HIGH-FREQUENCY MODELS OF THE BJT

- The dominant model used for small-signal analysis of a BJT in the forward-active region, the *h*-parameter model as presented in Chapter 3, does not contain frequency sensitive elements and is therefore invariant with respect to changes in frequency. It is therefore necessary to introduce a new BJT model or to reinterpret an old model to include frequency-dependent terms using the Ebers-Moll model as a basis for creating the new model.
- In the forward-active region and at low frequencies the Ebers-Moll Model can be replaced by the linear two-port model shown in Figure 10.4-2. This model is known as the hybrid-π model. It is similar to the *h*-parameter model used previously in this text, but has particular utility when frequency-dependent terms are included.

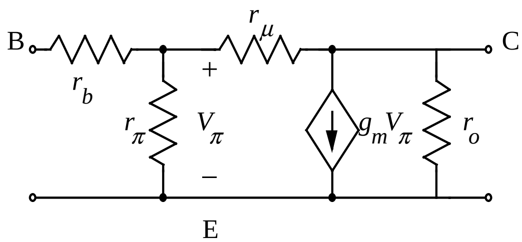

Figure 10.4-2 Low-frequency Hybrid-π BJT Model

- The relationships between *h*-parameter and hybrid-π models are related to the *h*-parameter model parameters by:

$$g_m = \frac{h_{fe}}{r_\pi} = \frac{|I_c|}{\eta V_t}, \qquad r_\pi = \beta_F \frac{\eta V_t}{|I_c|} = \frac{\beta_F}{g_m},$$

$$r_o \approx \frac{1}{h_{oe}} = \frac{|V_A|}{|I_c|}, \qquad r_b = h_{ie} - r_\pi .$$

- As will be seen in Section 10.7, the hybrid-π model is also useful in modeling FETs.
- The frequency-dependent component of transistor behavior is based on the capacitive component of p-n junction impedance. Once the capacitive nature of a p-n junction is known, a frequency dependent model for a BJT can be obtained.

Modeling a p-n Junction Diode at High Frequencies

- The charge buildup in the semiconductor region near a p-n junction under a voltage bias, causes a significant buildup of electrical charge on each side of the junction which exhibits acts as a capacitance. It is modeled as a capacitor shunting the dynamic resistance of the junction (Figure 10.4-3).

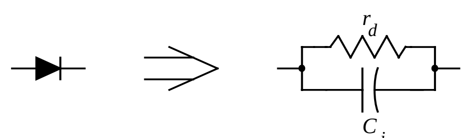

Figure 10.4-3 High-frequency model of a p-n junction

- In most electronic applications the p-n junction capacitance is dominated by the diffusion of carriers in the depletion regions. A good analytic approximation of this depletion capacitance, C_j, is given by: $C_j \approx \frac{C_{jo}}{\left(1 - \frac{V_d}{\ }\right)^m}$, (10.4-2)

where,

C_{jo} = small-signal junction capacitance at zero voltage bias,
ψ_o = junction built-in potential, and
m = junction grading coefficient ($0.2 < m \leq 0.5$) .

- A plot the junction capacitance as described by Equation 10.4-2 is shown in Figure 10.4-4.

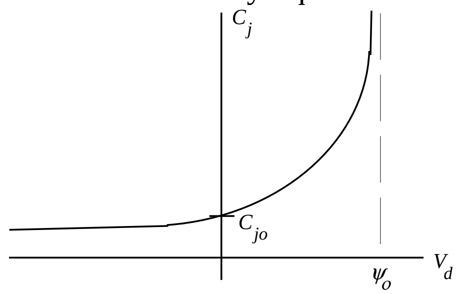

Figure 10.4-4 p-n Junction Depletion Capacitance

Modeling the BJT at High Frequencies in the Forward-Active Region

- In order to model the BJT at high frequencies, the hybrid-π model of Figure 10.4-2 is altered by shunting each p-n junction dynamic resistance with an appropriate junction capacitance.

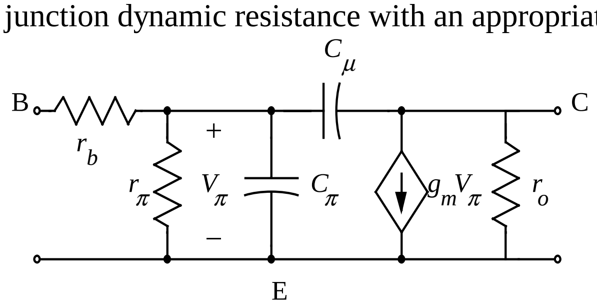

Figure 10.4-5 The High-Frequency Hybrid-π Model of a BJT

- The junction capacitance, C_μ, is *relatively* independent of quiescent conditions. Typical manufacturer data sheets provide a value for C_μ at a given reverse bias (typically, V_{CB} = 5 or 10 V).
- The forward-biased base-emitter junction exhibits greater variation with bias conditions: its junction capacitance, C_π, must therefore be determined with greater caution.
- In order to correlate these measurements with the hybrid-π parameters, an ac equivalent circuit of the test circuit must be created (Figure 10.4-7).
- The gain-bandwidth product: the product of short-circuit current gain,

  $A_I(\omega) = (g_m)\left(\frac{r_\pi}{1 + j\omega r_\pi (C_\pi + C_\mu)}\right) = \frac{h_{fe}}{1 + j\omega r_\pi (C_\pi + C_\mu)}$ at a particular frequency and that

  frequency has constant value for all frequencies greater than $\omega_{3dB} = \frac{1}{r_\pi (C_\pi + C_\mu)}$ is a common

  description: $\omega_T = \frac{h_{fe} - 1}{r_\pi (C_\pi + C_\mu)} \approx \frac{g_m}{C_\pi + C_\mu}$. (10.4-6)

- Manufacturers data sheets will either provide a value for ω_T or provide the gain at some other high frequency. The gain-bandwidth is given by: $\omega_T = A_m\, \omega_m$ (10.4-7)

  where ω_m is the frequency at which the manufacturer made the gain measurement and A_m is the gain at that frequency.