Power Gain of Single Stage BJT Amplifiers

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Introduction

This note explores the ultimate possible in power gain for a single stage BJT amplifier. This is important to know for it affects design decisions. Each of the three types of amplifiers, common-emitter, common-collector, and common-base 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 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_C or R_E to shunt output power. Thus, all of the output current is through the load. All capacitors are short circuits at the frequency of interest. Some circuits use resonant networks instead of transformers for the same effect.

Common Emitter Amplifier

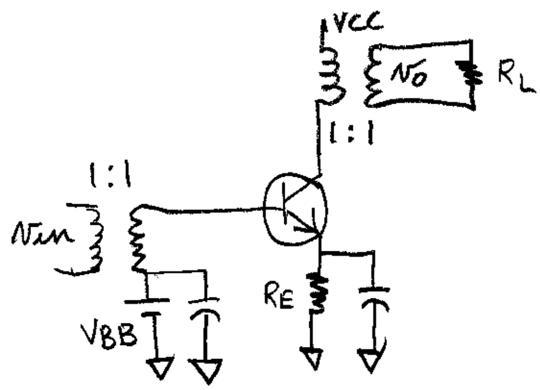

Figure 1: Common-emitter circuit for high power gain

The input resistance is given by

$$r_{in} = (B+1) * r_e \qquad \text{Eq. 1}$$

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The input power is given by

$p_{in} = v_{in}^2 / [(B+1) * r_e]$ Eq. 2

The input signal base current is given by

$i_b = v_{in} / [(B+1) * r_e]$ Eq. 3

The corresponding collector signal output current is given by

$i_c = B * i_b = v_{in} * B / [(B+1) * r_e]$ Eq. 4

The output power is given by

$p_o = i_c^2 * R_L = \{v_{in} * B / [(B+1) * r_e]\}^2 * R_L$ Eq. 5

The power gain can be calculated using the above results as

$$p_g = \frac{p_o}{p_{in}} = \frac{\{v_{in} * B / [(B+1) * r_e]\}^2 * R_L}{v_{in}^2 / [(B+1) * r_e]} = \frac{B^2 * R_L}{(B+1) * r_e}$$ Eq. 6

Since B is generally large the power gain can be simplified to

$p_g = B * R_L / r_e$ **Eq. 7**

The conclusions of Equation 7 are:

- Power gain is proportional to B
- Power gain is proportional to R_L – one caveat: R_L must be less than the shunt output resistance
- Power gain is proportional to I_E since r_e is inversely related to r_e – one caveat: r_e must be greater than the bulk resistance of the transistor

Since the beta of a typical transistor is in the 150 range and it is possible to make R_L be in the range of over three hundred times r_e then the ultimate power gain of the common-emitter amplifier is in the 50,000 range or about 47 dB. Under extreme conditions it might be possible to obtain a power gain over 50 dB.

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Common-Collector

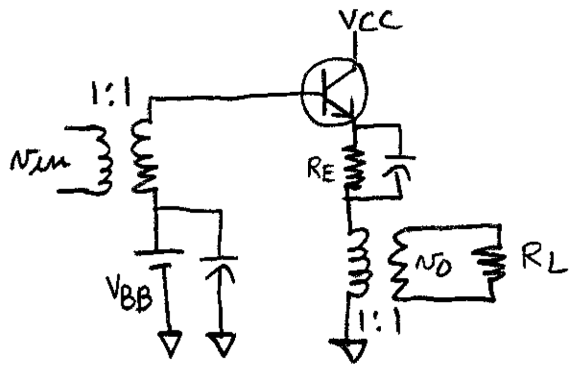

Figure 2: Common-collector circuit for high power gain

The input resistance depends on the load resistance and is given by

$r_{in} = (B+1)*(r_e + R_L)$ Eq. 8

The input power is given by

$p_{in} = v_{in}^2 / [(B+1)*(r_e + R_L)]$ Eq. 9

The voltage across the load is given by

$v_o = v_{in} * (R_L / (r_e + R_L))$ Eq. 10

The corresponding output power is given by

$p_o = v_o^2 / R_L = [v_{in} * (R_L / (r_e + R_L)]^2 / R_L$ Eq. 11

The power gain can be calculated using the above results as

$$p_g = \frac{p_o}{p_{in}} = \frac{[v_{in} * (R_L / (r_e + R_L)]^2 / R_L}{v_{in}^2 / [(B+1)*(r_e + R_L)]} = \frac{(B+1) * R_L}{r_e + R_L}$$ Eq. 12

Since B is large and R_L is usually much greater than re the power gain can be simplified to:

$p_g = B$ **Eq. 13**

Since beta is typically in the 150 range then the ultimate power gain of a common-collector amplifier is around 150 or about 22 dB. A few dB more gain is possible with higher beta but that is it.

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Common Base

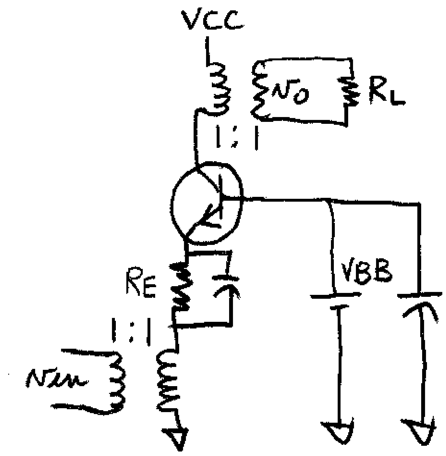

Figure 3: Common-base circuit for high power gain

The input resistance is given by

$r_{in} = r_e$ Eq. 14

The input power is given by

$p_{in} = v_{in}^2 / r_e$ Eq. 15

The emitter or input current is given by

$i_e = v_{in} / r_e$ Eq. 16

The corresponding collector current is given by

$i_c = i_e * B / (B+1) = v_{in} * B / [(B+1) * r_e]$ Eq. 17

The output power is given by

$p_o = i_c^2 * R_L = \{v_{in} * B / [(B+1) * r_e]\}^2 * R_L$ Eq. 18

The power gain can be calculated using the above results as

$$p_g = \frac{p_o}{p_{in}} = \frac{\{v_{in} * B / [(B+1) * r_e]\}^2 * R_L}{v_{in}^2 / r_e} = \frac{B^2 * R_L}{(B+1)^2 * r_e}$$ Eq. 19

Since B is large, the power gain can be simplified to

$p_g = R_L / r_e$ **Eq. 20**

About the highest practical rato of R_L / r_e is in the three hundred range – perhaps mid to upper hundreds at the extreme. Thus, the ultimate power gain of a common-base stage is in the 20 to 30 dB range. The practical limit of how large R_L can be is the shunt output resistance of the collector circuit.

Conclusions

The common-emitter 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-collector and common-base amplifiers are similar in their ultimate power gains but the ultimate is only about one hundredth of the capabilities of the common-emitter amplifier. 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.