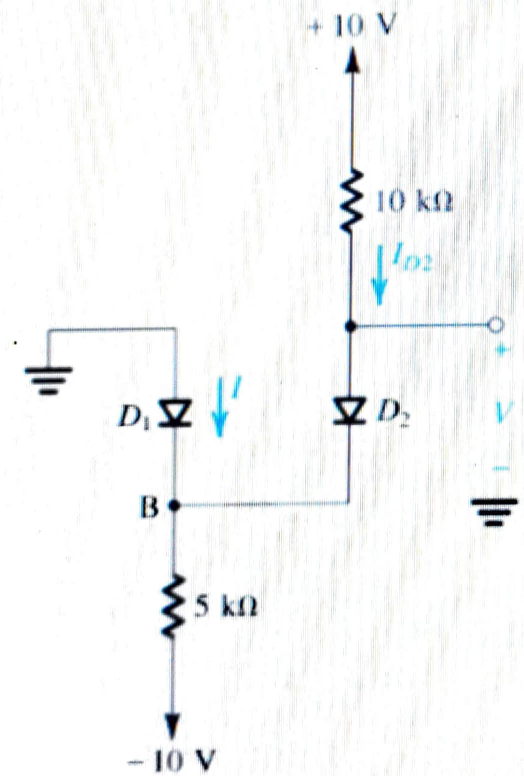
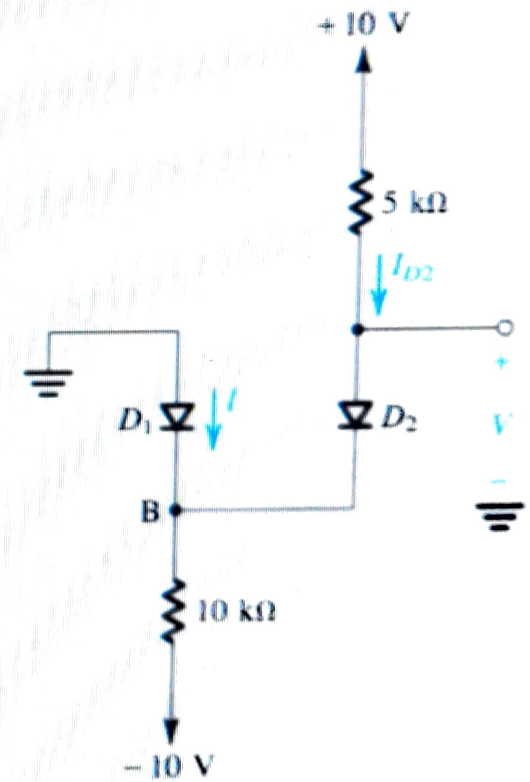
Problems

- Find V and I. Assume diodes to be ideal.

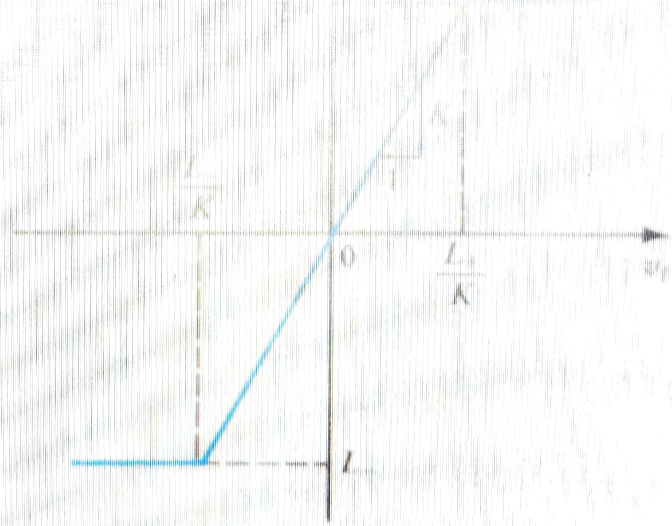




e meeting

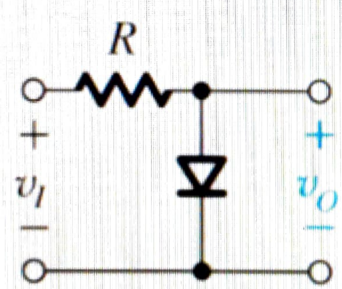
Diode applications

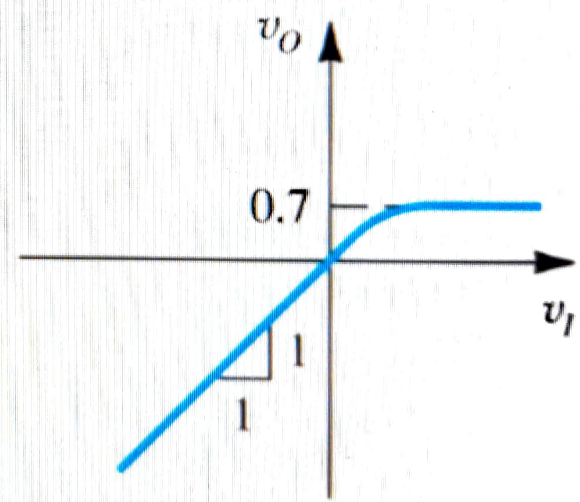
- Limiter circuits
- Clamped capacitor
- Voltage doubler



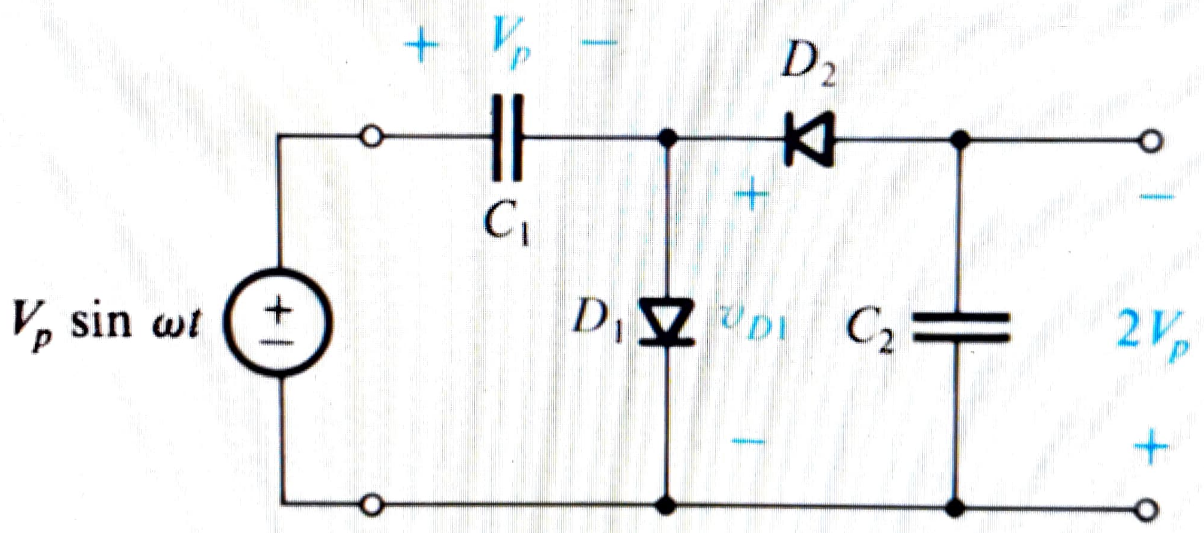
Limiter circuits

- Transfer characteristic of a limiter circuit

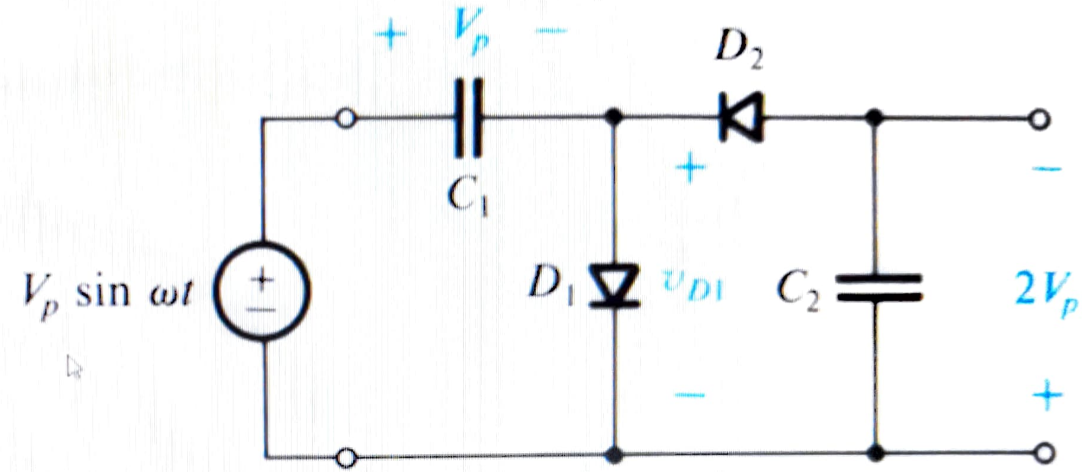


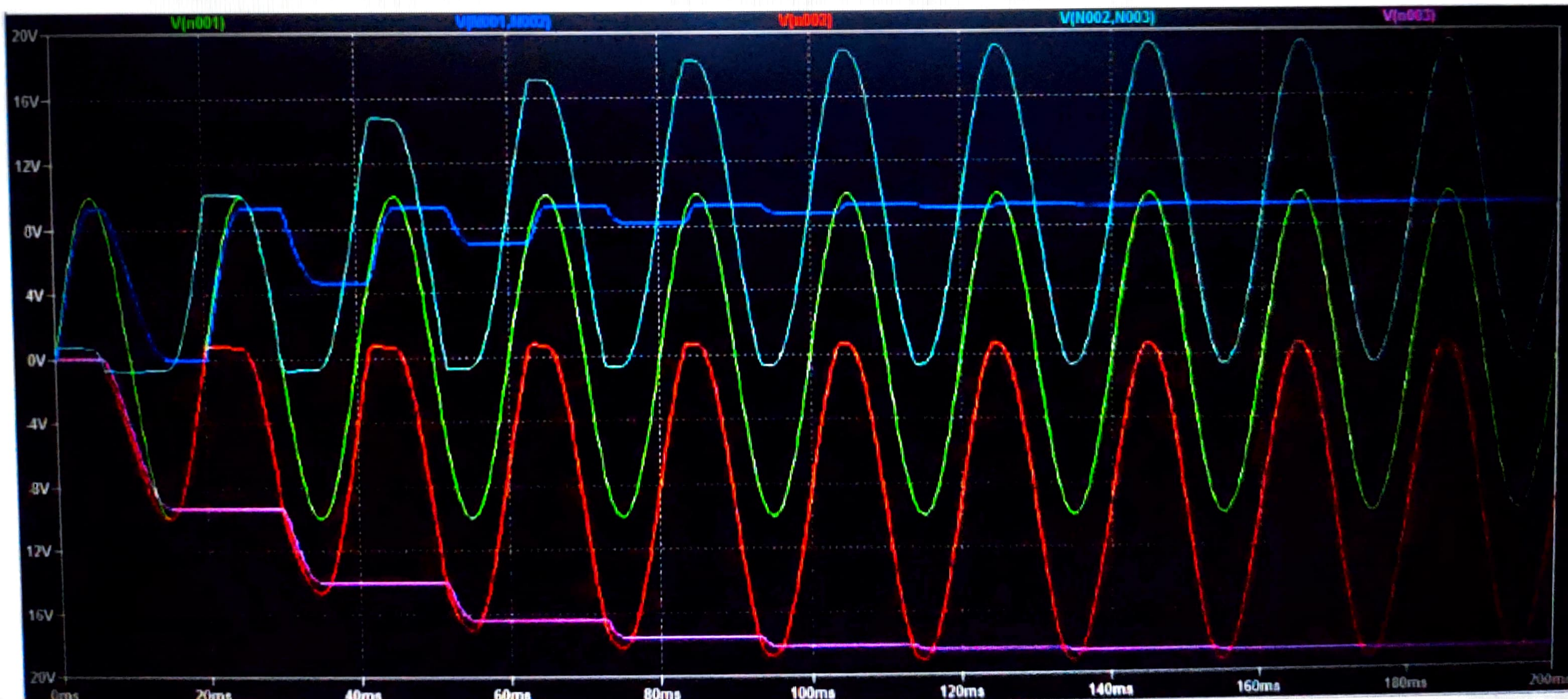


Voltage doubler



C = 10μF


+ V_p −
D_2
C_1
V_p sin ωt
D_1
v_{D1}
C_2
$2V_p$


V(n001)
V(N002,N003)
20V
16V
12V
8V
4V
0V
0ms
20ms
40ms
60ms
80ms
100ms
120ms
140ms
160ms
180ms
200ms

Material classification

Gold
O_2

- Material classification based on conductivity (σ)/resistivity (ρ)
  - Conductors
  - **Semiconductors**
  - Insulators

1
3
2

$R = 0$

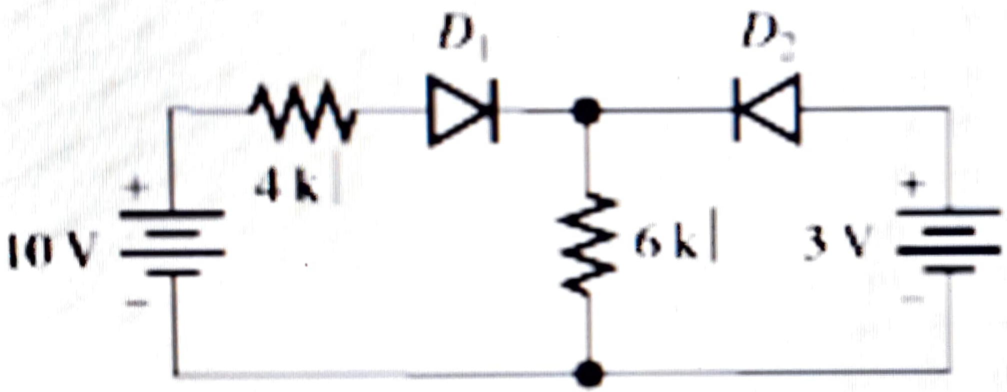
$R = \infty$

$$\sigma = \frac{1}{\rho}$$

Ca
water
carbon
P

$$R = \rho \frac{l}{A}$$

- Find current flowing in 6kΩ resistor. Assume ideal diode model

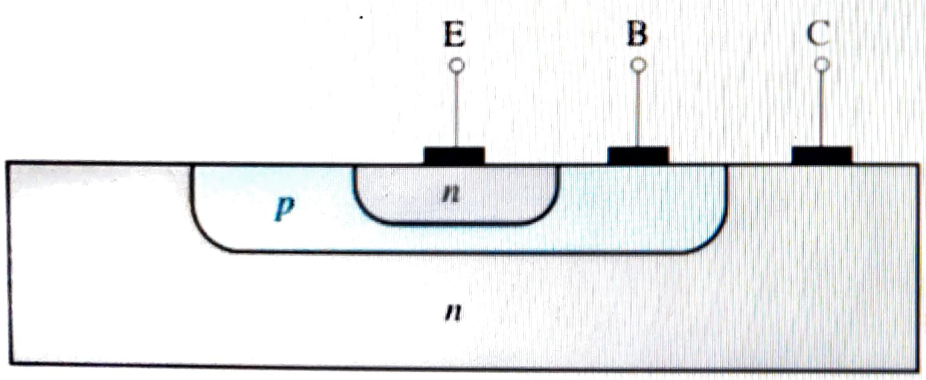


D1	D2
ON	ON
OFF	OFF
ON	OFF
OFF	ON

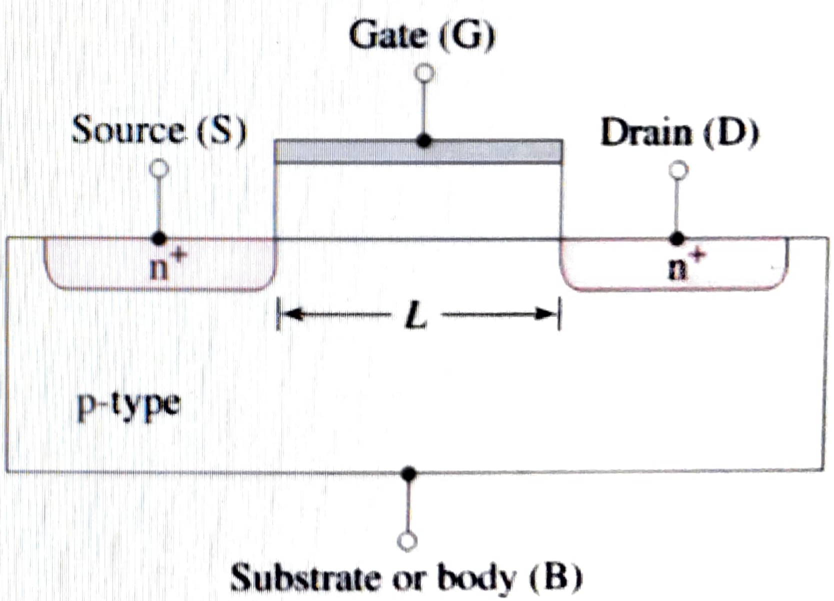
Transistors

- *Transistor*
  - *Transfers resistance*
- Transistor types
  - BJT (bipolar)
  - FET (Unipolar)

Applications
- **Amplifier**
- **Switch**

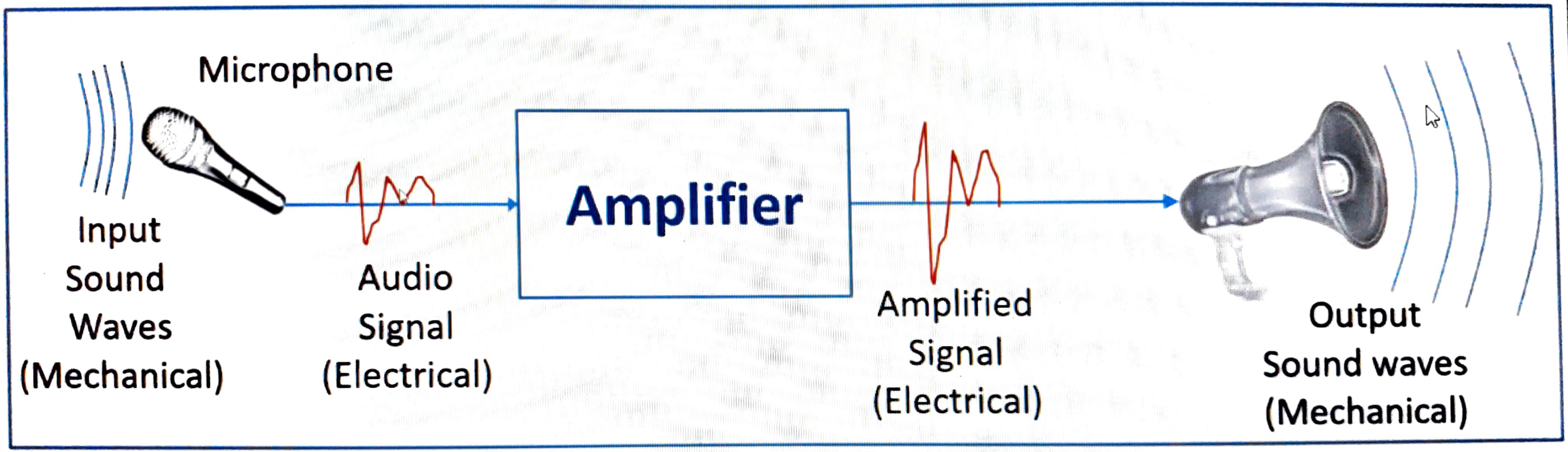


BJT



MOSFET

Amplifier: Basic PA system



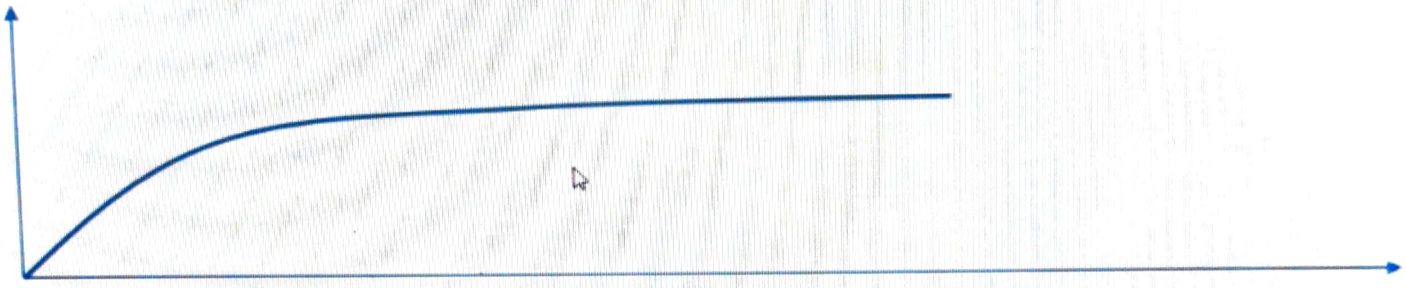
To amplify audio signal

1. **Sound wave → electrical signal**
2. **Amplified electrical signal**
3. **Electrical signal → Amplified sound wave**

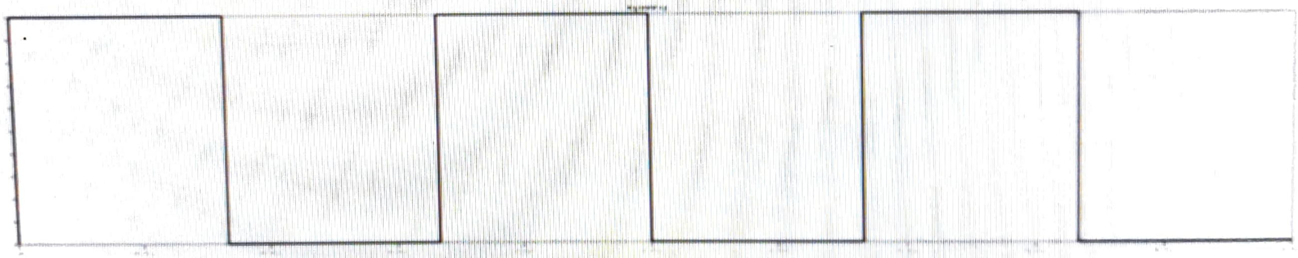
PA: Public Address

Switching

Analog

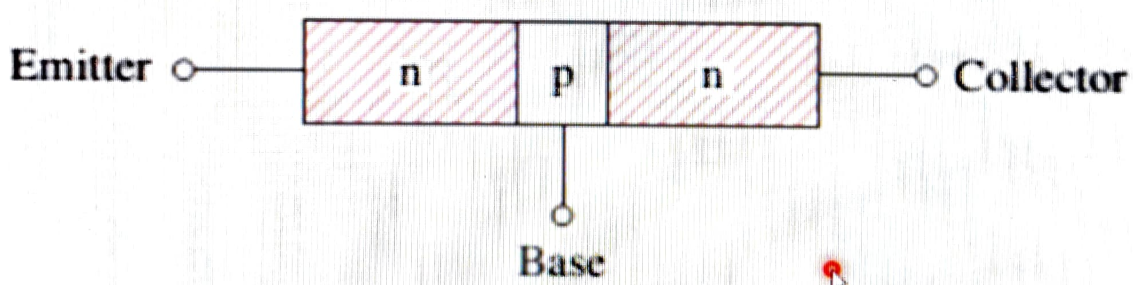


Digital



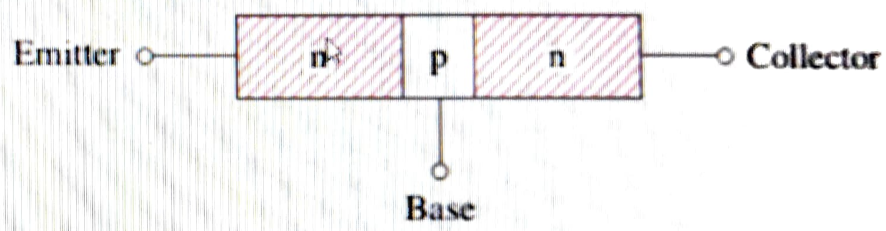
Bipolar junction transistor

- Transistor principle:
  the voltage between two terminals (Emitter and Base) controls the current through the third terminal (Collector)



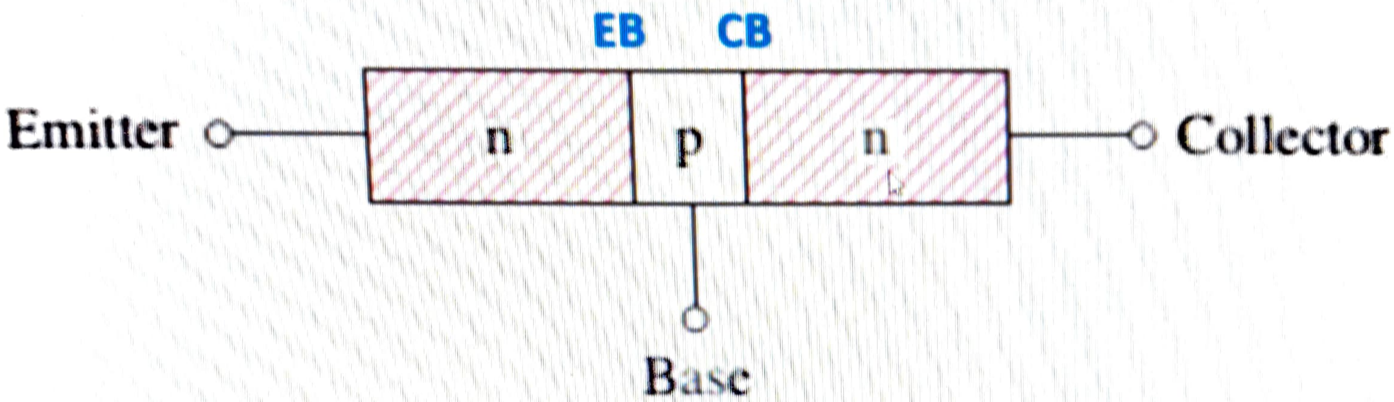
Bipolar junction transistor (BJT)

- Three doped regions
- Three terminals
- Two pn junctions
- Single pn junction has two modes
  - FB
  - RB
- BJT has two junctions
  - Four modes of operation



Majority carriers
Minority carriers

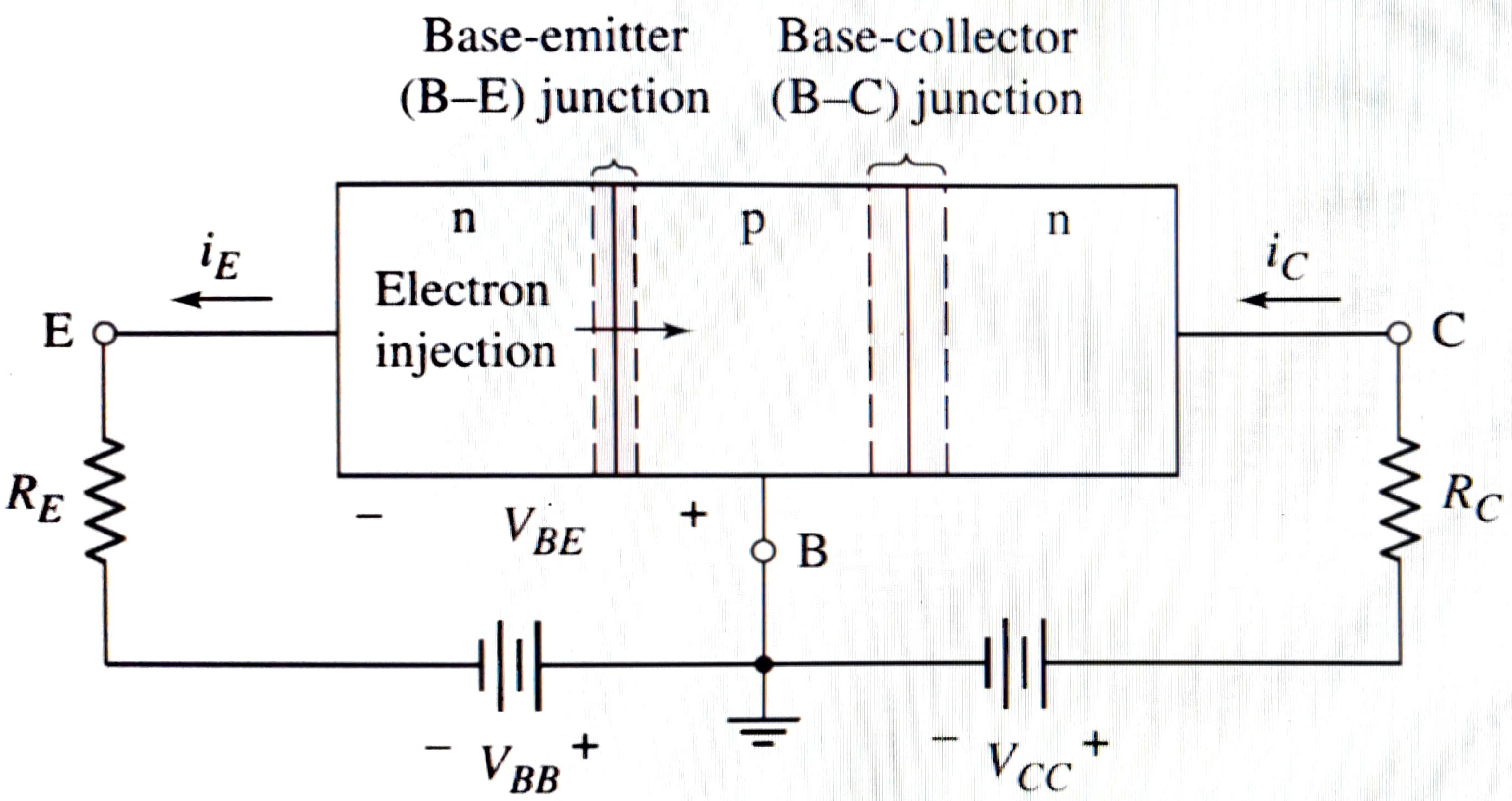
Modes of operation

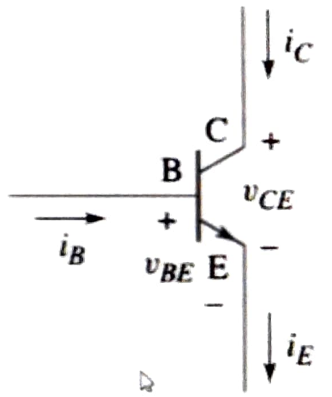


EB	CB	Mode
FB	RB	Active
FB	FB	Saturation
RB	RB	Cut-off
RB	FB	Reverse active

Draw the structural diagrams clearly mentioning the depletion region widths.

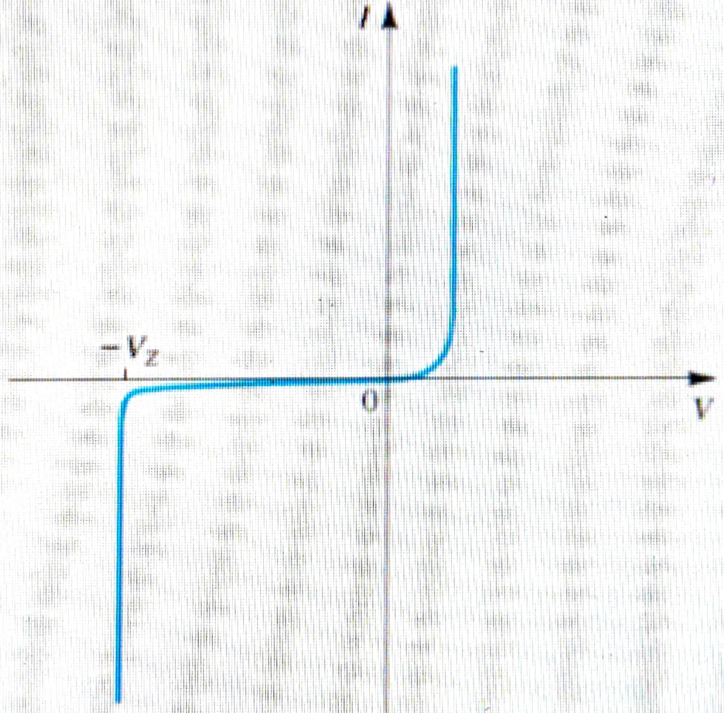
Transistor as an amplifier



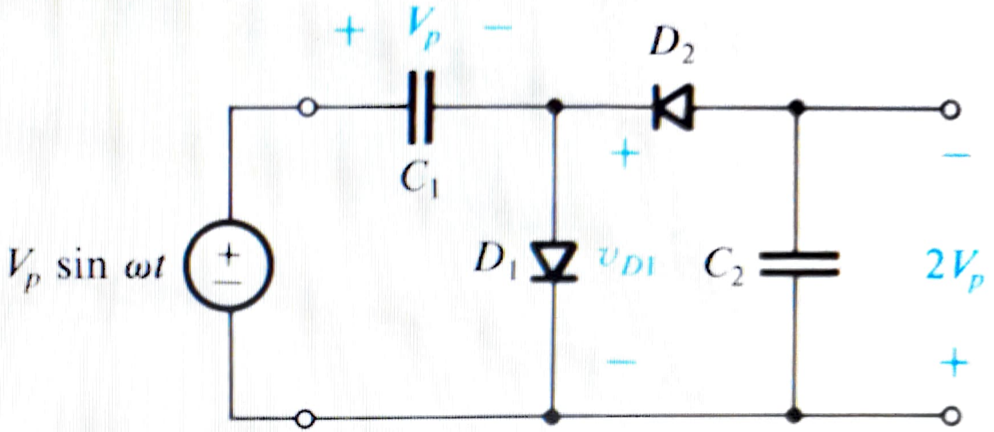


Current flow in a *npn* transistor biased to operate in the active mode

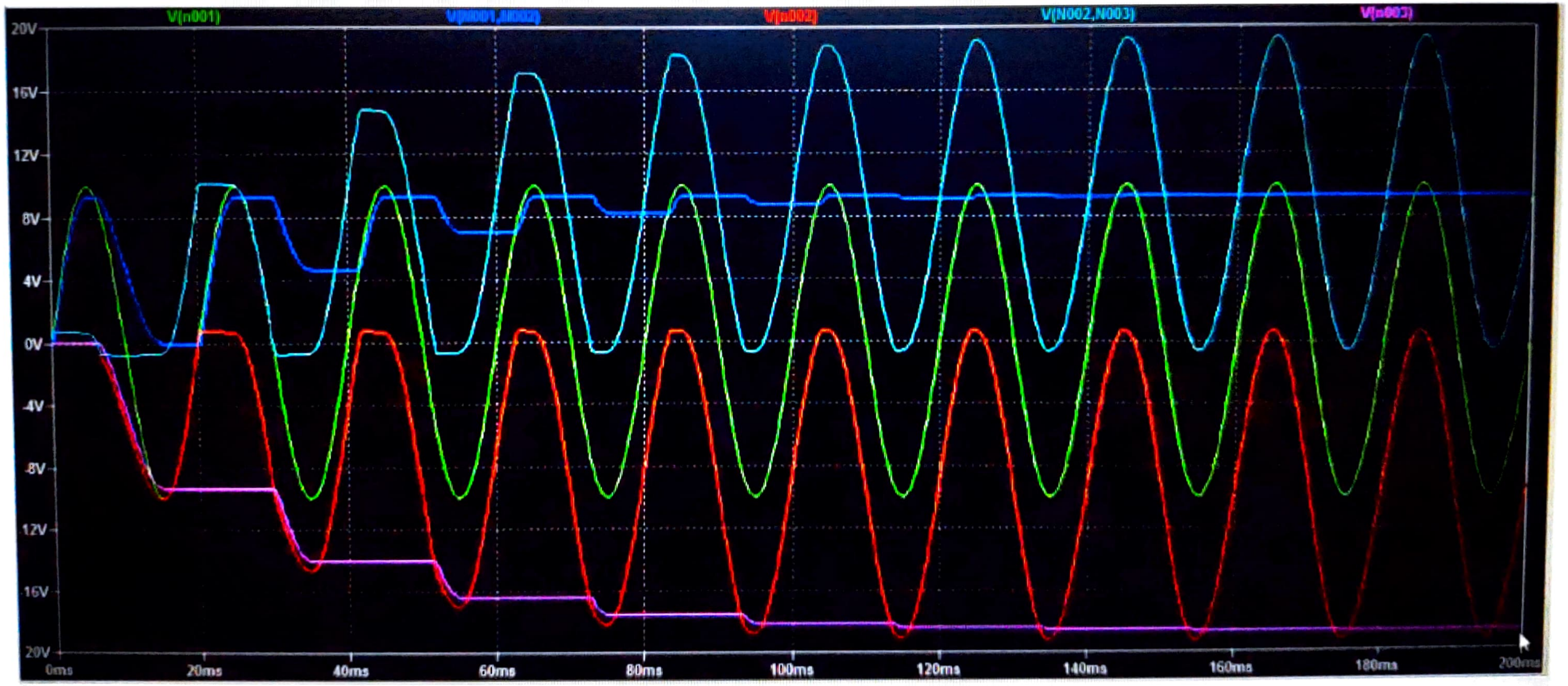
I-V characteristics of diode



$C = 10\mu F$

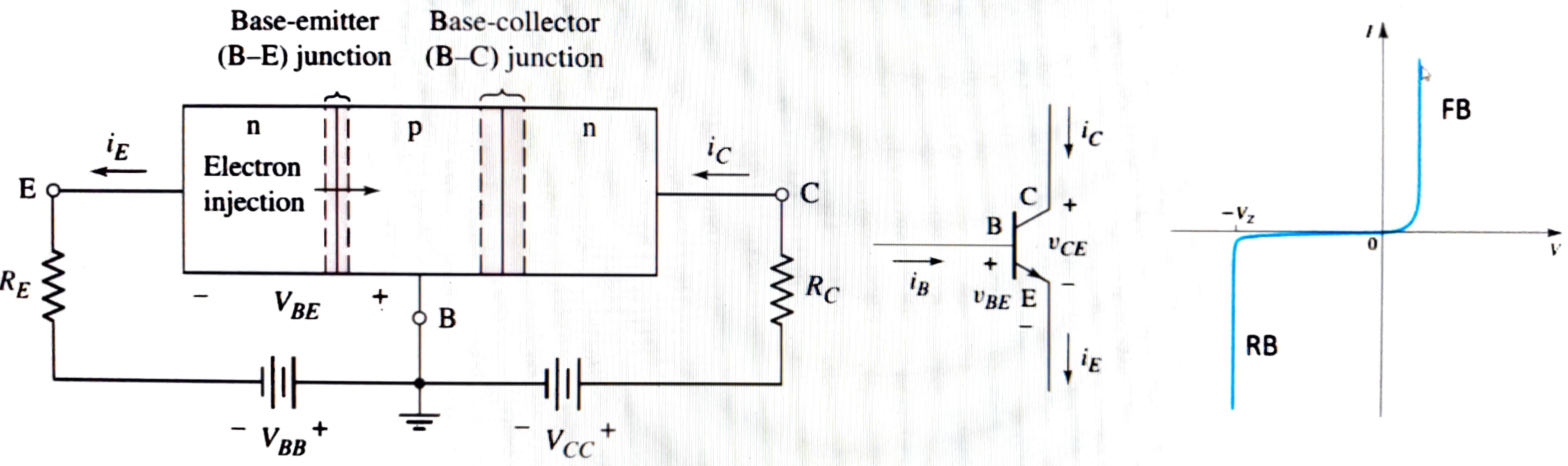


+ V_p −
D_2
C_1
+
−
$V_p \sin \omega t$
D_1
v_{D1}
C_2
$2V_p$
−
+



V(n001)
V(N002,N003)
20V
16V
12V
8V
4V
0V
-4V
-8V
-12V
-16V
-20V
0ms
20ms
40ms
60ms
80ms
100ms
120ms
140ms
160ms
180ms
200ms

Transistor as an amplifier



Current flow in a *npn* transistor biased to operate in the active mode

The pn Junction

n p

P $10^{15}/cm^3$

$e^- \rightarrow 10^4/cm^3$

h B

- **Operation with**
  - Open-Circuit Terminals
  - Applied voltage across the terminals
    - Forward Bias
    - Reverse Bias

n-type

p-type

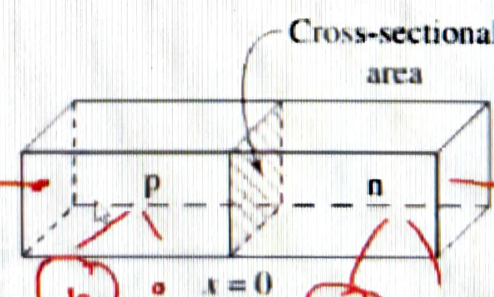
P

Si

Si

e^-

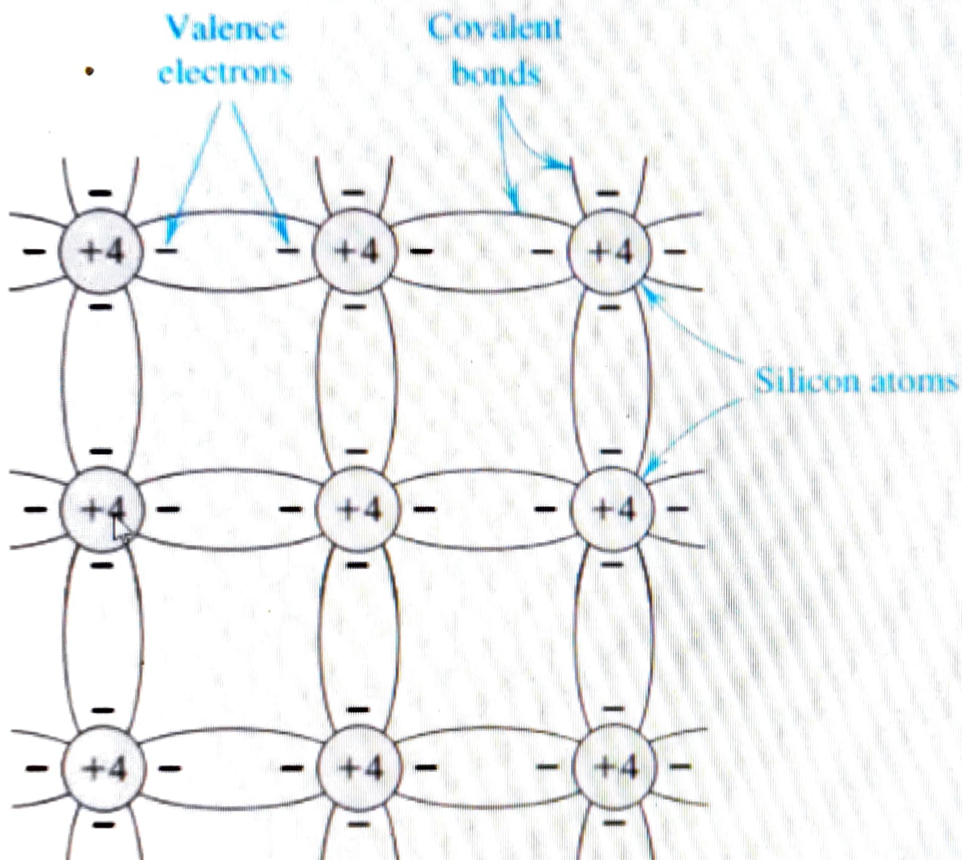
h



h e V

3D representation showing
the cross-sectional area

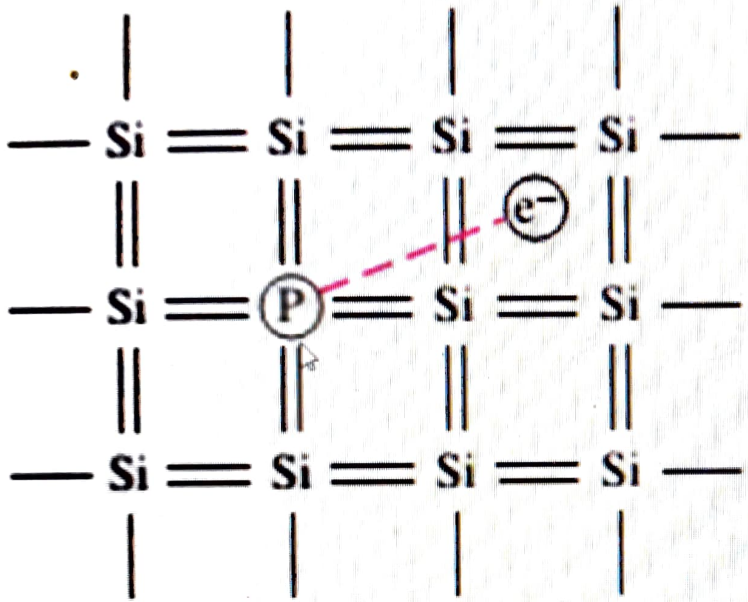
Single crystal silicon at $T = 0$ K



Silicon Lattice constant 5.43 Å

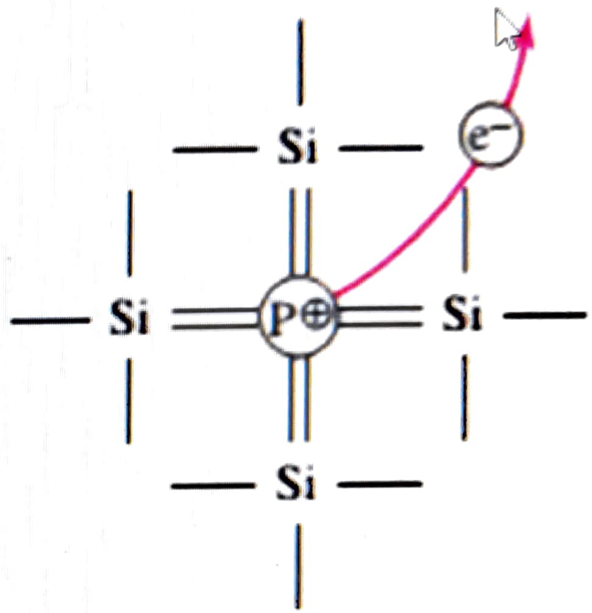
Two-dimensional representation of single crystal silicon at $T = 0$ K; all valence electrons are bound to the silicon atoms by covalent bonding

n-type semiconductor



Two-dimensional representation of a silicon lattice doped with a phosphorus atom and valence electron

e⁻ mobile carrier



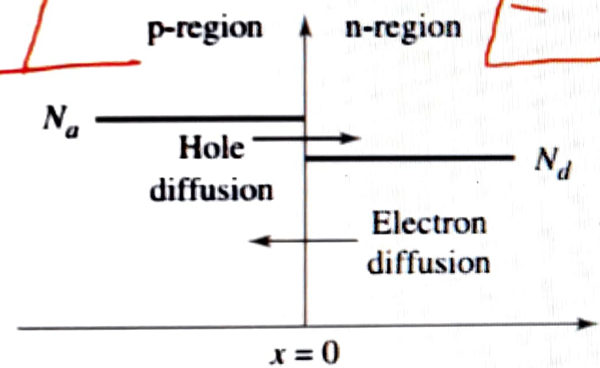
the resulting positively charged phosphorus ion after the fifth valence electron has moved into the conduction band

P⁺ immobile ion

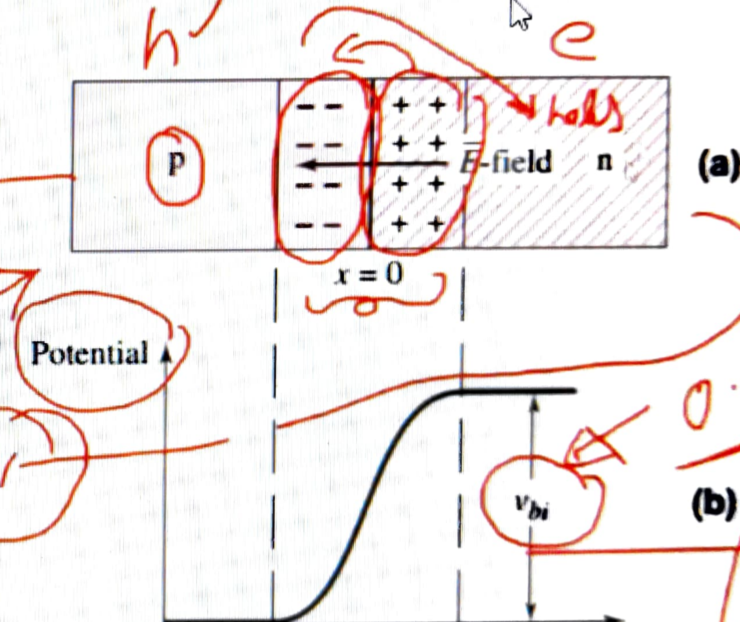
The pn Junction

0.7V

Operation with Open-Circuit Terminals



Initial diffusion of holes and electrons

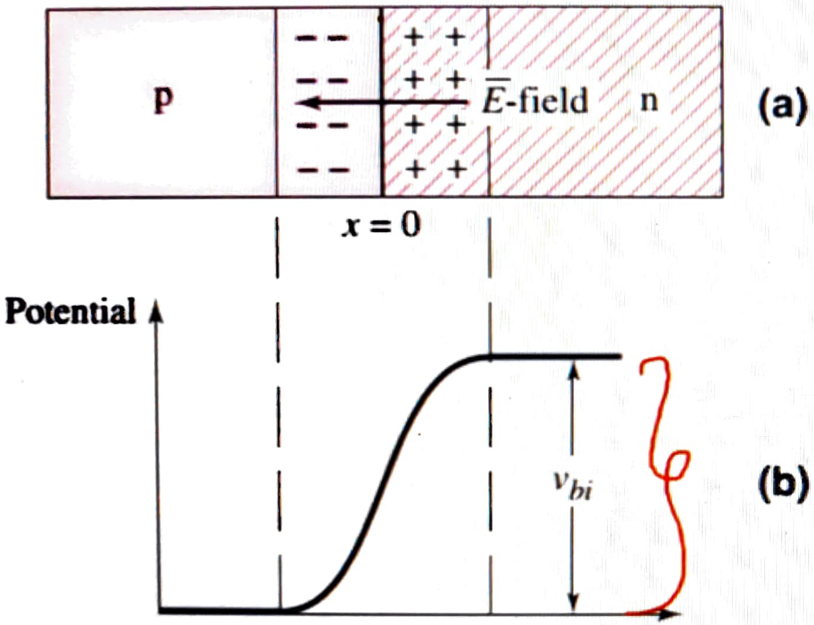


The pn junction in thermal equilibrium.

(a) The space charge region with negatively charged acceptor ions in the p-region and positively charged donor ions in the n-region; the resulting electric field from the n- to the p-region.

(b) The potential through the junction and the built-in potential barrier V_{bi} across the junction.

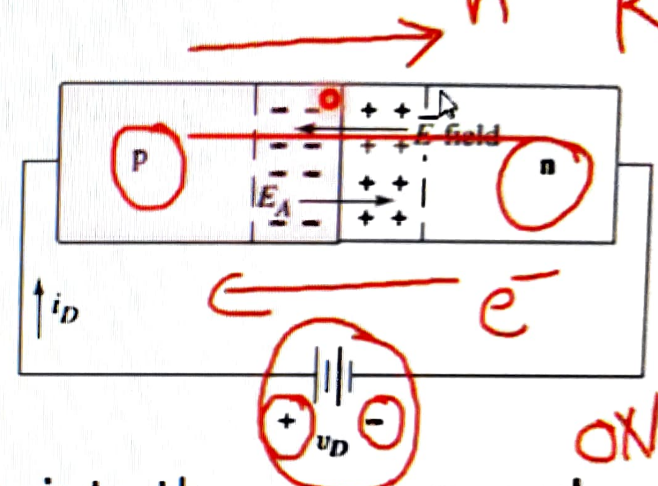
Built-in potential



Barrier

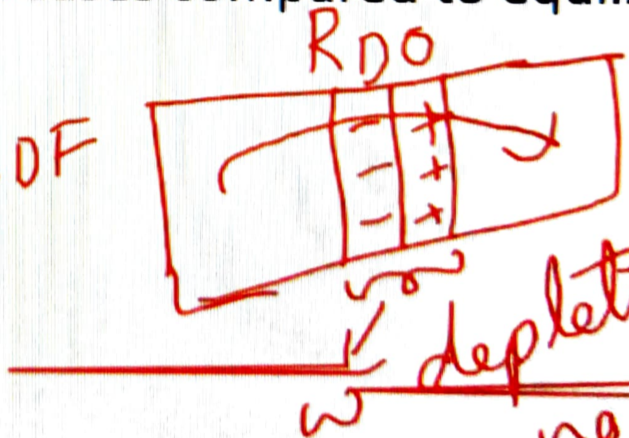
Forward-Biased pn Junction

R_{DF}



- If a positive voltage v_D is applied to the p-region and negative voltage to n-region then the diode is forward biased
- Majority carrier electrons from the n-region diffuse into the p-region, and majority carrier holes from the p-region diffuse into the n-region
- Width of the space charge region decreases compared to equilibrium width of the space charge region

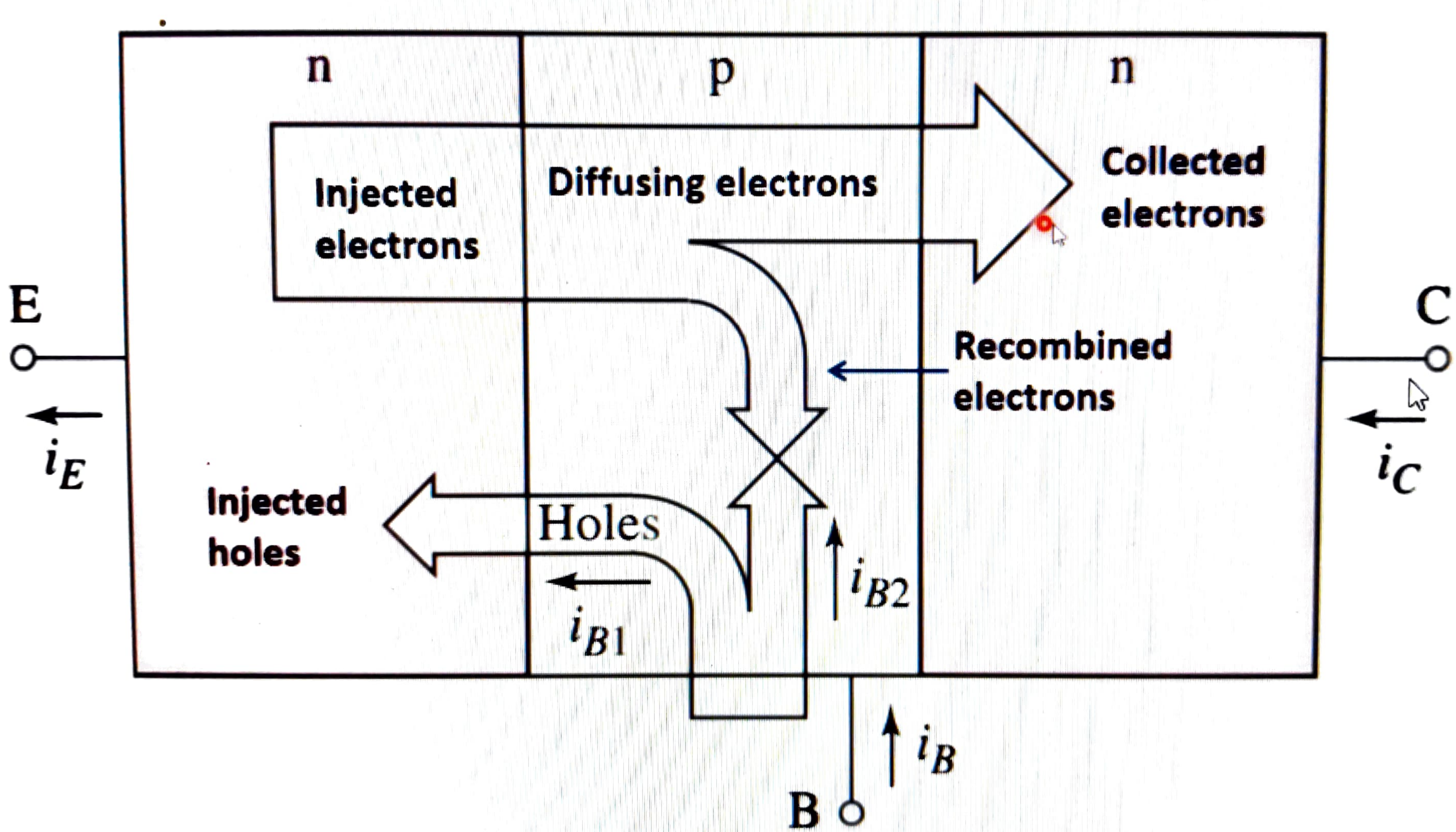
$R_{DO} > R_{DF}$



depletion region
no mobile carriers

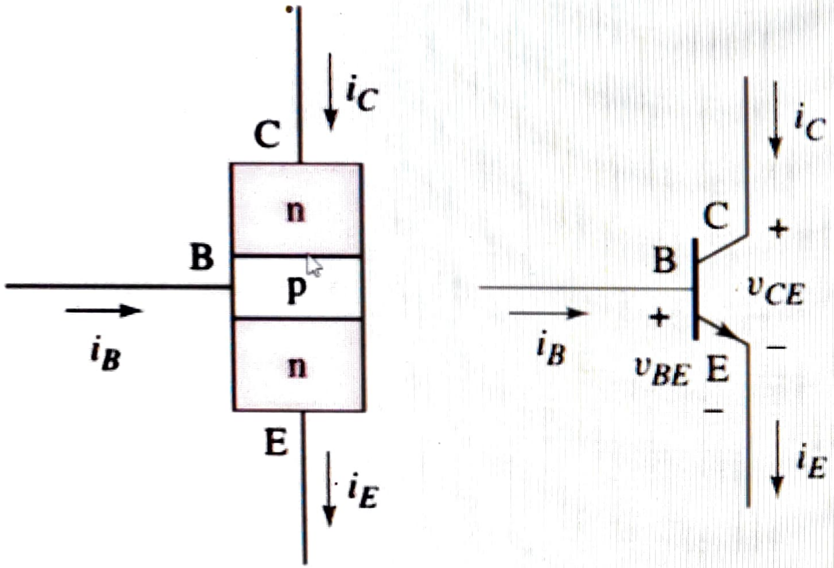
Currents in npn BJT

Doping levels: Emitter high, colletor low and base moderate

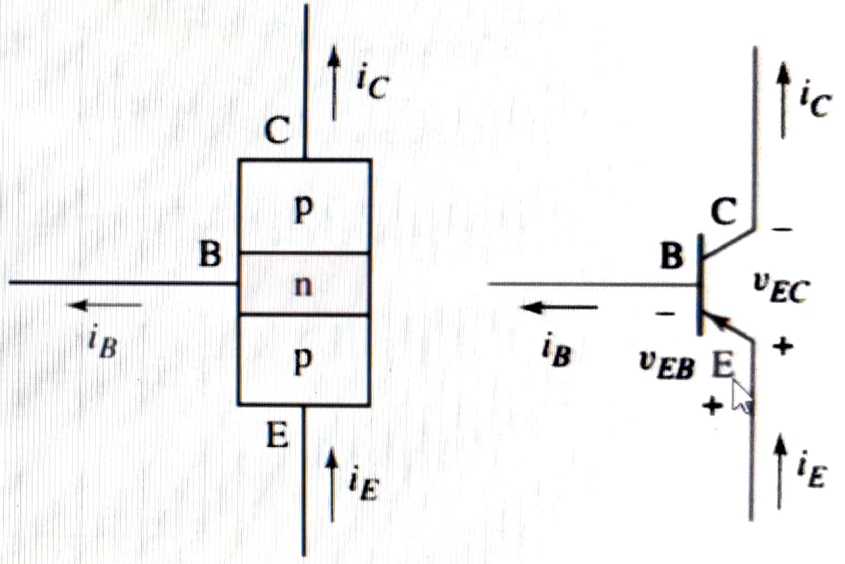


Electron and hole currents in a npn bipolar transistor biased in the forward-active mode

Block diagrams and circuit symbols for BJT

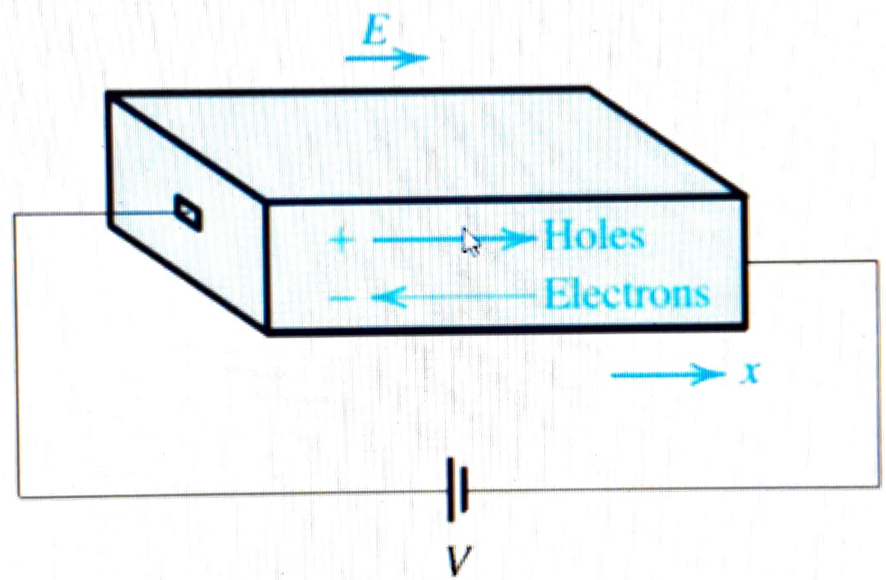


NPN transistor



PNP transistor

Directions of applied electric field and resulting carrier drift velocity and drift current density



An electric field E established in a bar of silicon causes

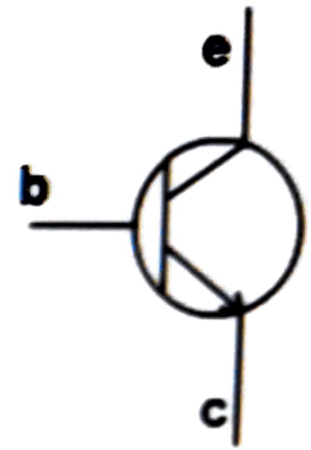
- the holes to drift in the direction of E and
- the free electrons to drift in the opposite direction of E
- Both the hole and electron drift currents are in the direction of E

Currents in BJT

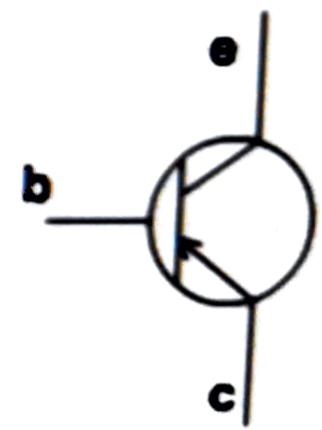
- The total current flowing into the transistor must be equal to the total current flowing out of it
- the emitter current I_E is equal to the sum of the collector (I_C) and base current (I_B)
- $I_E = I_C + I_B$
- $I_C = \alpha I_E$
- $I_C = \beta I_B$
- α = Common base current gain
- β = Common emitter current gain

$$I_C = I_S e^{V_{BE}/V_T}$$

$$\beta = \frac{\alpha}{1-\alpha}$$



npn



pnp

Problem

Objective: Calculate the collector and emitter currents, given the base current and current gain.

Assume a common-emitter current gain of $\beta = 150$ and a base current of $i_B = 15\ \mu A$. Also assume that the transistor is biased in the forward-active mode.

Solution: The relation between collector and base currents gives

$$i_C = \beta i_B = (150)(15\ \mu A) \Rightarrow 2.25\ \text{mA}$$

and the relation between emitter and base currents yields

$$i_E = (1+\beta)i_B = (151)(15\ \mu A) \Rightarrow 2.27\ \text{mA}$$

the common-base current gain is

$$\alpha = \frac{\beta}{1+\beta} = \frac{150}{151} = 0.9934$$