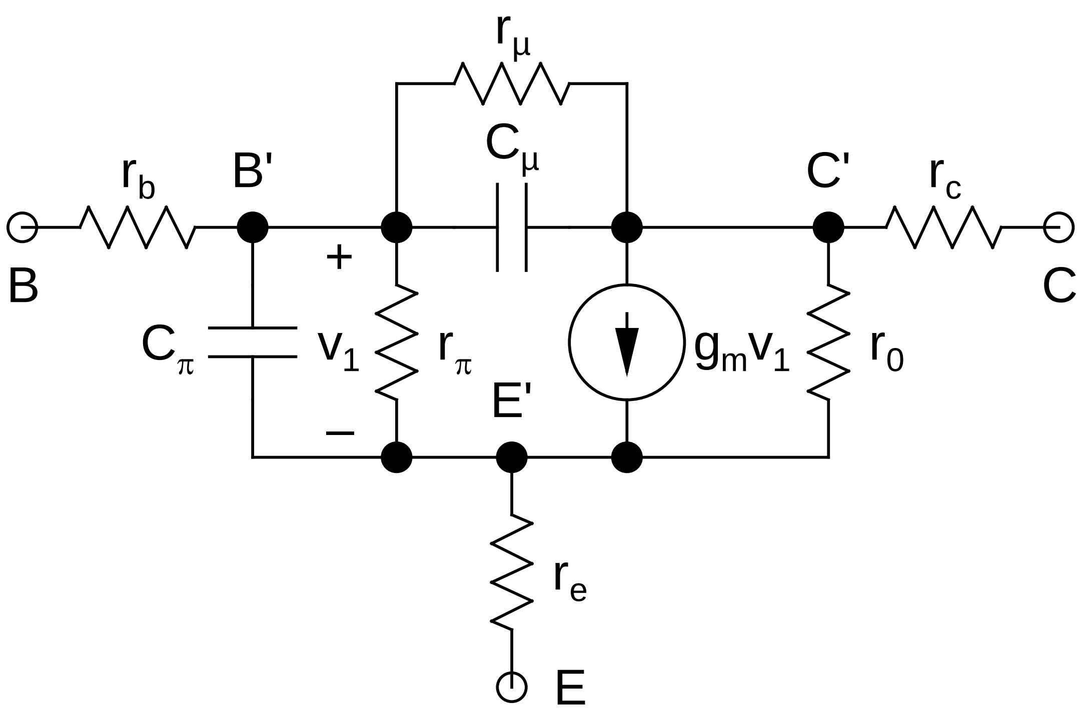
- ***Collector-Base Capacitance*** (C_μ):

$$C_\mu = \frac{C_{\mu 0}}{\left(1 - \frac{V_{BC}}{V_{0,BC}}\right)^m}$$

  - $C_{\mu 0}$: ***Collector-base depletion capacitance at zero bias***
  - $V_{0,BC}$: ***Built-in voltage of collector-base junction***
  - m: ***Grading coefficient*** (1/2 for ***abrupt step junction***, 1/3 for ***linearly graded junction***)

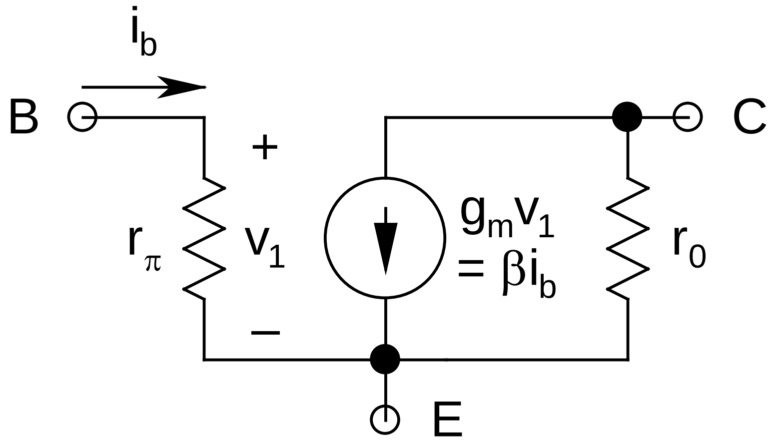
- ***Quasi-Neutral Emitter, Base, and Collector Resistances*** (r_e, r_b, and r_c):
  - In ***IC BJT***, ***emitter highest doped***, ***followed by base***, with ***collector being least doped***
  - Thus, $r_c > r_b > r_e$
  - ***Typical values***:
    - $r_e \sim$ 5-10 Ω
    - $r_b \sim$ 100-200 Ω
    - $r_c \sim$ can be as high as kΩ
  - ***Become important only at very high frequencies***

The Hybrid-π Model



E,B,C: Extrinsic (or External) Terminals
E',B',C': Intrinsic (or Internal) Terminals

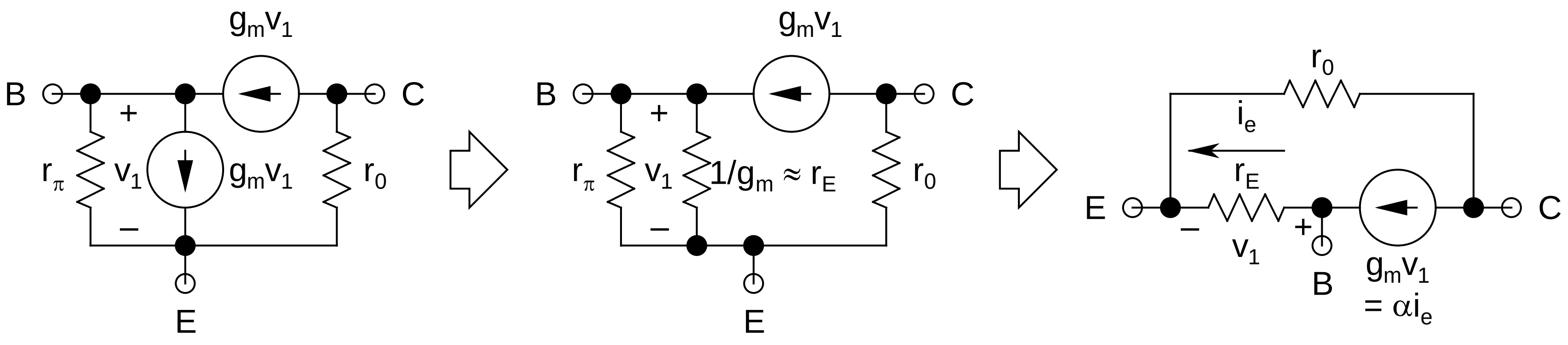
- ***Simplifications***:
  - r_e, r_b, r_c can be ***safely neglected*** under ***low to moderate frequencies*** of operation
  - r_μ can be ***neglected***, since it's ***extremely large***
  - At ***low to moderate frequencies***, the ***capacitive reactances*** of C_π and C_μ will be ***extremely large*** $\Rightarrow$ can be ***neglected***
  - Leads to the ***Low-Frequency T-Model***, having only ***three components***: r_π, $g_m v_1$, and r_0
  - ***Simplest possible equivalent results if r_0 is also neglected***!



Low-Frequency T-Model

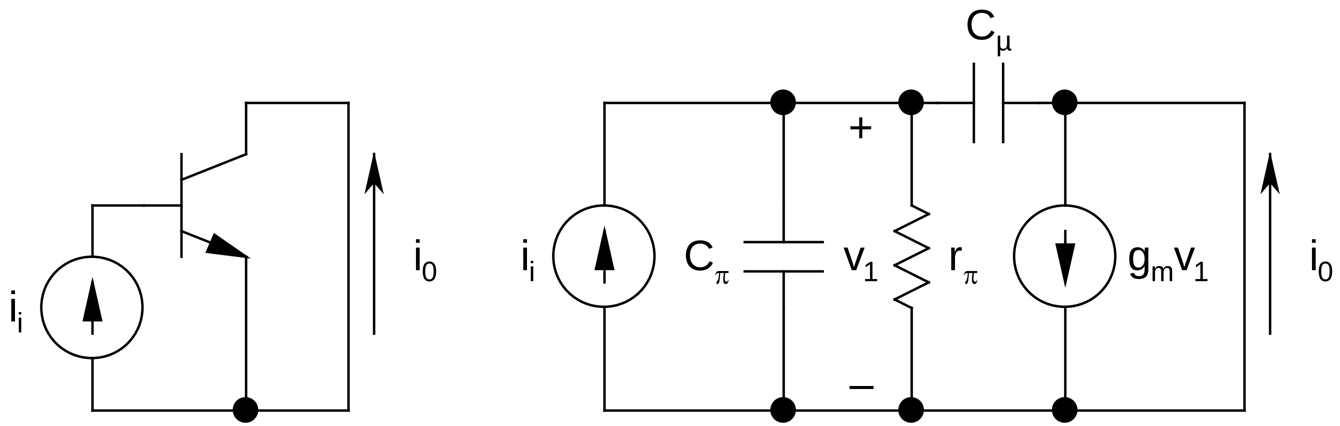
- **Note**: The ***output circuit*** resembles a ***non-ideal current source*** of ***magnitude*** $g_m v_1$ (or equivalently, βi_b) with ***output resistance*** r_0

- *This model is appropriate when the ac input is applied to base*
- *When the ac input is applied to the emitter, then need to draw this circuit in a slightly different way*



Frequency Specifications of BJTs

- ***Four important characteristic frequencies***:
  - ***Beta Cutoff Frequency*** (f_β)
  - ***Unity Gain Cutoff Frequency*** (f_T)
  - ***Alpha Cutoff Frequency*** (f_α)
  - ***Maximum Operable Frequency*** (f_{max})



- $i_0 \approx g_m v_1$ (***neglecting reverse transmission through C_μ***)
- $v_1 = i_i Z_{eq}$

$$Z_{eq} = \frac{r_\pi}{1 + s r_\pi \left(C_\pi + C_\mu \right)} \qquad \left(s = j\omega \right)$$

- Thus:

$$\beta(j\omega) = \frac{i_0(j\omega)}{i_i(j\omega)} = \frac{\beta_0}{1 + j\omega/\omega_\beta}$$

β_0 (= $g_m r_\pi$): ***Low-frequency short-circuit common-emitter current gain***

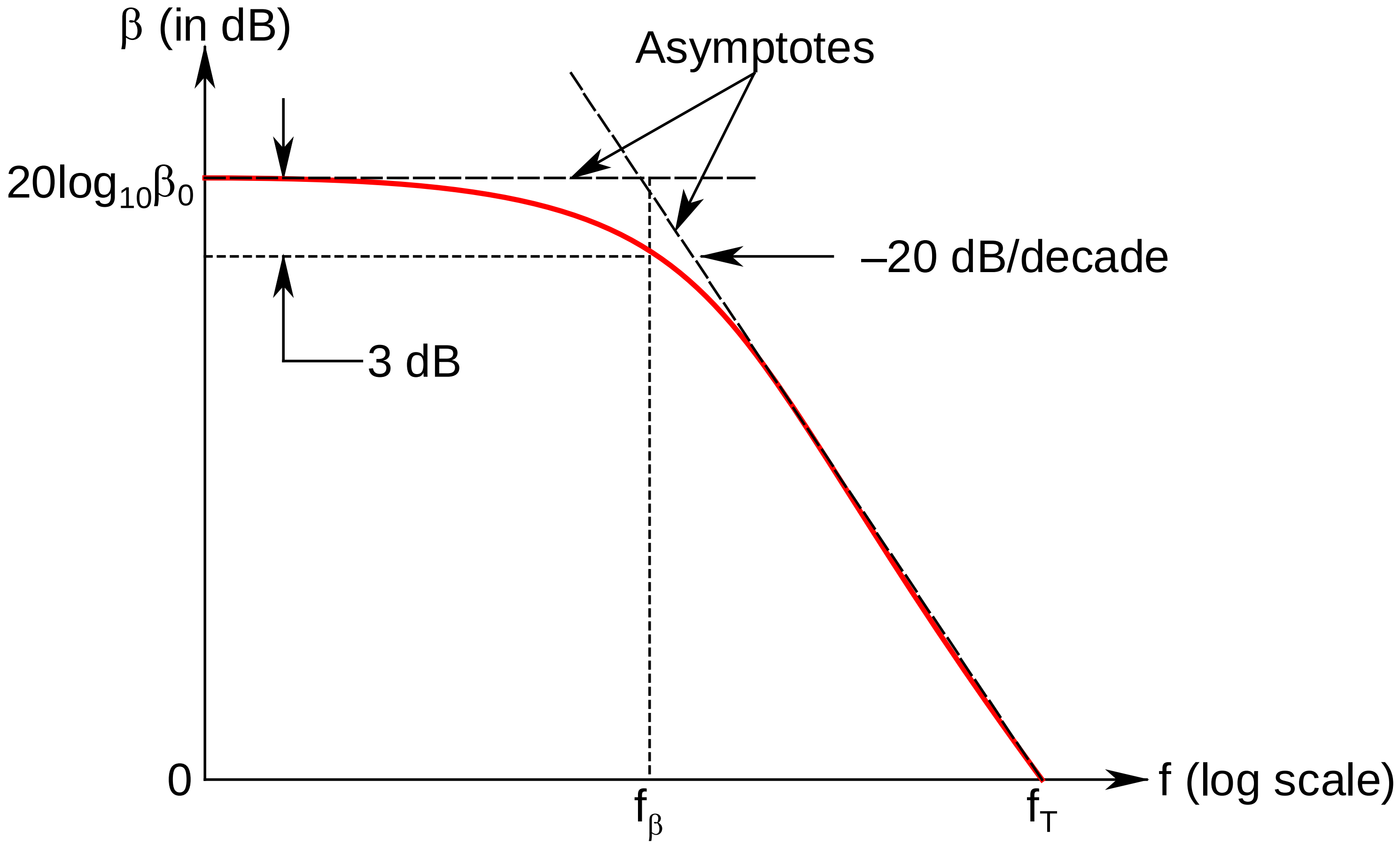
$$\omega_\beta = \frac{g_m}{\beta_0\left(C_\pi + C_\mu\right)}$$

- f_β [= $\omega_\beta/(2\pi)$]: ***Beta Cutoff Frequency***
- At $f = f_\beta$, $\beta = \beta_0/\sqrt{2}$

- For $f >> f_\beta$:

$$\beta(j\omega) \simeq \frac{g_m}{j\omega\left(C_\pi + C_\mu\right)}$$

- At $\omega = \omega_T = g_m/(C_\pi + C_\mu)$, $|\beta| = 1$
- f_T [$= \omega_T/(2\pi)$]: ***Unity Gain Cutoff Frequency*** (also known as ***Unity Gain Bandwidth***)
- **Note**: $f_T = \beta_0 f_\beta$
- ***$f_T > f_\beta$, and their spacing depends on β_0***


β (in dB)
Asymptotes
20log₁₀β₀
–20 dB/decade
3 dB
0
f (log scale)
fβ
fT

- ***Actual measurement of f_T difficult*** - ***measured indirectly***
- ***Measurement done at $f_x >> f_\beta$***, where ***β has dropped to about 5-10***
- Then, $f_T = \beta(f_x)f_x$
- Using $\alpha = \beta/(\beta + 1)$:

$$\alpha(j\omega) = \frac{\beta(j\omega)}{1+\beta(j\omega)} = \frac{\alpha_0}{1+j\omega/\omega_\alpha}$$

α_0 [$= \beta_0/(\beta_0 + 1)$]: ***Low-frequency short-circuit common-base current gain***