BJT Amplifiers

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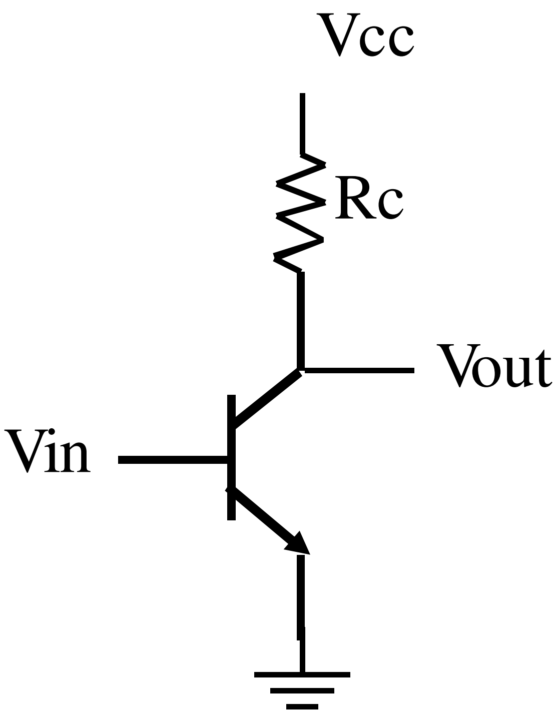
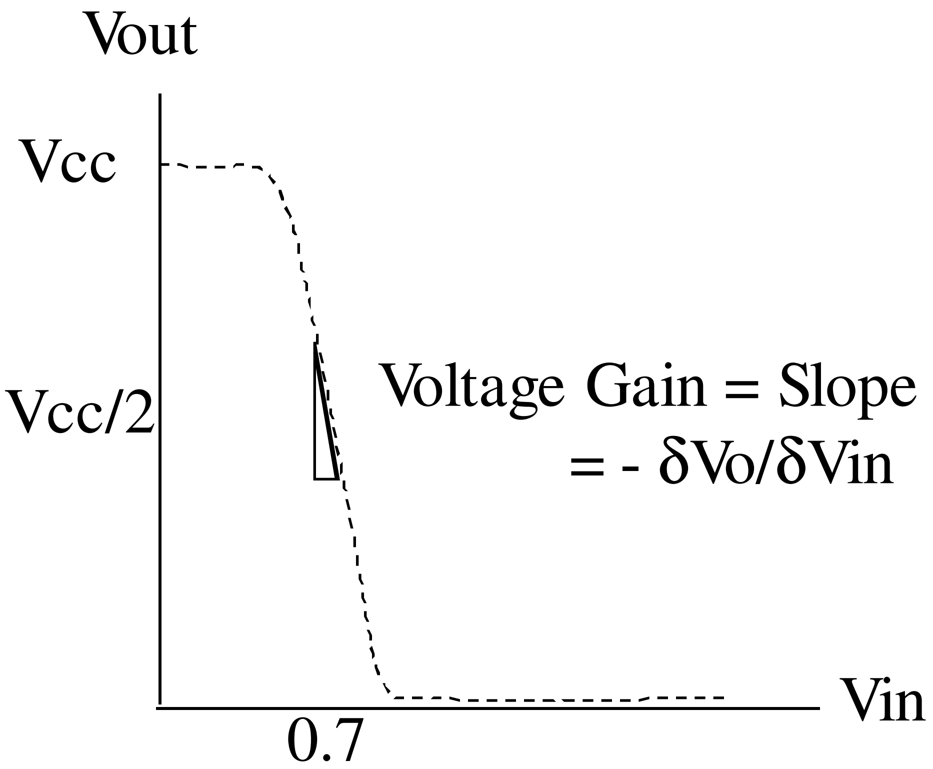
3-23-12 BJT_Amplifiers.ppt

OUTLINE

Biasing of the BJT
One Transistor Amplifiers, CE, CB, CC
Small Signal Models
Multistage AC Coupled Amplifiers
References
Homework Questions

VOUT VS VIN FOR CE BJT INVERTER CIRCUIT





Voltage Gain = Slope
= - δVo/δVin

VOUT VS VIN FOR CE BJT INVERTER CIRCUIT

$IE = I_{SE}\, e^{VBE/VT}$ and $IC = \alpha\, IE$

$$\begin{aligned} Vout &= Vcc - RcIc \\ &= Vcc - Rc\, \alpha\, IE \\ &= Vcc - Rc\, \alpha\, I_{SE}\, e^{VBE/VT} \end{aligned}$$

Find the slope when Vout is ~ Vcc/2

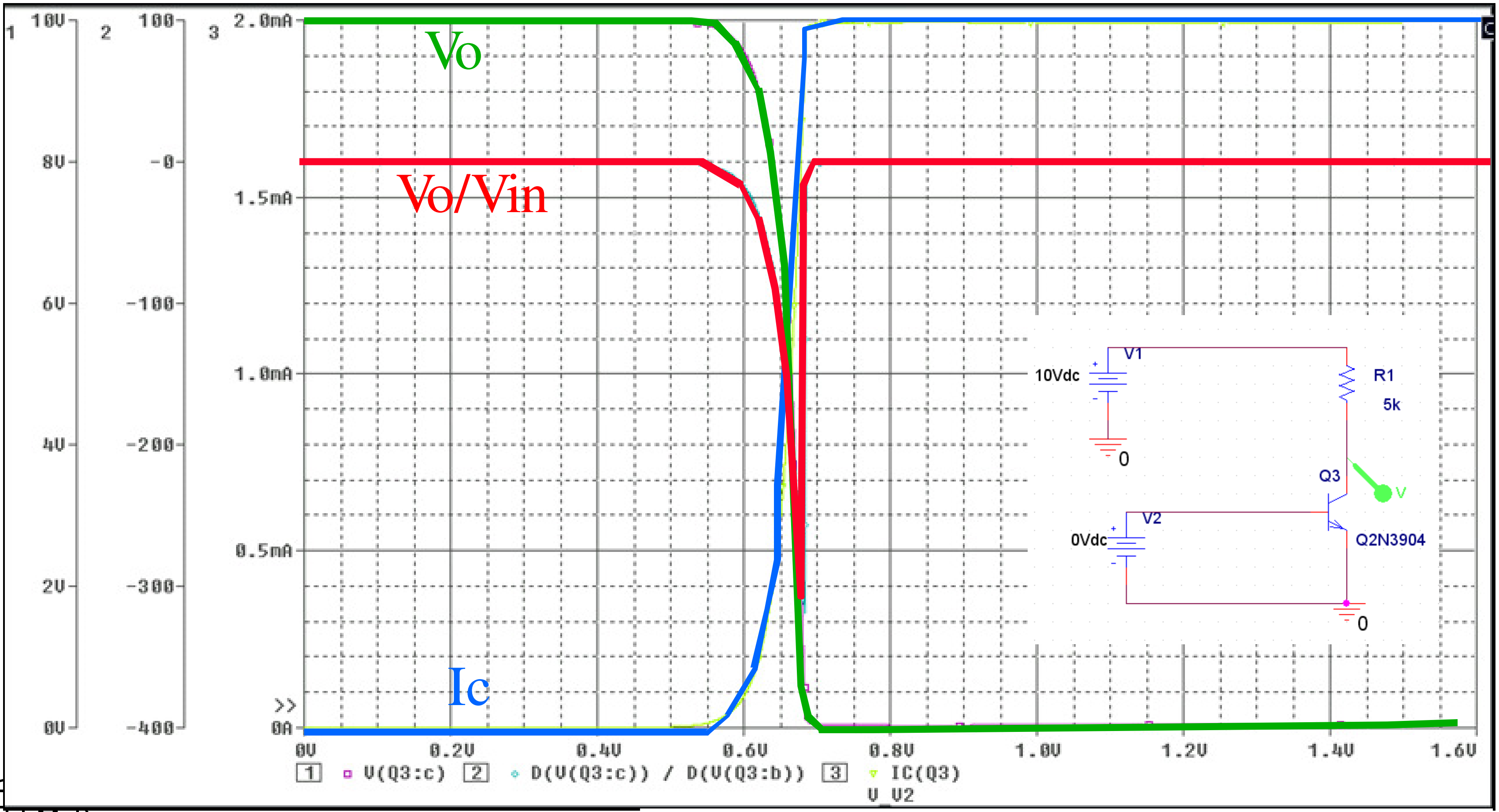
we can show in a few steps the following:

$$\frac{\delta\, Vout}{\delta\, Vin} = -Rc\ Ic\ (q/KT)$$ where Ic is the value when Vout ~ Vcc/2

If Vcc=10V, Rc=5Kohm, Then Ic is ~1mA and

$$\frac{\delta\, Vout}{\delta\, Vin} = -\ 5K\ (1/0.026)\ 1mA = -\ 192\ V/V$$

SPICE ANALYSIS OF BJT INVERTER



Note: Vo/Vin is negative (inverting) and has a value of ~-150 at Ic=1mA

SPICE OUTPUT FILE

```
**** 09/11/09 10:26:56 *********** Evaluation PSpice (Nov 1999) ***************
 ** Profile: "SCHEMATIC1-BJT_Inverter" [ C:\Documents and Settings\lffeee\Desktop\SPICE\Project_3_BJT_Inverter\bjt_inverter-SCHEMATI
 ****     CIRCUIT DESCRIPTION
*******************************************************************************
** Creating circuit file "bjt_inverter-SCHEMATIC1-BJT_Inverter.sim.cir"
*Libraries:
.lib "C:\Program Files\OrcadLite\Capture\Library\PSpice\eval.lib"
*Analysis directives:
.DC LIN V_V2 0 1.5 .0001
.INC "bjt_inverter-SCHEMATIC1.net"
**** INCLUDING bjt_inverter-SCHEMATIC1.net ****
* source BJT_INVERTER
R_R1         N00033 N00036  5k
V_V1         N00036 0 10Vdc
V_V2         N00030 0 0Vdc
Q_Q3         N00033 N00030 0 Q2N3904
**** RESUMING bjt_inverter-SCHEMATIC1-BJT_Inverter.sim.cir ****
.INC "bjt_inverter-SCHEMATIC1.als"
**** INCLUDING bjt_inverter-SCHEMATIC1.als ****
.ALIASES
R_R1            R1(1=N00033 2=N00036 )
V_V1            V1(+=N00036 -=0 )
V_V2            V2(+=N00030 -=0 )
Q_Q3            Q3(c=N00033 b=N00030 e=0 )
.ENDALIASES
**** RESUMING bjt_inverter-SCHEMATIC1-BJT_Inverter.sim.cir ****
.END
```

Note: see last page of this document for more information on BJT SPICE parameters

```
****     BJT MODEL PARAMETERS
********************************************************
             Q2N3904
             NPN
         IS    6.734000E-15
         BF  416.4
         NF    1
        VAF   74.03
        IKF    .06678
        ISE   6.734000E-15
         NE   1.259
         BR    .7371
         NR    1
         RB   10
         RC    1
        CJE   4.493000E-12
        MJE    .2593
        CJC   3.638000E-12
        MJC    .3085
         TF  301.200000E-12
        XTF    2
        VTF    4
        ITF    .4
         TR  239.500000E-09
        XTB    1.5
         CN   2.42
          D    .87
```

2N3904 DATA SHEET

FAIRCHILD
SEMICONDUCTOR ™

2N3904 / MMBT3904 / PZT3904

NPN General Purpose Amplifier

This device is designed as a general purpose amplifier and switch. The useful dynamic range extends to 100 mA as a switch and to 100 MHz as an amplifier.

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	200	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

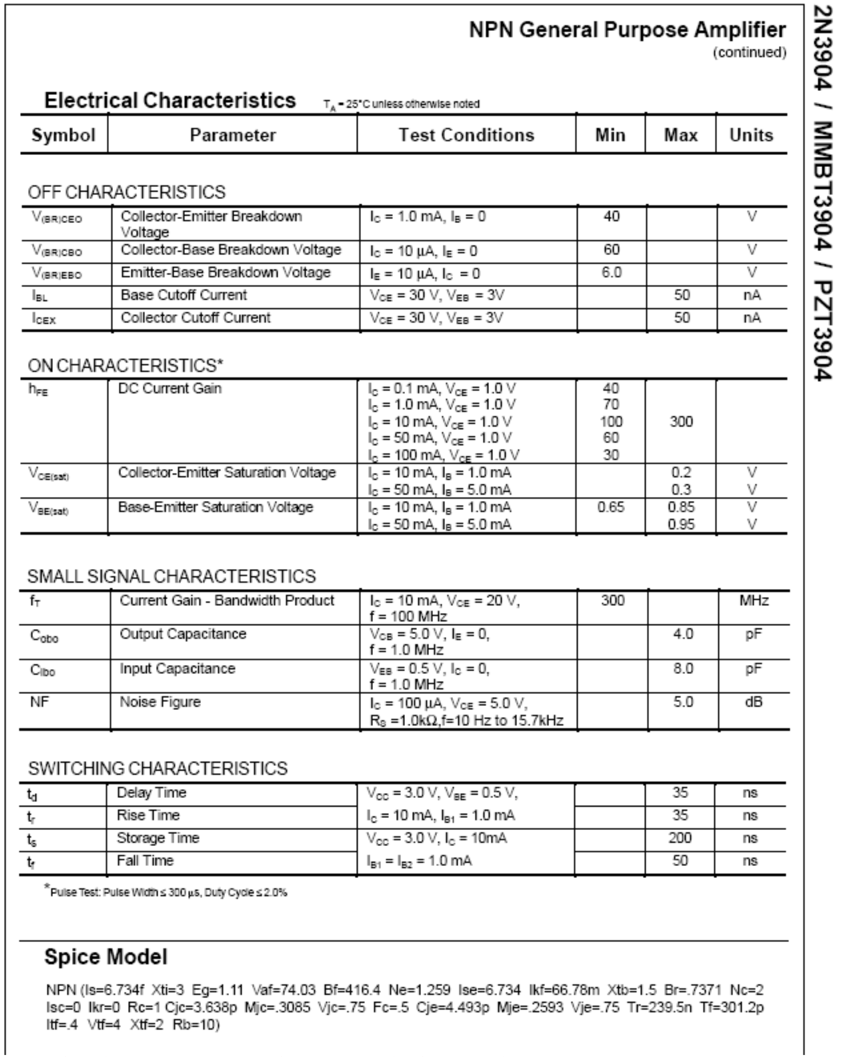
NOTES:
1) These ratings are based on a maximum junction temperature of 150 degrees C.
2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Thermal Characteristics T_A = 25°C unless otherwise noted

Symbol	Characteristic	Max			Units
		2N3904	*MMBT3904	**PZT3904	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

*Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06."

**Device mounted on FR-4 PCB 36 mm X 18 mm X 1.5 mm; mounting pad for the collector lead min. 6 cm^2.



2N3904 / MMBT3904 / PZT3904

NPN General Purpose Amplifier
(continued)

Electrical Characteristics T_A = 25°C unless otherwise noted

Symbol	Parameter	Test Conditions	Min	Max	Units
OFF CHARACTERISTICS					
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	I_C = 1.0 mA, I_B = 0	40		V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	I_C = 10 µA, I_E = 0	60		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	I_E = 10 µA, I_C = 0	6.0		V
I_{BL}	Base Cutoff Current	V_{CE} = 30 V, V_{EB} = 3V		50	nA
I_{CEX}	Collector Cutoff Current	V_{CE} = 30 V, V_{EB} = 3V		50	nA
ON CHARACTERISTICS*					
h_{FE}	DC Current Gain	I_C = 0.1 mA, V_{CE} = 1.0 V I_C = 1.0 mA, V_{CE} = 1.0 V I_C = 10 mA, V_{CE} = 1.0 V I_C = 50 mA, V_{CE} = 1.0 V I_C = 100 mA, V_{CE} = 1.0 V	40 70 100 60 30	300	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	I_C = 10 mA, I_B = 1.0 mA I_C = 50 mA, I_B = 5.0 mA		0.2 0.3	V V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	I_C = 10 mA, I_B = 1.0 mA I_C = 50 mA, I_B = 5.0 mA	0.65	0.85 0.95	V V
SMALL SIGNAL CHARACTERISTICS					
f_T	Current Gain - Bandwidth Product	I_C = 10 mA, V_{CE} = 20 V, f = 100 MHz	300		MHz
C_{obo}	Output Capacitance	V_{CB} = 5.0 V, I_E = 0, f = 1.0 MHz		4.0	pF
C_{ibo}	Input Capacitance	V_{EB} = 0.5 V, I_C = 0, f = 1.0 MHz		8.0	pF
NF	Noise Figure	I_C = 100 µA, V_{CE} = 5.0 V, R_S =1.0kΩ,f=10 Hz to 15.7kHz		5.0	dB
SWITCHING CHARACTERISTICS					
t_d	Delay Time	V_{CC} = 3.0 V, V_{BE} = 0.5 V,		35	ns
t_r	Rise Time	I_C = 10 mA, I_{B1} = 1.0 mA		35	ns
t_s	Storage Time	V_{CC} = 3.0 V, I_C = 10mA		200	ns
t_f	Fall Time	I_{B1} = I_{B2} = 1.0 mA		50	ns

*Pulse Test: Pulse Width ≤ 300 µs, Duty Cycle ≤ 2.0%

Spice Model

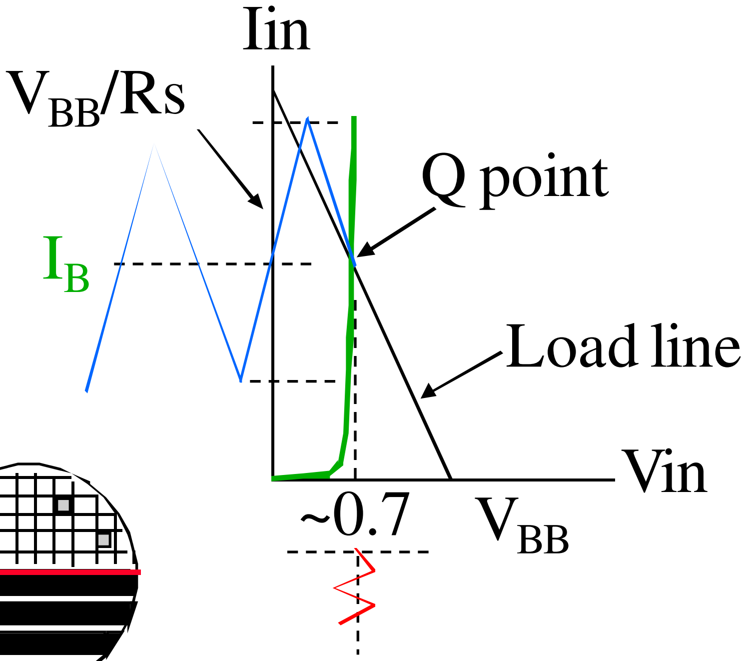
```
NPN (Is=6.734f  Xti=3  Eg=1.11  Vaf=74.03  Bf=416.4  Ne=1.259  Ise=6.734  Ikf=66.78m  Xtb=1.5  Br=.7371  Nc=2
Isc=0  Ikr=0  Rc=1 Cjc=3.638p  Mjc=.3085  Vjc=.75  Fc=.5  Cje=4.493p  Mje=.2593  Vje=.75  Tr=239.5n  Tf=301.2p
Itf=.4  Vtf=4  Xtf=2  Rb=10)
```

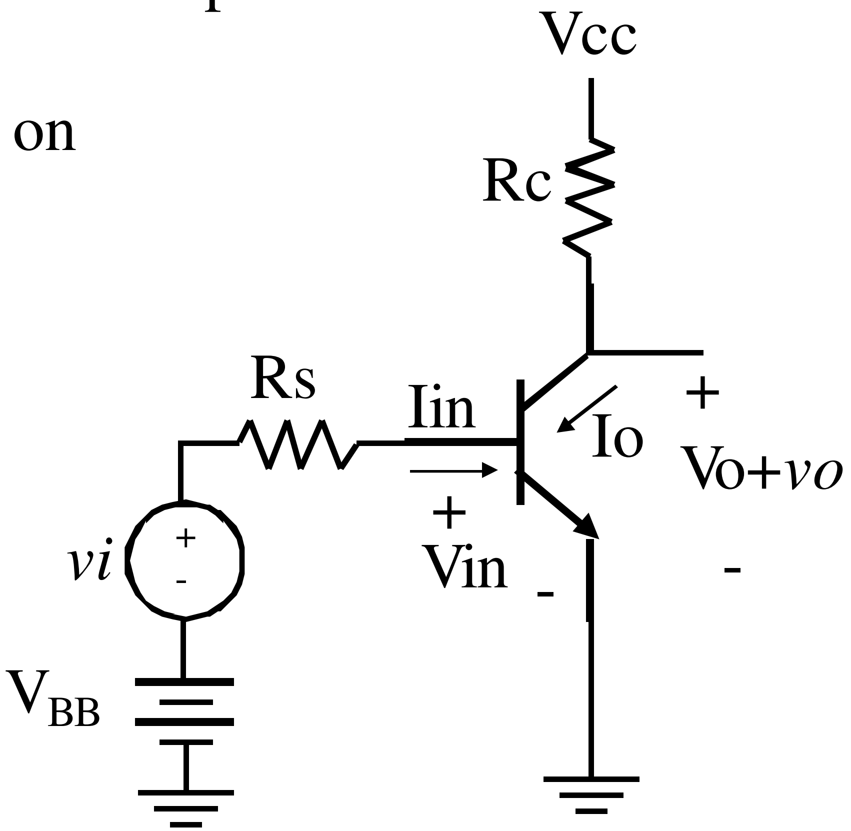
Note: see last page of this document for more information on BJT SPICE parameters

CE BJT AMPLIFIER - BIASING

We want to forward bias the BE junction and reverse bias the BC junction and then add a small changing voltage to the input and realize a larger changing voltage at the output.

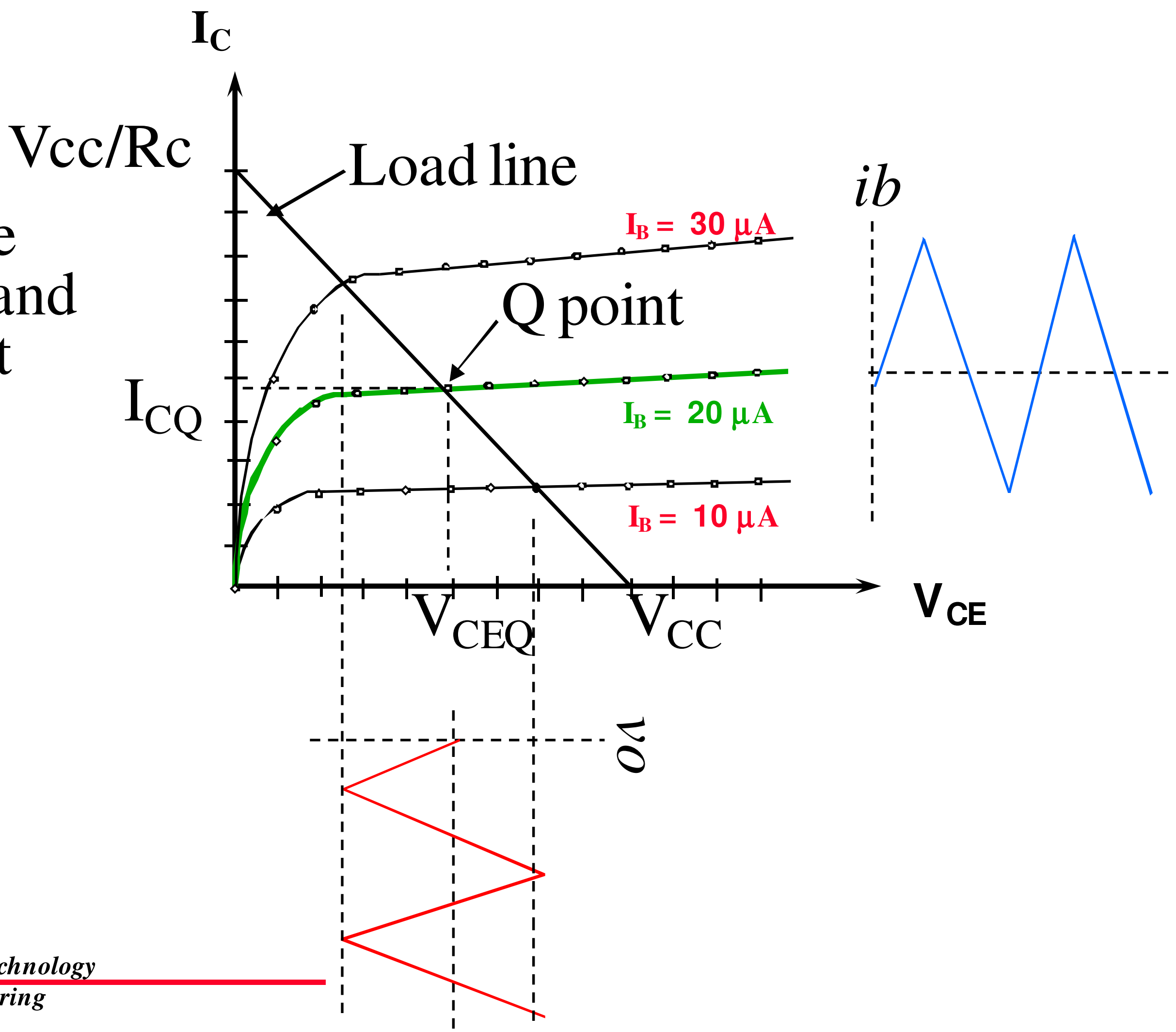
V_{BB} and Rs can provide any combination of Iin and Vin shown on the input load line.



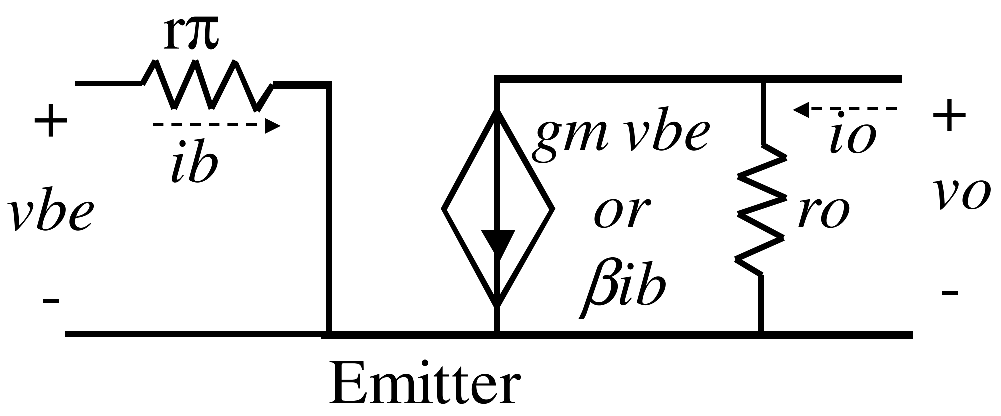


CE BJT AMPLIFIER - BIASING

V_{CC} and Rc can provide any combination of Io and Vo shown on the output load line.



SMALL SIGNAL MODEL OF CE BJT



rπ represents the input resistance seen looking into the base
gm is the transconductance at the Q point collector current
ro represents the output resistance as seen looking into the collector

The values of these parameters all change with Q point so first find I_C from large signal DC analysis (Ebers-Moll Model and circuit analysis)

SMALL SIGNAL MODEL OF CE BJT

First find IC at the Q point then find *gm*, *ro* and *rπ*

$$gm = \frac{\delta IC}{\delta VBE} = \frac{\delta\, ISe^{VBE/VT}}{\delta VBE} = \boxed{gm = \frac{IC}{VT}}$$

Where VT = KT/q

$$ro = \left(\frac{\delta IC}{\delta VCE}\right)^{-1} = 1/\text{slope} \qquad \boxed{ro\ = VA/IC}$$

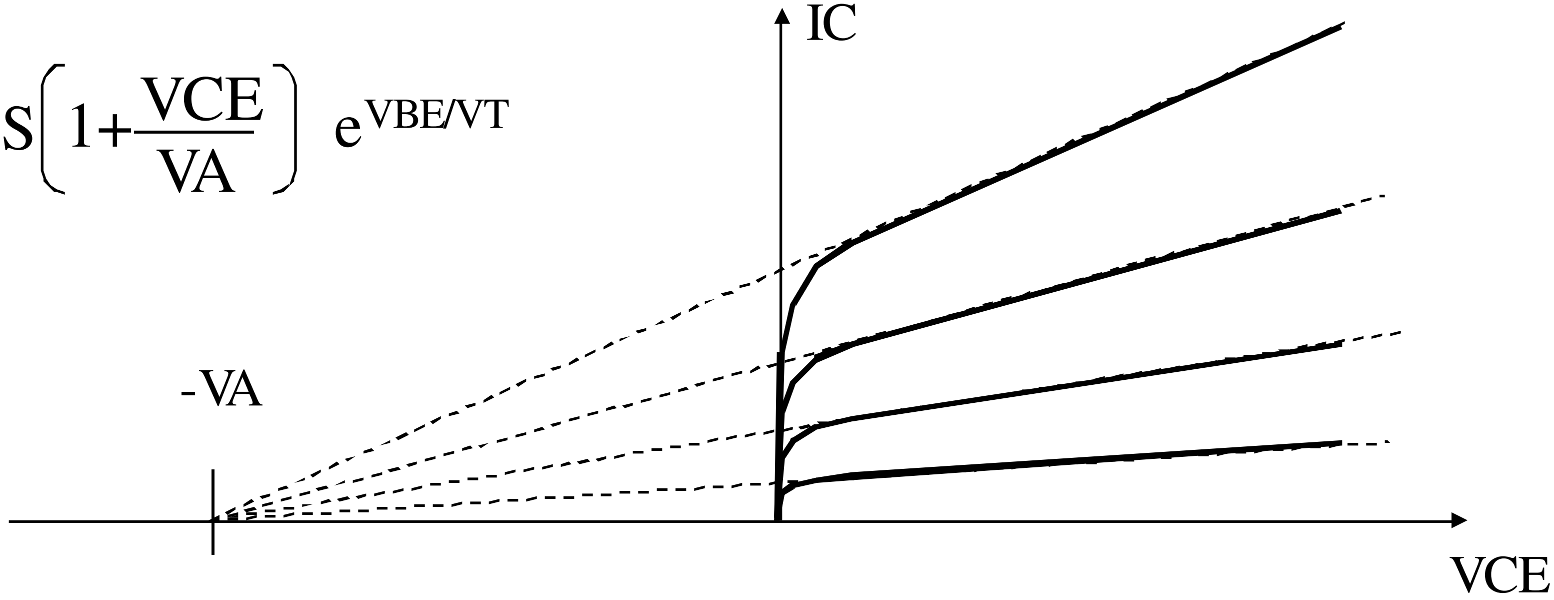
Where VA = Early Voltage

$$r\pi = \frac{\delta VBE}{\delta IB} = \frac{\delta VBE}{\delta IC/\beta} = \frac{VT}{IC}\beta = \boxed{r\pi = \beta / gm}$$

EARLY VOLTAGE

Increasing VCE increases the reverse bias on the BC junction increasing the width of the space charge layer resulting in a decrease in the base with an increase in concentration gradient and an increase in collector current. To account for this the equation relating the collector current to the VBE can be modified slightly as shown:

$$IC = IS\left(1+\frac{VCE}{VA}\right)\ e^{VBE/VT}$$



This is one of the many modifications to make the BJT models more accurate. Other modifications include resistors to account for series resistance in the collector, base and emitter.

EBERS-MOLL MODEL OF NPN BJT

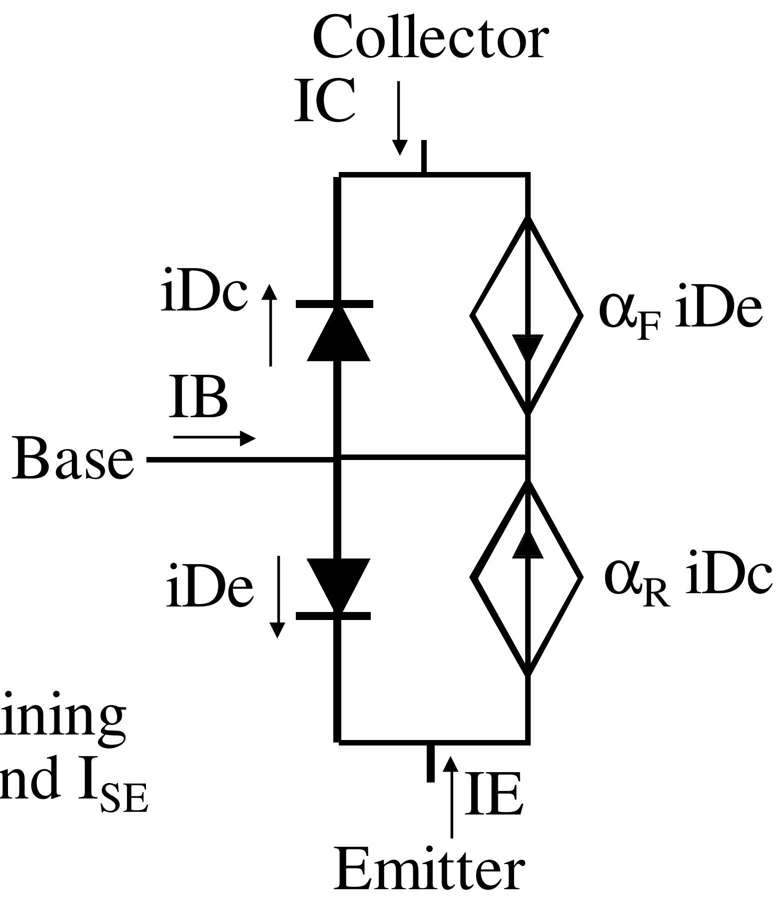
This type of model works in all four regions of operation

$$IC = \alpha_F\, iDe - iDc$$
$$IE = -iDe + \alpha_R\, iDc$$

The diode currents are:

$$iDc = I_{SC}\, (e^{Vbc/VT} - 1)$$
$$iDe = I_{SE}\, (e^{Vbe/VT} - 1)$$

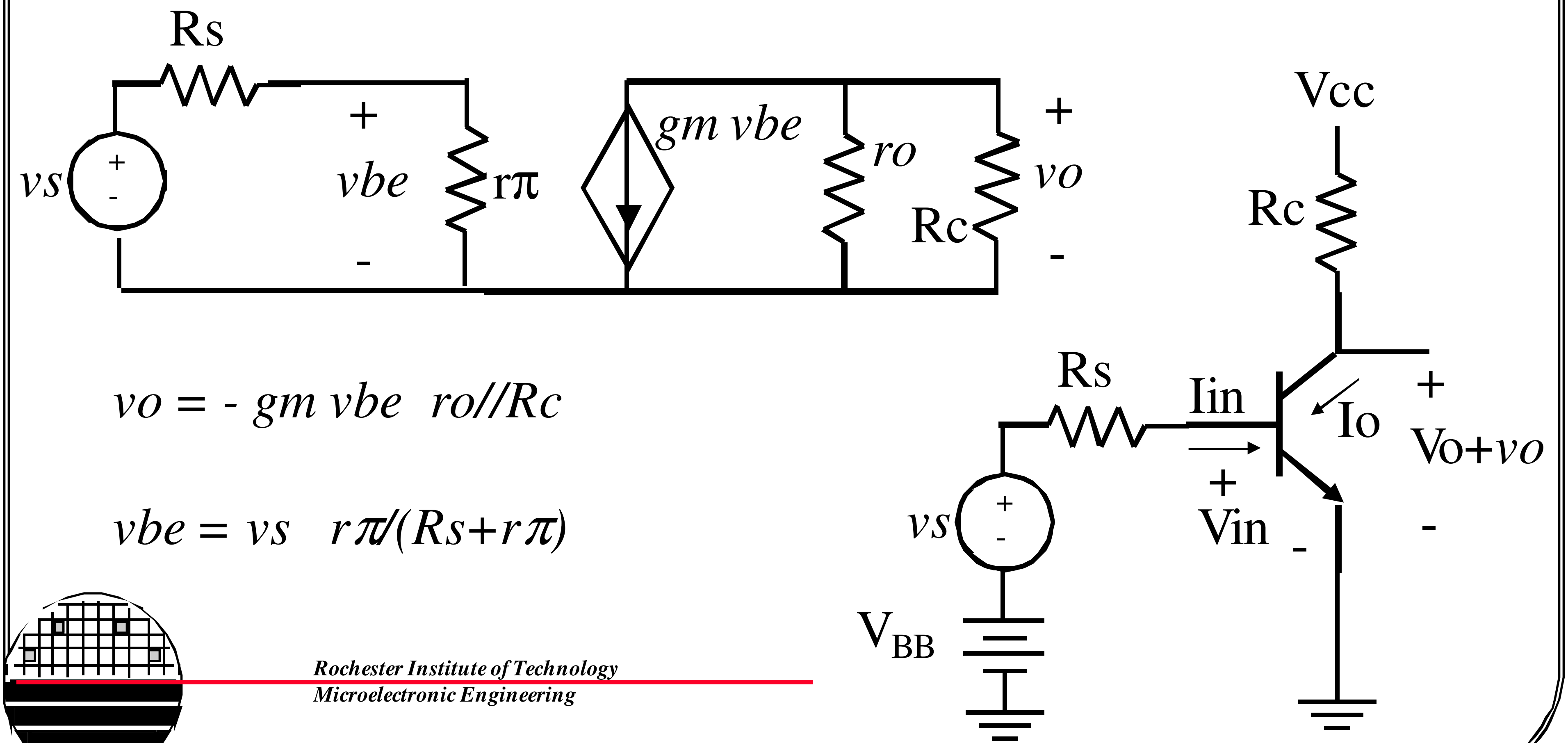
Transistors are modeled by determining appropriate values of: α_F, α_R, I_{SC} and I_{SE}



Noτε: β is often given instead of α but $\alpha = \beta/(1+\beta)$

SMALL SIGNAL ANALYSIS

Replace the transistor with its small signal model (at I_{CQ}), replace DC voltage sources with shorts and DC current sources with opens.



$$vo = -\,gm\ vbe\ \ ro//Rc$$

$$vbe = vs\ \ r\pi/(Rs+r\pi)$$

ANALYSIS

Find:

$$vo = - vs\frac{r\pi}{r\pi+Rs}\ gm\ \ ro//Rc$$

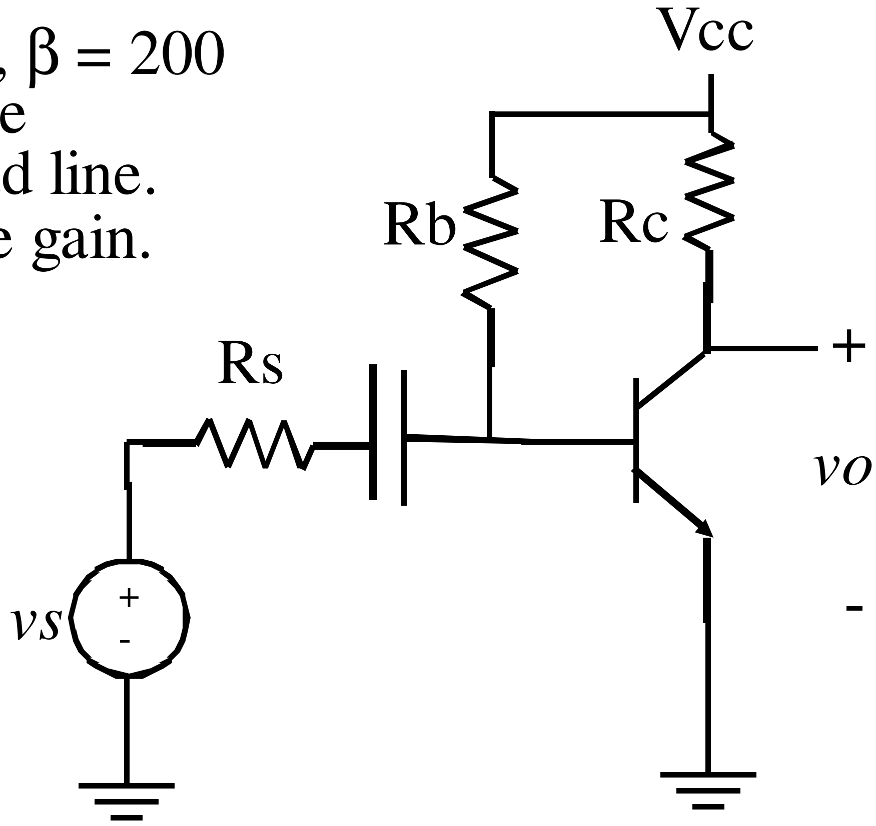
$$Ro = ro//Rc$$

$$Rin = r\pi$$

Note: maximum possible voltage gain when Rb=0 and Rc=infinity is VA/VT might be ~ 3000

CE BJT AMPLIFIER EXAMPLE 1

Example: If Vcc = 20V, Rc = 5K, β = 200 and Va = 100. Find Rb to bias the transistor in the middle of the load line. Calculate the small signal voltage gain. Repeat for β = 100, 300



Note: capacitor is a short at frequency of interest, Instead of a VBB of previous circuit use the VCC, Rb is quite large to get small base currents and may be a source of thermal noise.

ANALYSIS OF CIRCUIT ON PREVIOUS PAGE

Approach:

1. Do DC analysis to find IC.
2. Calculate gm, rπ and ro
3. Draw ac equivalent circuit
4. Find vo/vi, rin and rout

$$vo = -\ vs \frac{r\pi//Rb}{r\pi//Rb + Rs}\ gm\ ro//Rc$$

$$Ro = ro\ //\ Rc$$

$$Rin = R\pi//\ \mathrm{Rb}$$

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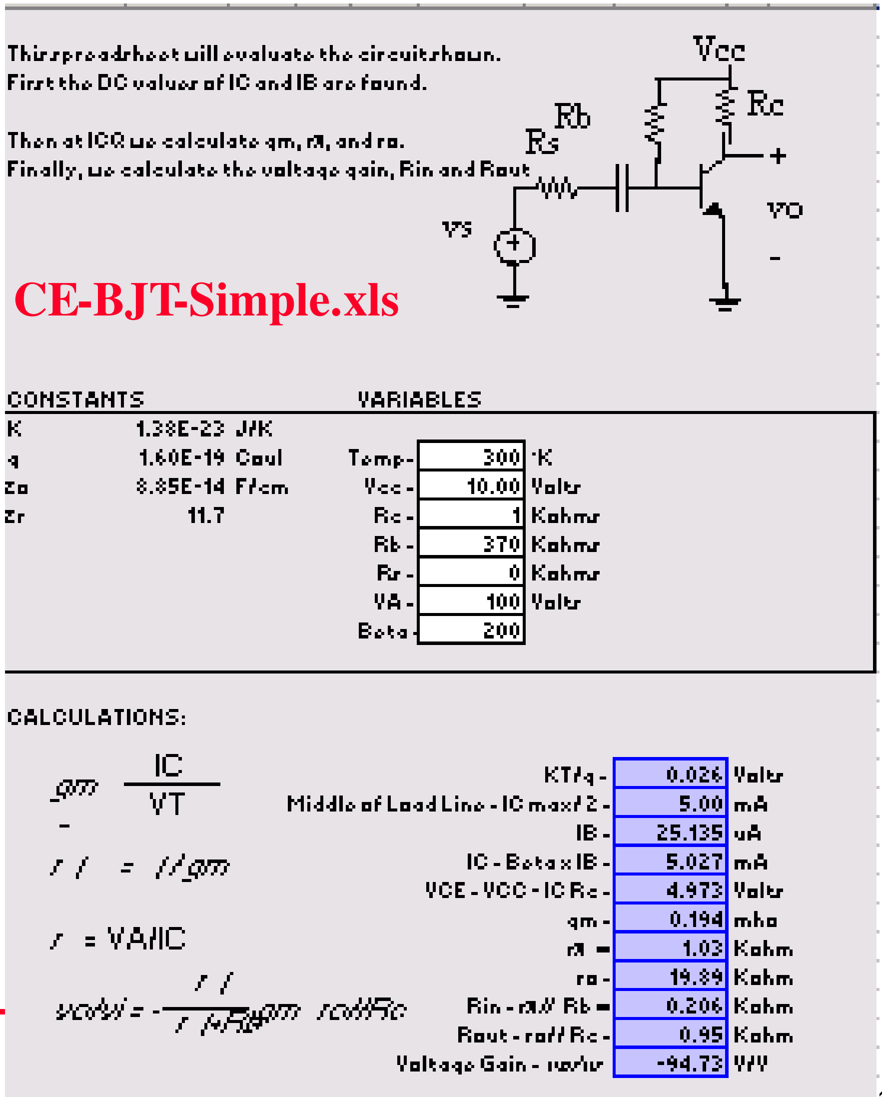
SIMPLE BJT CE AMPLIFIER CALCULATOR

Check the results by doing the calculations by hand.



This spreadsheet will evaluate the circuit shown.
First the DC values of IC and IB are found.

Then at ICQ we calculate gm, rπ, and ro.
Finally, we calculate the voltage gain, Rin and Rout

CE-BJT-Simple.xls

CONSTANTS

K	1.38E-23	J/K
q	1.60E-19	Coul
εo	8.85E-14	F/cm
εr	11.7	

VARIABLES

Temp -	300	°K
Vcc -	10.00	Volts
Rc -	1	Kohms
Rb -	370	Kohms
Rs -	0	Kohms
VA -	100	Volts
Beta -	200	

CALCULATIONS:

gm = IC / VT

rπ = β/gm

ro = VA/IC

vo/vs = - β / (rπ+Rs) gm ro//Rc

KT/q -	0.026	Volts
Middle of Load Line - IC max/ 2 -	5.00	mA
IB -	25.135	uA
IC - Beta x IB -	5.027	mA
VCE - VCC - IC Rc -	4.973	Volts
gm -	0.194	mho
rπ =	1.03	Kohm
ro -	19.89	Kohm
Rin - rπ// Rb =	0.206	Kohm
Rout - ro// Rc -	0.95	Kohm
Voltage Gain - vo/vs	-94.73	V/V

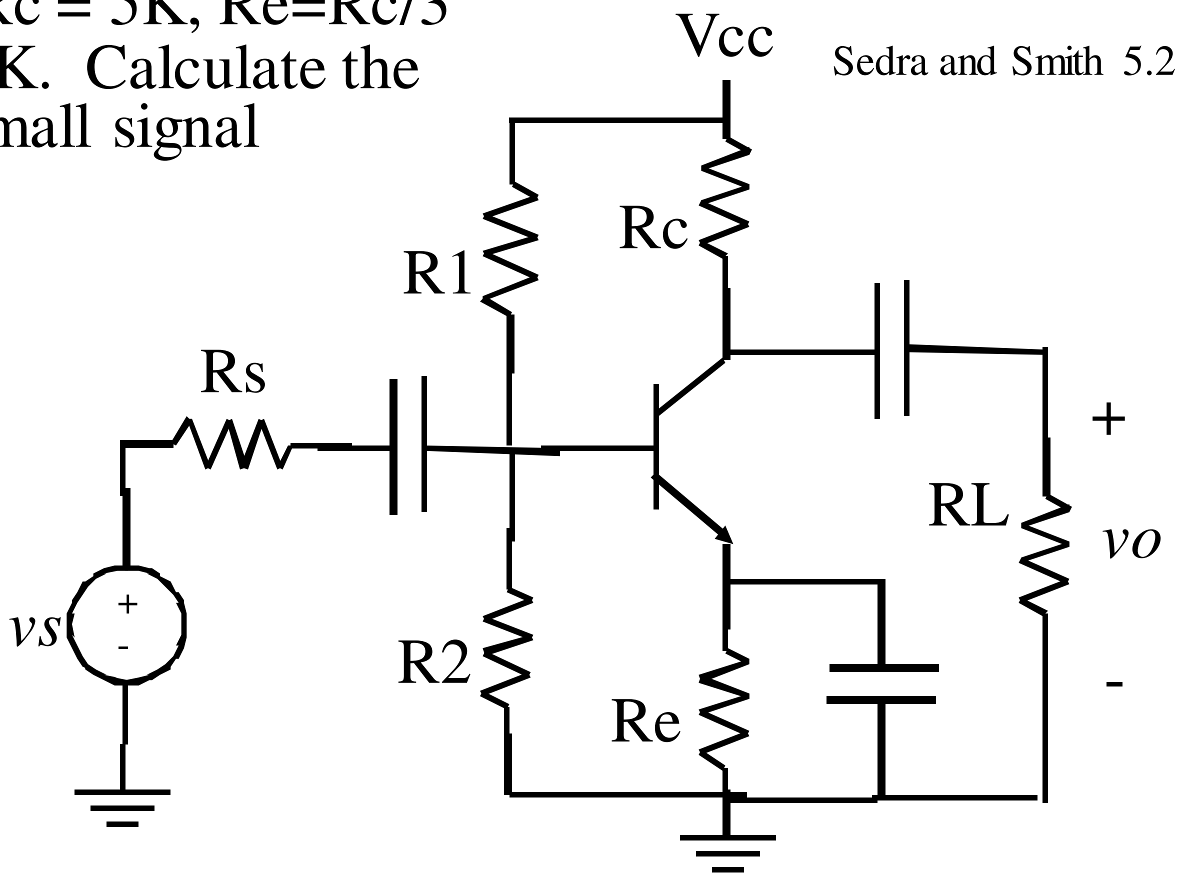
Find IcQ for Beta of 100 and 300

CE BJT AMPLIFIER EXAMPLE 2 (ANALYSIS)

Example: If Vcc = 20V, Rc = 5K, Re=Rc/3 β = 200, R1=30k, R2=10K. Calculate the DC value of IC and the small signal voltage gain.

Repeat for β = 100, 300

Sedra and Smith 5.21



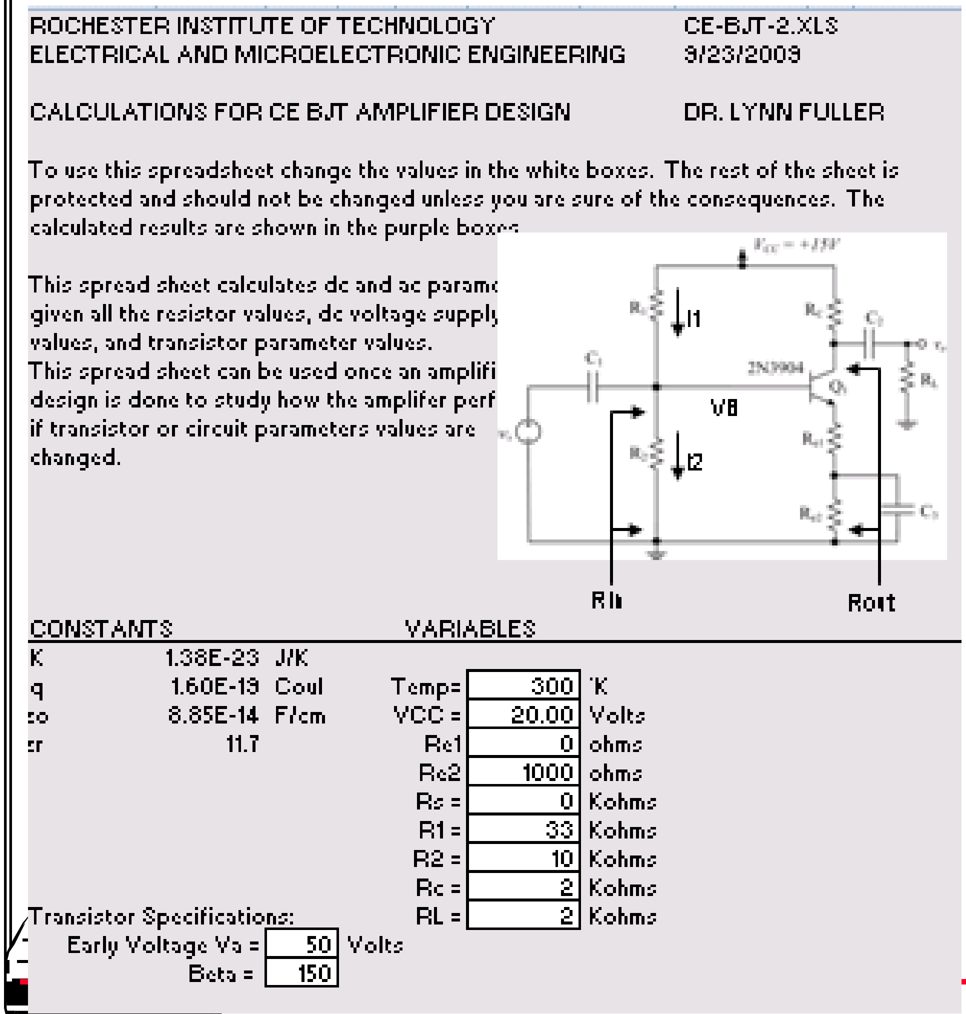
Note: capacitors are a short at frequency of interest. Re provides less sensitivity of Q point to Beta. R1 and R2 give lower equivalent value of RB and less noise.

ANALYSIS OF CIRCUIT ON PREVIOUS PAGE

Approach:

1. Find Thevenin equivalent of R1, R2 and VCC.
2. Do KVL around the BE loop to find IB.
3. Find IC = Beta IB
4. Calculate gm, rπ and ro.
5. Draw the ac equivalent circuit.
6. Find the voltage gain vo/vi, rin and rout

SPREAD SHEET ANALYSIS PREVIOUS CIRCUIT



ROCHESTER INSTITUTE OF TECHNOLOGY CE-BJT-2.XLS
ELECTRICAL AND MICROELECTRONIC ENGINEERING 9/23/2009

CALCULATIONS FOR CE BJT AMPLIFIER DESIGN DR. LYNN FULLER

To use this spreadsheet change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes

This spread sheet calculates dc and ac parame
given all the resistor values, dc voltage supply
values, and transistor parameter values.
This spread sheet can be used once an amplifi
design is done to study how the amplifer perf
if transistor or circuit parameters values are
changed.

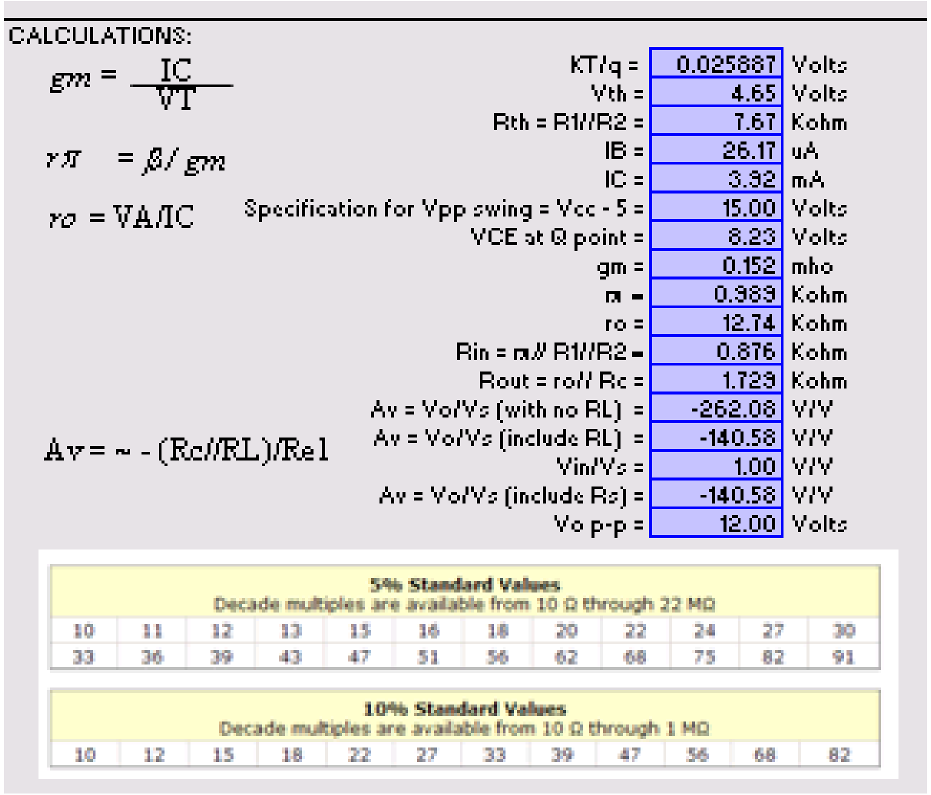
CONSTANTS VARIABLES

K	1.38E-23	J/K
q	1.60E-19	Coul
εo	8.85E-14	F/cm
εr	11.7	

Temp=	300	'K
VCC =	20.00	Volts
Re1	0	ohms
Re2	1000	ohms
Rs =	0	Kohms
R1 =	33	Kohms
R2 =	10	Kohms
Rc =	2	Kohms
RL =	2	Kohms

Transistor Specifications:

Early Voltage Va =	50	Volts
Beta =	150	



CALCULATIONS:

$gm = \frac{IC}{VT}$

$r\pi = \beta / gm$

$ro = VA/IC$

$Av = \sim -(Rc//RL)/Re1$

KT/q =	0.025887	Volts
Vth =	4.65	Volts
Rth = R1//R2 =	7.67	Kohm
IB =	26.17	uA
IC =	3.92	mA
Specification for Vpp swing = Vcc - 5 =	15.00	Volts
VCE at Q point =	8.23	Volts
gm =	0.152	mho
rπ =	0.989	Kohm
ro =	12.74	Kohm
Rin = rπ// R1//R2 =	0.876	Kohm
Rout = ro// Rc =	1.729	Kohm
Av = Vo/Vs (with no RL) =	-262.08	V/V
Av = Vo/Vs (include RL) =	-140.58	V/V
Vin/Vs =	1.00	V/V
Av = Vo/Vs (include Rs) =	-140.58	V/V
Vo p-p =	12.00	Volts

5% Standard Values
Decade multiples are available from 10 Ω through 22 MΩ

10	11	12	13	15	16	18	20	22	24	27	30
33	36	39	43	47	51	56	62	68	75	82	91

10% Standard Values
Decade multiples are available from 10 Ω through 1 MΩ

10	12	15	18	22	27	33	39	47	56	68	82

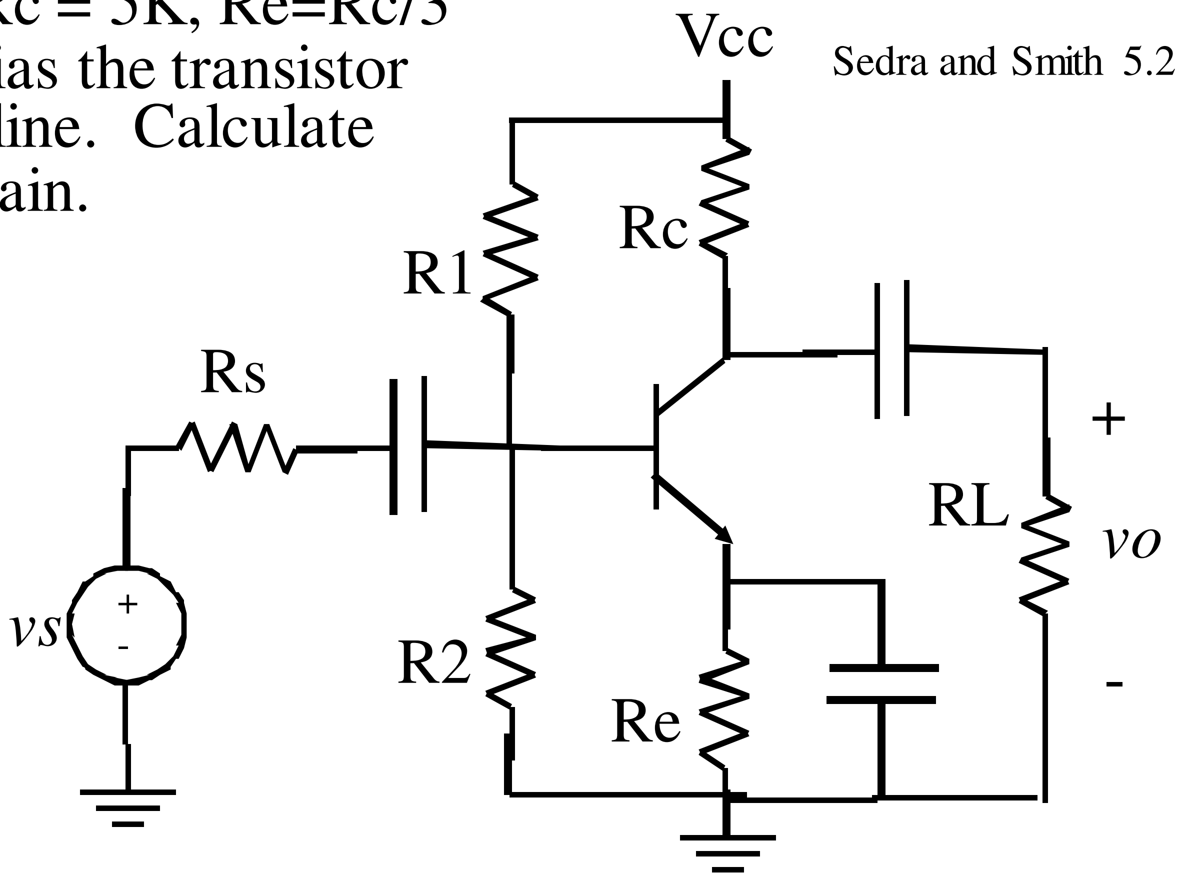
CE-BJT-Analysis.xls

CE BJT AMPLIFIER EXAMPLE 3 (DESIGN)

Example: If Vcc = 20V, Rc = 5K, Re=Rc/3 β = 200 Find R1, R2 to bias the transistor in the middle of the load line. Calculate the small signal voltage gain.

Repeat for β = 100, 300

Sedra and Smith 5.21



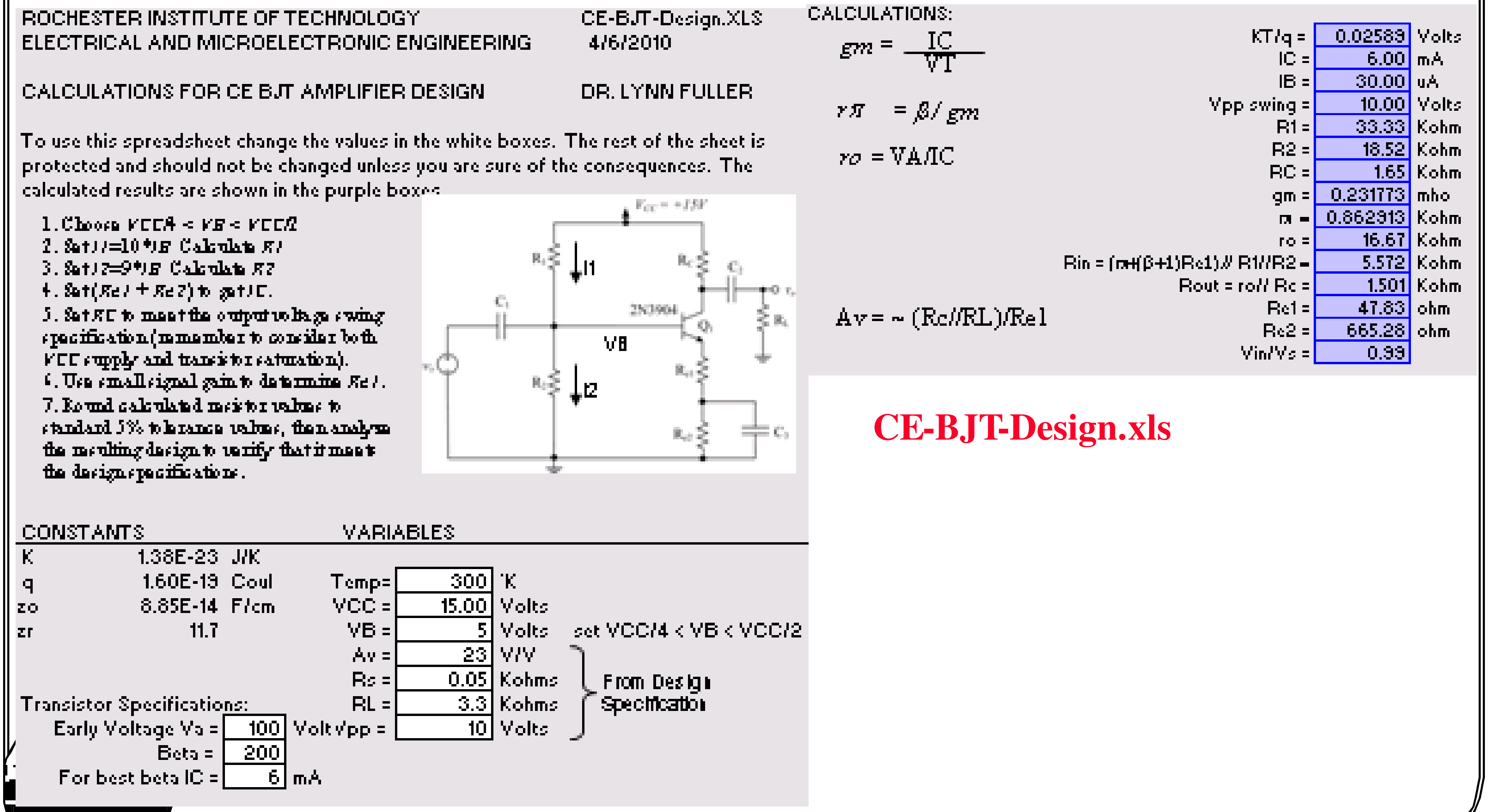
Note: capacitors are a short at frequency of interest. Re provides less sensitivity of Q point to Beta. R1 and R2 give lower equivalent value of RB and less noise.

DESIGN CALCULATIONS FOR CIRCUIT ON THE PREVIOUS PAGE

Approach:

1. Pick supply voltage, VCC.
2. Pick IC where transistor has good Beta, etc.
3. Choose VB between VCC/4 and VCC/2 say VCC/3
4. Set I1 = 10 IB find R1
5. Set I2 = 9 IB find R2
6. Calculate RE to get IC
7. Calculate RC to place VCE near middle of DC load line.
8. Calculate gm, rπ, ro
9. Draw ac equivalent circuit, include selection of RL and RS
10. Calculate vo/vi, rin and rout

SPREAD SHEET CE BJT DESIGN



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CE-BJT-Design.XLS
4/6/2010

CALCULATIONS FOR CE BJT AMPLIFIER DESIGN

DR. LYNN FULLER

To use this spreadsheet change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes.

1. Choose VCC/4 < VB < VCC/2
2. Set I1=10*IB Calculate R1
3. Set I2=9*IB Calculate R2
4. Set (Re1 + Re2) to get IC.
5. Set RC to meet the output voltage swing specification (remember to consider both VCC supply and transistor saturation).
6. Use small signal gain to determine Re1.
7. Round calculated resistor values to standard 5% tolerance values, then analyze the resulting design to verify that it meets the design specifications.

CONSTANTS

K	1.38E-23	J/K
q	1.60E-19	Coul
zo	8.85E-14	F/cm
zr	11.7	

VARIABLES

Temp=	300	'K	
VCC =	15.00	Volts	
VB =	5	Volts	set VCC/4 < VB < VCC/2
Av =	23	V/V	From Design Specification
Rs =	0.05	Kohms	
RL =	3.3	Kohms	
Volt Vpp =	10	Volts	

Transistor Specifications:

Early Voltage Va =	100	
Beta =	200	
For best beta IC =	6	mA

CALCULATIONS:

$$gm = \frac{IC}{VT}$$

$$r\pi = \beta / gm$$

$$ro = VA/IC$$

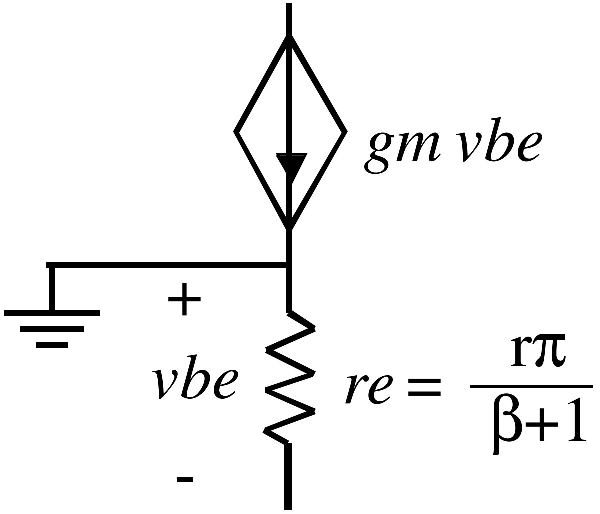
Av = ~ (Rc//RL)/Re1

KT/q =	0.02589	Volts
IC =	6.00	mA
IB =	30.00	uA
Vpp swing =	10.00	Volts
R1 =	33.33	Kohm
R2 =	18.52	Kohm
RC =	1.65	Kohm
gm =	0.231773	mho
rπ =	0.862913	Kohm
ro =	16.67	Kohm
Rin = (rπ+(β+1)Re1)// R1//R2 =	5.572	Kohm
Rout = ro// Rc =	1.501	Kohm
Re1 =	47.83	ohm
Re2 =	665.28	ohm
Vin/Vs =	0.99	

CE-BJT-Design.xls

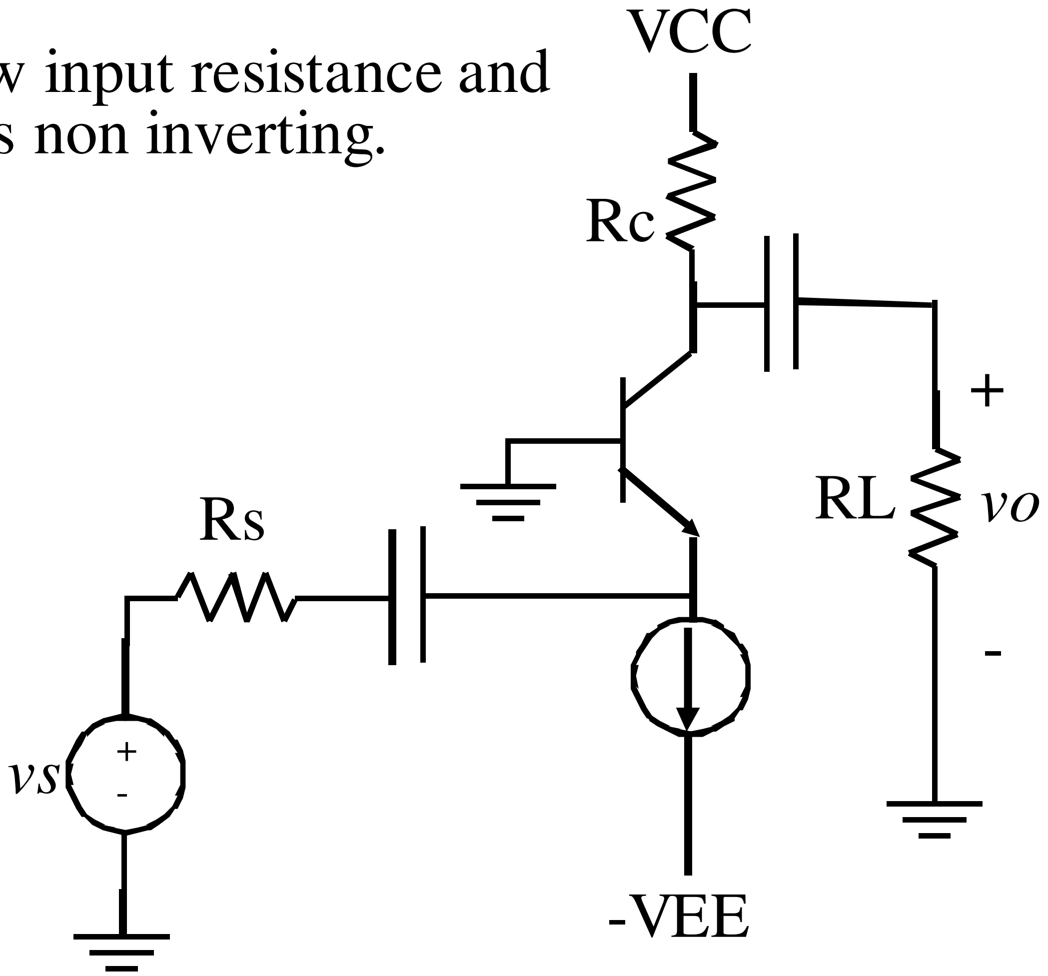
COMMON BASE AMPLIFIER

The CB BJT amplifier has low input resistance and has the same gain as CE but is non inverting.



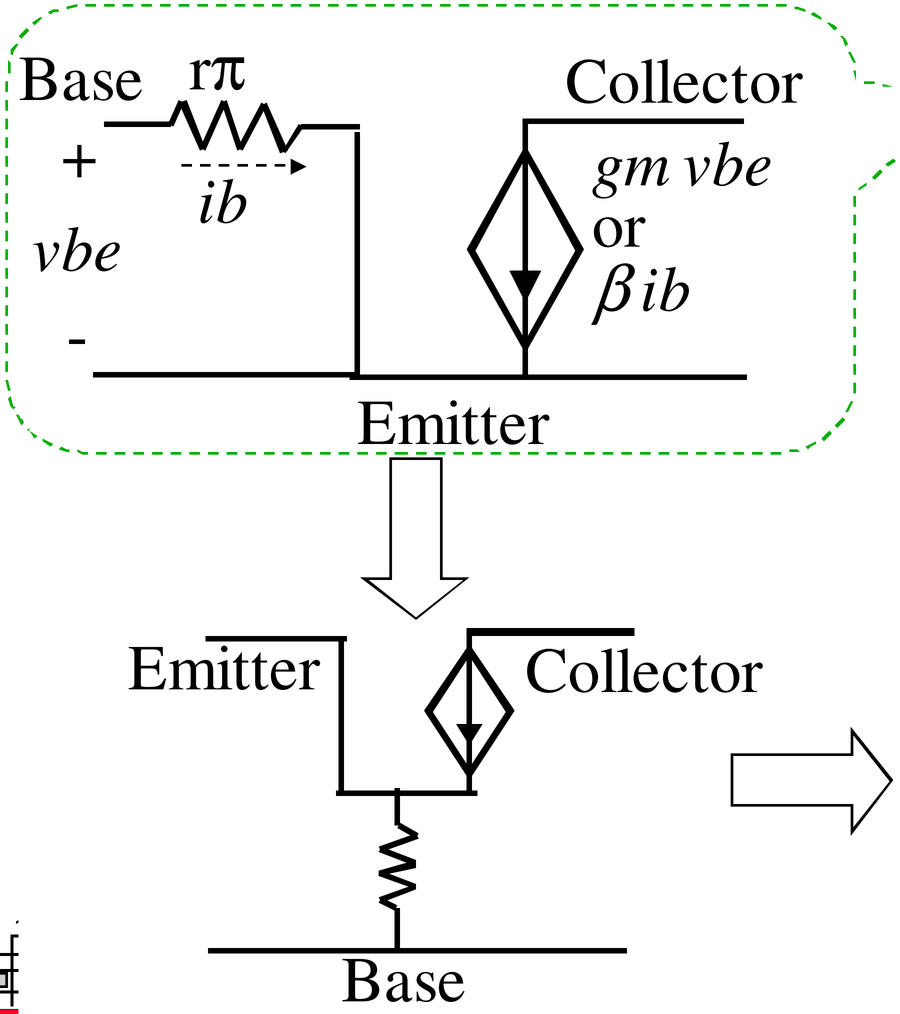
$$re = \frac{r\pi}{\beta+1}$$

Small signal equivalent Circuit for CB



Note: capacitors are a short at frequency of interest

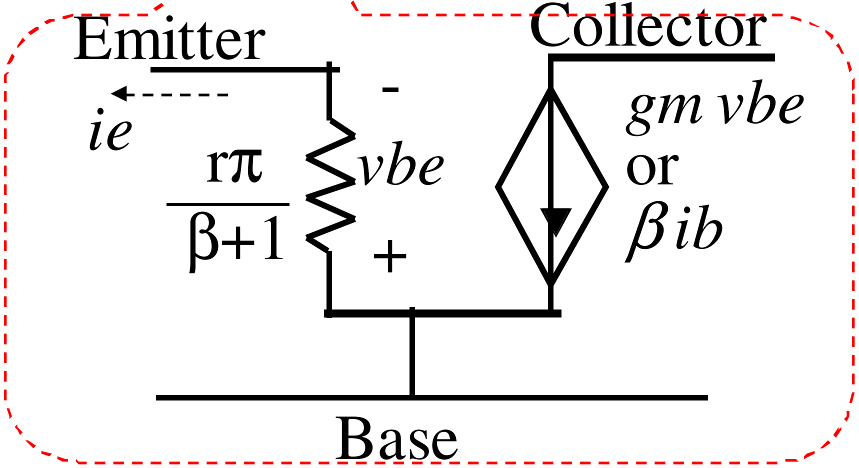
DERIVE COMMON BASE VERSION OF SMALL SIGNAL MODEL



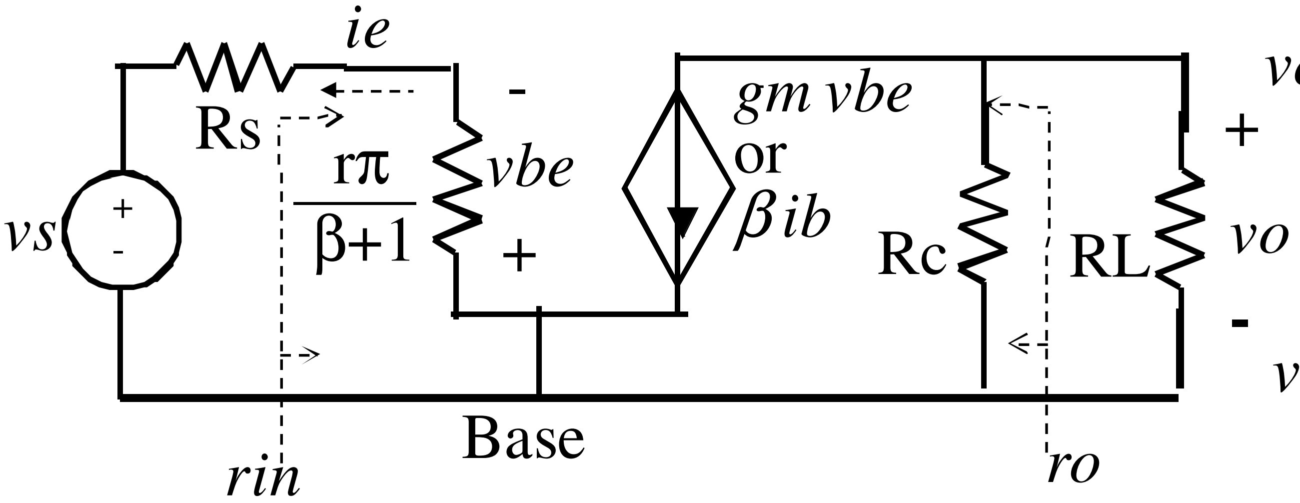
$$Ic = gm\ vbe = gm\ ib\ r\pi$$

$$Ic = gm\ vbe = gm\ ie\ \frac{r\pi}{\beta+1}$$

$$= gm\ ib\ (\beta+1)\ \frac{r\pi}{\beta+1}$$



CB AMPLIFIER VOLTAGE GAIN



$$vo = - gm\ vbe\ Rc//RL$$

$$vbe = - vs \frac{\frac{r\pi}{\beta+1}}{Rs + \frac{r\pi}{\beta+1}}$$

$$rin = \frac{r\pi}{\beta+1}$$

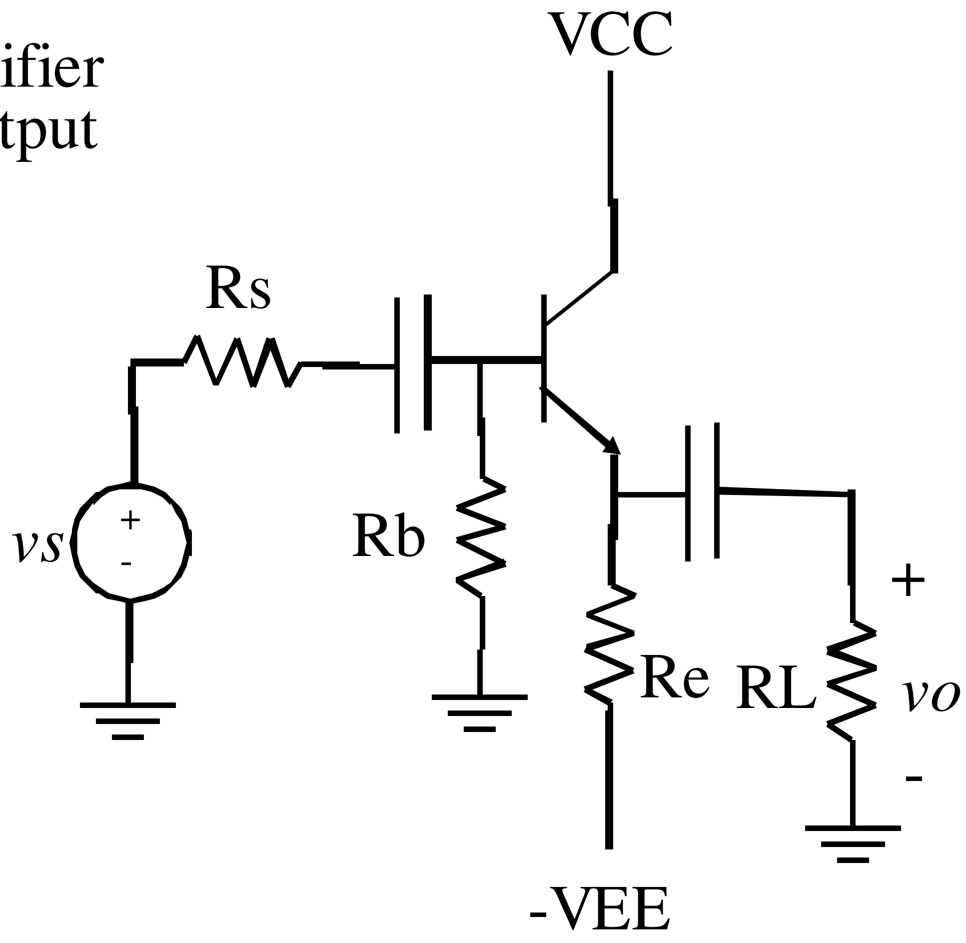
$$ro = Rc$$

$$\frac{vo}{vs} = gm \frac{\frac{r\pi}{\beta+1}}{Rs + \frac{r\pi}{\beta+1}} Rc//RL$$

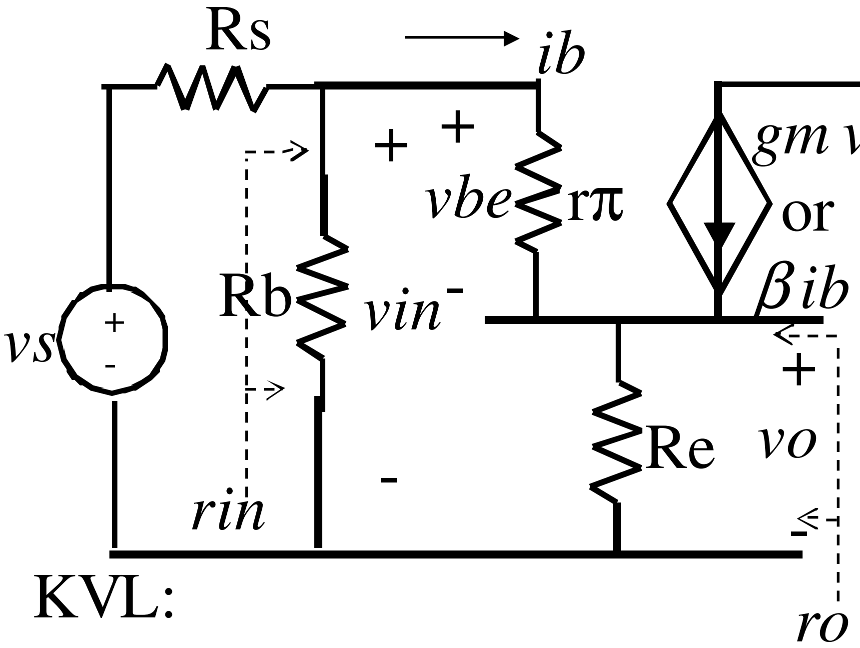
If Rs=0 same vo/vs as CE amplifier (but non inverting)

COMMON COLLECTOR AMPLIFIER

The CC or emitter follower amplifier has high input resistance, low output resistance and voltage gain ~1



CC SMALL SIGNAL ANALYSIS (RIN, VOLTAGE GAIN)



$$vo = Re\,(\beta + 1)\,ib$$

$$vin = vs\,\frac{Rb//Rin'}{Rs + Rb//Rin'}$$

$$\frac{vo}{vs} = \frac{vo}{ib}\,\frac{ib}{vin}\,\frac{vin}{vs}$$

$$\boxed{\frac{vo}{vs} = \left(\frac{Re\,(\beta + 1)}{r\pi + Re\,(\beta + 1)}\right)\left(\frac{Rb//Rin'}{Rs + Rb//Rin'}\right)}$$

Can be ~1

KVL:

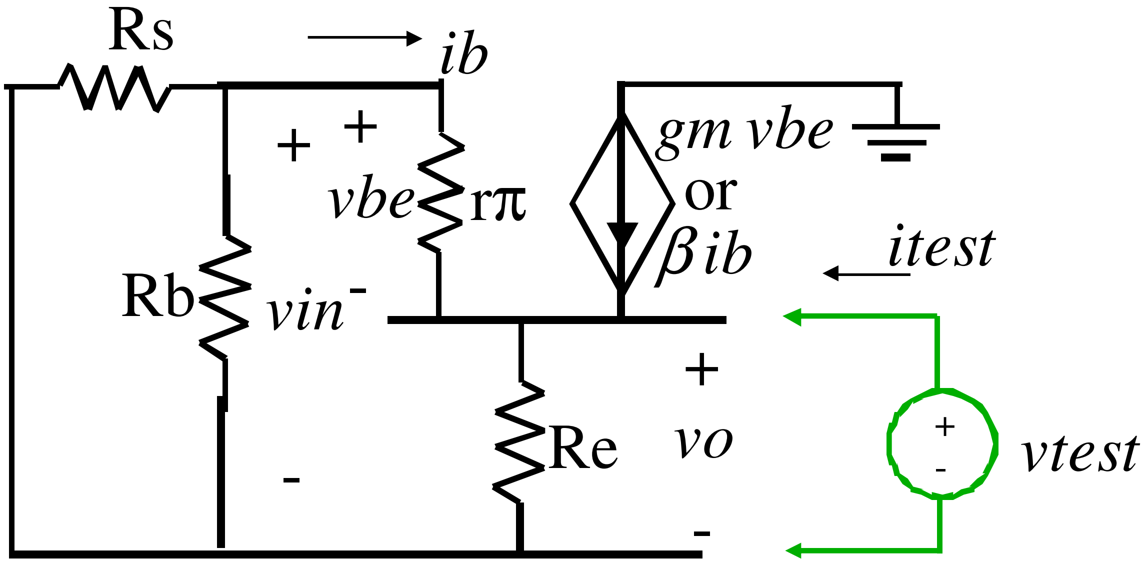
$$ib\,r\pi + Re\,(\beta + 1)\,ib - vin = 0$$

$$ib = \frac{vin}{r\pi + Re\,(\beta + 1)} \longrightarrow Rin' = vin/ib = r\pi + Re\,(\beta + 1)$$

$$\boxed{Rin = Rb//Rin' = Rb//\ [r\pi + Re\,(\beta + 1)]}$$

Can be high

CC SMALL SIGNAL ANALYSIS (OUTPUT RESISTANCE)



$$Ro = vtest/itest$$

$$\boxed{Ro = Re // \frac{(r\pi + Rx)}{(1+\beta)}}$$

Can be low

Let Rx = Rs//Rb

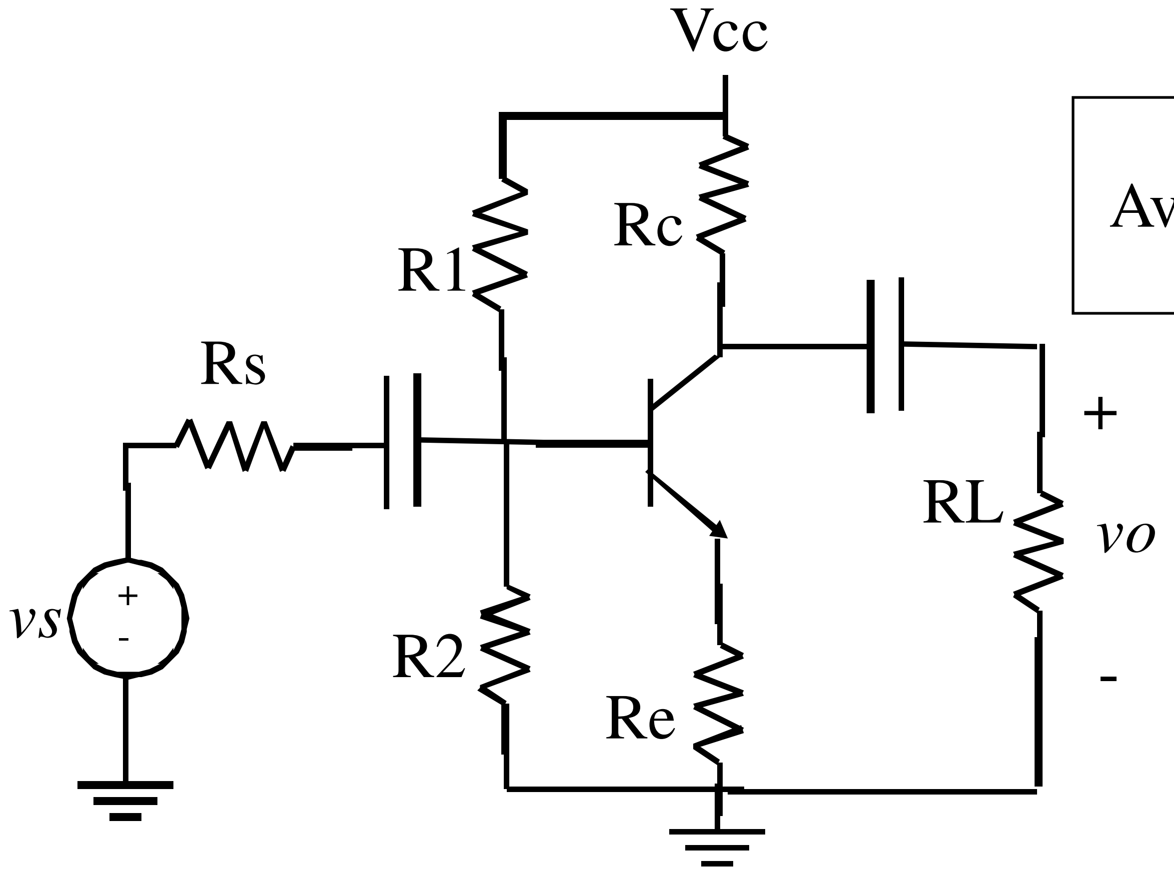
KCL:

$$itest = \frac{vtest}{Re} + \frac{vtest}{(r\pi + Rx)} - \beta ib$$

$$\text{and } ib = -\frac{vtest}{(r\pi + Rx)}$$

$$itest = \frac{vtest}{Re} + \frac{vtest}{(r\pi + Rx)}(1+\beta)$$

CE AMPLIFIER WITH EMITTER FEEDBACK



$$Av = \frac{-\ \beta\ (Rc//RL)}{(\beta+1)\ (re + Re)}$$

Where re = $r\pi/(\beta+1)$

$$Av = \sim -\ \frac{Rc//RL}{Re}$$

SUMMARY FOR SINGLE TRANSISTOR AMPLIFIERS

	CE	CB	CC	CE plus Re
Rin	**Medium**	**Low**	**Highest**	**High**
Ro	**Rc**	**Rc**	**Low**	**Rc**
Av= *vo/vin*	**High**	**High**	**<1**	**~Rc/Re**

If you wish to include the effect of the source resistance RS on overall voltage gain *vo/vs* then reduce the gain by multiplying *vo/vin* by Rin/(Rin+RS)

If you wish to include the effect of a load resistor RL on the overall voltage gain *vo/vs* then replace Rc with Rc//RL

SUMMARY FOR SINGLE TRANSISTOR AMPLIFIERS

$\alpha = IC/IE$

$\beta = IC/IB$

$\alpha = \beta/(\beta+1)$

$\beta = \alpha/(1-\alpha)$

Rth = Thevenin equivalent of Base DC Bias network

	CE	**CB**	**CC**	**CE plus Re**
Rin	$r\pi$// Rth	$[r\pi/(\beta+1)]$//Rth	Rth//$[r\pi + (\beta+1)$(RE//RL)]	Rth//$[r\pi + (\beta+1)$RE]
Ro	RC//*ro*	RC//*ro*	RE//[($r\pi$+ (RS//Rth))/$(\beta+1)$]	RC//*ro*
Av = *vo/vin*	-gm (RC//RL//*ro*)	+*gm*(RC//RL//*ro*)	$\frac{(RE//RL)\ (\beta+1)}{r\pi + (RE//RL)\ (\beta+1)} = \sim 1$	~ RC/RE

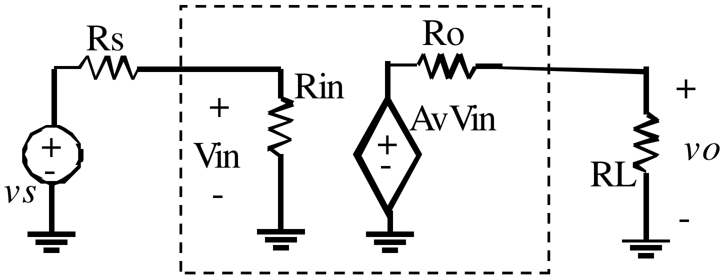
$gm = IC/VT$

Where VT = KT/q
= 0.026 at room T

$ro = VA/IC$

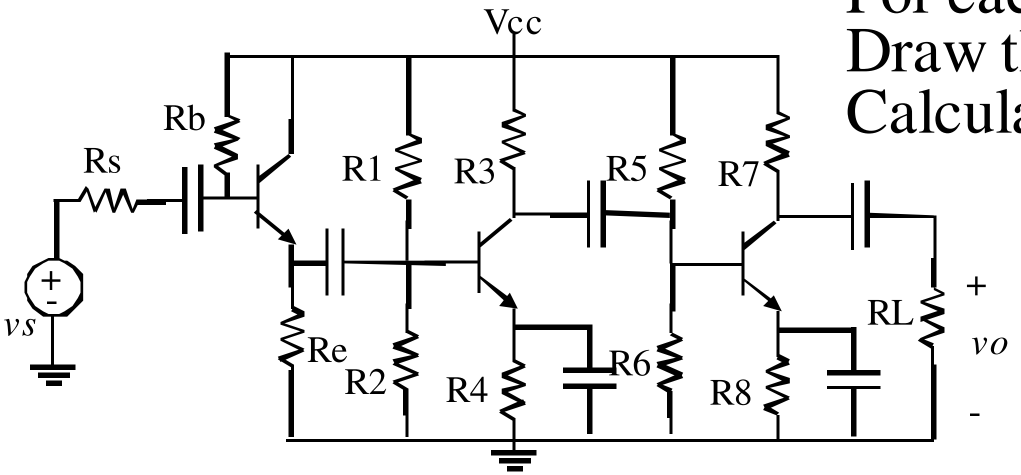
Where VA = Early Voltage

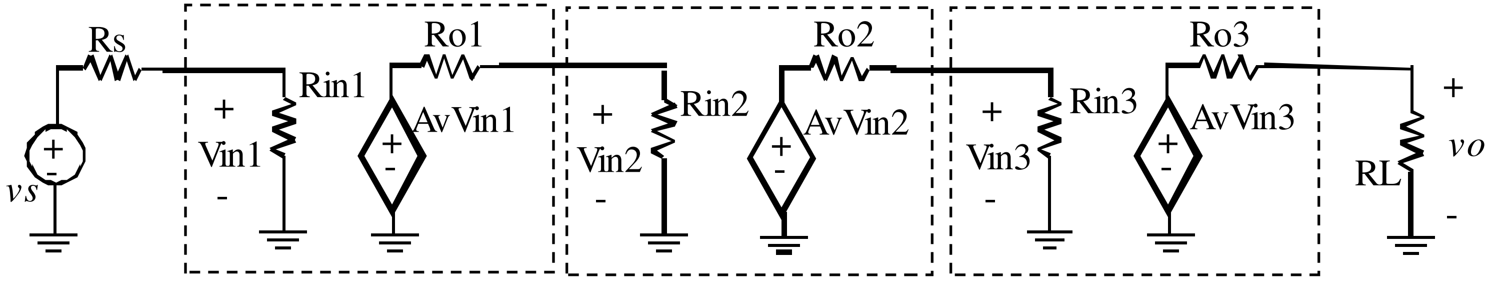
$r\pi = \beta / gm$



AC COUPLED MULTISTAGE AMPLIFIERS

For each stage calculate IC, gm, rπ, ro
Draw the ac equivalent circuit
Calculate the output voltage



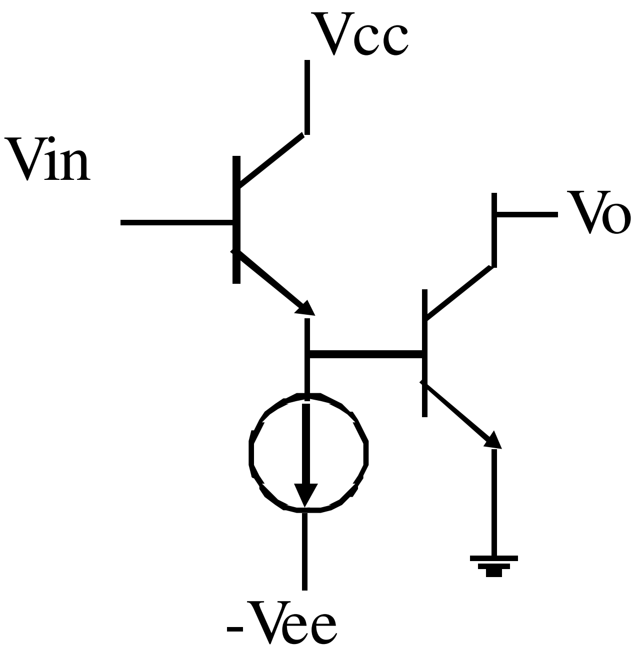


Stage 1 Stage 2 Stage 3

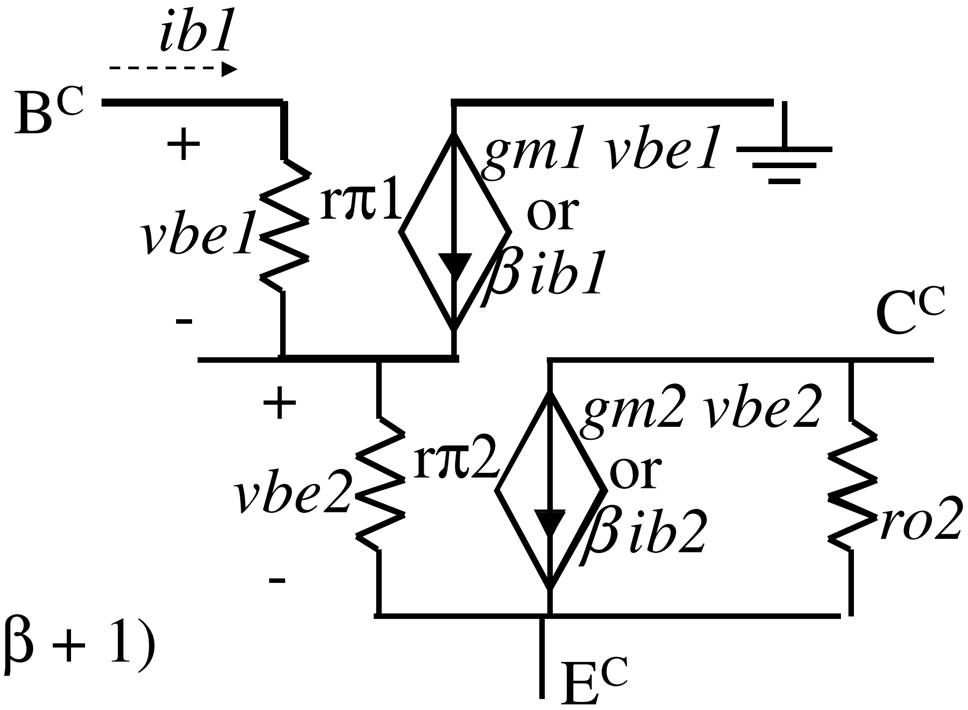
TWO TRANSISTOR DC COUPLED AMPLIFIERS

CC-CE
CC-CC
Darlington
CE-CB (Cascode)

CC-CE AND CC-CC CONFIGURATION



$\beta^C = \beta\ (\beta + 1)$

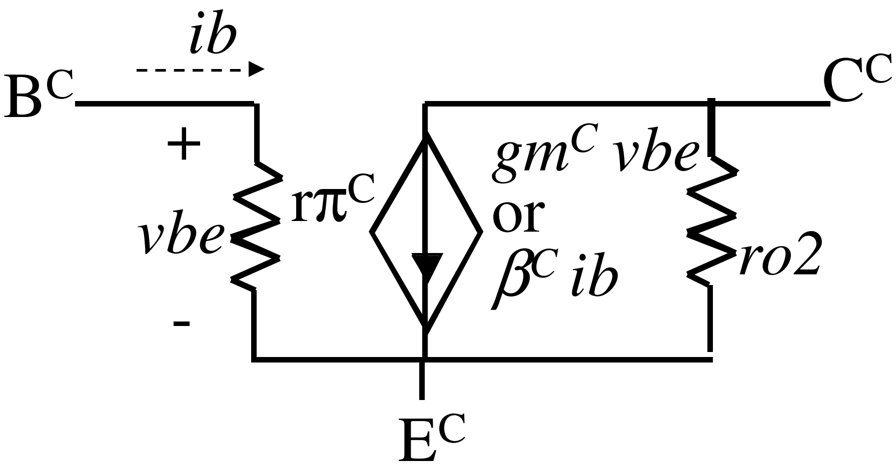


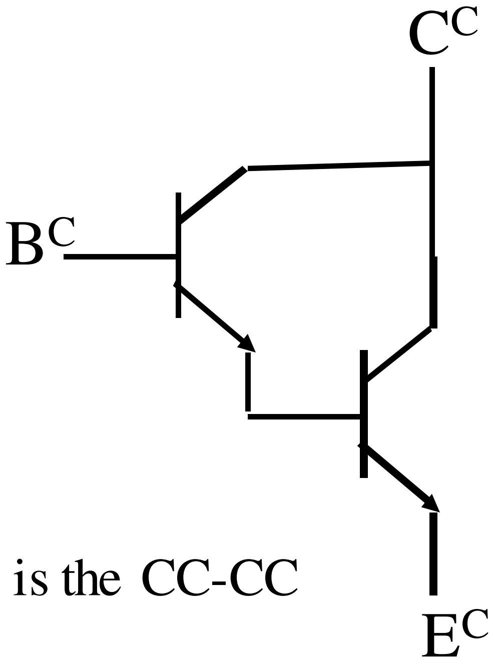
$r\pi^C$ = combined CC-CE input resistance $= r\pi 1 + (\beta + 1)\ r\pi 2$

$ro^C = ro2$

$$gm^C = \left(\frac{gm2}{1 + \frac{r\pi 1}{(\beta+1) r\pi 2}} \right)$$

DARLINGTON CONFIGURATION

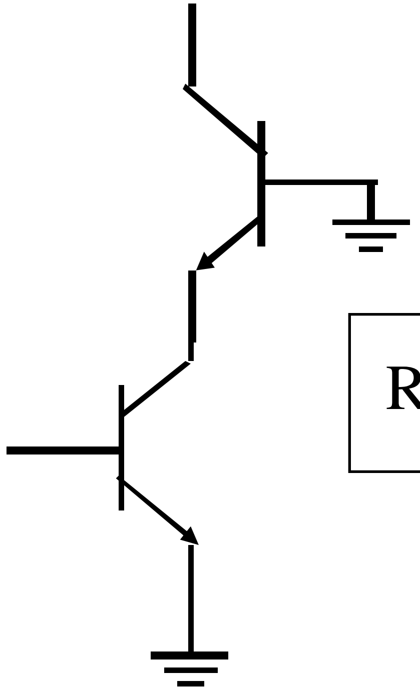




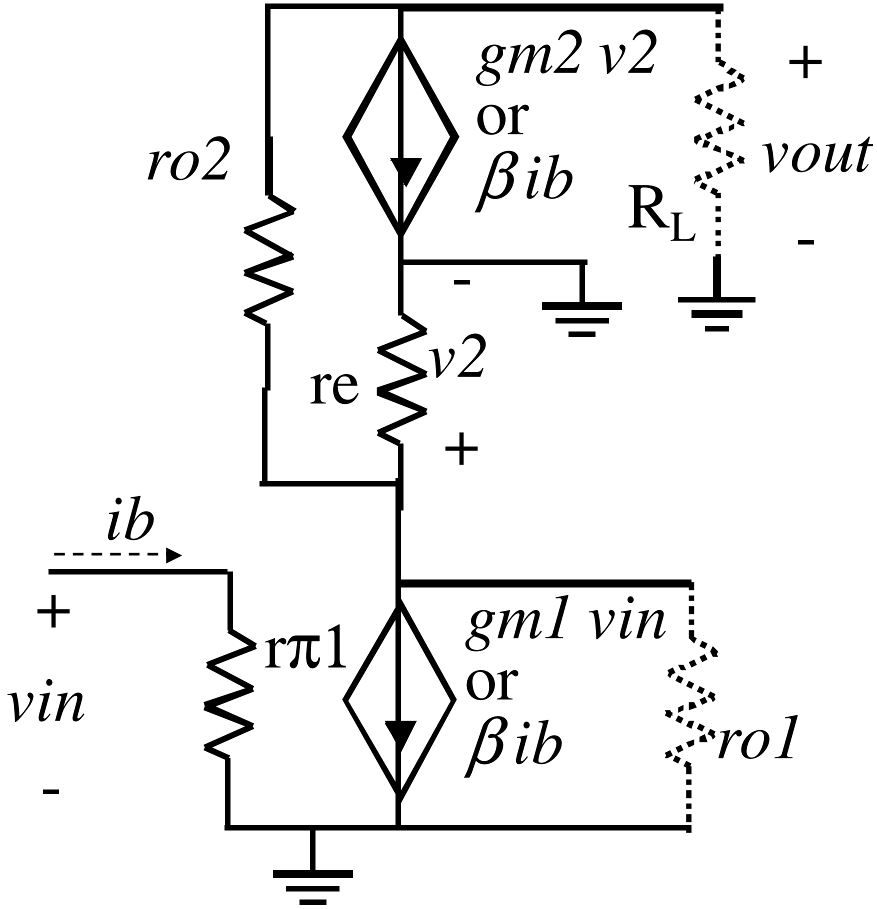
1. The darlington, when used in the CC configuration is the CC-CC configuration already discussed.

2. In the common emitter configuration the darlington is similar to the CC-CE configuration except that the collector of Q1 does not go to the supply, but rather it goes to the output. This reduces the output resistance and increases the input capacitance. Thus the CC-CE is preferred over the darlington.

CE-CB CASCODE CONFIGURATION



Rin = rπ1



Note: *ro1* is in parallel with *re* so we can neglect ro1

CE-CB CASCODE CONFIGURATION

Note: if the load is a current source then RL is infinite and $gm2\ v2$ flows in ro2 only.

Thus $\quad v2 = (gm1Vin + gm2\ v2)\ re$

So $\quad (1 - gm2\ re)\ v2 = gm1\ re\ Vin$ which gives us $v2/Vin$

and $\quad Vout = -\ gm2\ v2\ ro2 - v2$

$\quad or\ Vout = -\ (gm2\ ro2 + 1)v2$

neglect

$$Av = Vout/Vin = Vout/v2 \times v2/vin = -\ (gm2\ ro2 + \cancel{1}\ )\ \frac{gm1\ re}{(1 - gm2\ re)}$$

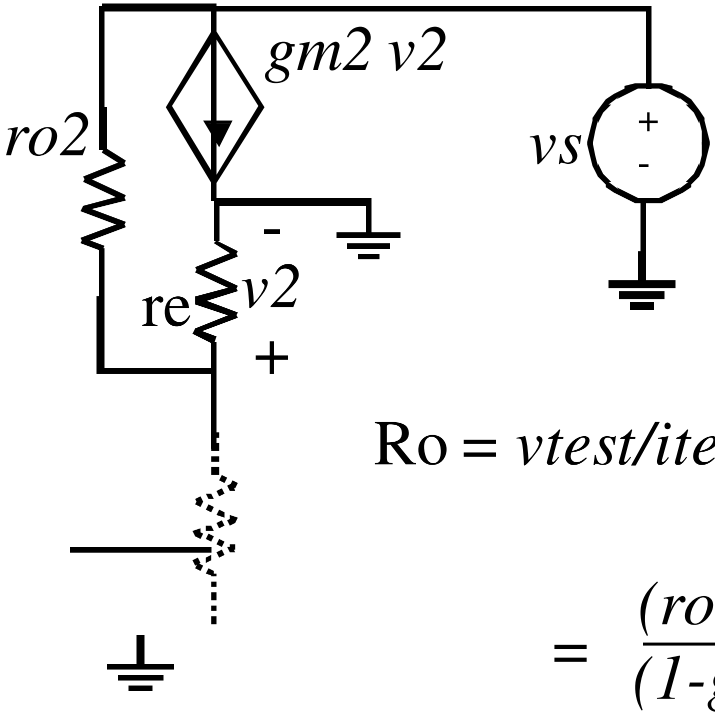
But $\alpha = Ic/Ie = gm2v2/(v2/re) = gm2re$

And $\alpha/\ (1\text{-}\alpha) = \beta$

Thus $\boxed{Av = gm2\ ro2\ \beta}$

CE-CB CASCODE CONFIGURATION

Ro^c is found by "killing" the input source and calculating vtest/itest applied to the output.



$$Itest = gm2\ v2 - v2/re$$

$$Vtest = -\ (v2/re2\ ro2 + v2)$$

$$Ro = vtest/itest = \frac{-\ ((ro2/re2) + 1)}{ro1(gm2 - 1/re2)} = \frac{-((ro2) + \overset{\text{neglect}}{re2})}{(gm2re2 - 1)}$$

$$= \frac{(ro2) \qquad 1}{(1\text{-}gm2re2)} = \boxed{ro2\ \beta = Ro}$$

CE-CB CASCODE CONFIGURATION

Summary: $R_{in} = r\pi1$
$R_{out} = ro2\ \beta$
$Av = gm2\ ro2\ \beta$
(no miller capacitance)

REFERENCES

1. Sedra and Smith, chapter 5.
2. Device Electronics for Integrated Circuits, 2nd Edition, Kamins and Muller, John Wiley and Sons, 1986.
3. The Bipolar Junction Transistor, 2nd Edition, Gerald Neudeck, Addison-Wesley, 1989.
4. Data sheets for 2N3904

HOMEWORK – BJT AMPLIFIERS 2012

1. Derive the equation on page 4 for δVout/δVin.

2. Calculate the maximum possible voltage gain for a CE amplifier when biased by an ideal current source (RC is infinite) and Rs = 0 and RL is infinite. State appropriate assumptions.

3. Calculate the voltage gain, input resistance and output resistance of the circuits provided below.
   - 3.1 Simple CE
   - 3.2 CE
   - 3.3 CC

4. Make a spread sheet that will do the calculations for the circuit in problem 3.3.

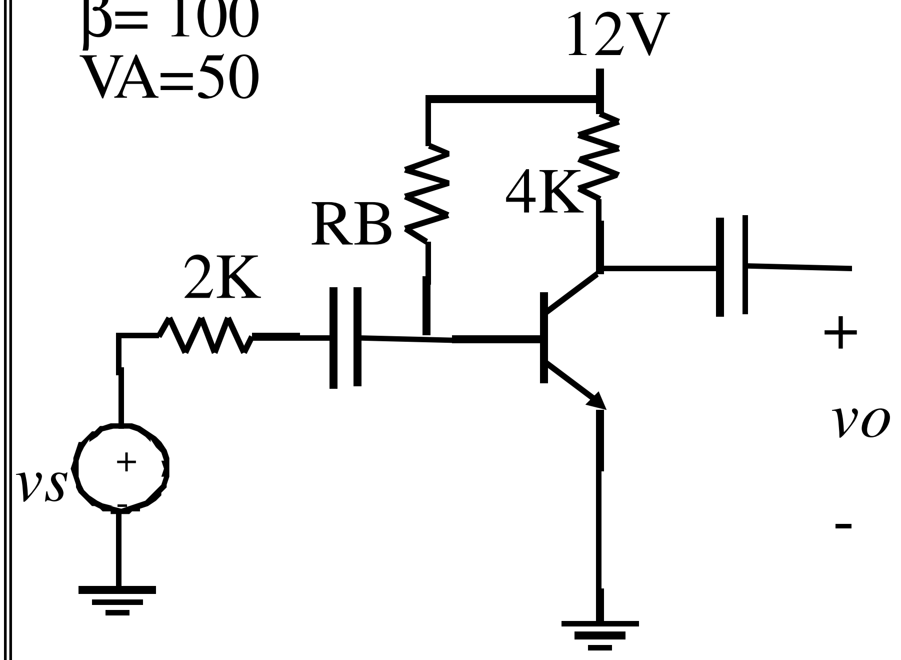
5. Calculate the voltage gain for the multistage amplifier circuit shown below.

HOMEWORK –BJT AMPLIFIERS 2012

Pro 3.1

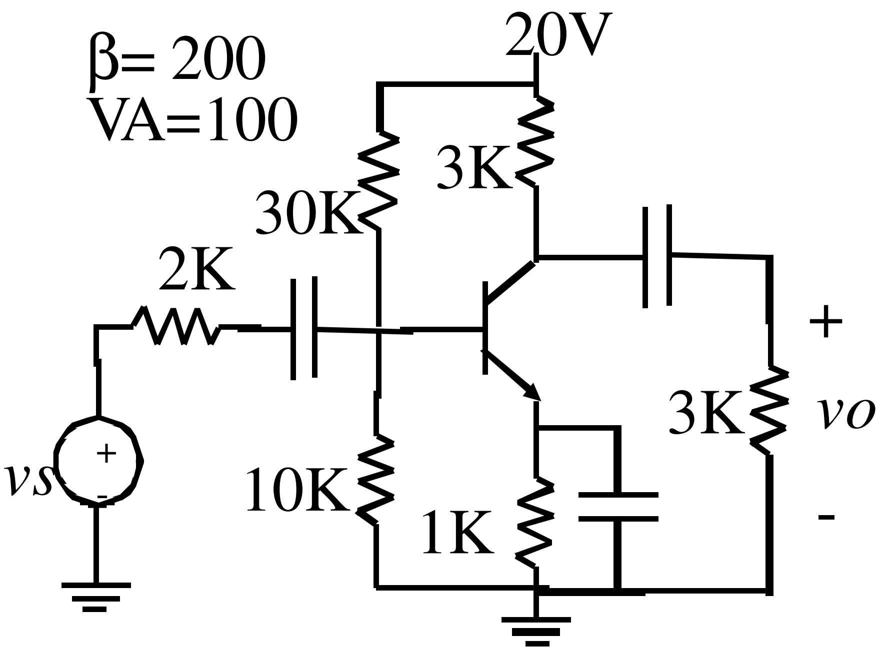
Find RB to make IC= 2 mA

β= 100
VA=50



Pro 3.2

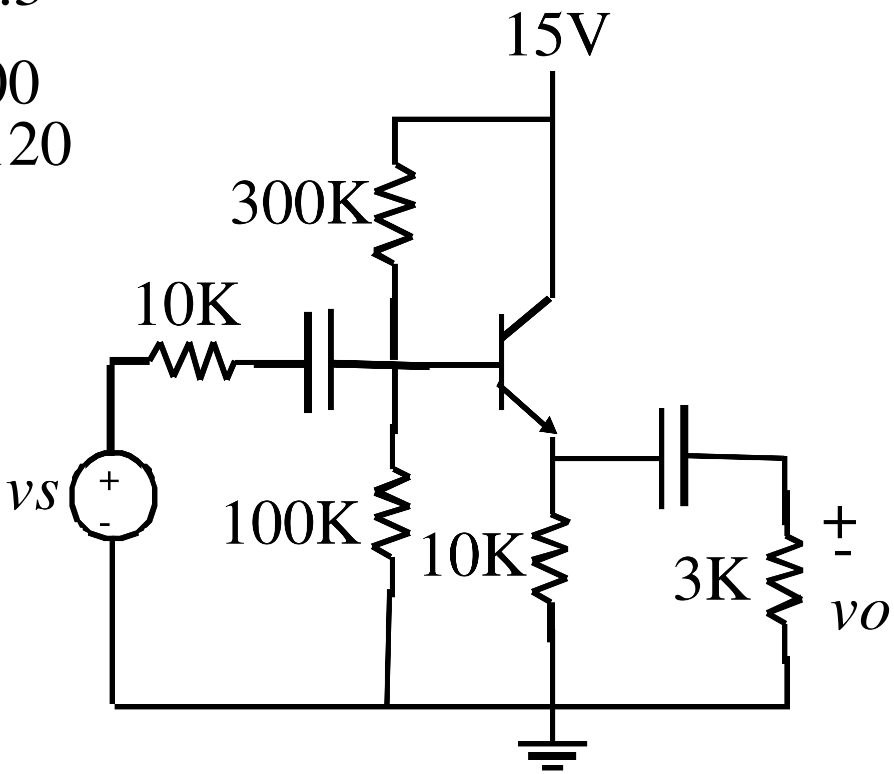
β= 200
VA=100



HOMEWORK –BJT AMPLIFIERS 2012

Pro 3.3

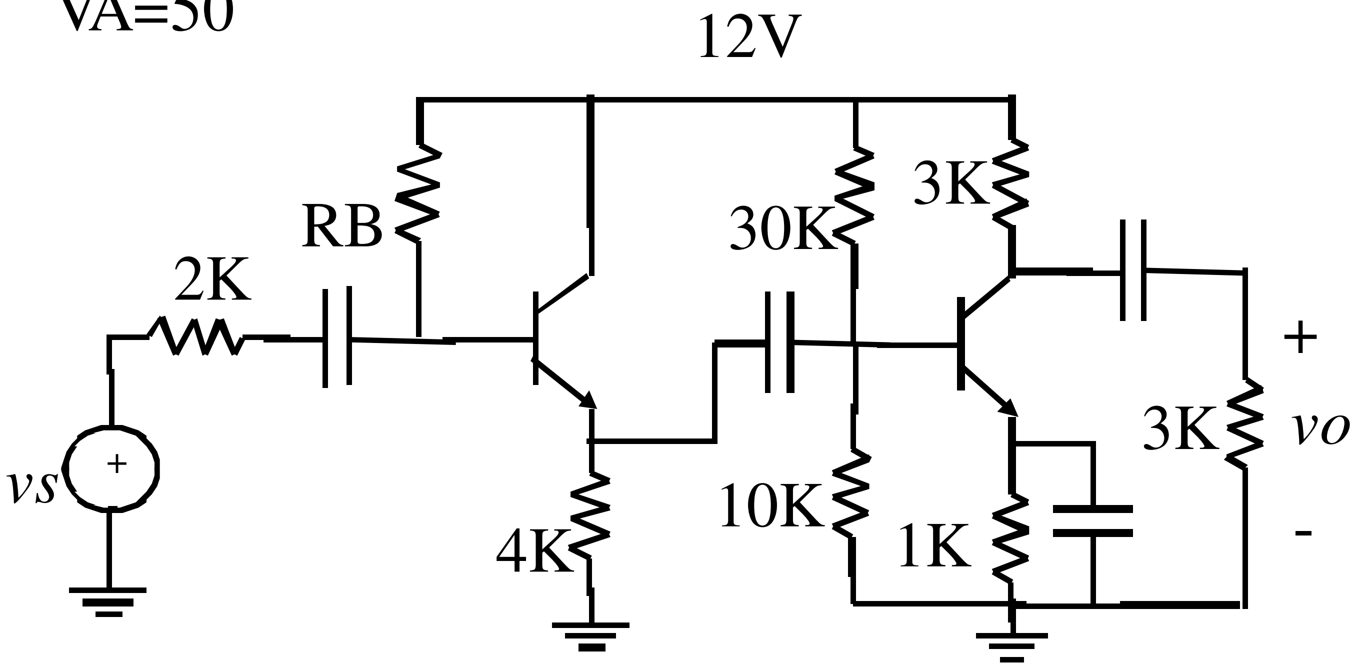
$\beta= 300$
VA=120



HOMEWORK –BJT AMPLIFIERS 2012

Pro 5

$\beta= 100$
VA=50



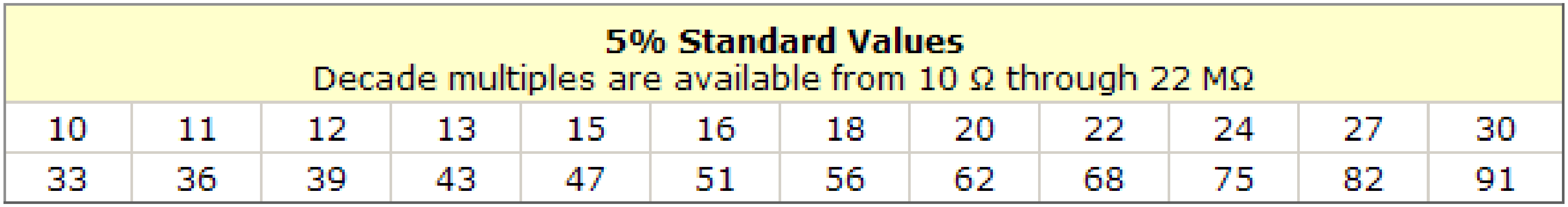
BJT SPICE PARAMETERS

Name	Parameter	Unit	Default
IS	transport saturation current	A	1.0E-16
BF	ideal maximum forward beta	-	100
NF	forward current emission coefficient	-	1.0
VAF	forward Early voltage	V	infinite
IKF	corner for forward beta high current roll-off	A	infinite
ISE	B-E leakage saturation current	A	1.0E-13
NE	B-E leakage emission coefficient	-	1.5
BR	Ideal maximum reverse beta	-	1
NR	reverse current emission coefficient	-	1
VAR	reverse Early voltage	V	infinite
IKR	corner for reverse beta high current roll-off	A	infinite
ISC	B-C leakage saturation current	A	0
NC	B-C leakage emission coefficient	-	0.5
NK	high current roll-off coefficient	-	0.5
ISS	substrate p-n saturation current	A	0
NS	substrate emission coefficient	-	0.5
RE	emitter resistance	Ohm	0
RB	zero bias base resistance	Ohm	0
RBM	minimum base resistance	Ohm	RB
IRB	current where RB falls halfway to RBM	A	infinite
RC	collector resistance	Ohm	0
CJE	B-E zero-bias depletion capacitance	F	0

BJT SPICE PARAMETERS

Name	Parameter	Unit	Default
VJE	B-E built-in potential	V	0.75
MJE	B-E junction exponential factor	-	0.33
CJC	B-C zero-bias depletion capacitance	F	0
VJC	B-C built-in potential	V	0.75
MJC	B-C junction exponential factor	-	0.33
XCJC	fraction of B-C capacitance connected to base	-	1
CJS	zero bias collector substrate capacitance	F	0
VJS	substrate junction built-in potential	V	0.75
MJS	substrate junction exponential factor	-	0
FC	coeff. Forward bias depletion capacitance	-	0.5
TF	ideal forward transit time	sec	0
XTF	coefficient for bias dependence of TF	-	0
VTF	voltage describing VBC dependence of TF	V	infinite
ITF	TF dependency on IC	A	0
PTF	excess phase at freq=1.0/(TF2pi) Hz	deg	0
TR	ideal reverse transit time	sec	0
QCO	epitaxial region charge factor	Coul	0
RCO	eitaxial region resistance	Ohm	0
VO	carrier mobility knee voltage	V	10
GAMMA	epitaxial region doping factor	-	1E-11
EG	energy gap for temperature effect on IS	eV	1.11
more			

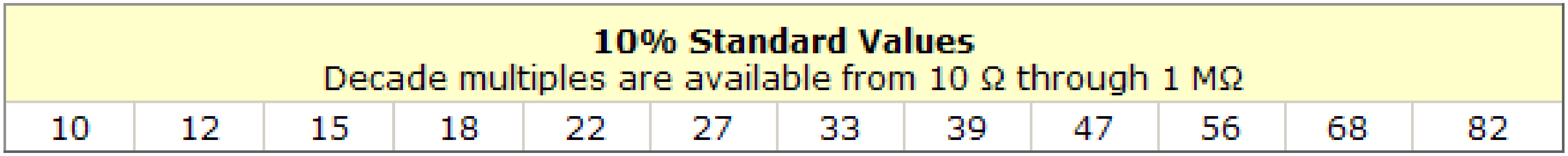
STANDARD RESISTOR VALUES



5% Standard Values

Decade multiples are available from 10 Ω through 22 MΩ

10	11	12	13	15	16	18	20	22	24	27	30
33	36	39	43	47	51	56	62	68	75	82	91

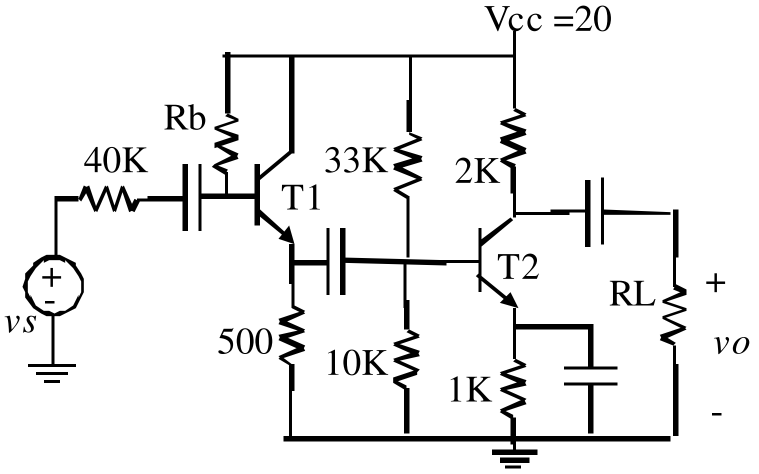


10% Standard Values

Decade multiples are available from 10 Ω through 1 MΩ

10	12	15	18	22	27	33	39	47	56	68	82

Old Exam
BJT Amplifiers



Assume Beta = 150
VA= 50
RL = 2K
Capacitors are shorts for ac analysis

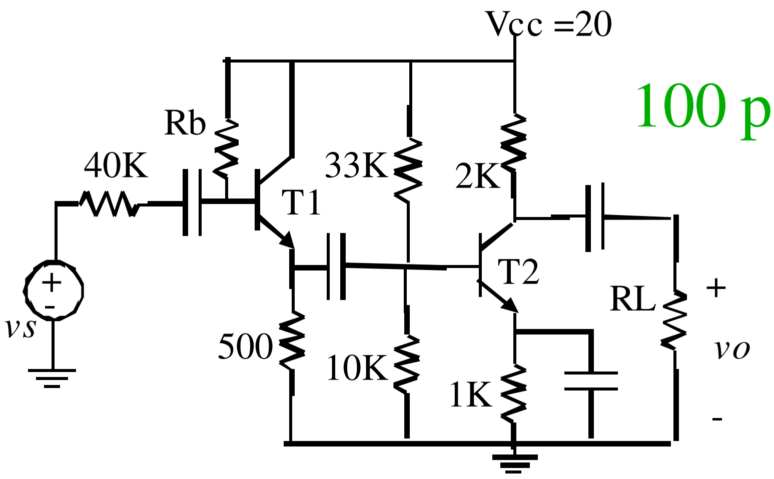
Calculate the value of Rb to bias T1 in the middle of the DC load line.

Calculate dc value of IC for T2

Calculate gm, rπ and ro for T1 and T2

Calculate the voltage gain *vo/vs*

Old Exam
BJT Amplifiers



100 points total

Assume
Beta = 150
VA= 50
RL = 2K
Capacitors are shorts for ac analysis

Calculate the value of Rb to bias T1 in the middle of the DC load line.

5 points

Load line max Ic is 20/500 = 40 mA
KVL: ib Rb + 0.7 +(β+1)ib 500 -20 = 0
5 points ib= 20mA/β and β=150
Find: Rb = 70Kohm **5 points**

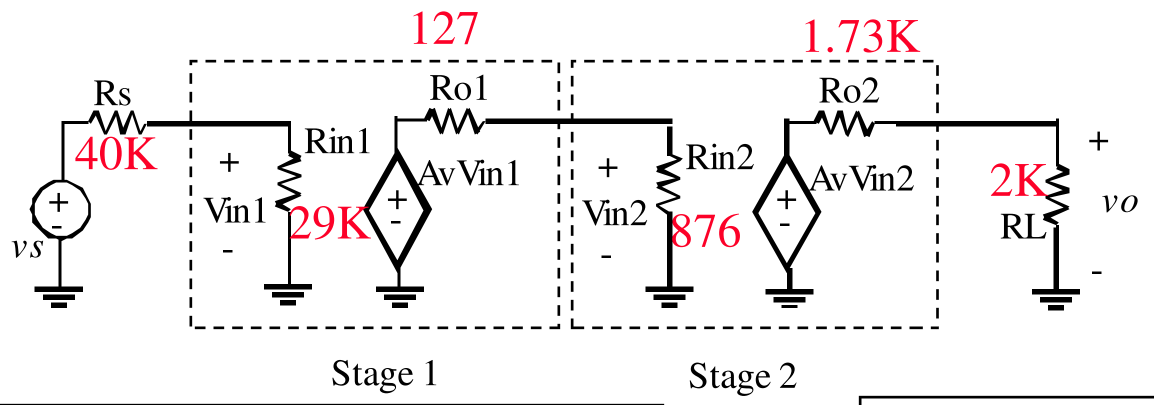
Calculate dc value of IC for T2

Rth = 33K//10K = 7.67K **5 points**
Vth= (20) 10K/ (10K+33K) = 4.65 volts
KVL: ib Rth + 0.7 +(β+1)ib 1K -Vth = 0 **5 points**
Find: ib = 26.2 μA and Ic = 3.92 mA **5 points**

Calculate gm, $r\pi$ and ro for T1 and T2

	gm = Ic/VT **5 points**	$r\pi$ = β/gm **5 points**	ro = VA/IC **5 points**
For T1:	gm = 20mA/0.026=0.769 S	$r\pi$ = 150/gm=195 ohm	ro = 50/20mA = 2.5K
For T2	gm = 3.92mA/0.026=0.151 S	$r\pi$ = 150/gm=0.989Kohm	ro = 50/3.92mA = 12.7K

Calculate the voltage gain *vo/vs*



$Rin1 = (r\pi + (\beta+1)(Re//Rin2))//RB = 29K$

5 points

$Ro1 = (r\pi + RB//Rs)/(\beta+1)//Re = 127$ohms

5 points

$Av1 = 1$ **5 points**

$Rin2 = r\pi\ //Rth = 0.876K$

5 points

$Ro2=Rc//ro=1.73K$

5 points

$Av2 = -\beta\ (Rc//ro)/r\pi = -261$

5 points

vo= {RL/(RL+Ro2)}Av2 {Rin2/(Ro1+Rin2)} Av1 {Rin1/(Rs+Rin1)} vs

5 points

vo/vs = -(0.54)(261)(0.862)(1)(0.42)= -51.7 **5 points**