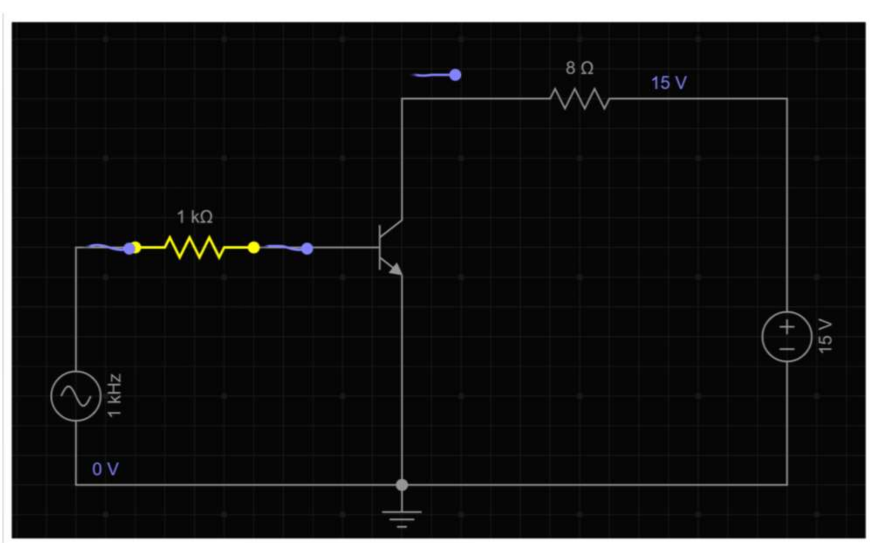
BJT Biasing Techniques

1. Base Bias
2. Fixed Bias
3. Collector Feedback bias
4. Potential Divider Bias

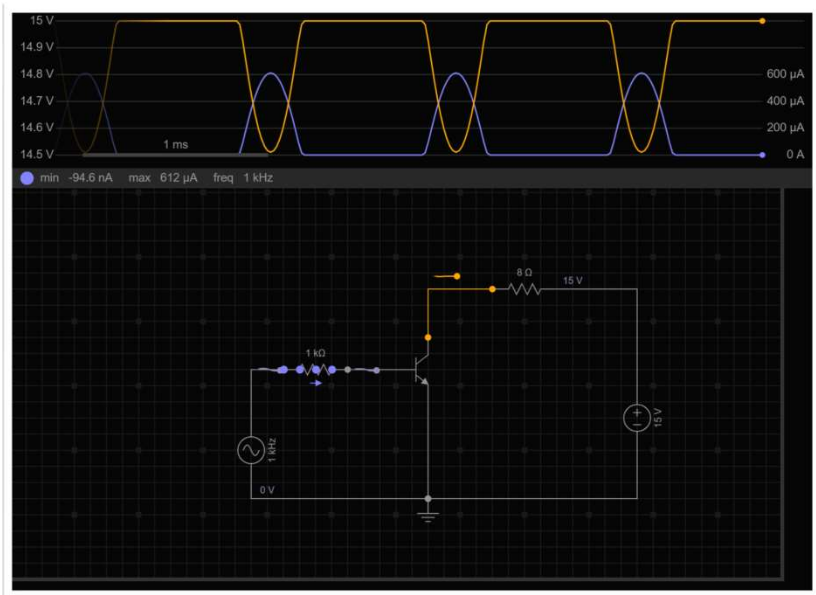
Ex. Find the biasing issue in this circuit

Amplitude 1.5 V

Frequency 1 kHz



Output is half wave Rectified

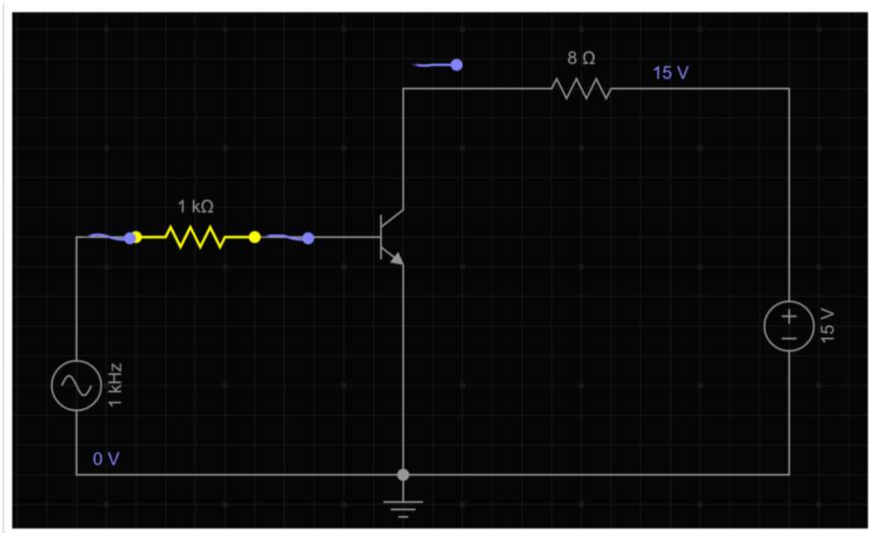


DC Bias of BJT Junctions

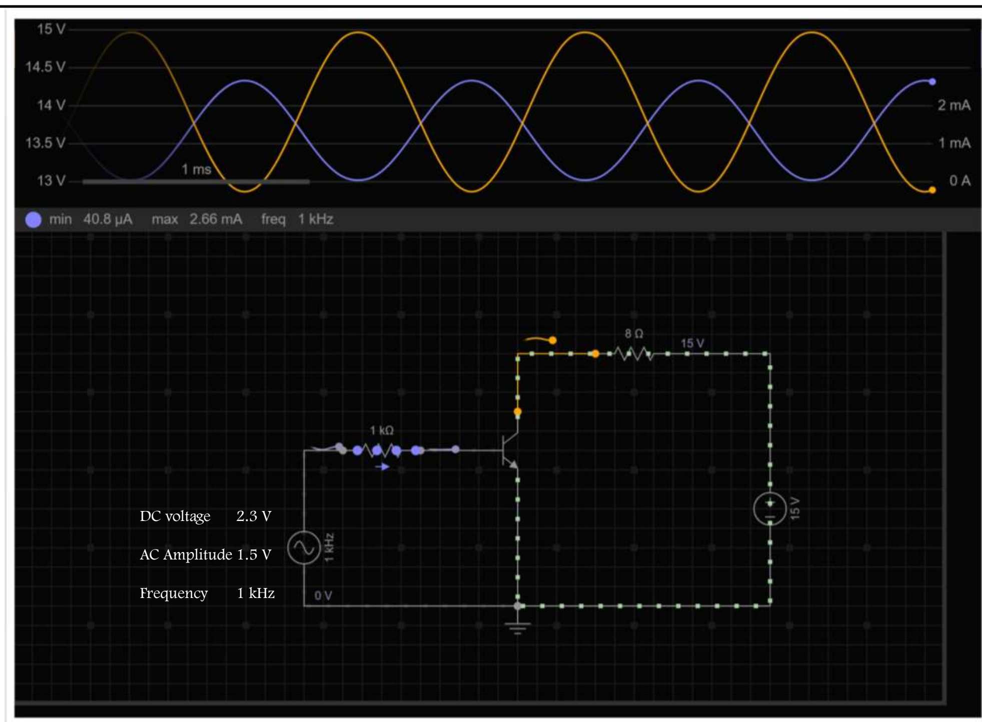
- Transistor must be in its active mode throughout the entire cycle of the input AC signal.
  - This is called ‘Class A’ operation.

- Solution :
  - Superimpose the small input AC signal on a DC voltage.

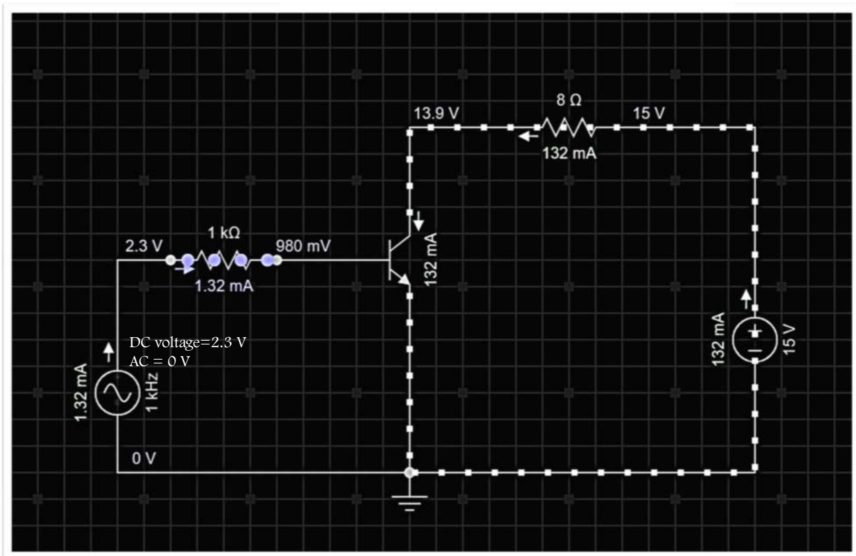
The Base Bias



DC bias 2.3 V
Amplitude 1.5
Frequency 1 kHz

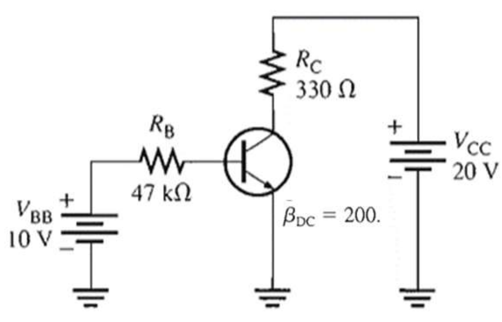


DC Analysis



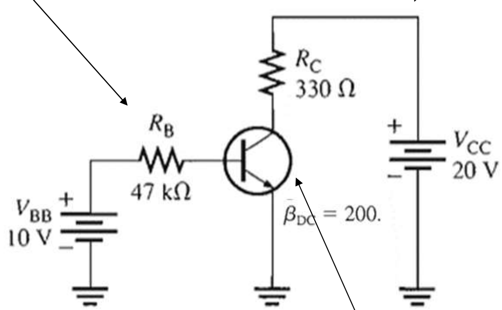
Tutorial Question

Analyze this circuit. Find I_B, I_C and V_{CE} and plot the DC load line



$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{10 - 0.7}{47} = 198\mu A$$

$$I_C = \beta I_B = (200).(0.198) = 39.6mA$$



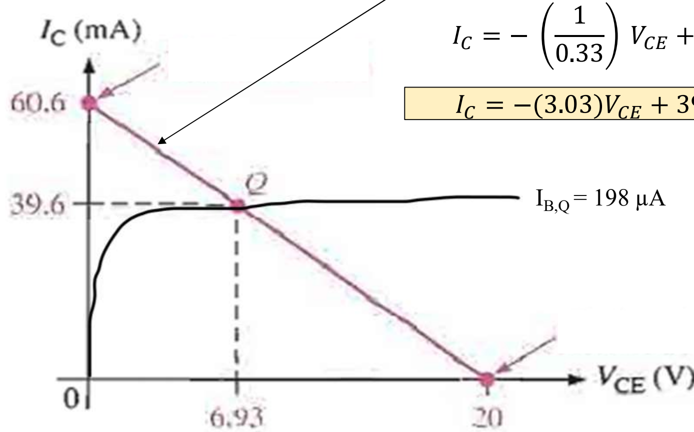
$$V_{CE} = V_{CC} - I_C R_C = 20 - (39.6).(330) = 6.93\text{V}$$

DC Load Line

$$I_C = -\left(\frac{1}{R_L}\right) V_{CE} + \left(\frac{V_{CC}}{R_L}\right)$$

$$I_C = -\left(\frac{1}{0.33}\right) V_{CE} + \left(\frac{20}{0.33}\right) mA$$

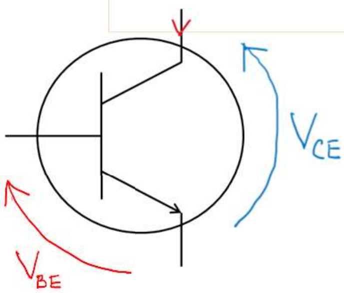
$$I_C = -(3.03)V_{CE} + 39.6mA$$



Simplified Math Model of a BJT

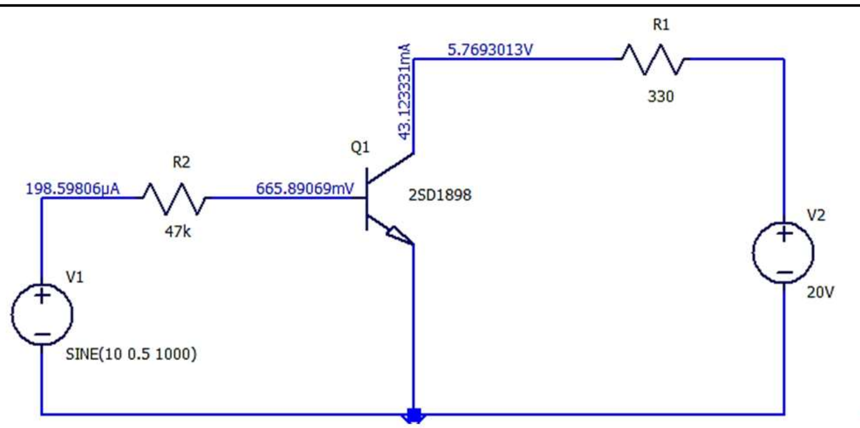
$$i_C = I_S e^{V_{BE}/V_T}\left(1 + \frac{v_{CE}}{V_{AF}}\right)$$

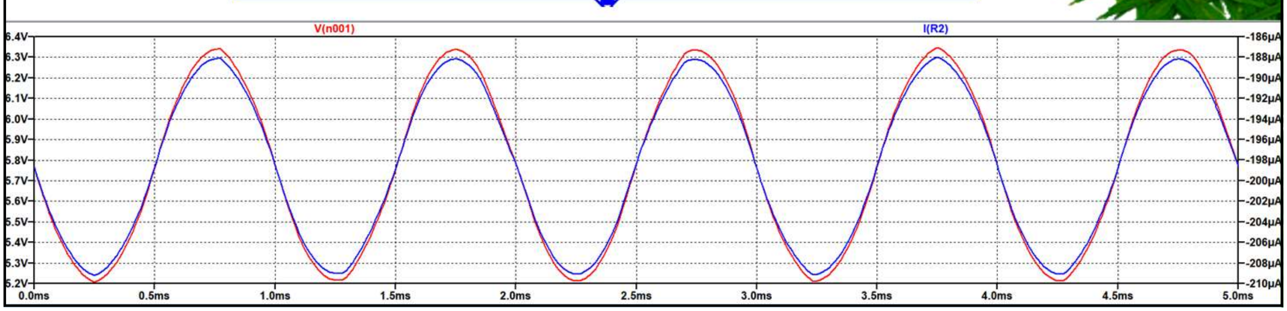
$$i_B = \frac{I_S}{\beta_F} e^{V_{BE}/V_T}$$



I_S = Saturation current
V_T =Thermal equivalent voltage
β_F =Forward current gain in CE config.
V_{AF} =Forward early voltage

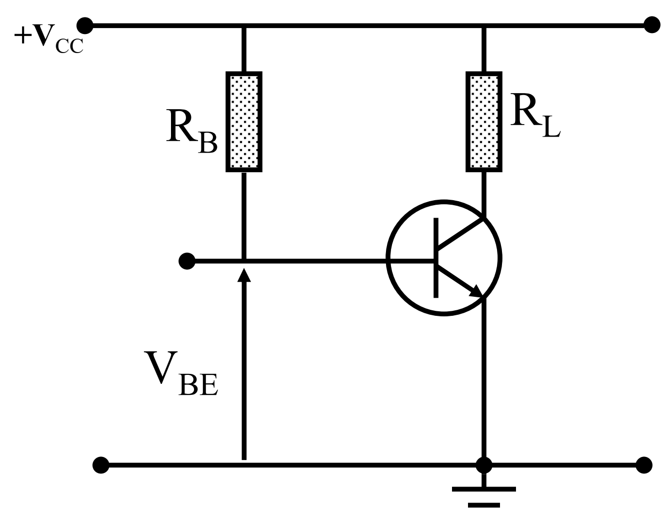
Early voltage parameter that describes the variation in the effective width of the base region due to changes in V_{CB}. This effect(known as the Early effect) leads to a slight increase in the collector current with an increase in the collector-emitter voltage





The Fixed Bias

Fixed Bias Circuit



Apply KVL

$$V_{BE} + I_B.R_B = V_{CC}$$

For analyzing

$V_{BE} + I_B.R_B = V_{CC}$

$I_B.R_B = V_{CC} - V_{BE}$

0.7 V Typical

$I_{B,Q} = (V_{CC} - V_{BE,Q}) / R_B$

For designing

$V_{BE} + I_B.R_B = V_{CC}$

$I_B.R_B = V_{CC} - V_{BE}$

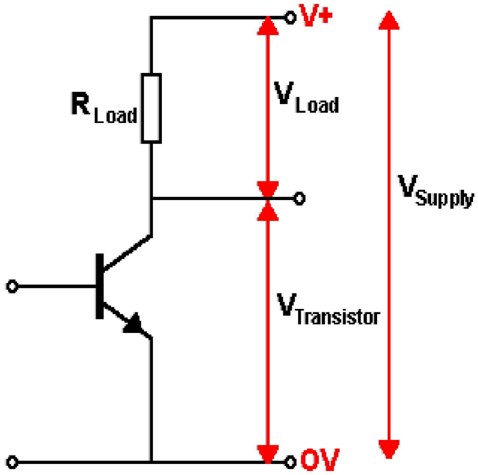
0.7 V Typical

$R_B = (V_{CC} - V_{BE,Q}) / I_{B,Q}$

Plotting DC Load Line

Selecting Static Output Characteristics

DC Load Line



$V_{Load} = I_C \times R_L$

$V_{Transistor} = V_{CE}$

$V_{Supply} = V^+ = V_{CC}$

Using Kirchoff's Voltage Law …

$V_{CE} + I_C \times R_L = V_{CC}$

DC Load Line

$V_{CE} + I_C \times R_L = V_{CC}$

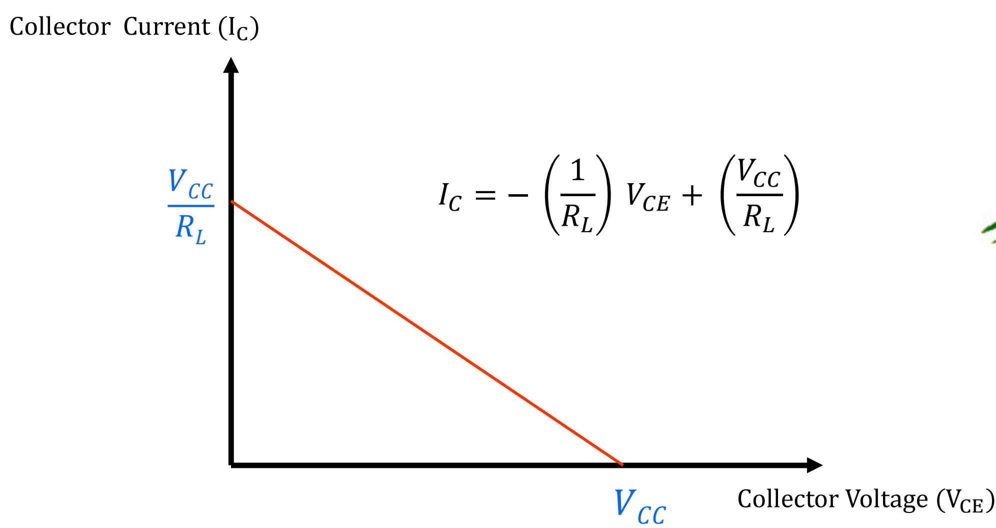
$I_C \times R_L = -(V_{CE}) + V_{CC}$

$$I_C = -\left(\frac{V_{CE}}{R_L}\right) + \left(\frac{V_{CC}}{R_L}\right)$$

$$I_C = -\left(\frac{1}{R_L}\right) V_{CE} + \left(\frac{V_{CC}}{R_L}\right)$$

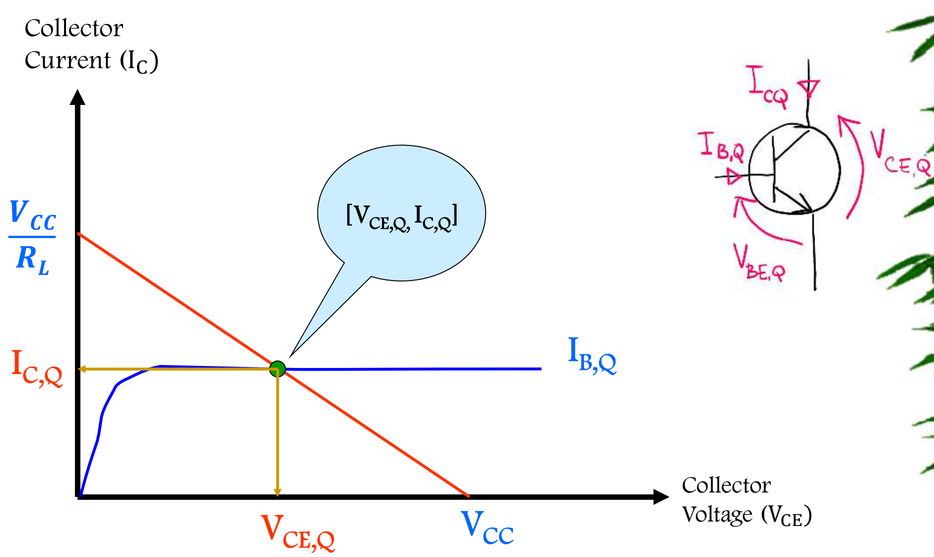
$$Y = m.X + C$$

DC Load Line is KVL in Graphical Form



$$I_C = -\left(\frac{1}{R_L}\right)V_{CE} + \left(\frac{V_{CC}}{R_L}\right)$$

Operating Point (Q Point)

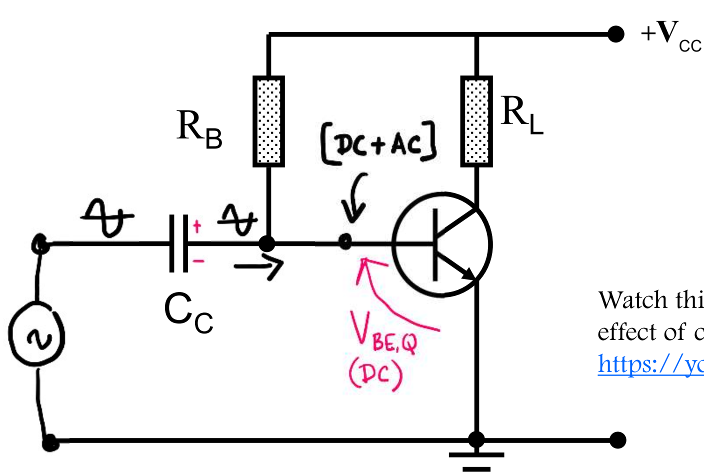


Feeding the Input

- Input signal is a small a.c. signal (called drive signal)
    - Eg. Audio from a microphone

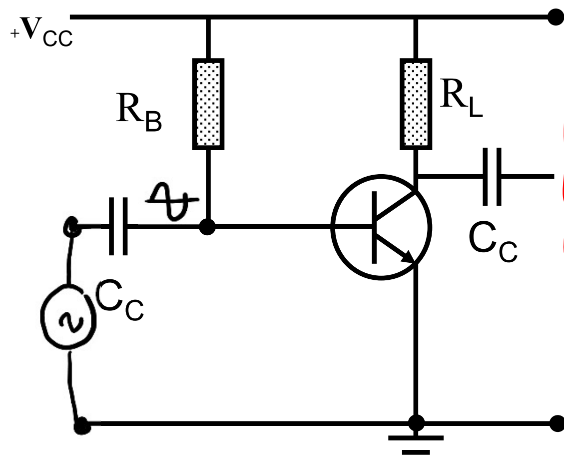
- Input signal should be arranged to ride on the d.c. bias. This is called superimposing ac on dc.
    - A coupling capacitor can be used for this purpose.
    - It will superimpose small ac signal on the dc base bias.

Use of input coupling capacitor



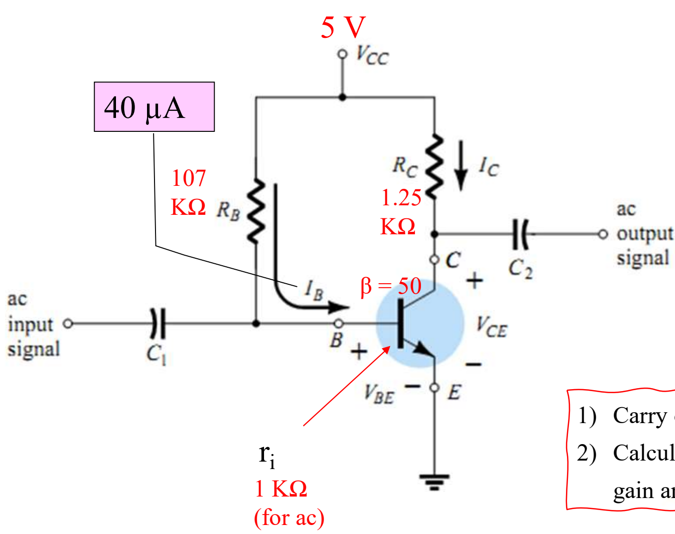
Watch this Video to understand the effect of coupling capacitor.
https://youtu.be/eF8e-FmtDh4

Use of an output coupling capacitor



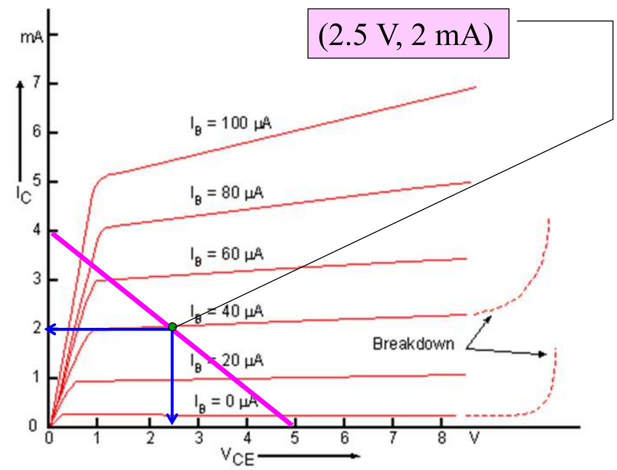
- DC level ($V_{CE,Q}$) does not appear here.
- Only the amplified ac signal will come out.

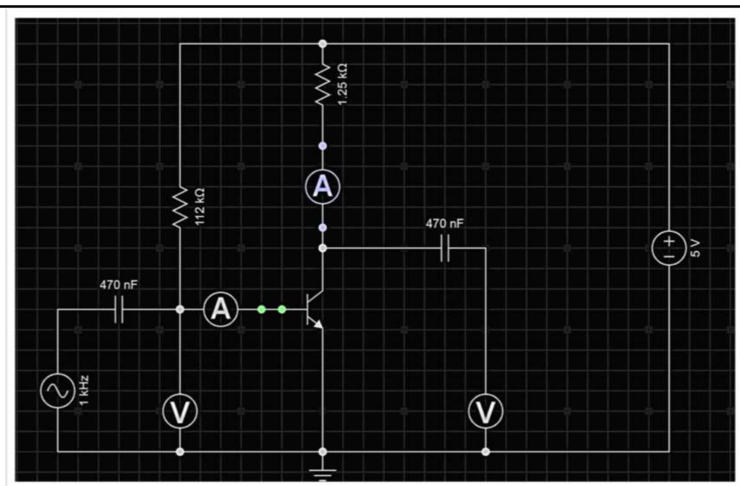
An Example of a CE Amplifier



1) Carry our dc analysis
2) Calculate voltage gain, current gain and the power gain

Load Line on Static Output Characteristics

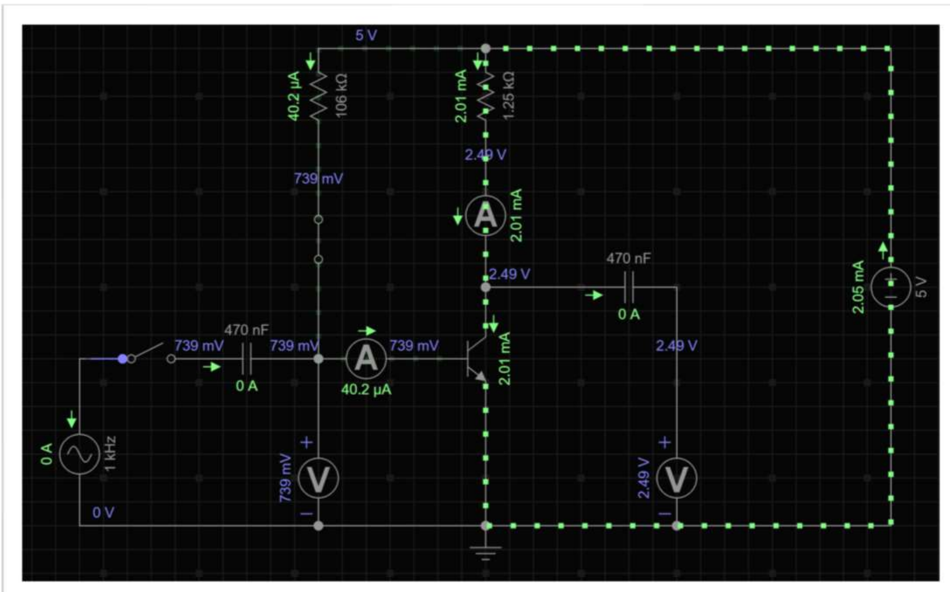




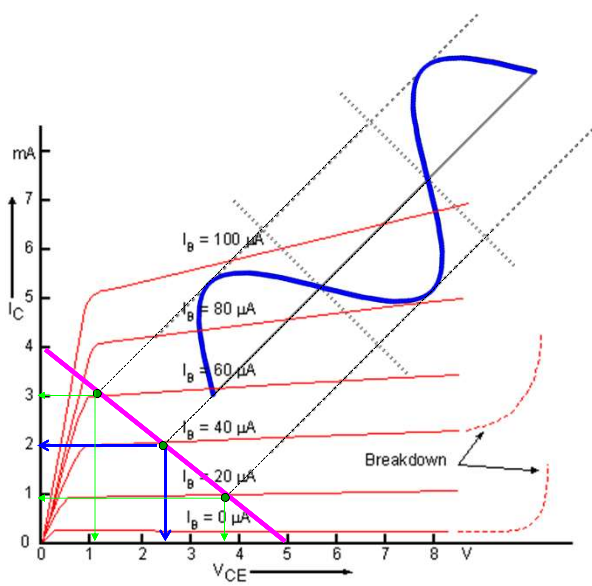
DC voltage	0 V
Amplitude	16.8 mV
Frequency	1 kHz

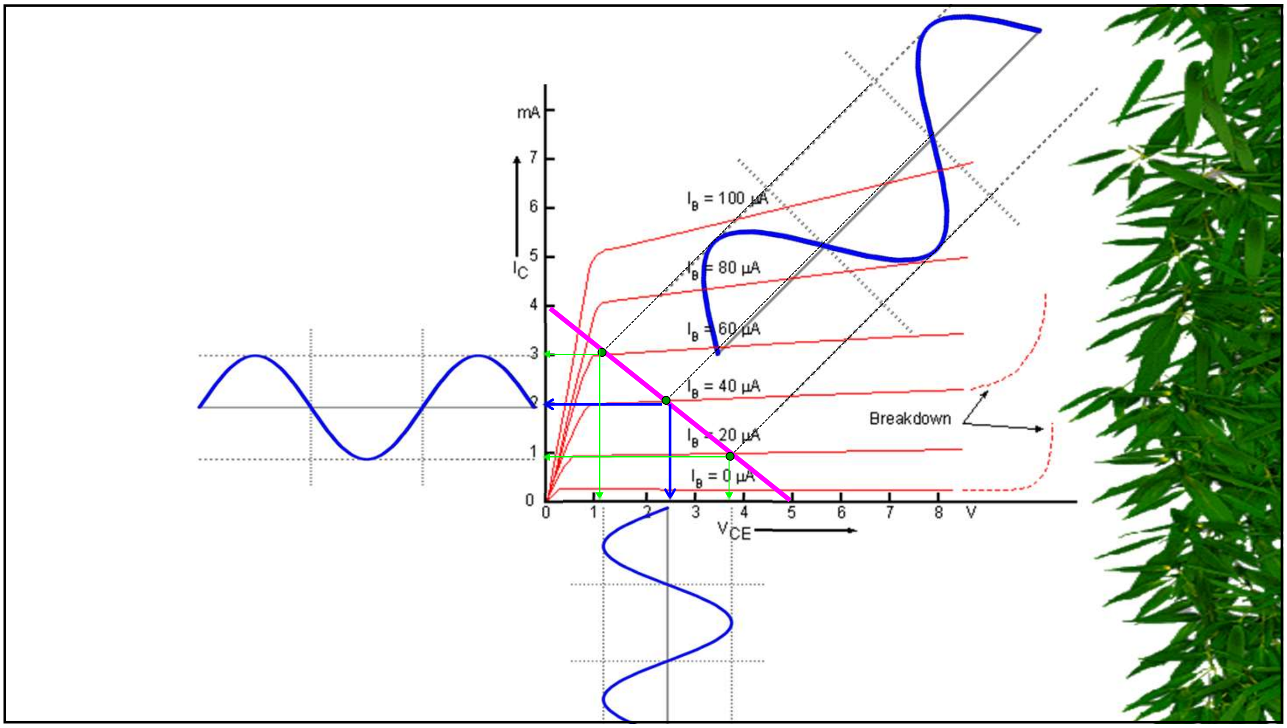
Saturation current	1 fA
Forward beta	50
Collector resistance	1 Ω
Base resistance	1 Ω
Emitter resistance	1 Ω

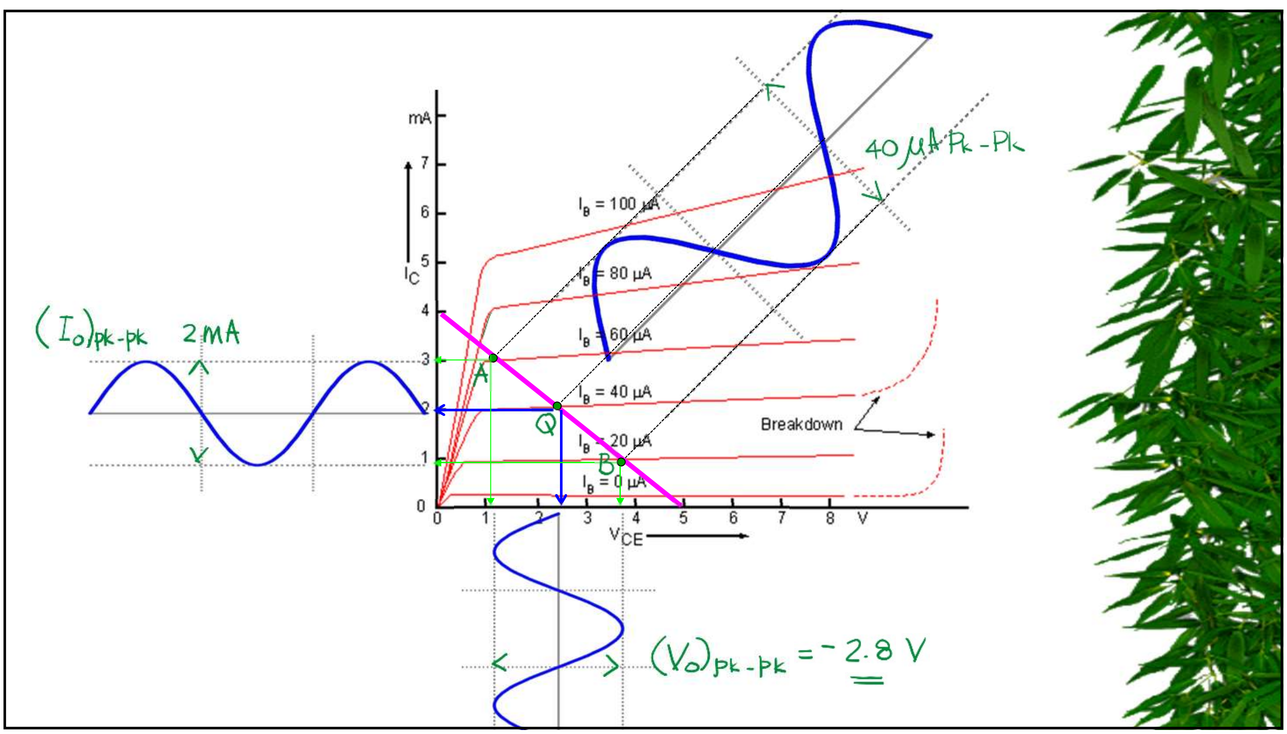
DC Analysis

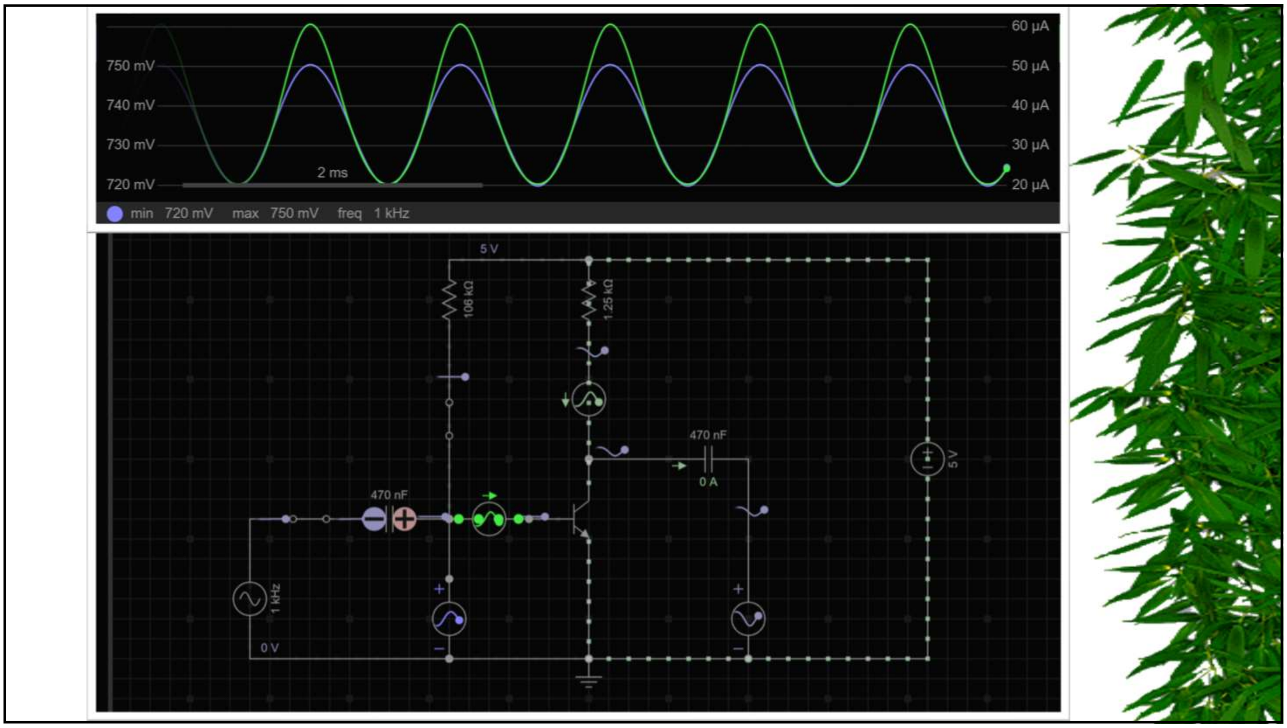


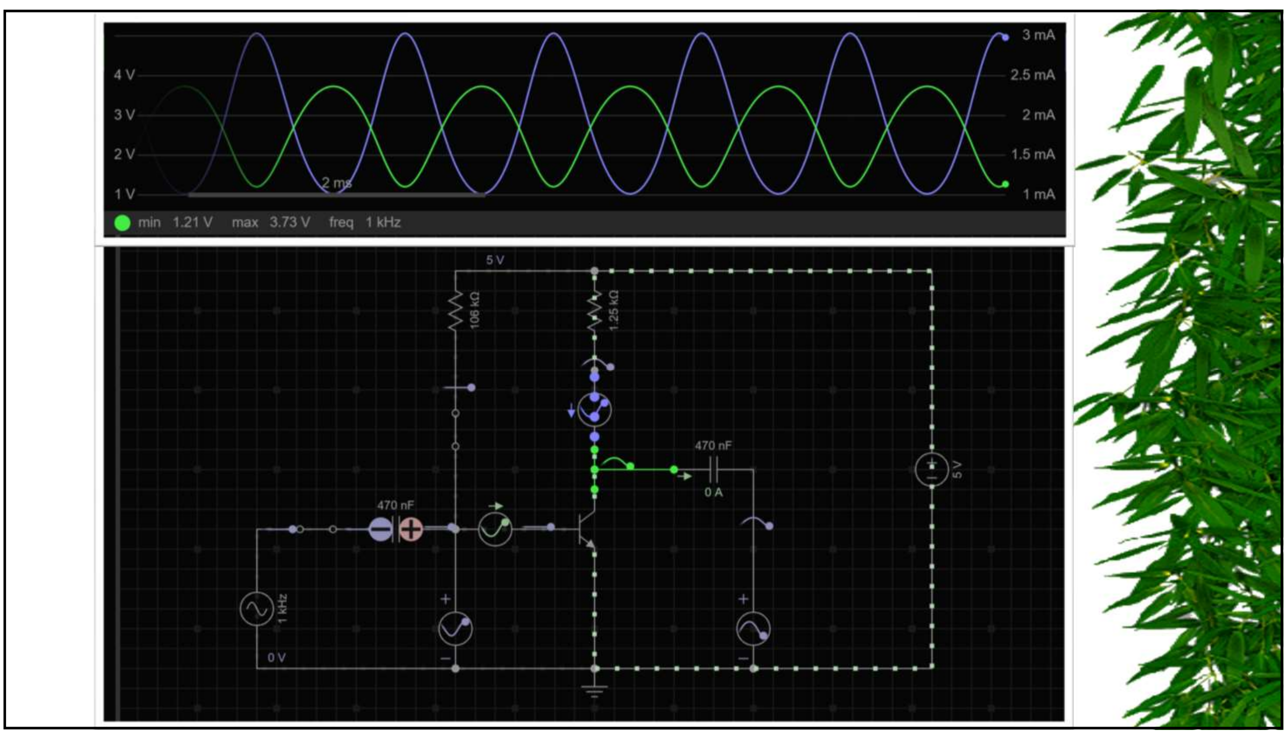
Load Line on Output Characteristics (Cont.)




mA
7
6
5
4
3
2
1
0
I_C
I_B = 100 µA
I_B = 80 µA
I_B = 60 µA
I_B = 40 µA
I_B = 20 µA
I_B = 0 µA
Breakdown
0 1 2 3 4 5 6 7 8 V
V_{CE}


mA
7
6
5
4
3
2
1
0
I_C
I_B = 100 µA
I_B = 80 µA
I_B = 60 µA
I_B = 40 µA
I_B = 20 µA
I_B = 0 µA
Breakdown
0 1 2 3 4 5 6 7 8 V
V_{CE}
40 µA Pk-Pk
$(I_o)_{pk-pk}$ 2 mA
A
Q
B
$(V_o)_{pk-pk}$ = ~2.8 V


750 mV
740 mV
730 mV
720 mV
60 µA
50 µA
40 µA
30 µA
20 µA
2 ms
min 720 mV max 750 mV freq 1 kHz
5 V
106 kΩ
1.25 kΩ
470 nF
0 A
470 nF
1 kHz
0 V
5 V


4 V
3 V
2 V
1 V
3 mA
2.5 mA
2 mA
1.5 mA
1 mA
2 ms
min 1.21 V max 3.73 V freq 1 kHz
5 V
106 kΩ
1.25 kΩ
470 nF
0 A
470 nF
1 kHz
0 V
5 V

Gain Calculations of an Amplifier

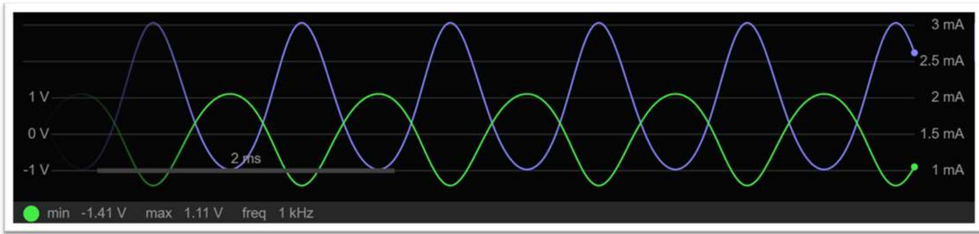
- Gain is a ratio between an output parameter and the corresponding input parameter
- Gain is specified in three ways
  - Power Gain (G)
  - Voltage Gain (A_v)
  - Current Gain (A_i)

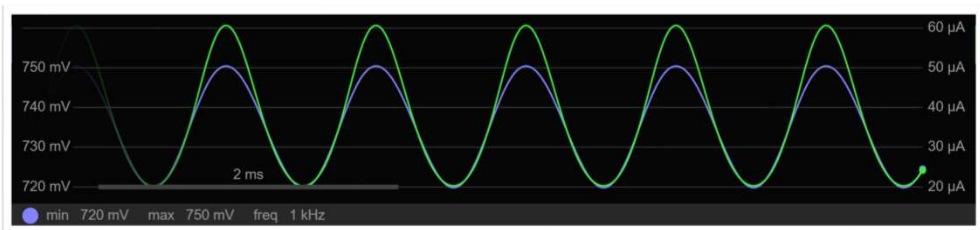
Current Gain of an Amplifier

- Ratio between the peak-peak output current variation and the peak-peak input current variation

$$A_i = \frac{I_{o,(pk-pk)}}{I_{i,(pk-pk)}}$$

Ex. Find the current gain of the circuit





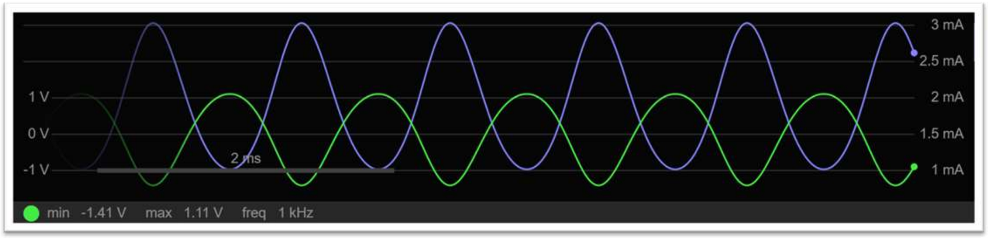
$$A_i = \frac{I_{o,(pk-p\ \ )}}{I_{i,(pk-pk)}}$$

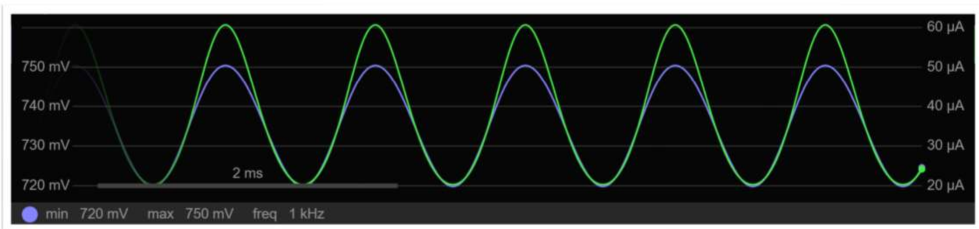
Voltage Gain of an Amplifier

- Ratio between the peak-peak output voltage variation and the peak-peak input voltage variation

$$A_v = \frac{V_{o,(pk-pk)}}{V_{i,(pk-pk)}}$$

Ex. Find the voltage gain of the circuit. Assume input resistance as 1 KΩ





$$A_v = \frac{V_{o,(pk-p\ \ )}}{V_{i,(pk-pk)}}$$

Power Gain of an Amplifier

- Ratio between the output signal power and the input signal power

$$G = \frac{P_o}{P_i}$$

Power Gain of an Amplifier

Power = voltage x current

$$G = \frac{V_o . I_o}{V_i . I_i} = \left(\frac{V_o}{V_i}\right).\left(\frac{I_o}{I_i}\right) = |A_v|.|A_i|$$

$$\boxed{G = |A_v|.|A_i|}$$

Ex. Find the power gain of the circuit

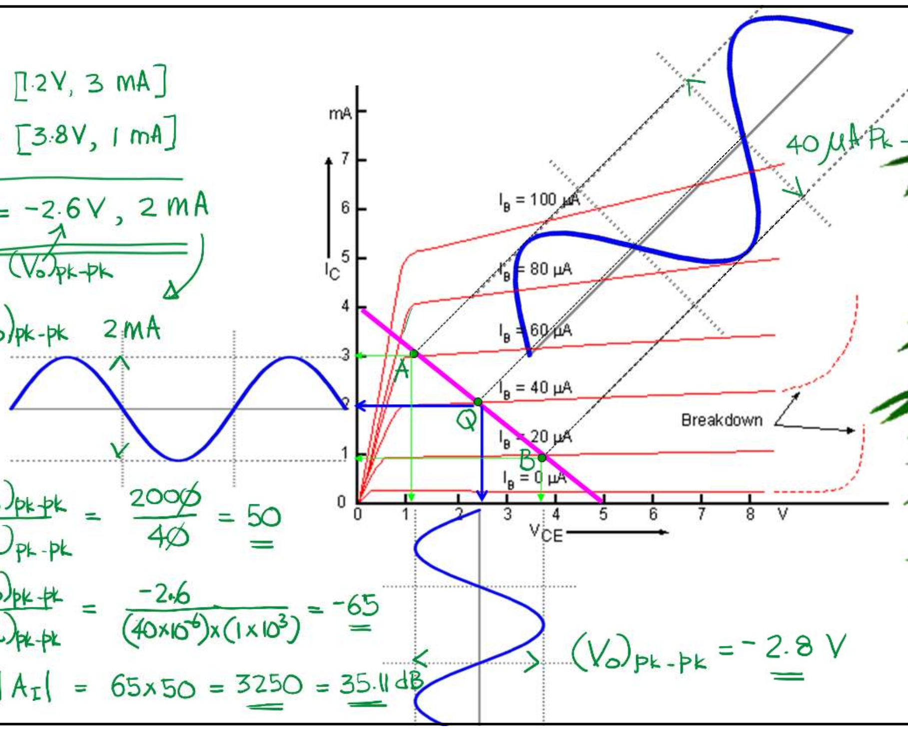
A = [1.2V, 3 mA]

B = [3.8V, 1 mA]

(A - B) = -2.6V, 2 mA

$(V_o)_{pk-pk}$

$(I_o)_{pk-pk}$ 2 mA

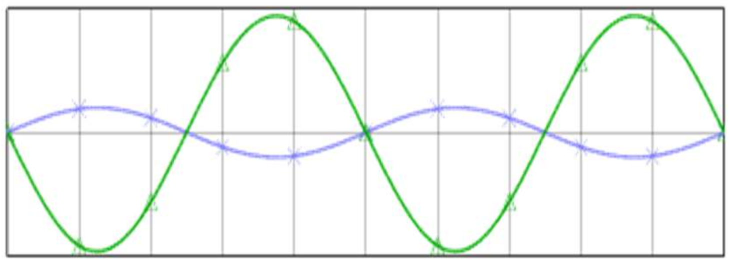


$$A_I = \frac{(I_o)_{pk-pk}}{(I_i)_{pk-pk}} = \frac{200\cancel{0}}{4\cancel{0}} = 50$$

$$A_V = \frac{(V_o)_{pk-pk}}{(V_i)_{pk-pk}} = \frac{-2.6}{(40\times10^{-6})\times(1\times10^{3})} = -65$$

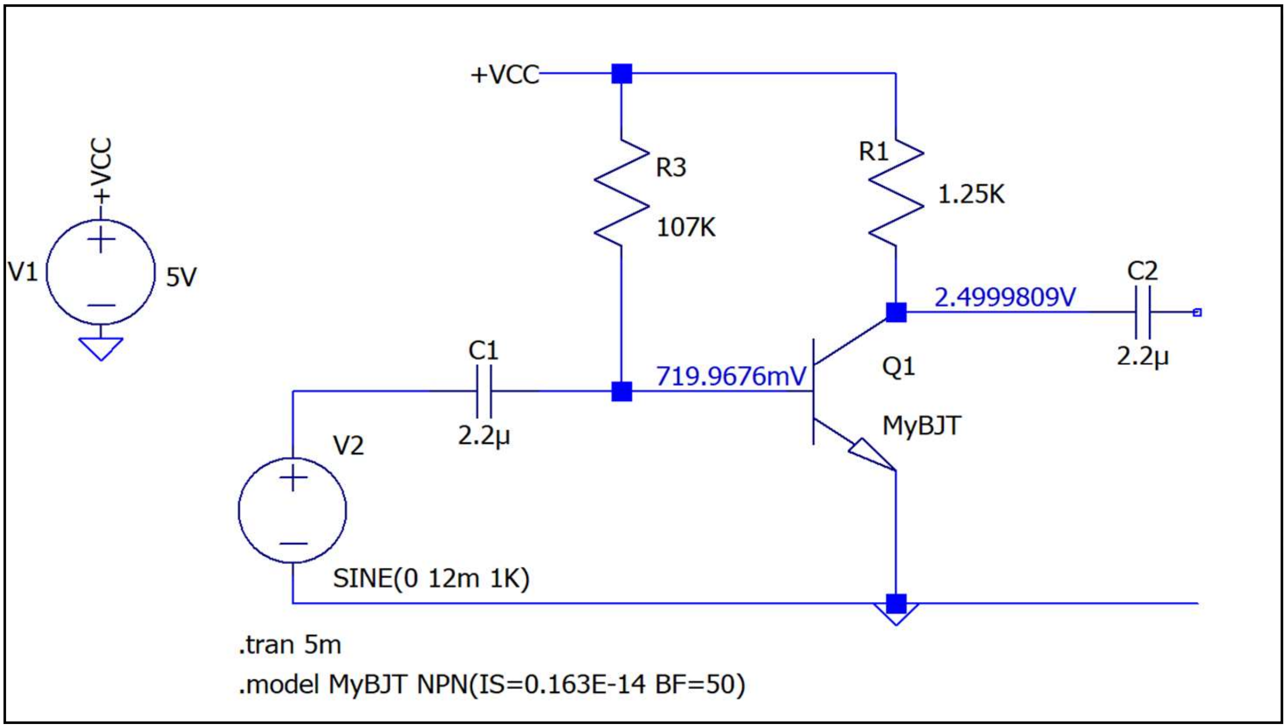
$$G = |A_V|.|A_I| = 65\times50 = 3250 = 35.11\,dB$$

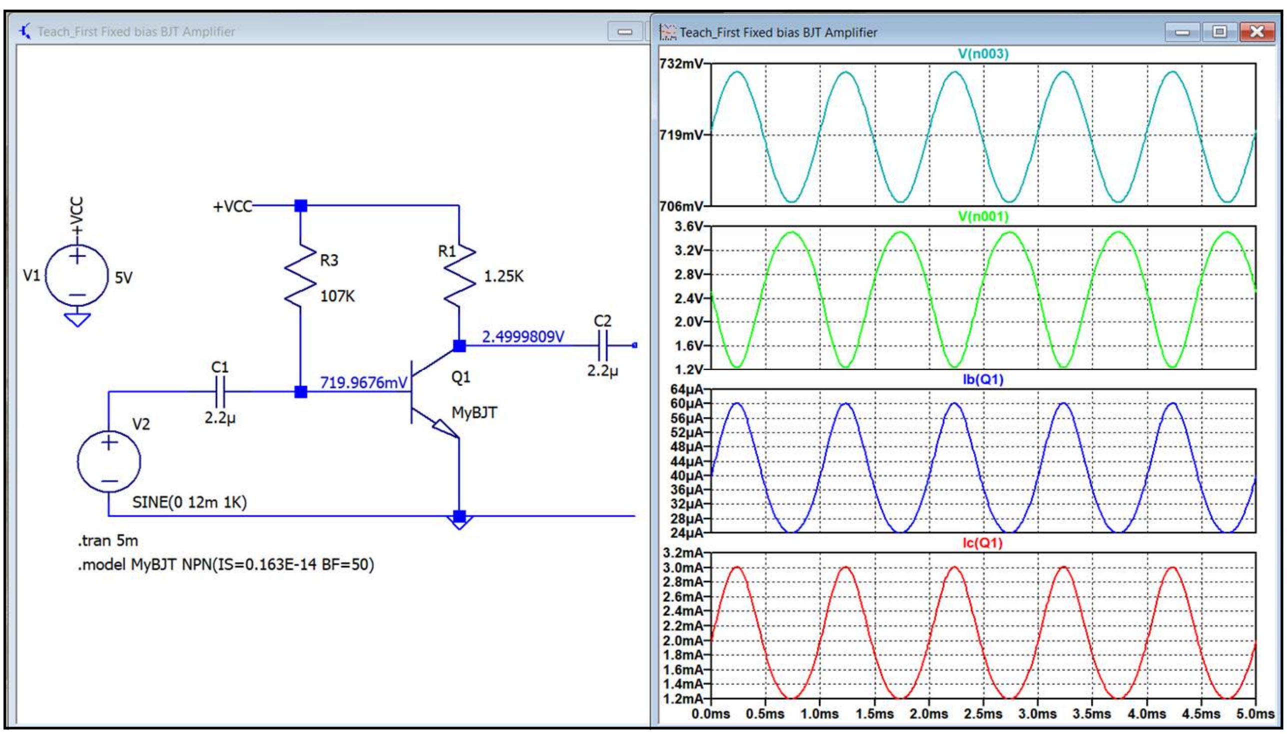
Input voltage vs. Output voltage

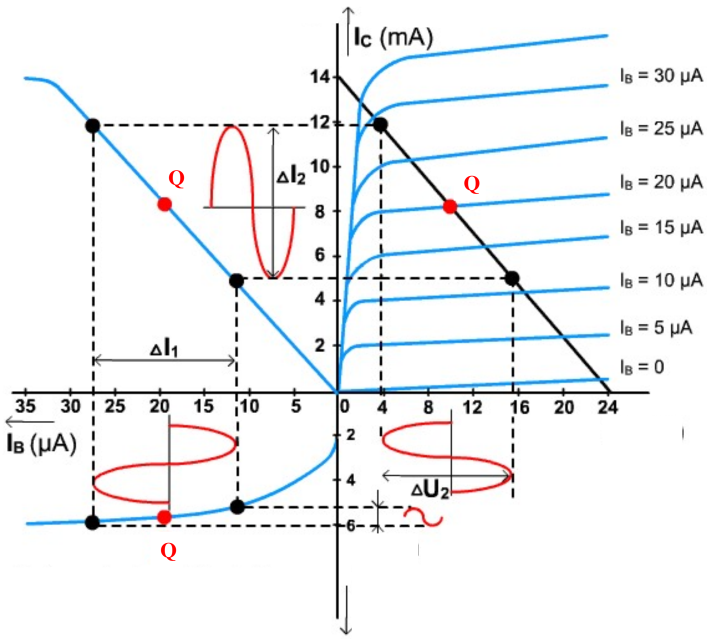


Phase Inversion

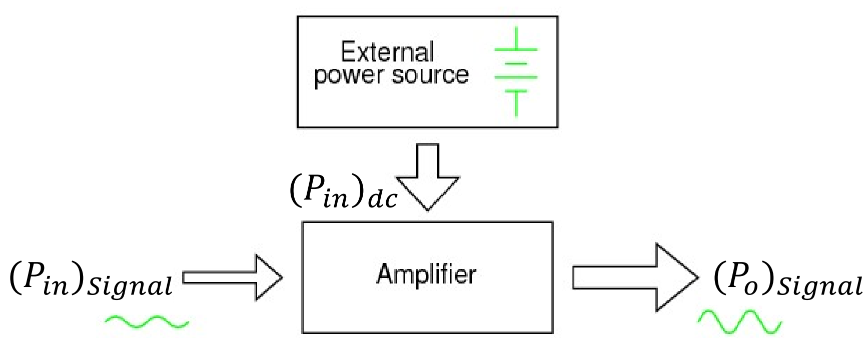
- Output voltage measured between emitter and collector on a common-emitter amplifier, is 180 degrees out of phase with the input voltage waveform.
- Common-emitter amplifier is called an *inverting* amplifier circuit.


+VCC
V1
5V
R3
107K
R1
1.25K
C2
2.4999809V
2.2µ
C1
719.9676mV
Q1
MyBJT
V2
2.2µ
SINE(0 12m 1K)
.tran 5m
.model MyBJT NPN(IS=0.163E-14 BF=50)


Teach_First Fixed bias BJT Amplifier
V(n003)
V(n001)
Ib(Q1)
Ic(Q1)
0.0ms 0.5ms 1.0ms 1.5ms 2.0ms 2.5ms 3.0ms 3.5ms 4.0ms 4.5ms 5.0ms



Power Efficiency of an Amplifier



Power Efficiency = Proportion of the input DC power converted to useful output signal power

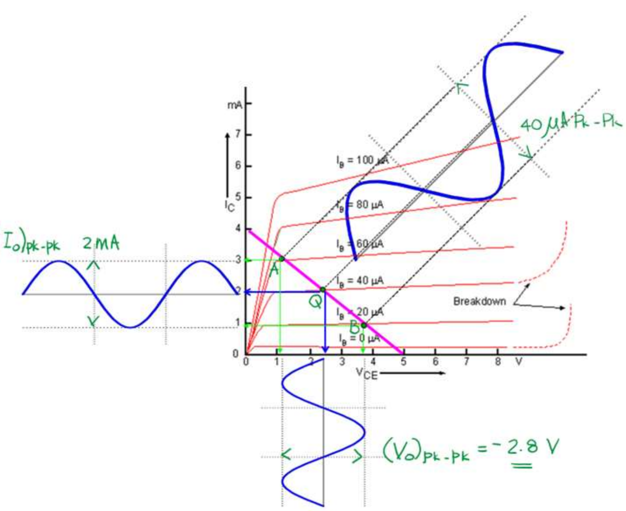
Power Efficiency of an Amplifier

Efficiency = Proportion of the input DC power converted to useful output signal power

$$\eta = \frac{(P_o)_{Signal}}{(P_{in})_{dc}} = \frac{(V_o.I_o)_{signal}}{(V_{dc}.I_{dc})_{bias}}$$

$$\eta = \frac{\left(\frac{V_{o(pk-pk)}}{2.\sqrt{2}}\right).\left(\frac{I_{0(pk-p\ \ )}}{2.\sqrt{2}}\right)}{V_{dc}.I_{dc}}$$

Ex. Find the power efficiency of the example amplifier



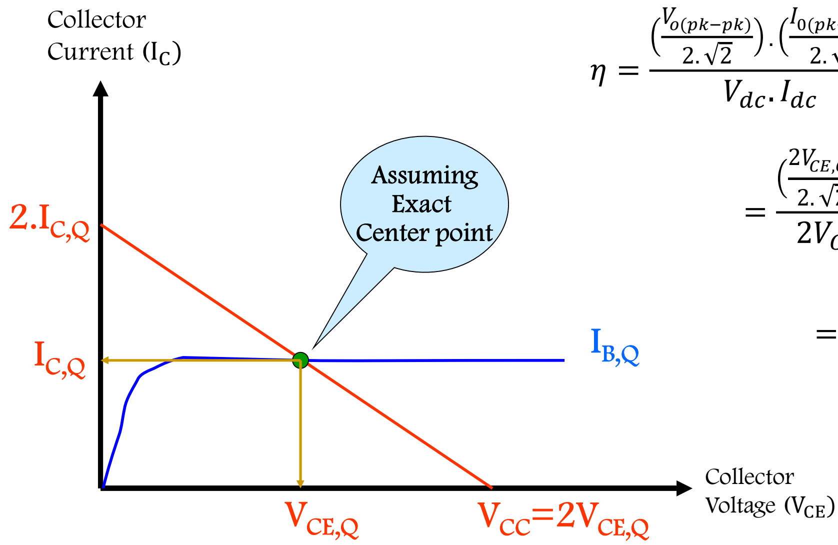
$$\eta = \frac{\left(\frac{V_{o(pk-p\ \ )}}{2.\sqrt{2}}\right).\left(\frac{I_{0(pk-pk)}}{2.\sqrt{2}}\right)}{V_{dc}.I_{dc}}$$

$$= \frac{\left(\frac{2.8}{2.\sqrt{2}}\right).\left(\frac{2}{2.\sqrt{2}}\right)}{5\ x\ 2.04}$$

$$= \frac{\left(\frac{2.8}{2.\sqrt{2}}\right).\left(\frac{2}{2.\sqrt{2}}\right)}{5\ x\ 2.04}$$

= 0.0686 !

Theoretical Max. Efficiency of Class A



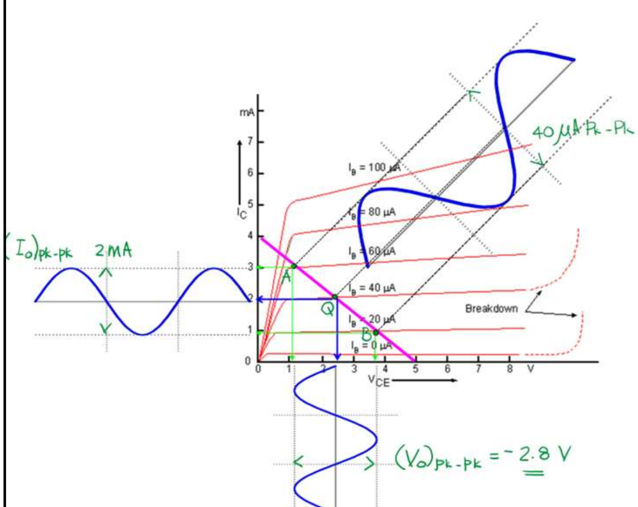
$$\eta = \frac{\left(\frac{V_{o(pk-pk)}}{2.\sqrt{2}}\right).\left(\frac{I_{0(pk-p\ \ )}}{2.\sqrt{2}}\right)}{V_{dc}.I_{dc}}$$

$$= \frac{\left(\frac{2V_{CE,Q)}}{2.\sqrt{2}}\right).\left(\frac{2I_{C,Q)}}{2.\sqrt{2}}\right)}{2V_{CE,Q}.I_{C,Q}}$$

$= 0.25 = 25\%$

$= 25\%$

Power Dissipation in the BJT



P_d= ($V_{BE,Q}$. $I_{B,Q}$)+ ($V_{CE,Q}$ x $I_{C,Q}$)

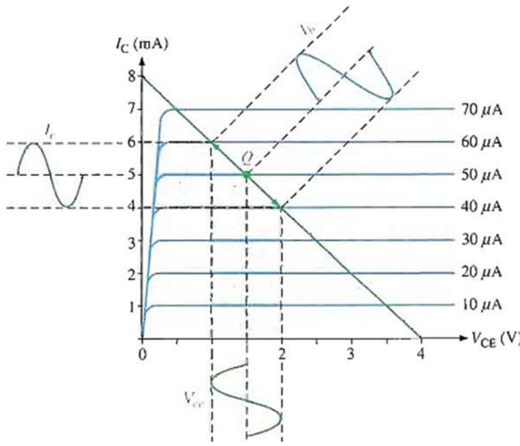
$P_d \approx V_{CE,Q}$ x $I_{C,Q}$

$P_d \approx$ 2.5 x 2 mW

$P_d \approx$ 5 mW

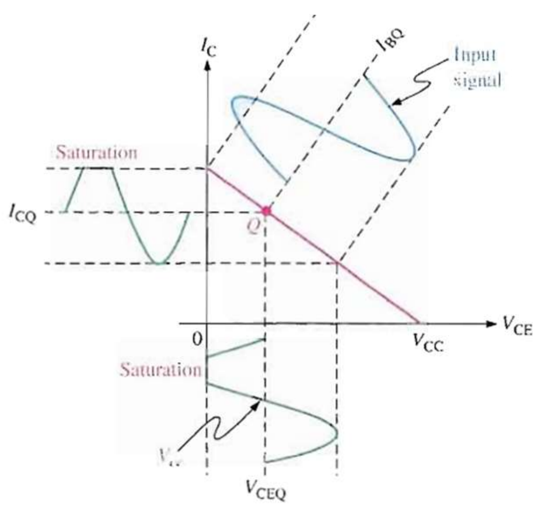
Also known as collector power dissipation

Ex. Calculate A_v A_i and G

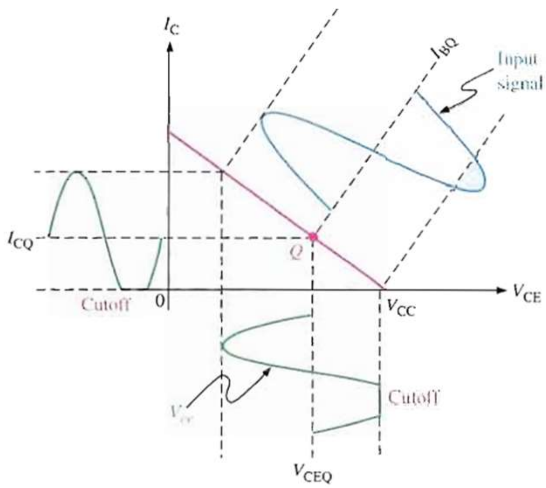


Assume R_i = 1 KΩ for BE junction

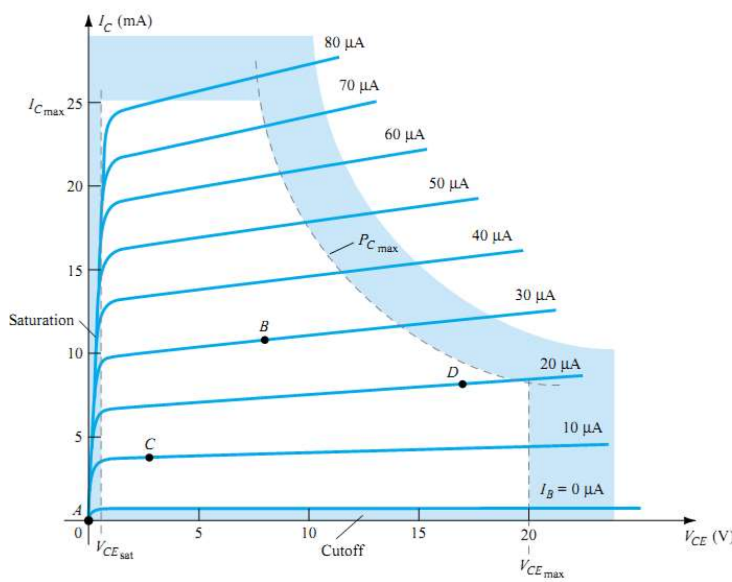
Incorrect Q Point



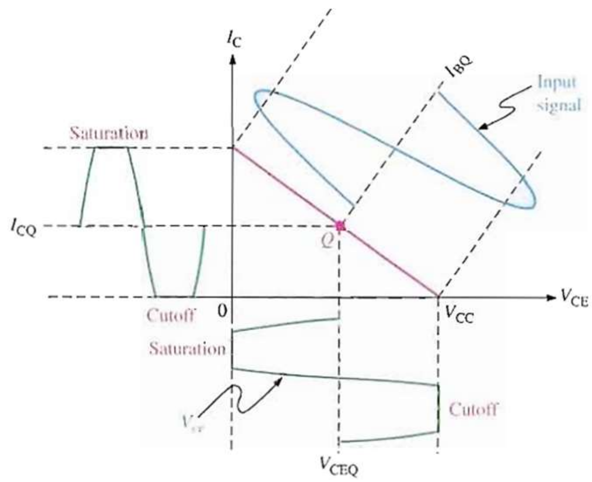
Incorrect Q Point

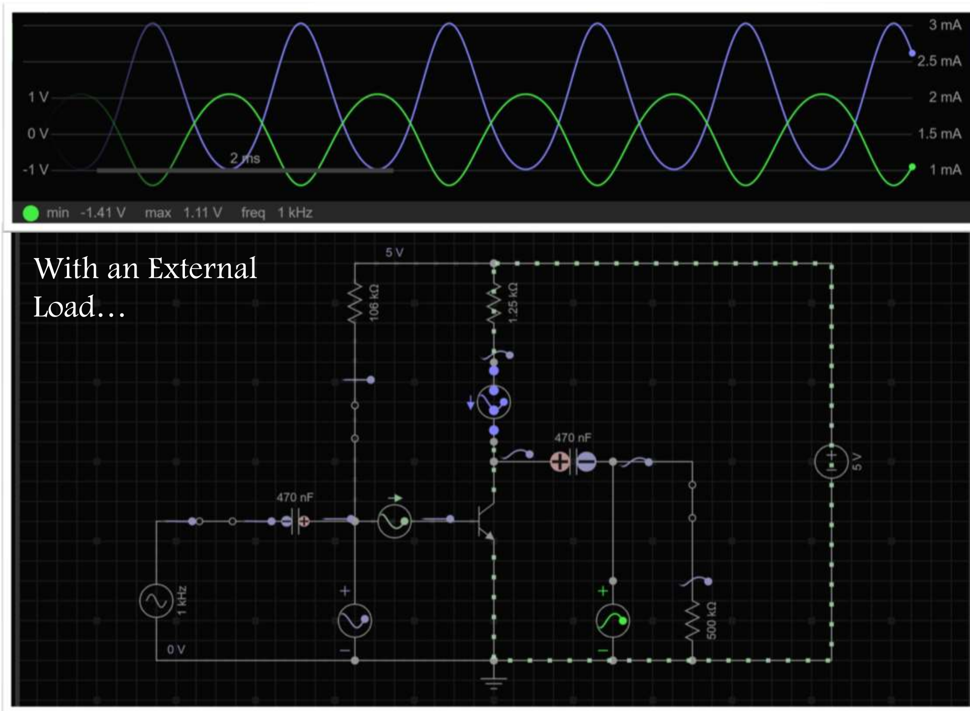


Q Point

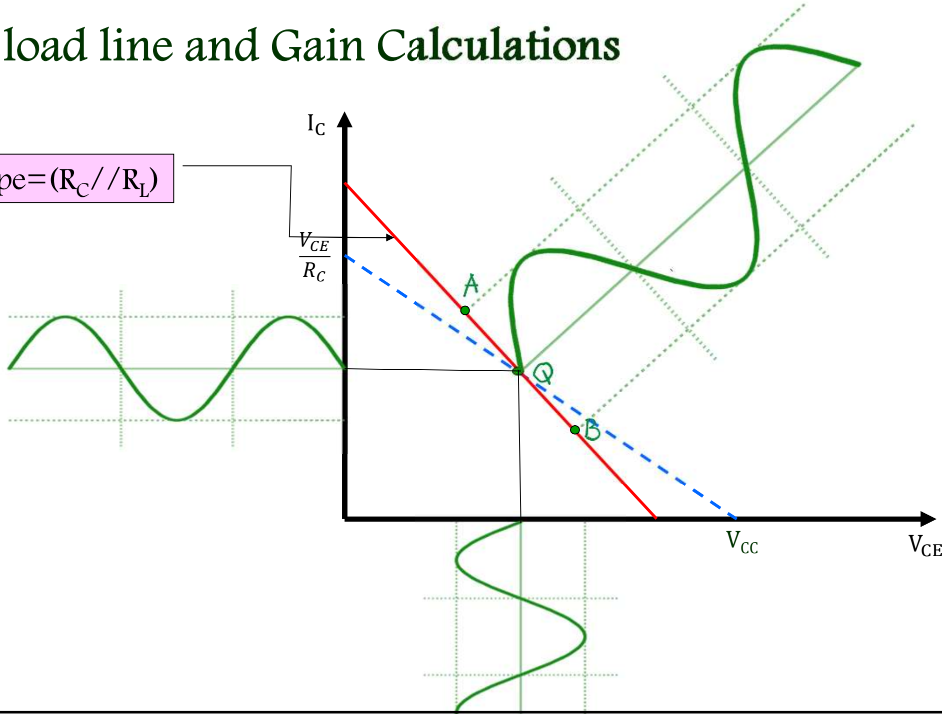


Too much drive…





AC load line and Gain Calculations



Thermal Runaway

- Power is dissipated in the collector and hence it is made physically larger than the emitter and base region.
- As the power is dissipated the base-collector junction temperature increase.
- The reverse leakage current I_{CBO} increases due to the flow of thermally generated minority carriers

$$I_C = \alpha I_E + I_{CBO}$$

Thermal Runaway

- Process is cumulative leading eventually to the destruction of the transistor.
- Thermal runaway can be prevented by using a heat sink.
- Emitter degenerative feedback can also be used.