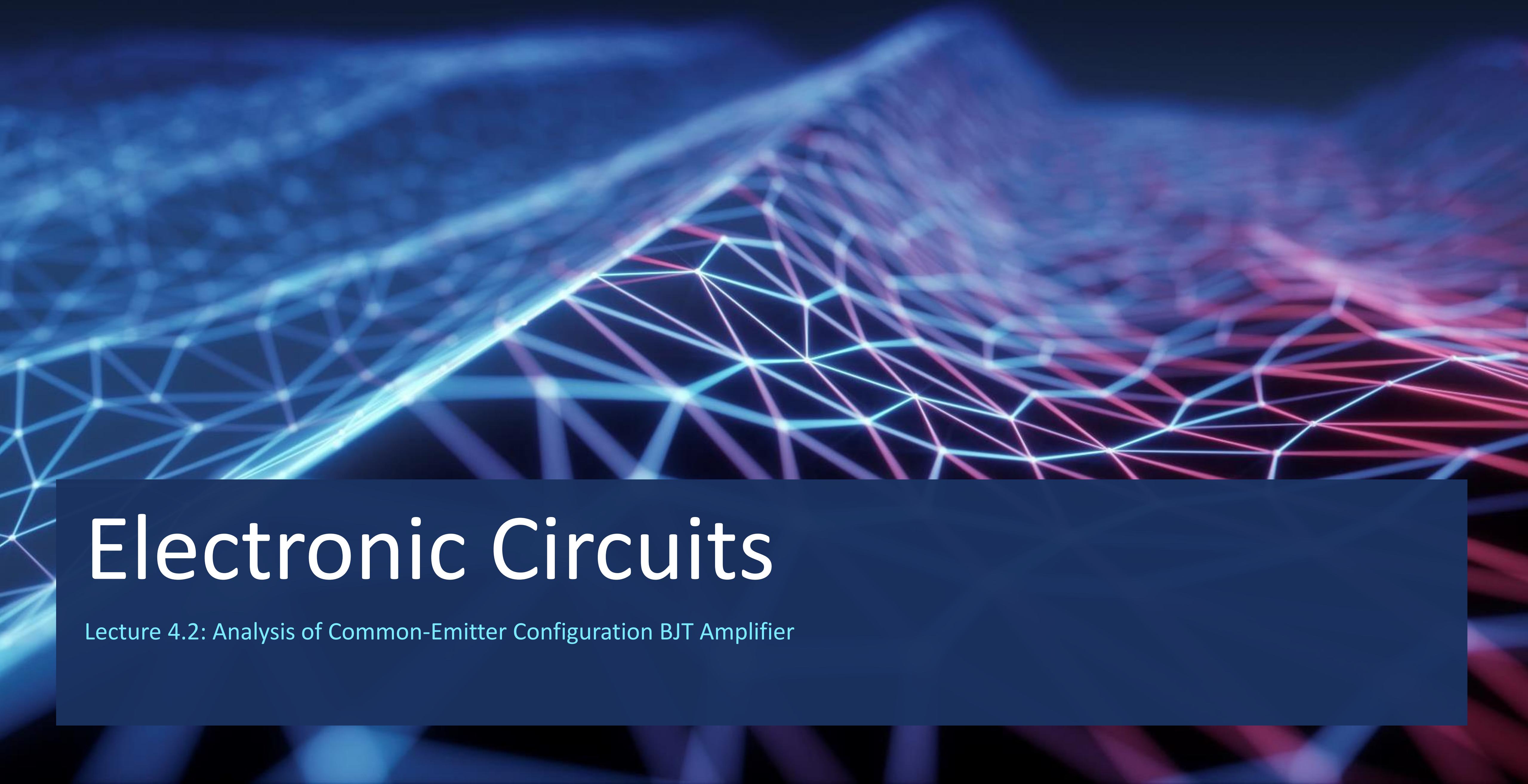


Electronic Circuits

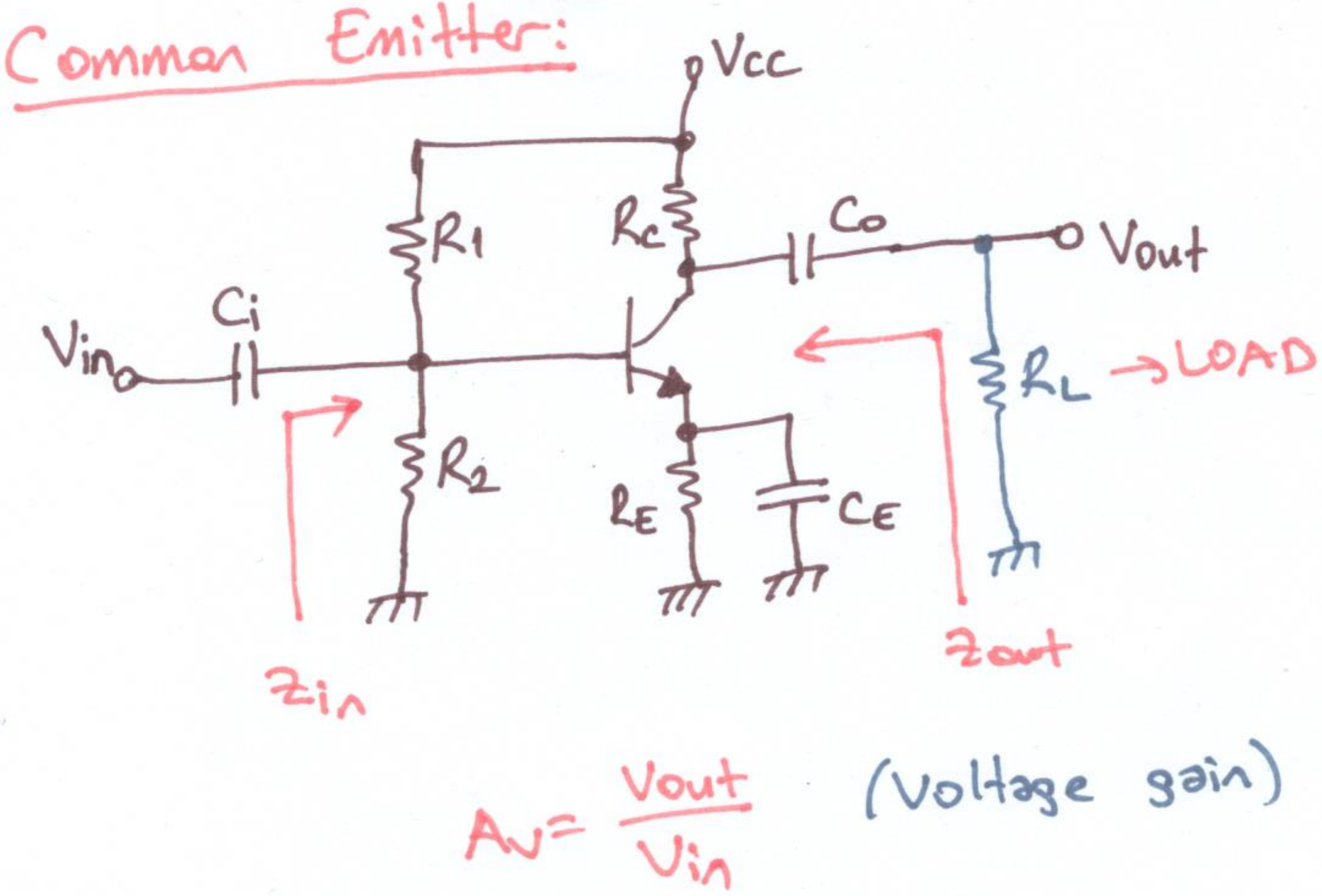
Lecture 4.2: Analysis of Common-Emitter Configuration BJT Amplifier

Amplifier Analysis

- DC Analysis
  - C → open, L → short, find re that is one of AC equivalent circuit parameters.
- AC Analysis (Mid-Frequency Analysis)
  - Cs → short, Ls → open, DC sources eliminated, find Av.
- AC Analysis (Low-Frequency Analysis)
  - DC sources eliminated, Cs and Ls are NOT eliminated, find fc lower corner frequencies for HPF.
- AC Analysis (High-Frequency Analysis)
  - DC sources eliminated, Cs and Ls are eliminated, but new Cs are added, find fc higher corner frequencies for LPF.

- Warning: This list possibly doesn’t fit to Electronics-based department lectures.

Common-Emitter Amplifier: Circuit

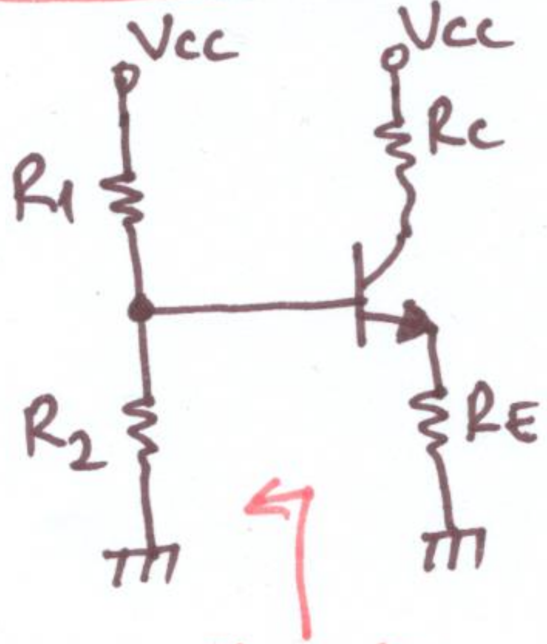


$A_V = \frac{V_{out}}{V_{in}}$ (Voltage gain)

Common-Emitter Amplifier: DC Analysis (1)

#1: DC Analysis: To determine DC operating point.

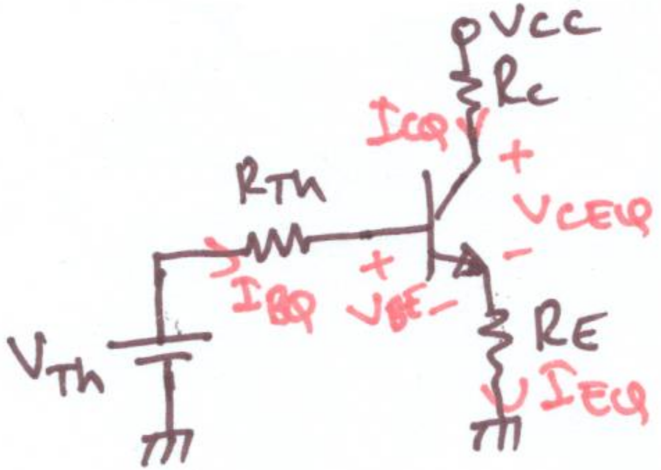
- All capacitors are open circuit.
- All inductors are short circuit.
- The main aim is to determine r_e!
- Other goals are I_{BQ}, I_{CQ}, I_{EQ}, V_{CEQ}, V_{CQ}.



Thevenin equivalent?

- $I_E = I_B + I_C$
- $I_C = \beta \cdot I_B$
- $r_e = \dfrac{26\ (mV)}{I_{EQ}\ (mA)}$

Common-Emitter Amplifier: DC Analysis (2)



$$V_{Th} = \frac{R_2}{R_1+R_2}\cdot V_{cc}$$

$$R_{Th} = R_1 // R_2 = \frac{R_1\cdot R_2}{R_1+R_2}$$

Find I_{BQ} ← $-V_{Th} + R_{Th}\cdot I_{BQ} + V_{BE} + R_E\cdot I_{EQ} = 0$

Find V_{CEQ} ← $-R_E\cdot I_{EQ} - V_{CEQ} - R_c\cdot I_{CQ} + V_{cc} = 0$

Find I_{CQ} ← $I_{CQ} = \beta\cdot I_{BQ}$

Find I_{EQ} ← $I_{EQ} = I_{CQ} + I_{BQ} = (\beta+1)\cdot I_{BQ}$

Find r_e ← $r_e = \frac{26\ (mV)}{I_{EQ}\ (mA)}\ \Omega$

Common-Emitter Amplifier: AC Analysis (1)

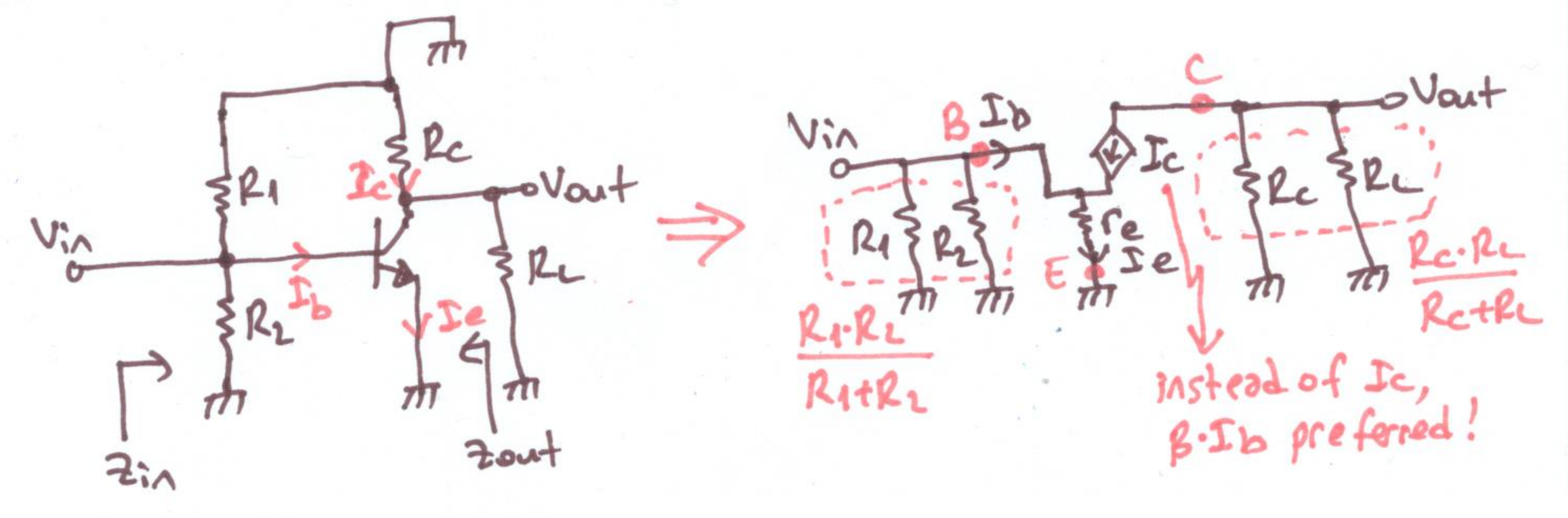
#2: AC Analysis:

(Mid-Frequency Analysis)

To determine desired AC behavior.

- All capacitors are short circuit.
- All inductors are open circuit.
- The aim is to determine A_v, Z_{in}, Z_{out}!
- DC sources are eliminated by voltages are short circuit and currents are open circuit.
- We can use small-signal equivalent BJT model.
- r_e is from DC analysis!

Common-Emitter Amplifier: AC Analysis (2)



instead of Ic, β·Ib preferred!

Common-Emitter Amplifier: AC Analysis (3)

$$V_{in} = r_e \cdot I_e$$

$$V_{out} = \frac{R_C \cdot R_L}{R_C + R_L} \cdot (-I_c)$$

$$\rightarrow A_v = \frac{V_{out}}{V_{in}} = -\frac{R_C \cdot R_L}{(R_C + R_L) \cdot r_e}$$

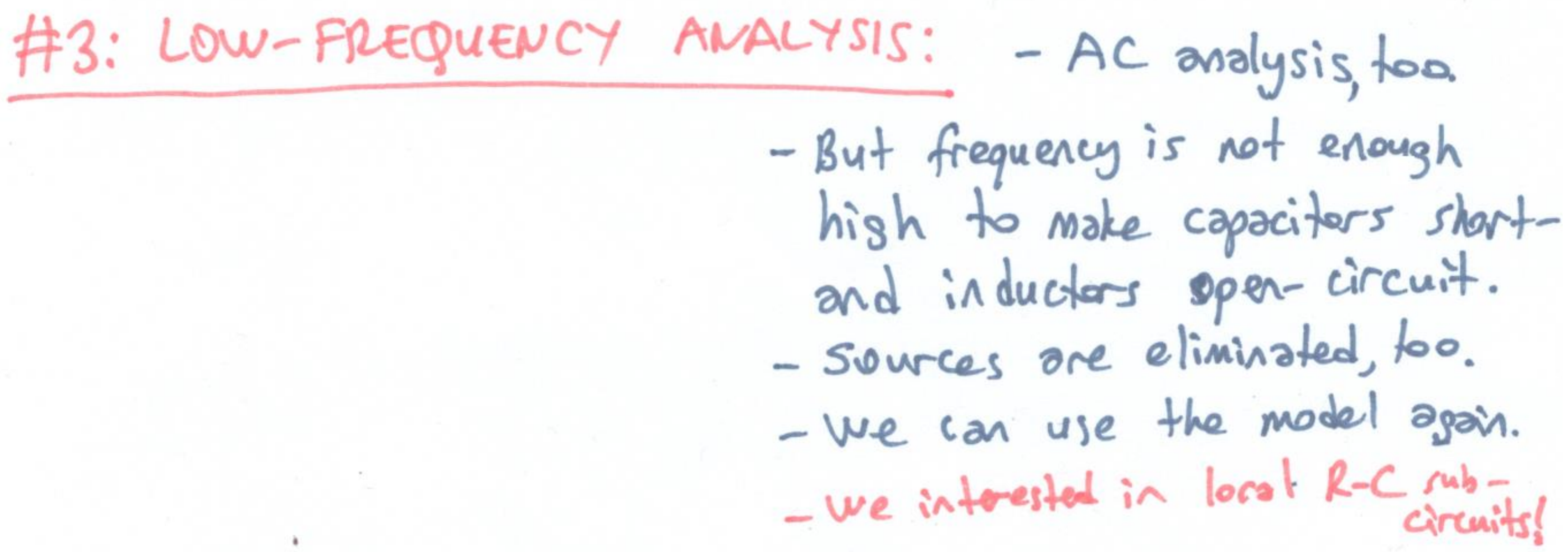
$$Z_{in} = R_1 // R_2 // \underbrace{((\beta+1) \cdot r_e)}$$

↳ The r_e is on the E side, so its effect on the B side is amplified by $(\beta+1)$.

$$Z_{out} = \underbrace{R_C}$$

↳ Since current source has resistance of ∞ and R_L is the load not the part of the amplifier itself.

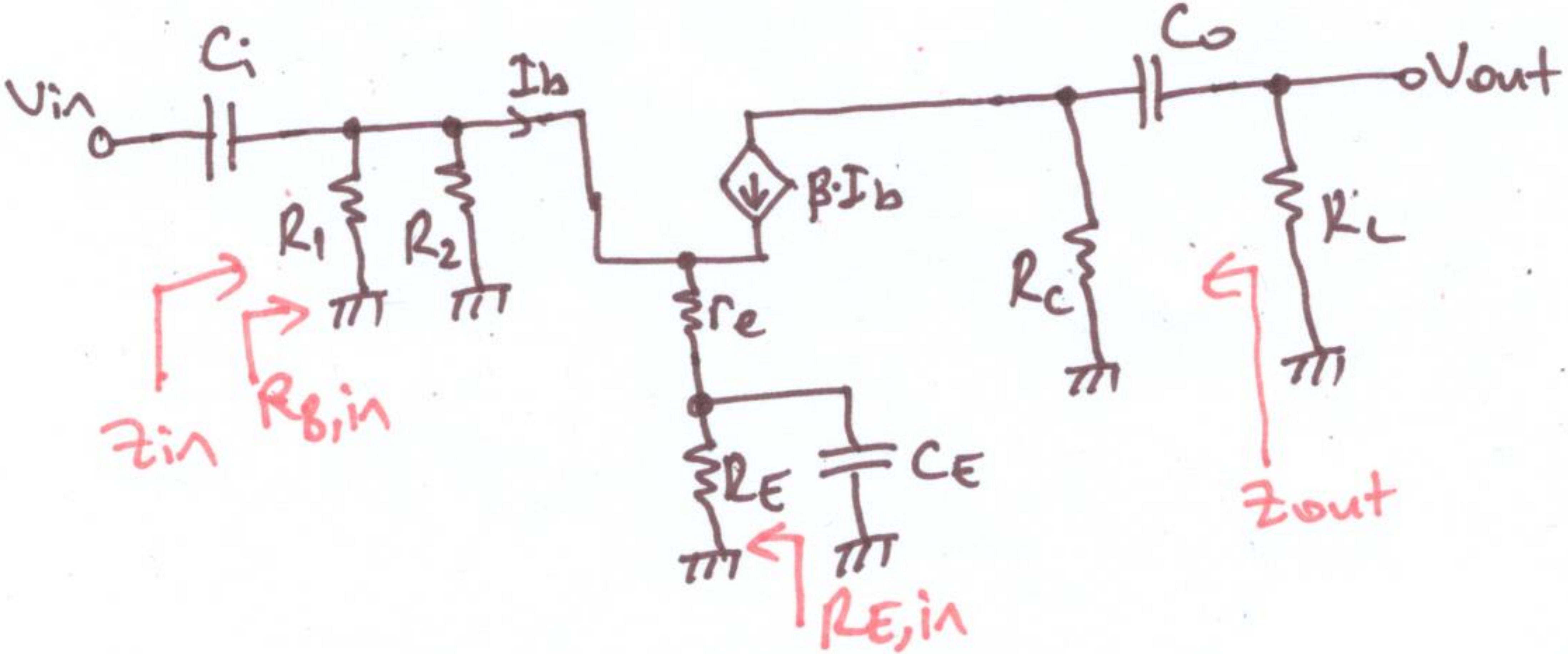
Common-Emitter Amplifier: Low-Frequency Analysis (1)



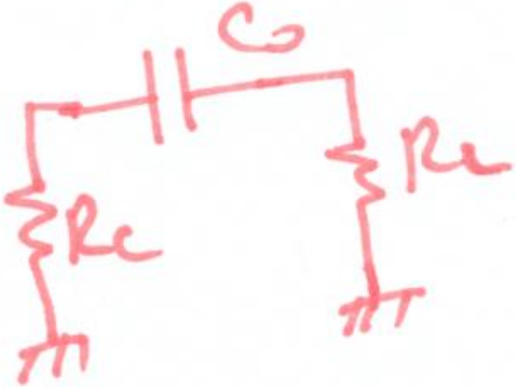
#3: LOW-FREQUENCY ANALYSIS:

- AC analysis, too
- But frequency is not enough high to make capacitors short- and inductors open- circuit.
- Sources are eliminated, too.
- We can use the model again.
- we interested in local R-C sub-circuits!

Common-Emitter Amplifier: Low-Frequency Analysis (2)



Common-Emitter Amplifier: Low-Frequency Analysis (3)



$$f_{c1} = \frac{1}{2\cdot\pi\cdot(R_C+R_L)\cdot C_o}$$

$$f_{c2} = \frac{1}{2\cdot\pi\cdot R_{B,in}\cdot C_i}$$

and

$$f_{c3} = \frac{1}{2\cdot\pi\cdot R_{E,in}\cdot C_E}$$

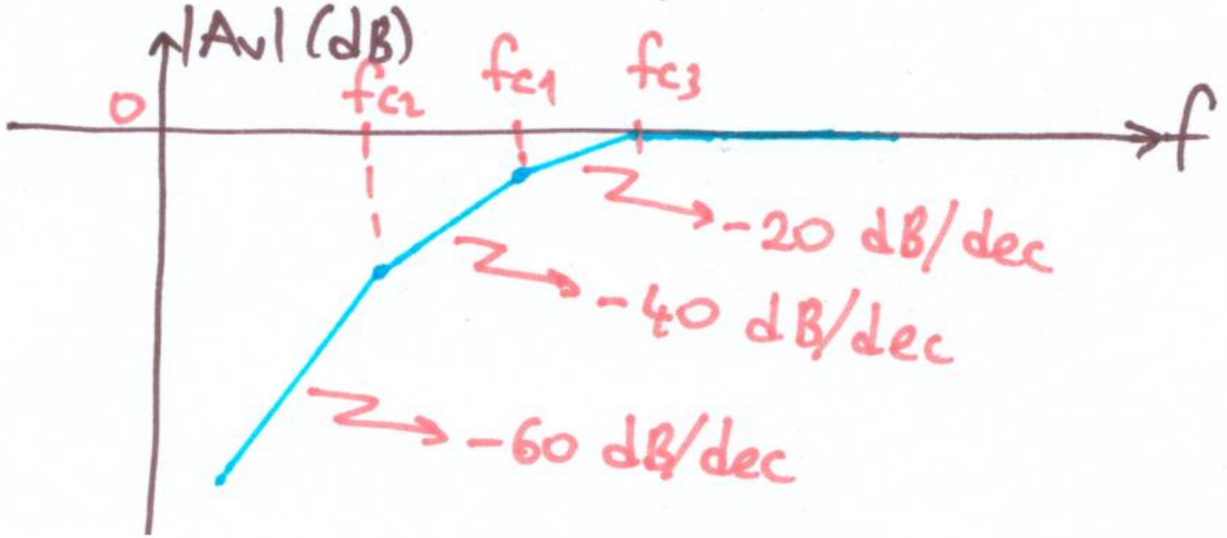
$$R_{B,in} = R_{Th} // ((\beta+1)\cdot r_e)$$

$$R_{E,in} = R_E // \left(r_e + \frac{R_{Th}}{\beta+1}\right)$$

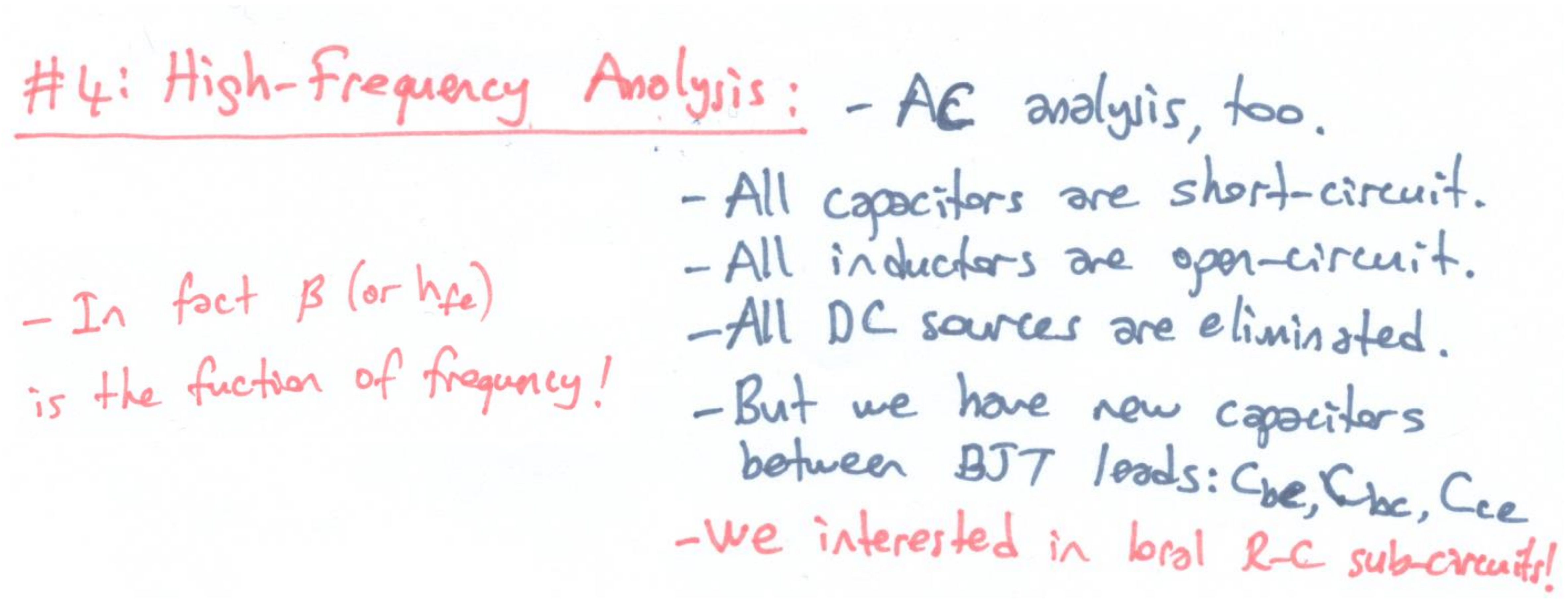
Common-Emitter Amplifier: Low-Frequency Analysis (4)

- There are some assumptions to simplify. But the more accurate result can be found via s-domain analysis :)

If $f_{c2} < f_{c1} < f_{c3}$,



Common-Emitter Amplifier: High-Frequency Analysis (1)

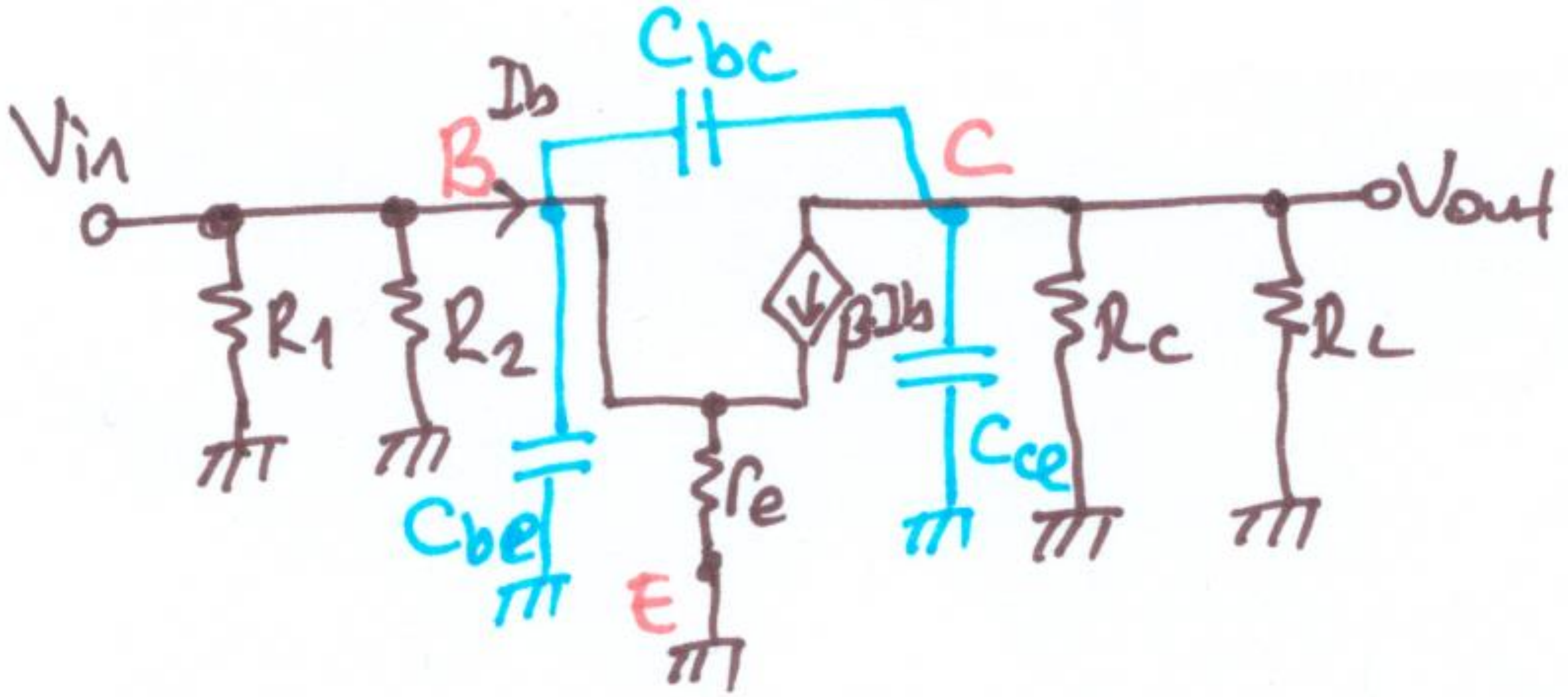


#4: High-Frequency Analysis: - AC analysis, too.

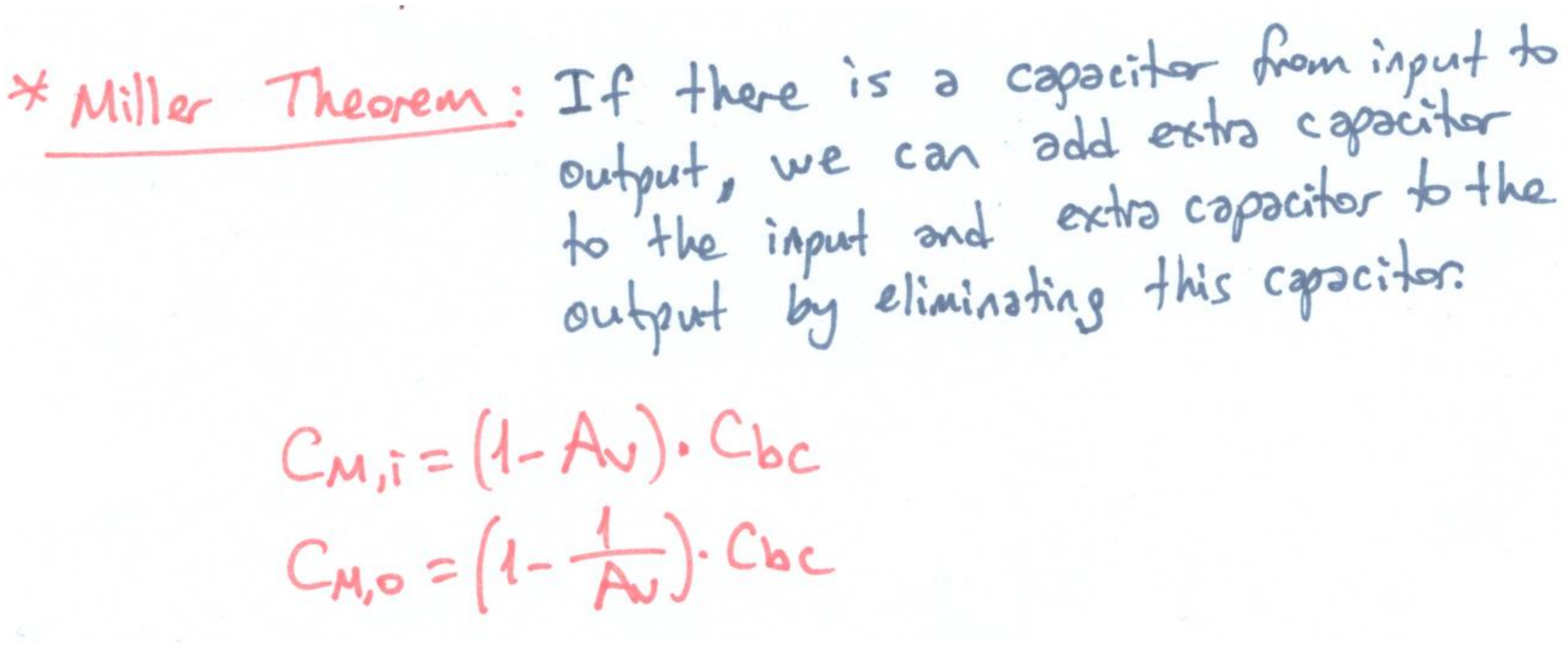
- All capacitors are short-circuit.
- All inductors are open-circuit.
- All DC sources are eliminated.
- But we have new capacitors between BJT leads: C_{be}, C_{bc}, C_{ce}
- We interested in local R-C sub-circuits!

- In fact β (or h_{fe}) is the fuction of frequncy!

Common-Emitter Amplifier: High-Frequency Analysis (2)



Common-Emitter Amplifier: High-Frequency Analysis (3)

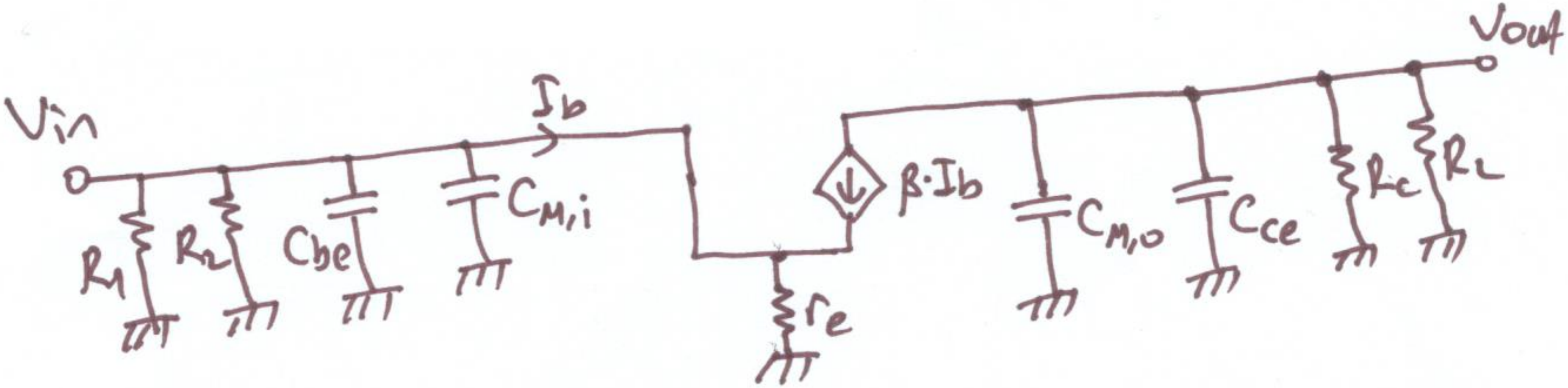


* **Miller Theorem:** If there is a capacitor from input to output, we can add extra capacitor to the input and extra capacitor to the output by eliminating this capacitor.

$$C_{M,i} = (1 - A_v) \cdot C_{bc}$$

$$C_{M,o} = \left(1 - \frac{1}{A_v}\right) \cdot C_{bc}$$

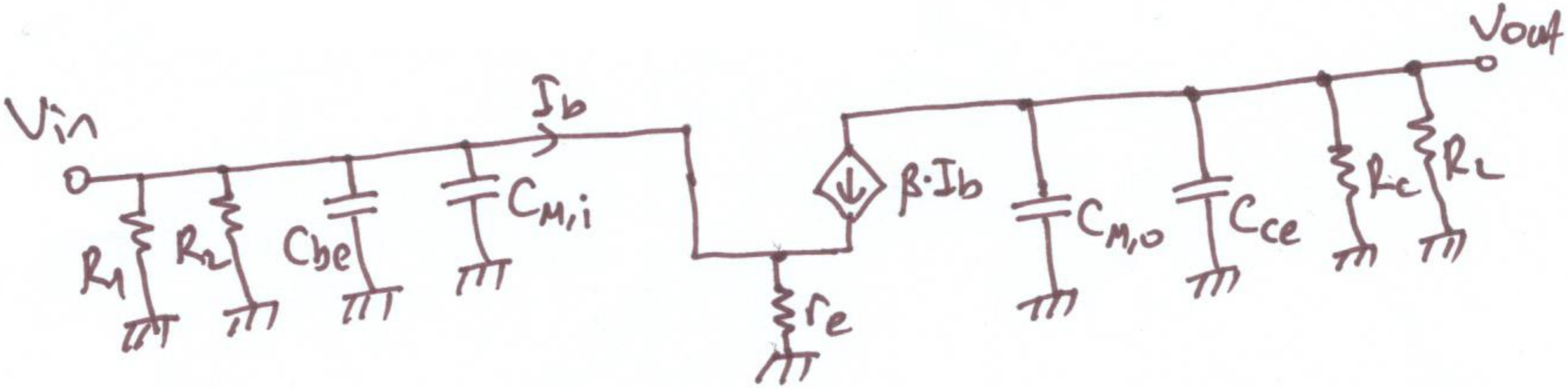
Common-Emitter Amplifier: High-Frequency Analysis (4)



$$f_{c4} = \frac{1}{2\cdot\pi\cdot\left(R_1 // R_2 // ((\beta+1)\cdot r_e)\right)\cdot\left(C_{be}+C_{M,i}\right)}$$

$$f_{c5} = \frac{1}{2\cdot\pi\cdot\left(R_C // R_L\right)\cdot\left(C_{M,o}+C_{ce}\right)}$$

Common-Emitter Amplifier: High-Frequency Analysis (5)

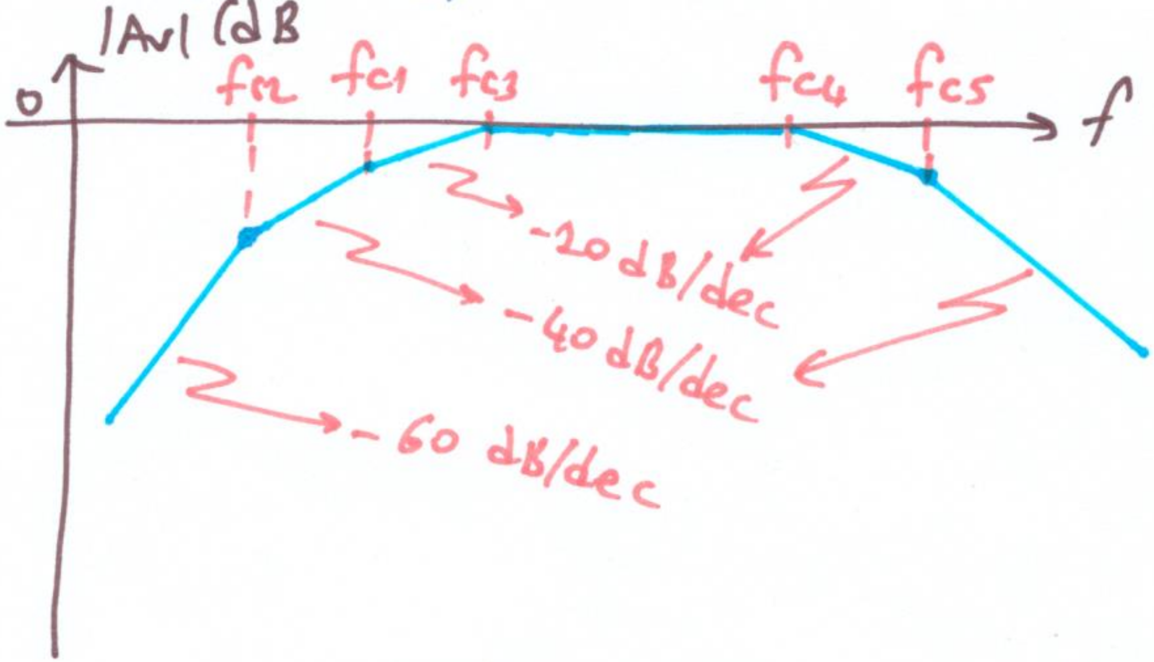


$$f_{c4} = \frac{1}{2\cdot\pi\cdot\left(R_1 // R_2 // ((\beta+1)\cdot r_e)\right)\cdot\left(C_{be}+C_{M,i}\right)}$$

$$f_{c5} = \frac{1}{2\cdot\pi\cdot\left(R_C // R_L\right)\cdot\left(C_{M,o}+C_{ce}\right)}$$

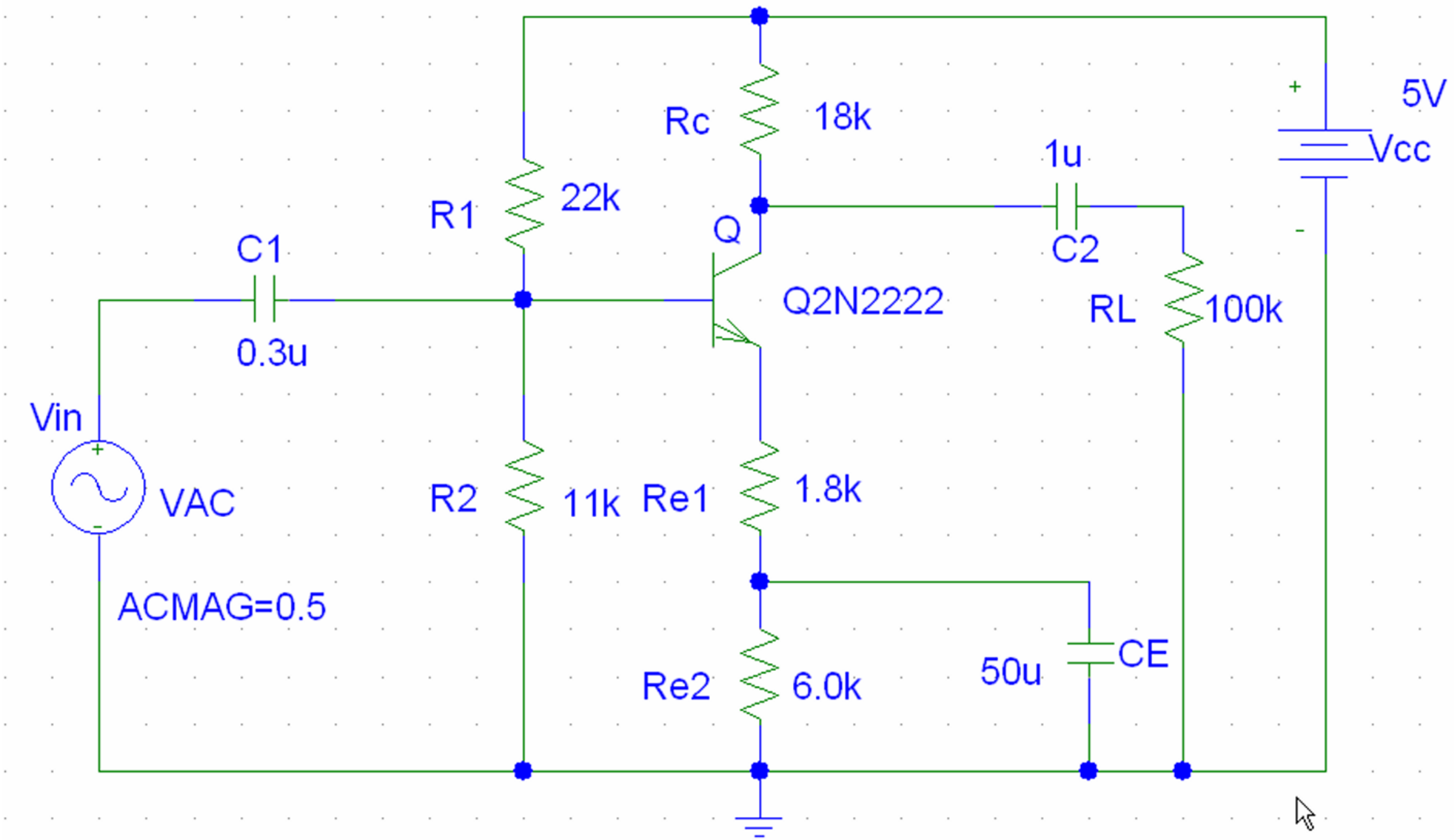
Common-Emitter Amplifier: High-Frequency Analysis (6)

If $f_{c4} < f_{c5}$,



The complete frequency-response of a common-emitter BJT amplifier.

Common-Emitter Amplifier: LTspice Example (1)



Common-Emitter Amplifier: LTspice Example (2)

Note that:

(a) Input signal is VAC (instead of usual VSIN) in the circuit since we need frequency response of the output voltage. AC Sweep is done only with VAC with only amplitude specified. Different frequency will be applied by the simulator.

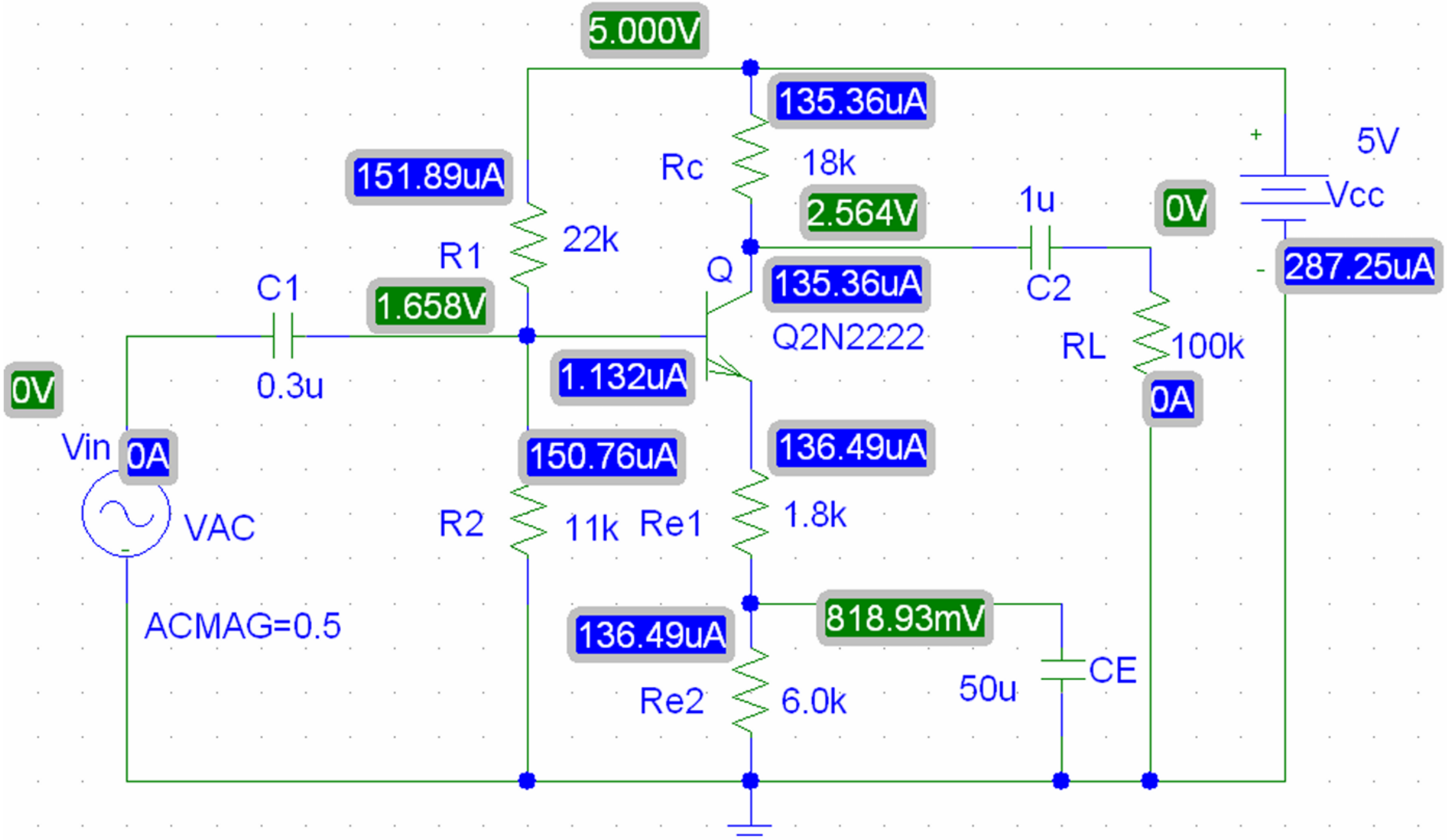
(b) To ease the limitation of power supply by IOBoard, V_{CC} is supplied by 5V source.

(c) The load resistance in the circuit is chosen 100kΩ. This value may be significantly different from your assigned work. You, I mean, you need to do some work too. Right?

(d) Why those values of resistors? Try to answer by DC analysis. Find expected voltage gain from the DC analysis.

(e) Why those values of capacitors? Perform AC analysis and find expected low and high cutoff frequencies.

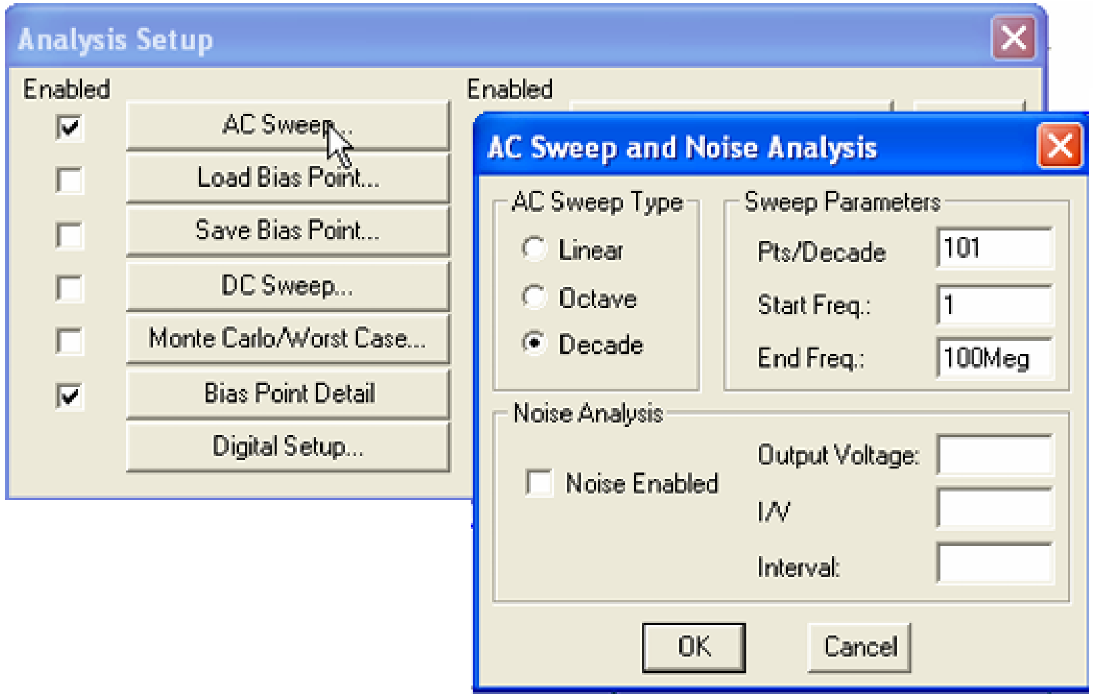
Common-Emitter Amplifier: LTspice Example (3)



Common-Emitter Amplifier: LTspice Example (4)

AC Sweep

To do AC Sweep, your AC source must be VAC. You decide only ACMAG (AC magnitude), and I picked 0.5 in the circuit above. In the AC Sweep we have to assign our frequency band of interest. Here I set from 0 to 100MHz.



Analysis Setup

Enabled

- ☑ AC Sweep...
- ☐ Load Bias Point...
- ☐ Save Bias Point...
- ☐ DC Sweep...
- ☐ Monte Carlo/Worst Case...
- ☑ Bias Point Detail
- Digital Setup...

AC Sweep and Noise Analysis

AC Sweep Type

- ○ Linear
- ○ Octave
- ● Decade

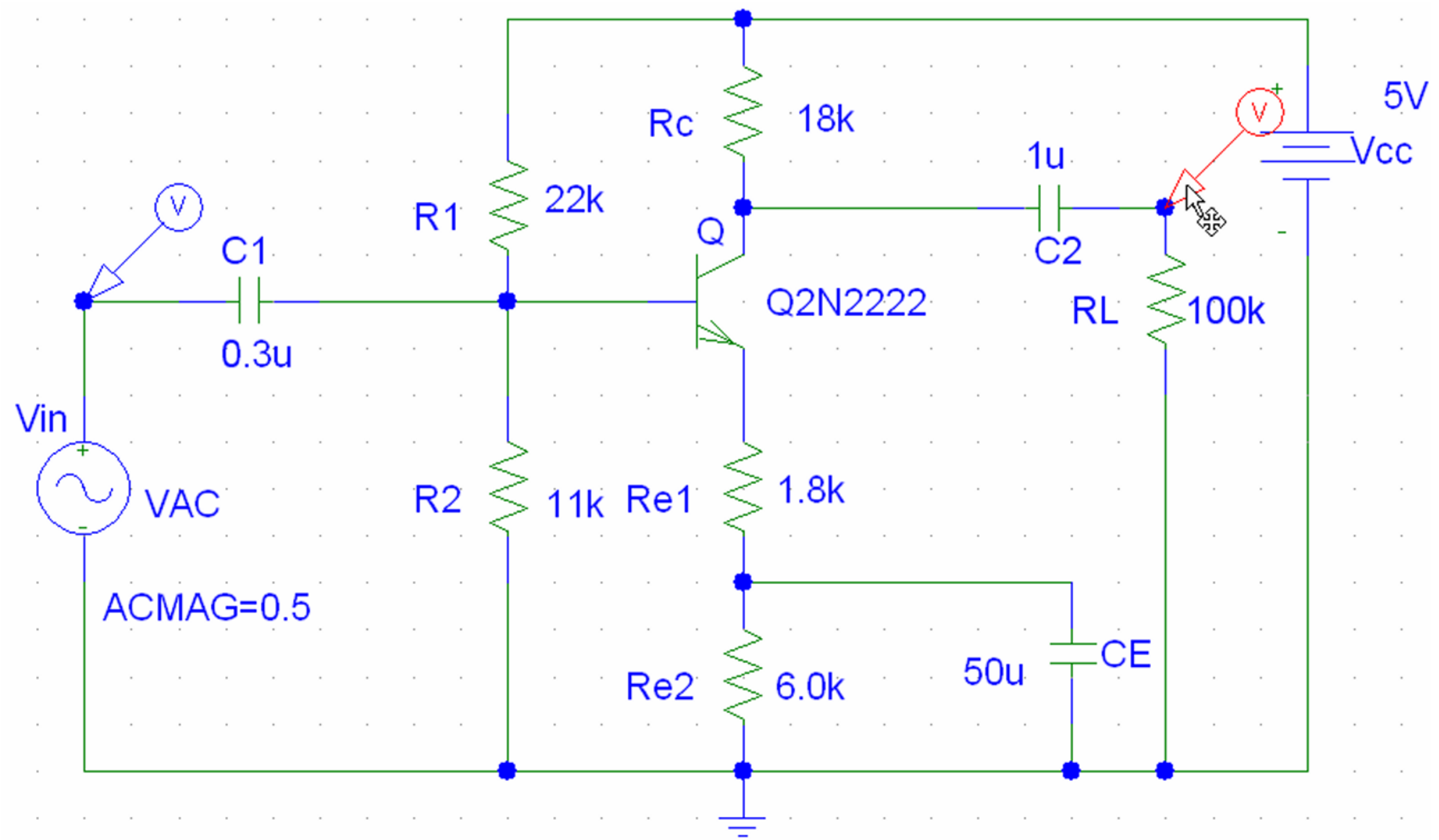
Sweep Parameters

Pts/Decade: 101
Start Freq.: 1
End Freq.: 100Meg

Noise Analysis

☐ Noise Enabled
Output Voltage:
I/V
Interval:

Common-Emitter Amplifier: LTspice Example (5)

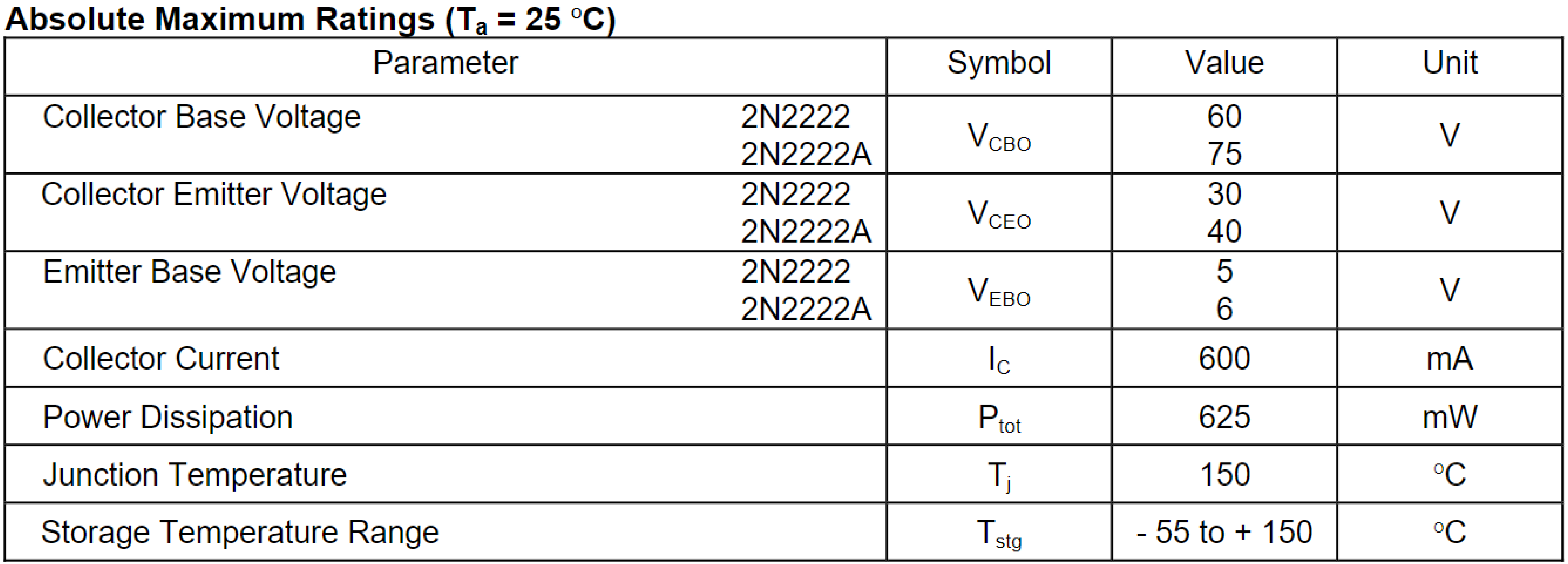


Common-Emitter Amplifier: LTspice Example (6)

Common-Emitter Amplifier: LTspice Example (7)

The green tracing is the voltage at the load and red, the input voltage, at each of the frequency at the range of 0 - 100MHz. What is the low cutoff frequency? What is the high cutoff frequency? What is the mid-band voltage gain?
How can you change the cutoff frequencies by changing capacitor values?
How do you change the gain by changing resistor values?
Do you see the influence of load, so called "load effect"?

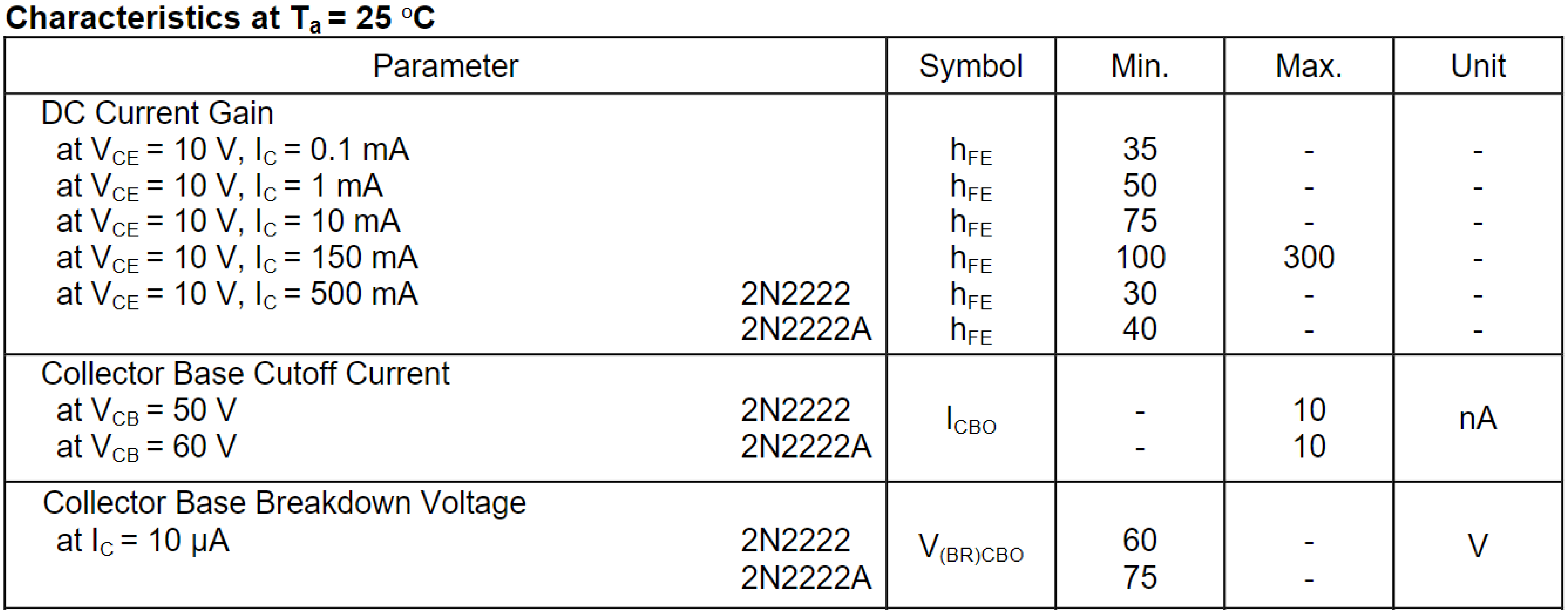
Common-Emitter Amplifier: 2N2222 Catalogue (1)



Absolute Maximum Ratings (T_a = 25 °C)

Parameter		Symbol	Value	Unit
Collector Base Voltage	2N2222	V_{CBO}	60	V
	2N2222A		75	
Collector Emitter Voltage	2N2222	V_{CEO}	30	V
	2N2222A		40	
Emitter Base Voltage	2N2222	V_{EBO}	5	V
	2N2222A		6	
Collector Current		I_C	600	mA
Power Dissipation		P_{tot}	625	mW
Junction Temperature		T_j	150	°C
Storage Temperature Range		T_{stg}	- 55 to + 150	°C

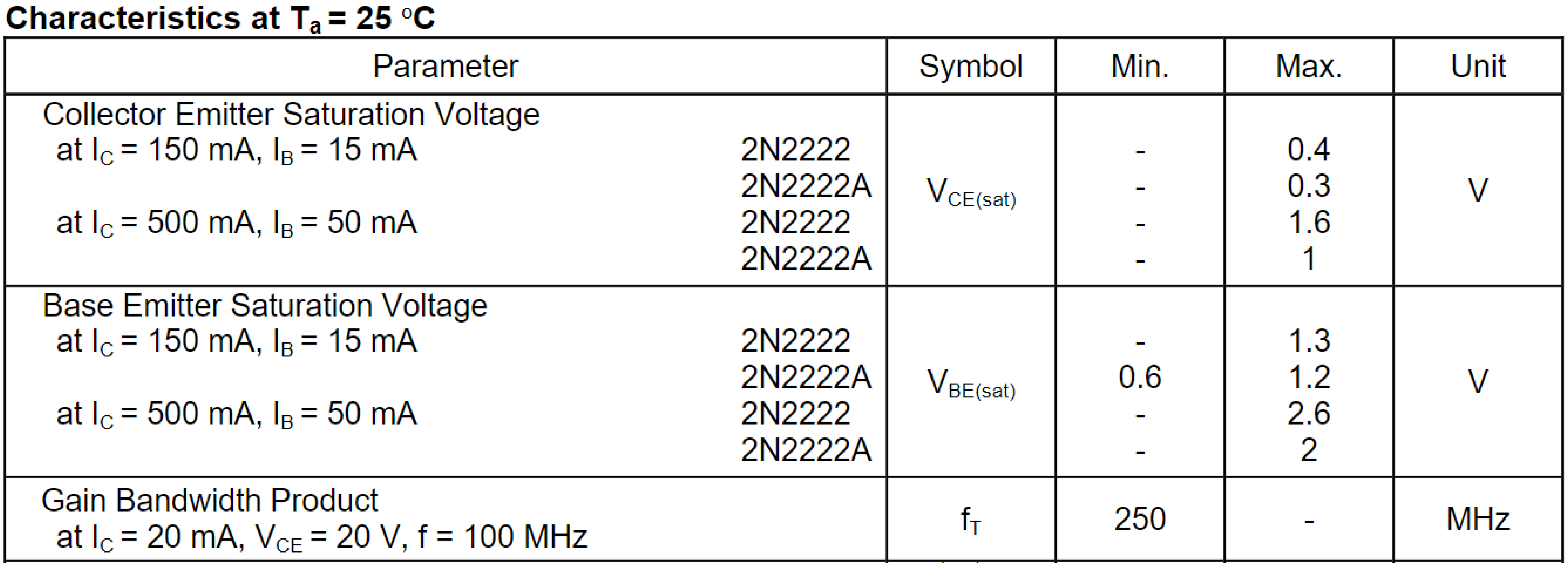
Common-Emitter Amplifier: 2N2222 Catalogue (2)



Characteristics at $T_a = 25\ ^{o}C$

Parameter		Symbol	Min.	Max.	Unit
DC Current Gain					
at $V_{CE} = 10$ V, $I_C = 0.1$ mA		h_{FE}	35	-	-
at $V_{CE} = 10$ V, $I_C = 1$ mA		h_{FE}	50	-	-
at $V_{CE} = 10$ V, $I_C = 10$ mA		h_{FE}	75	-	-
at $V_{CE} = 10$ V, $I_C = 150$ mA		h_{FE}	100	300	-
at $V_{CE} = 10$ V, $I_C = 500$ mA	2N2222	h_{FE}	30	-	-
	2N2222A	h_{FE}	40	-	-
Collector Base Cutoff Current					
at $V_{CB} = 50$ V	2N2222	I_{CBO}	-	10	nA
at $V_{CB} = 60$ V	2N2222A		-	10	
Collector Base Breakdown Voltage					
at $I_C = 10\ \mu A$	2N2222	$V_{(BR)CBO}$	60	-	V
	2N2222A		75	-	

Common-Emitter Amplifier: 2N2222 Catalogue (3)

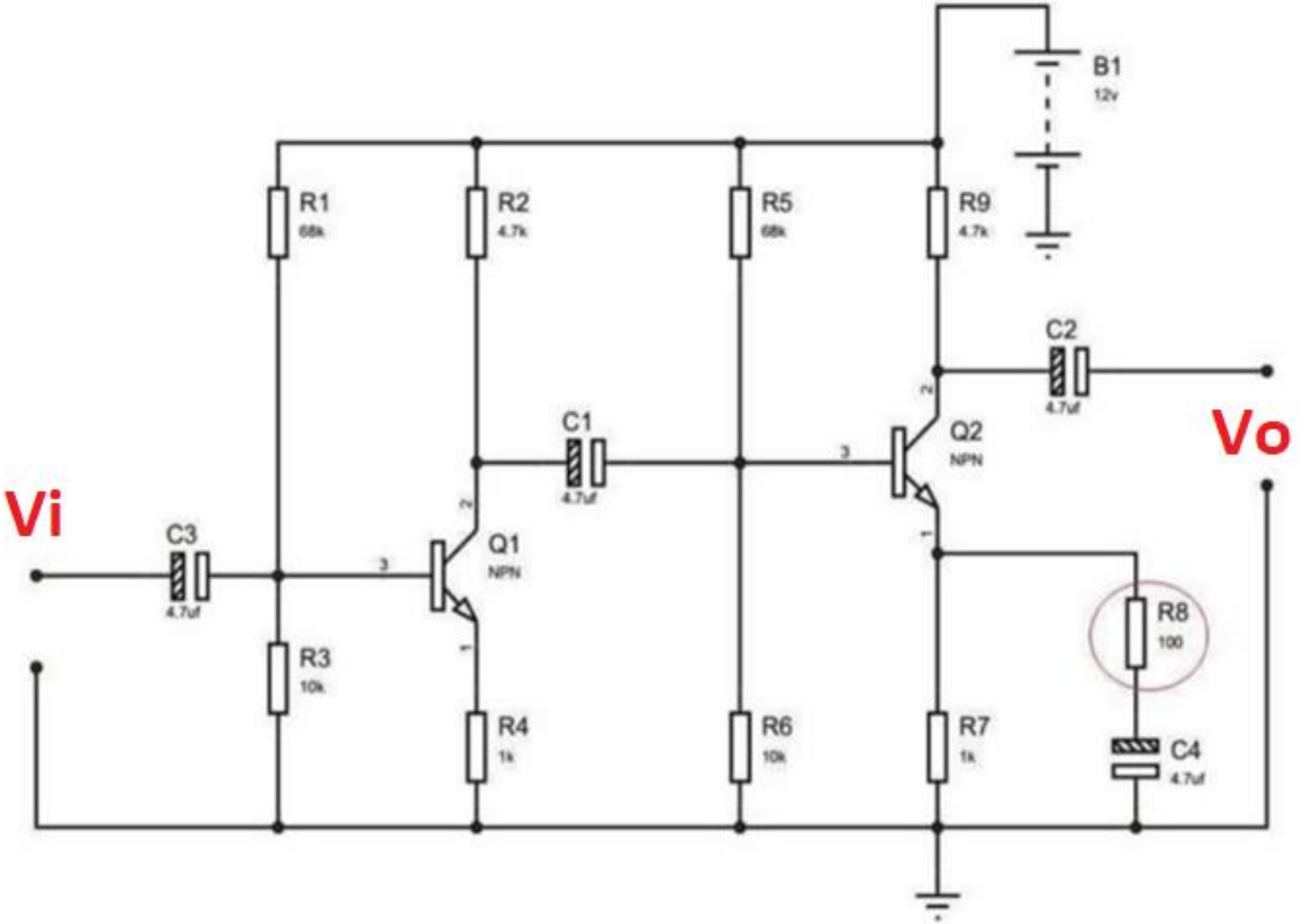


Characteristics at $T_a = 25\ ^{o}C$

Parameter		Symbol	Min.	Max.	Unit
Collector Emitter Saturation Voltage					
at $I_C = 150$ mA, $I_B = 15$ mA	2N2222	$V_{CE(sat)}$	-	0.4	V
	2N2222A		-	0.3	
at $I_C = 500$ mA, $I_B = 50$ mA	2N2222		-	1.6	
	2N2222A		-	1	
Base Emitter Saturation Voltage					
at $I_C = 150$ mA, $I_B = 15$ mA	2N2222	$V_{BE(sat)}$	-	1.3	V
	2N2222A		0.6	1.2	
at $I_C = 500$ mA, $I_B = 50$ mA	2N2222		-	2.6	
	2N2222A		-	2	
Gain Bandwidth Product at $I_C = 20$ mA, $V_{CE} = 20$ V, f = 100 MHz		f_T	250	-	MHz

Left to Students

- If we add an extra resistor (Rs) in series of the Vin, what will be change in equations?
- If we remove the C_E capacitor , what will be change in equations?
- If we connect two amplifiers in cascade connection (see the circuit on the right), what will be change in equations? Is there any change in corner frequencies?



Thanks for listening ☺

YALÇIN İŞLER

Assoc. Prof.