Common Collector CC Amplifier Design **Richard Cooper**

Vout is not inverted so the gains Av and Ai are positive.

Designing procedure of common collector BJT amplifier has three areas. First, we have to set the Q-point, which is the DC operating point. Since, there is no specification regarding the Q-point in the design requirements; it leaves the designer enough freedom to choose the operating point as necessary for the application. However, remember that the specifications are in terms of input and output impedance, gain, frequency response characteristics and peak output voltages ultimately restricts the Q-point in a narrow window. It is difficult to derive this point without some intelligent guess and the following steps would work out for the given conditions. We will start to choose a Q-point to allow maximum output voltage swing

For the Common Collector configuration, the circuit diagram shown in CC Figure 1. The small signal equivalent model in CC Figure 3.

For this configuration, same steps are involved for the calculation of Rb1, Rb2 and Re with few minor changes. Note that Rc is absent in this case.

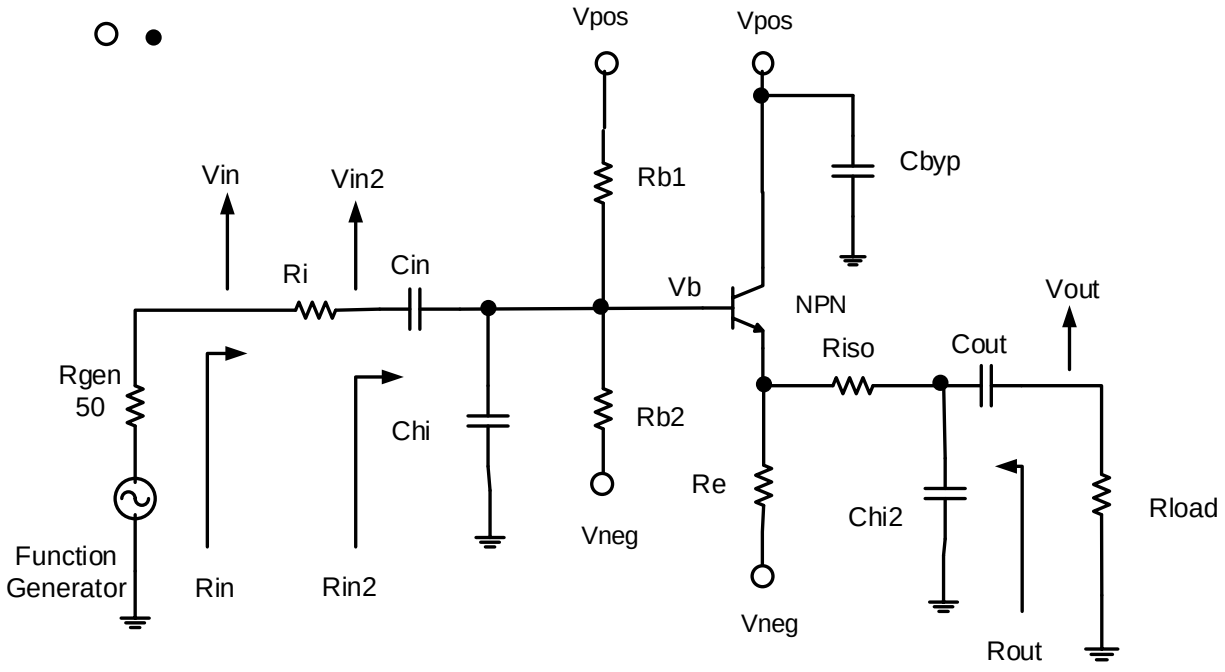

Figure 1: BJT Common Collector CC configuration

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CC Part 1: Measure the device parameters use CC Figure 2

Measure transistor parameters I_{Cest}, $V_{CE}sat$, β_{DC}, β_{DC},V_E, V_{CE}, β_{AC}, β_{DC}, ro, and rπ

Step CC 1.1: Estimate the Ic collector current Q-point use I_C estimate ≈ 2.6 * I_{load} peak this is not the solution to your design Q-point. We can use an estimated I_C because r_o and β will not change very much with small changes in Q-point

Step CC 1.2: The saturated Vce voltage $V_{CE\text{-}sat}$: From the curves CC Fig. 2 estimate $V_{CE}sat$ the point where the curve begins to flattens out ≈ 0.2 Vdc

Step CC 1.3: Calculate the midpoint V_E and V_{CE} : **Step CC 2.1**

Step CC 1.4: Find ro, β_{AC}, β_{DC}, and r_π: Step CEwRef 1.5

ro = $\Delta V_{CE} / \Delta I_C$ the slope of a I_B curve near the Q-point.

$\beta_{AC} = \Delta I_C / \Delta I_B$ measured around Q-point est.

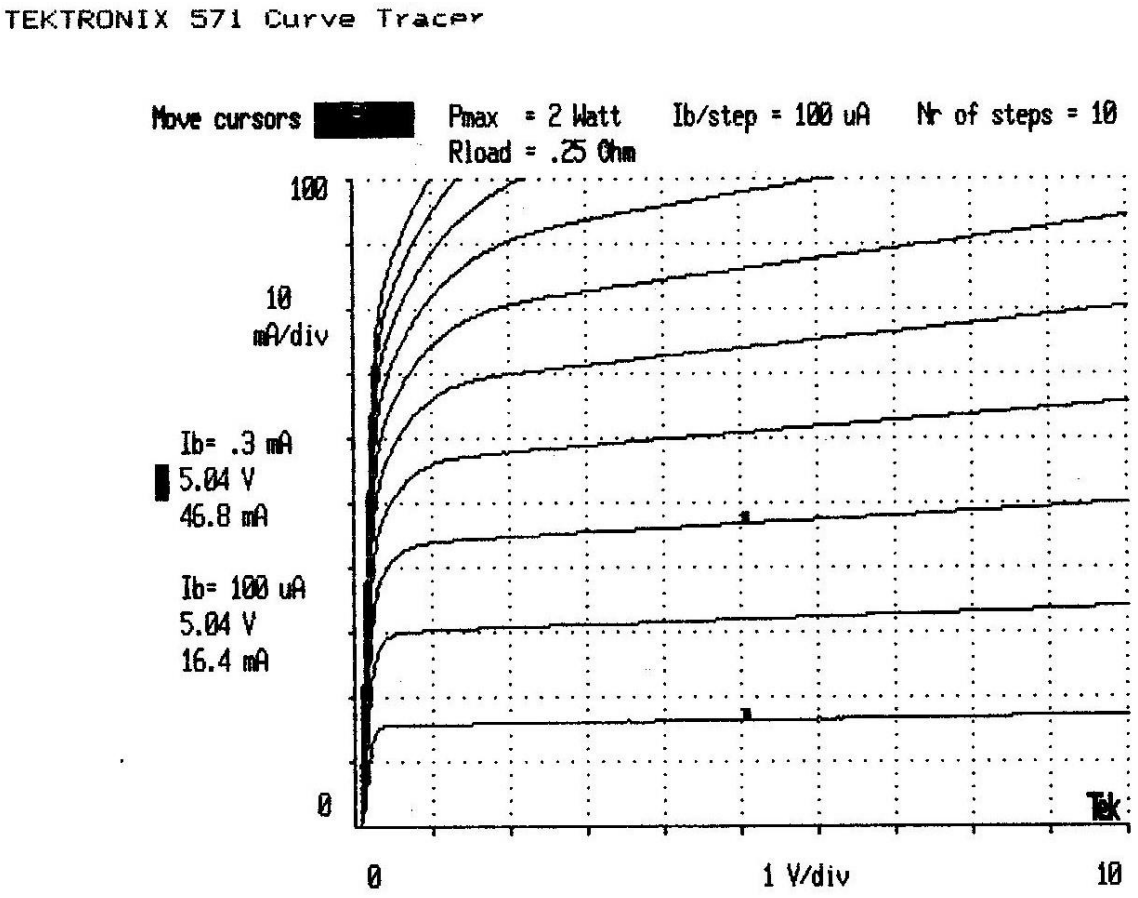
$\beta_{DC} = I_C / I_B$ measured around Q-point est

$r_\pi = (\beta_{DC} V_T) / I_C$ rπ is base to emitter resistance of the Hybrid Pie model.

Where $V_T = kT/q$ at room temperature is $V_T \approx 26mV$.

Plot the estimated Q-point (V_{CE},I_C) on the BJT characteristics curve.

Note: If the equation has Just β the use B_{AC}.



CC Figure 2: CC BJT curve. The first curve is I_B = 100uA

X axis is V_{CE}, Y axis is I_C

To find which I_B curve you are you on count from a known cure (First Ib curve Ib = 5uA) by the step size at the top of the curve label step = 5uA.

ro = ΔV_{CE} / ΔI_C Where V_{CE} is the X Axis. We do not want to start at zero because the first part of the curve is nonlinear we want to use the area where the curve is liner. So chose V_{CE} between 1V to 10V therefore ΔV_{CE} = 10V – 1V = 9V. Where I_C is the Y Axis. We pick an I_B curve close to our estimated or actual Q-Point and measure the current I_C:1at two points along the I_B curve at V_{CE} = 1V the second I_C: 2 current at V_{CE} = 10V $\Delta I_C = I_C{:}2 - I_C{:}1 = 0.3$mA The calculation of ro at the chosen I_B curve **ro = ΔV_{CE} / ΔI_C**

B_{AC} = ΔI_C / ΔI_B at the V_{CE} (from step **CC 1.3)** on the X-Axis find the ΔI_B which is the current I_B between the two I_B cures on both sides of the Q-Point. Where the two I_C the currents associated with the two points on the I_B curves at V_{CE}.

$\beta_{DC} = I_C / I_B$ at the V_{CE} (from step **CC 1.3:)** on the X-Axis find the I_B which is the current I_B form the cures closes to the Q-Point. Where the I_C the currents associated with the point on the I_B curves at V_{CE}.

CC Part 2: Find the Q-point

Step CC2.1: Derive V_E and V_{CE} Q- point

We will start with V_E(max) and V_E(min).

V_{CE}sat = 0.2V

V_{BE} = 0.7Vdc Use the higher value because the Base and Collector current is higher buffer stage.

VoutEmitter = Vout + I_{Load} * Riso The AC output voltage at the emitter.

V_E(max) = Vcc – V_{CE}sat – (VoutEmitter + 20%VoutEmitter)

V_E(min) = Vee + VoutEmitter + 20% VoutEmitter

$V_E = (V_E(max) + V_E(min)) / 2$ Midpoint V_E Q-point

Vc = Vcc

$V_{CE} = V_C - V_E$ The V_{CE} Q-point

Step CC2.2: Now find the value of Re and I_E

The DC equation: $(V_E - Vee) = Re * I_E$
The AC equation: VoutEmitter = i_e (Re || ro || (R_{Load} + Riso))
Rewrite: VoutEmitter = i_e Re (ro || (R_L + Riso))/ (Re + (ro || (R_L + Riso)) Parallel resistance equation
Substituting in $(V_E – Vee) = i_e$ Re
Combined equation: VoutEmitter = $(V_E – Vee)$(ro || (R_{Load} + Riso)) / (Re+ (ro || (R_{Load} + Riso))))

Solve for R_E; Add 20% VoutEmitter t so the collector current is not set to an edge.

$$Re = \frac{V_E - Vee}{V_{outEmitter} + 20\% V_{outEmitter}} (ro \parallel (R_L + Riso)) - (ro \parallel (R_L + Riso))$$ Rearranged combined equation

Calculate I_E, I_C, and rπ
$I_E = (V_E – Vee)/ Re$
$Ic = I_E (\beta_{DC} / (\beta_{DC} + 1))$

rπ = (β_{DC} vt) / I_C rπ is base to emitter resistance Hybrid Pie model.
Where vt = kT/q at room temperature is vt ≈ 26mV.

CC Part 3: Find Rb1, and Rb2. (2 Methods)

Method 1.

(Do not use Method 1 for your design.) Use step CC3.2

Step CC3.1: Calculate Rb1, Rb1. Based on I_B

We will set the current in the base bias resisters Rb1, and Rb2 lower then 10*Ib from the CE amplifier keep the Rin to a higher value.
Irb1 = 3*I_B and Irb2 = 2*I_B Current thru the base bias resistors
$V_B = (V_E) + V_{BE}$ Q - point values
$Rb1 = (Vcc - V_B) / 3\ I_B$
$Rb2 = (V_B - Vee) / 2\ I_B$

Rb = Rb1 || Rb2 Base bias resistors.

Method 2.
(Use this Method)

Step CC3.2: Calculate Rb1, and Rb2 Based on the requested Rin
Require Rin set to a given value. Need Vcc, Vb, rπ, ro, β, Re, Rload, and Ib.
Given Rin calculate Rin2.
$V_B = V_E + V_{BE}$ Q - point values
$I_B = I_C / \beta_{DC}$

Rin2 = Rin –Ri Solve Rin2 needed to Rin requirements.

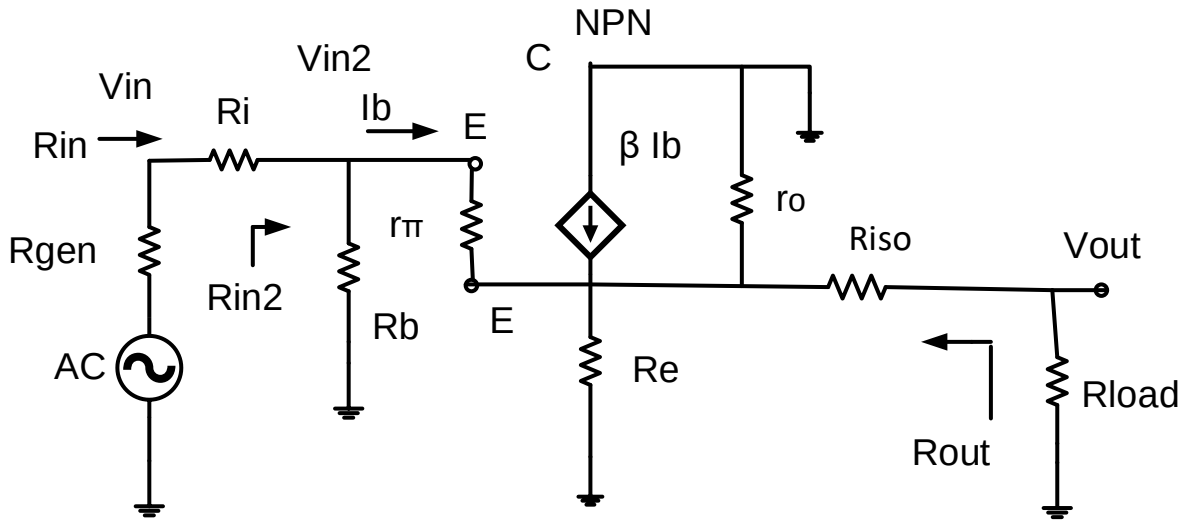
Solve for Rb from Rin2 and Rbase.
Rbase = rπ + (β_{DC} + 1) ((ro || Re || (Riso + Rload))) Impedance looking into BJT base at midband.

Rb = 1 /((1 / Rin2) – (1 / Rbase)) Solve for Rb from Rin2, and Rbase to meet Rin requirements.

Find Rb1 first then Rb2

$Rb1 = (V_{CC} – Vee) / (((V_B – Vee)/ Rb) + I_B)$ Solve for Rb1.

Solve Rb2 from V_B and current thru Rb2: $I_{Rb2} = I_{Rb1} – I_B$
$Rb2 = (V_B – Vee) / (((V_{CC} –V_B) /Rb1) –I_B)$



CC Figure 3: Small signal equivalent model for common collector model

CC Part 4: Calculate Rin, Rout, Av, and Ai

Step CC4.1: Input Impedance:

Rb = Rb1 || Rb2

Rbase = rπ + (β + 1) ((ro || Re || (Riso + Rload))) Impedance looking into BJT base.

Rin2 = Rb || Rbase

Rin = Rin2 + Ri Note: Ri is the resistor in the input used as a shunt to measure input current.

Step CC4.2: Output Impedance

RemitterBase is the impedance looking in the BJT emitter towards the base.

RemitterBase = (rπ + Rb || (Ri + Rgen)) / (β + 1)

Rout = (Re|| ro || RemitterBase) + Riso

The CC amplifier is known as a **Buffer Amplifier** because lower output impedance.

Step CC4.3: Derivation of Av Voltage Gain

Av is positive: Vout is not inverted.

Referring to CC Fig.3, let us find Av = Vout / Vin which would be a key step in calculating Av.

Rbase = rπ + (β + 1) ((ro || R_E || (Riso + Rload))) Impedance looking into BJT base.
Rb = Rb1 || Rb2
Rin2 = Rb || Rbase
Rin = Ri + Rin2
RemitterBase = (rπ + Rb || (Ri + Rgen)) / (β + 1) Impedance looking into the BJT emitter towards the Base.
Rout = (Re || ro || RemitterBase) + Riso
AC Voltage at the emitter.
AC voltage VoutEmitter = ie (Re || ro || (Riso + Rload))
AC voltage VoutEmitter = (β + 1) ib (Re || ro || (Riso + Rload))
Voltage across the load resistor Vout = VoutEmitter * (Rload / (Rload +Riso))
AC voltage Vout = (β + 1) i_b (Re|| ro || (Riso + Rload)) * (Rload / (Rload +Riso))
AC Voltage at the function generator Vin = Vin2 (Rin / Rin2)
AC Voltage at the base Vin2 = V_{BE} + VoutEmitter
Vin2 = rπ i_b + i_b (β +1) (Re || ro || (Rload + Riso)) = i_b (rπ + (β+1) (Rs || ro || (Rload +Riso)))
Av2 = Vout / Vin2 = (β+ 1) i_b (Re || ro || (Rload + Riso)) / i_b (rπ + (β+1) (Re || ro || (Rload + Riso)))
Vin = Vin2 (Rin / Rin2) Voltage divider Vin to Vin2
Need Vout to find Av.

Vout = VoutEmitter * (Rload / (Rload +Riso)) Voltage divider VoutEmitter to Vout
Or rewriting VoutEmitter = Vout * ((Rload +Riso) / Rload) Find VoutEmitter from Vout.

Av = Vout / Vin = (Rin2 / Rin) (Rload /(Rload + Riso)) (β+ 1) i_b (Re || ro || (Rload + Riso)) / i_b (rπ + (β+1) (Re || ro || (Rload + Riso)))
Canceling out i_b and including the factor for Vin2 to Vin gives

This is the final equation for Av = Vout / Vin Av is positive: Vout is not inverted

Calculation of the Av.

Av = (Rin2 / Rin) (Rload /(Rload + Riso)) (β + 1) (R_E ‖ ro ‖ (Rload + Riso)) / (rπ + (β+1) (Re ‖ ro ‖ (Rload + Riso)))

Thus, the voltage gain should be close to 1. Hence, the output follows the input. So, the Common Collector configuration is also known as an Emitter follower.

Step CC4.4: Calculation of the Ai Current Gain

$$\text{Ai} = \frac{Iload}{Iin} = \frac{Vout/_{Rload}}{Vin/_{Rin}} = \text{Av}\frac{\text{Rin}}{\text{Rload}}$$

Step CC4.5: Power gain

G = Pout / Pin = Vout * Iload / Vin * Iin = Av * Ai
In decibels G_{dB} = 10log (Av * Ai)

Step CC4.6: Vin and Voc of Vgen
Input signal level need to produce the required output voltage.
Vin = Vout / Av

The **open circuit voltage** of the generator to produce the required output voltage.
Because of Voltage divider because the output impedance of the Rgen = 50Ω

Vgen = Vin (Rgen + Rin) / Rin

Use this value in LTspice and the laboratory Function generator.

CC Part 5: Frequency response.

The capacitor values can be calculated as before (CE amp), the only difference being *n* = 2 for low pass calculations since we are using two capacitors instead of 3.
With the Q-point being set after the sequence of steps, we can go for the selection of capacitors and finally connect the signal generator at input and measure the output amplified waveform.

Step CC5.1: Low frequency cut off. F_L

First we will select C_{in}, and C_{out} which jointly would set the roll-off beyond the lower cut-off frequency. Set any frequency within the range as your lower cut-off frequency and let us call it f_L. Two capacitors will introduce 2 zeros in the transfer function of the system. Because we will set 2 pole at the same frequency we must use the Band Width Shrinkage factor.

$$\text{BWshrinkage} = \sqrt{2^{\frac{1}{n}} - 1} \quad \text{n = 2}$$

Where n is the number of zeros for low frequency breakpoints at same frequency.
Setting 2 frequencies equal, we will, multiply the F_L by the Band Width Shrinkage factor

Set each break point to $F_{Cin} = F_{Cout} = F_L \sqrt{2^{1/2} - 1}$

Find the C for each breakpoint f_{Cin}, and f_{Cout}, where n = 2.

$$C = \frac{1}{2\pi f_C\ (\text{R seen by C})}$$

Where C is the capacitor that sets the breakpoint f_{Cin}, and f_{Cout}

R is the Thevenin equivalent resistance seen by the capacitor.

Step CC 5.2: High frequency cut off. F_H

Chi, and Chi2 on the contrary, sets the high cut-off frequency f_H which is to be set from the specified range. Where n = 2 the number of high frequency break points at the same frequency.

In this case because Chi, and Ch2 are set to the same break point. We must use the band shrinkage factor with n = 2. We need only to find a two poles at F_h / bandshrinage = $f_{chi} = f_{ch2}$ to set the high frequency cutoff.

Setting the 2 high frequencies break point equal, we will, divide the Fh (high frequency cutoff desired) by the Band Width Shrinkage factor

Set each break point to Fchi = Fchi2 = Fh / $\sqrt{2^{1/2} - 1}$

Rbase = rπ + ((β + 1) * (ro || Re || (Rload + Riso))) Impedance looking into BJT base.

Rb = Rb1 || Rb2

Rin2 = Rb || Rbase

R seen by C_{hi} R_{Chi} = (Rgen + Ri) || Rin2

$$C_{hi} = \frac{1}{2\pi f_{Chi}\ (\text{R seen by } C_{hi})}$$

R seen by C_{hi2} R_{Chi2} = Rout || Rload

$$C_{hi2} = \frac{1}{2\pi f_{Chi2}\ (\text{R seen by } C_{hi2})}$$

The following table enlists the particular expressions.

Thevenin equivalent resistance seen by the capacitor.

Rsig	Rgen+Ri
C_{in}	Rsig + Rin2
Cout	R_{Load} + Rout
Chi	Rsig || Rin2
Chi2	Rout || Rload

CC Table 1: Resistance Seen By Capacitors