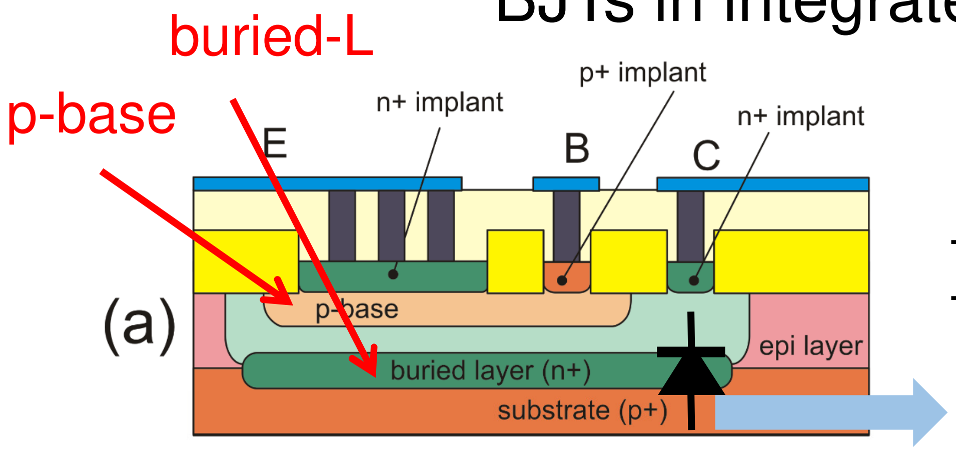
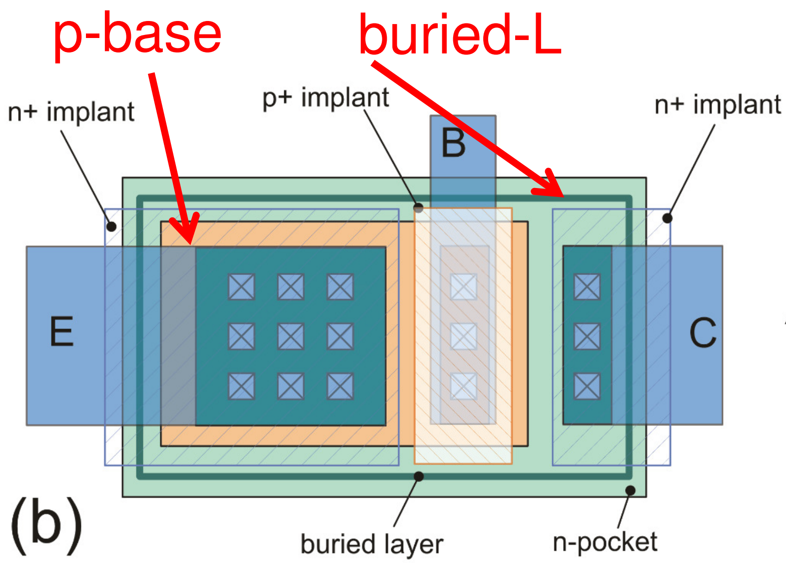
BJTs in integrated circuits: Vertical NPN

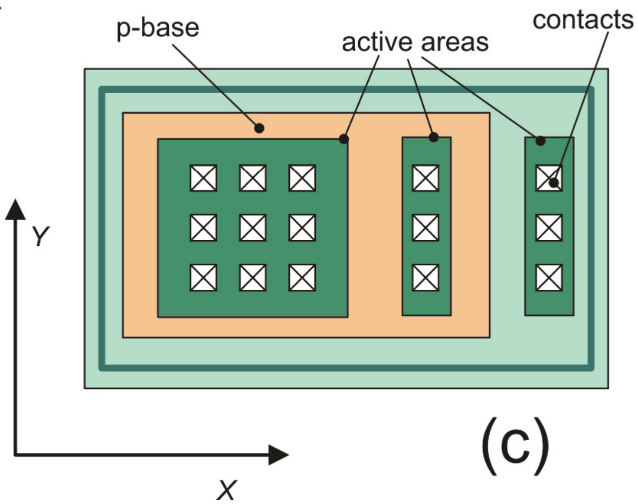


BiCMOS: CMOS + p-base and buried-layer

The **n-pocket** can be an n-well
The **buried-layer** a buried-well of a triple-well CMOS

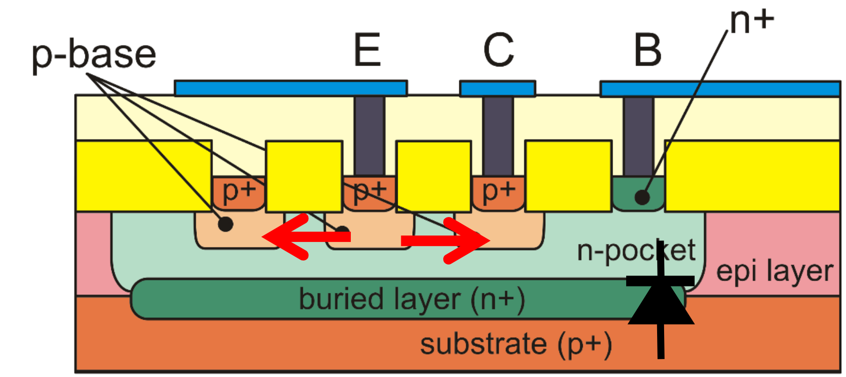
A diode between collector and substrate is present → capacitance



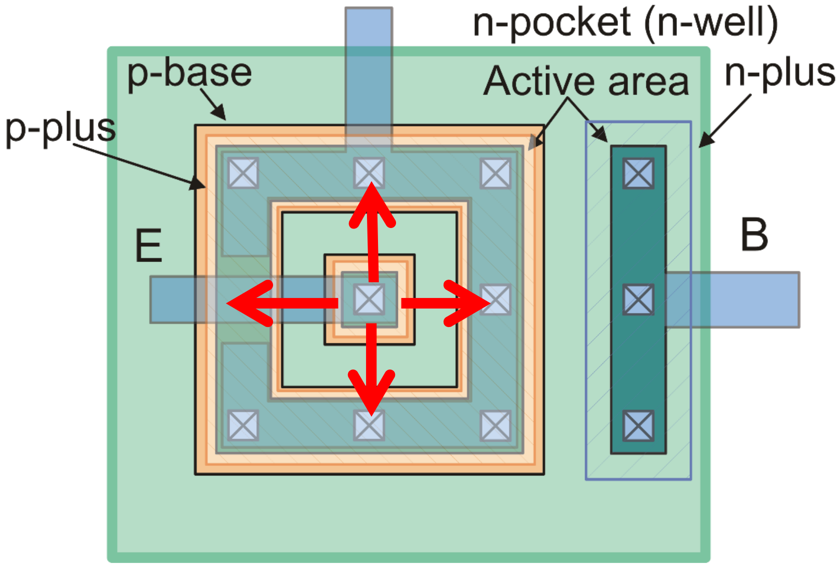


Same as (b) but with the Metal 1 removed

The lateral PNP



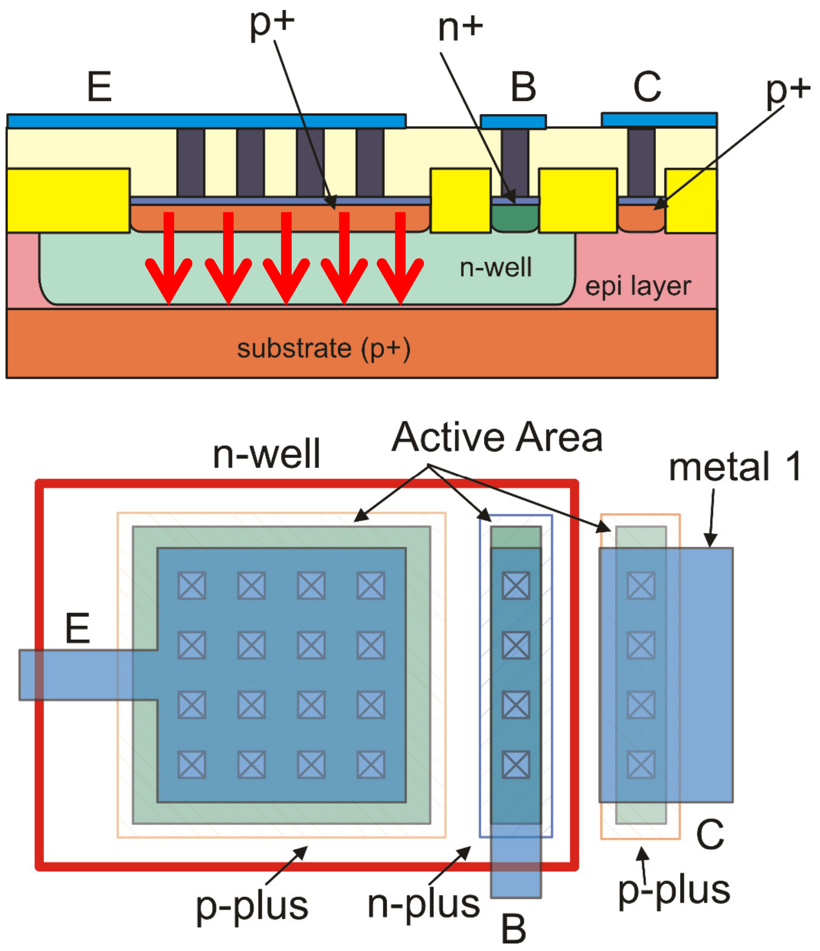
Slower than vertical devices due to large base series resistance ($r_{bb'}$) and base-to substrate capacitance



Lower early voltage (V_A), due to non-optimal collector doping.

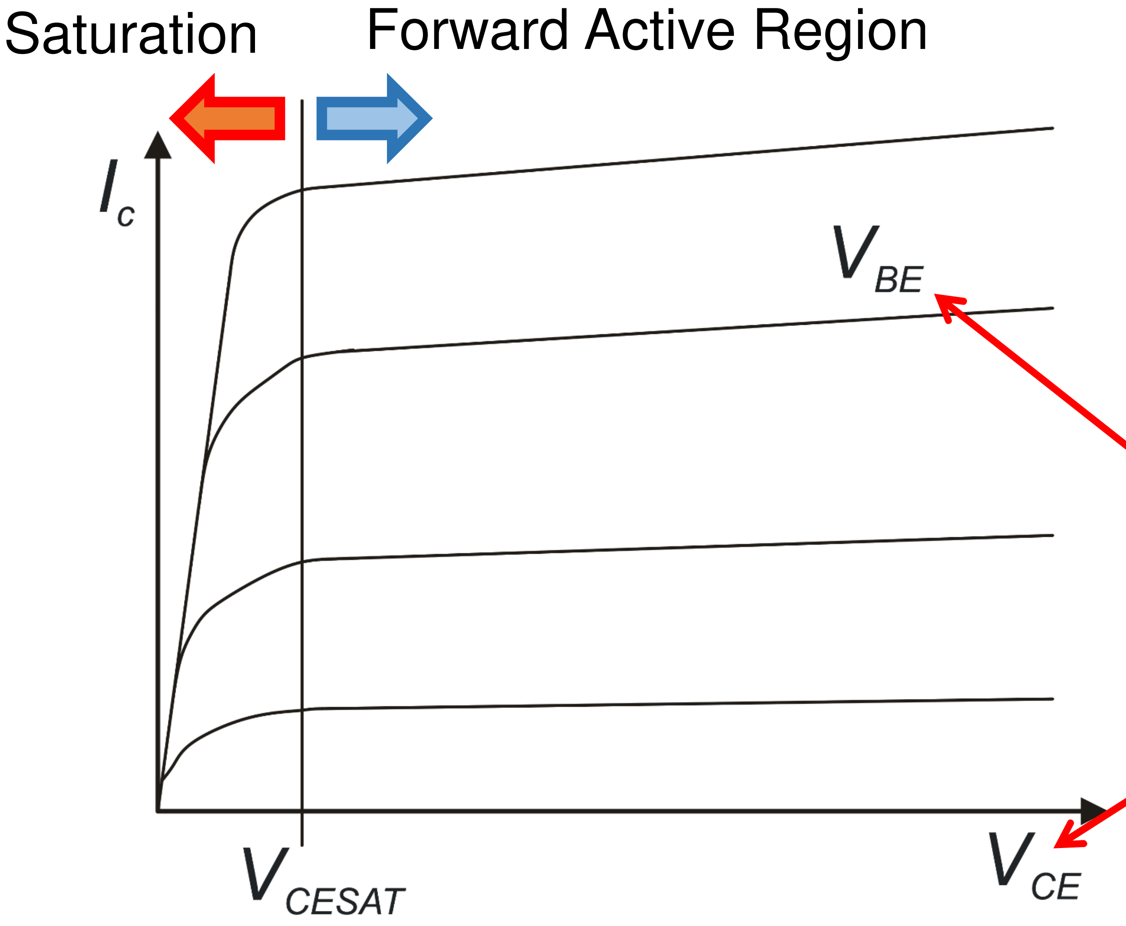
Larger than vertical devices for the same current capability

The substrate PNP: compatible with standard CMOS n-well processes



Limitation: The collector is committed to the substrate, (forced to V_{SS})

BJT output characteristics



$$V_{CESAT} \cong 0.2 \text{ V}$$

V_{BE}, V_{CE} : control voltages

I_C, I_B: dependent currents

BJT model in the forward active zone

$$I_C = I_S e^{\frac{V_{BE}}{V_T}} \left(1 + \frac{V_{CB}}{V_A}\right) \qquad V_{CB} = V_{CE} - V_{BE}$$

$$I_B = \frac{I_C}{\beta_F}$$

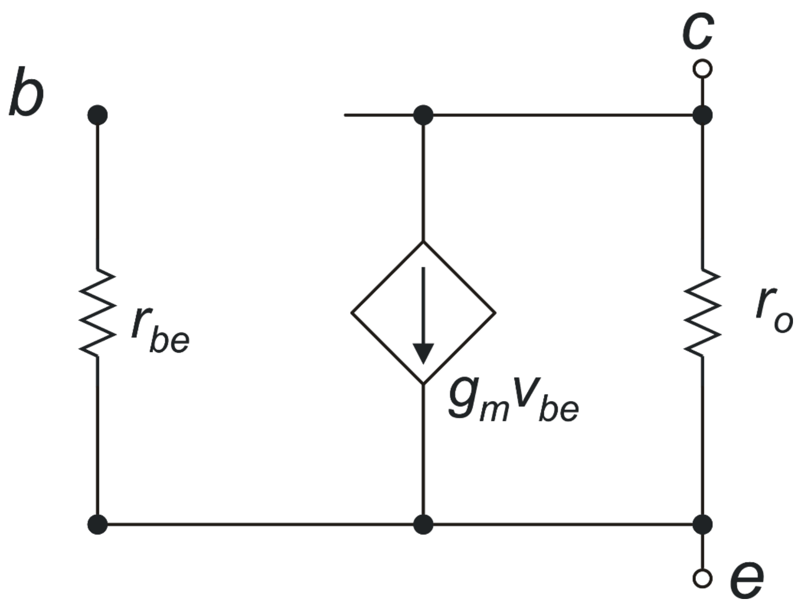
Sometimes this expression is used in order to refer to V_{BE} and V_{CE} as control voltages:

$$I_C \cong I_S e^{\frac{V_{BE}}{V_T}} \left(1 + \frac{V_{CE}}{V_A}\right)$$

For calculation of I_C and I_B in all operating zones (saturation, cut-off, forward active, reverse active) the Ebers-Moll model should be used.

BJT: small signal model

Small signal dc model



$$g_m = \frac{I_C}{V_T} \qquad r_0 \cong \frac{V_A}{I_C}$$

$$r_{be} = \beta_F \frac{1}{g_m}$$

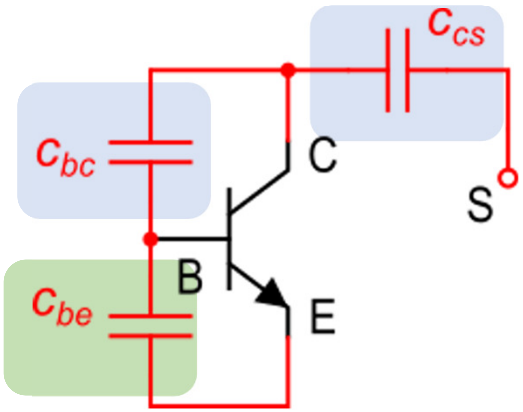
Equivalence with the MOSFET parameters

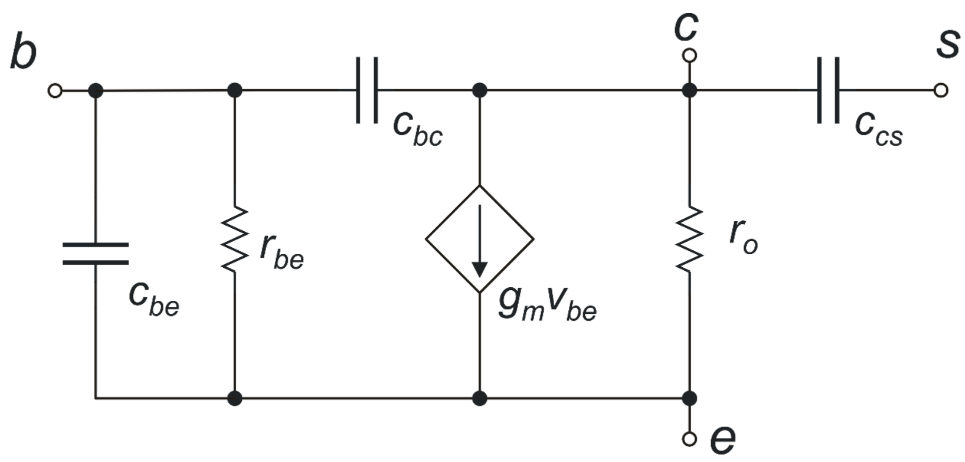
$$g_m = \frac{I_D}{V_{TE}} \qquad r_d = \frac{1}{g_d} = \frac{1}{\lambda I_D} = \frac{\lambda^{-1}}{I_D}$$

BJT		MOSFET
V_T	⇔	V_{TE}
V_A	⇔	λ^{-1}

BJT capacitances in forward active region (vertical npn)

$$c_{bc} = \frac{C_{JC}}{\left(1+\frac{V_{CB}}{V_{JC}}\right)^{m_{jc}}}$$





$$c_{cs} = \frac{C_{JS}}{\left(1+\frac{V_{CS}}{V_{JS}}\right)^{m_{js}}}$$

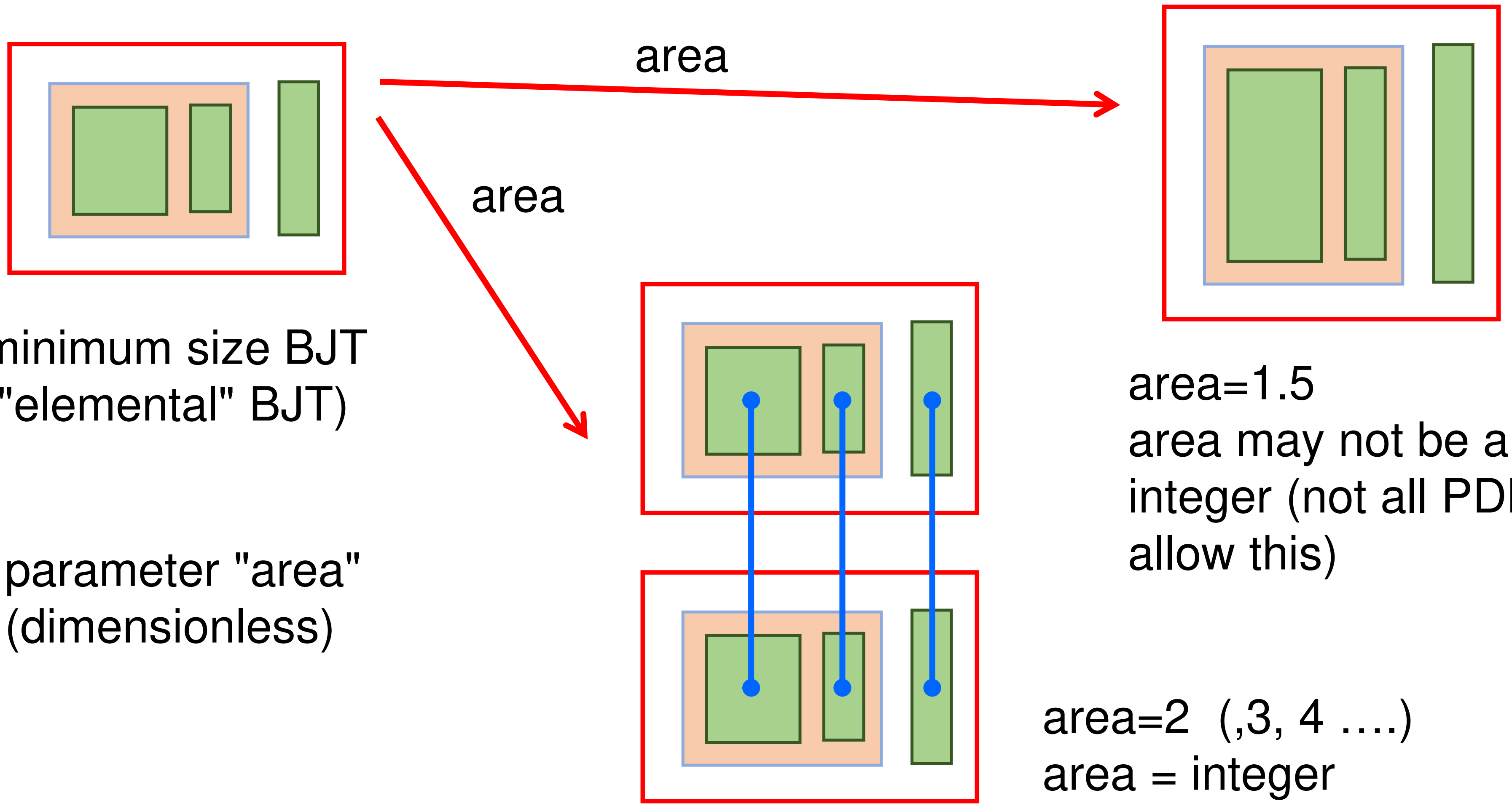
$$c_{be} = \frac{C_{JE}}{\left(1-\frac{V_{BE}}{V_{JE}}\right)^{m_{je}}} + C_{de}$$

$$c_{de} = \tau_F g_m$$

Transition frequency

$$f_T \cong \frac{1}{2\pi\tau_F}$$

BJTs in Integrated Circuit: instance parameters



minimum size BJT
("elemental" BJT)

parameter "area"
(dimensionless)

area=1.5
area may not be an
integer (not all PDKs
allow this)

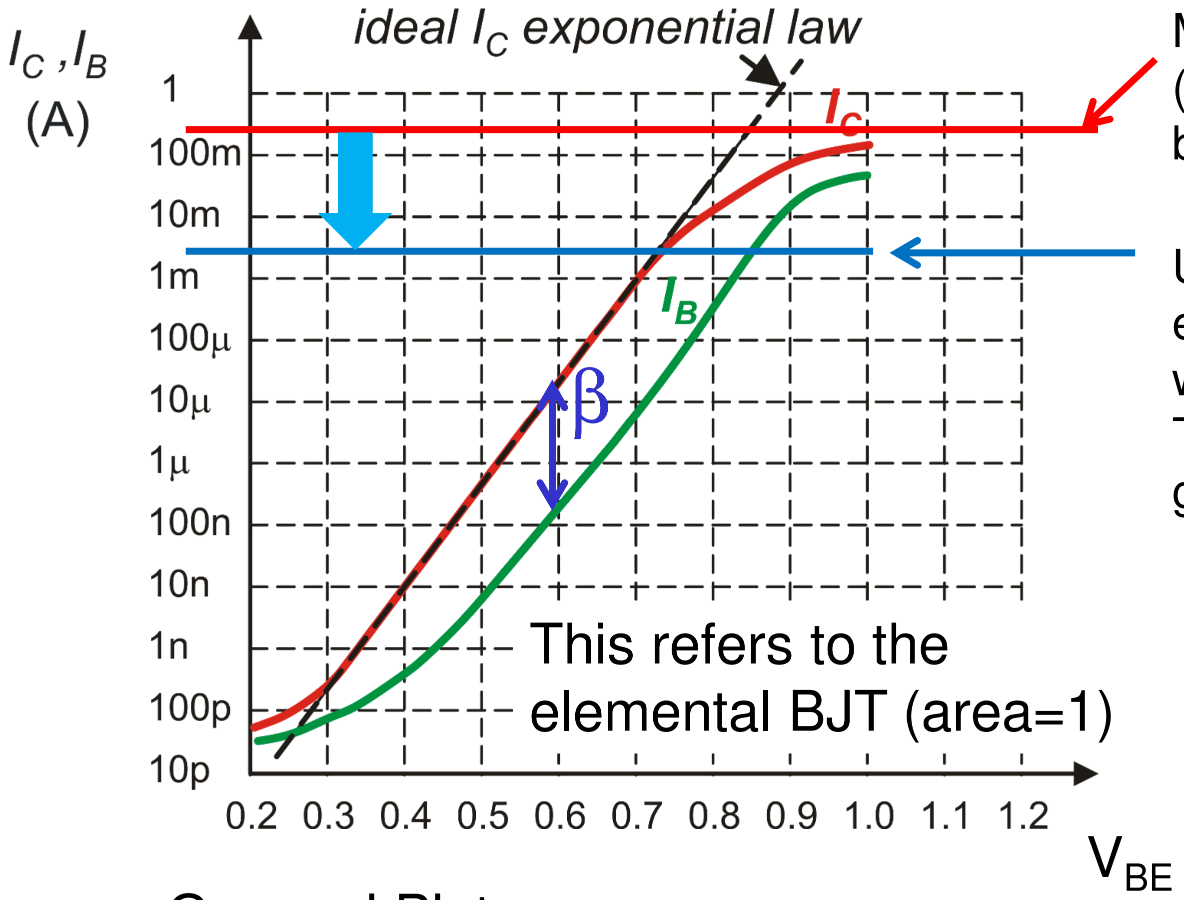
area=2 (,3, 4 ….)
area = integer

BJT sizing: Effect of the area parameter on the electrical parameters

Electrical effects of area parameter:

elemental BJT	elemental BJT with area specified as an instance parameter
I_S →	$area \times I_S$
V_A →	V_A
β →	β
C_{JE} →	$area \times C_{JE}$
…..	…..

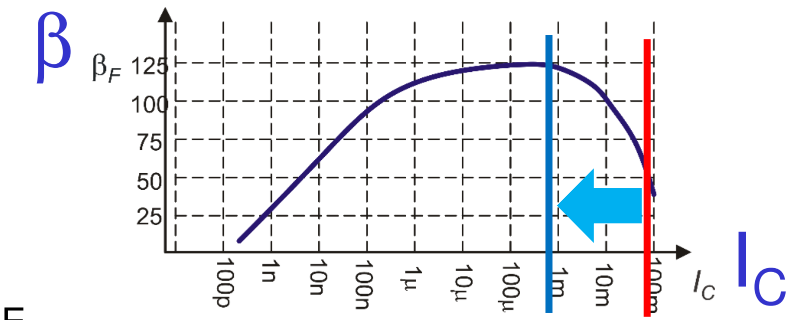
BJT sizing: Gummel plot and beta plot



Gummel Plot

My BJT has to carry this current (200 mA). The elemental BJT would be damaged

Using a BJT with area=100 would be equivalent to make the elemental BJT work with a current 100 times smaller. This corresponds to the operating point given by the blue line



Beta Plot