5. EXPERIMENT 5. JFET NOISE MEASURE- MENTS

5.1 Object

The objects of this experiment are to measure the spectral density of the noise current output of a JFET, to compare the measured spectral density to the theoretical spectral density, and to determine the lower flicker noise corner frequency below which excess noise generated by generation-recombination centers in the JFET intrinsic region dominates.
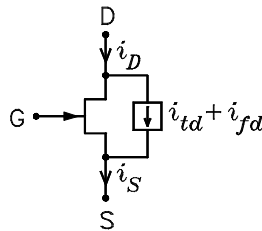
5.2 Theory

Figure 5-1   JFET noise equivalent circuit.

The noise equivalent circuit of a JFET is shown in Fig. 5-1, where $\overline{i_{td}^2}$ is the mean-square thermal drain noise current and $\overline{i_{fd}^2}$ is the excess or mean-square flicker noise current. These are given by

$$\overline{i_{td}^2} = 4kT \left(\frac{2g_m}{3}\right) \Delta f \tag{5.1}$$

$$\overline{i_{fd}^2} = \frac{K_f I_D}{f} \Delta f \tag{5.2}$$

where g_m is the small-signal transconductance and K_f is the flicker noise coefficient. The small-signal transconductance is given by either of the two relations

$$g_m = \frac{-2}{V_{TO}} \sqrt{I_D I_{DSS}} = 2\sqrt{\beta I_D} \tag{5.3}$$

where V_{TO} is the threshold or pinch-off voltage, I_D is the quiescent drain current, I_{DSS} is the drain-to-source saturation current, and β is the transconductance coefficient. In the active mode or saturation region, the drain current is given by either of the two relations

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{TO}}\right)^2 = \beta\left(V_{GS} - V_{TO}\right)^2 \tag{5.4}$$

I_{DSS} is related to β by

$$I_{DSS} = \beta V_{TO}^2$$

and β is a function of the drain-to-source voltage V_{DS} given by

$$\beta = \beta_0\left(1 + \lambda V_{DS}\right)$$

where β_0 is the value of β for $V_{DS} = 0$. For the n-channel JFET, both V_{GS} and V_{TO} are negative. The small signal transconductance g_m is positive. (Note that this β has nothing to do with the β for a BJT.)

The flicker noise coefficient K_f is related to the flicker noise corner frequency f_{flk} by

$$K_f = \frac{16kT}{3} f_L \sqrt{\frac{\beta}{I_D}} \tag{5.5}$$

Thus the mean-square flicker noise current can also be expressed as

$$\overline{i_{fd}^2} = 4kT\left(\frac{2g_m}{3}\right)\frac{f_L}{f}\Delta f \tag{5.6}$$

This illustrates that the flicker noise corner frequency f_{flk} is the frequency at which the mean-square thermal and flicker currents are equal in magnitude. Thus f_{flk} may be experimentally determined by measuring the frequency at which the total noise current increases by 3 dB over the value in the region at which thermal noise dominates, i.e. the region where the noise is flat or white.

5.3   Laboratory Procedure

5.3.1   Curve Tracer Measurements

Use the transistor curve tracer to obtain data for I_D for ten values of V_{GS} for $V_{DS} = 10\,\text{V}$. Because the JFET is a depletion mode device all the values of the gate-to-source voltage are negative. If the JFET is in the saturation region

$$\sqrt{I_D} = \sqrt{\beta}\left(V_{GS} - V_{TO}\right) \tag{5.7}$$

which is a straight line with a slope of $\sqrt{\beta}$ and a y intercept of $-\sqrt{\beta}V_{TO}$. Perform a linear regression analysis to obtain the optional least squares estimate of β and V_{TO}. Because the JFET is a depletion mode device all the values of V_{GS} and the value of V_{TO} will be negative.

5.3.2 Biasing

The circuit shown in Fig. 5-2 is the test circuit for measuring the JFET noise. When this circuit is assembled on the solderless breadboard, the power supply rails should be decoupled with a $100\,\Omega$ resistor and a $100\,\mu\text{F}$ capacitor.
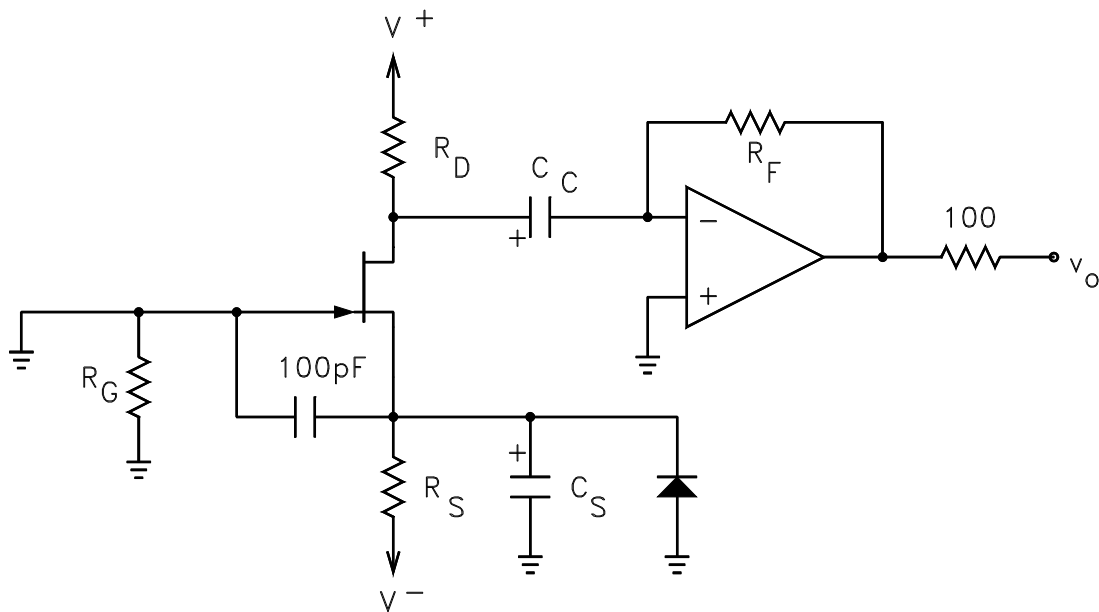

Figure 5-2   JFET Noise Measurement Circuit

Assemble the circuit shown in Fig.5-2. The purpose of the diode is to prevent the accidental application of a positive gate-to-source voltage larger the a pn junction drop which would destroy the JFET. Use a TL071 as the op amp, a 2N5457 N Channel JFET as the transistor that is the device under test, and a 1N4148 diode. The component values are $R_D = 7.5\,\text{k}\Omega$, $R_S = 20\,\text{k}\Omega$, $R_G = 12\,\text{k}\Omega$, $R_F = 10\,\text{k}\Omega$, $C_C = 10\,\mu\text{F}$, and $C_S = 330\,\mu\text{F}$. Measure the actual value of the resistors with either a digital multimeter or an RCL meter. Set the dc power supply to produce $V^+ = 15\,\text{V}$ and $V^- = -15\,\text{V}$. Turn the dc power supply on. Measure the value of the dc drain and source currents. Do this by measuring the dc voltages across R_D and R_S and dividing by the resistance value. If they are not approximately equal something is awry. Because the JFET is a depletion mode device that means the V_{GS} must be negative; with the gate being grounded that requires the source terminal to be at a positive voltage. Measure the value of the source voltage to ensure that it is positive.

5.3.3 Frequency Response

Experimentally determine the frequency response of the JFET and op amp in combination. To do this, disconnect the short from the gate to ground, and connect the function generator output to the gate. The theoretical value of the voltage gain is

$$A_v = \frac{V_o}{V_g} = -g_m R_F \tag{5.8}$$

where V_g is the generator voltage. Note that the amplitude of V_g must be small enough so that the output is not distorted.

 Assemble the circuit again as shown in Fig. 5-2. Namely, remove the function generator from the circuit and turn it off and connect the gate to circuit ground.

5.3.4 JFET Noise, and Corner Frequency

Connect the Dynamic Signal Analyzer to the output of the op amp. Using a total analysis band of $100\,\mathrm{kHz}$, measure the spectrum of output. From the spectrum obtained, decide on an optimum frequency to measure the noise so that the midband white noise generated by the JFET is not affected by excess or flicker noise. Plot the spectrum obtained. From the display, determine the flicker noise corner frequency f_{flk} at which the noise voltage increases by 3 dB from the value in the white noise region.

5.4 Laboratory Report

5.4.1 Comparison of Experimental and Theoretical Spectra

Compare the measured noise spectral densities for the white noise region of the spectrum to that predicted by the theoretical formula for $\overline{i_{td}^2}$. What is the lower corner frequency below which the excess noise dominates? A major source of error in this calculation is the excess noise in the measurement system. If this dominates, the excess noise generated by the JFET may be difficult to determine.

5.4.2 Computation of $\overline{v_n^2}$

Reflect the $\overline{i_{td}^2}$ and $\overline{i_{fd}^2}$ noise sources to the JFET gate and compute $\overline{v_n^2}$. Use the experimental data from 5.3.3 of the procedure. (Divide the voltage at the output of the op amp by $g_m R_F$

to obtain $\sqrt{\overline{v_n^2}}$.) Compare the experimental values with the theoretical values predicted by the equation

$$v_n^2 = \frac{\overline{i_{td}^2} + \overline{i_{fd}^2}}{g_m^2} = 4kT\left(\frac{2}{3g_m}\right)\Delta f + \frac{K_f I_D \Delta f}{g_m^2 f} \tag{5.9}$$