DATA SHEET

Ideas for design
Small-signal Field-effect Transistors

Product specification
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JFET CONSTANT-CURRENT SOURCES

The simplest JFET current source is shown in Fig.1. The JFET has been selected rather than a MOS-FET because it does not require gate bias (depletion mode). The current will be reasonably constant for a V_{DS} larger than several volts. However, because of I_{DSS} spread, the current is unpredictable. This can be seen, for example, with the 2N5484 which has a specified I_{DSS} of 1 to 5 mA. The circuit is attractive because of its simplicity. (Current regulator diodes are JFETs with the gate tied to the source, sorted according to current).

With a small variation this circuit gives an adjustable current source (see Fig.2). Resistor R back-biases the gate by $V = I_D \times R$, thus reducing I_D. The value of R can be calculated from the I_D/V_G characteristic for that particular JFET. This circuit makes it possible to set the current (must be less than I_{DSS}) as well as to make this current more predictable.

A JFET current source always shows some variation of output current with output voltage because of its finite output impedance, even if built with source resistor.

An improvement can be made by using a second JFET to hold the drain-source voltage of the current source constant (see Fig.3). The JFET Q2 has a larger I_{DSS} and is connected in series with the current source. It passes the (constant) drain current from Q1 through to the load, whilst holding the drain at Q1 at a fixed voltage; namely the gate-source voltage that makes Q2 operate at the same current as Q1. Q2 therefore shields Q1 from voltage swings at its output, and since Q1 is not subject to drain voltage variations, it provides constant current.

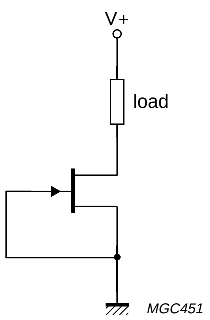

Fig.1 Simple JFET current source.

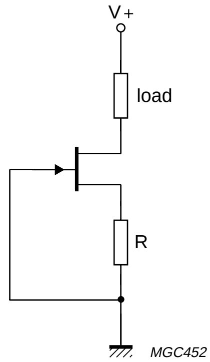

Fig.2 Adjustable JFET current source.

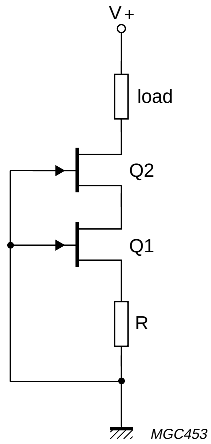

Fig.3 Adjustable JFET current source with high output impedance.

JFET SOURCE FOLLOWERS AND AMPLIFIERS

There are normally three major considerations to be taken into account when designing amplifiers: voltage gain, distortion and noise, and the importance of each of these depends on the application. This is also true for the type of circuit configuration used. There are three basic circuit configurations for JFETs:

- Common source configuration (CSC)
- Common gate configuration (CGC)
- Common drain configuration (CDC).

The choice of circuit configuration depends on the design requirements with respect to:

- Input impedance (high in CSC and CDC)
- Impedance matching to signal source and load
- Distortion (lowest in CGC).

Common-drain amplifiers, or source followers, and common-source amplifiers are analogous to emitter followers and common-emitter amplifiers in bipolar transistors. However, the absence of DC gate current makes it possible to realize very high input impedances. Such amplifiers are essential when dealing with the high-impedance signal sources encountered in measurement and instrumentation.

It is convenient to use a self-biasing scheme with a single gate-biasing resistor to ground.

Figure 4 shows a source follower, Fig.5 a common- source amplifier. The gate-biasing resistor can be quite large (at least 1 MΩ), because the gate leakage current is in the order of nA.

Matched FETs can be used to construct high input impedance front-end stages for bipolar differential amplifiers, op-amps and comparators.

There are many applications in which the signal source impedance is intrinsically high, e.g. capacitor microphones, pH probes, charged particle detectors, or microelectrode signals in biology and medicine. In these cases a FET input stage is ideal.

Within some circuits there are situations where the following stage must draw little or no current. Common examples are analog ‘sample and hold’ and ‘peak detector’ circuits, in which the level is stored in a capacitor and will ‘droop’ if the next amplifier draws significant input current. In all these applications the negligible input current of a FET is an important feature.

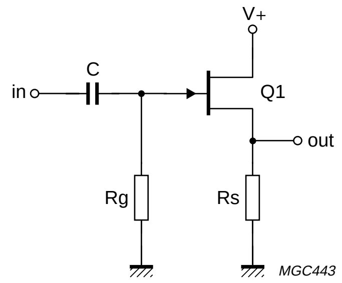

Fig.4 JFET source follower circuit.

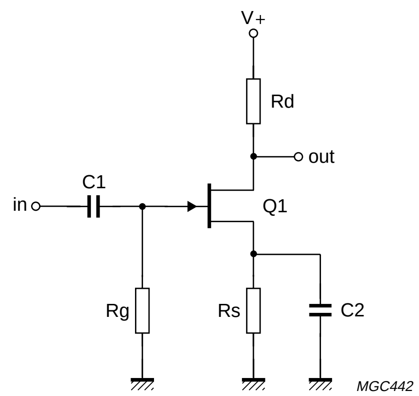

Fig.5 Common-source amplifier circuit.

JFET VOLTAGE CONTROLLED RESISTORS

Under certain biasing conditions, the on-resistance of the JFET is a function of the gate source voltage alone, so that the JFET will behave as an almost pure ohmic resistor.

Figure 6 shows the output characteristics of a PMBF4416 for relatively small positive and negative values of V_{DS} in the linear or triode region, where $V_{DS} < V_{GS} - V_{GSth}$. It can be seen that all characteristics pass through the origin (no offset) and are symmetrical and relatively linear. This means that the JFET can be used as a variable resistance in voltage controlled attenuators, analog multipliers, amplitude modulators, bandwidth controlled filters, automatic gain control circuits, and so on.

The channel resistance in the linear region is the inverse of the transconductance in the saturated region: $R_{DS} = 1/g_m$ at a given V_{GS}.

In the first quadrant, the boundaries are set by $V_{GS} = 0$ and $V_{GD} = -V_{GSth}$, in the third quadrant by $V_{GS} = -V_{GSth}$ and $V_{GD} = 0$.

In the first quadrant, as V_{DS} increases towards $V_{DSsat} = V_{GS} - V_{GSth}$, the value of R_{DSon} changes, causing distortion in voltage-controlled-resistor circuits. The same thing happens in the third quadrant, as the negative drain voltage exceeds the negative gate voltage and causes the gate-channel diode to start conducting.

This signal distortion must be as low as possible, while at the same time a large signal handling capability is desirable. The linearity can be improved by means of feedback from the drain to the gate (see Fig.7).

Now, part of the drain signal is applied to the gate. In the case of a positive V_{DS} signal, this reduces the gate voltage, increasing the drain current and pushing the bias line into the more linear part of the operating region.

When V_{DS} is negative, V_{GS} will go more negative, causing a reduction in drain current. This reduces the conduction of the gate channel diode, resulting in a more linear bias line.

The value of R1 and R2 should be equal, to maintain symmetry between the first and third quadrants.

Feedback is essential for a reasonably linear characteristic, and high values of I_{DSS} and V_{GSth} are preferred.

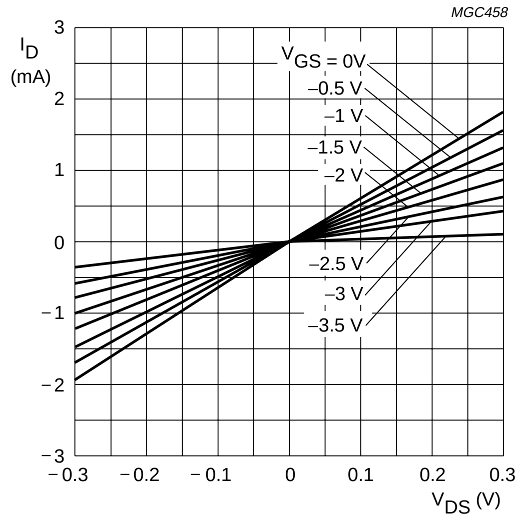

Fig.6 Output characteristics; PMBF4416.

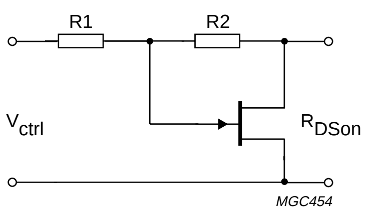

Fig.7 JFET voltage controlled resistor.

MOS-FET ANALOG SWITCHES

The combination of low on-resistance, extremely high off-resistance, low leakage current and low capacitance, makes FETs, particularly lateral MOS-FETs, ideal as voltage-controlled switching elements for analog signals.

Like mechanical switches, the FET switch is a bi-directional device; signals can go either way through it.

The circuit as shown in Fig.8 will switch signals in the –10 to +10 V range if the gate has been driven from –15 V (off) to +15 V (on); the body (back-gate) should then be tied to –15 V.

With any FET switch it is important to provide a load resistance in the 1 to 100 kΩ range in order to reduce capacitive feed-through of the input signal, that would otherwise occur during the off-state. If it is necessary to switch signals that may nearly reach the supply voltages, the simple N-channel switch shown in Fig.8 will not work, since the gate is not forward biased at the peak of the signal swing.

The solution is to use paralleled complementary MOS-FET switches (Fig.9). In this case the gate-drive is somewhat more complicated, since the N-channel FET needs to be positive biased with respect to the back-gate and the P-channel negative biased. This switch is also bidirectional; either terminal can be the input.

A useful application of FET analog switches is the ‘multiplexer’, a circuit that allows you to select any of several inputs, as specified by a control signal. The analog signal present on the selected input will be passed through to the output.

Because analog switches are bidirectional, an analog multiplexer is also a ‘demultiplexer’; a signal can be fed into the output and will appear on the selected input.

Voltage-controlled analog switches form essential building blocks for op-amps, integrators, sample-and-hold circuits and peak detectors.

Another application is in switchable RC low-pass filters. A multiplexer is used to select one out of a series of resistors, or independent switches are used to select one or more resistors in parallel.

As stated before, a load resistor is necessary to reduce capacitive feed-through (cross-talk).

If a switch that has really low cross-talk performance is needed, the circuit shown in Fig.10 could be used. When switches Q1 and Q2 are off, Q3 is on and will prevent any capacitive feed-through.

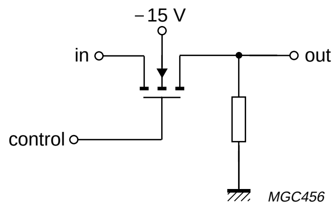

Fig.8 MOS-FET analog switch.

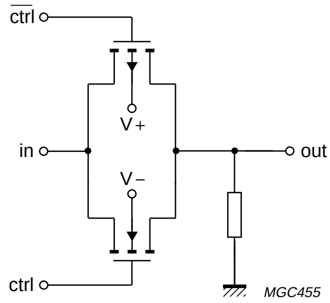

Fig.9 Paralleled complementary MOS-FET switches.

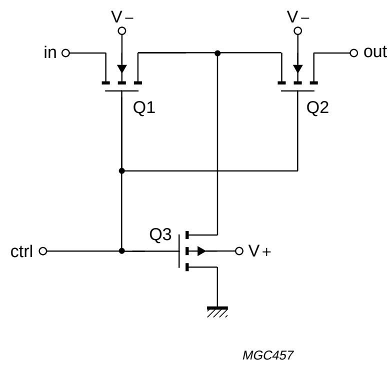

Fig.10 MOS-FET analog switch with low cross talk performance.

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