ECE 662 Project 0

Basic Common-Emitter Small Signal Transistor Amplifier

Due Dates:	Project schematic and layout:	Wednesday 9/11/19
	Final design/measurement writeup:	Friday 9/20/19

Objectives:

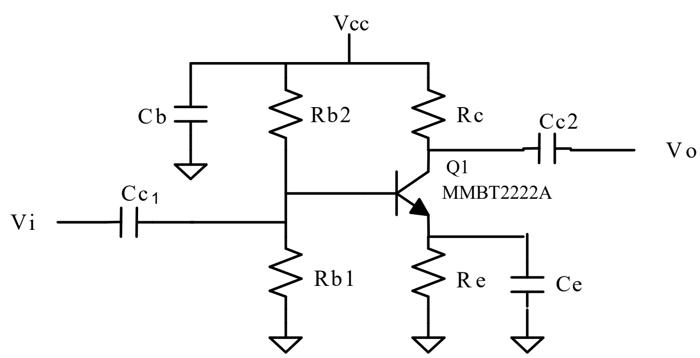
In project "0" you will design, build, and test a small-signal transistor amplifier like those you learned in your electronics course(s).. Such amplifiers are used (in modified forms) in the RF front-end stage of radio receivers for the reasons discussed in class.

Project 0 will demonstrate the problems inherent in achieving high gain at high frequencies with the basic configuration. Later, in project 1, we will modify our design to correct these problems, yielding the first of the four circuit boards needed for our semester goal - an FM radio receiver.

IMPORTANT: Project 0 is NOT a team-based project. Each student must do it themselves.

Circuit topology:

Use the standard 4-resistor biased common-emitter amplifier topology below. Your design tasks in this project consist of selecting resistor and capacitor values to bias the circuit and achieve a specified lower corner frequency, and then creating a circuit "layout". Guidelines for the design task are given in the following pages. Suggestions for doing the layout will be given in class.



Specifications:

Design your circuit to meet the following specifications:

- Operation from a single 5V supply.
- Collector current of 1 mA. (± 10%)
- Supply current of less than 1.5 mA.
- Small signal voltage gain of 50 (±20%).
- Lower corner frequency of 20 kHz (± 20%).
- Upper corner frequency as high as possible (we'll just see what we get and learn how to improve it in Pjt 1).

Suggested design procedure:

Step 1: Bias circuit design

Use the procedure described in the class handout (and/or in your previous electronics courses) to find resistor values for R_{b1}, R_{b2}, and R_e to give the specified collector current. Be sure to heed the specification on collector current and max total DC current, and to design so that your bias point will remain reasonably stable as $V_{be\text{-}on}$ and h_{FE} (a.k.a. Beta) change due to temperature and manufacturing tolerances. Recall that this is done by appropriate choice of voltage at the emitter and currents thru R_{b1}, R_{b2}. The nominal values for $V_{be\text{-}on}$ and h_{FE} can be found in the full datasheet in our class webpages (under Files>Datasheets).

Step 2: Collector resistor determination

As you should recall, the (unloaded) voltage gain of a common emitter amplifier is given by (ignoring effects of $r_o = 1 / h_{oe}$ which is pretty large in a BJT):

$$A_v \approx -g_m R_c$$

Using this expression, the specified Av, and a value of g_m estimated from $g_m = I_c/(n\,V_T)$ with n = 1, pick R_c. ***Note that in general, R_c cannot be chosen independently of the biasing solution***, since if it is too big, the transistor will not stay in the active region. Check this. Is $V_C > V_B$?

Step 3: Coupling and bypass capacitor selection

Find values of C_{C1},C_{C2}, and C_e, to meet the low frequency corner spec. In general, this requires knowing R_i and R_o, as well as worst-case source and load impedances expected in the application. It is perfectly OK (and common practice) to make coupling capacitors bigger than they need to be. For example, if your solution calls for C_{C1} = 500 pF, it is fine to use 1 nF or even 10 nF. Refer to class discussion and your previous course notes for more on picking Cc values and discussion concerning the dominant corner in an amp. Then think about which capacitor you should use to set the dominant highpass corner frequency here (C_{C1},C_{C2}, or C_e).

Determining a value for the emitter bypass cap Ce is a bit more abtuse. Using the time-constant method it can be shown that its reactance should be less than or equal to 1/gm at the desired corner frequency.

For the bypass cap Cb on the supply, use something with a small reactance compared to Rc. Why is this needed ?

IMPORTANT: Remember that we only have a limited range of R and C values to choose from. See the first-day handout and the boxes in lab for the values we have available. **ALSO:** *Values above 10nF or 100nF should be avoided* ***unless essential****, since they can cost more and increase the Bill of Materials (BOM) cost of a product !*

Step 4: Check design !

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Check your values by careful recalculation and if desired, using your favorite simulator. It is ***much*** easier to check and fix something now than to wait until after the design is constructed in the lab! If you choose to use a simulator, check the bias solution using a DC Operating-Point analysis, and the small signal gain and dominant high-pass corner frequency using an AC analysis and print the results. Otherwise, show how you checked your design and what the expected voltages, gain, and corner frequencies are and which corner frequency is dominant.

Layout:

Plan the placement of your parts on the circuit board by drawing a physical layout diagram on a piece of gridded paper. You will be using one of the 2x2" prototyping boards for this project. For ground connections, draw an X, or other clear indication at each point to denote spots where a "via" will need to be drilled and/or created by soldering a wire from the pad to the backside ground-plane.

For connection of power supply leads, as well as the input and output signals, you can use “twisted-pair” black and red hookup wire. Later, in project 1, the input and output signals will be connected using coax.

NOTE: You may discuss design procedures with others, but your design/writeups must be your own and unique. You must work out the equations and write it up (including figures) yourself !

Preliminary design write-up:

Write up your preliminary design in a neat form. You do not have to type it. The length should be about 3-5 pages including the figures.

In your write-up, <u>*you must include*</u>, <u>***IN THE FOLLOWING ORDER***</u>:

- A <u>**full schematic diagram**</u> with all reference designators and part values labeled on the component (NOT off to the side in a separate table.) Put them in the schematic. Also label the base, emitter, and collector nodes with the expected DC bias values.
- An <u>**AC small-signal diagram**</u> of your amplifier with a simplified transistor h-parameter model substituted for the transistor.
- Your <u>**layout diagram**</u>.
- A <u>**parts list**</u> showing the components you need. Include this as a page at the end of your write-up with the part values in a column on the left. Later, you can attach the SMD parts to the right of this column using clear plastic tape to help keep them organized while constructing the circuit.

.<u>***In addition***</u>, you should include a <u>*brief*</u> narrative and associated equations <u>***in an Appendix***</u> to justify your component value selections. It is <u>*NOT*</u> acceptable to pick values by trial and error, even with the help of a simulator. You should understand how the values are calculated and must demonstrate this understanding by showing how you checked your design in the Appendix.

Construction:

After you get your graded preliminary design back, make any required edits and construct your circuit on a 2x2" board. Remember that parts (mainly capacitors) can be damaged by excessive heat and thermal-shock during soldering. Tin the board (and wires for the input/output/power leads) first. Use minimum solder and the minimum time needed (usually less than 1 second if things are clean) to allow the solder to flow smoothly onto the board and parts.

For connection of power supply leads and input/output signals, you should use pieces of black and red hookup wire about 2" long and twisted. We will attach the supply and I/O signals to these with clip-leads during your measurements. Later in project 1 we will use coax for the I/O signals.

Be careful when drilling holes for connection to the ground-plane and use the larger soldering irons for those connections. Do NOT use the black iron with the sharp tip for this.

Measurements:

The following measurements should be performed and included in your final writeup. ***In this writeup, include your schematic (with component labels and values shown) and your layout.*** *Have these handy as you do your testing too, as it is senseless to debug things without this information at hand !*

As you take measurements and ultimately write them up***, include a brief but sufficient narative that someone unfamiliar with your work and the assignment (but familiar with normal laboratory procedures) can determine what you did.*** If you run into problems with your circuit, record them too, together with your solutions.

DC Bias Tests

Check/adjust the power supply, including the current-limit setting. Then apply 5V DC to your circuit. It is recommended that you start at zero volts and slowly increase the voltage, while monitoring current. Observe proper polarity!!! You don't want to have to rebuild it!

Check/record the transistor bias voltages and supply current, *comparing them with your designed values*.

- Voltages at base, emitter, and collector
- Supply current (***Measure with DMM*** since the power supplies can be inaccurate by +/- 1mA or more)

Show your results in tabular form, comparing the expected and measured values, and discussing any significant differences. (If values are very far off - you need to stop and debug your circuit before bothering to take any more measurements !)

Gain and Frequency Response Tests

IMPORTANT!!!

Set the signal generator amplitude to 10 mV or less for the following measurements. If you use a higher output level, your input will not be a "small signal" and may give incorrect readings (e.g. lower than expected gain) due to distortion of the output, and/or over-drive of the input.

Response from 10 kHz to 20 MHz:

Using the low-frequency Rigol waveform generator and the Agilent oscilloscope, you should measure the voltage gain as a function of frequency from 1 KHz to 20 MHz, using at least 3 points per decade (e.g. 1 kHz, 2 kHz, 5 kHz, 10 kHz, 20 kHz, 50 kHz, etc.).

Before beginning, check the generator and scope operation by connecting them together without your circuit attached. **This will allow you to measure/check the open-circuit voltage out of the generator (*which may be different than the displayed voltage ! Why?)*** Do this across the frequency range and record the values. Is it a reasonably flat response? Why are the measured values not equal to the displayed values (assuming they are not) ? *NOTE: To get down to 10mV with the waveform generator, you may have to use one or more 6dB attenuators.*

Now connect your circuit input to the generator and build a table of measured voltage values vs frequency. At each frequency, measure and record the displayed signal-generator voltage, the actual open-circuit voltage (from above), the voltage Vin at the input to your board where it is connected, the voltage Vb at the base of the transistor, and the output voltage Vout at the collector node. These values should be shown in a table in your writeup, with clearly labeled columns, where the first column is frequency and the others are these recorded values. Be clear on what is measured in each column (Vp, Vpp, etc.). Also be sure you have the scope set to 10:1 if using a 10:1 probe !

Compute and plot the ***voltage gain*** magnitude versus frequency in both linear and dB units *using a log frequency axis*. You should do three plots. One found from the gain defined as Vout/Vsource-open-circuit, one as Vout/Vin, and one as Vout/Vb (each with linear and dB curves). Identify the corner frequencies on your plots and discuss why they vary depending on where the measurements are taken.

Response from 100 kHz to 200 MHz:

Repeat the measurements above, but from 100 kHz to 200 MHz using the RF signal generator and the Spectrum Analyzer (in place of the waveform-gen and scope). To reduce your workload, and because we are now starting at midband (100 kHz), you may skip the measurement at the base of the transistor. Just measure Vout/Vin. For Vout, you will have to “back-out” the voltage from the displayed dBm values on the spectrum analyzer, using 50 Ohms as its input resistance value. As always, make sure you are comparing like values (Vrms, Vpp, Vpk ??) when taking voltage ratios to get gain.

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Why is the midband gain lower now? Why is the upper corner frequency higher?

Photo:

A photo of your final circuit should be included in your measurement writeup, either on the front page, or in an appropriate other location. A picture or two of the circuit test setups is also good. If you don't have a smartphone, there is a camera in the lab on the Systems Integration bench.

Summary:

At the end of your notebook entries for this project, provide a brief summary of how the measurements compared to the expected performance. If you failed to meet any specifications, discuss possible reasons.

Finally, discuss reasons why this amplifier design does not achieve the desired small-signal gain at high frequencies. Be clear, discussing the most important factors as elaborated in class and your previous electronics courses.