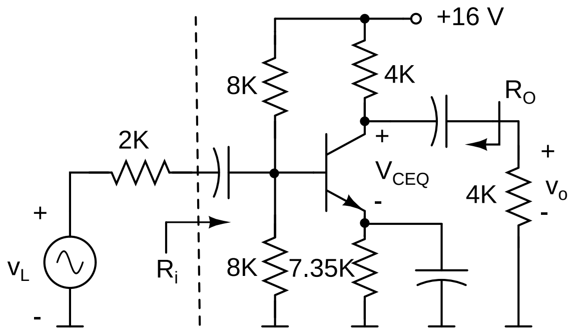
ANALOG CIRCUITS : PROBLEM SET 4a

shanthi@ee.iitm.ac.in

Problem 1

For the transistor shown $\frac{\eta kT}{q} = 40\,\text{mV}$, $\beta = 99$, $V_{BE} = 0.65\,\text{V}$ nominal. Find V_{CEQ}, R_i, R_O, A_v and the incremental power gain. Assume $v_L = (1\,\text{mV})\sin\omega t$.

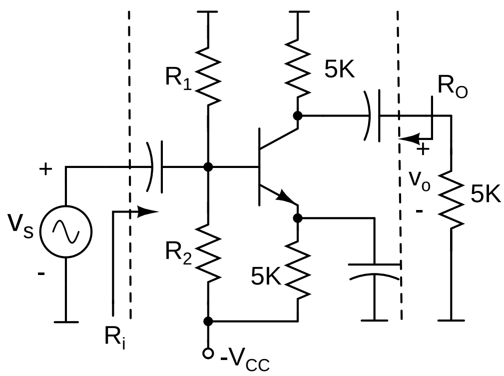


ANSWERS:

$V_{CEQ} = 4.65\,\text{V}, R_i = 2\,\text{K}, R_o = 4\,\text{K}, A_v = -24.75, \text{Power gain} = 1225.125$

Problem 2

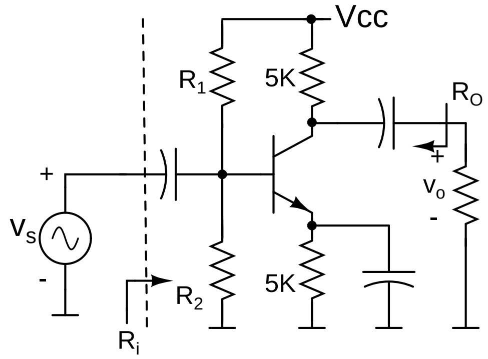
In the circuit shown, use $\alpha = 0.995$, $V_T = 25\,\text{mV}$. V_{CEQ} must be $5\,\text{V}$ and R_i - the resistance presented by the circuit to the driving region v_s must be $1.5\,\text{K}$. Use $V_{BE} = 0.7\,\text{V}$ nominally. Calculate V_{CC}, R_1 & R_2 to get a small signal gain of -200.



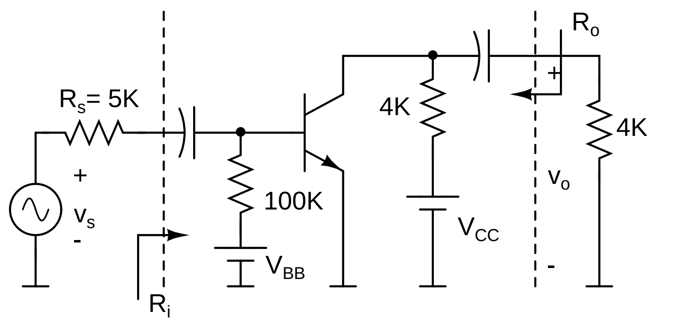
ANSWERS :

$V_{CC} = 25.101\,\text{V}, \text{R}_1 = 8.822\,\text{K}, \text{R}_2 = 6.609\,\text{K}$

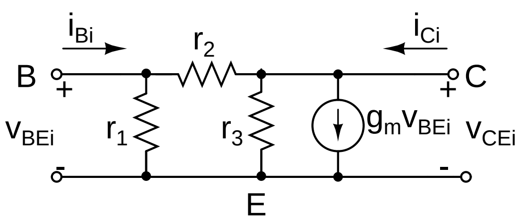
How would the answers be affected for the following circuit



Problem 3



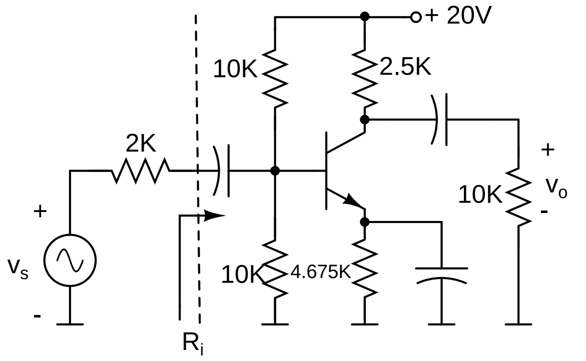
The input signal is small. A more comprehensive linear small-signal incremental equivalent circuit for the transistor is given in the form show below, where r_1, r_2, r_3, g_m are $4\,\text{K}\Omega$, $8\,\text{M}\Omega$, $100\,\text{K}\Omega$ & $50\,\text{mS}$. Calculate R_i, R_o and $\frac{v_o}{v_s}$.



ANSWERS :

$R_i = 3.671\,\text{K}, R_o = 3.654\,\text{K}, \frac{v_o}{v_s} = -41.499$

Problem 4



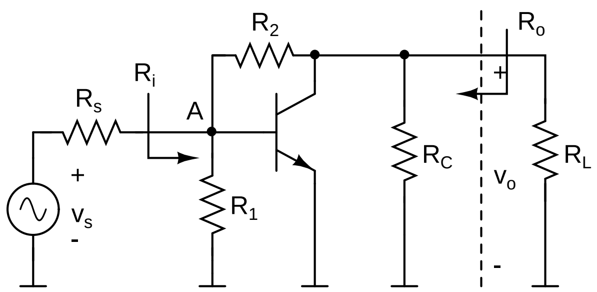
The applied signal is very small. Calculate R_i and $\frac{v_o}{v_s}$ using the approximate equivalent circuit for the transistor. V_T and β are 30 mV and 199 respectively.

ANSWERS :

$R_i = 1.875\,\text{K}, \frac{v_o}{v_s} = -64.194$

Problem 5

The signal picture of a CE amplifier is as shown.



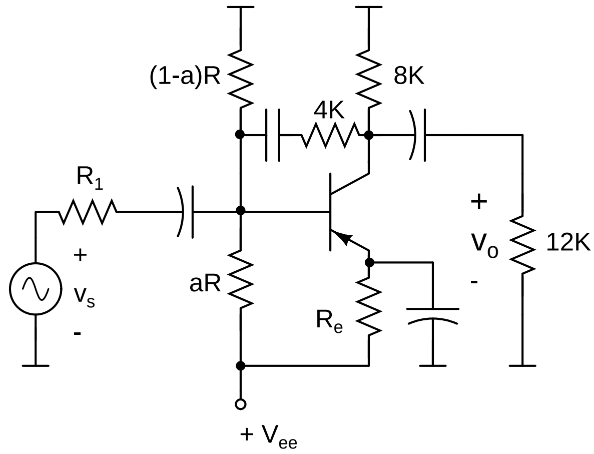
Find R_i, R_o and $\frac{v_o}{v_s}$ in terms of g_m, β and r_o. Find their limits when $\beta \to \infty$. The signal is small.

Problem 6

Assume in the figure shown that g_m is high enough to make the incremental voltage gain $\frac{v_o}{v_s}$ independent of the device. Assume all capacitors are large. Also assume that $aR \| (1-a)R \ll (1+\beta)R$. Take V_{EB} = 0.7 normally; $I_{EQ}R_e$ = 4.3V.

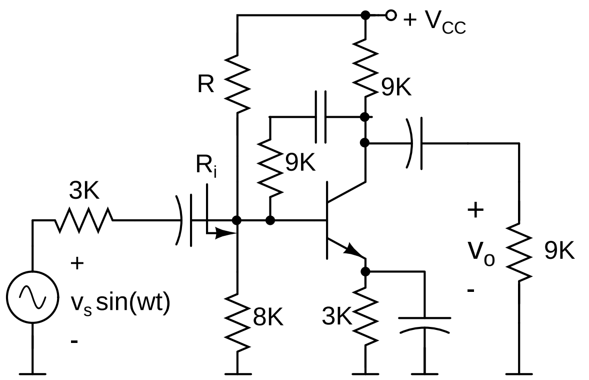
A gain of -4 is needed with the circuit being just capable of handling a maximum amplitude of 2V for the input sinusoid v_s. V_{ee} should be minimum possible for the specified $I_{EQ}R_E$. Calculate R_1, R_e , V_{ee} and a.

Next remove the external load of 12K. What will the limiting swings possible for v_o on either side now ? To what maximum amplitude will you have to restrict v_s if v_o is to be a full undistorted sine wave ?



Problem 7

The input sine wave has $v_s = 2.5\,\text{V}$. To get an undistorted output within swing limits, calculate V_{CC} and R. Take V_{BE} nominal = 0.65V. Also calculate R_i for small signals given that $\beta = 100$ and V_T = 25 mV.

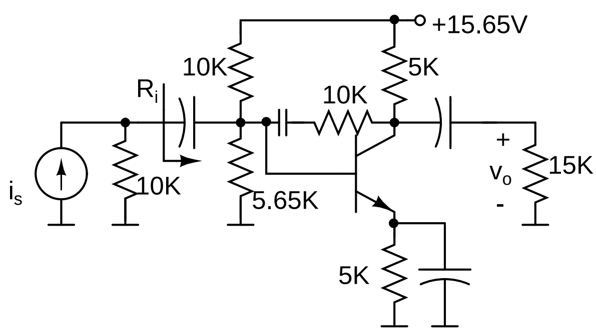


ANSWERS :

$V_{CC} = 38.15\,\text{V}, \text{R} = 29.448\,\text{K}, \text{R}_\text{i} = 29.5\,\Omega$

Problem 8

V_{BE} = 0.65 V nominally. V_T = 25 mV. For small signals, find R_i and $\frac{v_o}{i_s}$. Assume β = 250.

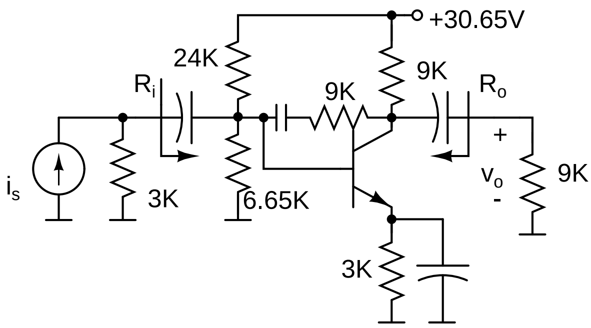


ANSWERS :

$R_i = 87.914\,\Omega, \frac{v_o}{i_s} = -9445.43\,\Omega$

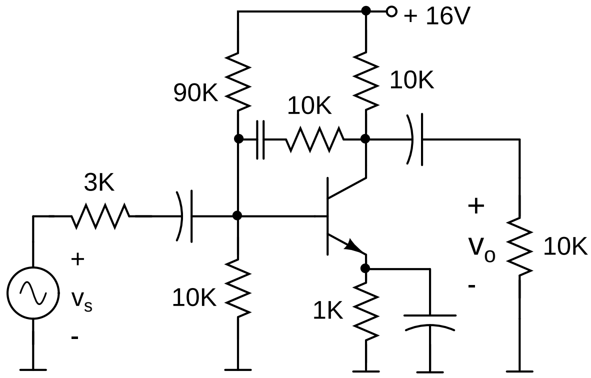
Problem 9

Assuming the signal to be very small calculate R_i, R_o and exact value of $\frac{v_o}{i_s}$. $\beta = 200$ and $r_o = 50\,\mathrm{K}$.

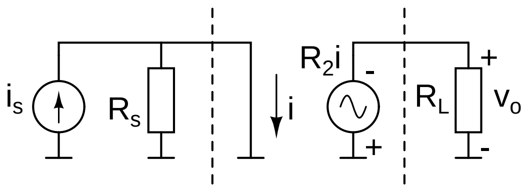


Problem 10

Take $V_T = 25\,\mathrm{mV}$, $\beta = 99$ and $V_{BE} = 0.6$ nominally. Determine $\frac{v_o}{v_s}$, R_i, R_o and the output swing limits.



This configuration acts like a current controlled voltage source (low input and output impedance) when $g_m \to \infty$.

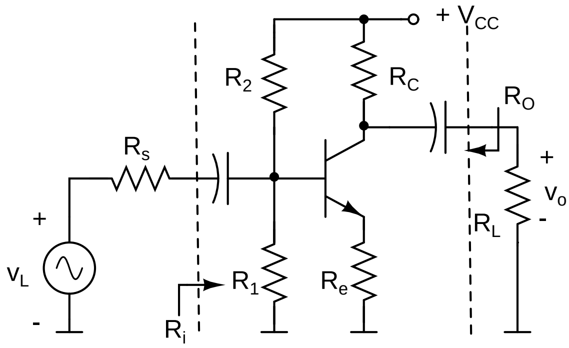


Answers:

$v_{omax} = 4.4\,\mathrm{V}, v_{omin} = -3.333\,\mathrm{V}, R_i = 72.581\Omega, R_o = 377.113\Omega$

Problem 11

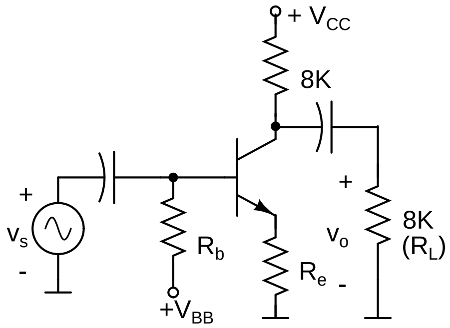
Yet another configuration of a CE amplifier is a shown.



Calculate for small signals R_i, R_o and v_o/v_s. (This is just circuit analysis). Give the limits for R_i, R_o and the conditions to be atisfied to make gain independent of the device. When $g_m \to \infty$, what type of a controlled source does the amplifier act like ?

Problem 12

The capacitances are very large. v_o, the output sinusoid, is to be linked with the input sinusoid by a device independent gain factor of 2, with a limiting amplitude of 8 V before clipping sets in. v_o should just begin to distort at both the extremes.



Find V_{CC}, V_{BB} and R_e. V_{BE} is 0.7 V, nominally. Given that $R_b \ll (\beta_{DC} + 1)R_e$, comment on the stability of the transistor operating point - that is, compute the change in emitter current when the nominal V_{BE} changes by $\pm 0.1\,\mathrm{V}$ due to device variability and/or ambient temperature.

Now let $R_L \to \infty$. What are the limiting swings now possible for v_o on the either side? To what value will you restrict the amplitude of v_s to get an undistorted sinusoidal output?

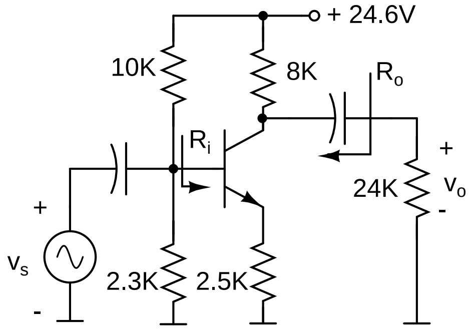
ANSWERS :

V_{CC} = 32.7 V ; V_{BB} = 4.7 V ; R_e = 2 K. when $R_L \to \infty$: v_{omax} = 16 V, v_{omin}=-9.6 V, v_{smax}=2.4 V

Problem 13

Take V_{BE} = 0.6 V nominally. Use the approximate equivalent circuit with $\frac{\eta kT}{q}$ = 24 mV and $\alpha = 0.99$. Calculate R_i

and R_o for small signals.



In the large signal case, if v_o is to be free of distortion determine the maximum possible positive and negative value of the input waveform.

ANSWERS :

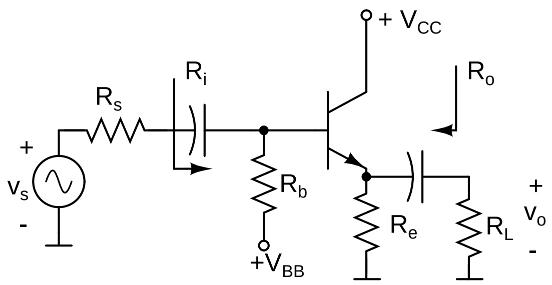
V_{smax} =2.11 V, v_{smin}=-4 V, R_i=251.5 K,R_o=8 K.

Problem 14

Design a circuit to get a gain of -2, independent of the device and free of distortion. V_{omax} = 10 V, with output being a sinusoid. The waveform of V_o hould just being to distort at both extremes. R_i should be in the range of 5 K, R_s is given to be 20Ω and R_L is 10K.

Problem 15

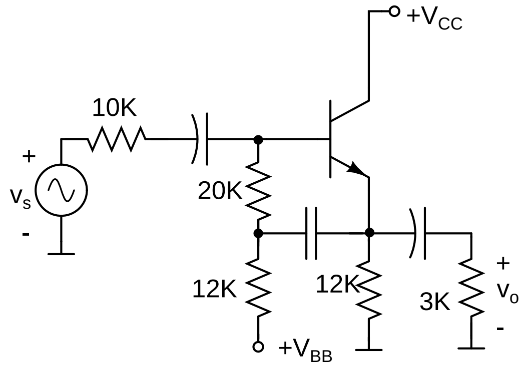
(Common Collector amplifier)



Calculate for small signals R_i, R_o and $\frac{v_o}{v_s}$. (Once again circuit analysis). Give the limits for R_i, R_o and the conditions to be satisfied to make gain independent of the device. What type of a controlled source does this amplifier act like when $g_m \to \infty$.

Problem 16

The transistor has very high β. With minimum possible V_{BB} and V_{CC}, the circuit should be able to handle the given drive of 5 V maximum amplitude. Calculate the values of V_{BB} and V_{CC} required.



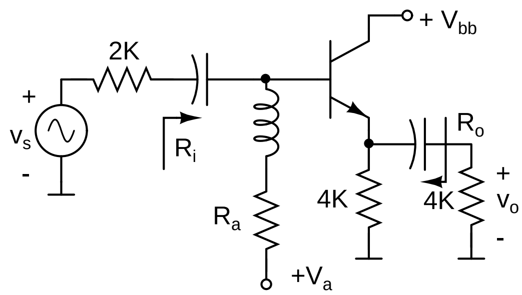
When the 3 K lead is removed, determine the swing possible for v_o on either side, and the maximum amplitude to which v_s must now be restricted if v_o is to be a full undistorted sine wave. Take V_{BE} = 0.7 V, nominally. Assume all capacitances are large.

ANSWERS :

$V_{CC} = 35.7\,\text{V}, V_{BB} = 30.7\,\text{V}, V_{omax} = 5\,\text{V}, V_{omin} = -15\,\text{V}$
v_s can have an amplitude of 5 V.

Problem 17

For small signals calculate R_i, R_o and $\frac{v_o}{v_s}$. The device has equivalent small signal y-parameters as follows :
y_{11} = 0.4 mS , y_{12} = 0, y_{21} = 40 mS, y_{22} = 25μS
These parameters are with emitter as common terminal.

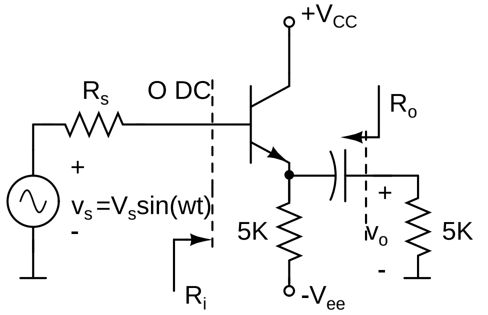


ANSWERS :

R_L=194.881 K, R_o=44.015,$\frac{v_o}{v_s}$=0.97714

Problem 18

V_s is 6 V. Calculate the values of V_{CC} and V_{ee} which will give a v_o waveform with distortion just commencing at positive and negative extremes.



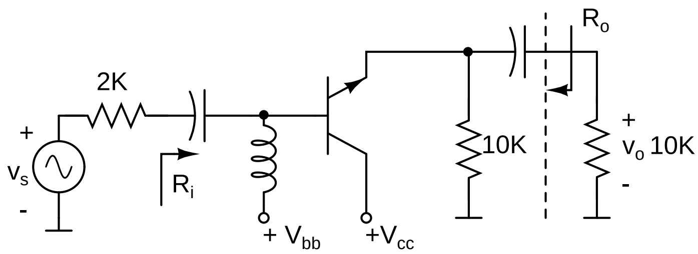
With the values found for V_{CC} and V_{ee} , use the approximate equivalent circuit for the transistor and determine R_i, R_o and v_o/v_s for small signals. Take V_T = 25 mV, β = 199.

ANSWERS :

$V_{CC} = 6\,\text{V}, V_{ee} = 12.65\,\text{V}, R_L = 502.083\,\text{K}, R_o = 35.168, \frac{v_o}{v_s} = 0.986$

Problem 19

Calculate R_i and R_o; the value of V_{CC} and V_{bb} which, with minimum input DC power to the stage, enable it to just handle the specified inout drive without distortion in v_o. Calculate also the small signal $\frac{v_o}{v_s}$. Take V_{BE} = 0.7 V nominally, r_e = 20Ω , α = 0.992 and V_S = 10V. In all cases, take the inductance and capacitors to be very large in value.

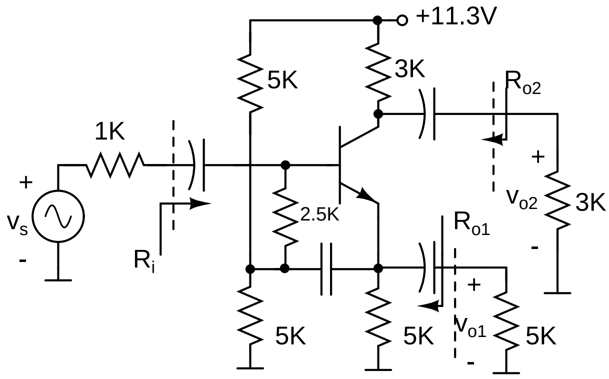


ANSWERS :

V_{CC} = 30 V, V_{bb} = 20.7 V, R_i = 627.5 K, R_o=99.01 Ohms, $\frac{v_o}{v_s}$ = 0.9804

Problem 20

All the coupling capacitors are very large in value. Take V_T = 25 mV, α = 0.99. Find for small signals R_i, R_{o1} as seen from the output terminal 1, R_{o2} as seen from output terminal 2, v_{o1}/v_s and v_{o2}/v_s.



ANSWERS :

R_i=64.375 K, R_{o2}=3 K, R_{o1}=43.39, $\frac{v_{o1}}{v_s}$=0.9656, $\frac{v_{o2}}{v_s}$=-1.1358

Problem 21

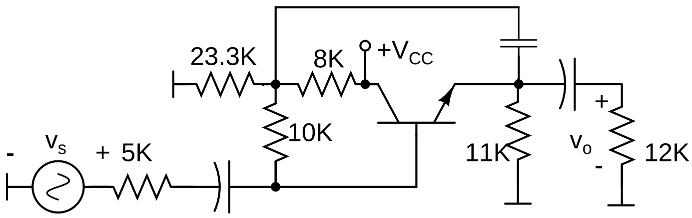
For very small signals, find v_o/v_s with the proper sign. Take V_{BE} = 0.65 V, nominally, V_T = 30 mV,α = 0.995 for all transistors. Also determined which transistor controls the upper limit of swing and which the lower one.

ANSWERS :

$\frac{v_o}{v_s}$ = 14609, T_5 controls lower swing limit - gets cut off when v_o = -1.46 V & T_4 controls upper swing limit - gets cut off when v_o = 3.90 V

Problem 22

V_{BE} = 0.65 V nominally. V_T = 25 mV. Calculate R_i for small signals. Also find the positive and negative limits for v_o if it is to be free from distortion. Take β = 200, V_{CC} = 15.65 V.



ANSWERS :

R_i = 455.7 K, V_{omax}=4 V, V_{omin}=-2.923 V

Problem 23

(COMMON BASE CONFIGURATION)

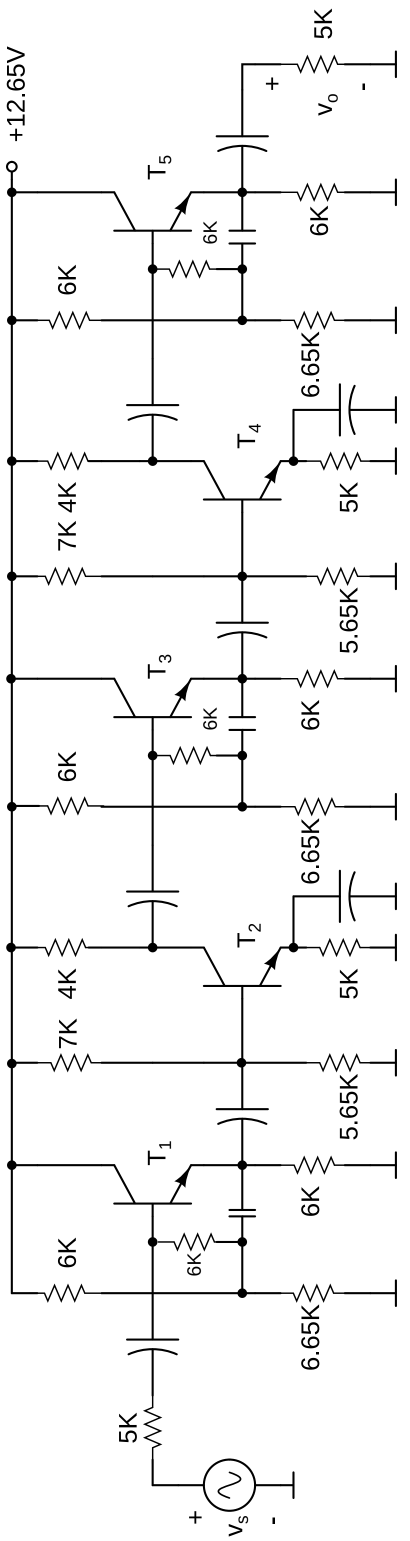
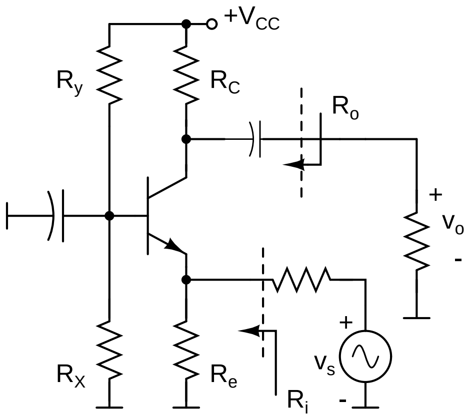


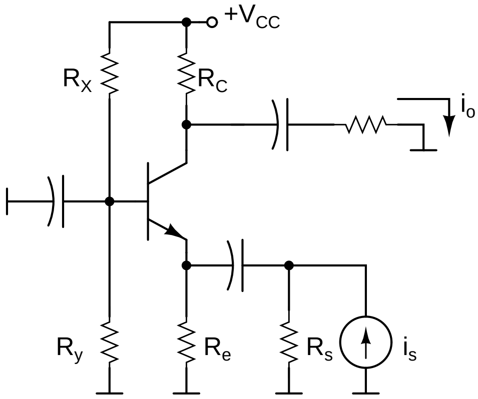
Figure 1: Circuit for Problem 21



Calculate for small signals R_i, R_o and v_o/v_s. Give the limits for R_i, R_o and the conditions to be satisfied to make v_o/v_s independent of device and free of distortion even for large signal case. What type of a controlled source does this amplifier act like when $g_m \to \infty$?

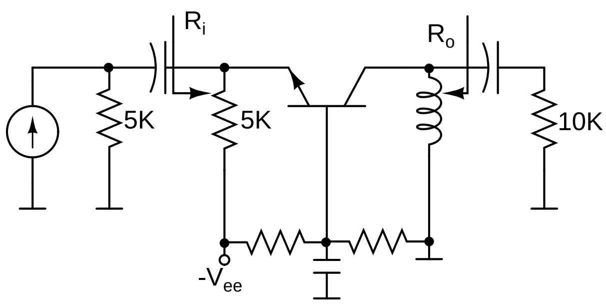
Problem 24

For the circuit shown below, let R_s = R_e = 4 K, $R_C \| R_L$ = 20 K. Calculate i_o/i_s given that h_{ib} = 20Ω, h_{rb} = 10^{-4}, h_{fb} = -0.99 and $1/h_{ob}$ = 2MΩ. Also, calculate R_i and R_o for the circuit. Finally, calculate i_o/i_s for the direct connection of the Norton equivalent and the load, without the transistor in between. Take R_C = R_L. To find R_o, take R_C to be part of load.



Problem 25

For small signals , find R_i and R_o, given that r_π = 2 K, β = 200, r_o = 30 K

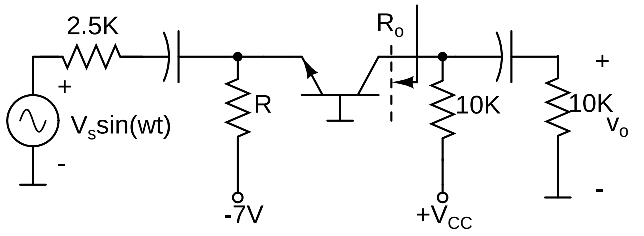


ANSWERS :

R_i = 13.206 Ohms, R_o = 3.364 MΩ

Problem 26

The input is a sine wave with V_S = 3.75V. To get an undistorted output sine wave within swing limits, Calculate V_{CC} and R.



If V_T = 25 mV, β = 200, r_o = 40 K, Calculate R_o. Take V_{BE} = 0.65 V nominally.

ANSWERS :

$V_{CC} = 22.5\,\text{V}, R = 4.233\,\text{K}, R_o = 2.596\,\text{M}$