

## Chapter 12-2. Transient (switching) response

(Section 12-2 in text, pages 449 – 458)

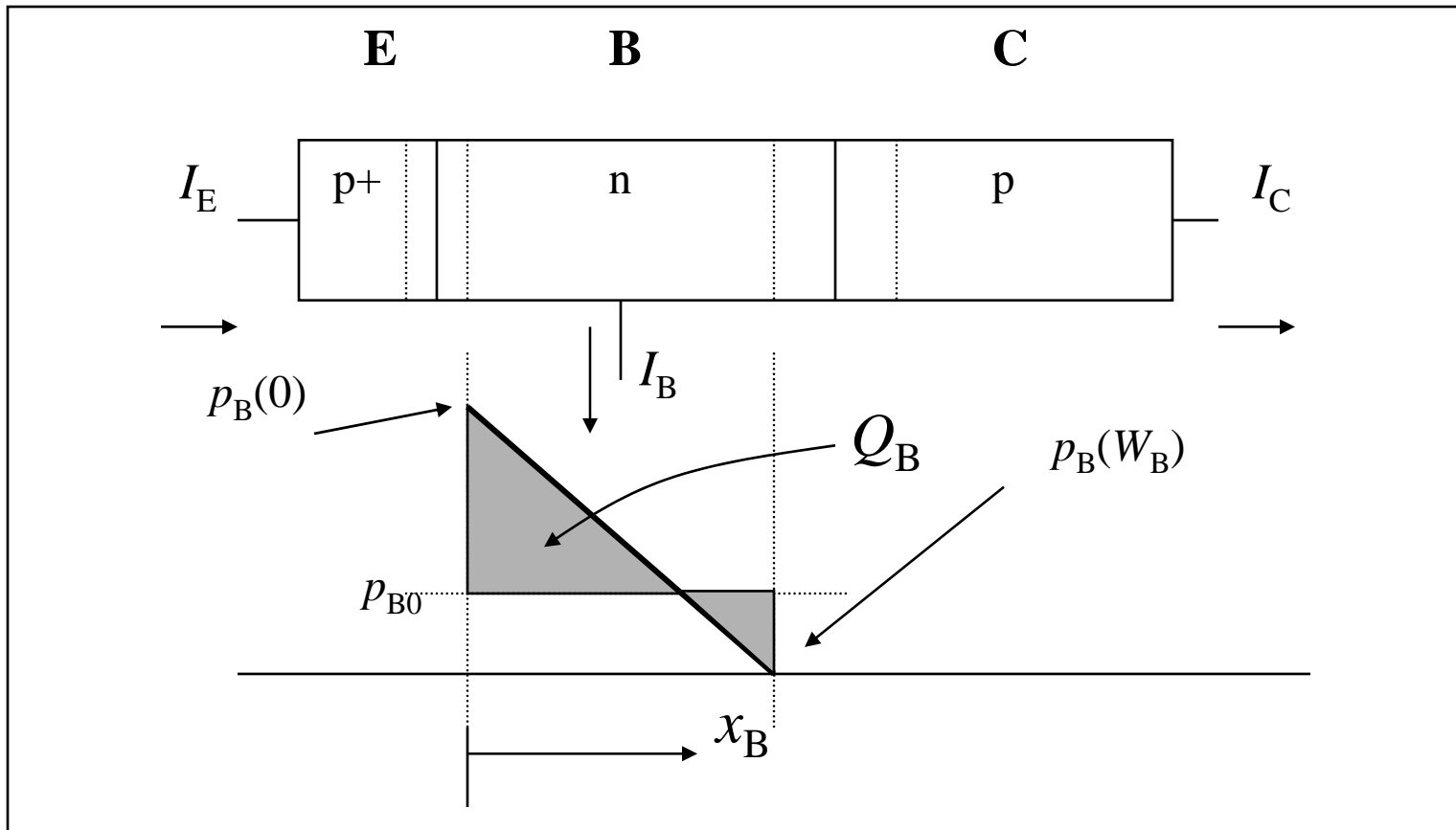
BJT finds extensive use as an electronic switch in complex logic circuits.

Provides faster switching speeds compared to a pn junction diode.

The time-delay between “on” and “off” states can be attributed to the build-up and removal of excess minority carrier charge from the base region.

# Transient response

Consider a pnp transistor



## Transient response: Base current

In the quasi-neutral region of the base, the base lead supplies electrons for:

Recombination with excess holes ( $= Q_B/\tau_B$ )

Increasing or decreasing of excess hole charge in base ( $dQ_B / dt$ )

- Under steady state, this part is zero (excess hole concentration is equal to excess electron concentration in neutral region)

Injection of electrons to emitter,  $I_{EN}$

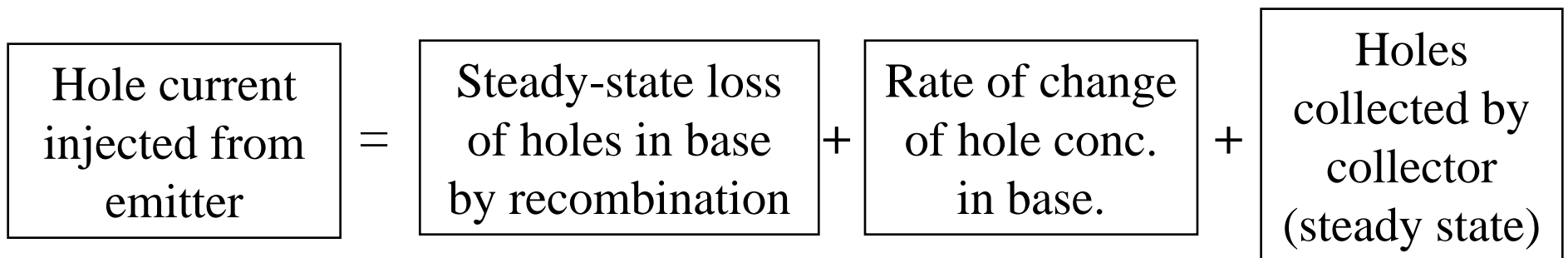
## Transient response (continued)

If we neglect the electrons emitted to the emitter (i.e.,  $\gamma = 1$ ) then,

$$I_B = \frac{Q_B}{\tau_B} + \frac{dQ_B}{dt} \quad \text{where } I_B \text{ and } Q_B \text{ are time dependent and } \gamma = 1.$$

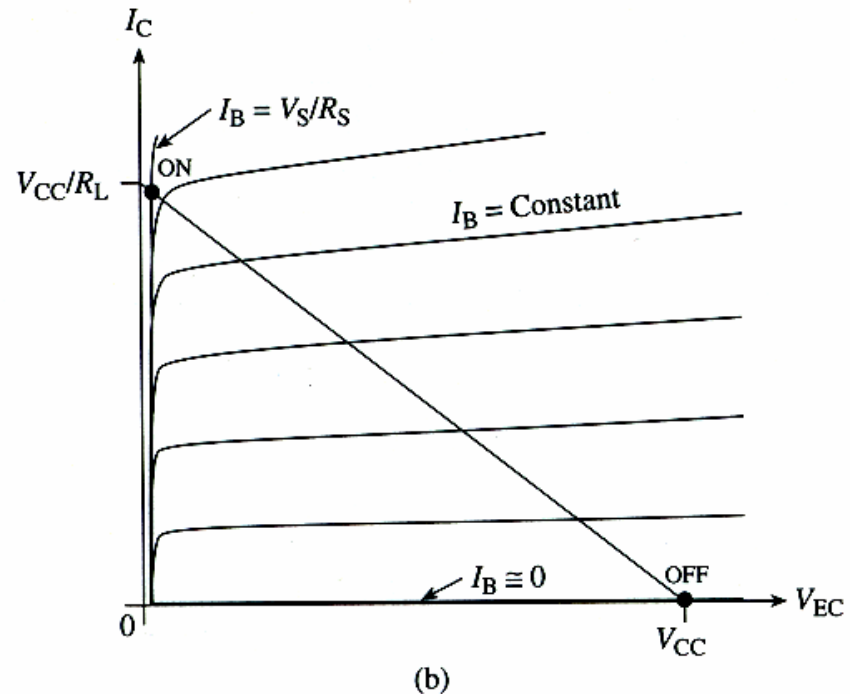
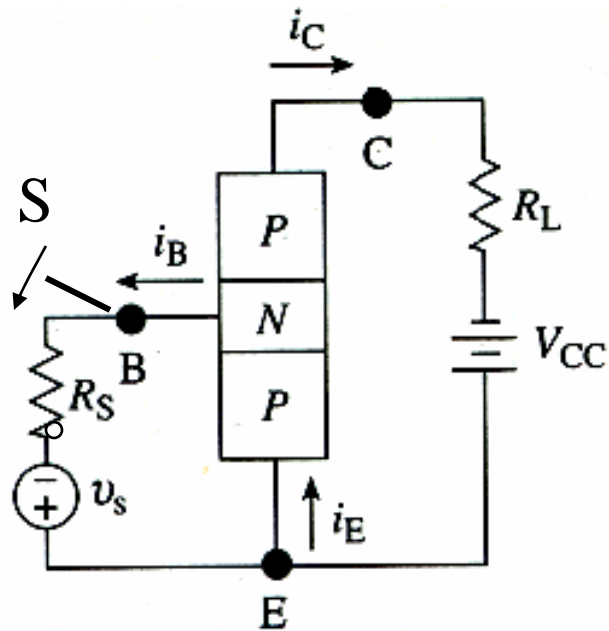
When the transistor is in forward active mode,  $I_C = \frac{\beta_{dc} Q_B}{\tau_B}$

$$I_E = I_B + I_C = \frac{Q_B}{\tau_B} + \frac{dQ_B}{dt} + \frac{\beta_{dc} Q_B}{\tau_B}$$



Apply these concepts to turning on a BJT.

## Idealized switching circuits



Let us say, base current is suddenly changed from zero to a value  $I_B$ , by turning on the switch. In the above circuit, the base current changes from zero to  $V_S/R_S$ , if we assume that  $V_S \gg V_{BE}$ , where  $V_{BE}$  is the forward voltage drop of emitter-base junction (approx. 0.7 V).

## Analysis of switching transients

Using the charge control model we just discussed, we can write,

$$I_B = \frac{Q_B}{\tau_B} + \frac{dQ_B}{dt} \quad \text{where } I_B \text{ is constant for } t > 0.$$

Or 
$$\frac{dQ_B}{dt} = I_B - \frac{Q_B}{\tau_B}$$

The general solution of this equation is: 
$$Q_B(t) = I_B \tau_B \left( 1 - e^{-\frac{t}{\tau_B}} \right)$$
 assuming the boundary condition that  $Q_B(t) = 0$  when  $t = 0$  (i.e. starting from “off” state).

As  $Q_B(t)$  increases from zero to  $I_B \tau_B$ , the collector current will also increase since the collector current is given by:

$$I_C = \frac{\beta_{dc} Q_B}{\tau_B} = \beta_{dc} I_B$$

## Analysis of switching transients (continued)

But the collector current **cannot increase continuously** since  $I_C$  is limited by the value of  $R_L$  and  $V_{CC}$ . Once,  $I_C$  reaches  $V_{CC}/R_L$ , then  $I_C$  cannot increase even though  $Q_B$  continues to increase. At this value of  $I_C$ ,  $V_{CE}$  is close to zero, and C-B junction gets **forward biased**, and the transistor is said to be in **saturation**.  $I_C$  is not equal to  $\beta_{dc} I_B$  anymore in saturation.

$$I_C = \frac{\beta_{dc} Q_B}{\tau_B} = \beta_{dc} I_B \left( 1 - \exp - \frac{t}{\tau_B} \right) \quad \text{for } 0 < t < t_r$$

$$I_C = V_{CC} / R_L \quad \text{for } t > t_r$$

During  $0 < t < t_r$ , the BJT is in **active mode**. At  $t = t_r$ , the collector current reaches the maximum value of  $V_{CC}/R_L$  and does not increase further. The time  $t_r$  is called **turn-on time** of the BJT.

## Analysis of switching transients (continued)

The **turn-on time**  $t_r$  can be obtained from:  $\beta_{dc} I_B \left( 1 - \exp - \frac{t_r}{\tau_B} \right) = I_C$

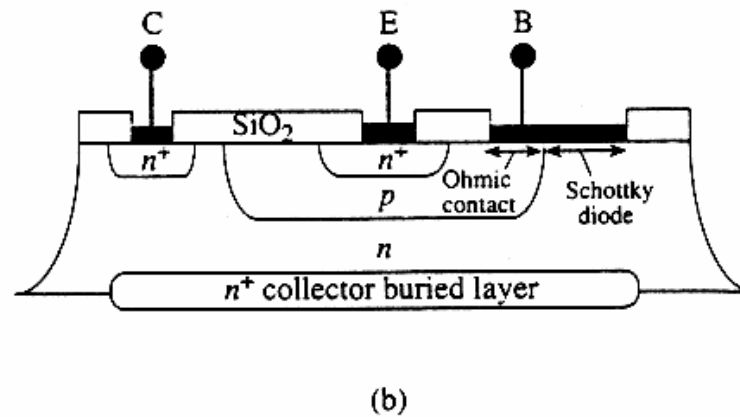
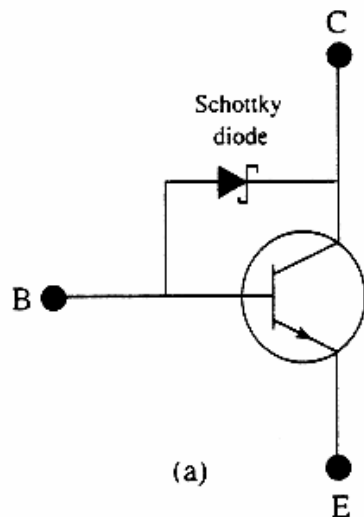
Rearranging and solving for  $t_r$ :  $t_r = \tau_B \ln \left( \frac{1}{1 - (I_C / \beta_{dc} I_B)} \right)$

Note that one can reduce the **turn-on time** by **increasing** the base current (faster storage charge build up). However, if you make the base current too large, you will be storing too much charge in the base during “**on**” so that it will affect the **turn-off time**.

# Methods to speed-up turn-off transients

Introduce R-G centers in base.

Use Schottky diode clamp to prevent BJT going into “deep” saturation.



## Examples of transient response

