2.7 HYBRID-PI MODEL

Bipolar transistors are commonly used in circuits that amplify time-varying or sinusoidal signals. In these linear amplifier circuits, the transistor is biased in the forward-active region and small sinusoidal voltages and currents are superimposed on dc voltages and currents. The sinusoidal parameters are of interest, so it is convenient to develop a small-signal equivalent circuit of the bipolar transistor using the small-signal admittance parameters of the pn junction.

The C, B, and E terminals are the external connections to the transistor, while the C’, B’, and E’ points are the idealized internal collector, base, and emitter regions.

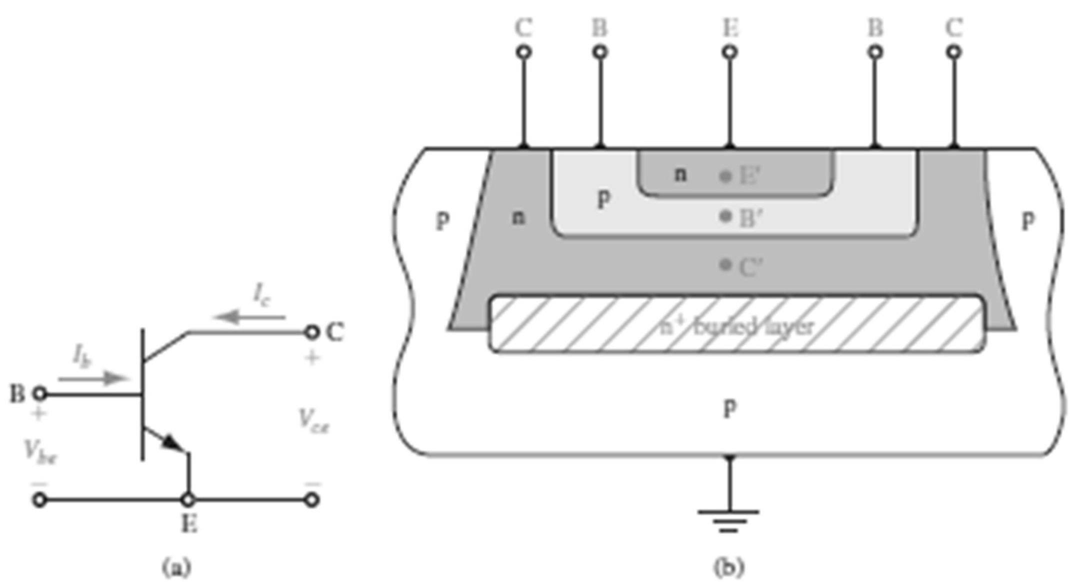

Fig:2.7.1 (a) Common-emitter npn bipolar transistor with small-signal current and voltages. (b) Cross section of an npn bipolar transistor for the hybrid-pi model.

(Source : Semiconductor Physics and Devices)

The equivalent circuit between the external input base terminal and the external emitter terminal. The resistance r_b is the series resistance in the base between the external base terminal B and the internal base region B’. The B’-E’ junction is forward biased, so $C\pi$ is the junction diffusion capacitance and r_π is the junction diffusion resistance.

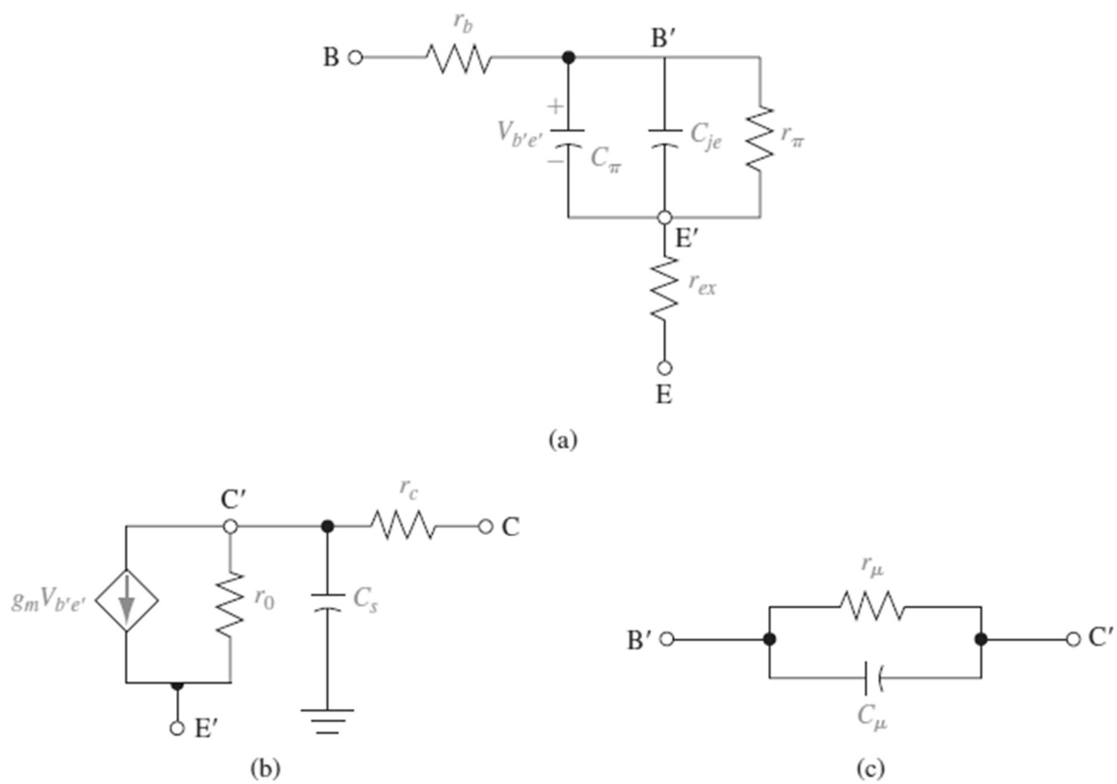

Fig:2.7.2 Components of the hybrid-pi equivalent circuit between (a) the base and emitter, (b) the collector and emitter, and (c) the base and collector.

(Source : Semiconductor Physics and Devices)

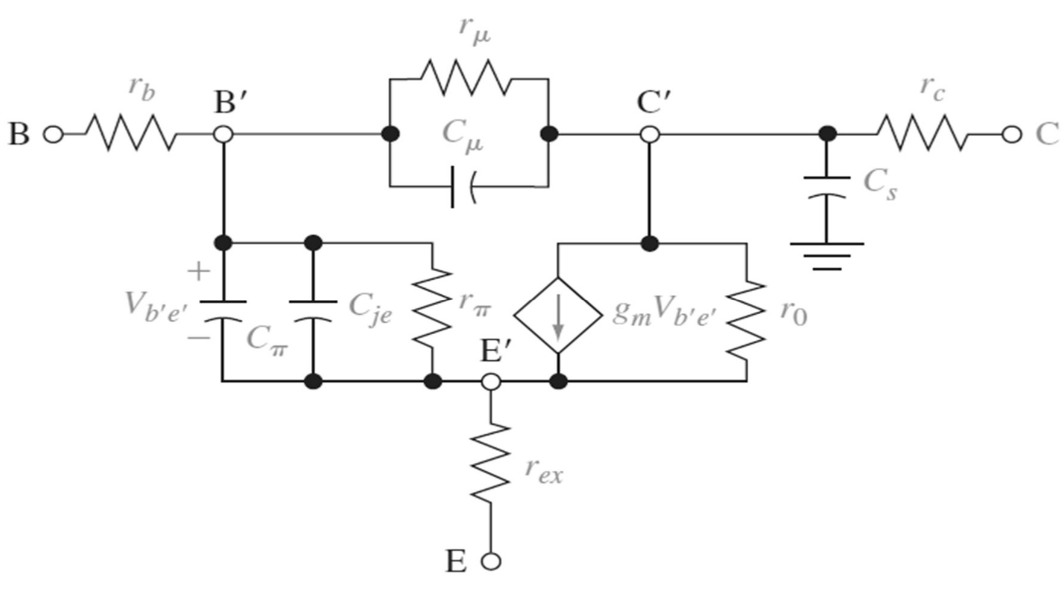

Fig:2.7.3 Hybrid-pi equivalent circuit.

(Source : Semiconductor Physics and Devices)

These two elements are in parallel with the junction capacitance, which is Cje. Finally, r_{ex} is the series resistance between the external emitter terminal and the internal emitter region. This resistance is usually very small and may be on the order of 1 to 2 Ω.

The r_c resistance is the series resistance between the external and internal collector connections and the capacitance C_s is the junction capacitance of the reverse-biased collector substrate junction. The dependent current source, $g_m V_{b'e'}$, is the collector current in the transistor, which is controlled by the internal base–emitter voltage. The resistance r_0 is the inverse of the output conductance g_0 and is primarily due to the Early effect.

The equivalent circuit of the reverse-biased B'-C' junction. The C_μ parameter is the reverse-biased junction capacitance and r_μ is the reverse-biased diffusion resistance. Normally, r_μ is on the order of mega ohms and can be neglected. The value of C_μ is usually much smaller than C_π but, because of the feedback effect that leads to the Miller effect and Miller capacitance, C_μ cannot be ignored in most cases.

The Miller capacitance is the equivalent capacitance between B' and E' due to C_μ and the feedback effect, which includes the gain of the transistor. The Miller effect also reflects C_μ between the C' and E' terminals at the output. However, the effect on the output characteristics can usually be ignored.