Designing the AC gain of a Common-Emitter Amplifier

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Oct. 7, 2004, rev. Sept 13, 2008

This note describes how to calculate the gain setting resistor, R_{E1}, in a common-emitter amplifier.

Case 1: Calculating R_{E1} for a specified unloaded stage gain

The equation for the unloaded or stage voltage gain of a common-emitter amplifier has been derived in earlier notes to be

$$Av = \frac{-B}{B+1} * \frac{R_C}{re + R_E'} \qquad \text{Eq. 1}$$

where B is the beta of the transistor, R_C is the collector resistor, re is the dynamic emitter resistance and RE' is the parallel combination of R_E and R_{E1}. In a given design problem everything is known except R_E'. Solving Equation 1 for R_E' gives

$$R_E' = \frac{B}{B+1} * \frac{R_C}{-Av} - re \qquad \text{Eq. 2}$$

Note that since Av is always a negative value (because the common-emitter amplifier inverts the phase of the signal) then –Av is always a positive value. Note also that it is possible for the calculation of R_E' to produce a negative number if the value of re is less than the first term. If this happens then it is not possible to achieve the specified Av.

Once we have R_E' we can calculate the required value of R_{E1} by solving parallel resistance in reverse. Noting that

$$R_E' = R_E \parallel R_{E1} = (R_E * R_{E1}) / (R_E + R_{E1}) \qquad \text{Eq. 3}$$

we can write

$$R_{E1} = (R_E * R_E') / (R_E - R_E') \qquad \text{Eq. 4}$$

It might be tempting to substitute Equation 2 into Equation 4 to obtain a direct calculation for R_{E1} but this only leads to an algebraic mess. It is better to keep the process as two steps – first calculate R_E' using Equation 2 and then use that result in Equation 4 to calculate R_{E1}.

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Case 2: Calculating R_{E1} for a specified loaded stage gain

A simple modification to Equation 1 give the loaded voltage gain of the amplifier. Noting that the load resistance, R_L, is effectively in parallel with R_C then we can write:

$$Avl = \frac{-B}{B + 1} * \frac{R_C \parallel R_L}{re + R_E'} \qquad \text{Eq. 5}$$

$$R_E' = \frac{B}{B + 1} * \frac{R_C \parallel R_L}{-Avl} - re \qquad \text{Eq. 6}$$

Thus, to calculate R_{E1} given the specified loaded gain of the amplifier, Avl, we first calculate R_E' using Equation 6 and then use that result in Equation 4 to calculate R_{E1}. Again, note that Avl is always a negative value so that –Avl is always a positive value.

Case 3: Calculating R_{E1} for a specified net gain

The equation for the net voltage gain of a common-emitter amplifier has been derived in earlier notes to be

$$Avn = \frac{Rin}{R_S + Rin} * \frac{-B}{B + 1} * \frac{R_C \parallel R_L}{re + R_E'} \qquad \text{Eq. 7}$$

Note that this equation combines the effect of input voltage division, unloaded stage gain, and output voltage division. Rin is the input resistance of the amplifier and R_S is the output resistance of signal source connected to the input of the amplifier. The input resistance of the amplifier has been derived in earlier notes to be

$$Rin = R_B \parallel [(B + 1) * (re + R_E')] \qquad \text{Eq. 8}$$

where R_B is the Thevenin resistance of the base bias system (i.e. $R_{B1} \parallel R_{B2}$ for voltage divider bias).

Substituting Equation 8 into Equation 7 gives

$$Avn = \frac{R_B \parallel [(B + 1) * (re + R_E')]}{R_S + R_B \parallel [(B + 1) * (re + R_E')]} * \frac{-B}{B + 1} * \frac{R_C \parallel R_L}{re + R_E'} \qquad \text{Eq. 9}$$

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Expanding the parallel resistance terms of the first factor gives

$$Avn = \frac{R_B * [(B + 1) * (re + R_E')]}{R_S * \{R_B + [(B + 1) * (re + R_E')]\} + [R_B * (B + 1) * (re + R_E')]} * \frac{-B}{B + 1} * \frac{R_C \parallel R_L}{re + R_E'}$$

Eq. 10

Equation 10 looks pretty bad but can be simplified by canceling common numerator and denominator factors to

$$Avn = \frac{-B * R_B * R_C \parallel R_L}{R_S * \{R_B + [(B + 1) * (re + R_E')]\} + [R_B * (B + 1) * (re + R_E')]} \qquad \text{Eq. 11}$$

Everything in Equation 11 is known except the value of R_E'. The solution (after a fair amount of algebraic manipulation) to R_E' is

$$R_E' = \frac{B}{B + 1} * \frac{R_B}{R_S + R_B} * \frac{R_C \parallel R_L}{-Avn} - \frac{R_S \parallel R_B}{B + 1} - re \qquad \text{Eq. 12}$$

Thus, to calculate R_{E1} given the specified net gain of the amplifier, Avn, we first calculate R_E' using Equation 12 and then use that result in Equation 4 to calculate R_{E1}. Note that with the two subtracted terms that a negative value of R_E' is possible. As before, a negative value of R_E' indicates that it is not possible for this stage to achieve the specified Avn. Again, note that Avn is always negative so that –Avn is always a positive value.