Common Emitter with Re that is partially is bypassed by Ce.

Richard Cooper

Vout is inverted so the gain Av and Ai are negative.

R_E = Ref + Reb the total R_E for the DC bias design.

Ref is the portion of Re that is not bypassed by Ce.

Reb is the portion of Re that is bypassed by Ce.

The first step is to find the Transistor characteristics around d the estimated Q-point

1. Choose Ve: Step CEwRef 1.1
2. Estimate the Ic collector current Qpoint: Step CEwRef 1.2: Choose Ic est, only used the VI curves.
3. The saturated Vce voltage $V_{CE\text{-}sat}$: Step CEwRef 1.3:
4. Calculate the midpoint V_C: Step CEwRef 1.4:
5. Find ro, β_{AC}, Vce_{SAT}, and r_π: Step CEwRef 1.5

ro = $\Delta V_{CE} / \Delta I_C$ the slope of a line thru 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

Vce_{SAT} = Vce begins to flatten.

$r\pi = (\beta V_T) / I_C$ r_π is base to emitter resistance of the Hybrid Pie model.

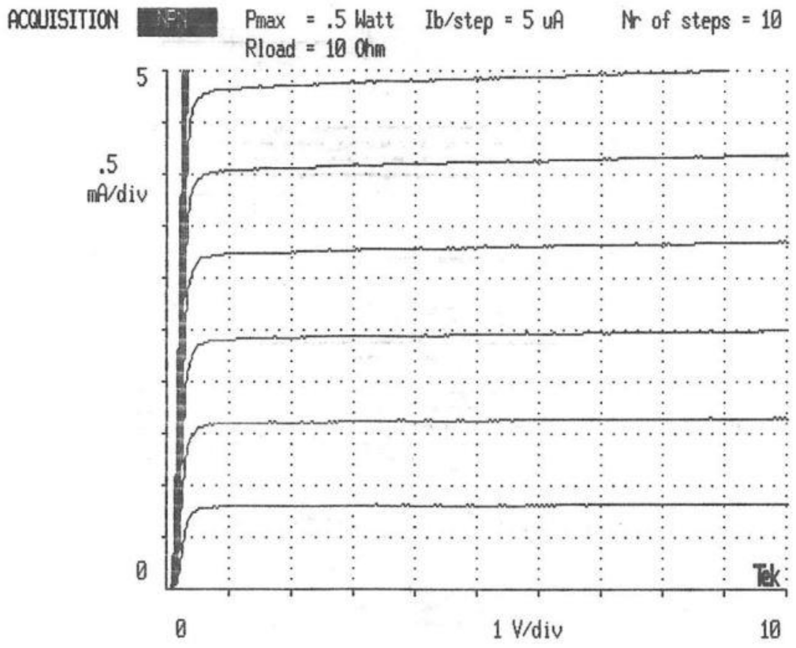
Where $V_{T =}$ kT/q at room temperature is $V_T \approx$ 26mV.

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}.

Skip to CEwRef Part 2: if you are given are Vce_{SAT}, r_o , r_π and β.

CEwRef Part 1: Measure the device parameters Vce_{SAT}, r_o , r_π and β from the VI curves of the transistor (BJT).



Characteristics Curve 2N3904 First Ib curve Ib = 5uA

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

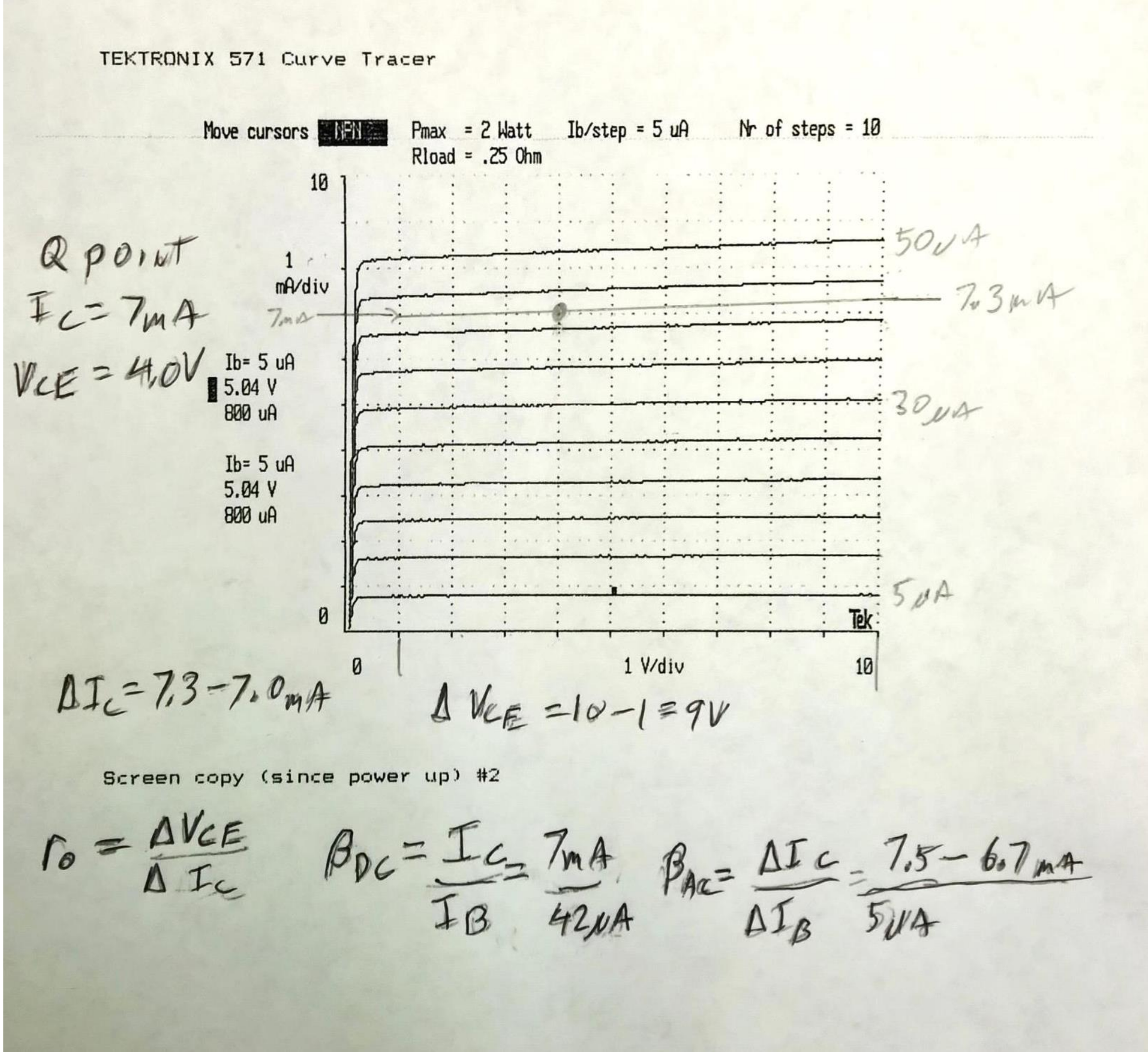
To find which I_B curve you are you on count from a known cure (First Ib curve Ib = 5uA) by the step size at the top of the curve label step = 5uA.

ro = $\Delta V_{CE} / \Delta I_C$ 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 = 10V ΔV_{CE} = 10V – 1V = 9V. Where I_C is the Y Axis. We pick an I_B curve close to out estimated or actual Q-Point and measure the current I_C at two points along the I_B curve at V_{CE} = 1V the second I_C current at V_{CE} = 10V ΔI_C = 7.3mA – 7.0mA = 0.3mA The calculation of ro at the chosen I_B curve **ro = $\Delta V_{CE} / \Delta I_C$ = 9V / 0.3mA = 30kΩ.**

$B_{AC} = \Delta I_C / \Delta I_B$ at the V_{CE} (from step **CEwRef 2.2:)** 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 2 I_C the currents associated with the 2 points on the I_B curves at V_{CE}.

$\beta_{DC} = I_C / I_B$ at the V_{CE} (from step **CEwRef 2.2:)** 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}.

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



TEKTRONIX 571 Curve Tracer

Move cursors NPN Pmax = 2 Watt Ib/step = 5 uA Nr of steps = 10
Rload = .25 Ohm

Ib= 5 uA
5.04 V
800 uA

Ib= 5 uA
5.04 V
800 uA

Screen copy (since power up) #2

Q point
$I_C = 7mA$
$V_{CE} = 4.0V$

$\Delta I_C = 7.3 - 7.0 mA$

$\Delta V_{CE} = 10 - 1 = 9V$

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \qquad \beta_{DC} = \frac{I_C}{I_B} = \frac{7mA}{42\mu A} \qquad \beta_{AC} = \frac{\Delta I_C}{\Delta I_B} = \frac{7.5 - 6.7 mA}{5\mu A}$$

Characteristics Curve for 2N2222

Sample calculation not your solution.

For the design of the amplifier, the 4 parameter values required are Vce_{SAT}, r_o , r_π and β. Derived from the transistor characteristics curve shown in BJT above, one can set an approximate Q-point (V_{CE} and I_C) in the active region and measure ro and β. We will solve for V_{ce} and estimate I_C.

Step CEwRef 1.1: Choose V_{Re} Same as Step CEwRef 2.1

Because V_{BE} will decrease ≈ 2.5mV / ˚ C rise we set V_E = between 2V to 3V. V_E and R_E will provide negative feedback to stabilize β and V_{BE}.

Step CEwRef 1.2: Choose Ic estimate.

For an approximate I_C Q-point use $I_C \approx 3.0^* I_{load}$ peak this is not the solution to your design Ic Q-point. We can use an approximate I_C because ro and β will not change very much with small changes in Q-point.

Step CEwRef 1.3: Vce_{SAT} (Vce saturation voltage)

The Vce_{SAT} (Vce saturation voltage) are found from the BJT characteristics curve where the curve begins to flatten out ≈ 0.2 Vdc.

Step CEwRef 1.4: Calculate the midpoint V_C

Re partially bypassed Re = Reb + Ref

Same as **Step CEwRef 2.2**

Midpoint selection will allow for maximum output voltage swing.

We will add 20% to Vout so the design is not on the edge of the solution. This will also help with the additional loading because of high frequency capacitors as the frequency approaches the high frequency break points.

$V_{C(max)} = V_{CC}$ - (Vout + 20%Vout)

$V_{C(min)} = V_E + V_{CE}$ sat + (Vout + 20%Vout)

$V_C = (V_{C(max)} + V_{C(min)}) / 2$ Midpoint V_C Q-point

$V_{CE} = V_C - V_E$ This is the Q-point V_{CE}

$V_E = V_{Re}$ - Vee

Step CEwRef 1.5 find ro, β_{AC}, Vce_{SAT}, and rπ.

ro = $\Delta V_{CE} / \Delta I_C$ the slope of a line thru Q-point collector to emitter resistance of Hybrid Pie model.

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

Vce_{SAT} = the Vce where the VI curve begins to flatten.

rπ = $(\beta V_T) / I_C$ rπ is base to emitter resistance of 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.

CEwRef Part 2: selecting Rc, RE = Ref +Reb , I_C and I_E.

Using BJT parameters and Vcc, Vout, and Rload, Rin

Step CEwRef 2.1: Choose V_{Re}

Because V_{BE} will decrease ≈ 2.5mV / ˚ C rise we set V_{Re} = between 2V to 3V. V_{Re} and R_E will provide negative feedback to stabilize β and V_{BE}.

Step CEwRef 2.2: Calculate the midpoint V_C

Re partially bypassed Re = Reb + Ref

Midpoint selection will allow for maximum output voltage swing.

We will add 20% to Vout so the design is not on the edge of the solution. This will also help with the additional loading because of high frequency capacitors as the frequency approaches the high frequency break points.

$V_{C(max)} = V_{CC} - (Vout + 20\%Vout)$

$V_{C(min)} = V_E + V_{CE}\text{ sat} + (Vout + 20\%Vout)$

$V_C = (V_{C(max)} + V_{C(min)}) / 2$ Midpoint V_C Q-point

$V_{CE} = V_C - V_E$ This is the Q-point V_{CE}

Step CEwRef 2.3: Calculate R_C .

Looking into the collector we see r_o + Ref || [(r_π + Rb1|| Rb2 || (Ri +Rgen)] / (β +1) ≈ r_o so we will use just r_o .

The DC equation: $V_{RC} = V_{CC} - V_C = I_C$ Rc voltage across Rc derived from Vcc and Q-point Vc.

The AC equation: $Vout_P = i_c$ (Rc || ro || R_L) output voltage $Vout_{peak}$

Rewrite AC: Vout = I_C Rc (ro || R_L) / (Rc + (ro || R_L)) Parallel resistance equation

Substituting in $V_{RC} = I_C R_C$

Combined equation: Vout = V_{RC} (ro || R_L) / (Rc + (ro || R_L))

Solve for Rc; Add 20%Vout so the collector current is not set to an edge.

$$\text{Rc} = \frac{V_{CC} - V_C}{V_{out} + 20\%Vout}\,(\text{ro} \parallel R_L) - (\text{ro} \parallel R_L)$$

Step CEwRef 2.4: Calculate I_C, I_E, and Re.

These are not the estimate values from Part 1

$I_C = (V_{CC} - V_C) / Rc$ The Q-point collector current.

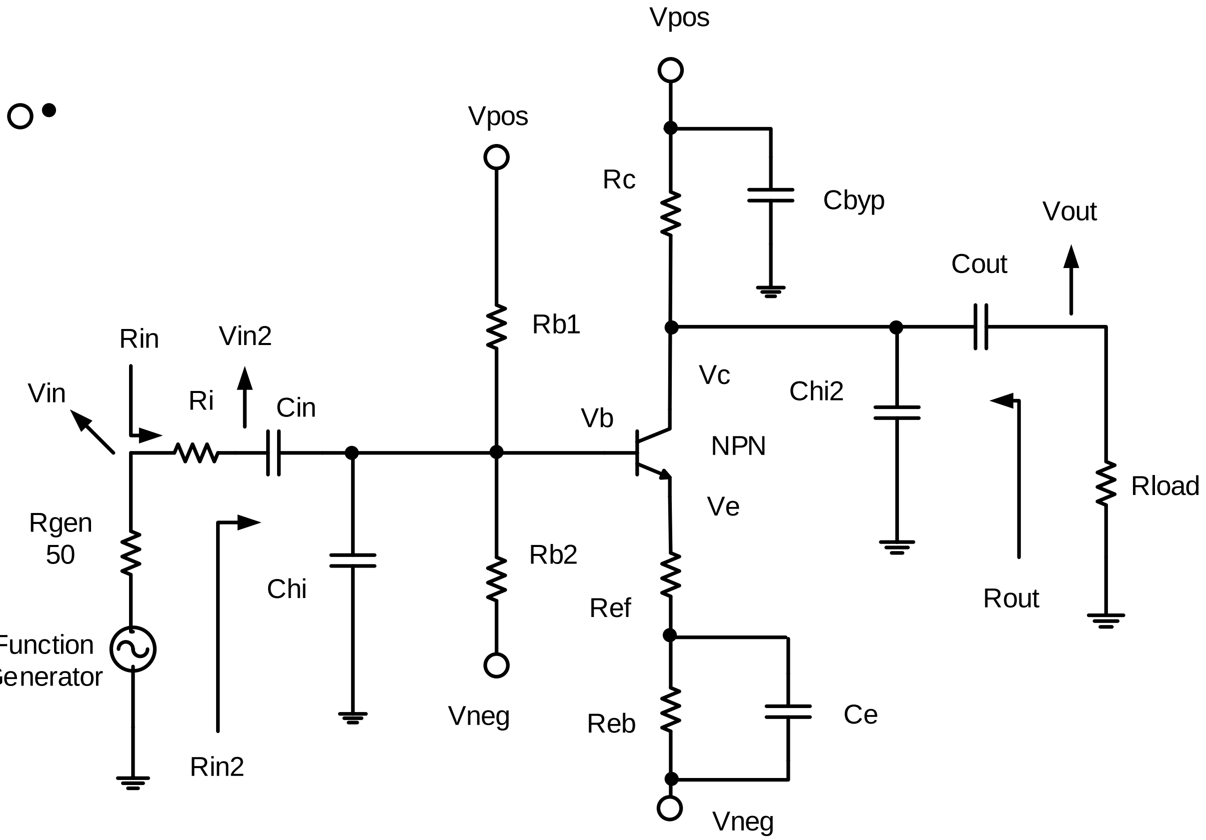
$I_B = I_C / \beta_{DC}$ The base current.

$I_E = I_C (\beta_{DC} + 1) / \beta_{DC}$ emitter current.

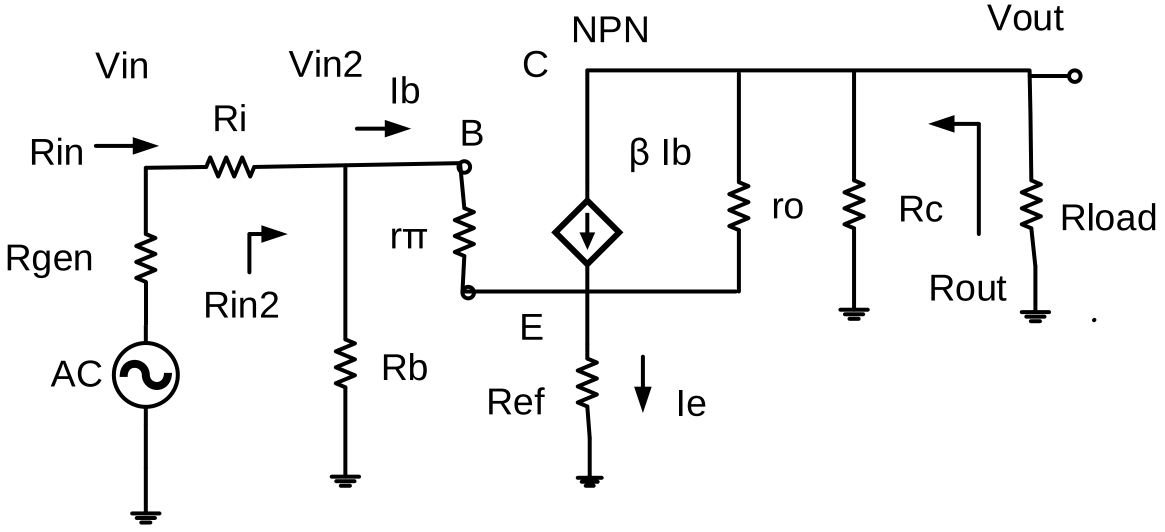
$Re = V_{Re} / I_E = (Ve + Vee) / I_E$ Total emitter resistance.

Thus, Q-point is (V_{CE}, I_C).

We now have, V_E, V_C, Rc, Re, I_C, I_E, V_{CE}, V_{CEsat}



CEwRef Figure 1: Amplifier with emitter partially bypassed.



CEwRef Figure 2: Small signal model with partial bypass of Re

CEwRef Part 3 Calculating impedance and Gain with Ref use Figure 2.

Remember the gain Av and Ai are negative for a common emitter amplifier.

We use the same Q-point and bias resistors Rb1, Rb2, Rc, and Re = Ref + Reb.

Step CEwRef 3.1: Find Ref based on Voltage Gain requested

Note: i_b is the AC base current that results from Vin.
Looking into the collector we see ro + Ref || [(rπ + Rb1|| Rb2 || (Ri +Rgen)] / (β +1)

Because the term (((Ri +Rgen) || Rb)+ rπ)/ (β +1) is small and it is in parallel with Ref at the emitter therefore we will use ro for the approximation.

AC voltage Vout = - β i_b (Rc || Rload || ro) Note: use the approximant ro because Ref is not known yet.
We do not need to solve for the AC signal i_b because it will be cancelled out later.

AC voltage Vin = (Rin/Rin2) Vin2 Input signal from the function generator.
AC voltage Vin2 = i_b (rπ + (β + 1) Ref) Input signal on the base
Given Rin calculate Rin2.
Rin2 = Rin – Ri Solve Rin2 needed to meet the Rin requirements.
Av2 = Av * Rin / Rin2 Av2 at base is the gain needed to meet Av requested. For CE Av is negative.
Av2 = Vout / Vin2 = -β (Rc || ro || Rload) / (r_π + (β + 1) Ref) voltage gain at base, we do not need to find i_b since i_b cancels. Av2 is negative which means that Vout is inverted.

Step CEwRef 3.2: Solve for Ref by using gain at base Av2.

Ref = [(- β (Rc || ro || Rload) / Av2) - rπ] / (β + 1) from Av2 or use equation below

Step CEwRef 3.3: Solve for Ref by using overall gain Av.

Av = Av2 * Rin2 / Rin
Av = Vout / Vin = - β (Rc || ro || Rload) / (Rin/Rin2) (rπ + (β + 1) Ref) voltage gain at input

We can see that voltage gain Av can be controlled by the value of Ref
Av = - β (Rin2/Rin) (Rc || ro || Rload) / (rπ + (β + 1) Ref)
Rearrange Av to solve for Ref from requested Av. Where Av is overall gain,

Ref = {[-β (Rin2/Rin) (Rc|| ro || Rload) / Av] - rπ} / (β + 1)

Remember Av is negative
Step CEwRef 3.4: Solve for Reb from Re and Ref
Remember that Re is the total emitter residence from step CEwRef 2.4.
Reb = Re – Ref

CEwRef Part 4: Find Rb1, Rb2, Rin, Rout, Ai, Power Gain G, Vin, and Voc of function generator.

Step CEwRef 4.1: Find Rb1 and Rb2 based on requested Rin

Require Rin set to a given value. Need Vcc, Vb, rπ and I_B (DC bias base current).
Given Rin calculate Rin2.

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

Solve for Rb from Rin2 and Rbase.

Rbase = rπ + (β_{DC} + 1) (Ref || (ro + Rc || Rload)) Looking into the Base of the BJT.

Rb = 1 /((1 / Rin2) – (1 / Rbase)) Solve for Rb needed to Rin requirements.

Find Rb1 first then Rb2
$I_B = I_C / \beta_{DC}$ DC bias base current.
Rb1 = (Vcc –Vee) / (((Vb – Vee) / Rb) + I_B) Solve for Rb1.
I_{Rb1} = Vcc-V_B / Rb1 Current thru Rb1
$I_{Rb2} = I_{Rb1} - I_B$ Current thru Rb2. Solve Rb2 from V_B -Vee and current thru Rb2:

Rb2 = (V_B – Vee)/ I_{Rb2} = V_B / (((Vcc –V_B) /Rb1) – I_B)

Step CEwRef 4.2: Input Impedance: AC characteristics

Rb = Rb1 || Rb2
Where Ref is the part of Re that is not bypassed by $C_{E.}$
Rbase = rπ + (β + 1) (Ref || (ro + Rc || Rload)) Looking into the Base of the BJT.
Rin2 = Rb || Rbase
Rin = Ri + Rin2

Step CEwRef 4.3: Output Impedance Rout with Ref

If Re partially bypassed with C_E bypassing Ref.

Rb = Rb1 || Rb2.

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

RemitterBase = (rπ + Rb || (Ri + Rgen)) / (β + 1)   Small value, because divided by β +1.

The complete equation below for Rout,

Rout = R_C || (ro + Ref || [rπ + Rb || (Ri + Rgen)] / (β +1))

Because ro is greater than 30kΩ.

You text book may approximate Rout = Rc || “large” = Rc.

Step CEwRef 4.4: Current Gain Ai

The current gain Ai can be obtained i_{load} and i_{in} or calculated from Av Rin and Rload.

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

Step CEwRef 4.5: Power gain G

G = Pout / Pin = Vout * Iload / Vin * Iin = Av * Ai

In decibels G_{dB} = 10log (Av * Ai)

Step CEwRef 4.6: 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 the Voltage divider between Vgen and Vin. The output impedance of the function generator is Rgen = 50Ω and the input impedance Rin of the amplifier. Voc is the setting of the voltage set on the function generator.

Voc of Vgen = Vin (Rgen + Rin) / Rin   Vgen is larger than Vin

Use this value in LTspice and the laboratory Function generator for output of signal source.

CEwRef Part 5: Frequency response with Ref

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 waveform.

Step CEwRef 5.1: Low frequency cut off. F_L

First we will select C_{in}, C_{out} and C_E 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. Three capacitors will introduce 3 zeros in the transfer function of the system. Because we will set 3 zeros at the same frequency we must use the Band Width Shrinkage factor.

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

Where n is the number of zeros for low frequency breakpoints at same frequency.

The low frequency cutoff average of the individual time constants with shrinkage faction apllided be we have set all the time constants the same.

$$f_L = \frac{f_{C_{in}} + f_{C_{out}} + f_{C_E}}{3\sqrt{2^{\frac{1}{3}} - 1}}$$

Setting 3 frequencies equal, we get,

$f_{Cin} = f_{Cout} = f_{CE} = f_L \sqrt{2^{1/3} - 1}$

Find the C for each breakpoint f_{Cin} , f_{Cout} , and f_{CE} where n = 3.

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

Where C is the capacitor that sets the breakpoint f_C

R is the Thevenin equivalent resistance seen by the capacitor.

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

RemitterbBase = (rπ + Rb || (Ri + Rgen)) / (β + 1)   Small value

R_{CE} = Reb || (Ref + (ro + R_C || R_{Load}) || RemitterBase)

Step CEwRef 5.2: High frequency cut off. F_H

C_{hi} Sets the higher cut-off frequency f_H which is to be set from the specified range.

In this case because Chi, and Ch2 are 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.

Set Fchi = Fchi2 = Fh / $\sqrt{2^{1/2} - 1}$

Rb = Rb1 || Rb2 Base bias resistors

Rbase = rπ + (β + 1) (Ref || (ro + Rc || Rload)) Looking into the Base of the BJT.

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 Note: use the correct Rout depending on Ref

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

The following table list the equivalent resistance expressions seen by the capacitors.

Capacitor	Resistance seen by Capacitor
RemitterBase	(rπ + Rb || (Ri + Rgen)) / (β + 1)
C_{in}	Rgen+Ri + Rin2
Cout	RLoad + Rout
C_E	Reb || (Ref + (ro + R_C || R_{Load}) || RemitterBase)
C_{hi}	(Rgen+Ri) || Rin2
C_{hi2}	Rout || Rload

CEwRef Table 1: Resistance Seen By Capacitors