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Class CET 323_01

LAB_04

Amplifiers High-Frequency Response

Reading

Floyd, Electronic Devices, Ninth Edition, Chapter 10.

Key Objectives

Part 2 : Compute and measure the three upper critical frequencies for a C_E amplifier and use them to compute the overall upper critical frequency, f_{cu}

Components needed

Part 2 : High-Frequency Response.

Resistor : One 10 Ω , one 47 kΩ , one 560 Ω , one 1.0 kΩ , one 3.9 kΩ , two 10 kΩ, one 68 kΩ

One **2N3904** ***npn*** transistor.

Capacitors : One 0.22 μF , one 1.0 μF , one 100 μF, two 1 000 μF, one to be determined by student.

Three 100 pF capacitor.

Part 2 : High-Frequency Response.

1. Essentially, the circuit for this part is the same as in Part 1 (with three additional capacitors). If you did not do part 1, measure the resistors listed in table 10_1 and their values before proceeding. It also useful if you know the β_{ac} for your transistor, if you do not know β_{ac}, you can assume a typical value; for the 2N3904 a value of 200 is reasonable.

2. Calculate the ac and dc parameter listed in Table 10_6 for the C_E amplifier shown in Figure 10_3. The purpose of C_4, C_5 and C_6 is to reduce the high frequency response to make it easier to measure; They do not affect any other parameter. Record the computed values in Table 10_6.

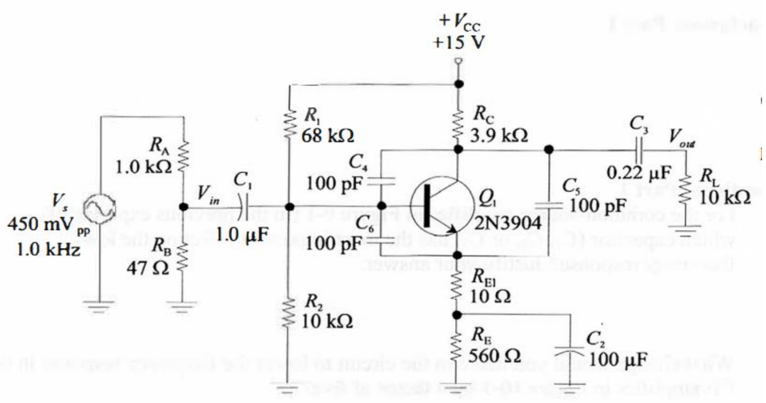

Figure 10-3

Computed Value Table 10_06

3. Construct the amplifier shown in Figure 10_3. Then measure and record the parameters listed table 10_6 and confirm your calculation. Recheck your work if the calculated and measure values differ significantly.

4. In this step, and in step 5 and 6 you will compute the upper critical frequency due to the input network. Capacitor C_4, C_5 and C_6 are included in this circuit to significantly reduce the upper frequency response and make it simple to measure if these capacitors were not present , the input capacitance, C_{in}, would be composed of just the transistor's internal base-emitter capacitance, C_{be}, and the Miller capacitance, $C_{in(Miller)}$ which is calculated from the internal base- collector capacitance, that is

$$\boxed{C_{in} = C_{be} + C_{in(Miller)}}$$

In the circuit in Figure 10_3, C_6 "swamps" C_{be}, so the base-emitter capacitance will be assumed to be just C_6 alone. Likewise, C_4 is much larger than the internal C_{bc} capacitance, so C_4 acting alone will be used to determine the input Miller capacitance. (In a small -signal transistor such as the 2N3904, the internal base-collector capacitance is typically between 3 pF and 5 pF).

By substitution,

$$\boxed{C_{in} = C_6 + C_4 (|A_V| + 1)}$$

(use absolute value of gain)

Record the input capacitance on the first line (step 4) of table 10_7.

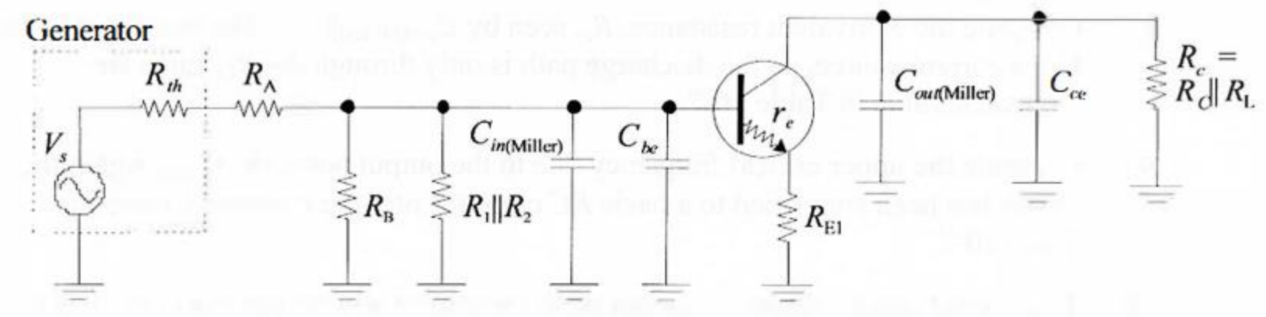

Figure 10-4

5. Compute the equivalent resistance, $R_{eq(in)}$, which is the discharge path for the input capacitor composed of $C_{in(Miller)}$ and C_{be}. (see Figure 10_4). $R_{eq(in)}$ is composed of four parallel paths, which are (R_A+R_{th}) \\ R_B \\ R_1 \\R_2 \\ (β_{ac}(R_{E1} + r_c)), Enter the computed value of $R_{eq(in)}$ in Table 10_7.
6. Compute the upper critical frequency due to the input network, $f_{c(in)}$. The frequency can be calculate using a simple RC circuit with R and C composed of the equivalent values found in steps 4 and 5. Enter the computed critical frequency in Table 10_7.

7. In this step, and in step 8 and 9, you will compute the upper critical frequency due to the output network. Start by finding the equivalent output capacitance , C_{out} as illustrated in figure 10_4. Assume C_{ce} is equal to C_5 since the added capacitor is much larger than the actual collector-emitter capacitance. This capacitance is in parallel with the output Miller capacitance, C_{out} is found from:

$$\begin{aligned} C_{out} &= C_{ce} + C_{out(Miller)} \\ &= C_5 + C_4\left(\frac{|A_V| + 1}{|A_V|}\right) \end{aligned}$$

(use absolute value of gain)

Record the output capacitance in Table 10_7.

8. Compute the equivalent resistance, R_c, seen by $C_{out(Miller)}$ // C_{ce}. The transistor looks like a current source, so discharge path is only through R_C // R_L. Enter the computed value in Table 10_7.

9. Compute the upper critical frequency due to the output network, $f_{c(out)}$. Again circuit has been simplified to the basic R_C circuit. Enter the computed value in Table 10_7.

10. The overall upper critical frequency of the amplified will be less than the lowest frequencies determined from the input and output networks. One way to estimate the combined effect is to use the product-over-sum rule with the two frequencies. Enter the computed overall frequency, f_{cu}, in Table 10_7. Then, observe the output signal in midband (about 1 kHz) and adjust the signal for 5.0 vertical divisions on the scope face. The output should appear undistorted. Increase the generator frequency until the output falls to 70.7 % (approximately 3.5 divisions) of the voltage observed in midband. This frequency is the upper critical frequency, f_{cu} Measure and record this frequency in the Table 10_7.

SOLUTION:

Compete Value of Table 10_6:

Essentially, the circuit for this part is the same as in Part 1, (with three additional capacitors), The purpose of C_4, C_5 and C_6 is to reduce the high frequency response to make it easier to measure; They do not affect any other parameter. Thus, the Computed value in the Table 10_6 as like as Table 10_2 of part 1.

Table 10_6

Parameter	Computed Value	Measured Value
V_B	1.9 V	1.9 V
V_E	1.2 V	1.1 V
I_E	2.15 mA	
V_C	6.63 V	6.9 V
V_{CE}	5.4 V	5.7 V
r_e	11.6 Ω	
A_V	129	5.3 V
V_{out}	6.02 V	5.9 V

Computed Value Table 10_06

✓ $V_B = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} = \left(\frac{10\ \text{k}\Omega}{68\ \text{k}\Omega + 10\ \text{k}\Omega}\right) 15\ V = 1.9\ V$ =>

$\boxed{V_B = 1.9\ V}$

✓ $V_E = V_B - 0.7\ V = 1.9\ V - 0.7\ V = 1.2\ V$ =>

$\boxed{V_E = 1.2\ V}$

✓ $I_E = \frac{V_E}{R_E} = \frac{V_E}{(R_{E1} + R_{E2})} = \frac{1.223\ V}{0.01\ \text{k}\Omega + 0.56\ \text{k}\Omega} = 2.15\ A$ =>

$\boxed{I_E = 2.15\ A}$

✓ $V_C = V_{CC} - V_{RC} = V_{CC} - (R_C \times I_C)$,

($I_E = I_B + I_C$ *but for* I_B *is very small (5 %)* => $I_E \approx I_C$)

✓ $V_C = V_{CC} - (R_C \times I_E) = 15\ V - (3.9\ \text{k}\Omega \times 2.15\ A) = 6.62\ V$ =>

$\boxed{V_C = 6.62\ V}$

✓ $V_{CE} = V_C - V_E = 6.62\ V - 1.2\ V = 5.4\ V$ =>

$\boxed{V_{CE} = 5.4\ V}$

✓ $r'_e = \frac{25\ mV}{I_E} = \frac{25\ mA}{2.15\ mA} = 11.6\ \Omega$ =>

$\boxed{r'_e = 11.6\ \Omega}$

(*Magic # the mo. voltage T 25°*)

Because a ***swamping*** resistor (R_{E1}) is used in the circuit, it appears in series, thus, we have the voltage gain equation is:

$$\boxed{A_V = \frac{R_c}{(r'_e + R_{E1})}}$$

$R_c = R_C \,//\, R_L$

- ✓ $R_c = R_C \,//\, R_L = \frac{R_C \times R_L}{R_C + R_L} = \frac{(3.9\ k\Omega)(10\ k\Omega)}{(3.9\ k\Omega + 10\ k\Omega)} = 2.8\ k\Omega$
- ✓ $A_V = \frac{R_c}{(r'_e + R_{E1})} = \frac{2.8\ k\Omega}{(11.65\ \Omega + 10\ \Omega)} = 129$ => $\boxed{A_V = 129}$

- ✓ $V_{out} = A_v \times V_{in}$

Apply formula The voltage gain from emitter to collector is developed as follows $V_{in} = V_e$; $V_{out} = V_c$

We have $A_V = \frac{V_{out}}{V_{in}} = \frac{V_c}{V_e} = \frac{I_C \times R_C}{I_e(r_e \backslash\backslash R_E)} \approx \frac{I_e R_c}{I_e(r'_e \backslash\backslash R_E)}$

=> $V_{out} \approx V_c = I_c \times R_c$ ($I_E \approx I_C$)

$V_{out} = (2.15\ mA)(\ 2.8\ k\Omega) =$ **6.02 V** => $\boxed{V_{out} = 6.02\ V}$

Table 10_7

Step	Parameter	Computed Value	Measured Value
4	C_{in}	13.1 nF	
5	$R_{eq(in)}$	44.2 Ω	
6	$f_{c(in)}$	273 kHz	
7	C_{out}	201 pF	
8	R_c	2.8 kΩ	
9	$f_{c(out)}$	282 kHz	
10	f_{cu}	138 kHz	**146 kHz**

Computed Value Table 10_07

✓ **Step 4** : Compute C_{in} . Apply Miller's theorem

$$\boxed{C_{in} = C_{be} + C_{in(Miller)}}$$

($C_{be} = C_6$; $C_{bc} = C_4$)

- $C_{in} = C_{be} + \mathbf{C_{bc} (|Av| +1)}$
- $C_{in} = C_6 + \mathbf{C_4 (|Av| +1)}$

$= 100\text{ pF} + 100\text{ pF}(129 + 1) = \mathbf{13\ 100\text{ pF}} = 13.1\text{ nF}$ => $\boxed{C_{in} = 13.1\text{ nF}}$

✓ **Step 5** : Compute $R_{eq(in)}$ It also useful if you know the β_{ac} for your transistor, if you do not know β_{ac}, you can assume a typical value; for the 2N3904 a value of 200 is reasonable.

The equivalent resistance, $R_{eq(in)}$, which is the discharge path for the input capacitor composed of $C_{in(Miller)}$ and C_{be}. (see Figure 10_4). $R_{eq(in)}$ is composed of four parallel paths, which are ($R_A + R_{th}$) \\ R_B \\ R_1 \\R_2 \\ (β_{ac}(R_{E1} + r'$_c$)),

We have formula compute the equivalent resistance, $R_{eq(in)}$ in circuit connected in parallel circuit as follows:

$$\boxed{\frac{1}{R_{eq(in)}} = \frac{1}{(R_{th} + R_A)} + \frac{1}{R_B} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{\beta_{ac}(R_{E1} + r'_c)}}$$

for R_{th} is very small ≈ 0 V, so can ignore.

$$\frac{1}{R_{eq(in)}} = \frac{1}{1\text{ k}\Omega} + \frac{1}{47\ \Omega} + \frac{1}{68\text{ k}\Omega} + \frac{1}{10\text{ k}\Omega} + \frac{1}{200\ (10\ \Omega + 11.6\ \Omega)}$$

✓ $\frac{1}{R_{eq(in)}} = 22.62 \Rightarrow R_{eq(in)} = \frac{1}{22.62} = 0.0442\ k\Omega = 44.2\ \Omega$ =>

$$\boxed{R_{eq(in)} = 44.2\ \Omega}$$

✓ **Step 6** : Compute $f_{c(in)}$

$$\boxed{f_{c(in)} = \frac{1}{2\pi R_{eq(in)} C_{in}}}$$

- $f_{c(in)} = \frac{1}{2\pi R_{eq(in)} C_{in}} = \frac{1}{2(3.14)\,(44.8\ \Omega)(13\,000\ pF)} = 0.273\ MHz$ =>

$$\boxed{f_{c(in)} = 273\ kHz}$$

✓ **Step 7** : Compute C_{out}. Apply Miller's theorem

$$\boxed{C_{out} = C_{ce} + C_{out(Miller)}}$$

$(C_{ce} = C_5 ; C_{bc} = C_4)$

⇨ $C_{out} = C_5 + C_4 \left(\frac{|A_V| + 1}{|A_V|}\right) = 100\ pF + 100\ pF\ (\frac{129 + 1}{129}) = 201\ pF$ =>

$$\boxed{C_{out} = 201\ pF}$$

✓ **Step 8** : Compute R_c, For $R_c = R_C \,//\, R_L$

We have:

- $R_c = R_C \,//\, R_L = \frac{R_C \times R_L}{R_C + R_L} = \frac{(3.9\ k\Omega)(10\ k\Omega)}{(3.9\ k\Omega + 10\ k\Omega)} = \mathbf{2.8}\ k\Omega$ => $\boxed{R_c = 2.8\ k\Omega}$

✓ **Step 9** : Compute $f_{c(out)}$.

The upper critical frequency for the output circuit is determined with the following equation,

$$\boxed{f_{c(out)} = \frac{1}{2\pi R_c C_{out}}}$$

- $f_{c(out)} = \frac{1}{2(3.14)(2.8\ k\Omega)(201\ pF)} = 0.282\ 9\ MHz$ => $\boxed{f_{c(out)} = 282\ kHz}$

Where $R_c = R_C \,//\, R_L$

Step 10 : Compute f_{cu} . The overall upper critical frequency of the amplified . One way to estimate the combined effect is to use the product-over-sum rule with the two frequencies.

Therefore, $f_{cu} = \frac{f_{c(in)} \times f_{c(out)}}{f_{c(in)} + f_{c(out)}} = \frac{(273\ kHz)(282\ kHz)}{(273\ kHz + 282\ kHz)} = \mathbf{138.7\ kHz}$ => $\boxed{f_{cu} = 138\ kHz}$

The overall upper critical frequency of the amplified by Measured Value , f_{cu} **= 146 kHz**