Choosing R_C for Common-Emitter and Common-Base Amplifiers

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October 8, 2005, rev. Sept. 11, 2008

This note describes the thought process for choosing the collector resistor, R_C, in the design of a common-emitter or common-base amplifier. There are no mathematics to calculate a value for R_C so this resistor must be chosen within a reasonable range depending on the value of the load resistance, R_L. The choice involves a tradeoff between high signal swing (i.e. relatively high power) delivered to the load resistance versus power gain of the amplifier. The maximum of one is the minimum of the other.

The key to making a good choice is to clearly understand what the goal for the amplifier is. If the amplifier is the final stage in an amplifier chain then the goal is generally maximum linear signal swing to the load – i.e. many volts peak to peak. If the amplifier is early in a cascade of amplifiers then the goal is generally maximum power gain as the output signal will be very small – perhaps millivolts.

Rather than discussing a particular ohmic value for R_C given a specific ohmic value for R_L, the discussion will be concerning the ratio of R_C to R_L, i.e. (R_C/R_L), as this reduces the problem to a single variable. There are two competing mathematics concerning (R_C/R_L). One is voltage division between the output resistance of the amplifier and the load – a low value of (R_C/R_L) makes the voltage division factor approach the ideal of 1.0. The other is power gain of the amplifier – a high value of (R_C/R_L) up to a point maximizes the power gain. There is no singular optimum choice. The choice is driven by making the appropriate tradeoff between the two competing mathematics of high power gain or high output signal swing. How to weight the choice depends on the application. Small signal amplifiers will generally be weighted towards high power gain. The output stage driving the load will generally be weighted towards high output signal swing.

The **output voltage division factor, ovdf**, of the amplifier is given by:

$$ovdf = \frac{R_L}{R_C + R_L} = \frac{1}{(R_C/R_L) + 1} \qquad \text{Eq. 1}$$

Although there are a number of interacting variables that affect the exact magnitude of the maximum possible linear output signal swing delivered to a load resistance, a general statement can be made that this maximum value is a strong direct function of the output voltage division factor. The ideal value for ovdf is 1.0, (i.e. $(R_C/R_L) = 0.0$) but the power gain of the amplifier is exactly 0.0 for that choice. Such an amplifier would be useless. Thus, for any amplifier, (R_C/R_L) must be greater than zero and further must be large enough so that the power gain of the amplifier is appreciably greater than 1.0.

There are a number of interacting variables concerning the power gain of the amplifier but a general statement can be made that the power gain of the amplifier can be increased up to a point by making R_C as large as practical. Thus, (R_C/R_L) should be high but the consequence is that the maximum linear output signal swing becomes small.

We need an equation for power gain only as a normalized function of (R_C/R_L). This equation assumes that other parameters that affect power gain remain constant for our decision process and thus are not variables. The power gain is normalized such that 1.0 represents the ultimate. To develop such an equation it is noted that the actual power gain of a common-emitter amplifier is generally a scalar to the parallel combination of R_C and R_L, $R_C \| R_L$. This combination is normalized by division by R_L. Thus, the equation for **normalized power gain, npg**, is as follows:

$$npg = \frac{R_C \| R_L}{R_L} = \frac{R_C * R_L}{(R_C + R_L) * R_L} = \frac{R_C}{R_C + R_L} = \frac{(R_C/R_L)}{(R_C/R_L) + 1} \qquad \text{Eq. 2}$$

Note that the final form of the equation for npg is expressed in the same ratio form, (R_C/R_L), as our discussion.

For these particular equations, the normalized product is a general indicator of the overall goodness of choice. A normalizing factor of four is used so that the product has a maximum value of 1.0.

A graph is a good way to simultaneously see the effect of a given choice when there are competing forces. For this case the idea is to plot (R_C/R_L) on the x-axis over a wide range and the corresponding values of ovdf and npg on the y-axis. The normalized product is also plotted for reference. This plot is shown in Figure 1.

One important factor that is not practical to illustrate in Figure 1 and that applies to common-emitter (and common-source) amplifiers is that the loaded stage voltage gain should be around ten or more in order to maximum output signal swing. At low voltage gains the input signal amplitude subtracts from the available output signal swing because the collector signal is phase inverted from the base signal. The effect of this is that although (R_C/R_L) should be generally low for large signal swing it must not be too low. Exactly what too low is depends on other parameters in the circuit. This is a limit that only occurs in low voltage gain common-emitter amplifiers.

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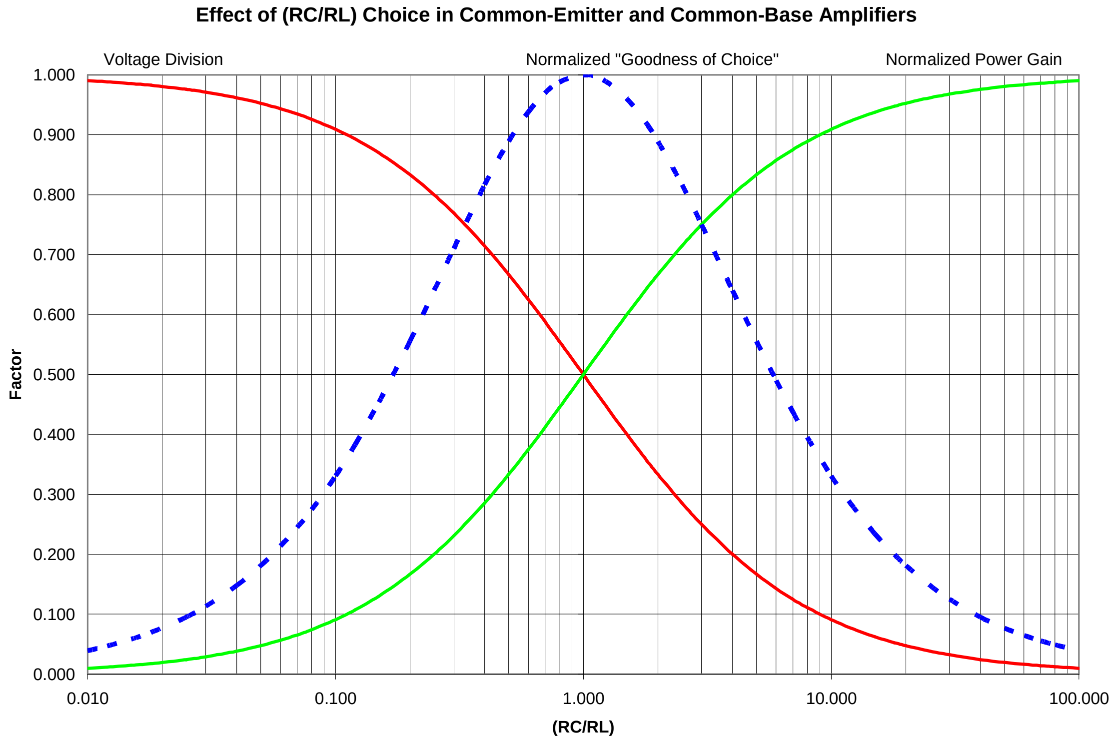

Figure 1: Effect of (RC/RL) choice

Do not jump to the conclusion that a choice of 1.0 for (R_C/R_L) gives the best overall results. The peak of the "Goodness of Choice" curve only indicates the general zone where good choices exist depending on what the goal is. One conclusion that is valid is that the "Goodness of Choice" factor is at least 0.9 for 0.5 < (R_C/R_L < 2. The voltage division factor and the normalized power gain vary a lot over that same range. Thus, for large output signal swing, (R_C/R_L) should be around 0.5 or less and for relatively high power gain, (R_C/R_L) should be about 2.0 or more. There is no definite hard limit for how far you can push the ratio but the increase in benefit in one factor is small compared to the loss in the other factor for 0.2 < (R_C/R_L) < 5.0.

There is one final point to discuss that simplifies the choice. There are situations for which it is desired that the output resistance of the amplifier be a standardized value typically equal to a standard load resistance. For low frequency amplifiers a common value is 600 ohms. In this case the choice is simple. Choose R_C to be equal to R_L (i.e. (R_C/R_L) = 1.0).