The University of Portland
Donald P. Shiley School of Engineering

EE371
Lab #2
Design Project
CE Amplifier Frequency Response

Assigned: Wed, Feb 19, 2020
Lab Checkoffs due: Wed, Mar 18, 2020
Final Report Due: Mon, Mar 22, 2020 (in EE352 class)

Your task is to independently design, build and test a single-stage PNP Common Emitter Amplifier circuit (CE Amp) as shown in Figure 1. (Note the external R_S resistor; please don't forget this). Figure 2 shows the front-end 10-to-1 attenuator input circuit that you should use in this lab (similar to Lab1). Your job is to determine all four unknown resistor component values in this circuit such that the following specifications are met:

1. $|A_M| \geq 125V/V$
2. $\omega_L \leq 2\pi(100Hz)$
3. $\omega_H \geq 2\pi(225kHz)$
4. $P_{DC} \leq 35mW$
5. $IC \geq 0.5mA$
5. Achieve nominal bias stability to temperature and β variation

You are required to:

1. Design a CE Amplifier circuit (i.e., determine all four unknown resistor values; see Figure 1) which meets all the design specifications listed above using the Hand-design techniques learned in class.
2. Verify your Hand-design using PSPICE simulation (AC Sweep and Bias Point Details).
3 Build, test and experimentally demonstrate your design in the Lab using your Lab Kit.
4. Record all your Hand, PSPICE and Lab values in the attached Summary Table.
5. Properly record all your Lab results and scratch calculations in your Lab Notebook (as usual) following the guidelines described in Lab1.
6. Get your Lab circuit checked-off by the Instructor.
7. Each student is required to write a their own Formal Lab Report with your final Summary Table included. Your Lab Report should follow the guidelines described in this document and in the Lab2 Final Report Grading Rubric (see website).

Circuit Design:

1. For your circuit design, refer to Figure 1.
2. You will use a 2N3906 PNP BJT transistor. A 2N3906 datasheet is attached for your reference.
3. For Hand analysis, assume the following PNP transistor parameters: $\beta=200$, $V_A=I_C/h_{oe}$ where $h_{oe}=25\mu mhos$, $V_{BE\text{-}on}=0.7V$, $V_T=25mV$.
4. For PSPICE simulation, use a QbreakP3 and assume the following PNP transistor parameters: BF=200, VAF=I_C/h_{oe}, where $h_{oe}=25\mu mhos$, TF=600pS, MJC=0, MJE=0, CJC=C_{obo} from datasheet, and CJE=C_{ibo} from the datasheet. Perform AC Sweep Analysis with Bias Point Details on.
5. Perform DC Hand analysis to start your circuit design and set your four resistor values (R_E, R_C, R_1, and R_2). Remember to follow the "1/3-rule" and the "1/10-rule". After this, you **must re-do your hand calculations precisely** and record in your Summary Table. Verify that you met the bias stability requirement to Temperature and β variation. Specifically, precisely re-

calculate all DC node voltages, branch currents and P_{DC}. Verify your DC Hand analysis in PSPICE (Bias Points Details). Record your results in your Summary Table.

6. Perform small-signal AC full Frequency Response Hand and PSPICE analyses to complete your circuit design. Calculate A_M, R_{in}, R_{out}, ω_L and ω_H. Note that you can calculate R_{in} and R_{out} with Hand analysis only; you cannot calculate R_{in} and R_{out} with PSPICE since you cannot run Transfer Function Analysis on this circuit. For Hand analysis, you will need to perform SCTC and OCTC analyses as shown in class. Note that you first need to determine C_π (using the "C_π-equation"), C_μ, g_m, r_π, r_o and f_t. You will need to consult the attached 2N3906 datasheet. For PSPICE simulation, you will need to perform AC Sweep with Bias Points Details. Record your results in your Summary Table.

Lab Experimentation:

1. **Measure and record** β of your 2N3906 PNP transistor using your DMM.
2. Build and test your circuit in the Lab using your Lab Kit. Use the front-end 10-to-1 attenuator input circuit as shown in Figure 2. IMPORTANT: **"Stagger"** the base and collector/emitter leads of your 2N3906 in your board-layout as explained in class.
3. **Measure and record all DC values.** As in Lab1, you should first build your circuit at home ("Manhattan" layout) and then verify all DC values. This will allow you to be much more efficient and less stressed in the Lab where you will do the more complex AC measurements (A_M, R_{in}, R_{out}, ω_L and ω_H) using the Function Generator and the Oscilloscope.
4. **Determine the small-signal AC frequency values (A_M, ω_H and ω_L)** of your circuit in the Lab by monitoring on the scope the p-p amplitudes of v_{out} and v_{in}. See Figure 2 for the v_{in} circuit. Specifically, **first, measure and record A_M** by setting the function generator amplitude such that you obtain an approximate 1V p-p amplitude at v_{out} at 10KHz (mid-band frequency) and then precisely measure v_{out} using "Cursors". Then precisely measure v_{in} using "Cursors". Then calculate $A_M=v_{out}/v_{in}$. **Second, measure and record $\omega_L=2\pi f_L$** by setting v_{out} to 1V p-p precisely at 10kHz using "Measure" and then adjusting the input frequency down (below 100Hz) until the amplitude of the output reaches –3dB (or $1/\sqrt{2}V=0.707V$) using "Measure". **Third, similarly measure and record $\omega_H=2\pi f_L$** by setting vout to 1V p-p precisely at 10kHz using "Measure" and then adjusting the input frequency up (above 200KHz) until the amplitude of the output again reaches –3dB (or $1/\sqrt{2}V=0.707V$) using "Measure".
5. **Determine the small-signal AC R_{in} and R_{out}** in the Lab using the technique described in the attached sheet (similar to Lab1).
6. Enter all your Lab data in your Lab Notebook as usual.
7. **Fill-in your Summary Table** (attached) with all your Hand, PSPICE, and Lab values.
8. **Get your lab circuit checked-off** by the Instructor.

Lab Report:

1. Your Formal Lab Report should be typed, double-spaced, neat, professional, concise and clear. It should contain the following sections:

   1) Title Page
   2) Executive Summary
   3) Hand design and analysis discussion (refer to attachment)
   4) PSPICE simulation discussion (refer to attachment)
   5) Lab results discussion (refer to Summary Table)
   6) Conclusions
   7) Summary Table (type-writtent)
   8) Attachment: Hand design and analysis (both DC and AC). Include final schematic.
   9) Attachment: PSPICE simulation printouts (annotated).
   10) Attachment: Copy of your signed lab notebook "check-off" page.

2. More specifically, your Lab Report should include the following:

1) A neat sketch of your final CE Amplifier circuit design schematic with all circuit component values clearly labeled.
2) Your DC hand and PSPICE analyses and Lab results. Label and circle all DC operating point node voltages and branch currents directly on your circuit schematic. Briefly show how you met the bias stability requirement.
3) Your small-signal AC Mid-Band Hand analysis and Lab results for R_{in} and R_{out}.
4) Your small-signal AC full Frequency Response Hand and PSPICE analyses and Lab results for A_M, $\omega_L=2\pi f_L$, and $\omega_H=2\pi f_H$. For your Hand analysis, you will use the SCTC and OCTC equations as shown in class. For PSPICE simulation, you should perform AC Sweep Analysis with Bias Point Details turned on.
5). All PSPICE simulation printouts which verify all your Hand-design calculations above (except for R_{in} and R_{out} which cannot be done in PSPICE). You should hand-in your PSPICE schematic, Bode Plots and an edited xxx.out file. Please label/annotate all your PSPICE printouts appropriately, as usual.
6) Your completed and type-written Summary Table with Hand, PSPICE and Lab values.

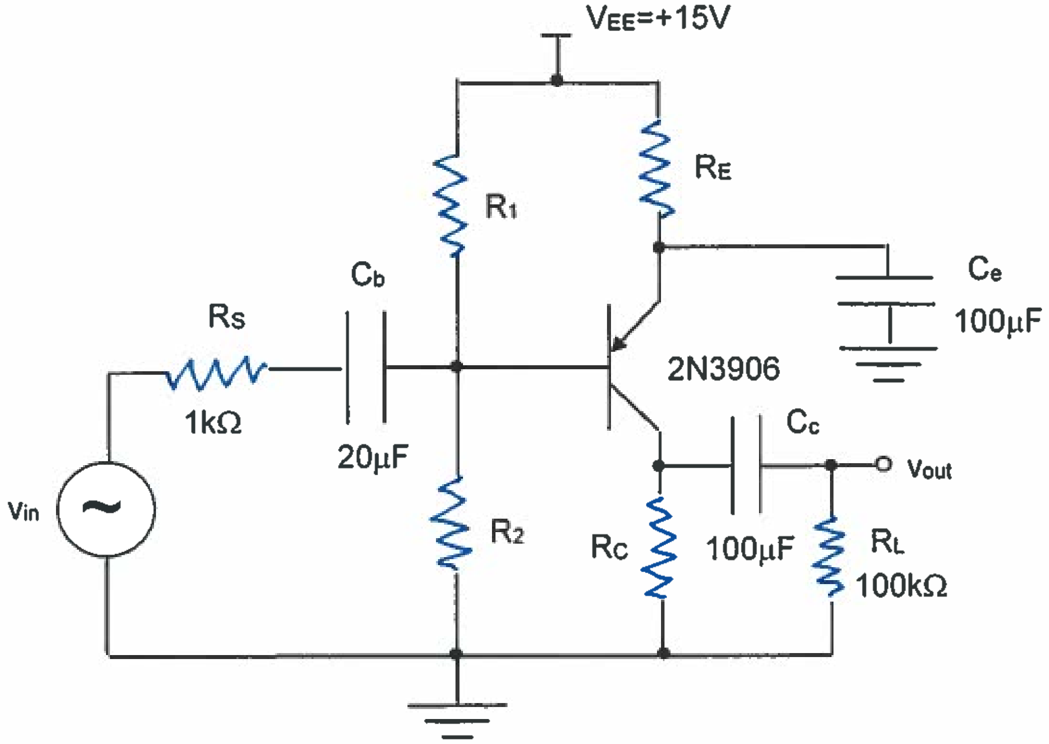


Figure 1.

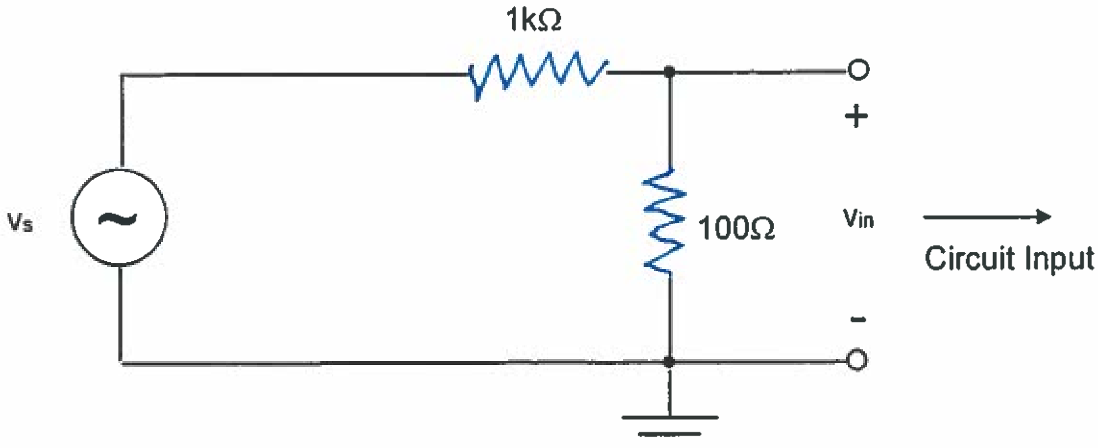
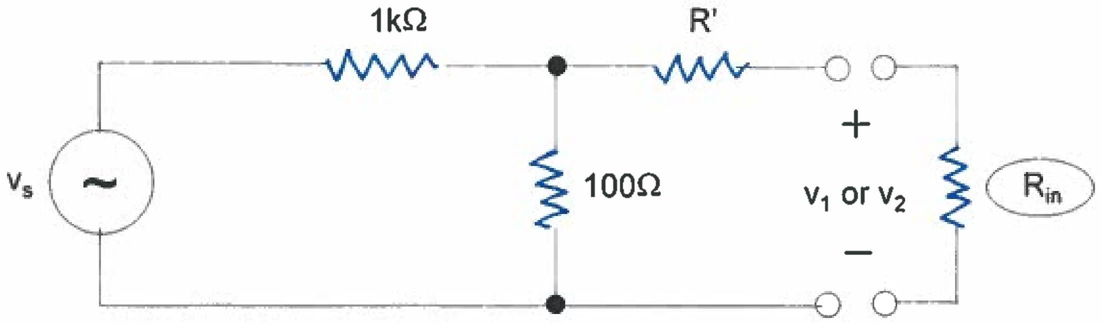


Figure 2.

R_{in} and R_{out} Measurements

1) R_{in} Measurement:



a) Select $R' \approx R_{in}$ (expected).

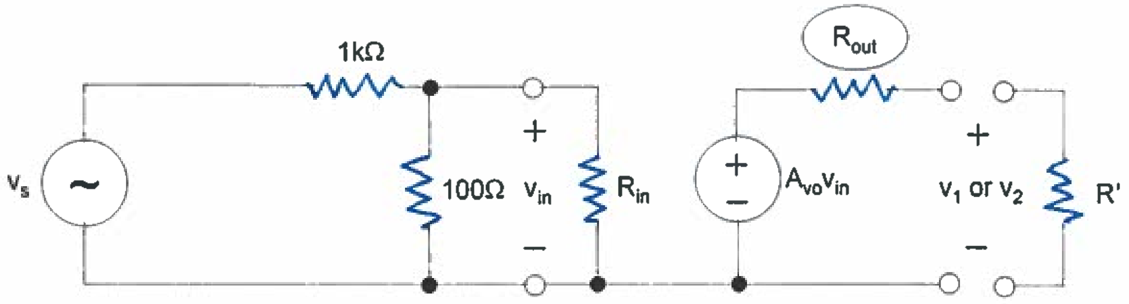
b) Replace the R_S 1kΩ resistor with your R' as shown above. Set v_s such that $v_2 \approx 50$mV p-p and approximately 10kHz. Accurately measure v_2 and record.

c) With the input source circuit (including R') disconnected from R_{in}, accurately measure the resulting open-circuit voltage of the input source circuit, v_1, and record.

d) Calculate R_{in} as follows:

$$R_{in} = R' \frac{v_2}{v_1 - v_2}$$

2) R_{out} Measurement:



a) Select $R' \approx R_{out}$ (expected). Remove R_L from circuit. Return the R_S 1kΩ resistor back in the circuit.

b) With R' connected to the output (i.e., in parallel with R_C), set v_s such that $v_2 = v_{out} \approx 0.5$V p-p with an approximate frequency of 10kHz. Accurately measure v_2 and record.

c) Disconnect R' and accurately measure the resulting open-circuit output voltage, v_1, and record.

d) Calculate R_{out} as follows:

$$R_{out} = R' \frac{v_1 - v_2}{v_2}$$

2N3905/2N3906 General-Purpose *pnp* Transistors*

2N3905
2N3906

CASE 29-02, STYLE 1
TO-92 (TO-226AA)

GENERAL PURPOSE TRANSISTOR

PNP SILICON

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	40	Vdc
Collector-Base Voltage	V_{CBO}	40	Vdc
Emitter-Base Voltage	V_{EBO}	5.0	Vdc
Collector Current — Continuous	I_C	200	mAdc
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	625 5.0	mW mW/°C
Total Power Dissipation @ T_A = 60°C	P_D	250	mW
Total Device Dissipation @ T_C = 25°C Derate above 25°C	P_D	1.5 12	Watts mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−55 to +150	°C

***THERMAL CHARACTERISTICS**

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	83.3	°C/W
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	°C/W

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic		Symbol	Min	Max	Unit
OFF CHARACTERISTICS					
Collector-Emitter Breakdown Voltage(1) (I_C = 1.0 mAdc, I_B = 0)		$V_{(BR)CEO}$	40	—	Vdc
Collector-Base Breakdown Voltage (I_C = 10 μAdc, I_E = 0)		$V_{(BR)CBO}$	40	—	Vdc
Emitter-Base Breakdown Voltage (I_E = 10 μAdc, I_C = 0)		$V_{(BR)EBO}$	5.0	—	Vdc
Base Cutoff Current (V_{CE} = 30 Vdc, V_{BE} = 3.0 Vdc)		I_{BL}	—	50	nAdc
Collector Cutoff Current (V_{CE} = 30 Vdc, V_{BE} = 3.0 Vdc)		I_{CEX}	—	50	nAdc
ON CHARACTERISTICS(1)					
DC Current Gain (I_C = 0.1 mAdc, V_{CE} = 1.0 Vdc)	2N3905 2N3906	h_{FE}	30 60	— —	—
(I_C = 1.0 mAdc, V_{CE} = 1.0 Vdc)	2N3905 2N3906		40 80	— —	
(I_C = 10 mAdc, V_{CE} = 1.0 Vdc)	2N3905 2N3906		50 100	150 300	
(I_C = 50 mAdc, V_{CE} = 1.0 Vdc)	2N3905 2N3906		30 60	— —	
(I_C = 100 mAdc, V_{CE} = 1.0 Vdc)	2N3905 2N3906		15 30	— —	
Collector-Emitter Saturation Voltage (I_C = 10 mAdc, I_B = 1.0 mAdc) (I_C = 50 mAdc, I_B = 5.0 mAdc)		$V_{CE(sat)}$	— —	0.25 0.4	Vdc
Base-Emitter Saturation Voltage (I_C = 10 mAdc, I_B = 1.0 mAdc) (I_C = 50 mAdc, I_B = 5.0 mAdc)		$V_{BE(sat)}$	0.65 —	0.85 0.95	Vdc
SMALL-SIGNAL CHARACTERISTICS					
Current-Gain — Bandwidth Product (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz)	2N3905 2N3906	f_T	200 250	— —	MHz
Output Capacitance (V_{CB} = 5.0 Vdc, I_E = 0, f = 100 kHz)		C_{obo}	—	4.5	pF

2N3905, 2N3906

ELECTRICAL CHARACTERISTICS (continued) ($T_A = 25°C$ unless otherwise noted.)

Characteristic		Symbol	Min	Max	Unit
Input Capacitance ($V_{BE} = 0.5$ Vdc, $I_C = 0$, $f = 100$ kHz)		C_{ibo}	—	10.0	pF
Input Impedance ($I_C = 1.0$ mAdc, $V_{CE} = 10$ Vdc, $f = 1.0$ kHz)	2N3905 2N3906	h_{ie}	0.5 2.0	8.0 12	k ohms
Voltage Feedback Ratio ($I_C = 1.0$ mAdc, $V_{CE} = 10$ Vdc, $f = 1.0$ kHz)	2N3905 2N3906	h_{re}	0.1 0.1	5.0 10	$X 10^{-4}$
Small-Signal Current Gain ($I_C = 1.0$ mAdc, $V_{CE} = 10$ Vdc, $f = 1.0$ kHz)	2N3905 2N3906	h_{fe}	50 100	200 400	—
Output Admittance ($I_C = 1.0$ mAdc, $V_{CE} = 10$ Vdc, $f = 1.0$ kHz)	2N3905 2N3906	h_{oe}	1.0 3.0	40 60	μmhos
Noise Figure ($I_C = 100$ μAdc, $V_{CE} = 5.0$ Vdc, $R_S = 1.0$ k ohm, $f = 10$ Hz to 15.7 kHz)	2N3905 2N3906	NF	— —	5.0 4.0	dB

SWITCHING CHARACTERISTICS

			Symbol	Min	Max	Unit
Delay Time	($V_{CC} = 3.0$ Vdc, $V_{BE} = 0.5$ Vdc $I_C = 10$ mAdc, $I_{B1} = 1.0$ mAdc)		t_d	—	35	ns
Rise Time			t_r	—	35	ns
Storage Time	($V_{CC} = 3.0$ Vdc, $I_C = 10$ mAdc, $I_{B1} = I_{B2} = 1.0$ mAdc)	2N3905 2N3906	t_s	— —	200 225	ns
Fall Time		2N3905 2N3906	t_f	— —	60 75	ns

(1) Pulse Width ≤ 300 μs, Duty Cycle ≤ 2.0%.

*Courtesy of Motorola, used by permission.

Lab #2 Summary Table

Parameter	Hand	PSPICE	Lab
I_E			
I_B			
I_C			
V_E			
V_B			
V_C			
I_{R1}			
I_{R2}			
$V_{BE\text{-}ON}$			
P_{DC}			
A_M			
$\omega_L=2\pi f_L$			
$\omega_H=2\pi f_H$			
R_{in}		N/A	
R_{out}		N/A	
V_A			N/A
β			
g_m			
r_π			
r_o			N/A
C_π			N/A
C_μ			N/A
f_T			N/A