- ***Base-Emitter Resistance*** (r_π):

$$r_\pi = \frac{v_i}{i_b} = \frac{\Delta V_{BE}}{\Delta I_B} \equiv \frac{dV_{BE}}{dI_C}\frac{dI_C}{dI_B}\bigg|_{V_{CE}\ \text{constant}} = \frac{\beta}{g_m} \simeq \beta r_E$$

➢For I_C = 1 mA and β =100: r_π = 2.6 kΩ

- ***Output Resistance*** (r_0):

$$r_0 = \frac{v_{ce}}{i_c} = \left[\frac{dI_C}{dV_{CE}}\right]^{-1}\bigg|_{V_{BE}\ \text{constant}} = \frac{V_A}{I_C} = \frac{V_A}{V_T}\frac{V_T}{I_C} = \frac{1}{\eta g_m}$$

- For I_C = 1 mA, V_{AN} = 130 V, and V_{AP} = 52 V: r_0(npn) = 130 kΩ and r_0(pnp) = 52 kΩ
- η (= V_T/V_A): 2×10^{-4} (npn) and 5×10^{-4} (pnp)
- $g_m r_0 = \eta^{-1}$

- ***Collector-Base Resistance*** (r_μ):

$$r_\mu = \frac{v_{ce}}{i_b} = \frac{\Delta V_{CE}}{\Delta I_B}\bigg|_{V_{BE}\ \text{constant}} = \frac{dV_{CE}}{dI_C}\frac{dI_C}{dI_B} = \beta r_0$$

- ***Oversimplification*** – ***actual value much higher*** (~ 5-10βr_0) > 100s of MΩ

- ***Emitter-Base Capacitance*** (C_π):

  $C_\pi = C_{je} + C_b$

  - C_{je}: ***Emitter-base depletion capacitance***

    $\approx 2C_{je0}$

    - C_{je0}: ***Emitter-base depletion capacitance at zero bias***

  - C_b: ***Emitter-base diffusion capacitance*** (known as ***base charging capacitance***)

    $= \tau_F g_m \quad (>> C_{je})$

    - τ_F: ***Base transit time***

  - $C_\pi\uparrow$ as $g_m\uparrow$ (***Problem***!)

- ***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***:
    - $r_e \sim 5\text{-}10\ \Omega$
    - $r_b \sim 100\text{-}200\ \Omega$
    - $r_c \sim$ can be as high as kΩ
  - ***Become important only at very high frequencies***