AN-6601
Low Noise JFET Amplifiers

Introduction

Discrete JFETs reign supreme as low noise amplifiers. JFETs are virtually free from the problems of current noise, popcorn noise and limited bandwidth which plague bipolar transistors and bipolar input op amps.

Unfortunately, JFETs are awkward to use because of low gain and the need of extensive biasing networks. However, monolithic op amps are cheap and easy to use but suffer from poor noise performance. By combining JFETs with an op amp yields single and differential input amplifiers that have the best of both worlds; low noise, high gain and ease of use.

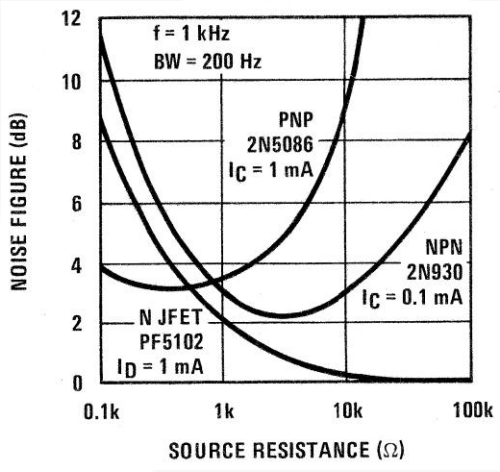

Figure 1. Bipolar and JFET Transistor Noise Comparison

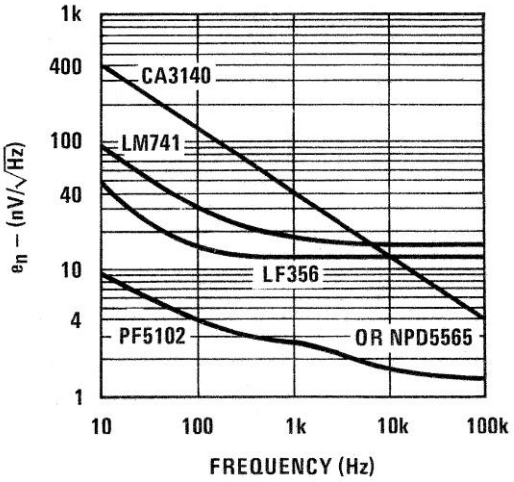

Figure 2. Discrete JFET and Op Amp Noise Comparison

The main problem with JFETs is that the voltage gain is limited by the size of the load resistance which is limited by the power supply voltage and the FET operating current. The voltage gain can be increased by combining the JFET (a transconductance amplifier) with an op amp current to voltage (I/V) amplifier, circumventing the limited load resistor.

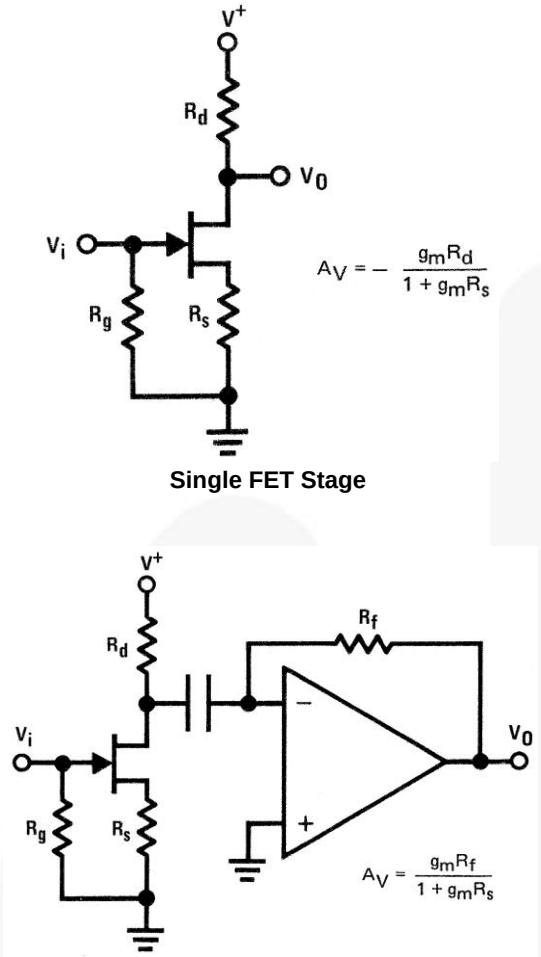

Figure 3. FET Gain Stages

In the FET/op amp configuration, the FET AC drain current is shunted to the op amp virtual ground and through its feedback resistor, bypassing the FET drain resistor, Rd. The drain resistor is used to bias the FET in a linear region with the feedback resistor, Rf, used to set the gain.

Biasing problems associated with lot and device to device parameter variations are minimized by biasing the source through a large resistor to the negative supply of the op amp. A portion of the source resistor should be unbypassed to minimize gain variations between FETs. From a design standpoint, the maximum AC drain current should be 1/10 of the FET quiescent current for low distortion. The unbypassed portion of the source resistor should be limited to 220 Ω for minimum noise and to increase the op amp feedback resistor (decreased AC current).

Expressions for the single and differential amplifier configurations are needed for optimizing the noise to meet system noise requirements.

Amplifier noise performance is adequately described by modeling the noise sources as a series voltage generator and a shunt current generator with a series voltage generator for the source resistance thermal noise. The thermal noise of a resistor is given by Nyquist's relation and has a spectral density given by $e_n^2 R$ where:

$$e_n^2 R = 4kTR$$

$e_n^2 R$ = mean square noise voltage per unit bandwidth (nV^2/Hz)

k = Boltzmann constant (1.38×10^{-23} VAS/°K)

T = absolute temperature (°K)

R = resistance (Ω)

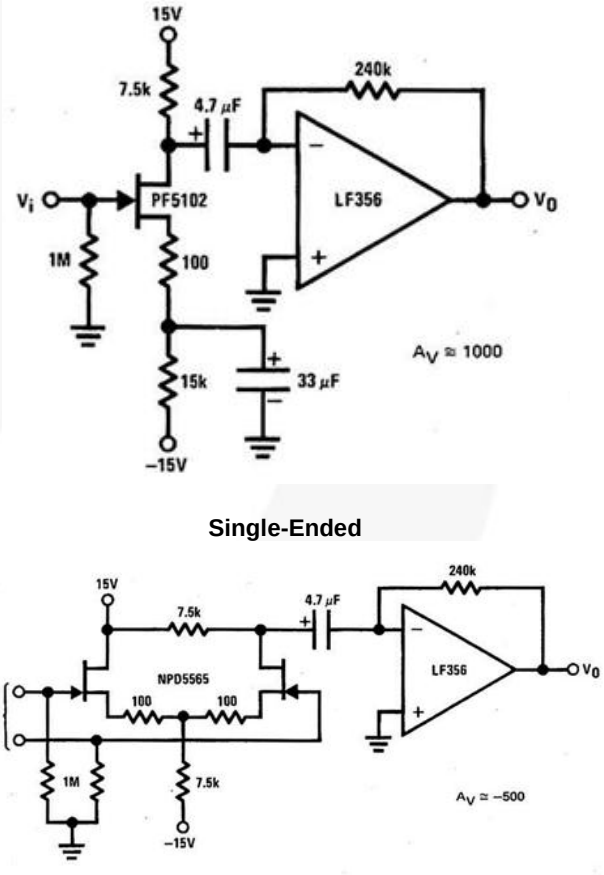

Figure 4. High Gain FET/Op Amp AC Amplifiers

The single ended and differential input amplifier input noise (FET noise current is negligible) is given by the RMS sum of the noise generators.

Single-ended:

$$e_{nt}^2 = e_{nf}^2 + e_{ns}^2 + \left(\frac{1 + g_m R_s}{g_m R_d}\right)^2 (e_{nA}^2 + e_{nR}^2 + i_{nA}^2 R^2)$$

Differential Input:

$$e_{nt}^2 = 2\,(e_{nf}^2 + e_{ns}^2) + 4\left(\frac{1 + g_m R_s}{g_m R_d}\right)^2 (e_{nA}^2 + e_{nR}^2 + i_{nA}^2 R^2)$$

with

e_{nt} = total input noise voltage (nV/√Hz)

e_{nf} = FET noise voltage (nV/ √Hz)

e_{nA} = op amp noise voltage (nV/√Hz)

i_{nA} = op amp noise current (pA/√Hz)

e_{ns} = source resistor thermal noise (nV/√Hz)

e_{nR} = drain and feedback (R_d//R_f) resistor thermal noise (nV/√Hz)

g_m = FET transconductance at the FET operating current (mmho)

R = parallel resistance of R_d and R_f (Ω)

The differential configuration has higher noise and lower

gain than the single-ended version, but is useful when low distortion or balanced inputs are of paramount importance.

The noise of the op amp and the FET drain resistor is reduced by the gain of the FET portion of the amplifier $\frac{g_m R_d}{1+g_m R_s}$. The noise of the feedback resistor has little effect on the noise but in conjunction with the drain resistor, it can have a dramatic effect on the total circuit noise. The drain resistor is the input leg of an inverting amplifier with the op amp and the feedback resistor. This amplifier has a gain of —Rf/Rd which boosts the op amp noise, limiting the size of Rf to about 390 k.

Practical low noise, high gain AC amplifiers can be built using a low noise JFET and just about any op amp. The op amp needs to meet the slew rate and bandwidth requirements of the circuit, eliminating selected low noise op amps or complex discrete amplifiers.

A note of caution is in order for the op amp noise. Virtually any JFET input or bipolar input op amp can be used without trouble, but MOSFET input op amps should be avoided. MOSFET 1/f noise is one or more orders of magnitude greater than discrete JFETs, JFET op amps or bipolar input op amps. MOSFETs have 1/f corner frequencies (where the noise power rises as 1/f) starting as high as 100 kHz. The other forms of amplifiers have 1/f corner frequencies of 1 kHz and less. Quite a difference.

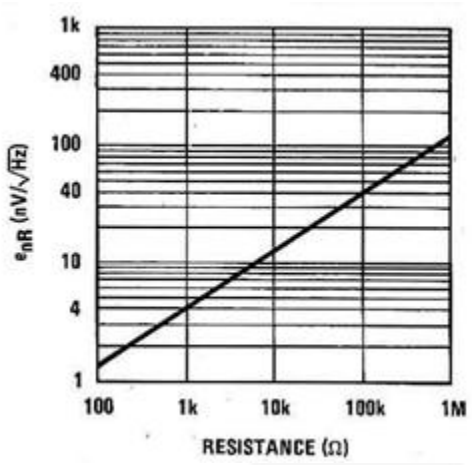

Figure 5. Thermal Noise vs Resistance

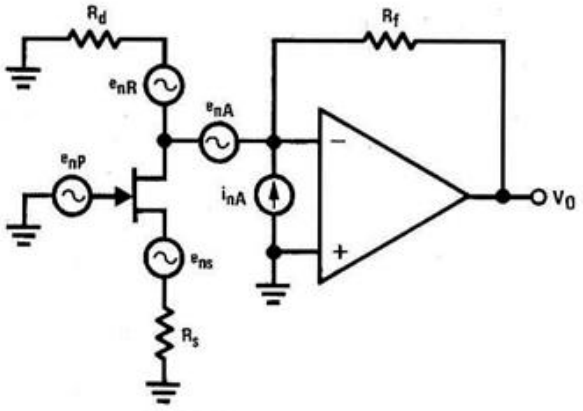

Figure 6. Single-Ended Noise Model

References

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