Electronic Circuits

ELEC 301

Mini-Project 2

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Part I

(a)Datasheet of 2N2222A

Table 1. The Small Signal Parameters h_{fe}, h_{ie}, and h_{oc} of 2N2222A

Description	Symbol	Range of value
Small Signal Current Gain	h_{fe}	50~300
Input Impedance	h_{ie}	2.0k Ω ~ 8.0k Ω
Output Impedance	h_{oc}	5.0μ 1/Ω ~ 35.0μ 1/Ω

*All data are for V_{CE} = 10V, Ic = 1mA, f = 1kHz and T = 25 Celsius. (Data from: *https://www.verical.com/datasheet/rectron-semiconductor-rf-bjt-2N2222A-4576108.pdf*)

(b) The characteristics of 2N2222A

i) I_B vs V_{BE}

The simulated circuits are designed in *Circuitmaker*.

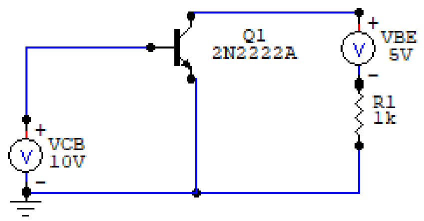


Figure 1. The test circuit of for I_B vs V_{BE}

The DC-simulation is applied. In the DC Analysis set up, the start value of V_{BE} is 0 V; the stop value is 650mV; the step value is 20mV. The plot of I_B vs V_{BE} is:

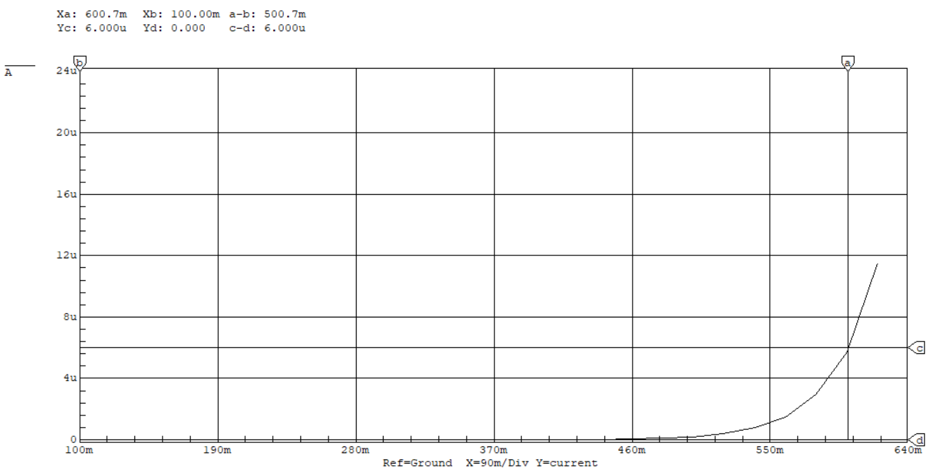


Figure 2. The plot of I_B vs V_{BE}

ii) <u>I_C vs V_{CE} with various I_B</u>

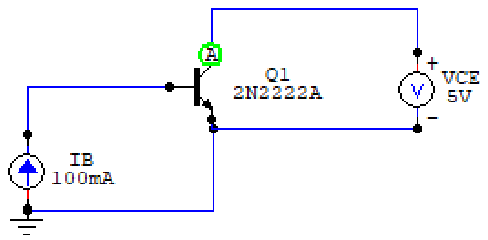


Figure 3. The test circuit for I_C vs V_{CE} with various I_B

The DC-simulation is applied. In the DC Analysis set up, the start value of V_{CE} is 0V; the stop value is 6 V; the step value is 10 mV. Another variable I_B is used. The start value of I_B is 1uA; the stop value is 10 uA; the step value is 1 uA. The plot of I_C vs V_{CE} with different I_B is:

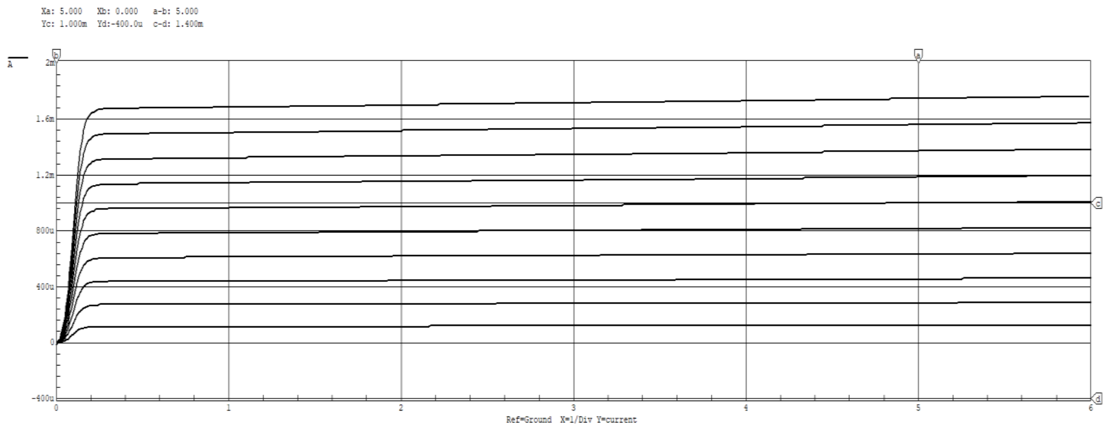


Figure 4. The plot of I_C vs V_{CE} with various I_B

iii) <u>I_C vs V_{CE} with various V_{BE}</u>

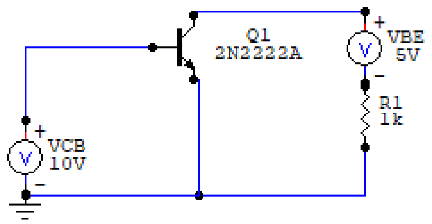


Figure 5. The test circuit for I_C vs V_{CE} with various V_{BE}

In the DC Analysis set up, the start value of V_{CE} is 0V; the stop value is 5 V; the step value is 100 mV. Another variable V_{BE} is used. The start value of V_{BE} is 0V; the stop value is 5V; the step value is 500mV. The plot of I_C vs V_{CE} with different V_{BE} is:

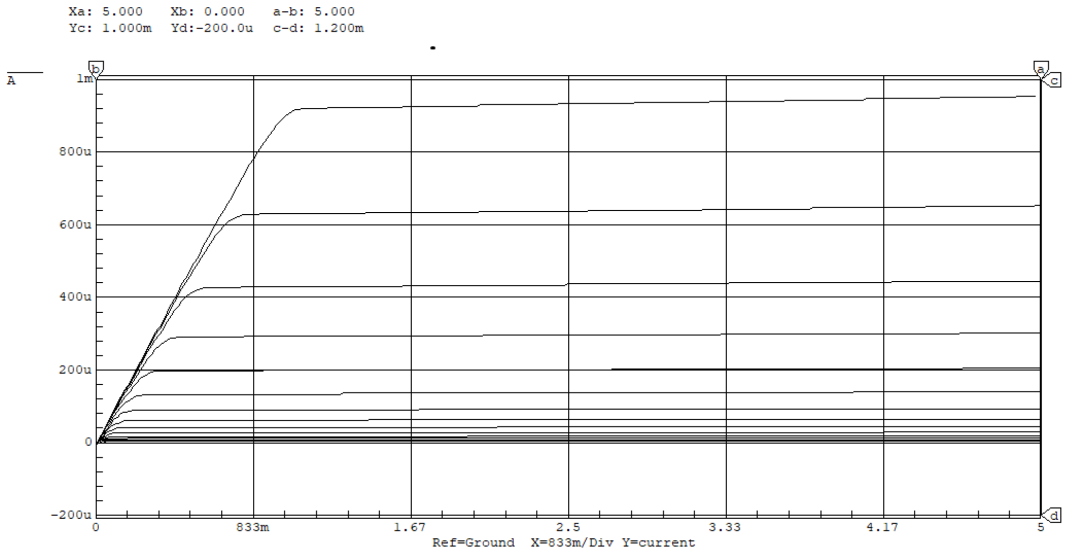


Figure 6. The plot of I_C vs V_{CE} with various V_{BE}

As shown in **Figure 4**, the step value of I_B is 1uA. There are 10 lines in the **Figure 4**, each of them represents the relationship between I_C and V_{CE} with a different I_B. The I_B for the bottom line is 1uA, for the top line is 10 uA. From **Figure 4**, when V_{CE} = 5V (line a) and I_C = 1mA line c), I_B is about 6 uA (the 6th line from bottom).

$$I_C = \beta * I_B$$

$$\beta = \frac{IC}{IB} = \frac{1\,mA}{6\,uA} = \boxed{\mathbf{166.67}}$$

According to the formula in the ELEC 301 lecture notes, gm, r_π and r_o can be calculated:

$$\text{gm} = \frac{IC}{VT}$$

In this case, the temperature is 25 Celsius. Thus, VT = 25 mV and I_C is 1 mA.

$$\text{gm} = \frac{1\,mA}{25\,mV} = 0.04\ \frac{1}{\Omega} = \boxed{\mathbf{0.04\ S}}$$

$$r_\pi = \frac{\beta * VT}{IC} = \frac{166.67 * 25\,mV}{1\,mA} = \boxed{\mathbf{4166.75\ \Omega}}$$

To find r_o and VA, the fundamental knowledge of BJT is needed.
Recall the Lecture 6 page 16 from ELEC 201 (Dr. Jesus Calvino-Fraga):

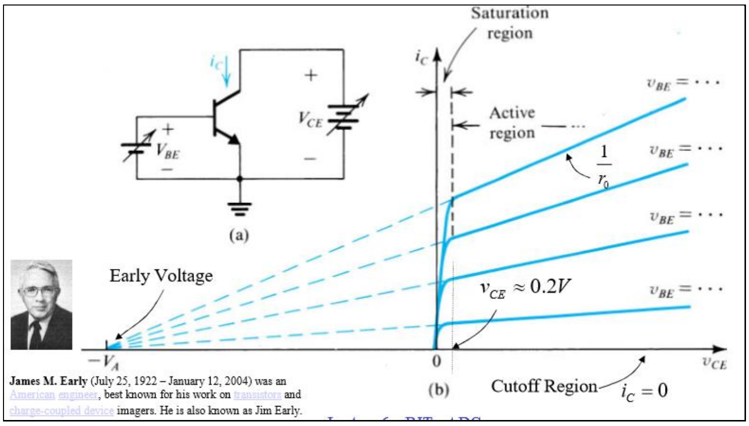


Figure 7. The characteristic of BJTs

*The author of **Figure 7** is Dr. Jesus Calvino-Fraga and with his explicit permission

As **Figure 7** shown, VA (Early Voltage) is the x-intercept of the extensions of the line of I_C vs V_{CE}. From **Figure 4**, the line I_B = 6 uA, called *line6* is chosen. Two points on *line6* are needed to generate the equation of the line. From the simulation plot, when I_{C1} = 960 uA, V_{CE1} = 1V; when I_{C2} = 1mA, V_{CE2} = 5V. The equation can be generated:

$$\text{Slope} = \frac{\text{IC2} - \text{IC1}}{\text{VCE2} - \text{VCE1}} = \frac{1mA - 960uA}{5V - 1V} = 0.00001$$

$$(Y - y1) = \text{Slope}\,(X - x1), \text{ (Take } I_C = 1\text{mA as y1 and } V_{CE} = 5\text{V as x1)}$$
$$Y = 0.00001X - x1{*}0.00001 + y1 = 0.00001X - 5V{*}0.00001 + 1mA = 0.00001X{+}0.00095$$

When Y = 0 (x-intercept):

$$0 = 0.00001X + 0.00095$$
$$X = -95\ (\text{-VA})$$
$$\boxed{\textbf{VA = 95 V}}$$

From the ELEC201 Lecture note, r_o can be calculated:

$$r_o \approx \frac{VA}{IC} = \frac{95\,V}{1\,mA} = \boxed{\textbf{95000 Ω}}$$

Admittance $y_o = 1/\,r_o = 10.526\ \mu S$

Table 2. The 'measured' value vs the value from datasheet

Symbol	Measured	Datasheet
β	166.67	50 ~ 300
r_π	4166.75	2000 ~ 8000 Ω
r_o	10.526	5µ ~ 35µ S

*The datasheet is from *https://datasheetspdf.com/pdf-file/490365/STMicroelectronics/2N2222A/1*.

As **Table 2** shown, the 'measured'(calculated) values are in the range of the value from datasheet. Thus, the simulated circuit and the calculations are acceptable.

(c) Vcc = 15 V and Ic = 1 mA

i) 'Measured'

From **Figure 4**, for the V_{CE} = 4 V and I_C = 1 Ma, I_B is about **6.05 µA** (**Slightly** above the 6th line from bottom).
From **Figure 2**, when I_B is 6.05 µA, the V_{BE} is 610mV = 0.601V.

$$I_E = I_B + I_C = 6.05\ \mu A + 1.0\ mA = 1.00605\ mA$$
$$V_{CE} \text{ is 4V of less and } R_E = 0.5R_C$$

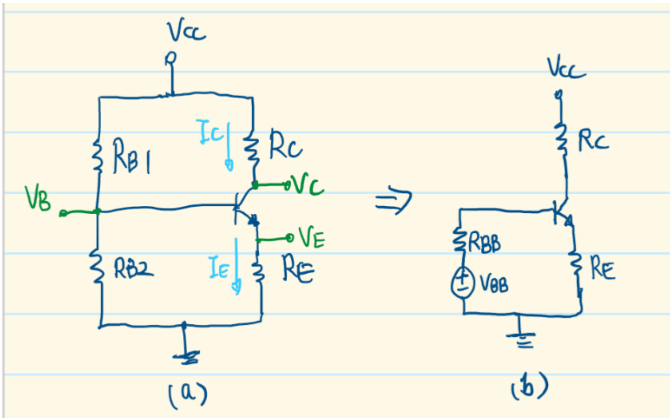


Figure 8. Simple bias network

From **Figure 8(a)**, $V_{CC} = I_C{*}R_C + V_{CE} + I_E{*}R_E$:

$$15V - 4V = 1mA * R_C + 1.0061mA*(0.5R_C)$$
$$R_C = \boxed{\mathbf{7318.45\ \Omega}}$$
$$R_E = 0.5R_C = \boxed{\mathbf{3659.23\ \Omega}}$$
$$V_C = V_{CC} - I_C{*}R_C = 15V - 1mA*7318.70\Omega = \boxed{\mathbf{7.68V}}$$
$$V_E = I_E{*}R_E = 1.006mA * 3659.35\Omega = \boxed{\mathbf{3.68V}}$$
$$V_B = V_E + V_{BE} = 3.68V + 0.601V = \boxed{\mathbf{4.28V}}$$

Applied KCL on node B in **Figure 8(a)**, The relationship R1 and R2 can be calculated (I_1 is the current through R_{B1}, I_2 is the current through R_{B2}):

$$I_1 - I_2 = \frac{VCC - VB}{RB1} - \frac{VB - 0}{RB2} = I_B$$

$$\frac{10.72}{RB1} - \frac{4.28}{RB2} = 6.05\ \mu A$$

$$R_{B1} = \frac{10.72 * RB2}{6.05\mu * RB2 + 4.28}$$

Assume $R_{B2} = \boxed{\mathbf{10k\Omega}}$:

$$R_{B1} = \boxed{\mathbf{24697.62\ \Omega}}$$

Thevenin Equivalent is applied on (a) to get (b) in **Figure 8**.

$$R_{BB} = R_{B1} || R_{B2} = \boxed{\mathbf{7117.96\ \Omega}}$$

$$V_{BB} = V_{CC} * [\frac{RB2}{RB1 + RB2}] = \boxed{\mathbf{4.323\ V}}$$

To verify the assumed value is valid:

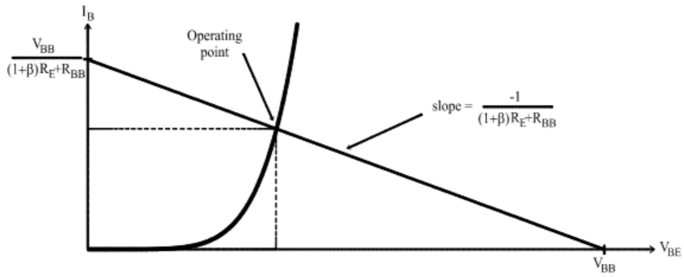


Figure 9. I_B vs V_{BE}

The calculated values are plugged in to get the slope and the y-intercept:

$$\text{Slope} = \frac{-1}{(1+166.67)*3659.23+7117.96} = -1.61*10^{-6}$$

$$\text{Y-intercept} = \frac{4.323\ V}{(1+166.67)*3659.23+7117.96} = 6.965*10^{-6}$$

At the operating point:

$$I_B = \text{Y-intercept} + \text{VBE*Slope} = 6.965*10^{-6} + 0.601V* -1.61*10^{-6} \approx 6.0\ \mu A$$

Thus, the assumed values are valid.

The figure below shows the Thevenin Equivalent circuit with the calculated resistances. The DC operating points are measured in this circuit.

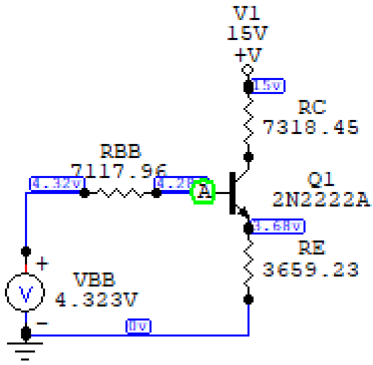


Figure 10. The Thevenin equivalent circuit with the calculated resistance

Table 3. The measurements of DC operating points.

	I_C (mA)	I_B (μA)	I_E (mA)	V_C (V)	V_B (V)	V_E (V)
Measured	0.999	6.034	1.005	7.69	4.28	3.68
Calculated	1.0	6.05	1.00605	7.68	4.28	3.68

As shown in **Table 3**, with the chosen resistors, the measured values and the calculated values are extremely close. Therefore, the chosen resistors RB1 and RB2 are useable to bias the BJT.

ii) Using 1/3rd Rule

For **Figure 8**, apply the 1st version of 1/3rd rule (I_C = 1mA), where I_1 is the current through R_{B1}, I_2 is the current through R_{B2}:

$$V_B = \frac{1}{3}\ V_{CC} = 15V/3 = \boxed{5V}$$

$$V_C = \frac{2}{3}\ V_{CC} = 15V*2/3 = \boxed{10V}$$

$$V_E = V_B - V_{BE} = 5V - 0.6V = \boxed{4.4V}$$

$$I_B = \frac{IC}{\beta} = 1\ mA\ /\ 166.67 = \boxed{6.0\ \mu A}$$

$$I_E = I_B + I_C = 6.0\ \mu A + 1.0\ mA = \boxed{1.006\ mA}$$

$$I_1 = \frac{IE}{\sqrt{\beta}} = \frac{1.006mA}{\sqrt{166.67}} = 77.92\ \mu A$$

$$I_2 = I_1 - I_B = 77.92\ \mu A - 6.0\ \mu A = 71.92\ \mu A$$

$$R_C = \frac{VCC - VC}{IC} = \frac{15v - 10v}{1\ mA} = \boxed{5\ k\Omega}$$

$$R_{B1} = \frac{VCC - VB}{I1} = \frac{15V - 5V}{77.92\mu A} = \boxed{128.29\ k\Omega}$$

$$R_{B2} = \frac{VB - 0}{I2} = \frac{5V}{71.92\mu A} = \boxed{\mathbf{69.52\ k\Omega}}$$

$$V_{BB} = V_{CC}*[\frac{RB2}{RB1+RB2}] = \boxed{\mathbf{5.27V}}$$

$$R_{BB} = R_{B1} \parallel R_{B2} = \boxed{\mathbf{45.09\ k\Omega}}$$

$$R_E = \frac{VE - 0}{IE} = \frac{4.4V}{1.006mA} = \boxed{\mathbf{4.37\ k\Omega}}$$

The circuit below shows the calculated resistances and the DC measurements:

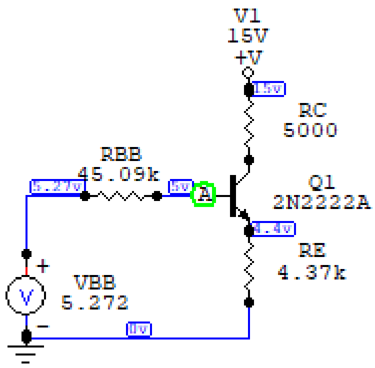


Figure 11. The 1/3rd rule circuit

Table 4. The measurements of DC operating points.

	I_C (mA)	I_B (μA)	I_E (mA)	V_C (V)	V_B (V)	V_E (V)
Measured	1.001	5.970	1.007	9.993	5.003	4.402
Calculated	1.000	6.000	1.006	10.000	5.000	4.400

As shown in **Table 4**, under the 1/3rd rule, the calculated values are very close to the actual values which are from the simulation.

iii) The use of the closest commonly available resistors

Table 5. The calculated and standard values

	Calculated (Ω)	Standard (Ω)
R_{B1}	128.29 k	130 k
R_{B2}	69.52 k	68 k
R_C	5 k	5.1 k
R_E	4.37 k	4.3 k
R_{BB}	45.09 k	44.65 k (calculated)

*The standard values are from: http://ecee.colorado.edu/~mcclurel/resistorsandcaps.pdf

The Standard-value resistors are placed into the circuit in Figure 11. The DC operating points are measured and listed below.

Table 6. The DC operating point with the assumed and standard resistors.

	I_C (mA)	I_B (μA)	I_E (mA)	V_C (V)	V_B (V)	V_E (V)
Assumed	1.001	5.970	1.007	9.993	5.003	4.402
Standard	1.023	6.064	1.017	9.812	5.001	4.400

After the resistors are replaced by the standard resistors, the operating currents and voltages does not have an obvious change compare to the assumed resistors. Therefore, these standard resistors can be used to bias this BJT.

iv) Compare the DC operating points in i), ii) and iii)

Table 7. The DC operating points in non-1/3rd rule, 1/3rd rule and the standard resistors.

	I_C (mA)	I_B (μA)	I_E (mA)	V_C (V)	V_B (V)	V_E (V)
Non-1/3rd	0.999	6.034	1.005	7.690	4.280	3.680
1/3rd	1.001	5.970	1.007	9.993	5.003	4.402
Standard	1.023	6.064	1.017	9.812	5.001	4.400

As shown in **Table 7**, the operating current in those three methods are comparable. However, the operating voltages (V_C, V_B and V_E) have high differences. The 1/3rd-rule and the standard-resistors models have relative higher operating voltages than the non-1/3rd rule model. In the non-1/3rd rule model, the resistors are quite small (~10kΩ) compare to the resistors used in the ii) and iii) (~50 kΩ). The high resistance can have more voltages than lower resistors. V_{CC} is constant. When the chosen resistors have high resistance, the voltages that go to the BJT (say V_C, V_B and V_E) are lower.

<u>(d) The replacement of 2N3904 and 2N4401</u>

In the standard-resistor circuit, the 2N2222A is replaced by 2N3904 and 2N4401. The measured DC operating points are listed in the **Table 7** below.

Table 7. The DC operating points of 2N2222A, 2N3904 and 2N4401 under the standard-resistor condition.

Transistors	I_C (mA)	I_B (μA)	I_E (mA)	V_C (V)	V_B (V)	V_E (V)
2N2222A	1.023	6.064	1.017	9.812	5.001	4.400
2N3904	0.982	8.287	0.990	9.994	4.902	4.265
2N4401	0.996	6.761	1.003	9.919	4.970	4.313

For all the three transistors, I_C is not 0 A, and V_{CE} (V_C-V_E) is higher than 0.2V. According to the **Figure 7,** these transistors are not in the cut-off region or saturation region because I_C is not equal to 0 A and V_{CE} is higher than 0.2 V. Even though the DC operating points of the three transistors have little differences, the standard-resistor circuit still can be used to bias all the three transistors since they are all in active region, and the operating points are reasonable.

Part II

The Common Emitter amplifier is built by the given resistor and three 10μF capacitors. The load resistor of **5.1 kΩ** is chosen because the output resistance RC is 5.1 kΩ. The same resistance transfers the maximum **power**. The circuit is shown in **Figure 12** (for 2N2222A).

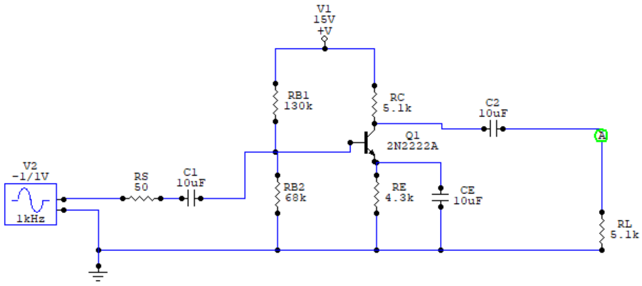


Figure 12. The Common Emitter Amplifier circuit

(a) Poles and Zeros

For **2N2222A**, to calculate the poles and zeros, the circuit is converted to the small-signal model. In this model, C_μ and C_π can be calculated by the formula (CJE, CJC, MJC, VJC and TF are found in SPICE in *Circuitmaker*):

$C_\pi \approx 2*CJE + TF*gm = \mathbf{74.88\ pF}$ $\qquad$ $C_\mu \approx CJC/(1+V_{CB}/VJC)^{MJC} = \mathbf{7.74\ pF}$

The **Miller Theorem** is applied to the small-signal model (k = **-100.68**). The circuit becomes:

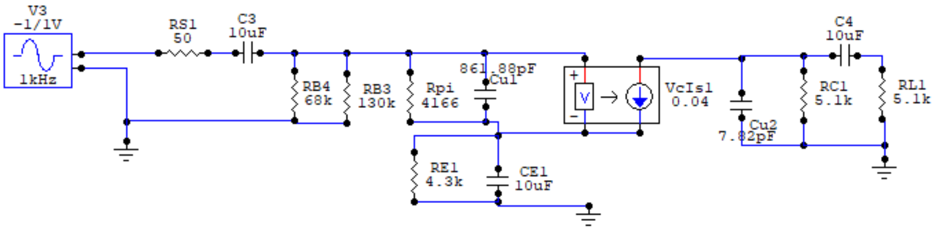


Figure 13. The Common Emitter Amplifier circuit with after Miller Theorem

ω_{Lz1} and ω_{Lz2} are at zero since C3 and C4 are coupling. To find the ω_{Lz3}, the admittance of the Emitter is 0. Thus, $\omega_{Lz3} = 1/(R_E*C_E) = \boxed{\mathbf{3.70\ Hz}}$

The Low-frequency poles can be calculated:

At the output:

$$\omega_{Lp2} = \frac{1}{10\mu F*(5.1k+5.1k)\Omega} = \boxed{\mathbf{1.56\ Hz}}$$

At the input, the SC/OC test is applied on C3 and CE1:

SC: $\tau^{sc}{}_{C3} = 10\mu F*(50+68k||130k||4166) = 0.0386s$

$$\tau^{sc}{}_{CE} = 10\mu F*(4.3k||\frac{4166+(68k||130k||50)}{1+166.7}) = 0.00025s$$

$\tau^{sc}{}_{CE}$ has smaller time constant (higher frequency) so it is valid. The $\omega_{Lp3} = 1/\tau^{sc}{}_{CE} = \boxed{\mathbf{636.67\ Hz}}$

Then, OC test is applied to C3:

$$\tau^{oc}_{C3} = 10\mu F*(50+68k||130k||(4166+167.7*4.3k)) = 0.421s$$

$$\omega_{Lp1} = 1/\tau^{oc}_{C3} = \boxed{0.38\ \text{Hz}}$$

Then, the High-frequency poles can be calculated:

At the input: $\omega_{Hp1} = \dfrac{1}{861.88pF*(50||68k||130k||4166)\Omega} = \boxed{3.74\ \text{MHz}}$

At the output: $\omega_{Hp2} = \dfrac{1}{7.82pF*(5.1k||5.1k)\Omega} = \boxed{8.57\ \text{MHz}}$

The Bode and Phasor plot are below:

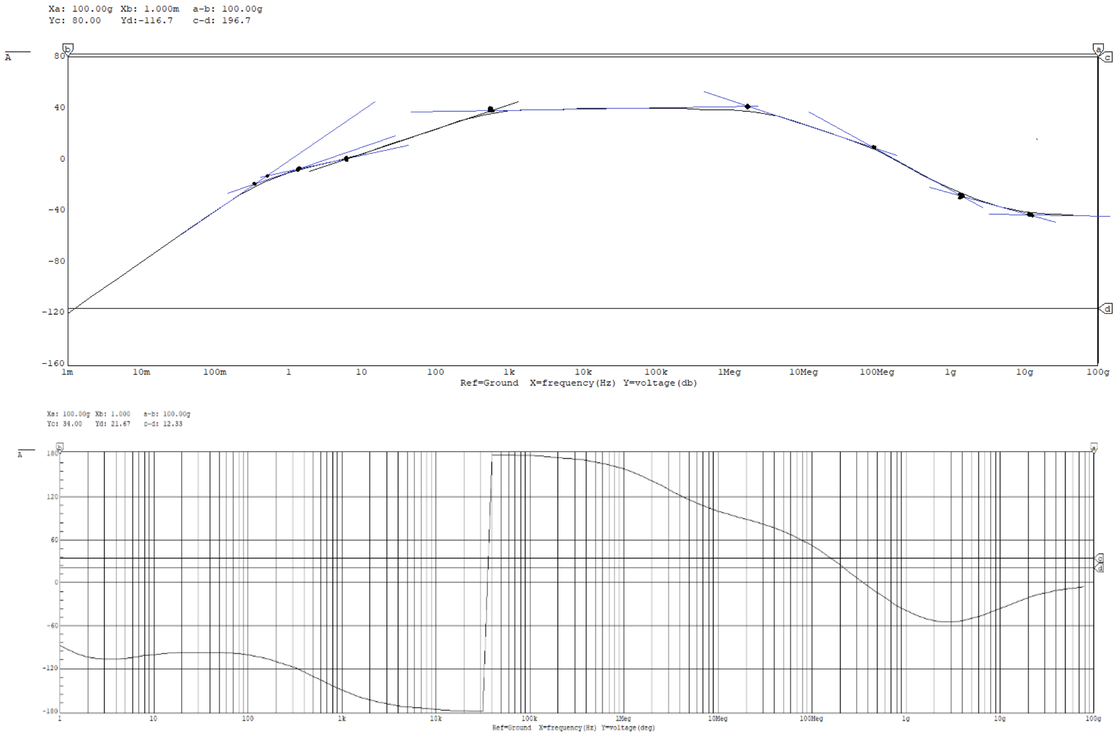


Figure 14. The BOD and PHR diagram of 2N2222A

Table 8. Pole and Zeros for 2N2222A

(Hz)	ω_{Lp1}	ω_{Lp2}	ω_{Lp3}	$\omega_{Lz1/Lz2}$	ω_{Lz3}	ω_{Hp1}	ω_{Hp2}
Calculated	0.38	1.56	636.67	0	3.70	3.74M	8.57M
Measured	0.36	1.58	648.6	0	3.63	3.16M	157.6M

The table shows that the calculated low-frequency poles and zeros are comparative to the measured value. However, the high-frequency poles are shifted a huge scale. The reason is that the calculated values are based on the **Miller Theorem**. In addition, the measured graph shows two high-frequency zeros which cannot be calculated since the H-frequency zeros tends to be ∞.

For **2N3904**, the same bias circuit is used and the 2N2222A is replaced by 2N3904. The C_π and C_μ can be calculated by the same formula. C_π = 25 pF ; C_μ = 1.75 pF. The low-frequency poles, zeros and high-frequency poles are calculated by the same method used in the calculations of poles and zeros of 2N2222A. The result and the Bode and phasor diagram are below:

Table 9. Pole and Zeros for 2N3904

(Hz)	ω_{Lp1}	ω_{Lp2}	ω_{Lp3}	$\omega_{Lz1/Lz2}$	ω_{Lz3}	ω_{Hp1}	ω_{Hp2}
Calculated	0.38	1.56	636.67	0	3.70	15.89M	35.26M
Measured	0.40	1.59	664.9	0	3.65	14.01M	299.0M

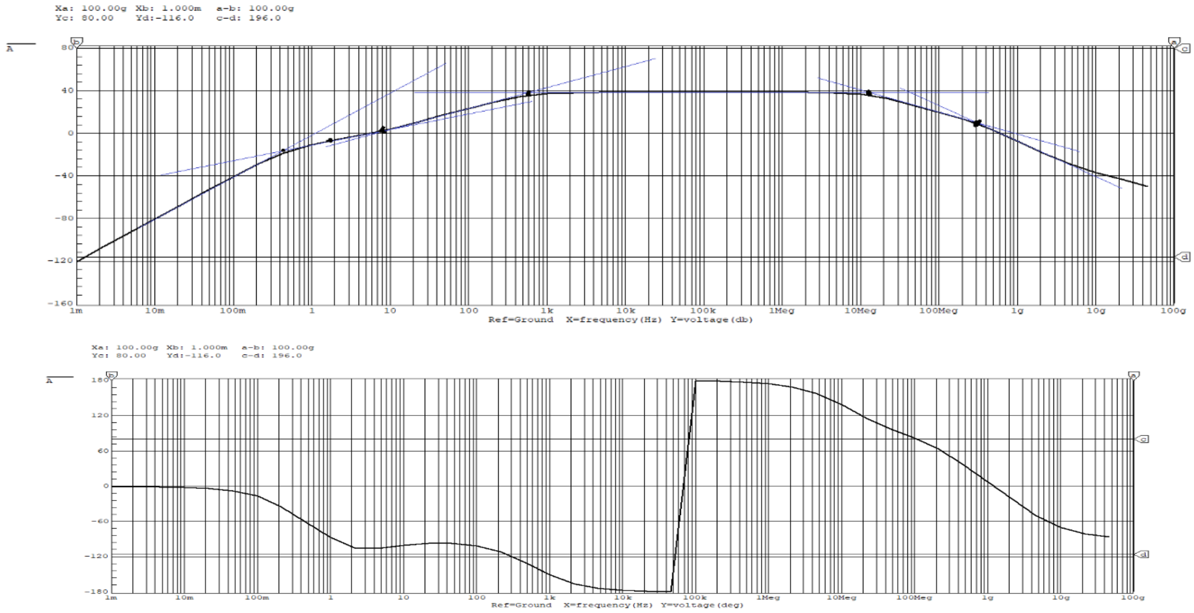


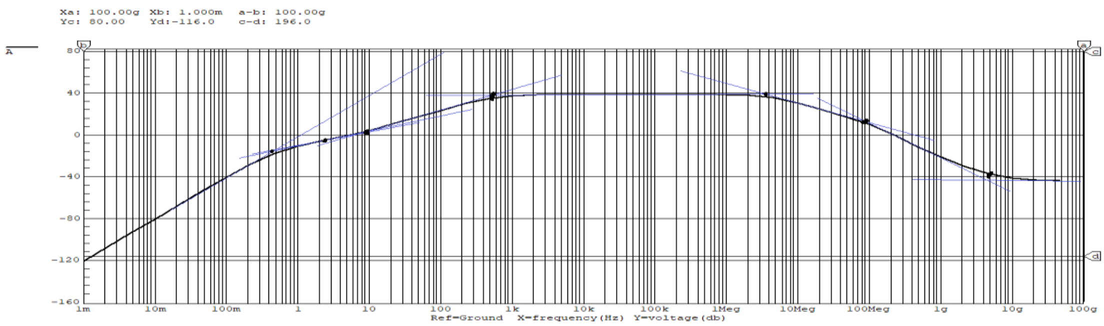
Figure 15. The BOD and PHR diagram of 2N3904

The calculated values are comparative to the measured values except the high-frequency poles. Even though there are two high-frequency zeros on the measured diagram, the zeros cannot be calculated since the capacitances tend to be ∞.

For **2N4401**, the same bias circuit is used and the 2N3904 is replaced by 2N4401. The C_π and C_μ can be calculated by the same formula. $C_\pi = 67.28$ pF ; $C_\mu = 5.15$ pF. The low-frequency poles, zeros and high-frequency poles are calculated by the same method used in the calculations of poles and zeros of 2N2222A. The result and the Bode and phasor diagram are below:

Table 10. Pole and Zeros for 2N4401

(Hz)	ω_{Lp1}	ω_{Lp2}	ω_{Lp3}	$\omega_{Lz1/Lz2}$	ω_{Lz3}	ω_{Hp1}	ω_{Hp2}
Calculated	0.38	1.56	636.67	0	3.70	5.46M	12.00M
Measured	0.37	1.53	658.3	0	3.65	3.82M	84.21M



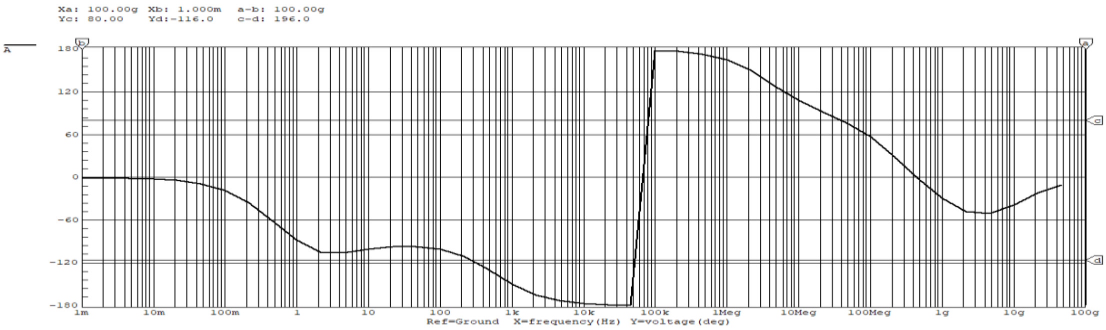


Figure 16. The BOD and PHR diagram of 2N4401

As shown above, the calculated values and measured values are also similar. The high-frequency zeros on the figure still cannot be calculated. The shift of bandwidths of 2N2222A, 2N3901 and 2N4401 are different because they are from the small signal model and the Miller's Theorem. The different C_π and C_μ provides different high-frequency poles.

(b) Various Amplitude of input signal

From **Figure 14**, the mid-band bandwidth is from 630 Hz to 3.1 MHz. Therefore, **10 kHz** is chosen for the generator. The diagram that represents the relationship between Vs and Vo is below:

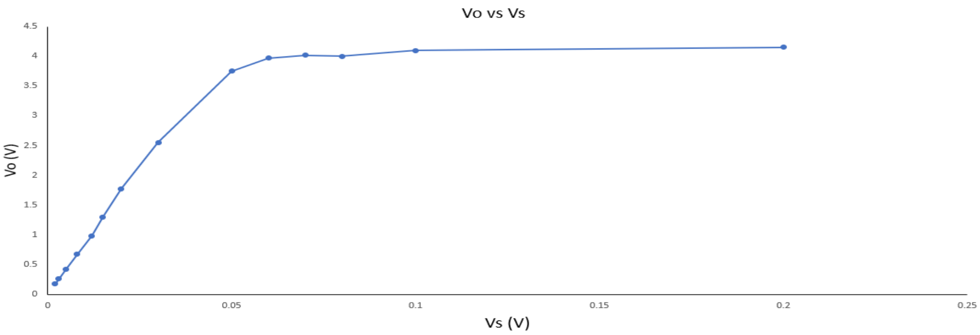


Figure 17. The diagram of Vs vs Vo

It can be seen from the figure that the relationship between the input signal and the output signal becomes non-linear near **Vs = 0.05 V**. The reason is when Vs is greater than this value, the transistor is in saturated mode, so the output signal is not significant anymore.

(c) Input Impedance at mid band

For **2N2222A**, the Oscilloscope probe is located at the right node of C1 in **Figure 12** (the 50 Ω resistor is removed). The peak to peak voltage and peak to peak current are measured: Vin = 0.02V ; Iin = 3.98μA. Therefore, the measured input impedance is equal to Zin = Vin / Iin = $\boxed{\textbf{5.03 k}\Omega\textbf{.}}$ The calculated input impedance is equal to Zin = $R_{B1}||R_{B2}||R\pi$ = $\boxed{\textbf{3.81 k}\Omega}$

For **2N3904** and **2N4401**, the same method above is used to get the measured input impedance and the calculated input impedance. The results are listed in the table below:

Table 11. The input impedance of 2N4401, 2N3904 and 2N4401

Model	Measured (kΩ)	Calculated (kΩ)
2N2222A	5.03	3.81
2N3904	4.16	3.40
2N4401	4.22	2.80

From the table, the calculated impedances are relatively smaller than the measured values. Even though the calculated values and the measured values have small deviations, the calculated values are still expected.

(d) <u>Output Impedance at mid band</u>

To calculate the output impedance, the input generator is shorted, and the RL is removed. Another generator is moved to the load terminals with a small resistor in series to measure the current.

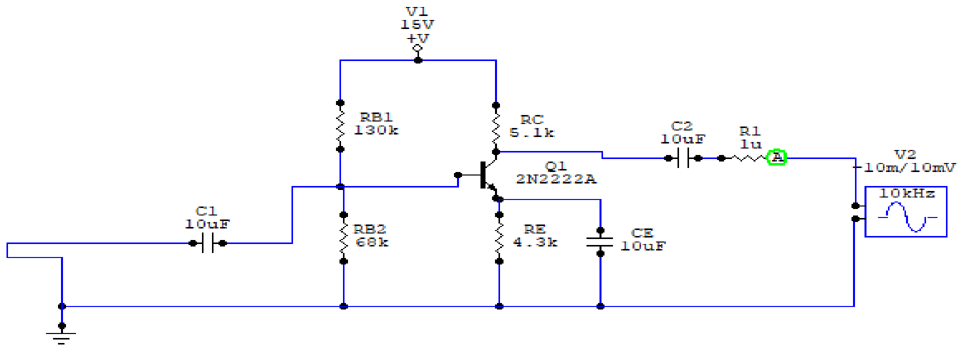


Figure 18. The circuit to measure the output impedance

For **2N2222A**, the Oscilloscope probe is located at the right node of R1 in **Figure 18** to measure the current. The peak to peak voltage and peak to peak current are measured: V_{out} = 0.02V ; I_{out} = 3.85μA. Therefore, the measured output impedance is equal to $Z_{out} = V_{out} / I_{out}$ = $\boxed{\textbf{5.19 k}\Omega}$. The calculated output impedance is the load impedance, in this case, Z_{out} = $\boxed{\textbf{5.1 k}\Omega}$. For **2N3904** and **2N4401**, the same method above is used to get the measured output impedance and the calculated output impedance. The results are listed in the table below:

Table 12. The output impedance of 2N4401, 2N3904 and 2N4401

Model	Measured (kΩ)	Calculated (kΩ)
2N2222A	5.19	5.1
2N3904	5.21	5.1
2N4401	5.23	5.1

From **Table 12**, the calculated output impedances are close to the measured output impedances for all the three models. It is safe to say that the calculated values are accurate.

(e) The best-performance transistor

In **Figure 14, 15 and 16**, 2N3904 and 2N4401 have the highest mid-band gain (40 decibel) at the mid band, which is higher than the mid-band gain of 2N2222A (slightly lower than 40 dB). In addition, the 2N2222A has the bandwidth from 600 Hz – 3.74 MHz; 2N3904 has the bandwidth from 600 Hz – 15.89 MHz which is the widest in these three transistors; 2N4401's bandwidth is from 600Hz – 5.46 MHz. Among them, 2N3904 has the highest mid-band gain and the widest work region (bandwidth). Therefore, **2N3904** gives the best performance.

Conclusion

In part I, the transistor is biasing by designing a bias circuit. The circuit is converted to the small-signal model by calculating the β, Rπ, gm and Ro. The DC operating points are then measured in the *Circuitmaker*. In this circuit, the resistance (RB1, RB2, RC, RE) are determined to make sure the transistor can work at the DC operating points. To calculate and determine these resistances, the Miller Theorem and the $1/3^{rd}$ rule are used. In part II, a common-emitter amplifier is investigated. The location of low-frequency and high-frequency poles and zeros are calculated and compared with the measured values. The calculated values are reasonable. In addition, the bandwidths and the mid-band gains of 2N2222A, 2N3904 and 2N4401 are compared, and a summary is conducted that 2N3904 has the best performance due to the widest bandwidth and the highest mid-band gain. This mini project provides advanced knowledge of BJTs, which is useful in the future career.

Reference

[1] ELEC 301 Notes

[2] A. Sedra and K. Smith, “Microelectronic Circuits.”5th(or higher)Ed., Oxford UniversityPress, New York.

[3] CircuitMaker^{TM} (or other circuit simulator) User’s Manual.

[4] Notes on Canvas.

[5] ELEC 201 Notes