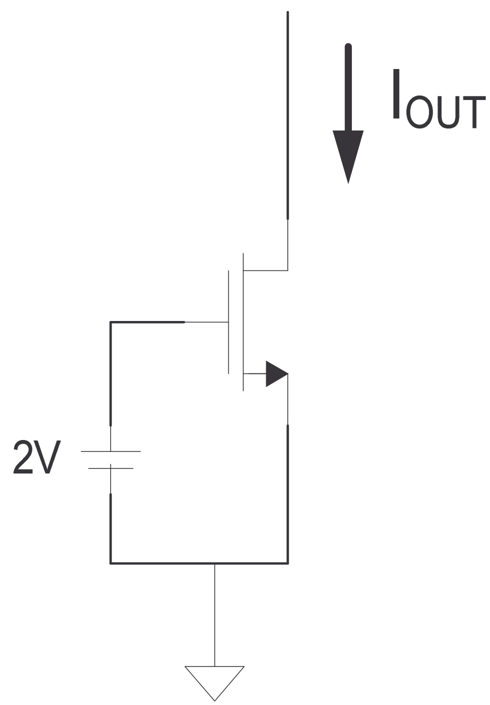
EE 434
Lecture 22

Properties of Bipolar Devices

Quiz 16

A dc current source is shown. If the device has width W=50u, length L=1.2u, uCox=100uAV^{-2}, VT=.75V and λ=.04V^{-1}, determine

a) The nominal output current
b) The small signal output impedance
c) The minimum output voltage to maintain operation as a current source



And the number is ….

1 8 7 5 3

6 9 4 2

7

Quiz 16

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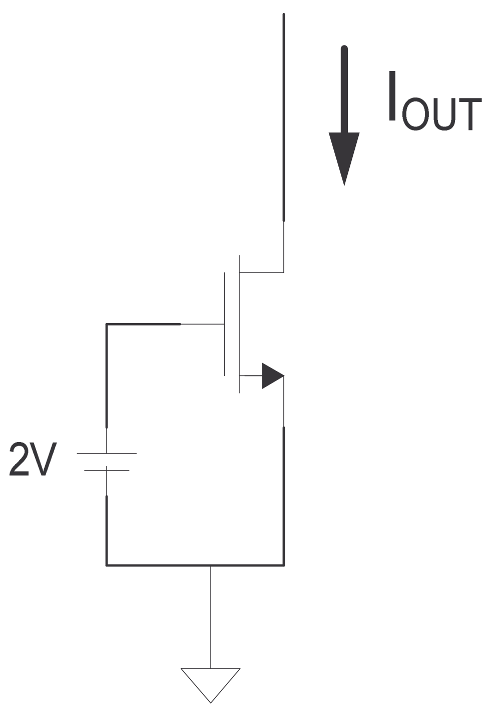
Solution



$$I_{DQ} \cong \mu C_{OX} \frac{W}{2L} (V_{EB})^2$$

$$\mathbf{I_{DQ}} \cong 10^{-4} \frac{\mathbf{50}}{\mathbf{2 \bullet 1.2}} (\mathbf{2 - .75})^{\mathbf{2}} \, mA$$

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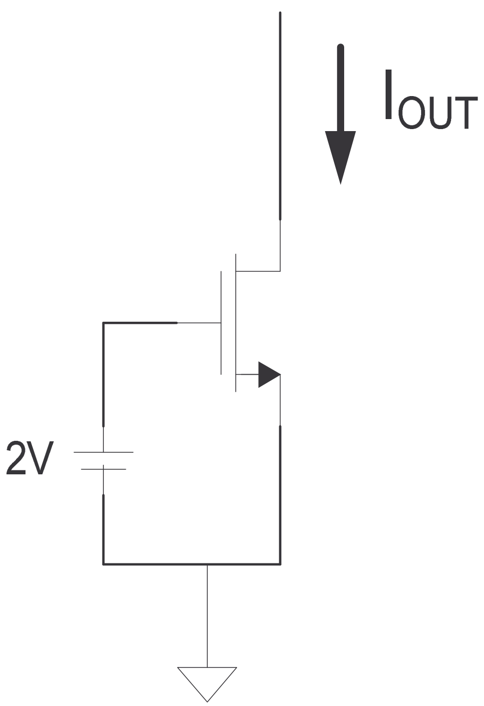

$$I_{DQ} \cong \mu C_{OX} \frac{W}{2L} (V_{EB})^2$$

$$\mathbf{I_{DQ}} \cong 10^{-4} \frac{\mathbf{50}}{\mathbf{2 \bullet 1.2}} (\mathbf{2 - .75})^{\mathbf{2}} \, mA = \mathbf{3.25} \, mA$$

Quiz 16

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a) The nominal output current
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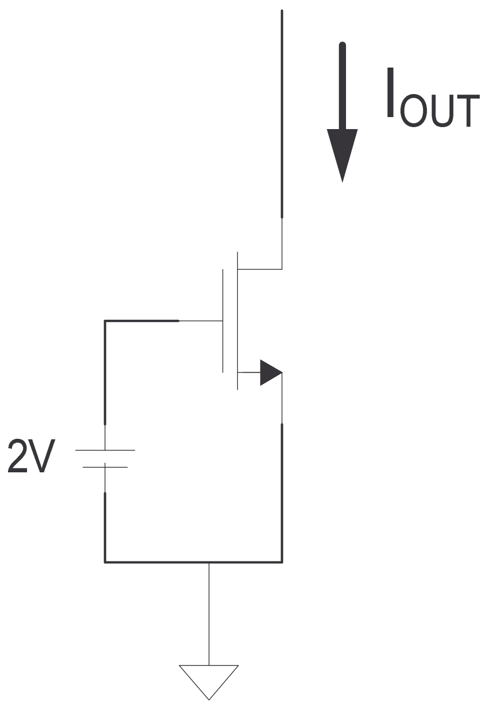

$$R_{OUT} = \frac{1}{g_o}$$

$$\mathbf{R_{OUT}} = \frac{\mathbf{1}}{\lambda \mathbf{I_{DQ}}} = \frac{1}{.04\mathbf{v}^{-1} \bullet 3.25mA} = 7.7K\Omega$$

Quiz 16 A dc current source is shown. If the device has width W=50u, length L=1.2u, uCox=100uAV^{-2}, VT=.75V and λ=.04V^{-1}, determine

a) The nominal output current
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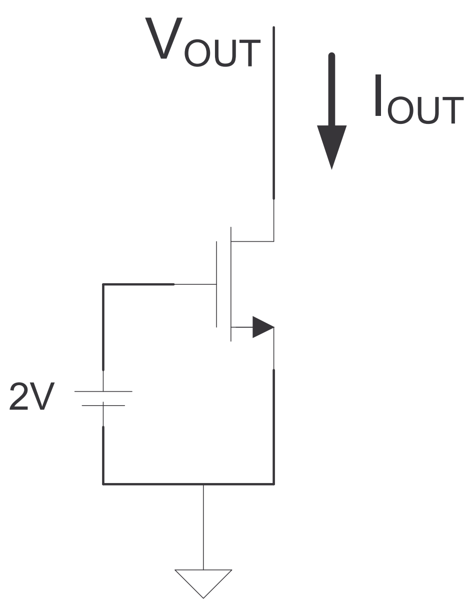


To maintain saturation region operation, $V_{DS}>V_{GS}-V_T$

$V_{OUT}>2V-.75V=1.25V$

Review from Last Time

Alternate equivalent small signal model for BJT includes current dependent current source as alternative to transconductance source

For a bipolar transistor

$$\mathbf{g_m >> g_\pi >> g_o}$$

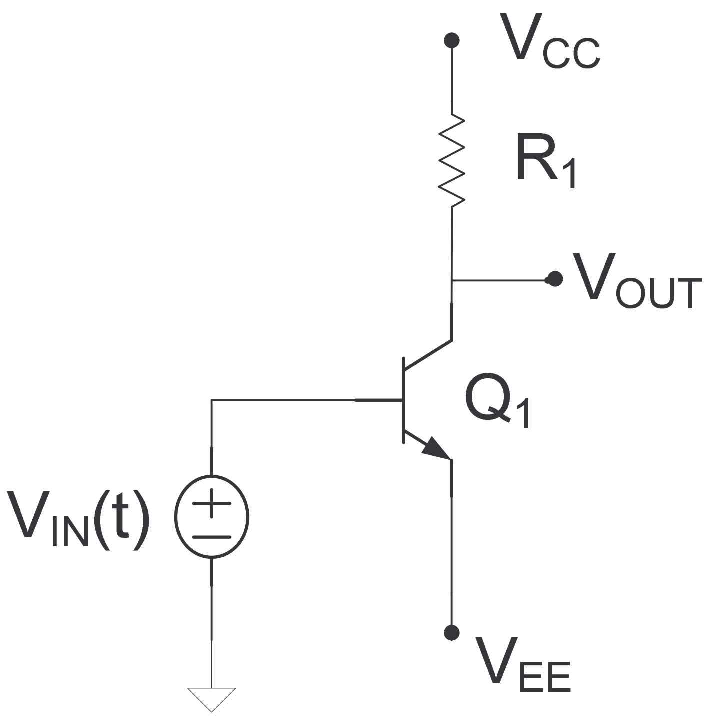
g_m for the BJT is much larger than that of the MOSFET (good)
g_π for BJT is much larger than that of the MOSFET (not so good)

Other Properties of BJT

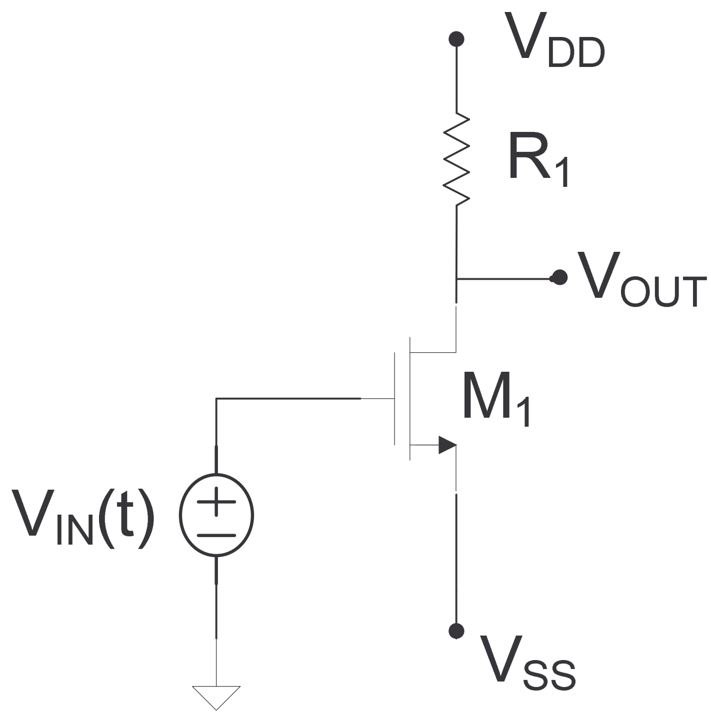
- Alternate Equivalent Small Signal Model
- Relative magnitude of small signal parameters
  - Simplified small signal model
- Comparison of BJT and MOSFET

Comparison of MOSFET and BJT

BJT



MOSFET



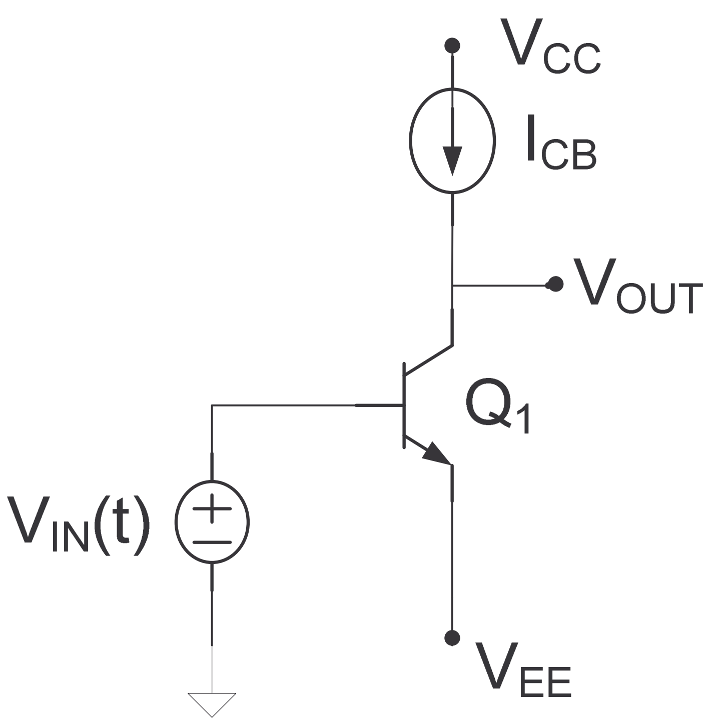
Assume BJT operating in FA region, MOSFET operating in Saturation

Assume same quiescent output voltage and same resistor R_1

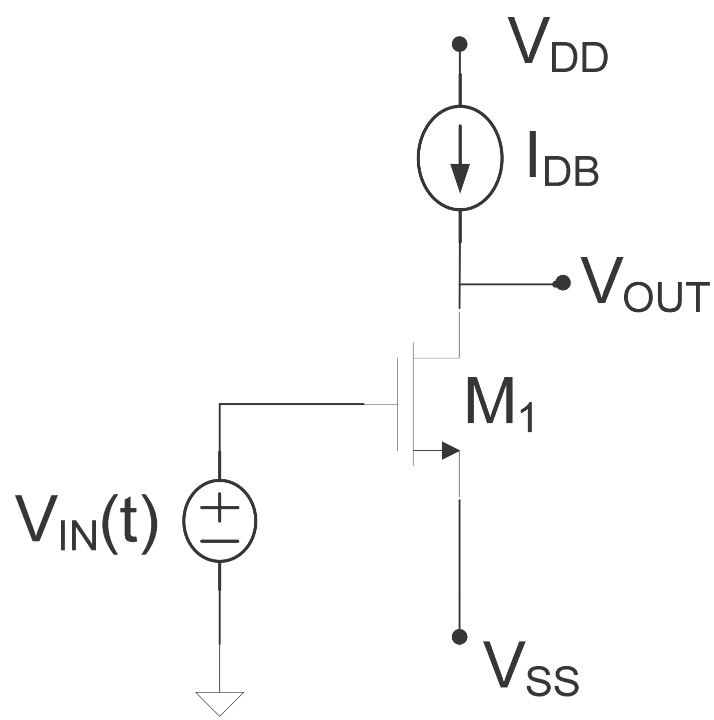
One of the most widely used amplifier architectures

Comparison of MOSFET and BJT

BJT



MOSFET



Assume BJT operating in FA region, MOSFET operating in Saturation

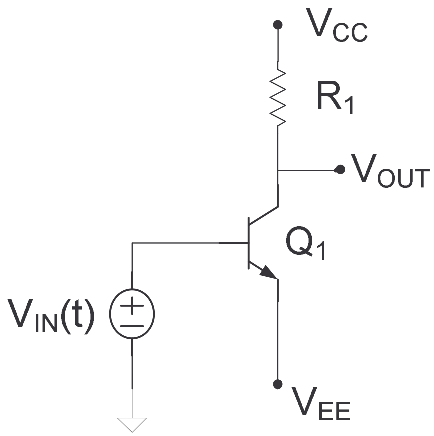
Assume same bias current

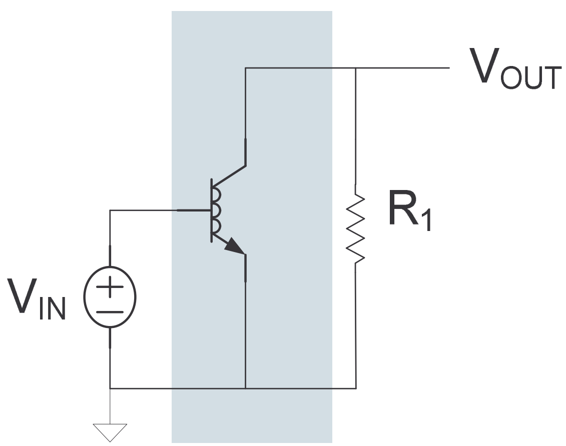
One of the most widely used amplifier architectures in integrated applications

Special Case of Previous Architecture

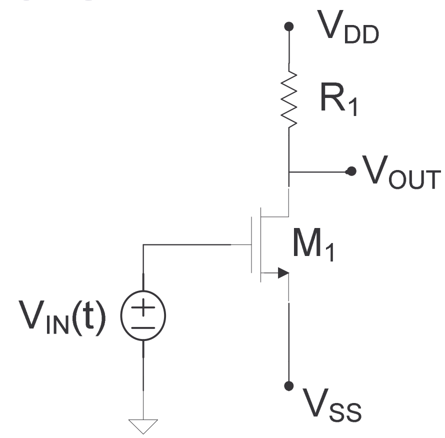
Comparison of MOSFET and BJT

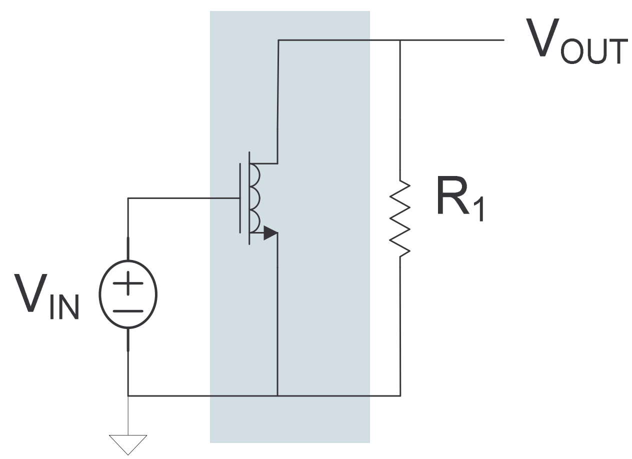
BJT





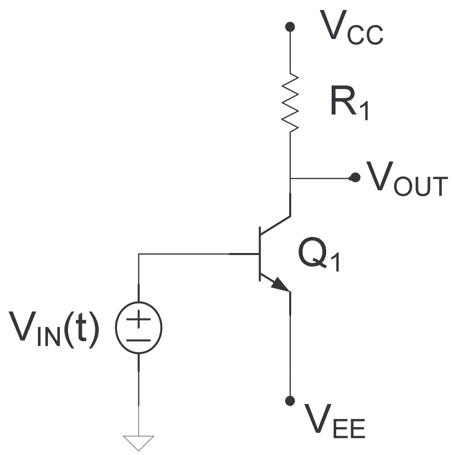
MOSFET

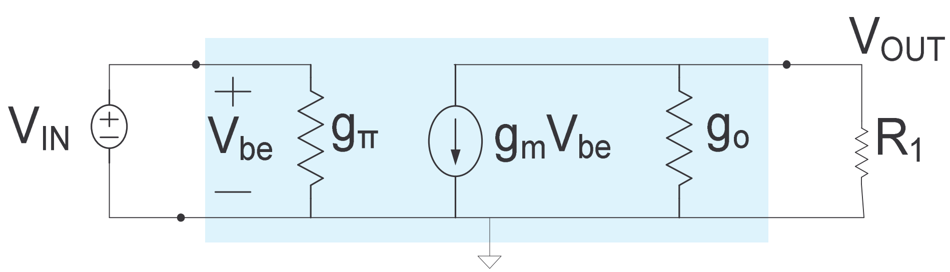




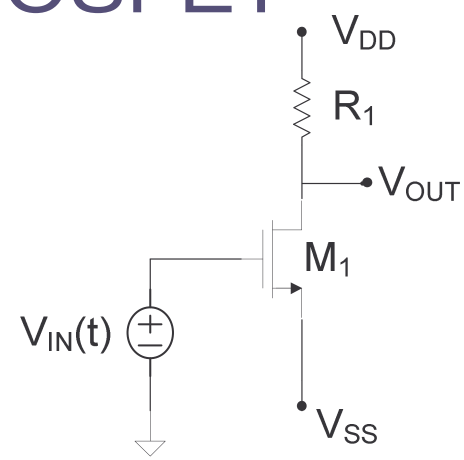
Comparison of MOSFET and BJT

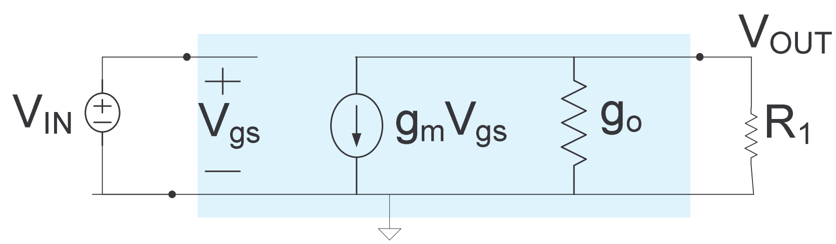
BJT





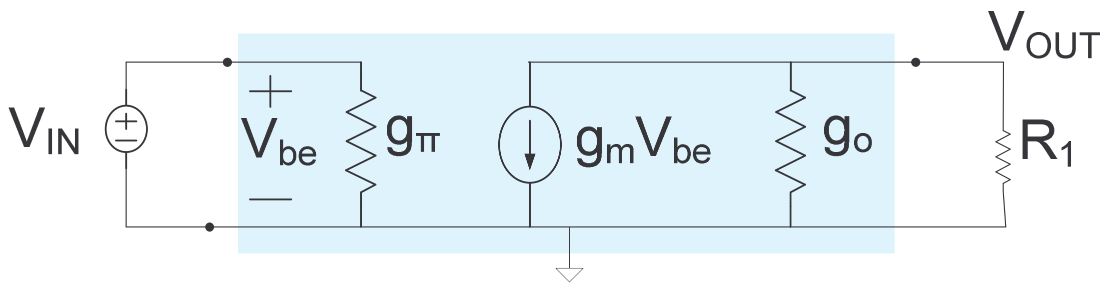
MOSFET





Comparison of MOSFET and BJT

BJT



$$G_1 = R_1^{-1}$$

$$v_{OUT} = -\frac{g_m}{g_o + G_1} v_{IN}$$

$$A_V = \frac{v_{OUT}}{v_{IN}} = -\frac{g_m}{g_0 + G_1}$$

$$v_{OUT} \cong -\frac{g_m}{G_1} v_{IN}$$

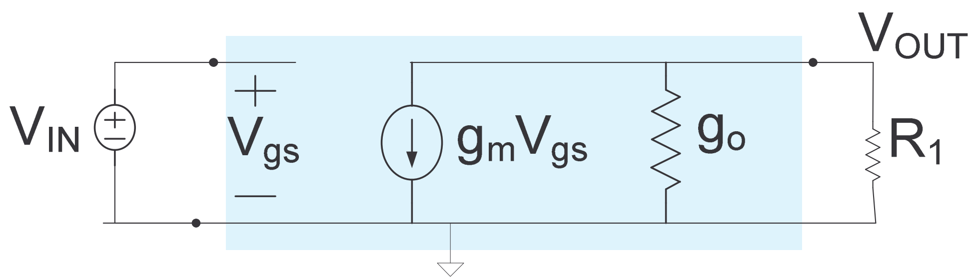
$$A_V = \frac{V_{OUT}}{V_{IN}} = -g_m R_1$$

$$g_m = \frac{I_{CQ}}{V_t}$$

$$A_V = -\frac{I_{CQ} R_1}{V_t}$$

Comparison of MOSFET and BJT

MOSFET



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$$v_{OUT} \cong -\frac{g_m}{G_1} v_{IN}$$

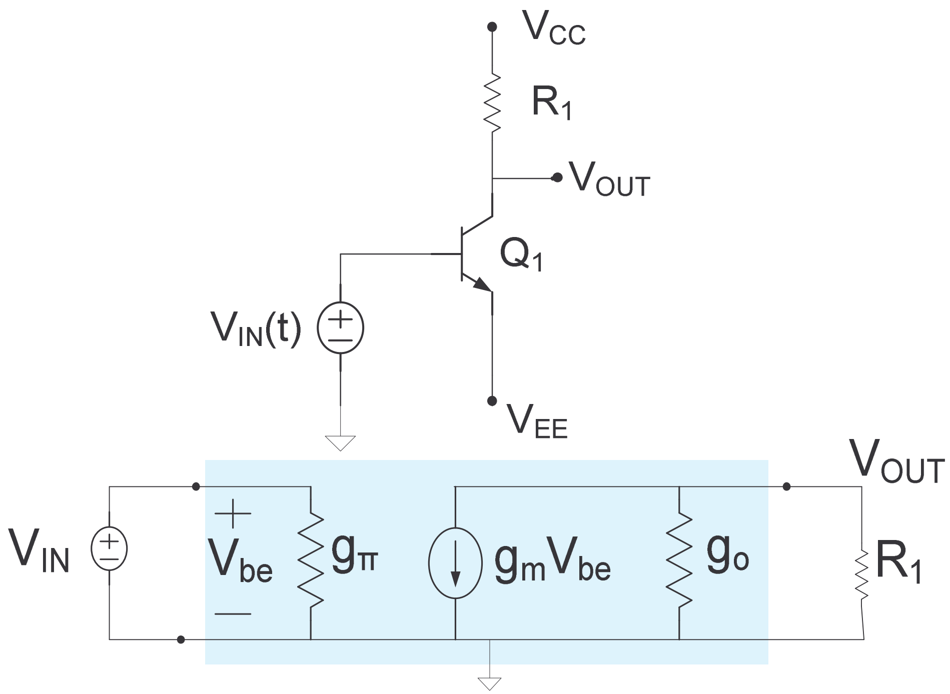
$$A_V = \frac{V_{OUT}}{V_{IN}} = -g_m R_1$$

$$g_m = \frac{2I_{DQ}}{V_{EB}}$$

$$A_V = -\frac{2I_{DQ}R_1}{V_{EB}}$$

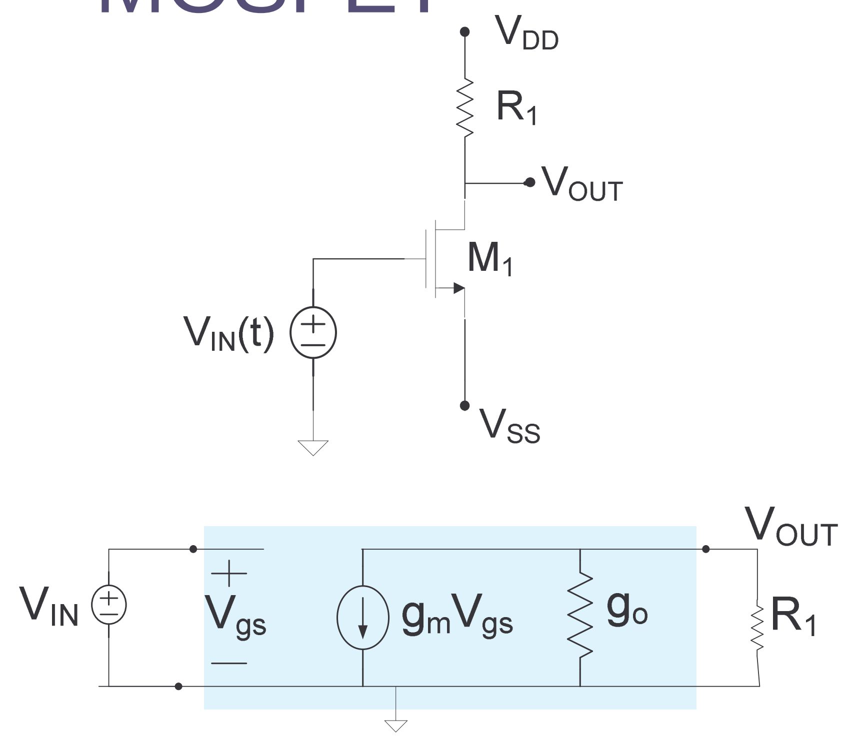
Comparison of MOSFET and BJT

BJT



$$A_{VB} = -\frac{I_{CQ}R_1}{V_t}$$

MOSFET



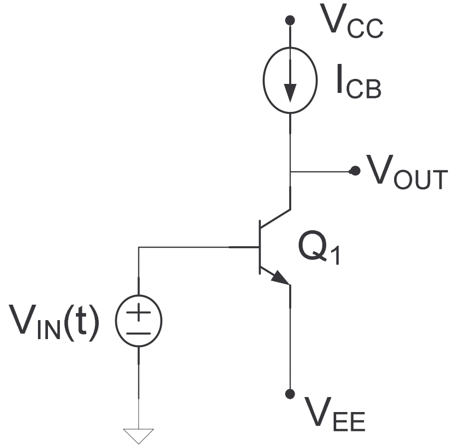
$$A_{VM} = -\frac{2I_{DQ}R_1}{V_{EB}}$$

$$\frac{A_{VB}}{A_{VM}} = \frac{V_{EB}}{2V_t}$$

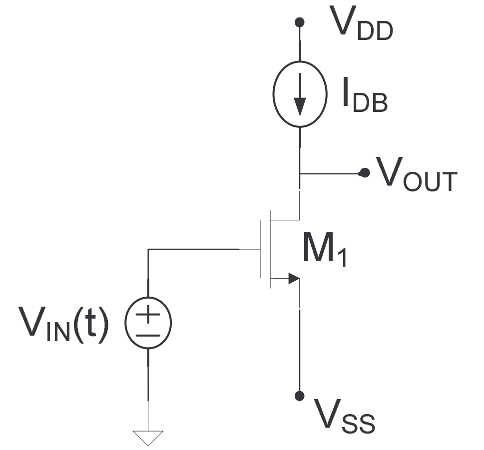
A_{VB} is typically much larger than A_{VM} for this basic amplifier architecture

Comparison of MOSFET and BJT

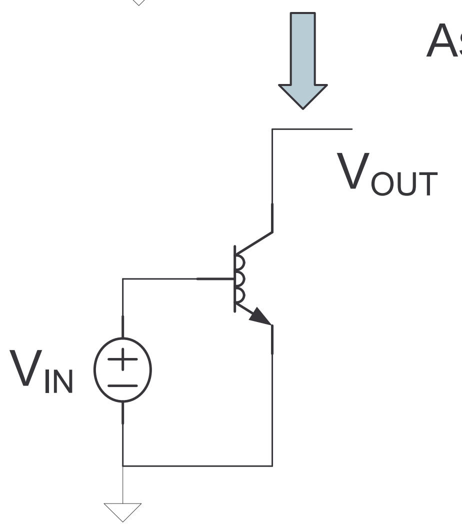
BJT

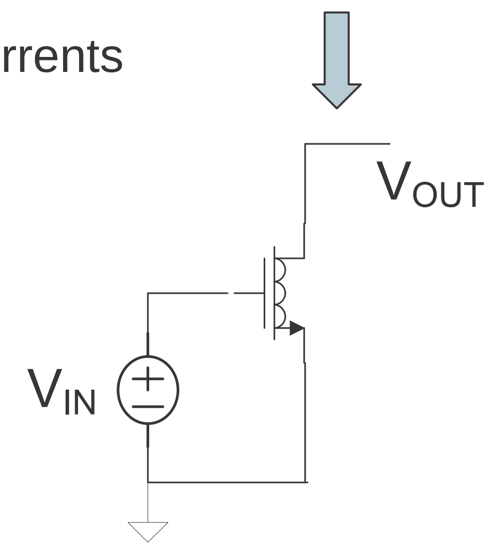


MOSFET



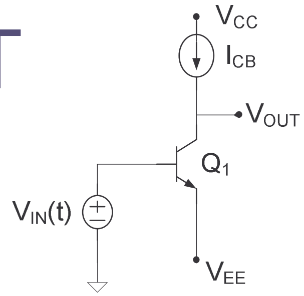
Assume same bias currents

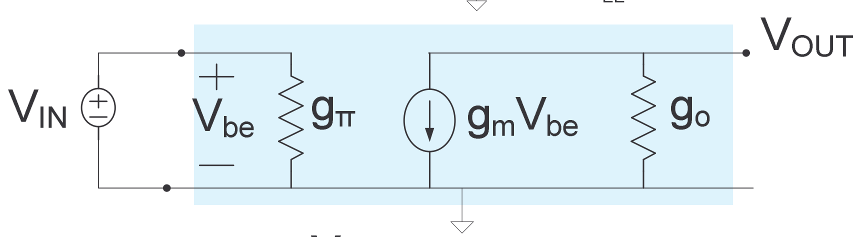




Comparison of MOSFET and BJT

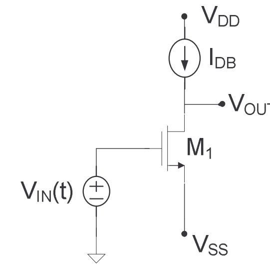
BJT

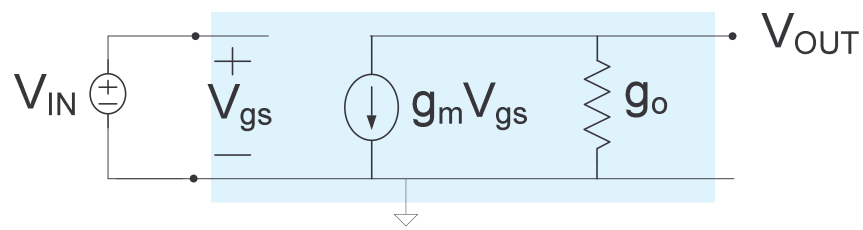




$$A_V = \frac{V_{OUT}}{V_{IN}} = -\frac{g_m}{g_0}$$

MOSFET





$$A_V = \frac{V_{OUT}}{V_{IN}} = -\frac{g_m}{g_0}$$

Identical functional form

$$\frac{A_{VB}}{A_{VM}} = \frac{\left[\frac{g_{mB}}{g_{oB}}\right]}{\left[\frac{g_{mM}}{g_{oM}}\right]} = \left[\frac{g_{mB}}{g_{mM}}\right]\left[\frac{g_{oM}}{g_{oB}}\right]$$

Assuming same bias currents

$$\frac{A_{VB}}{A_{VM}} = \left[\frac{V_{EB}}{2V_t}\right]\left[\lambda V_{AF}\right]$$

Typically $A_{VB} >> A_{VM}$

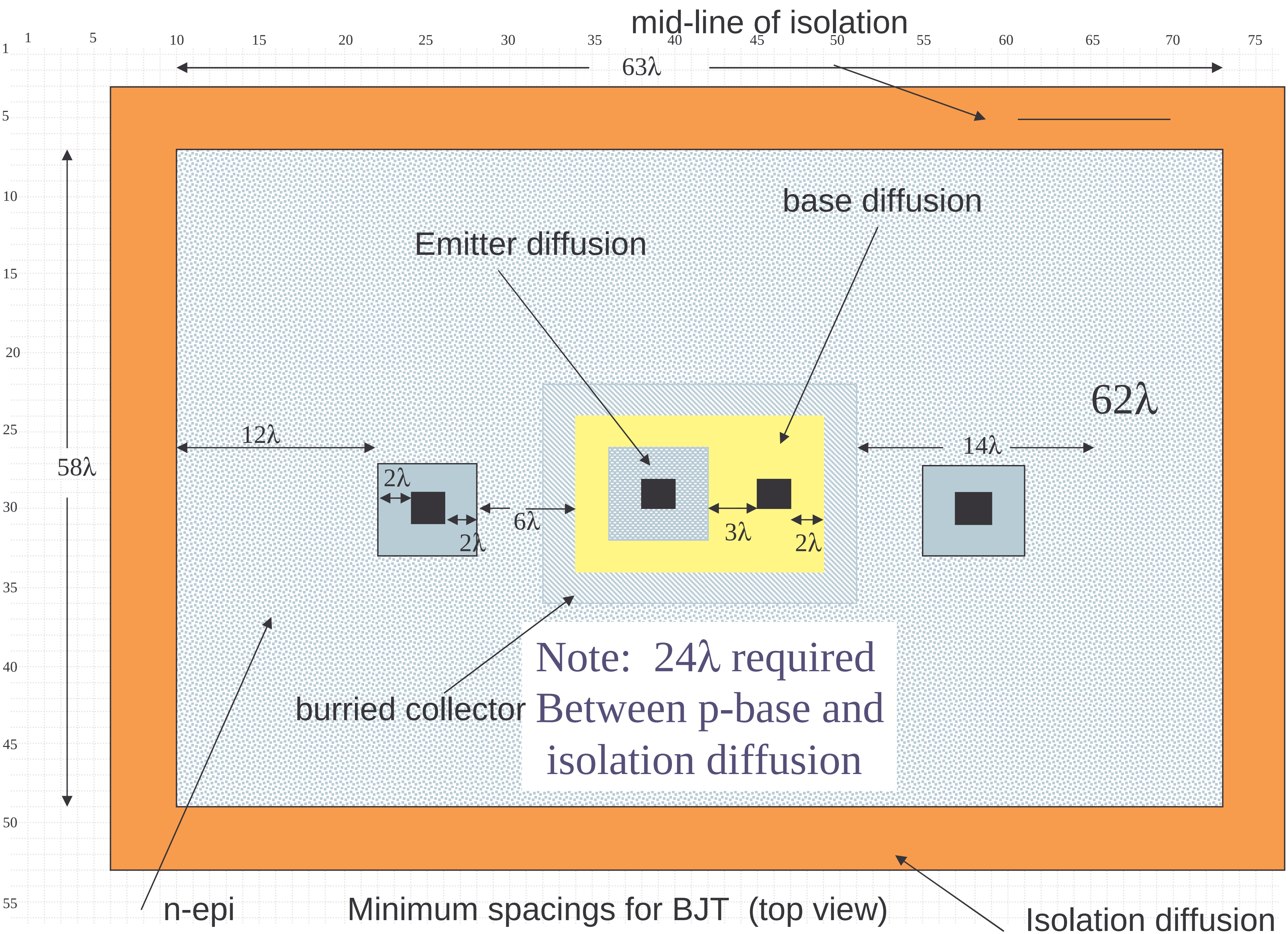
Comparison of MOSFET and BJT

How do the areas required for implementing a MOSFET compare to those required for a BJT

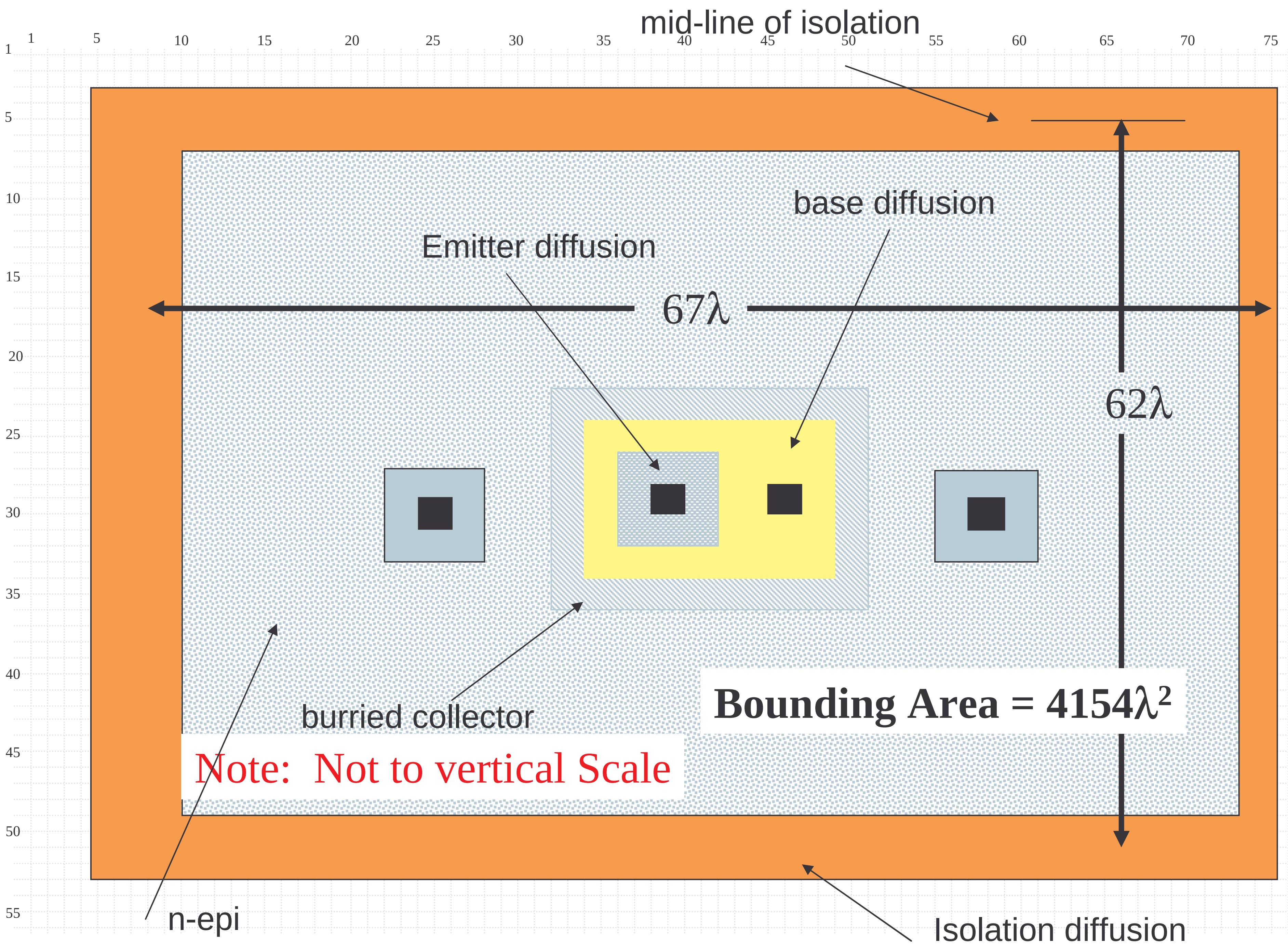
To make the comparison fair, will assume the same lithography equipment and that the minimum feature size both processes is 2λ

Refer the design rules for a bipolar process in the GAS text if additional details are needed

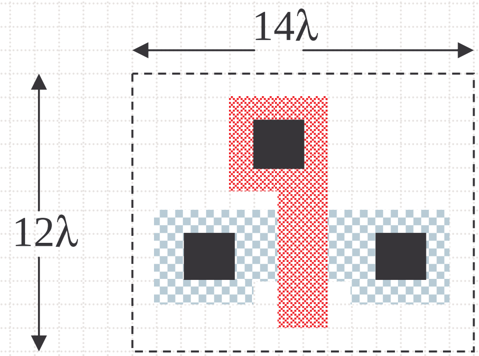
The following slides are adapted from the BJT technology presentation



Minimum spacings for BJT (top view)

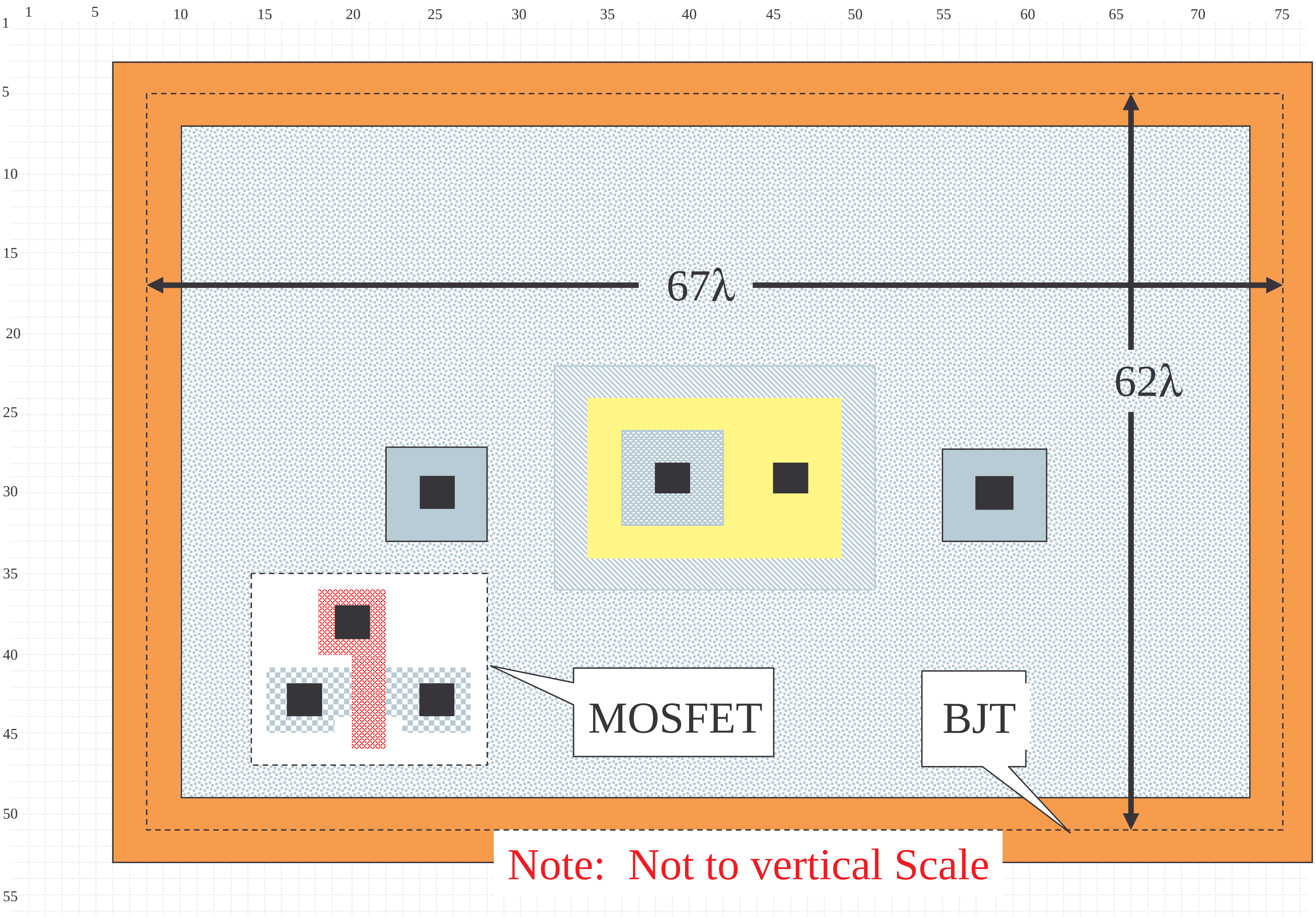

mid-line of isolation
base diffusion
Emitter diffusion
67λ
62λ
burried collector
Bounding Area = 4154λ²
Note: Not to vertical Scale
n-epi
Isolation diffusion

Minimum-Sized MOSFET



Bounding Area = $168\lambda^2$

Active Area = $6\lambda^2$

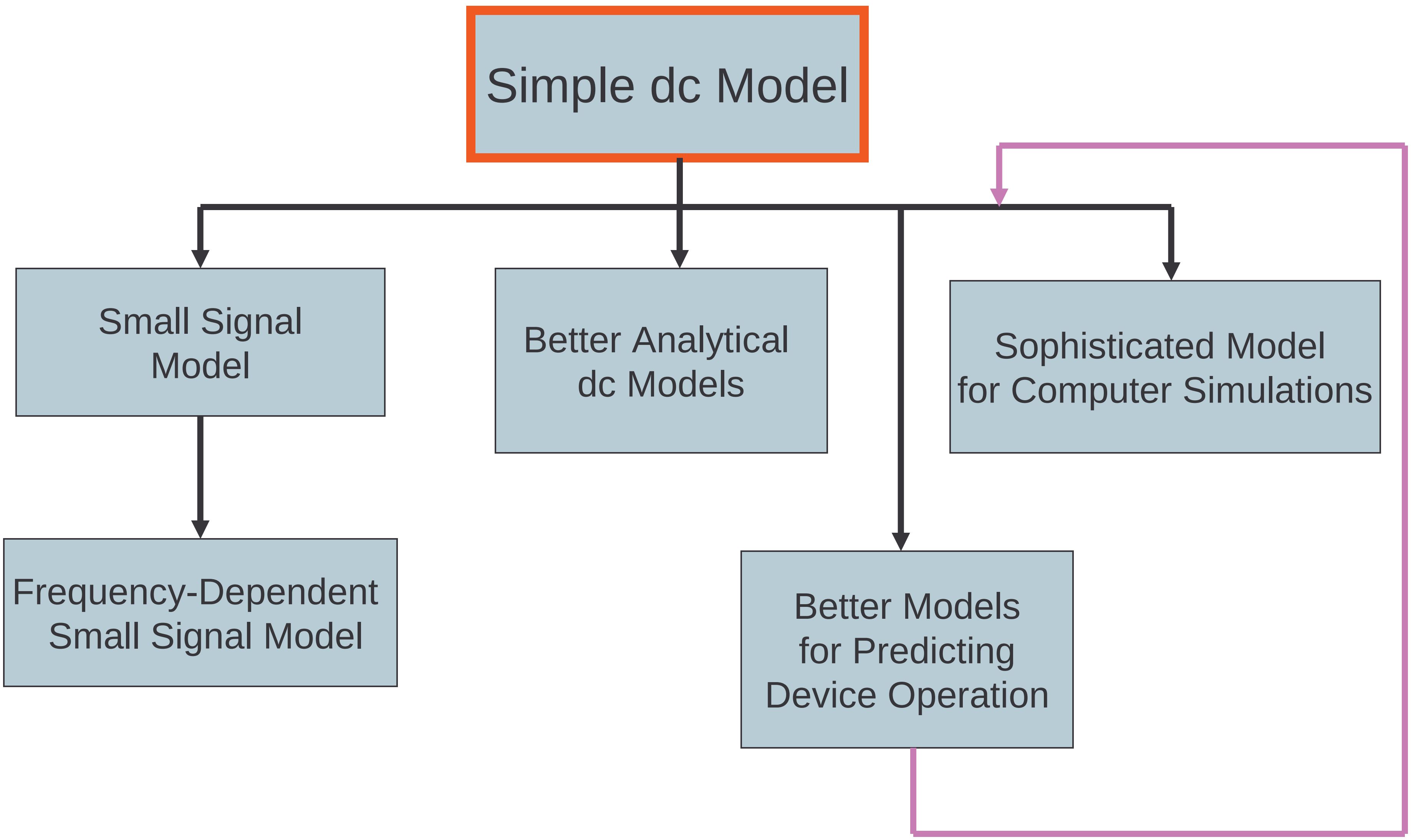


1
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
1
5
10
15
20
25
30
35
40
45
50
55
67λ
62λ
MOSFET
BJT
Note: Not to vertical Scale

Other Properties of BJT

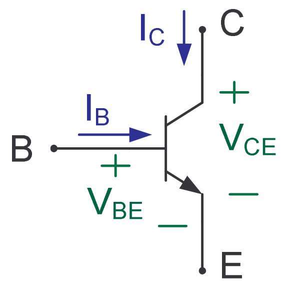
- Alternate Equivalent Small Signal Model
- Relative magnitude of small signal parameters
  - Simplified small signal model
- Comparison of BJT and MOSFET
- ⇨ Equivalent Circuit for dc biasing

Bipolar Models



Bipolar Models

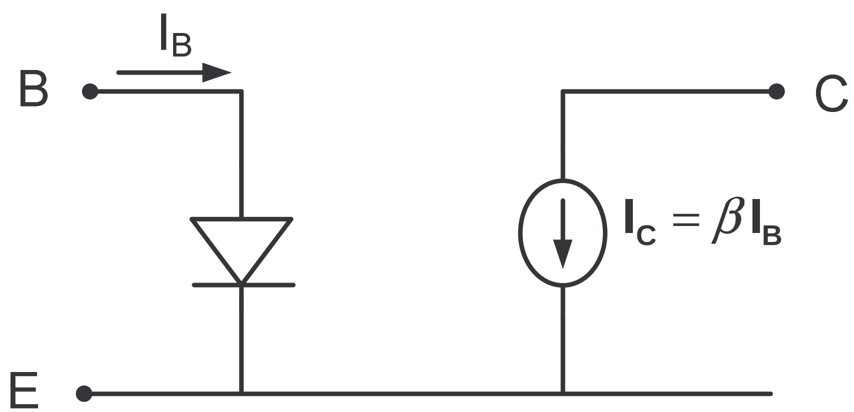
Simple dc Model for Biasing



$$I_B = \frac{J_S A_E}{\beta} e^{\frac{V_{BE}}{V_t}}$$

$$\mathbf{I_C = J_S A_E e^{\frac{V_{BE}}{V_t}}}$$

$$\mathbf{I_C} = \beta \mathbf{I_B}$$

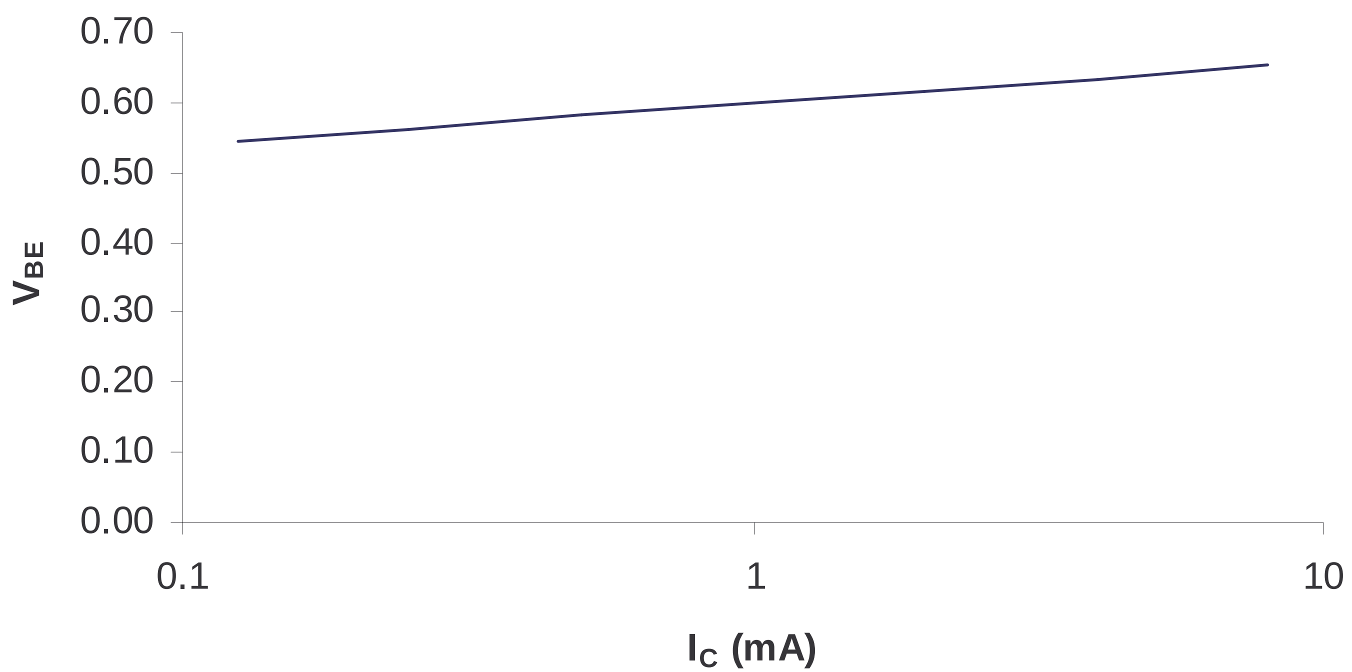


Although it may appear this is a model simplification, it is still highly nonlinear because the diode from BE is nonlinear

Recall

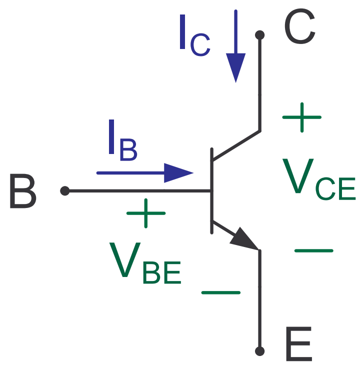
Transfer Characteristics

J_S=.25fA/u^2
A_E=400u^2



V_{BE} close to 0.6V for a two decade change in I_C around 1mA

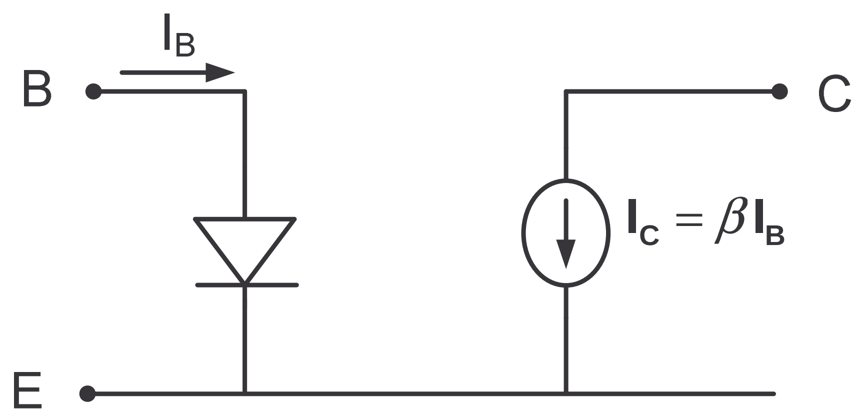
Bipolar Models



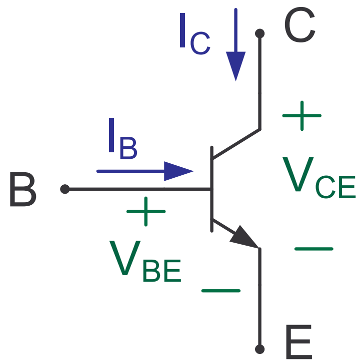
Simple dc Model for Biasing

$$I_B = \frac{J_S A_E}{\beta} e^{\frac{V_{BE}}{V_t}}$$

$$\mathbf{I_C} = \beta \mathbf{I_B}$$



V_{BE} is approximately 0.6V when in FA region

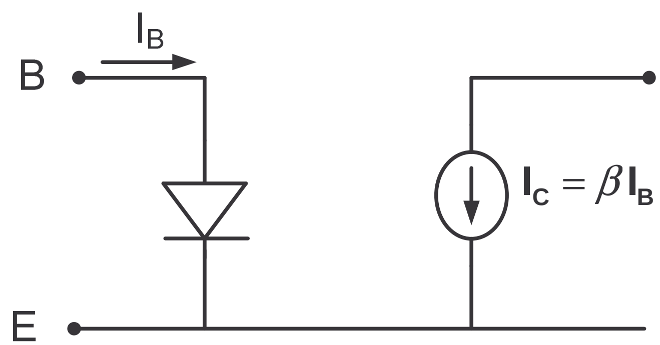


Bipolar Models

Simple dc Model for Biasing

$$I_B = \frac{J_S A_E}{\beta} e^{\frac{V_{BE}}{V_t}}$$

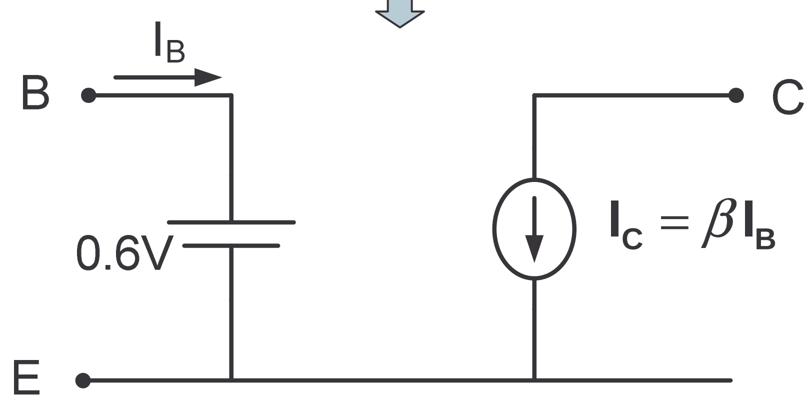
$$I_C = \beta I_B$$



V_{BE} is approximately 0.6V when in FA region

$$V_{BE} = 0.6V$$

$$I_C = \beta I_B$$



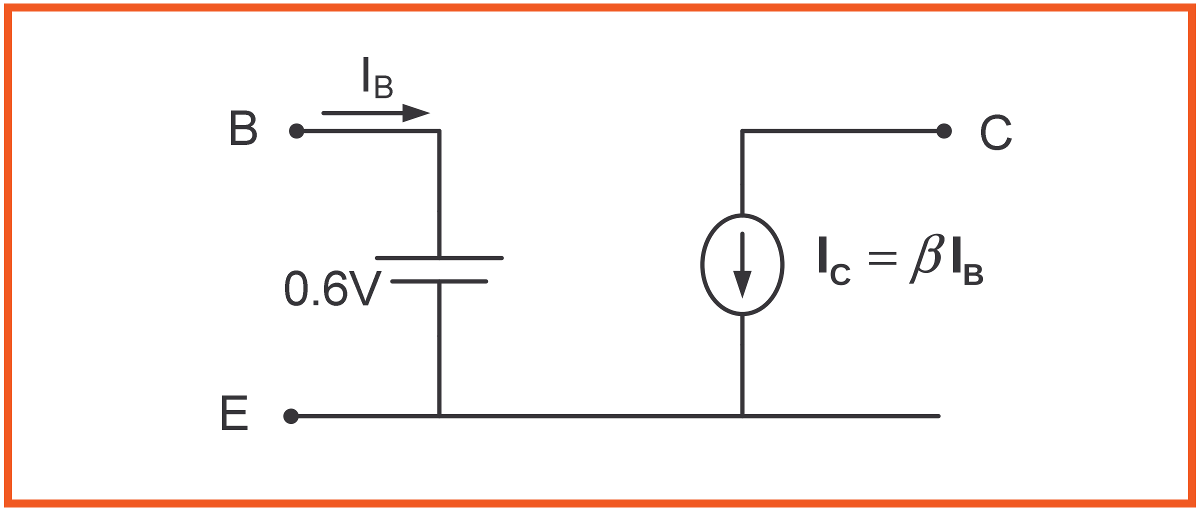
Dramatic Simplification in Model
Widely used for biasing

Bipolar Models

Simple dc Model for Biasing

V_{BE}=0.6V

$\mathbf{I_C} = \beta \mathbf{I_B}$



When is this model justifiable ?

When it doesn't make much difference in the analysis of a circuit whether V_{BE}=0.6V or 0.7V

When the VCE dependence on the collector current is negligable