

Monte Carlo Simulation Experiment

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Introduction

For this experiment the student will use a statistical technique known as the Monte Carlo method to answer the question of how much the quiescent collector current and AC gain varies in a common-emitter amplifier over the range of tolerances of the resistors, R_{B1} , R_{B2} , R_E , R_C and R_{E1} , the range of operating temperature, and the typical range of beta for the transistor. There are many degrees of freedom in this problem and although Algebra could be developed to directly compute the variation that can be very tedious and is fraught with possible errors or wrong assumptions in some of the relationships which can become quite complex. In larger engineering problems the degrees of freedom are so large as to make direct Algebraic calculation all but impossible. Yet, is it important to know what the typical and extreme variations are. So how does one determine the needed information when ordinary math won't work? The answer is to use a computer to test a sufficiently large number of random samples of all of the possible variations. This concept is known as the Monte Carlo method. The beauty of this method is that no knowledge or assumptions about variable relationships is needed. Standard analysis of the system is used except that all components and related parameters are allowed to randomly vary. The random values will cover all the possibilities if there are at least a certain minimum number of samples or iterations.

See http://en.wikipedia.org/wiki/Monte_Carlo_method for an introduction to the Monte Carlo method. Try an Internet search for the phrase, "Monte Carlo method" for more information.

See

http://www.vosesoftware.com/ModelRiskHelp/index.htm#Monte_Carlo_simulation/How_many_iterations_to_run.htm for discussion on determining how many iterations to run to be confident of meaningful results. Try an Internet search for the words, 'how many monte carlo runs are enough' for more information.

Design project

Using the standard design method in EE351 design a common-emitter amplifier as shown in Figure 1 with an unloaded voltage gain of 40 using a collector resistor of 3.3K and a quiescent collector voltage of 9 volts. The power supply voltage is 24 volts. The NPN transistor has a beta range of 80 to 240 and a nominal V_{BE} of 0.65 volts at 25 C. Design for a beta stability factor of 1.2 and a temperature stability factor of 1.2 for an operating temperature range from 5 C to 60 C – use $\Delta V_{BE}/\Delta T = -2$ mV/C. Design for the computed minimum value for V_{BB} and the computed maximum value for (R_B/R_E) . Round all resistors to standard values. **Show your design details and prove your design works (by analysis) before continuing with Monte Carlo simulation.**

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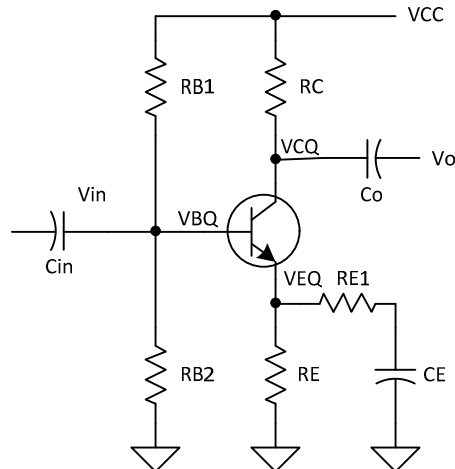


Figure 1: BJT common-emitter amplifier

Monte Carlo simulation

You can use your choice of either Excel or Matlab to perform the simulation.

All of the resistors for this experiment have a tolerance of ± 5 percent. The actual distribution of resistance values of a given resistor tends to be truncated Gaussian over the tolerance range. For this lab we are not going to worry about the specific distribution and use simple uniform distribution so that all resistance values over the tolerance range have equal probability. The effect of this simplification will make the analysis more pessimistic than reality but that is OK.

In Excel the `rand()` function returns a uniform random number between 0 and 1 each time it is called. Use the following equation to compute a random resistor value over a specified tolerance range in percent. Note: `%tol` would be 5 for $\pm 5\%$. `Rvalue` is the marked value of the resistor.

$$R_{\text{random}} = R_{\text{value}} * (1 + (\text{rand}() - 0.5) * 2.0 * (\% \text{tol} / 100)) \quad (1)$$

For a 10K, $\pm 5\%$ resistor, `Rrandom` will vary over the range from 9,500 to 10,500 ohms.

Use the following equation for the case where a range is specified rather than a nominal value and a tolerance (i.e. temperature and beta range).

$$T_{\text{random}} = T_{\text{min}} + (T_{\text{max}} - T_{\text{min}}) * \text{rand}() \quad (2)$$

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Results

1. Study the provided Internet links (and perhaps others as well) to determine how many iterations you should run to obtain credible results. Too few iterations produce meaningless results. You cannot really run too many but there is a point of diminishing returns as improvements only increase as the square root of the number of iterations. The objective is to determine a reasonable number of iterations to run. There is not a specific number – only a broad range – target to be somewhere in the broad range. Justify your choice. To gain experience with this try running a too small number such as 10 several times and observe how much the mean bounces around. Then run 1,000 iterations several times and note much less variation. You can press the F9 function key in Excel to repeat a run of iterations with new random numbers. A sample Excel file is provided on the class web site that can be adapted for this experiment. Note: Excel will plot the scatter points too large – edit the series so that the points are 3 units instead of the default.
2. Determine the average or mean value of ICQ and the standard deviation.
3. Determine the average or mean value of VCQ and the standard deviation.
4. Determine the average or mean value of AC gain and the standard deviation.
5. Plot the iteration sequence of ICQ and AC gain as shown in Figure 2 (of a different problem). You can combine the plots as shown or use separate plots – your choice.
6. Let all resistors have zero tolerance (i.e. no variation) and repeat the test for ICQ with only temperature and beta varying and find the resulting ratio of ICQ_{max} / ICQ_{min} . Compare this ratio to the design specification. Note that the design specification was based on temperature and beta independently and the combination of the two factors will increase the total variation. If the overall variation is deemed excessive then the design must be done with a stability factor of perhaps 1.1 for lower overall variation. Tighter tolerance resistors might be needed as well to achieve a desired stability.

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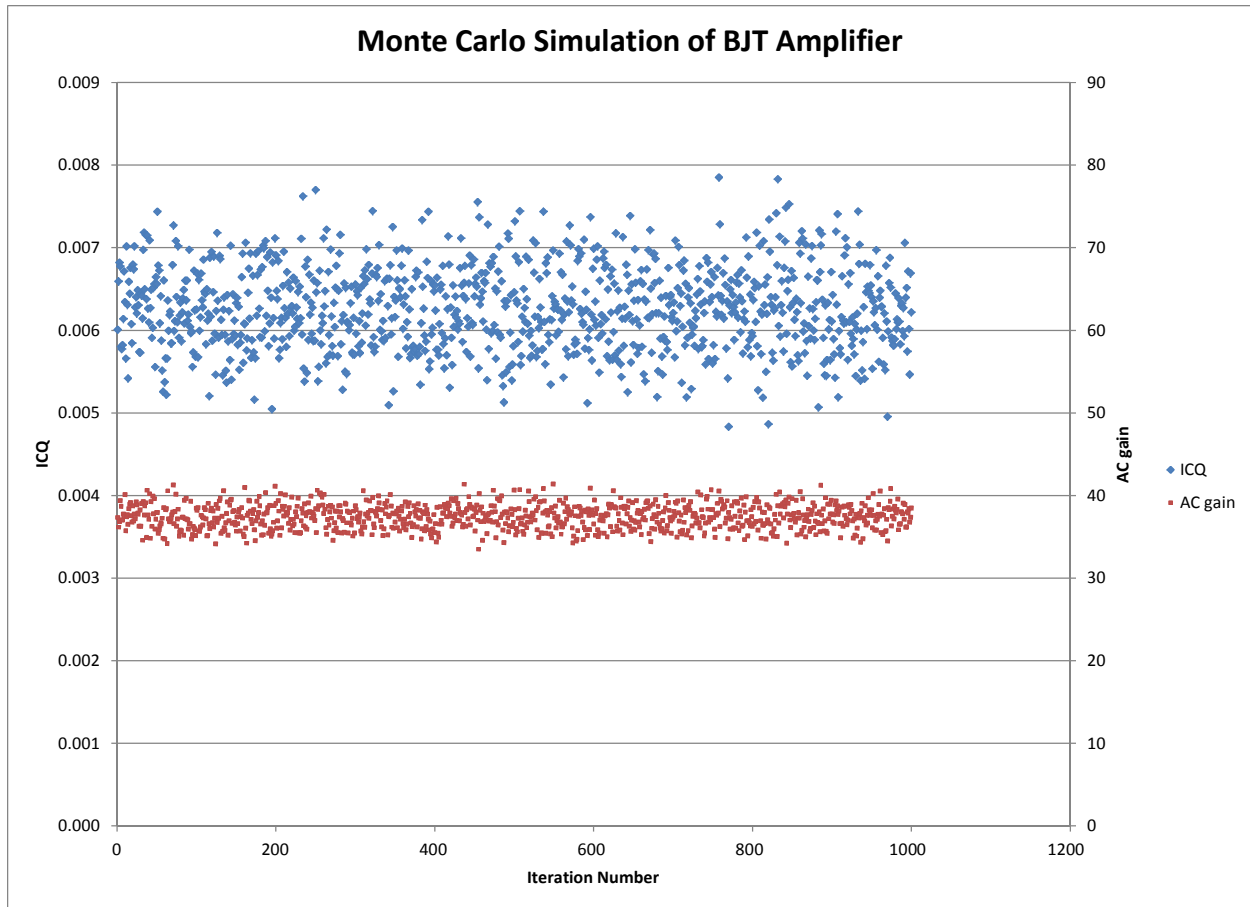


Figure 2: Monte Carlo Simulation of BJT Amplifier
(a different one than for this experiment)

The statistical results of the simulation are shown below.

	1000	Total number of iterations	
Max/Min =	1.625		
	ICQ	AC gain	VCQ
mean =	0.006265	37.443	5.736
min. =	0.004831	33.489	3.823
max. =	0.007850	41.403	7.215
std. dev. =	0.000500	1.451	0.529