EEE109 Lab 3

Frequency Response of A BJT Amplifier

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Abstract

In the third experiment, Pspice simulation is necessary to find frequency response of a BJT amplifier. However, BJT's characteristic should be measured firstly in the whole experiment. The most important characteristic is β, we need to starting from definition to measure β in the circuit. Then, using this basic characteristics, the amplifier which we talks common emitter amplifier and common collector amplifier will be simulated in Pspice. The circuit's resistance needs to be calculate first before simulation. By the end of report, these two amplifier will be compared and contrast by using the experiment data. The frequency response both common emitter amplifier and common collector amplifier in low to high frequency will be covered in this report.

1.Introduction

1.1 Background Information

This experiment used Pspice simulation which could help students reduce unnecessary problems. By using Pspice, the BJT in use is Q2N3904 which is in the base library of Pspice. We know that the β depend on I_C and I_B, however, β for the same version of BJT may different, in the circuit design, it is a floating value, if we need to design circuit, we need to consider this in the circuit. In this experiment, the β need to use a simple circuit to measure which is shown in Figure 1.

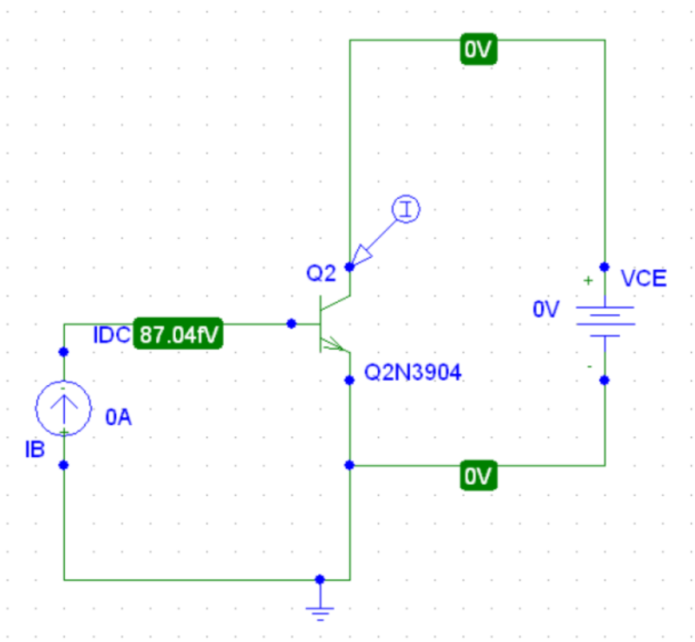


Figure 1 the circuit used to calculate the β

By using this circuit, Pspice provides a current source that supply current I_B from base, then measure different collector current I_C. Giving a formula that is $\beta = I_C / I_B$, by using this formula, a list of value of β will be covered in the result and calculation.

1.2 Common Emitter Amplifier

Common emitter amplifier is one of the basic BJT amplifier, the small signal input from base and then the output voltage is provided from the collection part[1]. The entire circuit should be biased in the amplification mode, however, as Figure 2, the output signal could be cut if the circuit is not in the amplification mode. The meaning of common emitter could be understood that the emitter is line on the ground.

One of the most important parameter is called voltage gain which uses A_v to instead of it. It is defined by V_{out} and V_{in}. By using common emitter amplifier circuit, the input signal and output signal is not same to each other, there is because the A_v is always negative. For common emitter amplifier, the voltage gain is greater than one, current gain is greater than one and also inout resistance is in the medium.

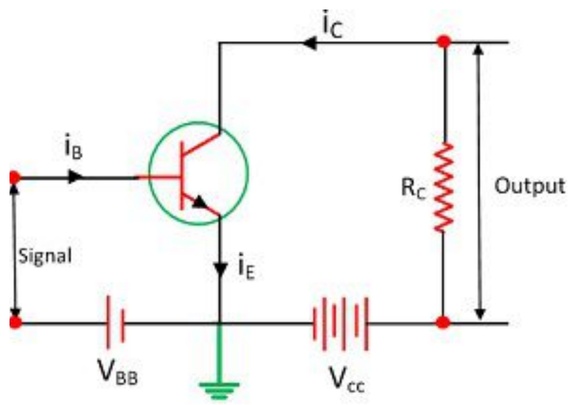


Figure 2: Simply Common Emitter Amplifier[1]

1.3 Aims and Objectives:

For this experiment, we need to calculate the different value of resistant both to common emitter and common collector amplifier circuits firstly. Secondly, the upper and lower cut off frequencies need to be calculated in common emitter amplifier. Thirdly, frequency response needs to be measure and record in this report. Fourthly, the low to high frequency range needs to be measure during 10 Hz to 10 GHz in common emitter BJT transistor, also the common collector's test frequency is between 10 Hz to 1 THz (Addiction Doc supports).

2. Theory:

2.1 Basic NPN's BJT of 2N3904 and it Characteristic

2N3904 is a basic NPN type BJT, it is used in the experiment circuit. Let introduce current's theory firstly, we know that NPN conclude two p-n junctions, by using this idea, the current in emitter could be described in the following formula.

$$i_E = I_{EO(e^{v_{BE}/V_T - 1})}$$

Because to the most circuit, negative one can be ignored, so the i_E could be marked by following formula:

$$i_E = I_{EO(e^{v_{BE}/V_T})}$$

As the same as i_E, i_C could be described in following formula:

$$i_C = I_{S(e^{v_{BE}/V_T})}$$

The reason why i_C is controlled by V_{BE}, it is because the vast majority of electrons moving from point E pass through P area and reach point C. Adding to the relationship of i_B, we could describe the α and β in the end which is shown in the following part:

$$i_C / i_B = \beta$$

$$\alpha = \beta / \beta + 1$$

It is worth noting that α and β is the basic property of BJT. The data we need to measure first is β. By suing this β, we could know the relationship between each current value.

2.2 Basic Relationship in Common Emitter Circuit

The basic Common Emitter Circuit is shown in Figure 3. The small signal is V_s, and the capacitor blocks the DC part from entering the AC part. Since the two resistors R1 and R2 make the circuit more complicated, here we apply the Thevenin effective circuit. To solve the small signal's Av and input and output resistance, we need to calculate DC solution and find the value of Q point. Then we give the AC solution.

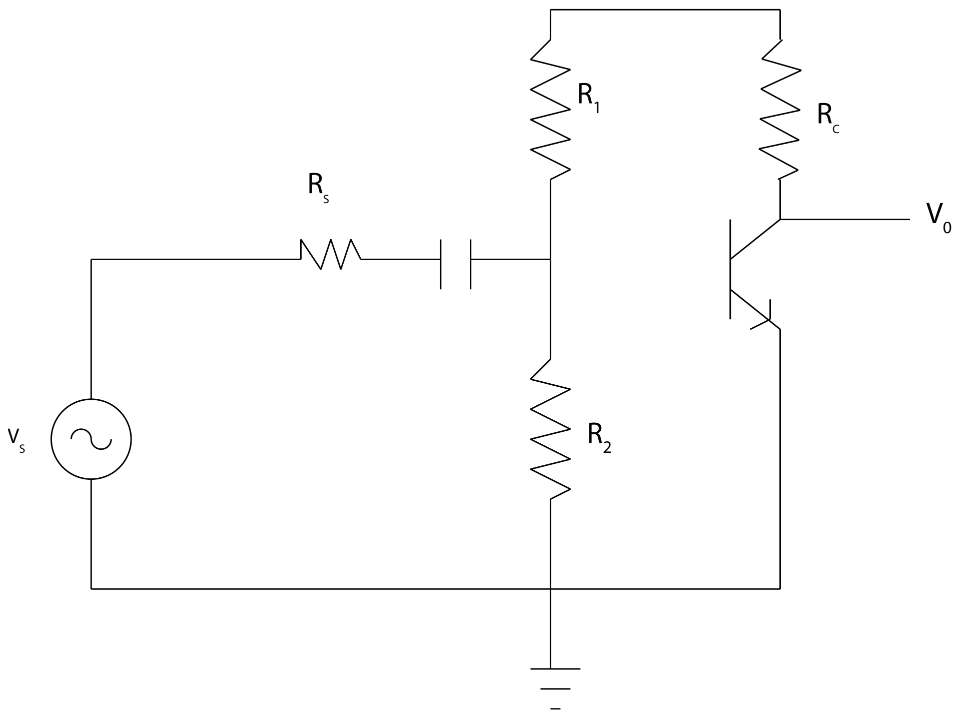


Figure 3: The basic Common Emitter Circuit

In order to calculate the communication solution, we propose the following formula:

$$r_\pi = V_{T\beta}/I_{CQ}$$

The transconductance is calculated as follows:

$$g_m = I_{CQ}/V_T$$

Small signal voltage gain:

$$A_v = V_o/V_s$$

2.3 Frequency test

In the frequency test, we use different ranges of input frequencies to measure the upper and lower frequency of the single-stage common-amplifier circuit. In fact, we need to know the following acknowledge which are lower cut-off frequency f_L, upper limit cutoff frequency f_H and the passband f_{bw}. The lower cut-off frequency f_L is when the signal frequency drops to a value which let Av to the $1/\sqrt{2}$, we call this to the lower cut-off frequency and if signal frequency up to a value which let Av to the $1/\sqrt{2}$, we call this to upper limit cutoff frequency. And the band between f_L and f_H, we called f_{bw}. In the discussion part, the experiment result will be discussed.

3. Circuit Design:

3.1 Testing β

In the first part of experiment, we designed a very simple circuit to test the 2N3904 BJT which is shown in the Figure 4. What needs to be understood in it is if base current is very small, the voltage of V_{BE} cannot be opened. However, when the current of base increased and give V_{CE} increased, we could get a graphic which included data of β. For the detailed data, it will be presented in the experimental data. In Pspice simulation, one of the small details is that the system default experimental temperature is 27 degrees Celsius. In fact, the voltage between $V_{BE(on)}$ is default 0.7 Volt.

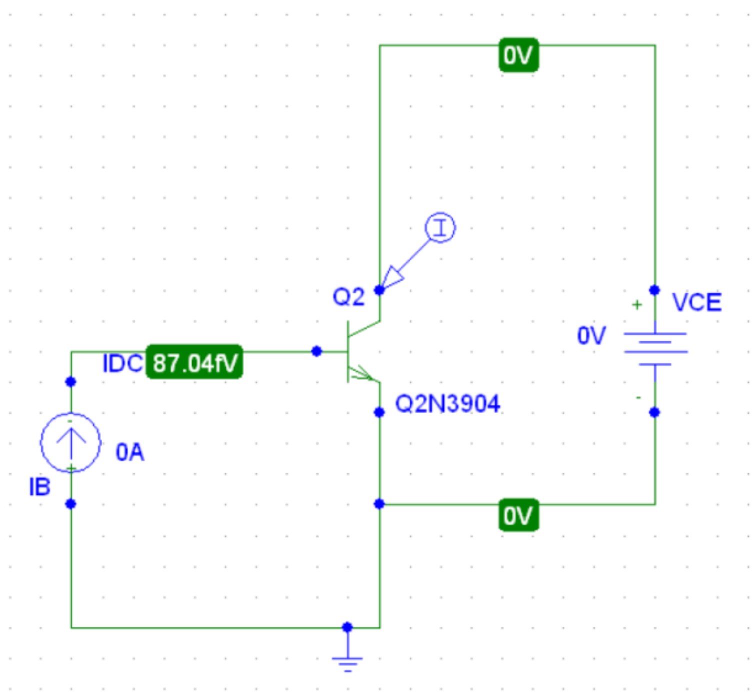


Figure 4: The circuit to test β

3.2 Common Emitter Circuit

The design circuit is shown in Figure 5 and Figure 6. Firstly, this report will talk about how to calculate each resistance for common emitter circuit. Secondly, the design of this circuit will be covered.

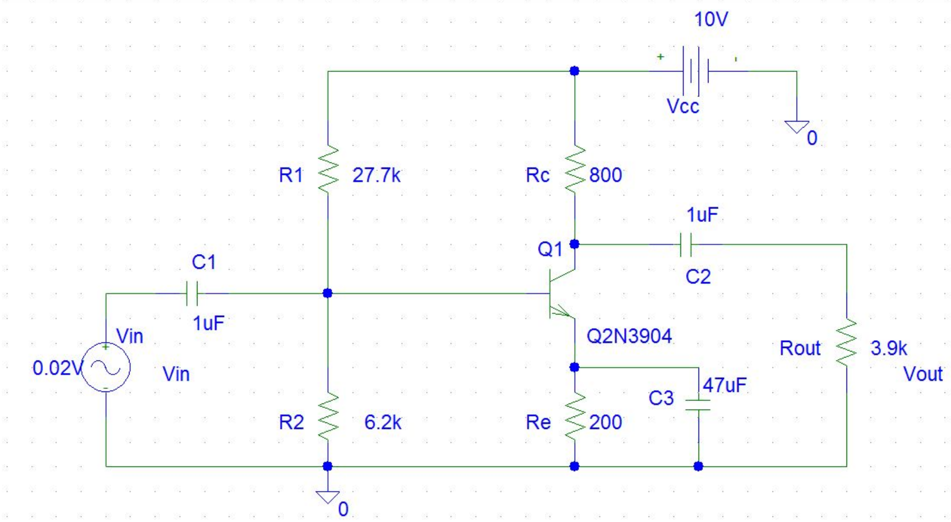


Figure 5: Common Emitter Circuit Design

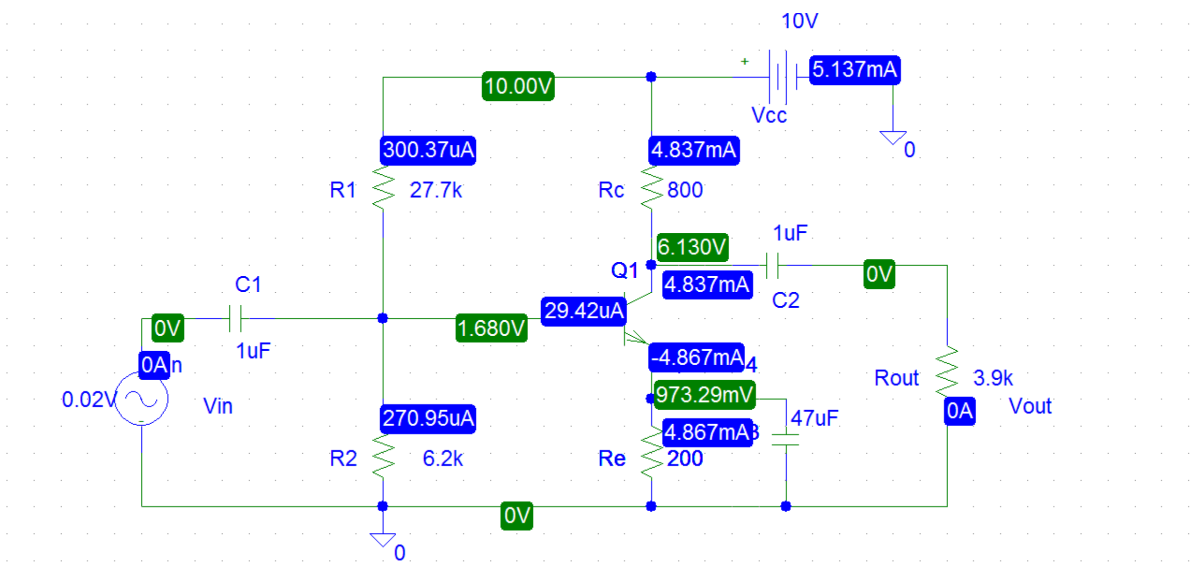


Figure 6: Common Emitter Circuit of Value

After calculating β, the resistance could be calculated. Firstly, with the basic BJT, we know the current relationship which is $Ie = Ib + Ic$. And we assume that $Ve = Vcc/10$ and $IR = 10Ib$. By using following equations we could get the resistance of R_c, R_e, R_1 and R_2.

$$V_{cc} = I_c R_c + V_{ce} + I_e R_e$$

$$I_e = I_b + I_c$$

Because of $I_c >> I_b$ and $\alpha = \beta/\beta + 1$, we could get that $I_c = I_e$.

Then, we assume that $V_{EB(on)} = 0.7$ volt, we could get:

$$V_b = V_e + 0.7$$

$$R_2 = V_b/9I_b$$

$$R_1 = (V_{cc} - V_b)/I_R$$

Because $IR = 10Ib$, we replace I_R to I_b:

$$R_1 = (V_{cc} - V_b)/10I_b$$

Finally, after calculation we have the following results, which are $R_1 = 27.7$ kΩ, $R_2 = 6.2$ kΩ, $R_c = 800$ Ω and $R_e = 200$ Ω.

Let discuss the design of this circuit, firstly, the capacitor C1 which is designed for isolated AC and DC. Then, the resistance R_1 and R_2 are divided voltages which let the resistance is not too large, so large resistance could not be able to use in integrated circuit. By using Thevenin's theorem, it would be combined to the R_{TH} and V_{TH}. This circuit has capacitor C_2 and C_3, which is installed at collector and emitter.

3.3 Common Collector Circuit

The whole circuit and specific current and voltage conditions of the circuit is shown in Figure 7. Because of $V_{cc} = V_{ce} + I_e R_e$, the resistances which are $R_1 = 14.34\ \mathrm{k\Omega}$, $R_2 = 221.12\ \mathrm{k\Omega}$ and $R_e = 1000\ \Omega$.

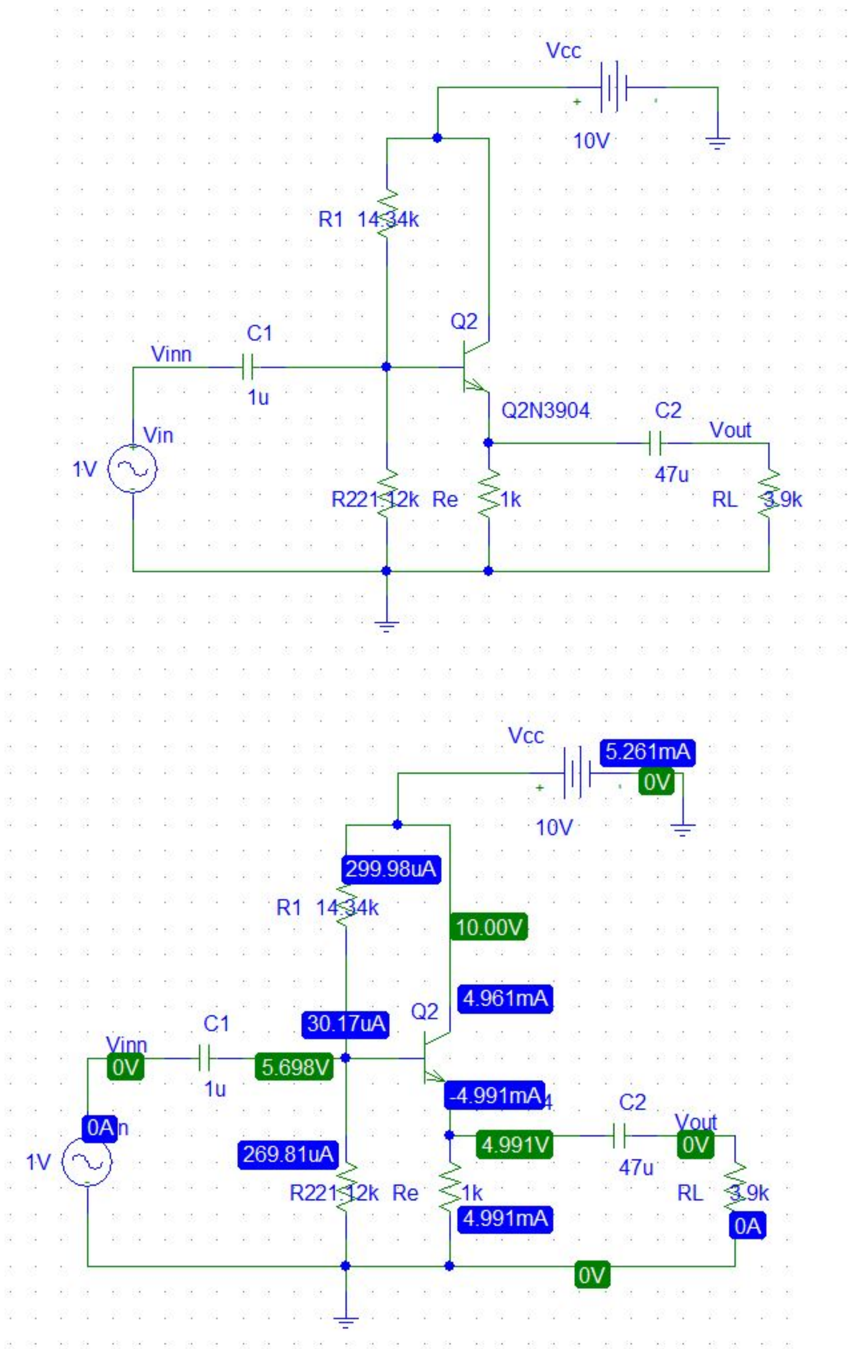


Figure 7: Common Collector Circuit

4. Experimental Method:

4.1 Experiment Equipment

In this experiment, the BJT is BJT 2N3904. For resistance, the load resistance is 3.9 kΩ, other resistance should be calculate firstly and the use in the Pspice. However, the result of each resistances are not integers, in the real world, we cannot directly use such strange resistance values to experiment, because these resistances may not be produced. This is also the inadequacy of computer simulation. For capacitor which are 1 μF and 47 μF.

4.2 β Measurement Method

Firstly, we need to use the Figure 4 to build up in Pspice, each parts of element should be find in the Pspice library. One possible error is that the 2N3904 component cannot be found. The solution is to search for Q2N3904. Then using wire to connect each component. The ground wire must be added or the simulation may fail. Secondly, set the range of I_{DC} in analysis part. It is shown in Figure 8.

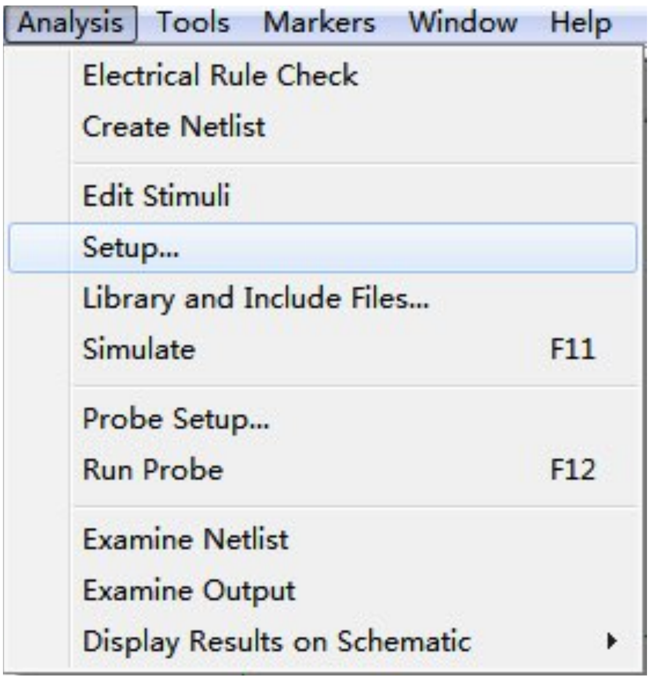


Figure 8: Setting on analysis

Then after press this button, the voltage and current's range should be set up. It is shown in Figure 9 and Figure 10.

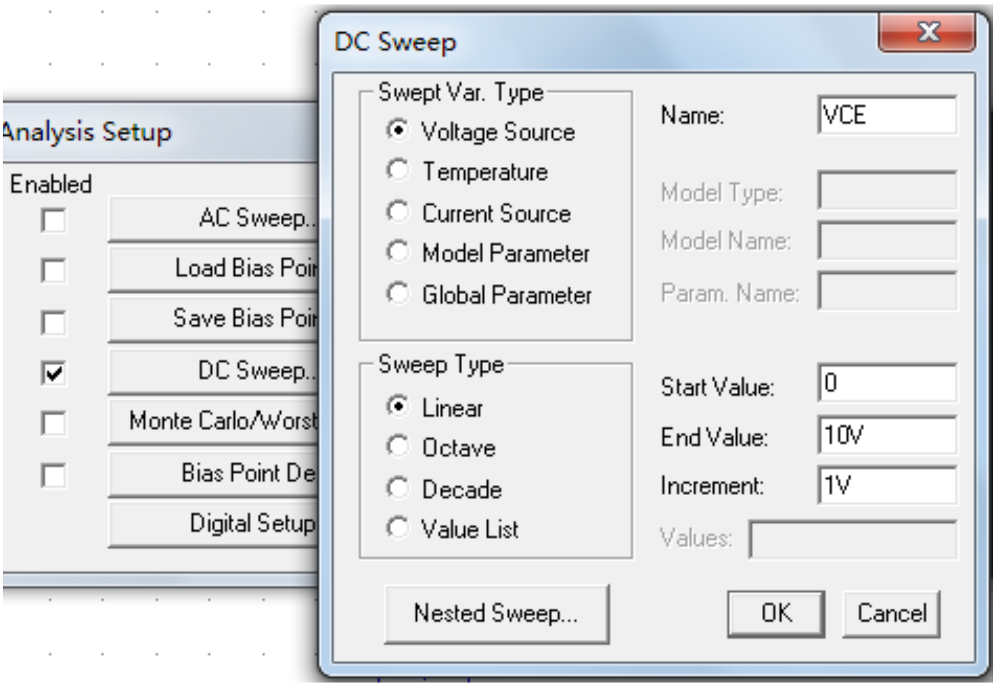


Figure 9: Voltage range settings

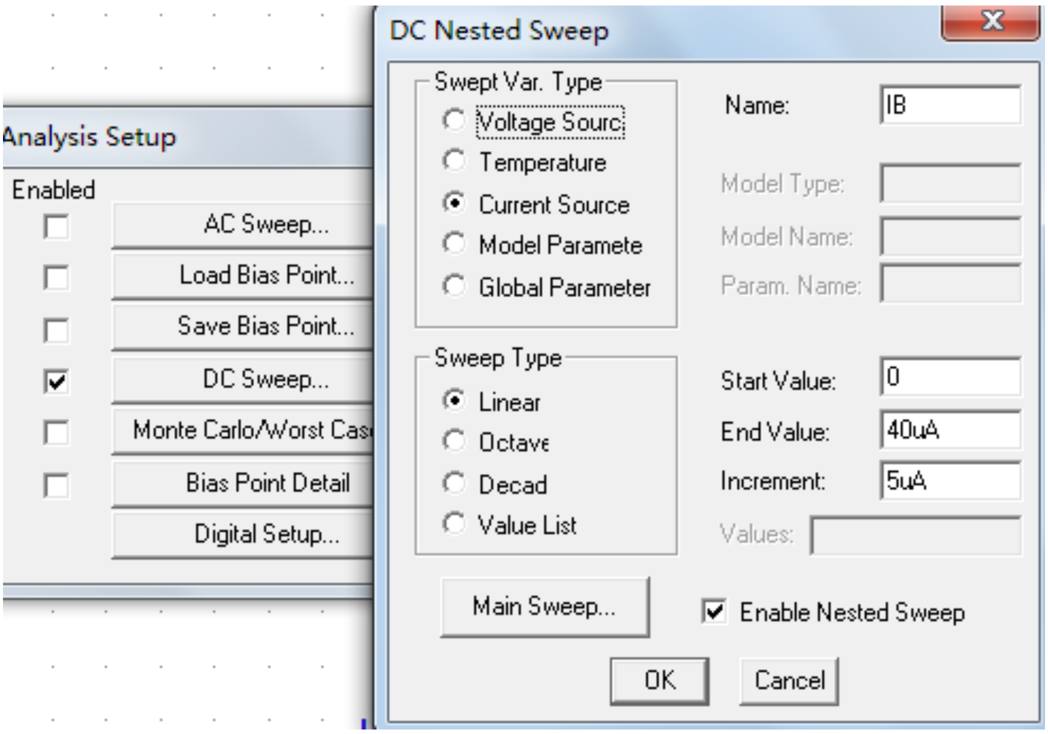


Figure 10: Current range settings

For each step of current, it increases 5 μA in each steps. For voltage, it increases 1 V in each steps.

4.3 Build up common emitter amplifier circuit

Firstly the common emitter amplifier circuit should be built in Pspice. Then use AC sweep and noise analysis to simulate this circuit. Set AC sweep type to decade and start frequency to 10 Hz and maximum end frequency to 10 GHz. Next, run the simulator and add trace, which is shown in Figure 11.

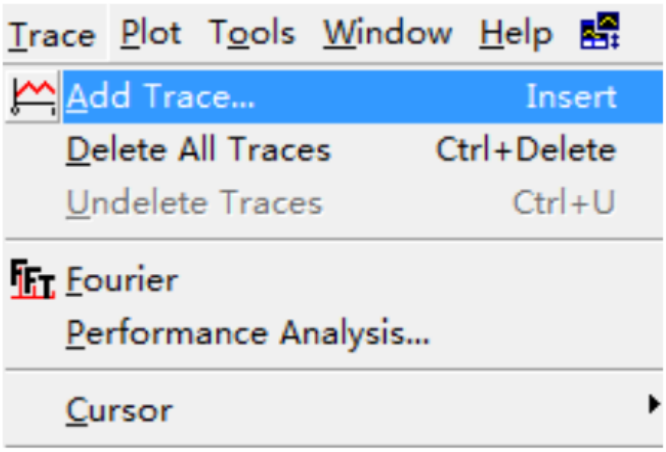
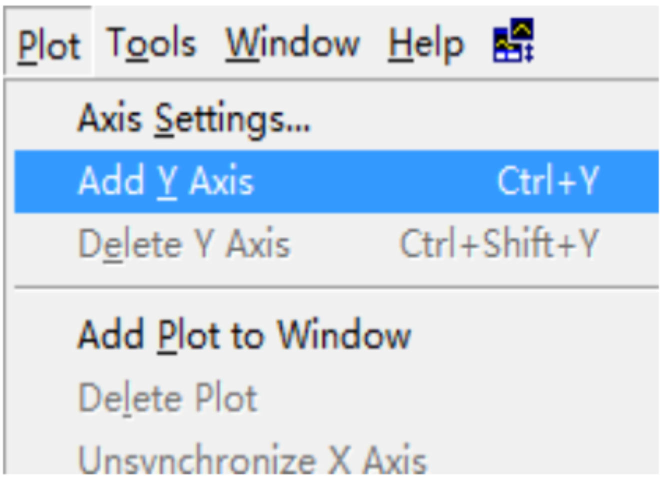


Figure 11: Add Trace function

A new interaction will let user to input trace. Four data should be includes in experiments. The first thing



is V_{in} and V_{out}, after adding this trace, a new Y axis should be added which is shown in Figure 12.

Figure 12: Adding Y Axis

Other trace which should be added are Av which use dB($V(V_{out}/V_{in})$). And then is phase difference between V_{in} and V_{out} should be input in the graphics. But one of the problems is whether the phase difference between the input voltage and the output voltage should be subtracted. We know that the phase difference between the two subtractions is not significant on the graph.

4.4 Build up common collector amplifier circuit

The method of operation of this experiment is no different from the method of operation in 4.3. It is only necessary to note that in the additional manual, the maximum range of frequencies is set to 1 GHz.

5. Result and Calculation:

5.1 Result of β

The result is shown in Figure 13. The first thing we need to observe is that the Early effects is existing. The evidence is that the line is not completely horizontal. If we extend these lines in reverse, we can get Early voltage.

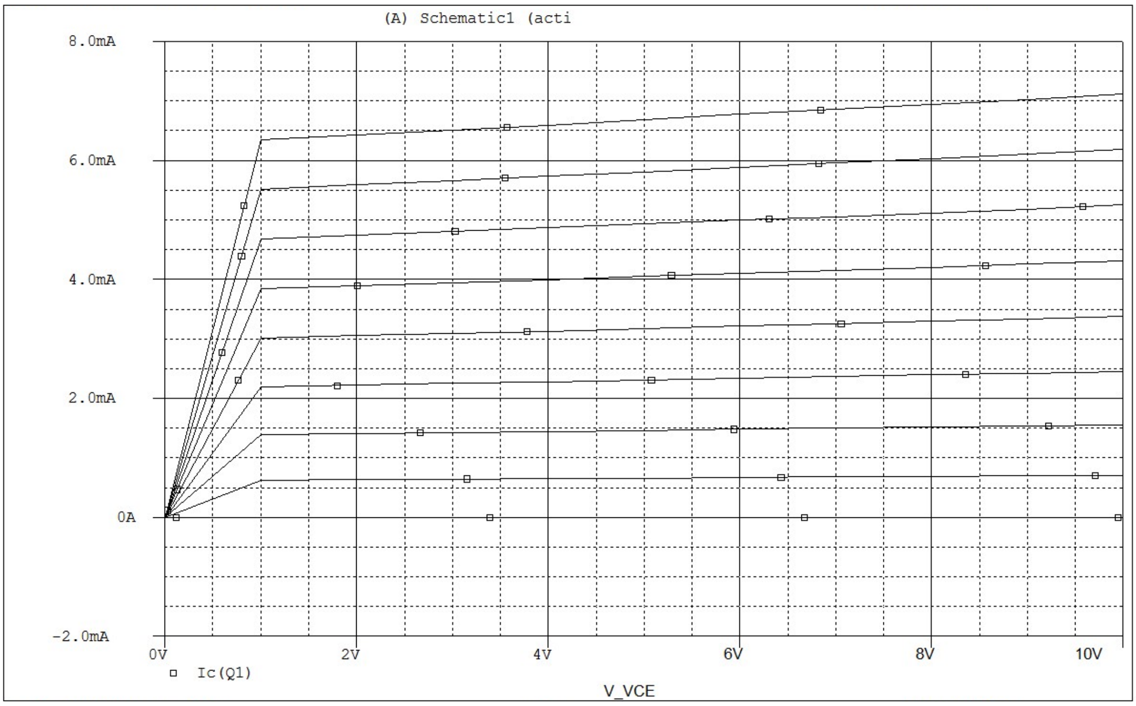


Figure 13: The result of current and voltage

By reading this data, we can draw the β which is in the Table 1.

$I_B(\mu A)$	I_C(mA)	β
0	0.00	
5	0.63	126
10	1.40	140
15	2.19	146
20	3.01	151
25	3.83	153
30	4.68	156
35	5.52	158
40	6.39	160

Table 1

Then we get the β that equals to 166.7, this is because when V_{CE} equals to 5 volts, the I_B equals to 30 μA and I_C equals to 5 mA, by using $\beta = I_C/I_B$, we could get this value. After the value of β ix obtained, we could get other resistances.

5.2 Common Emitter Frequency Response Test

The result is shown in Figure 14 which describes V_{in} and V_{out}, Av, phase difference. However, the 3 db point may be as precise as described, this is because when the simulation software is running, the cursor movement has a certain range, and we can't make this point move exactly 3db down. From the results we can see the 3db point correspond to the frequency is almost 761 Hz. And we can clearly see that as the frequency increases, the output voltage first increases and then reaches a plane, and then decreases. The absolute value of the phase difference between the two gradually increases. The signal gain first increases, then reaches a plane and finally decreases.

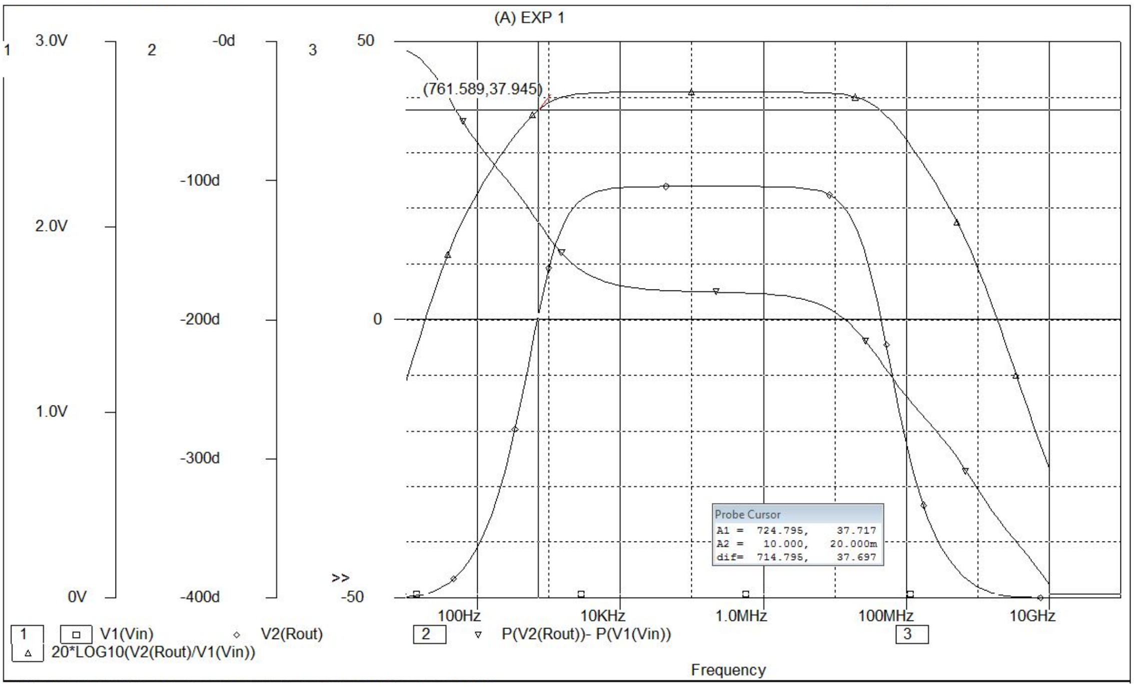


Figure 14: Common Emitter Frequency Response

The value is listed in the following Table 2:

Frequency	V1(Vin)	V2(Rout)	DB(V2(Rout)/ V1(Vin))	P(V2(Rout))- P(V1(Vin))
10	0.02	0.005510174	-11.19729387	-6.120872131
25.11886432	0.02	0.03555378	4.997115843	-24.06505228
50.11872336	0.02	0.113104587	15.04900467	-48.99204938
100	0.02	0.272166408	22.67609072	-72.71263554
199.5262315	0.02	0.561049809	28.95942866	-92.09785611
501.1872336	0.02	1.232314519	35.79383159	-118.7072429
1000	0.02	1.776078568	38.96864375	-140.6636956
1995.262315	0.02	2.077205575	40.32898987	-158.1878917
5011.872336	0.02	2.194044477	40.80430883	-171.0170236
10000	0.02	2.21215334	40.87570483	-175.4855971
19952.62315	0.02	2.216772244	40.89382178	-177.7565349

50118.72336	0.02	2.21808026	40.89894542	-179.1688198
63095.73445	0.02	2.218170174	40.89929751	-179.3741445
79432.82347	0.02	2.218226165	40.89951675	-179.5461542
100000	0.02	2.218259975	40.89964914	-179.6940021
125892.5412	0.02	2.218278914	40.8997233	-179.8255581
158489.3192	0.02	2.218287195	40.89975573	-179.947826
199526.2315	0.02	2.218286615	40.89975345	-180.0673214
251188.6432	0.02	2.218276827	40.89971513	-180.1903958
316227.766	0.02	2.218255853	40.899633	-180.3236076
398107.1706	0.02	2.218219147	40.89948927	-180.4740487
501187.2336	0.02	2.218158764	40.89925283	-180.6497267
630957.3445	0.02	2.21806167	40.89887262	-180.8599894
794328.2347	0.02	2.217906865	40.89826638	-181.1160182
1000000	0.02	2.217661286	40.89730458	-181.4314166
1995262.315	0.02	2.215677954	40.88953301	-182.92217
5011872.336	0.02	2.201761155	40.83480439	-187.3587983
10000000	0.02	2.154484461	40.6462676	-194.4951635
19952623.15	0.02	1.992484441	39.96729905	-207.5132114
50118723.36	0.02	1.398495724	36.89262314	-234.5232449
100000000	0.02	0.832413953	32.38618731	-255.130749
199526231.5	0.02	0.432233055	26.69375982	-272.8864667
501187233.6	0.02	0.153919596	17.72527859	-298.7483332
1000000000	0.02	0.057640706	9.193986093	-322.3141012

Table 2

5.3 Common Collector Frequency Response Test

The result is shown in Figure 15 and 3db point is added on the graphics. The 3db is pointed in almost 17 Hz. It is worth noting that the frequency range required to be increased to 1THz in the additional operating manual. The change in phase difference is significantly different from the previous experiment. The change in phase difference is first reduced and then reached a stable interval, then decreased again and finally increased.

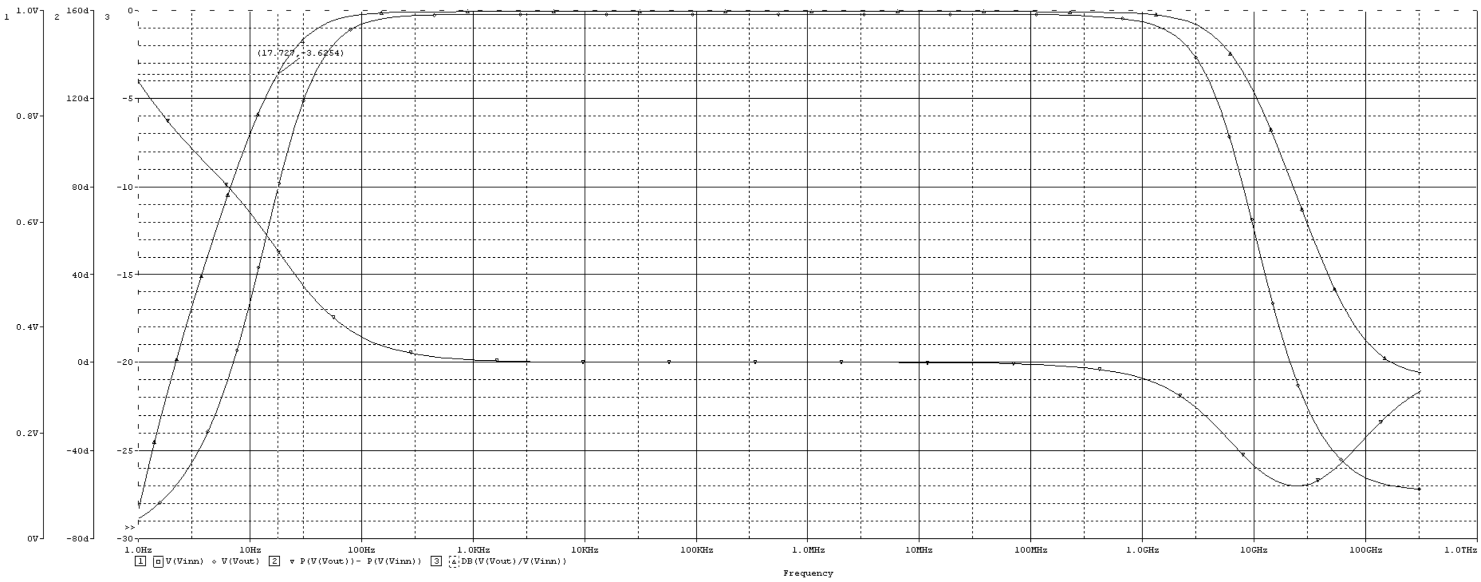


Figure 15: Common Collector Frequency Response

The value is listed in the following Table 2:

Frequency	V(Vinn)	V(Vout)	P(V(Vout))-P(V(Vinn))	DB(V(Vout)/V(Vinn))
1	1	0.037983	127.6965403	-28.40822517
3.981071706	1	0.191086	90.78781011	-14.37543494
5.011872336	1	0.239847	85.51045524	-12.40130647
6.309573445	1	0.298347	80.07551607	-10.50557376
7.943282347	1	0.36711	74.31864351	-8.704075174
10	1	0.445474	68.12678915	-7.023555669
19.95262315	1	0.70357	47.27156988	-3.053855813
25.11886432	1	0.778804	40.23247824	-2.171435686

31.6227766	1	0.840783	33.63350393	-1.506323489
39.81071706	1	0.888412	27.70274751	-1.027712689
50.11872336	1	0.922968	22.55896939	-0.696270304
63.09573445	1	0.946957	18.21911176	-0.473395368
79.43282347	1	0.963089	14.63016694	-0.326674812
100	1	0.9737	11.70314952	-0.231493578
199.5262315	1	0.987811	5.919703523	-0.106523355
501.1872336	1	0.991906	2.36290511	-0.070588373
1000	1	0.992488	1.184694937	-0.065496395
3981.071706	1	0.992671	0.297587278	-0.063894951
5011.872336	1	0.992675	0.236367943	-0.063855271
6309.573445	1	0.992678	0.187735568	-0.063829881
7943.282347	1	0.99268	0.149100534	-0.06381424
10000	1	0.992681	0.118405502	-0.063804241
19952.62315	1	0.992683	0.059224578	-0.06379155
31622.7766	1	0.992683	0.037216839	-0.063788621
39810.71706	1	0.992683	0.029445562	-0.063788263
50118.72336	1	0.992683	0.023242365	-0.063787653
79432.82347	1	0.992683	0.014284768	-0.063787054
100000	1	0.992683	0.01105334	-0.063787163
501187.2336	1	0.992683	-0.001621229	-0.063787321
1000000	1	0.992683	-0.006766901	-0.063787264
1995262.315	1	0.992683	-0.015271981	-0.06378858
5011872.336	1	0.992682	-0.039616335	-0.063795157
7943282.347	1	0.992681	-0.063012113	-0.063808148
10000000	1	0.992679	-0.07939555	-0.063820186
50118723.36	1	0.992589	-0.39806798	-0.06461248
100000000	1	0.992317	-0.791777447	-0.066992947
5011872336	1	0.813043	-31.0488346	-1.797728468
10000000000	1	0.583611	-46.83862479	-4.677523771
19952623150	1	0.347496	-55.82221366	-9.181010453
50118723363	1	0.167384	-49.29885534	-15.52574351
1E+11	1	0.11528	-34.07578343	-18.76493473
1.99526E+11	1	0.097558	-19.45849013	-20.21475026
3.16228E+11	1	0.093554	-12.67121503	-20.57873687

Table 2

6. Discussion:

6.1 Experimental error

First experimental error is that computer simulations can be directly utilized by calculated resistance values, but this may not be the case in real life. Another problem is that using the simulator to find 3db points may have errors. This is due to my operation problem. When moving the cursor, I can't find the exact position of 3db very accurately because there is an error in the movement of the cursor.

6.2 Experiment improvement

The first experimental error cannot be eliminated in the simulator, but in the actual operation, we can calculate the range of b and consider the range of the actual resistance, which can effectively take the actual circuit into consideration.

For the second experimental error, my way to improve the accuracy is to use Pspice's internal search bar tool, we can accurately find every point we need, of course, the simulator is only by linearizing one experimental data. In addition, this value is not particularly accurate. To improve the accuracy, we can increase the scanning interval of the Pspice frequency. If the frequency scanning interval is shortened, the drawing will be more accurate.

7. Conclusion:

In conclusion, by using Pspice simulation, a very complicated circuit can be simulated on a computer. In fact, this experiment was originally performed on a practical breadboard, but it is very difficult to operate on a very small breadboard, and the experimental circuit is complicated and eventually It was changed to a computer simulation. In this experiment, I understood how to build a circuit and measure some key parameters such as β. And for both common emitter and common collector, the nature of their frequencies is reflected in this experiment.

8. References:

[1] B. L. Liu, “the fundamental of the BJT Amplifying circuit.” in the *fundamental of the electronic circuit*, the second Edition, e. L. Qu Ed. Beijing, China: Higher Education Press, 2013, pp. 51-53

[2]Gup Liu, "What is Common Emitter Amplifier? Operation & Collector Current Analysis - Circuit Globe", *Circuit Globe*, 2018. [Online]. Available: https://circuitglobe.com/common-emitter-amplifier.html.