Differential Amplifier

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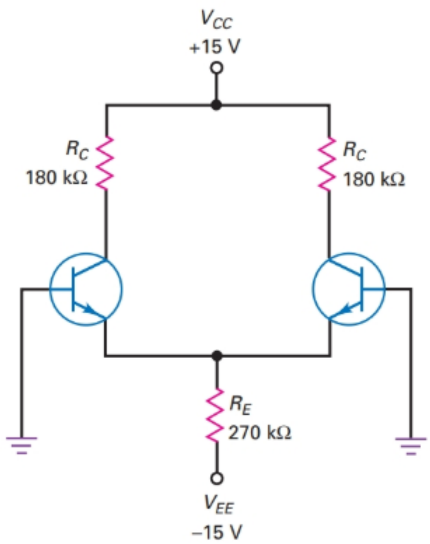
1 What are the ideal currents and voltages in Fig. 15-33?



Tail current

I_T = V_{EE}/R_E = 15V/270kΩ = 55.6μA

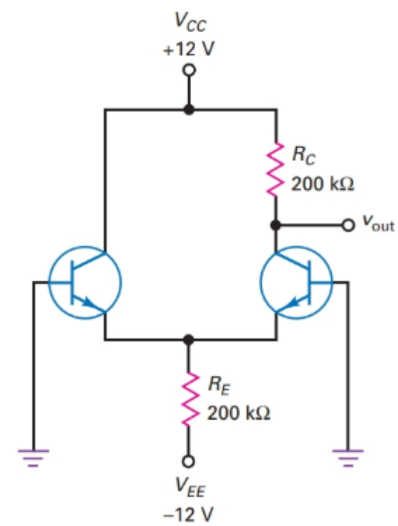
Each emitter current is half of the tail current

I_E = I_T/2 = 27.8μA

For ideal voltage

V_C = V_{CC}-I_C*R_C = 15V-27.8μA*180 kΩ = 10V

2 What are the ideal currents and voltages in Fig. 15-34?



Tail current

I_T = V_{EE}/R_E = 12V/200kΩ = 60μA

Each emitter current is half of the tail current

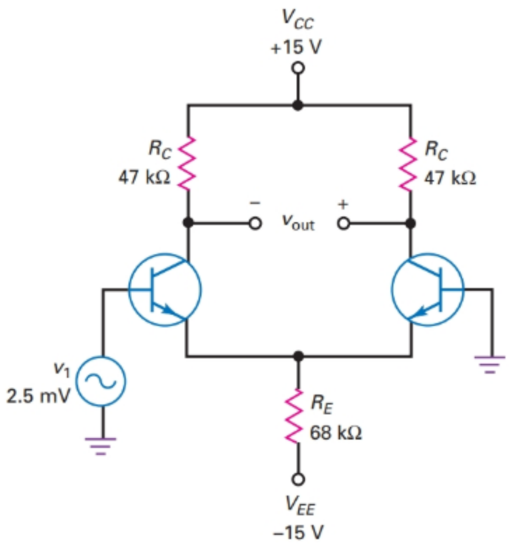
I_E = I_T/2 = 30μA

For ideal voltage

V_C = V_{CC} - I_C * R_C = 12V - 30μA * 200 kΩ = 6V

V_C on the right transistor is 6V
V_C on the left transistor is 12V since R_{C1} is 0 on the left side

3 In Fig. 15-35, what is the ac output voltage? If β = 275, what is the input impedance of the diff amp? Use the ideal approximation to get the tail current.



This is non inverting input and differential output

Tail current

I_T = V_{EE}/R_E = 15V/68kΩ = 220μA

Each emitter current is half of the tail current

I_E = I_T/2 = 110μA

r'_e = 25mV/110μA = 227Ω

The voltage gain of differential output

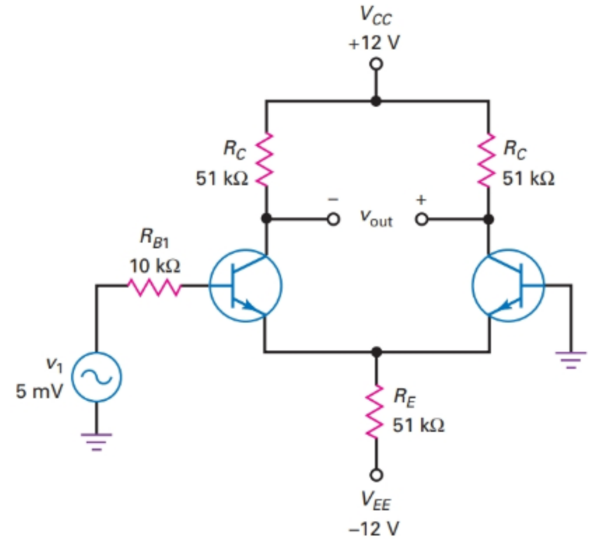
A_v = R_c/r'_e = 47kΩ/227Ω = 206.8

The ac output voltage is

V_{out} = $A_v(V_{in})$ = 206.8 * 2.5mV = 518mV

In differential amplifier, the input impedence is twice as high
$Z_{in(base)}$ = 2 * β
V_C = V_{CC} - I_C * R_C = 15V - 27.8$\mu\Omega$ * 180 kΩ = 10V

4 The differential amplifier of Fig. 15-36 has Av = 360, $I_{in(bias)}$ = 600 nA, $I_{in(off)}$ = 100 nA, and $V_{in(off)}$ = 1 mV. What is the output error voltage? If a matching base resistor is used, what is the output error voltage?



Known

Non inverting input, Differential output

A_v = 360

($I_{in(bias)}$) = ($I_{b1} + I_{b2}$)/2
$I_{in(bias)}$ = 600 nA
$I_{in(off)}$ = ($I_{b1} - I_{b2}$)
$I_{in(off)}$ = 100 nA

$V_{in(off)}$ = V_{Error}/A_v
$V_{in(off)}$ = 1 mV

Drived formulas

V_{1err} = (R_{b1}-R_{b2})*$I_{in(bias)}$
V_{2err} = [(R_{b1}+R_{b2})*$I_{in(off)}$]/2
V_{3err} = $V_{in(off)}$
V_{err} = A_v (V_{err} + V_{2err} + V_{3err})

R_{b1}= 10kΩ
R_{b2} = 0kΩ

Three unwanted dc error inputs
V_{1err} = (R_{b1}-R_{b2})*$I_{in(bias)}$
= (10kΩ) * 600 nA = 6mV

V_{2err} = [(R_{b1}+R_{b2})*$I_{in(off)}$]/2
= (10kΩ * 100 nA)/2 = 0.5mV

V_{3err} = $V_{in(off)}$ = 1mV

The output error voltage
V_{err} = A_v (V_{err} + V_{2err} + V_{3err}) = 360(6mV + 0.5mV + 1mV) = 2.7V
The output error voltage is 2.7V

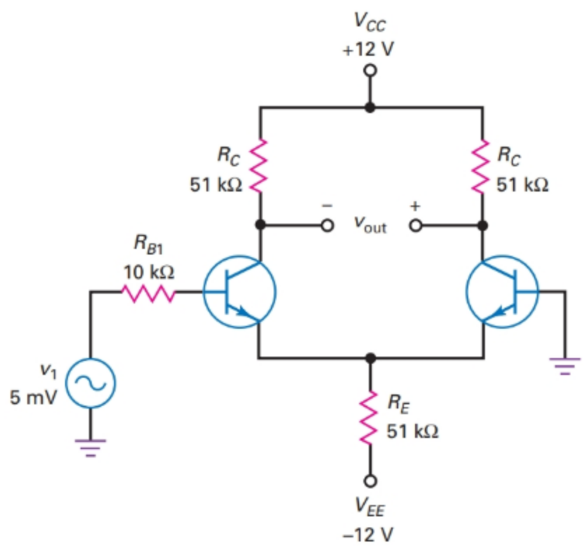
When matching base resistance is 10k is used on the inverting side

V_{1err} = 0
V_{2err} = $R_B * I_{in(off)}$ = 10kΩ * 100nA = 1mV
V_{3err} = $V_{in(off)}$ = 1mV

V_{err} = A_v (V_{1err} + V_{2err} + V_{3err}) = 360(2mV) = 720mV

Error output voltage is 720mV when matching resistor is used on the based side

5 The diff amp of Fig. 15-36 has Av = 250, $I_{in(bias)}$ = 1 μA, $I_{in(off)}$ = 200 nA, and $V_{in(off)}$ = 5 mV. What is the output error voltage? If a matching base resistor is used, what is the output error voltage?



Known

non inverting input, differential output

A_v = 250

$I_{in(bias)}$ = $(I_{b1} + I_{b2})$/2
$I_{in(bias)}$ = 1 μA
$I_{in(off)}$ = $(I_{b1} - I_{b2})$
$I_{in(off)}$ = 200 nA

$V_{in(off)}$ = V_{Error}/A_v
$V_{in(off)}$ = 1 mV

Drived formulas

V_{1err} = (R_{b1}-R_{b2})*$I_{in(bias)}$
V_{2err} = [(R_{b1}+R_{b2})*$I_{in(off)}$]/2
V_{3err} = $V_{in(off)}$
V_{err} = A_v (V_{err} + V_{2err} + V_{3err})

R_{b1}= 10kΩ
R_{b2} = 0kΩ

Dc error inputs
V_{1err} = (R_{b1}-R_{b2})*$I_{in(bias)}$
= (10kΩ) * 1 μA = 10mV

V_{2err} = [(R_{b1}+R_{b2})*$I_{in(off)}$]/2
= [(10kΩ) * 200 nA]/2 = 1mV

V_{3err} = $V_{in(off)}$ = 5mV

The output error voltage
V_{err} = A_v (V_{err} + V_{2err} + V_{3err}) = 250(10mV + 1mV + 5mV) = 4V
The output error voltage is 4V

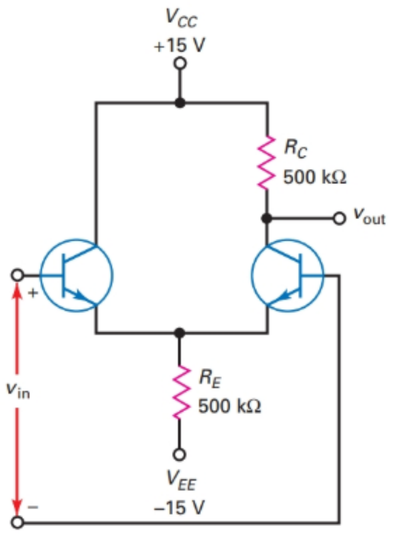
When matching base resistance is 10k is used on the inverting side

V_{1err} = 0
V_{2err} = $R_B * I_{in(off)}$ = 10kΩ * 200nA = 2mV
V_{3err} = $V_{in(off)}$ = 5mV

V_{err} = A_v (V_{1err} + V_{2err} + V_{3err}) = 250(2mV) = 1.75V

Output error voltage 1.75V when matching resistor is used on the based side.

6 What is the common-mode voltage gain of Fig. 15-37? If a common-mode voltage of 20 μV exists on both bases, what is the common-mode output voltage?



The common mode gain

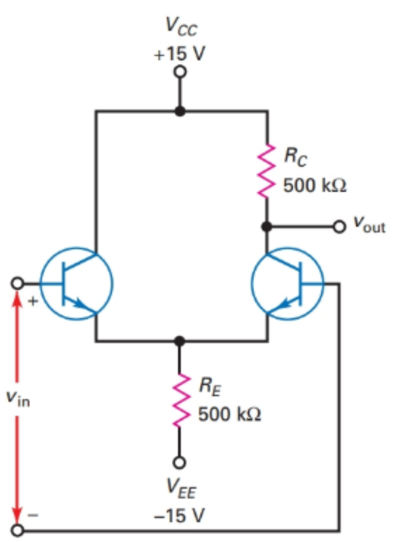
$A_{V(cm)}$ = R_C/(2*R_E) = 500kΩ/(2*500kΩ) = 0.5

The output voltage is

V_{out} = $A_{V(CM)}$ * $V_{in(CM)}$ = 0.5*20μV = 10μV

The common mode output voltage
V_{out} = 10μV

7n Fig. 15-37, v_{in} = 2 mV and $v_{in(CM)}$ = 5 mV. What is the ac output voltage?



V_{in} = 2mV

$V_{in(CM)}$ = 5mV

I_T = (15V - 0.7V)/(500kΩ) = 28.6 μA
I_E = I_T/2 = 14.3 μA

r'_e = 25mV/14.3μA = 1748Ω

A_v = r_c/(2*r'_e) = 500kΩ/(2*1748Ω) = 143

V_{out} = A_v * V_{in} = 143*2mV = 286mV

Hence the output voltage is 286mV.

Commmon mode voltage gain
$A_{V(cm)}$ = R_C/(2*R_E) = 500kΩ/(2*500kΩ) = 0.5

The output voltage is

V_{out} = $A_{V(CM}$ * $V_{in(CM}$ = 0.5*5mV = 2.5 mV

8 A 741C is an op amp with Av = 100,000 and a minimum $CMRR_{dB}$ = 70 dB. What is the common-mode voltage gain? If a desired and common-mode signal each has a value of 5 V, what is the output voltage?

CMRR = $A_v/A_{v(CM)}$
A_V = 250
$CMRR_{db}$= 70db
V_{in} = 5μV
$V_{in(CM)}$ = 5μV

CMRR = $10^{CMRR_{db}/20}$ = $10^{70/20}$ = 3162.3

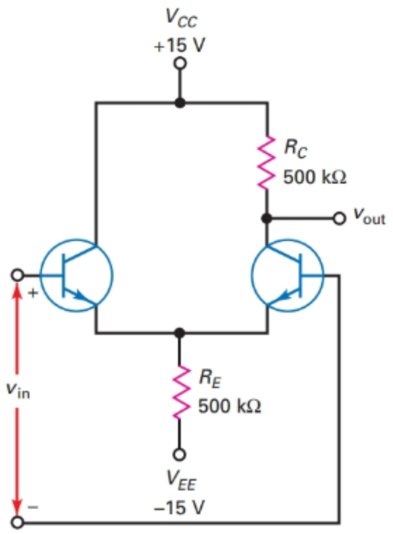
$A_{v(CM)}$ = $A_v/CMRR$ = 100000/3162.3 = 31.62

The desired output component

V_{out1} = A_V*V_{in} = 100000(5μV) = 0.5V

Common mode output
V_{out2} = $A_{V(CM)}$ $V_{in(CM)}$ = (31.62V) (5 μV) = 0.158mV

9 If the supply voltages are reduced to 110 V and 210 V, what is the common-mode rejection ratio of Fig. 15-37? Express the answer in decibels.



I_T = (10V - 0.7V)/(500kΩ) = 18.6 μA
I_E = I_T/2 = 9.3 μA

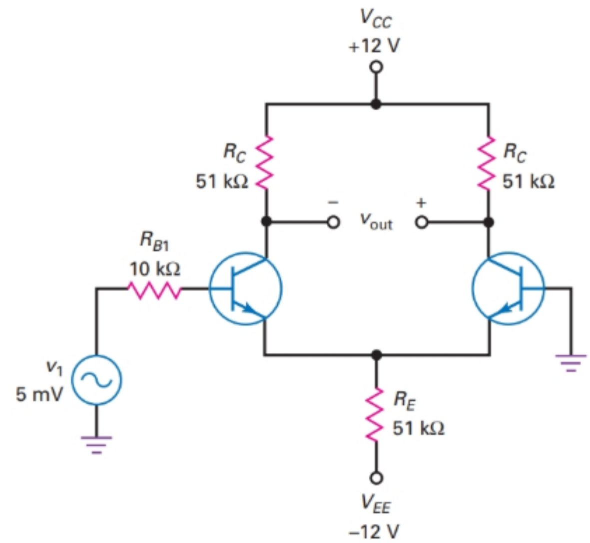
r'_e = 25mV/9.3μA = 2688Ω

Since this amplifier is single ended output the formula is A_v = r_c/(2*r'_e)
A_v = r_c/(2*r'_e) = 500kΩ/(2*2688Ω) = 93

And the common mode voltage gain is
$A_{v(CM)}$ = r_c/(2*r_e) = 500kΩ/(2*500kΩ) = 0.5
CMRR = $A_v/A_{v(CM)}$ = 93/0.5 = 186

$CMRR_{db}$ = 20*log(CMRR) = 20log(186) = 45.4dB

10 A load resistance of 27 kΩ is connected across the differential output of Fig. 15-36. What is the load voltage?



I_T = (12V - 0.7V)/(51kΩ) = 0.2216 mA
I_E = I_T/2 = 0.1108 mA

r'_e = 25mV/0.1108 mA = 225.63Ω

Since it is differential output the formula is A_v = r_c/r'_e
A_v = r_c/(r'_e) = 51kΩ/(225.63Ω) = 226

v_{out} = A_v * v1 = 226 * 5mV = 1.13V
ac output voltage = 1.13V

R_{th} = 2*R_C = 2*51kΩ = 102kΩ

V_L = V_{out}*(R_l)(R_{th}+R_l) = 1.13V *(27kΩ) /(102kΩ+27kΩ) = 237mV
Hence, the load voltage is 237mV