BJT Amplifier Design
Sample Laboratory Report

Lab # 1/ Fall 2005
ECE 617
Some Previous Student
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Abstract

The transistor is the most fundamental active component of amplification in most modern electronic circuits. In this laboratory exercise two bipolar junction transistors (BJTs) were used, along with the necessary resistors and capacitors, to form a common emitter amplifier and a common collector amplifier. The amplifier design process was taken through the various stages of hand calculations, computer simulation, prototyping, and verification. Calculations to determine circuit elements led to a circuit design. The circuit design was entered into a Multisim schematic. Along with verification of the designs functionality, DC power requirements and efficiency were calculated. A deviation of less than 10 % was found in the amplifier's DC power and BJT transistor's power simulation results when compared to the ones measured using the prototype.

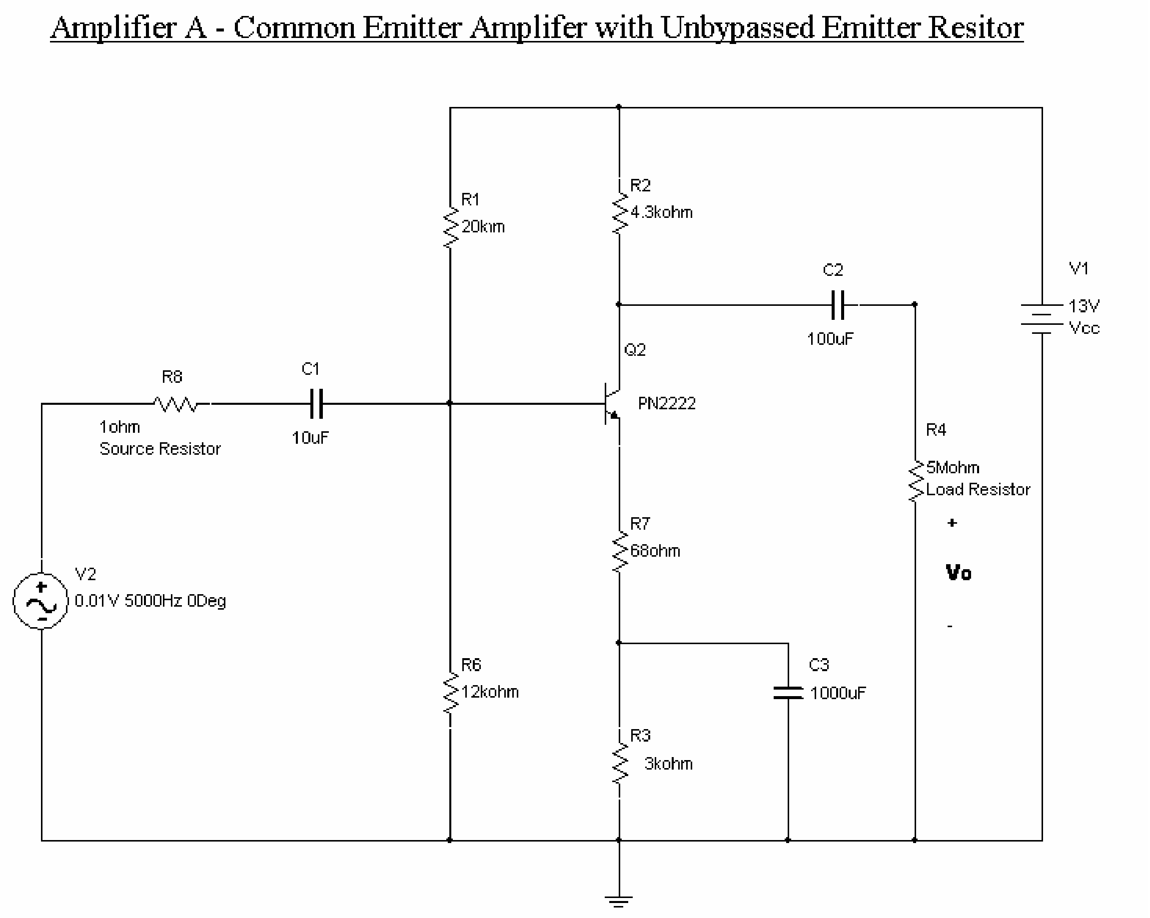
The design was evaluated with Multisim's SPICE based simulator. Results varied between the simulation and the prototype measurements: 24% variation in efficiency, 3% variation in the amplifier's DC power dissipation and a 3.1% variation in the BJT power requirements. The effects of circuit performance were studied during simulation by varying the transistor's Beta by ± 50%, the resistors by ± 5%, and the capacitors by ± 20%. For the variation of Beta, the output gain ranged between 48.25V/V and 47.75V/V (for the common emitter amplifier) and between .9952V/V and .9942V/V (for the common collector amplifier). Using Monte Carlo analysis of all the components were varied: the common-emitter amplifier's gain ranged between 52V/V and 42V/V and the common-collector amplifier's gain was nearly unchanged.

A parts list was developed and the transistor amplifier circuit was prototyped and tested in the laboratory. The measurements of actual component values were recorded, as well as, the DC source voltage. The amplifiers collector, base, and emitter voltages were measured to determine if the amplifier was biased correctly. The AC gain was measured with and without the load and source resistances connected.

The effects of cascading the amplifiers were studied. When the common-emitter amplifier was the first stage, followed by the common collector, the voltage gain was 31.44 V/V when connected to a load of 200 ohms. With the amplifier stages reversed, and connected to a load of 400 ohms, the voltage gain dropped to 1.19 V/V. The prototypes were then labeled and saved.

The measured and simulated results are presented in this report along with a discussion of how the circuit parameters were determined. The summary discusses the effects of parameter variation and how the measurements were made.

The circuit schematics are shown in Figures 1 and 2. Calculations used to determine circuit element values are shown in Appendix A.



Amplifier A - Common Emitter Amplifer with Unbypassed Emitter Resitor

Figure 1, Amplifier A

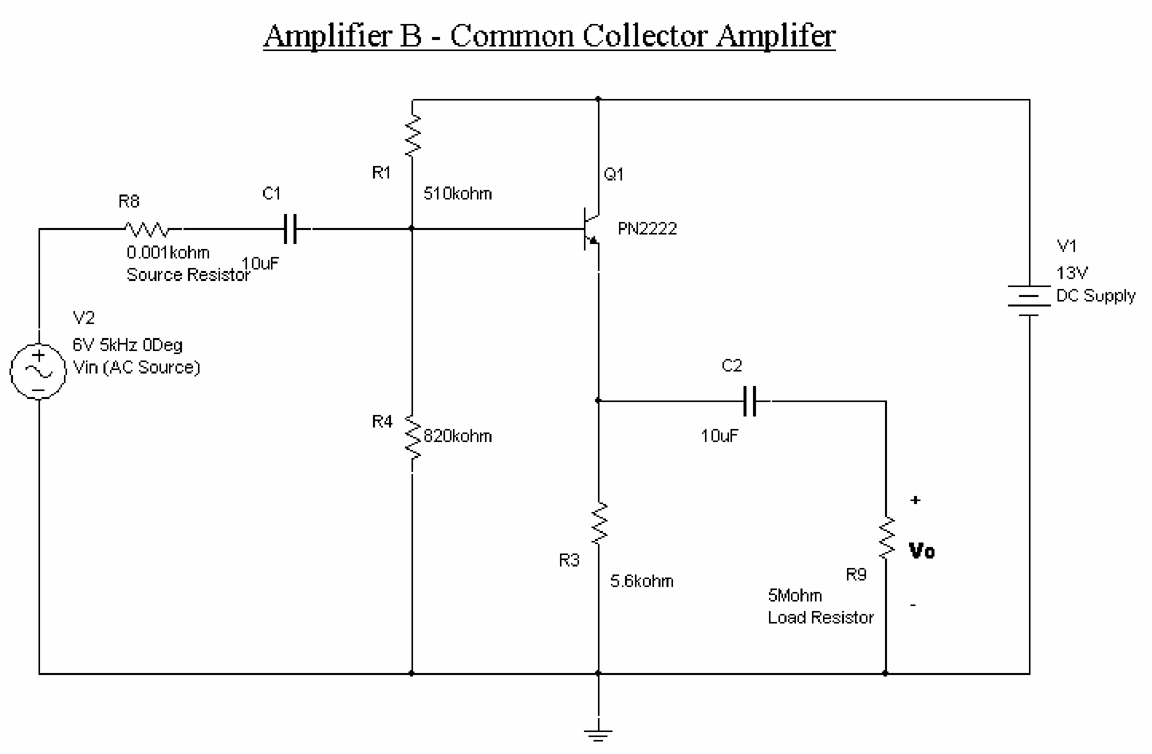


Figure 2, Amplifier B

The simulation results are shown in Figures 2 through 10.

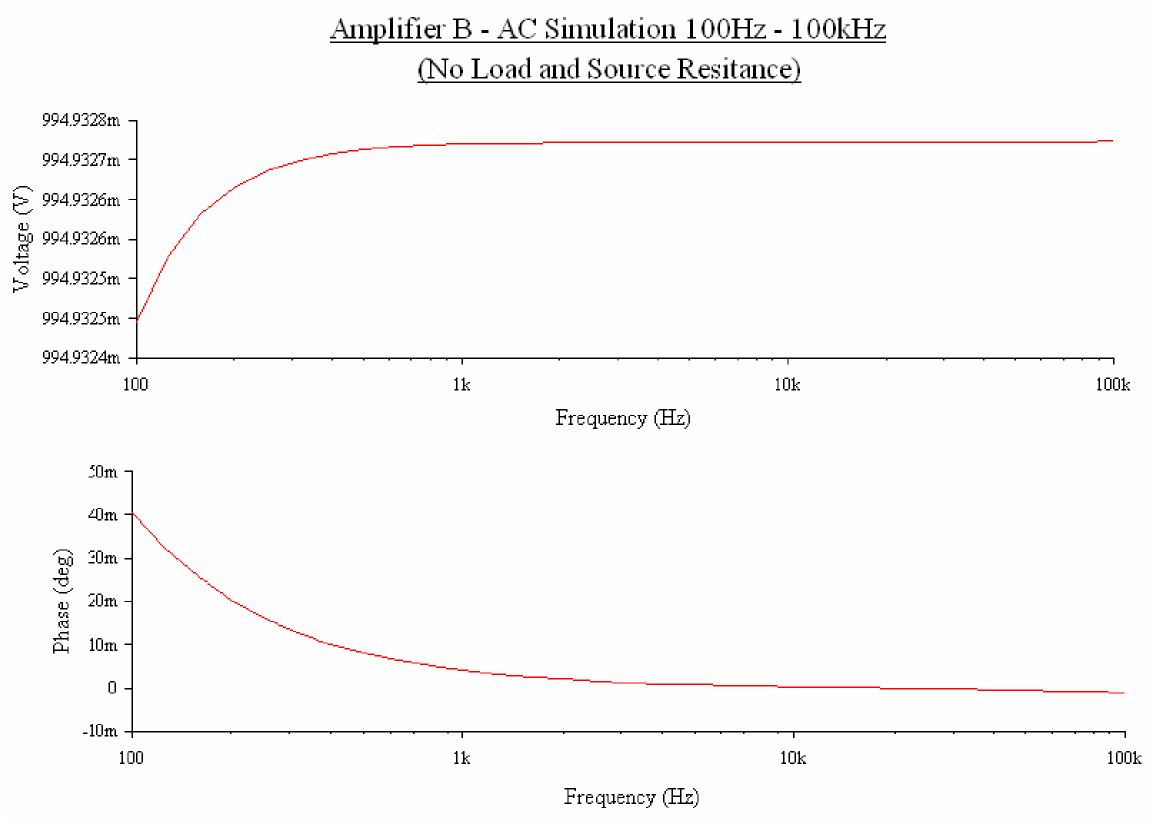


Figure 3, Simulation Results for Amplifier B

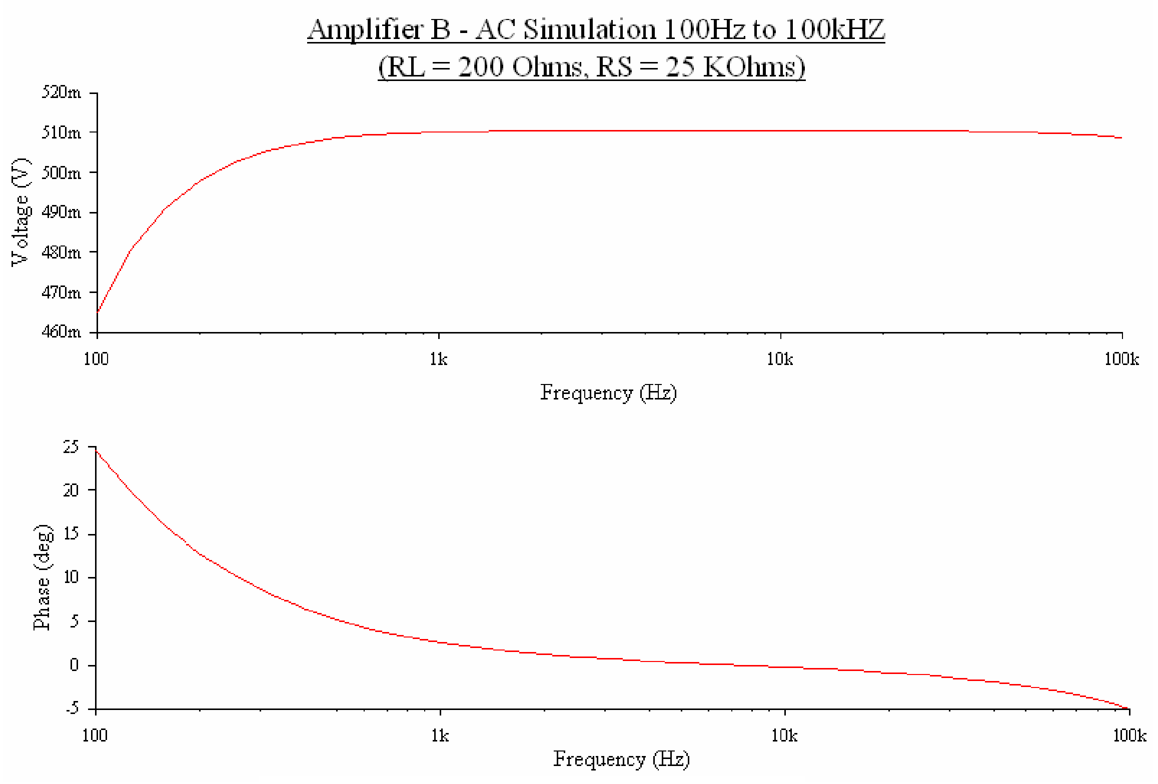


Figure 4, Simulation Results for Amplifier B
with Source and Load Resistors

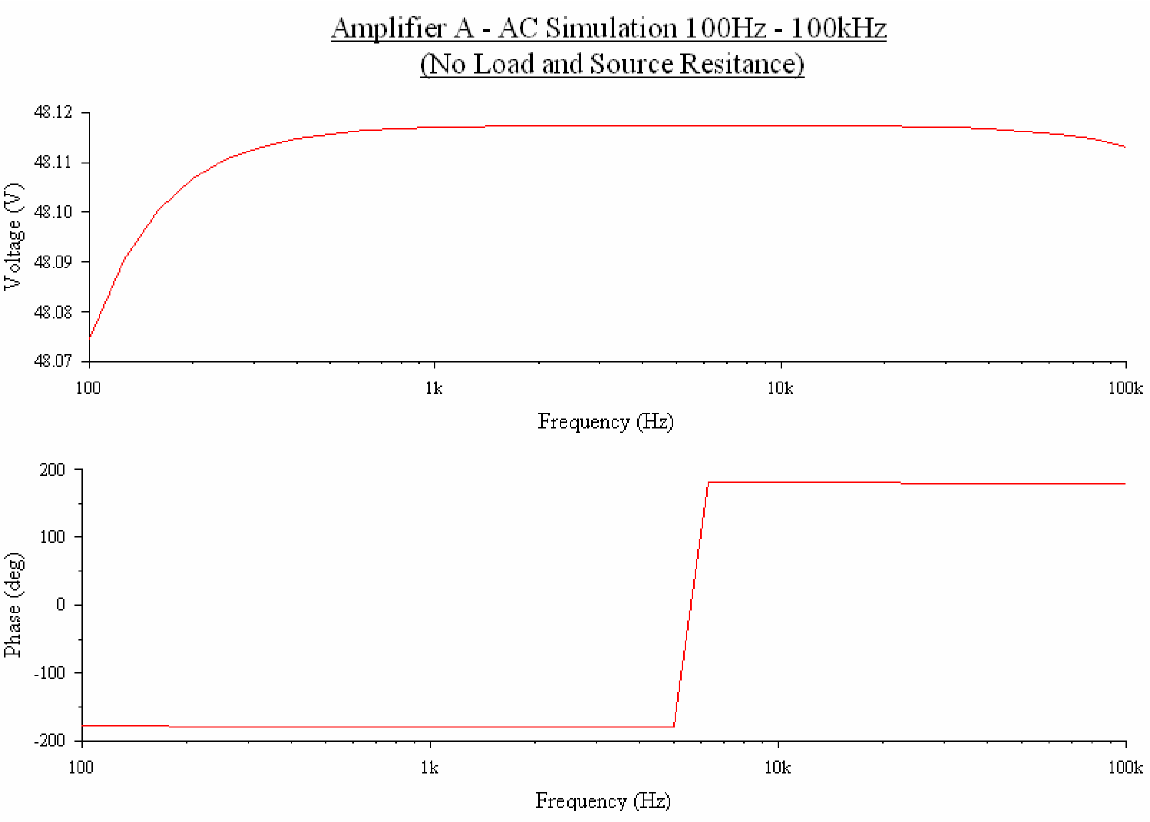


Figure 5, Simulation Results for Amplifier A

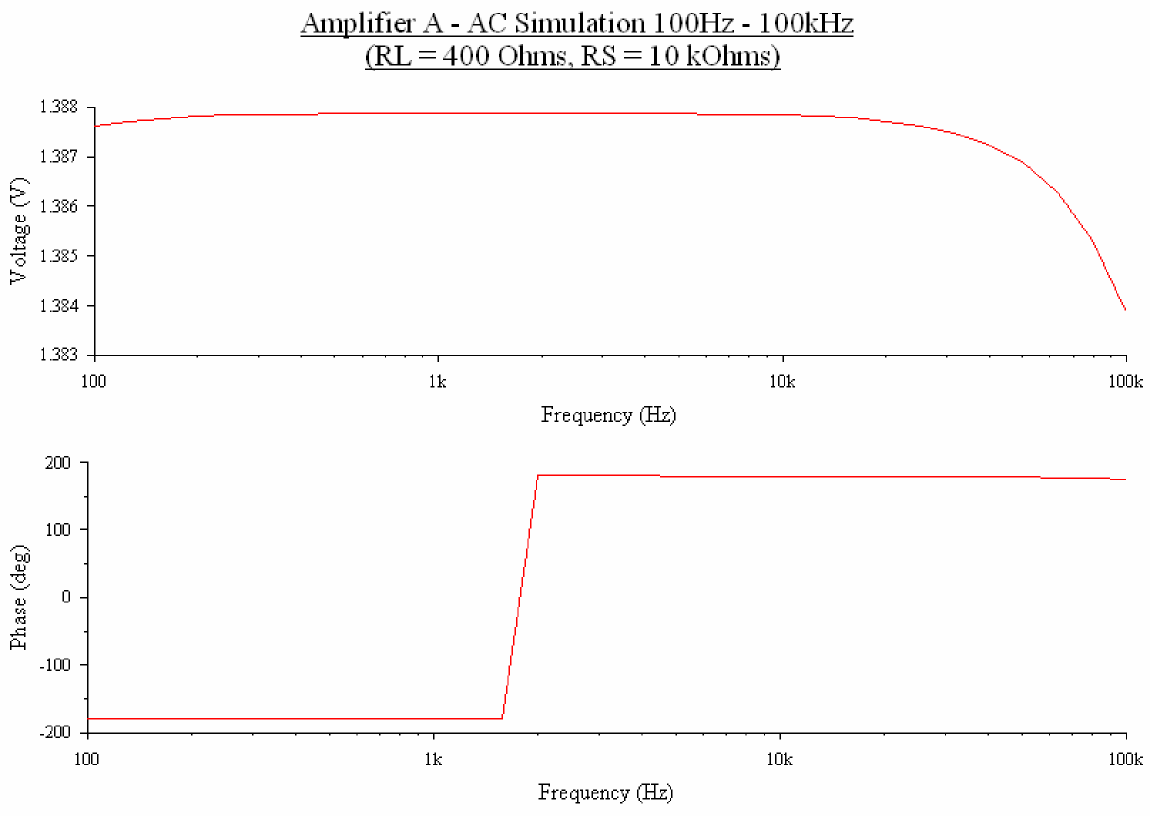


Figure 6, Amplifier A with Load and Source Resistances

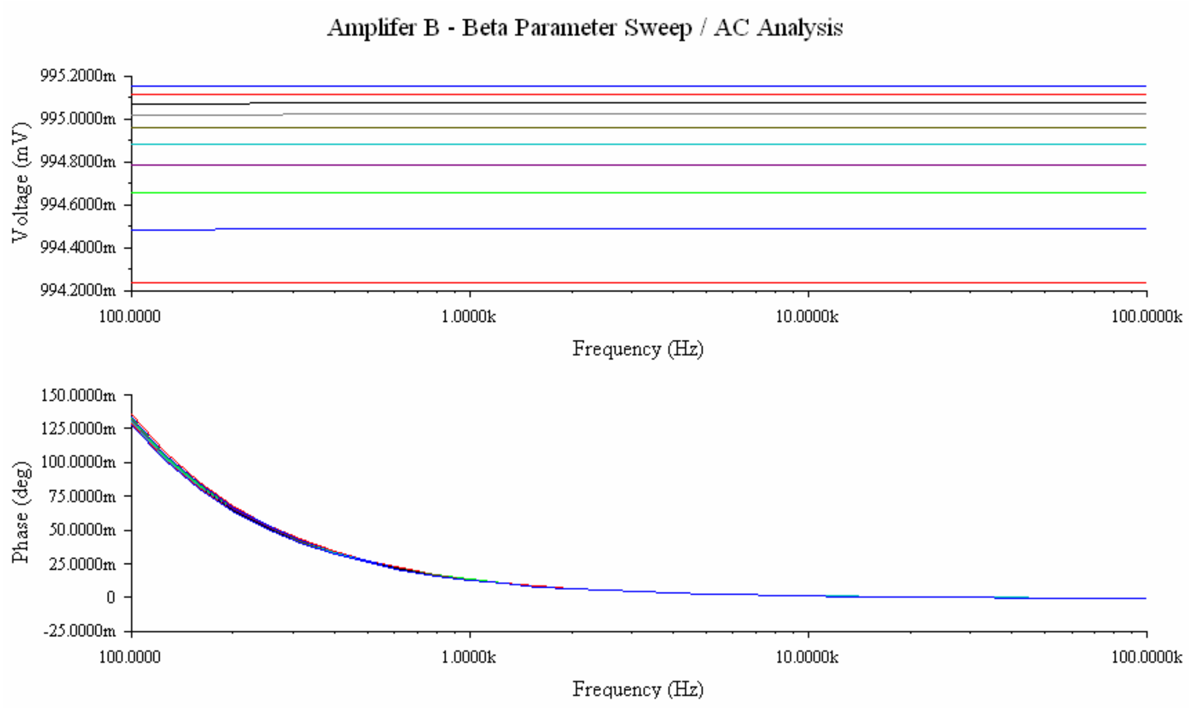


Figure 7, Amplifier B During Parameter Sweep

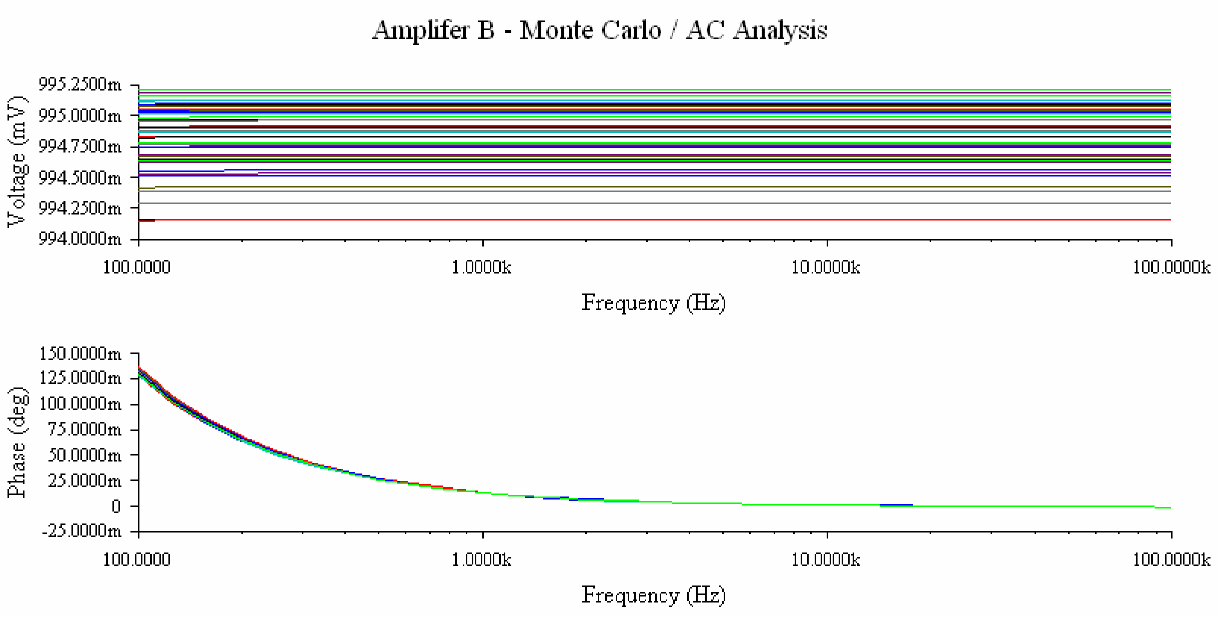


Figure 8, Amplifier B During Monte Carlo Analysis

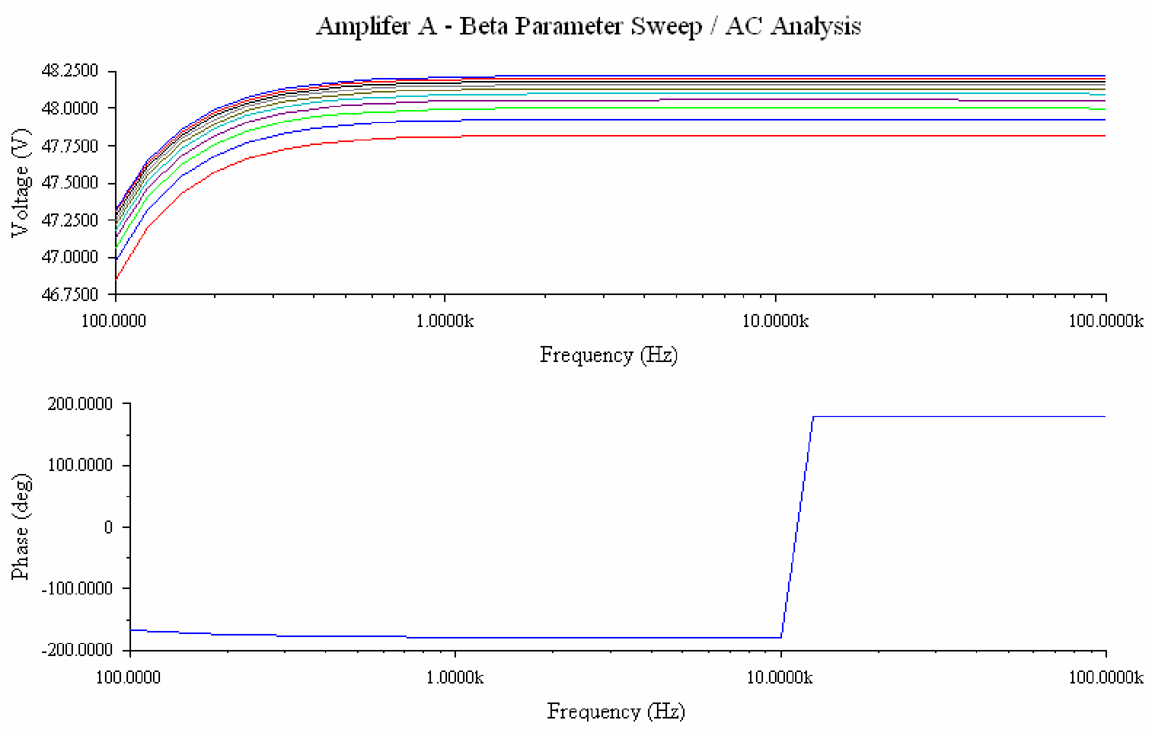


Figure 9, Amplifier A During Parameter Sweep

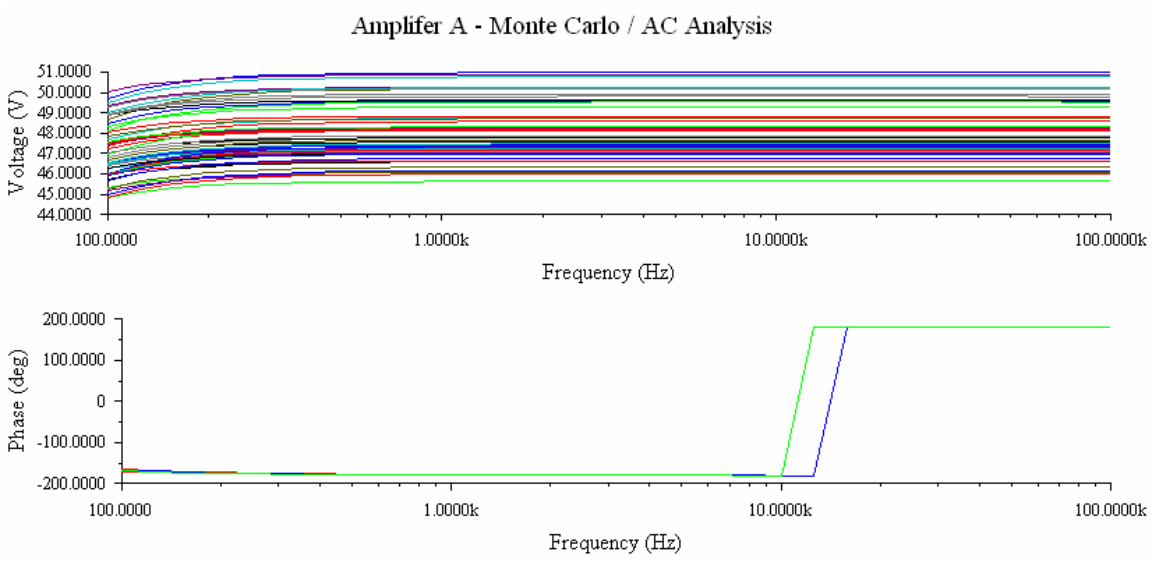


Figure 10, Amplifier A During Parameter Sweep

Table 1 tabulates the differences between measured and simulated results.

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Table 1	In-Lab measurements vs. Simulation results					
	Amp A - CEA			Amp B – CCA		
	In-Lab	Simulation	%	In-Lab	Simulation	%
DC Volts @ Base	4.729V	4.81042V	1.7%	5.75V	6.10590V	5.8%
DC Volts @ Emitter	4.083V	4.15756V	1.8%	5.238V	5.46308V	4.1%
DC Volts @ Collector	7.226V	7.20990V	.2%	12.935V	13V	.5%
AC Voltage Gain with Load @ 5kHz	1.3877V/V	1.28 V/V	8.4%	.447 V/V	.51 V/V	12.4%
AC Voltage Gain without Load @ 5kHz	48.115V/V	46.4 V/V	5.7%	.925 V/V	.9949 V/V	7%
Amp DC Power dissipation	22.701mW	22.881mW	.8%	12.419mW	12.800mW	3%
Transistor DC Power dissipation	17.396mW	17.729mW	1.9%	12.285mW	12.682mW	3.1%
Efficiency of Amp	1.312 %	1.416%	7.3%	.586%	.772%	24%

Table 1, In-Lab Measurements vs. Simulation Results

Table 2 compares the gains between amplifier A and B under different loading conditions.

Table 2.	Gain V/V	
@ 5kHz	Amplifier A	Amplifier B
Unloaded	46.4 V/V	.925 V/V
With Load	3.67 V/V	.864 V/V
With Source	15.1 V/V	.852V/V
With Load + Source	1.28 V/V	.447 V/V

Table 2, Measured Gains for Amplifier A and B

Table 3 lists the results obtained when the amplifiers were cascaded together.

Table 3.	Overall Gain V/V	
@ 5kHz	A cascaded with B	B cascaded with A
With RL_A	33.83V/V	4.02 V/V
With RL_B	3.88V/V	44.45 V/V
With $RL_A + RL_B$	3.34 V/V	3.78 V/V

Table 3, Measured Cascaded Gains

Summary

The design procedure is a step by step process that flows through the definition of the function of the product through the prototyping, testing and design verification. The first step in the process is the proper definition and understanding of the specifications that the final product should meet. This would include a system level design that is technology independent and some aspects of engineering judgment as to whether the criteria as defined can be effectively achieved with the technology and within the cost parameters available. Although this stage of design was not a part of this laboratory exercise it can be a very important aspect of the design process. Identifying flaws or problems within the specifications can eliminate costly dead ends later in the design process when the flaws in the design specifications make it impossible to design a solution that meets all the assigned criteria within the cost and manufacturing parameters.

With these factors considered a circuit level design, based on the appropriate technology can be developed. This laboratory exercise was well defined in that the technology, bipolar junction transistor, was selected in advance, as well as, a specific model and type of BJT and circuit layout. The predefinition of open circuit gain parameters, and Beta tolerance levels also restricted the design and allowed a focus on designing a stable Beta tolerant circuit. A circuit design was then a matter of making some assumptions (transistor biasing levels) and choosing the appropriate component values to achieve them. Using the rule of thirds it was possible to determin voltages at the transistor collector, base and emitter. For the common emitter amplifier a 13 volt supply leads to 8 2/3 V at the collector and 4 1/3 V at the emitter. Knowing that the voltage drop from base to emitter is approximately 0.7v leads to a base voltage approximately 5 volts. For the common collector amplifier the base voltage was chosen at ½ the supply voltage and the emitter became just that voltage minus the diode drop. Assuming a reasonable current (2mA) then allowed the selection of emitter and collector resistors. Expressing V_O and V_{in} in terms of base current allows a gain expression to be derived and the unbypassed emitter resistor to be calculated.

The next phase moves the design process from schematic entry to simulation. The simulation should be used as a verification tool and not as a design tool since all possible theoretical results in a simulation may or may not work in reality. For example the simulator might let you select resistor values that would place a current in the range of amps through the transistor, whereas a real transistor would be destroyed under these conditions. With a realistic design done in advance, the simulator can be a useful tool in demonstrating that the design meets the specifications. Here the original designs proved to be mostly adequate. The DC analysis function allows the DC biasing of the design to be verified. Using the parameter sweep function and Monte Carlo analysis provided simulation results related to the variations in the non-ideal circuit elements and their effects on circuit performance. The transient analysis was used to calculate the maximum voltage amplitude (before distortion). Power dissipation and efficiency was also calculated from the simulation results.

During simulation the original design proved to be less effective as desired. The design was modified slightly to improve performance. In particular, the emitter resistance of the common emitter circuit proved to be a little too high causing an asymmetric clipping of the output voltage. The input impedance assumptions of the common collector also proved to be too high and the overall impedance had to be brought down while keeping the ratio the same. With these changes made the simulations were rerun and found to be within specifications and acceptable.

Armed with the simulation results and modified designs the final stages of prototyping and testing could begin. The prototyping phase allows the final real-world verification of the design and should be done to provide hard evidence of a proper solution before being released for fabrication. The first stage is the development of a parts list and then the corresponding selection of components. The components should be verified from their external markings or with a ohm meter. In constructing the circuit the idea of using the least amount of extra wire or lead length should be of importance. This helps to cut down on noise and helps with overall stability. With the circuit components appropriately placed on the breadboard the DC power was measured and applied to the circuit. Measuring the DC voltages throughout the circuit and comparing it to the simulated values indicated that the amplifier was DC biased correctly.

With the circuit operating in the correct DC bias region, the AC voltage source was applied and the output voltage measured. Both amplifiers at this stage showed a clean output and also a gain well within the given parameters: the common collector had a gain of .925V/V and the common emitter had a gain of 46.4 V/V (well within the <0.5 V/V and 42 – 52 V/V specifications). The greatest variation from simulation was a 12.4% difference in gain of the common collector when the load was applied, but the amplifier still was above the open circuit gain parameter of 0.5% V/V. With the DC voltages measured the power dissipation was calculated and deviations of less than 3.1% were found from the corresponding simulation results. Adding a load and source resistances to the circuits dramatically affected their performance, but again this was also seen in simulation. Differences of less than 24% were observed in amplifier efficiency when comparing simulation results to prototype measurements. Most of this difference can be explained by the inaccurate ability the set the amplifier to its maximum output while taking measurements.

With both circuits built and tested and working properly, the investigation of amplifier cascading started with the cascade of A to B, a common emitter amplifier with an open gain of 46.4 V/V with a common collector amplifier with a gain of approximately .925 V/V. With only the load of 198 ohms placed on amplifier B and both source resistors removed the cascade showed a gain of 3.88 V/V. This is lower than the intuitive idea of simply multiplying the gains of cascaded amplifiers. This effect is due to the loading effects of amplifier A on the input of amplifier B. Thus this cascading is more like the product of the gains of amplifier A with a load resistor and amplifier B with a load resistor. This is not exact either since there is also a source loading of A on B to consider as well.

The amplifier stages were reversed. Keeping a 386 ohm load resistor on amplifier A and removing the other source and load resistors led to a gain of 4.02 V/V. This configuration corresponds more closely with the product of the gains of amplifier B unloaded and amplifier A with a load and source resistor is approximately 3.39 V/V. Therefore the internal amplifier loading must be much less with this configuration. Again looking at the bottom of Table 3 reveals that keeping both load resistors only slightly lowers over all gain.

There were several problems encountered in building and testing the transistor amplifier designs. The most notable was the lack of grounding of the load resistors in the first run through of the measurements. This lead to very good gain measurements as can be imagined and one stunningly impossible efficiency calculation of 180%! Thus a second round of measurements was taken and gain was substantially reduced. The second problem was again with load and source resistors and required a third and final retake of measurement data. This was due to swapping of load and source resistors of amplifier B, most likely in the rush to retake measurements the second time. This was again revealed in an efficiency calculation of well over 20%, which was suspect especially when the simulation result was less than 1%. Both of these errors demonstrate the value of the simulation results. The laboratory measurements should match the simulation results.

There are real world applications to this laboratory exercise in terms of looking at the interaction of amplifiers and source and load impedances. A functional amplifier is a critical element in almost all analog designs, without it signal sources might never be large enough to be useful. In audio applications alone there are thousands of amplifiers. An audio mixing console is simply repeating rows of amplifiers and gain stages meant to allow the combination and gain of multiple signal sources into one stronger output signal. Although many designs have moved to integrated circuits and Op amp designs, these are nothing more than prepackaged multiple cascaded transistor amplifiers encased in a multi-pin package. Thus the design and study of single transistor designs is still highly relevant.

The design methodology allows the efficient and proper design of engineering projects. This laboratory exercise demonstrated the various stages of the methodology and allowed its use. The simulation results of both amplifiers allowed the investigation of Beta tolerance through simulation. The Monte Carlo analysis also allowed the variation of multiple elements in a circuit. This flexibility allows a much wider range of design verification than could be accomplished through laboratory measurements. This allows circuits to be designed to operate in a more efficient manner and reduces cost by allowing elements with low tolerances to be used. The prototyping and testing stage provides experience with circuit measurements techniques and verification processes. The cascading of A to B and B to A showed that the input/output resistance of amplifiers is important in overall circuit design and can significantly affect the final performance of a multiple stage design.