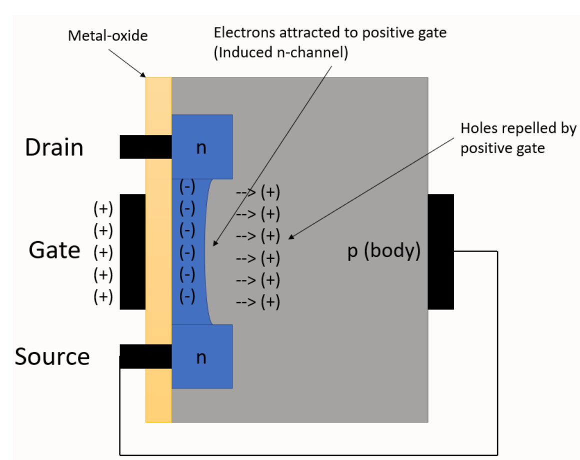

Figure 3:
N-Channel E-MOSFET

Additionally, the gate terminal is shielded by a depletion region in a JFET and by the metal-oxide layer in a MOSFET; this prevents charge carriers from leaving the gate. A small leakage current does flow through the gate of a JFET, but this is often negligible. In a BJT, though, there is no such shielding. A relatively small amount of charge carriers leave through the base terminal, and the operation of a BJT is defined by the relationship between the base and collector currents. The presence of this base current along with two depletion regions contributes to shot noise, which is the biggest negative to using BJTs in signal amplification applications.

Flicker Noise Advantage of JFETs

Often called 1/f and pink noise, flicker noise is marked by proportionality in power to the frequency of the associated signal. While the causes of flicker noise aren't completely understood, JFETs typically perform better than MOSFETs in this area. This may be due to the metal-oxide layer of a MOSFET interfering with the flow of the charge carriers. MOSFET flicker noise has been drastically reduced in the past decade or two, but JFETs can still deliver less flicker noise, when required.

JFET Applications

As a result of low noise and a low gain, JFETs are ideal for use in audio preamplifiers. The signal taken from a microphone or other audio device is typically very low voltage. When a great deal of amplification is required, passing this signal directly to a high-gain BJT or MOSFET filter can make it noisy beyond recognition. A preamplifier increases signal voltage enough to be noise-resistant before being passed onto a higher gain amplifier. High input impedance (minimal input current) and low output impedance (minimal distortion of output voltage from other components) is desirable, which make the common source JFET topology ideal. Below is a single stage amplifier using Central's 2N3819 JFET. A potentiometer is used as a volume control. JFET common source amplifiers tend to have a gain of approximately 10.

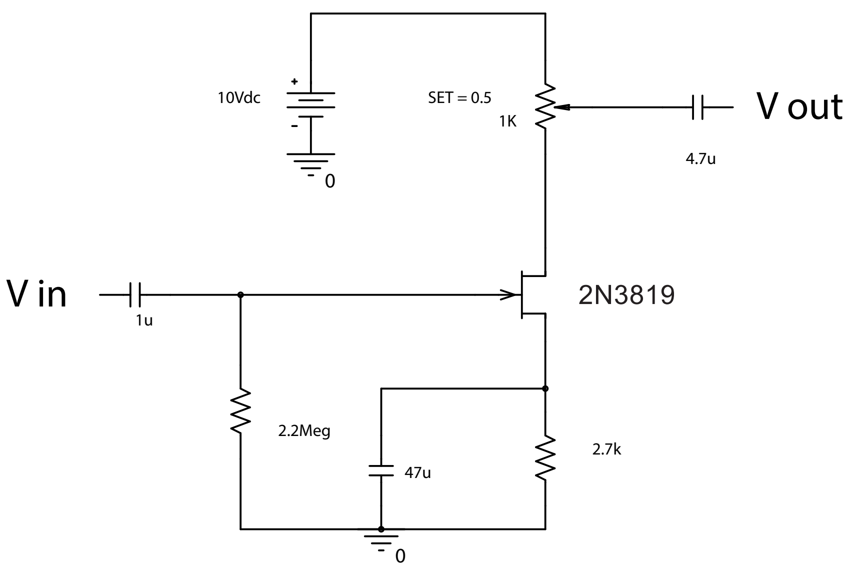

Figure 4:
Single stage amplifier with Central's 2N3819 JFET

One negative of using JFETs is the high input capacitance compared to MOSFETs, which may limit bandwidth in certain applications. A workaround for this problem is to build a cascode amplifier, to drastically lower input capacitance by reducing the impact of the Miller effect. The input of a cascode is a common source amplifier, and it is loaded by a common gate, which produces the output voltage. Miller capacitance is proportional to voltage gain, and the cascode shifts the voltage gain from the common source to the common gate, thus reducing the capacitance.

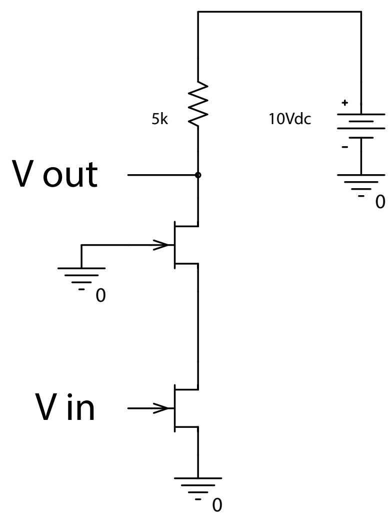

Figure 5:
Cascode amplifier

Conclusion

In recent years, JFETs are somewhat of a middle ground among transistors: not quite as high in gain as BJTs, and not quite as fast in switching as MOSFETs. However, the nearly infinite input impedance and remarkably low noise make JFETs an ideal choice for certain analog applications where noise-free operation is essential.

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