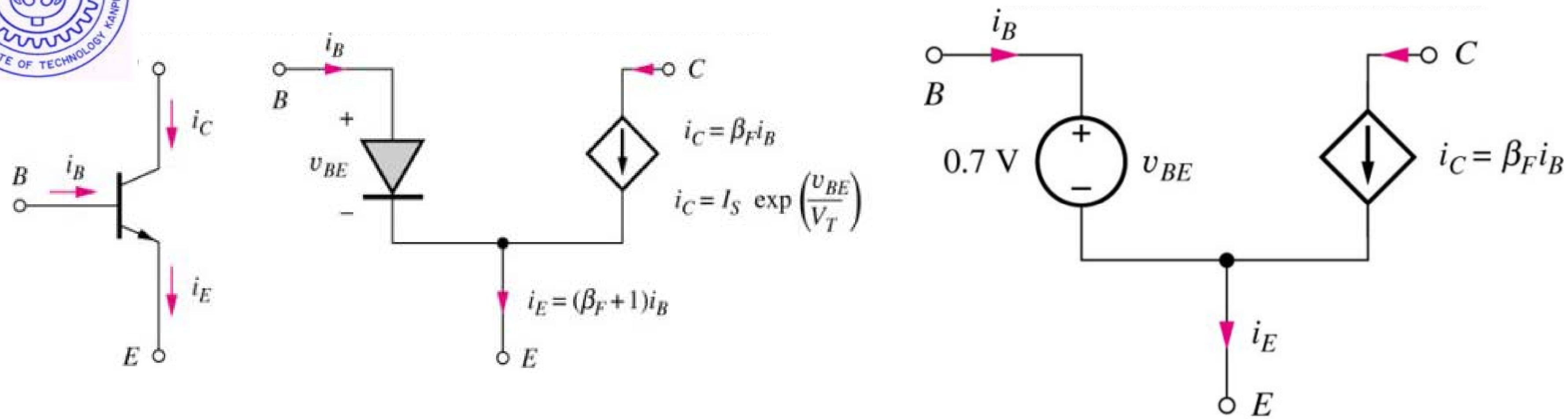
ESc201, Lecture 19: Bipolar Junction Transistor (Small signal Model)



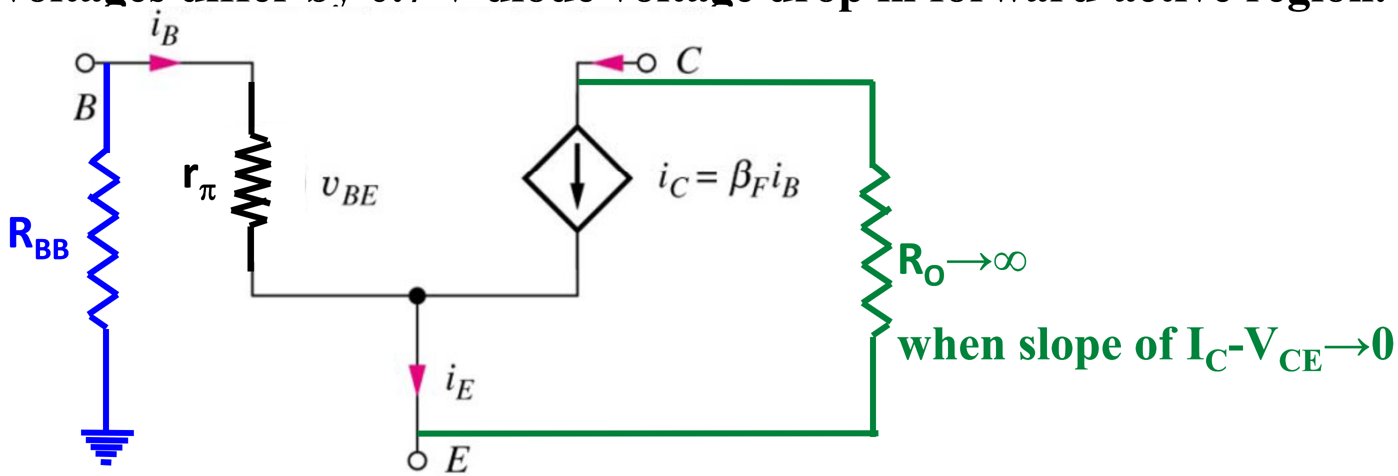
Current in base-emitter diode is amplified by common-emitter current gain β_F and appears at collector-base and collector currents are exponentially related to base-emitter voltage.

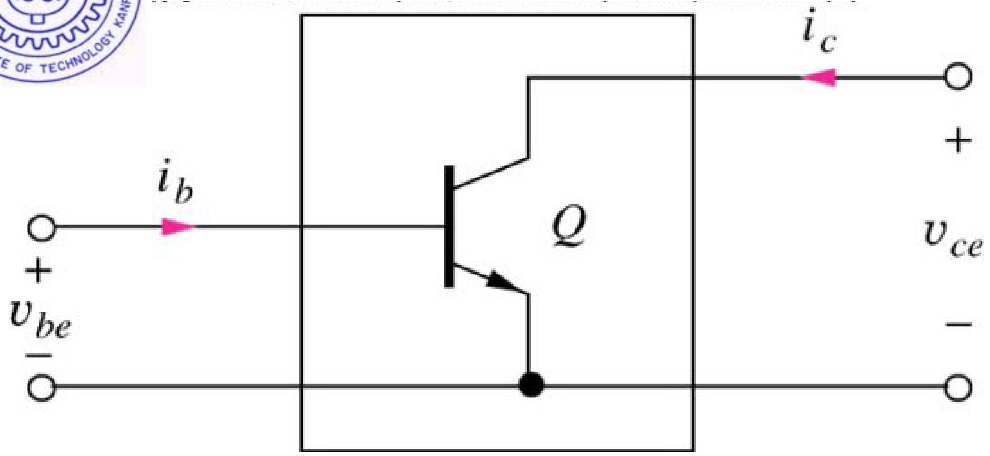
Base-emitter diode is replaced by constant voltage drop model(V_{BE} = 0.7 V) since it is forward-biased in forward-active region.

DC base and emitter voltages differ by 0.7 V diode voltage drop in forward-active region.

$R_{BB} = R_1 \| R_2$

Later use just R_B instead of R_{BB} .





Using 2-port *y*-parameter network, the port variables can represent either time-varying part of total voltages and currents or small changes in them away from Q-point values.

$$i_b = y_{11} v_{be} + y_{12} v_{ce}$$
$$i_c = y_{21} v_{be} + y_{22} v_{ce}$$

$$I_B = \frac{I_C}{\beta_F} = \frac{I_E}{\beta_F + 1} \cong \frac{I_{E_S} \times e^{V_{BE}/V_T}}{\beta_F}$$

$$y_{11} = \left.\frac{i_b}{v_{be}}\right|_{v_{ce}=0} = \left.\frac{\partial i_B}{\partial v_{BE}}\right|_{\text{Q-point}} = \frac{I_C}{\beta_o V_T}$$

$$y_{21} = \left.\frac{i_c}{v_{be}}\right|_{v_{ce}=0} = y_{21} = \left.\frac{\beta_o i_b}{v_{be}}\right|_{v_{ce}=0}$$
$$= \left.\frac{\beta_o \partial i_B}{\partial v_{BE}}\right|_{\text{Q-point}} = \frac{I_C}{V_T}$$

Assume that D.C. β_F= A.C. β_o and
Transistor in forward active (CE reverse biased).

$$y_{12} = \left.\frac{i_b}{v_{ce}}\right|_{v_{be}=0} = \left.\frac{\partial i_B}{\partial v_{CE}}\right|_{Q-\text{point}} = 0$$

$$y_{22} = \left.\frac{i_c}{v_{ce}}\right|_{v_{be}=0} = \left.\frac{\partial i_C}{\partial v_{CE}}\right|_{\text{Q-point}}$$
$$= \frac{I_C}{V_A + V_{CE}} \cong 0$$

With the asumption that $V_A \to \infty$ (slope =0)

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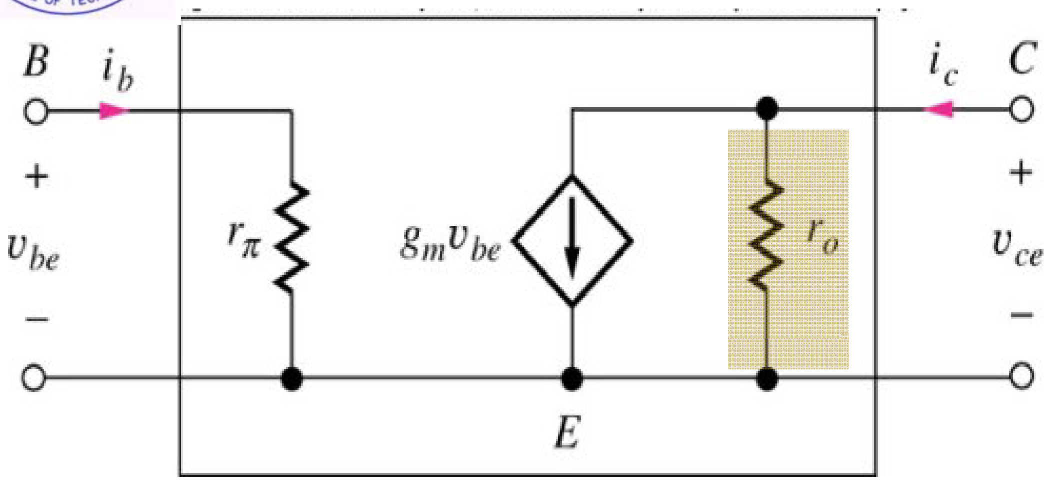
Hybrid-Pi Model of BJT



Input resistance = r_π (but there could be capacitance in parallel from the depletion layer capacitance for high frequency considerations)

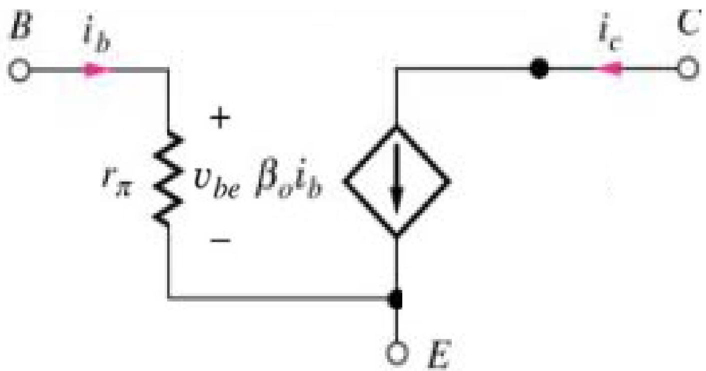
$$\text{Transconductance} = y_{21} = g_m = \frac{I_C}{V_T}$$

$$\text{Input resistance } = r_\pi = \frac{1}{y_{21}} = \frac{\beta_o V_T}{I_C} = \frac{\beta_o}{g_m}$$

$$\text{Output resistance} = r_o = \frac{1}{y_{22}} = \frac{V_A + V_{CE}}{I_C} \simeq \frac{V_A}{I_C} \to \infty (\text{Open})$$

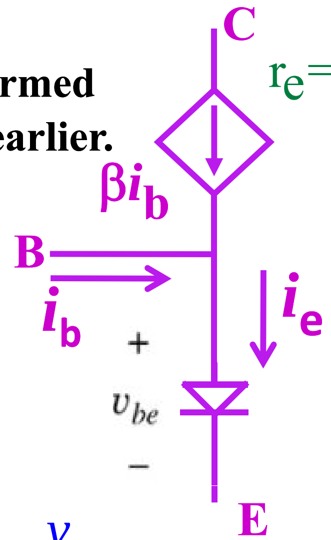
Therefore Small-signal parameters are controlled by the Q-point biasing.

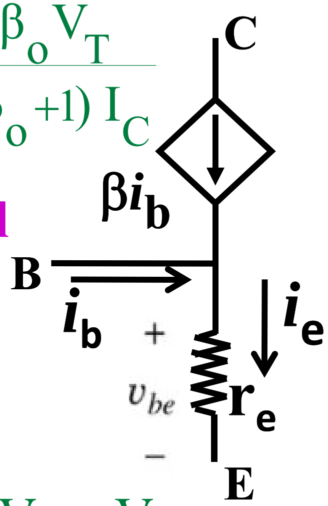
Voltage -controlled current source $g_m v_{be}$ can be transformed into current-controlled current source, as has been used earlier.



$$r_e = \frac{r_\pi}{\beta_o + 1} = \frac{\beta_o V_T}{(\beta_o + 1)\, I_C}$$

T Model of BJT





$$v_{be} = i_b r_\pi, \quad \therefore g_m v_{be} = g_m i_b r_\pi = \beta_o i_b \quad \text{and} \quad i_c = \beta_o i_b + \frac{v_{ce}}{r_o} \simeq \beta_o i_b \Big|_{r_o \to \infty}$$

$$r_e = \frac{\alpha V_T}{I_C} \simeq \frac{V_T}{I_C} = \frac{1}{g_m}$$

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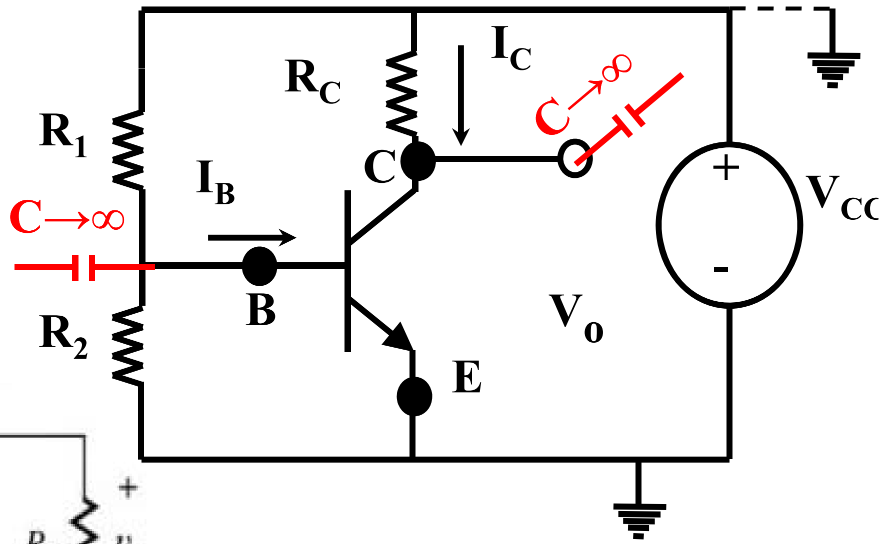
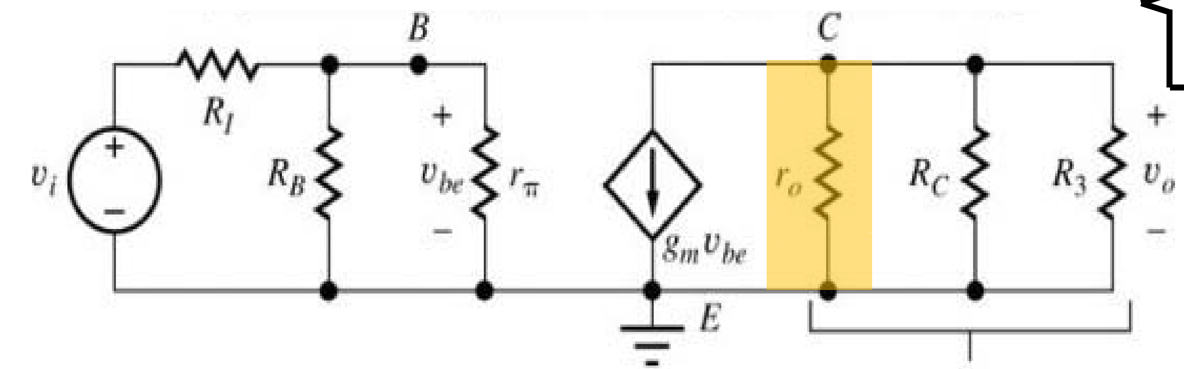
When Capacitor coupled output is taken, then the voltage offset at V_o does not matter, so V_o is chosen to give maximum swing.



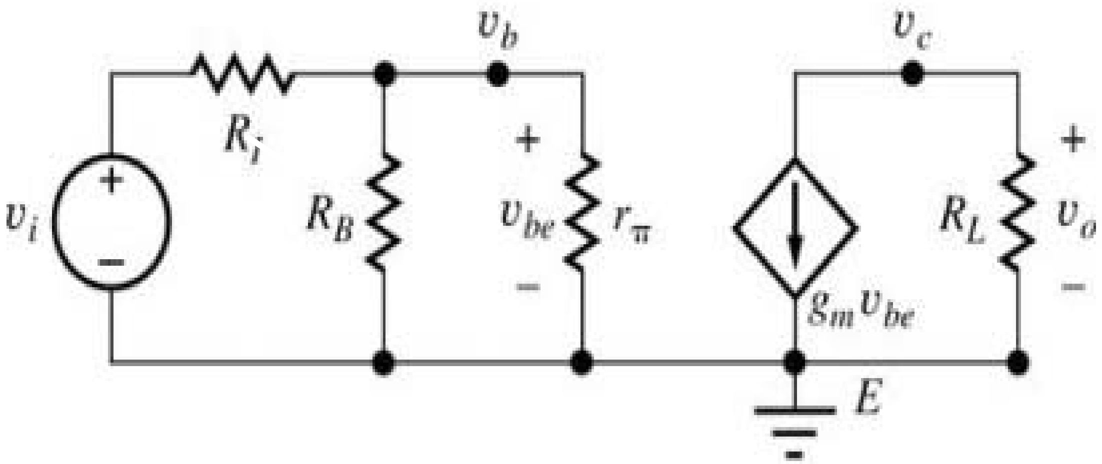
$$A_{v_{\text{Transistor}}} = \frac{v_c}{v_b} = \frac{v_o}{v_{be}} = -g_m R_L$$



$$R_L = R_C \| R_3$$

$$A_v = \frac{v_o}{v_i} = \left(\frac{v_o}{v_{be}}\right)\left(\frac{v_{be}}{v_i}\right)$$

$$= -g_m R_L \left(\frac{v_{be}}{v_i}\right)$$



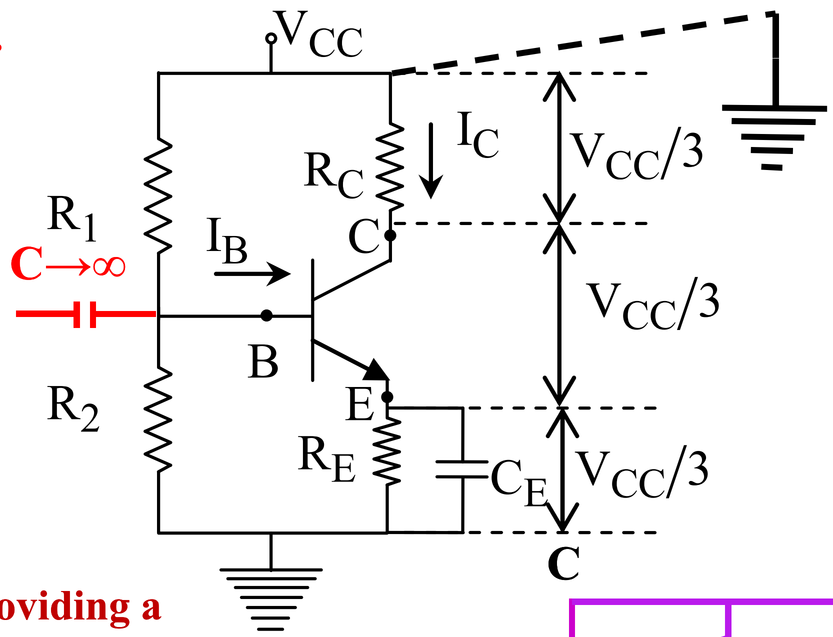
$$A_v = -g_m R_L \left[\frac{R_B \| r_\pi}{R_i + \left(R_B \| r_\pi\right)}\right]$$

Input potential divider

ESc201, Lecture 19: Bipolar Junction Transistor (Biasing under different cases)

The story of how some students in the laboratory could not do the Transistor Amplifier experiment as their Transistor went into saturation has been related to you in the class. This was due to variation of β over a wide range. How can one go around this problem?

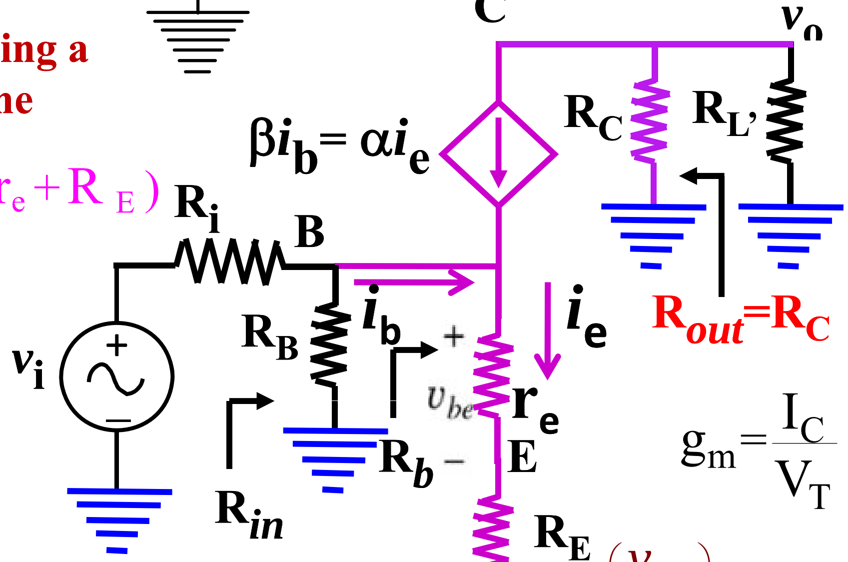
Add a resistor to the emitter (R_E). For large β there would be a larger voltage drop across R_C and R_E. Voltage drop across R_C changes V_{CE} but unless the drop is very large it would not take it into saturation. All it would do is reduce the dynamic range.



Whereas Voltage drop across R_E reduces V_{BE}, thus providing a feedback to reduce I_C and restores the currents closer to the design. BUT THERE CAN BE NO FREE LUNCH

$$v_o = -i_c(R_C||R_{L'}) = -\alpha i_e R_L \qquad v_b = i_e(r_e + R_E)$$

$$r_e = \frac{\beta_o}{g_m(\beta_o+1)} = \frac{\alpha}{g_m} \cong \frac{1}{g_m}$$



$$g_m = \frac{I_C}{V_T}$$

$$A_v = \frac{v_o}{v_i} = \left(\frac{v_o}{v_b}\right)\left(\frac{v_b}{v_i}\right) = -\frac{\alpha i_e R_L}{i_e(r_e + R_E)}\left(\frac{v_b}{v_i}\right)$$

$$= -\frac{\alpha i_e R_L}{i_e(r_e + R_E)} \frac{i_i[R_B||(\beta+1)(r_e+R_E)]}{i_i\{R_i + [R_B||(\beta+1)(r_e+R_E)]\}}$$

$$R_{in} = R_B||(\beta+1)(r_e+R_E)$$

$$\cong -\frac{(\beta/(\beta+1))R_L}{(r_e+R_E)} \frac{(\beta+1)(r_e+R_E)}{\{R_i+(\beta+1)(r_e+R_E)\}} = -\frac{\beta R_L}{\{R_i+(\beta+1)(r_e+R_E)\}}$$

$$\left(\frac{v_{be}}{v_b}\right) = \frac{1}{(1+g_m R_E)}$$

Effect of adding R_E

1. The voltage gain is now less dependent on β.
2. The input resistance is increased by a factor of $(1+g_mR_E)$.
3. The base to collector voltage gain is reduced by $1/(1+g_mR_E)$
4. For the same nonlinear distortion the input can be increased by a factor of $(1+g_mR_E)$
5. The frequency response in significantly improved.

As a particular example for β=100, R_L= 4.12kΩ, R_E=300Ω, and a $C_{Base\text{-}Collector}$=0.5pF
Without R_E the values are :
$A_{mid\ freq}$= -153, f_H= 1.56 MHz, GBWP =239 MHz.

With R_E the values are :
$A_{mid\ freq}$= -11.0, f_H= 13.9 MHz, GBWP =153 MHz.

And R_{in} must have increased by approximately a ratio of (153/11)=14 times.