Power Gain of Single Stage JFET Amplifiers

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Introduction

This note explores the ultimate possible in power gain for a single stage JFET amplifier. This is important to know for it affects design decisions. Each of the three types of amplifiers, common-source, common-drain, and common-gate are treated separately.

The purpose is to determine the ultimate power gain of the transistor without losses caused by the bias circuit. At high frequencies various transformer and resonant methods are used to eliminate all losses by the bias circuit as shown in the sample circuits. The ultimate power gain of the simple circuits discussed in this course are typically in the 6 to 12 dB range less because of bias circuit losses.

In the sample circuits shown, transformers and parallel resonant circuits (high impedance) are used to apply and extract signals from the amplifiers. For simplicity the transformers are shown with 1:1 turn ratios. In practice the turn ratios would be adjusted for optimum impedance match. As shown, the input resistance is just that looking into the transistor terminal and without the usual shunting (power loss) of bias resistors. Thus, all of the input current is into the transistor terminal. In the output circuit there is no R_D or R_S to shunt output power. Thus, all of the output current is through the load.

Common-Source

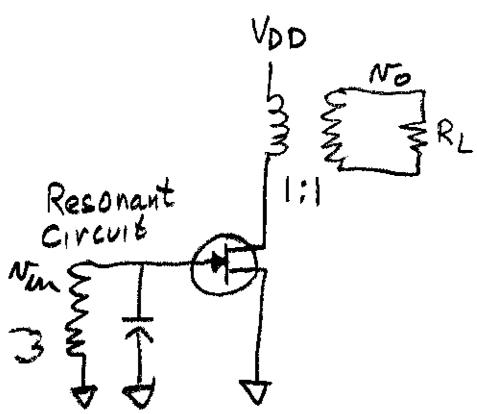

Figure 1: Common-source amplifier for high power gain

The input power is given by

$$p_{in} = v_{in}^2 / r_{in} \qquad \text{Eq. 1}$$

The output voltage is given by

$$v_o = v_{in} * g_m * R_L \qquad \text{Eq. 2}$$

Power Gain of Single Stage JFET Amplifiers

The corresponding output power is given by

$p_o = v_o^2 / R_L = v_{in}^2 * g_m^2 * R_L$ Eq. 3

The power gain is obtained by

$\mathbf{p_g = p_o / p_{in} = g_m^2 * R_L * r_{in}}$ **Eq. 4**

g_m is rarely higher than about 0.01 for a JFET. The input resistance, r_{in}, looking into the gate of a JFET is hard to say specifically but is generally in the 100M to 1G range. A median value of 300M will be used. RL could be several tens of thousands of ohms as a practical maximum – a nominal value of 50K will be used. Combining these values produces a power gain of 1.5E9 or roughly 90 dB – a huge value! At the ultimate extreme the power gain can be pushed up to around 100 dB. However, in practice a more typical power gain would be around 60 dB.

Common-Drain

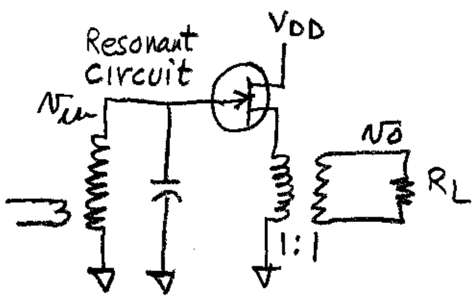

Figure 2: Common-drain circuit for high power gain

The input power is given by

$$p_{in} = \frac{v_{in}^2}{r_{in}} \qquad \text{Eq. 5}$$

The output voltage is given by

$$v_o = \frac{v_{in} * g_m * R_L}{1 + g_m * R_L} = \frac{v_{in}}{[1 / (g_m * R_L) + 1]} \qquad \text{Eq. 6}$$

Power Gain of Single Stage JFET Amplifiers

The corresponding output power is given by

$$p_o = \frac{v_{in}^2}{R_L * [1 / (g_m * R_L) + 1]^2} \quad \text{Eq. 7}$$

The power gain is obtained by

$$p_g = \frac{p_o}{p_{in}} = \frac{r_{in}}{R_L * [1 / (g_m * R_L) + 1]^2} \quad \text{Eq. 8}$$

It can be shown that the maximum power gain occurs when R_L is equal to $1/g_m$— i.e. the load impedance is matched to the output impedance of $1/g_m$. This lets us write Eq. 8 as

$$\mathbf{p_g = 0.25 * g_m * r_{in}} \quad \textbf{Eq. 9}$$

Using a high g_m of 0.01 and 300M for r_{in} produces a power gain of 750,000 or roughly 60 dB.

Common Gate

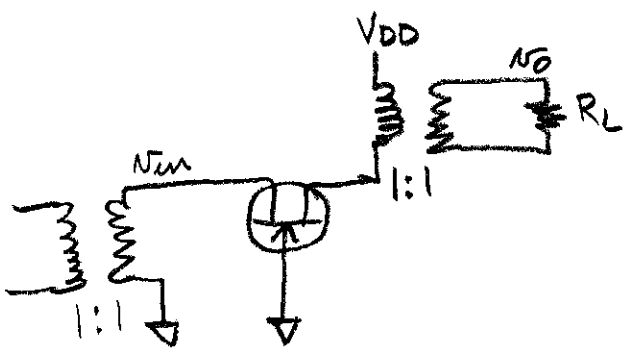

Figure 3: Common-gate circuit for high power gain

The input power is given by

$$p_{in} = v_{in}^2 / r_{in} = g_m * v_{in}^2 \quad \text{Eq. 10}$$

The output voltage is given by

$$v_o = v_{in} * g_m * R_L \quad \text{Eq. 11}$$

Power Gain of Single Stage JFET Amplifiers

The corresponding output power is given by

$$p_o = \frac{v_o^2}{R_L} = \frac{v_{in}^2 * g_m^2 * R_L^2}{R_L} = v_{in}^2 * g_m^2 * R_L \qquad \text{Eq. 12}$$

The power gain is obtained by

$$\mathbf{p_g = \frac{p_o}{p_{in}} = g_m * R_L} \qquad \textbf{Eq. 13}$$

Using a high gm of 0.01 and an R_L of 50,000 ohms, the ultimate power gain is around 500 or 27 dB. Although this value is much lower than the other two configurations, the common-gate amplifier has certain advantages at high frequencies over the other two.

Conclusions

The common-source amplifier is capable of the highest power gain of any of the three types of amplifiers. But that does not meat that it always achieves the highest gain. The common-drain amplifier is also capable of very high power gain. The common-gain amplifier has the lowest power gain. However, these amplifiers have different characteristics in terms of input and output impedance that can an advantage in various situations. No amplifier type is ideal for all situations. The engineer should use the type most appropriate for the job at hand.