RUMORE SU TRIPOLI

25-26-28 GEN

→ GENERATORI DI RUMORE IN INGRESSO AL DISPOSITIVO

- IGNOREREMO CORRELAZIONE TRA GENERATORI

GENERATORI EQUIVALENTI SU BJT (CON NOTAZIONE STANDARD, DIVERSA DA NOSTRO SOLITO)

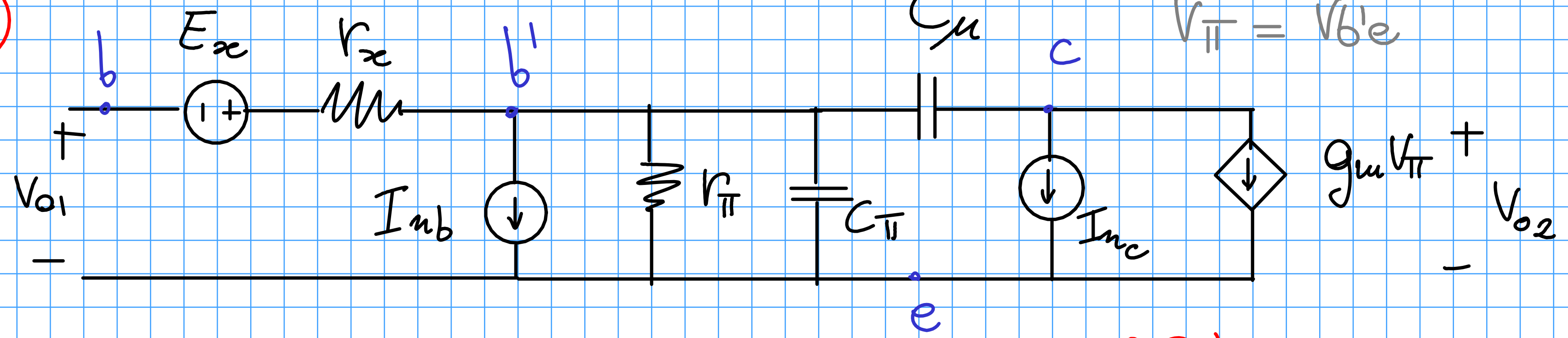
CIRCUITO DI GIACOLETTO

$C_\mu = C_{b'c}$ $\quad r_x = r_{b'e}$

$C_\pi = C_{b'e}$

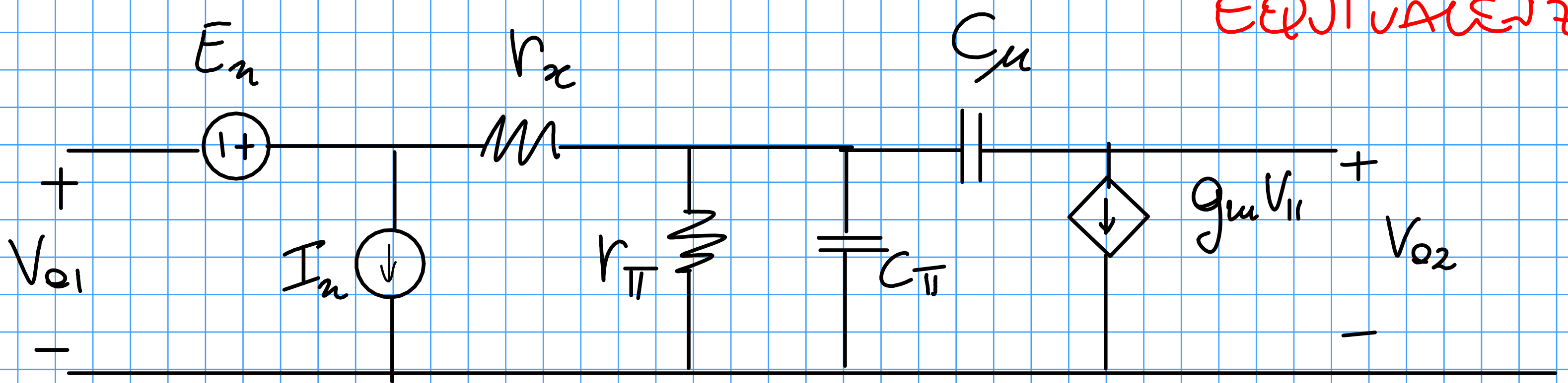
$V_\pi = V_{b'e}$

1



EQUIVALENZA

2



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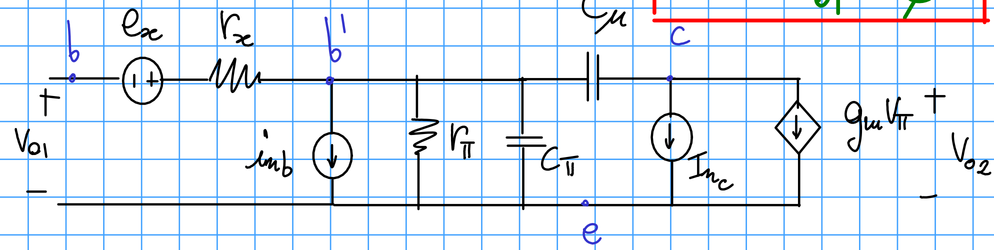
CALCOLO V_{o2} CON V_{o1} APERTO

$$V_{o2}\Big|_{V_{o1}=\emptyset} \quad ①$$



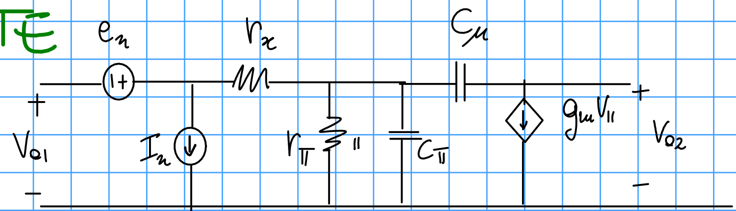
$$Z_\pi = r_\pi \,//\, \frac{1}{j\omega C_\pi} = \frac{r_\pi}{1+j\omega C_\pi r_\pi}$$

$$V_\pi = -Z_\pi\left[I_{nb} + I_{nc} + g_m V_\pi\right] \longrightarrow V_\pi = -\frac{Z_\pi}{1+g_m Z_\pi}\left(I_{nb}+I_{nc}\right)$$

$$V_{o2} = V_\pi - \frac{1}{j\omega C_\mu}\left(g_m V_\pi + I_{nc}\right)$$

$$V_{o2} = -\left[1-\frac{g_m}{j\omega C_\mu}\right]\frac{Z_\pi}{1+g_m Z_\pi} I_{nb} - I_{nc}\left\{\left[1-\frac{g_m}{j\omega C_\mu}\right]\frac{Z_\pi}{1+g_m Z_\pi} + \frac{1}{j\omega C_\mu}\right\}$$

CALCOLO V_{o2} NEL CIRCUITO EQUIVALENTE



$$V_{o2} = -\left[1-\frac{g_m}{j\omega C_\mu}\right]\frac{Z_\pi}{1+g_m Z_\pi} I_n$$

$$V_{o2}\Big|_{V_{o1}=0} \quad ②$$

IMPONGO UGUAGLIANZA TRA I DUE RISULTATI ① = ②

$$-\left[1-\frac{g_m}{j\omega C_\mu}\right]\frac{Z_\pi}{1+g_m Z_\pi}I_{nb}-I_{nc}\left\{\left[1-\frac{g_m}{j\omega C_\mu}\right]\frac{Z_\pi}{1+g_m Z_\pi}+\frac{1}{j\omega C_\mu}\right\}=-\left[1-\frac{g_m}{j\omega C_\mu}\right]\frac{Z_\pi}{1+g_m Z_\pi}I_n$$

RICAVO I_n :

$$I_n=\frac{-\left[1-\frac{g_m}{j\omega C_\mu}\right]\frac{Z_\pi}{1+g_m Z_\pi}I_{nb}-I_{nc}\left\{\left[1-\frac{g_m}{j\omega C_\mu}\right]\frac{Z_\pi}{1+g_m Z_\pi}+\frac{1}{j\omega C_\mu}\right\}}{-\left[1-\frac{g_m}{j\omega C_\mu}\right]\frac{Z_\pi}{1+g_m Z_\pi}}$$

SVILUPPO CONTI :

$$I_n=I_{nb}+I_{nc}+\frac{I_{nc}}{j\omega C_\mu}\,\frac{1+g_m Z_\pi}{Z_\pi}\,\frac{1}{1-\frac{g_m}{j\omega C_\mu}}$$

$$I_n = I_{nb} + I_{nc}\left[1 + \frac{1 + g_m z_\pi}{z_\pi (j\omega C_\mu - g_m)}\right]$$

$$I_n = I_{nb} + I_{nc}\left[\frac{z_\pi j\omega C_\mu - \cancel{g_m z_\pi} + 1 + \cancel{g_m z_\pi}}{z_\pi (j\omega C_\mu - g_m)}\right]$$

PER COME È CALCOLATO
IL CIRCUITO DI GIACOLETTO SI CONSIDERANO
VALIDI RISULTATI A FREQUENZE SOTTO $f_T / \underline{3}$

PER DEFINIZIONE $f_T = \dfrac{g_m}{2\pi(C_\mu + \cancel{C_\pi})}$ TRASCURABILE

$$\rightsquigarrow f < \frac{g_m}{2\pi\, \underline{3}\, C_\mu} \longrightarrow C_\mu \omega \ll g_m$$

APPLICO SEMPLIFICAZIONE

$$I_n = I_{nb} + I_{nc}\left[\frac{Z_\pi j\omega C_\mu + 1}{Z_\pi\left(\underline{j\omega C_\mu - g_m}\right)}\right]$$

$$\simeq -g_m$$

$$I_n = I_{nb} + I_{nc}\left[\frac{Z_\pi j\omega C_\mu + 1}{-\underline{g_m Z_\pi}}\right]$$

$$g_m Z_\pi = \frac{g_m r_\pi}{1+j\omega C_\pi r_\pi} = \frac{h_{fe}}{1+j\omega C_\pi r_\pi}$$

$$I_n = I_{nb} + I_{nc}\,\frac{\dfrac{r_\pi}{1+j\omega C_\pi r_\pi}j\omega C_\mu + 1}{-\dfrac{h_{fe}}{1+j\omega C_\pi r_\pi}}$$

$$I_n = I_{nb} - \frac{I_{nc}}{h_{fe}}\left[r_\pi j\omega C_\mu + 1 + j\omega C_\pi r_\pi \right]$$

$$I_n = I_{nb} - \frac{I_{nc}}{h_{fe}}\left[1 + j\omega r_\pi (C_\mu + C_\pi) \right]$$

$$= I_{nb} - I_{nc}\left[\frac{1}{h_{fe}} + \frac{j\omega}{g_m}(C_\mu + C_\pi) \right]$$

$$\boxed{I_n = I_{nb} - I_{nc}\left[\frac{1}{h_{fe}} + \frac{j\omega}{\omega_T} \right]}$$

$$S_{in} = S_{inb} + S_{inc}\left[\frac{1}{h_{fe}} + j\frac{\omega}{\omega_T} \right]^2 \simeq S_{inb} + S_{inc}\left[\frac{1}{h_{fe}^2} + \left(\frac{\omega}{\omega_T}\right)^2 \right]$$

$$\boxed{S_{i_n} = S_{i_{nb}} + S_{i_{nc}}\left[\frac{1}{h_{fe}^2} + \left(\frac{\omega}{\omega_T}\right)^2\right]}$$

$$S_{i_{nb}} = 2qI_B + 2qI_B\left(\frac{f_c}{f}\right)^{\gamma} + 2qI_c\left[\frac{1}{h_{fe}^2} + \left(\frac{\omega}{\omega_T}\right)^2\right]$$

NOTAZIONE FLICKER "PAZZA"

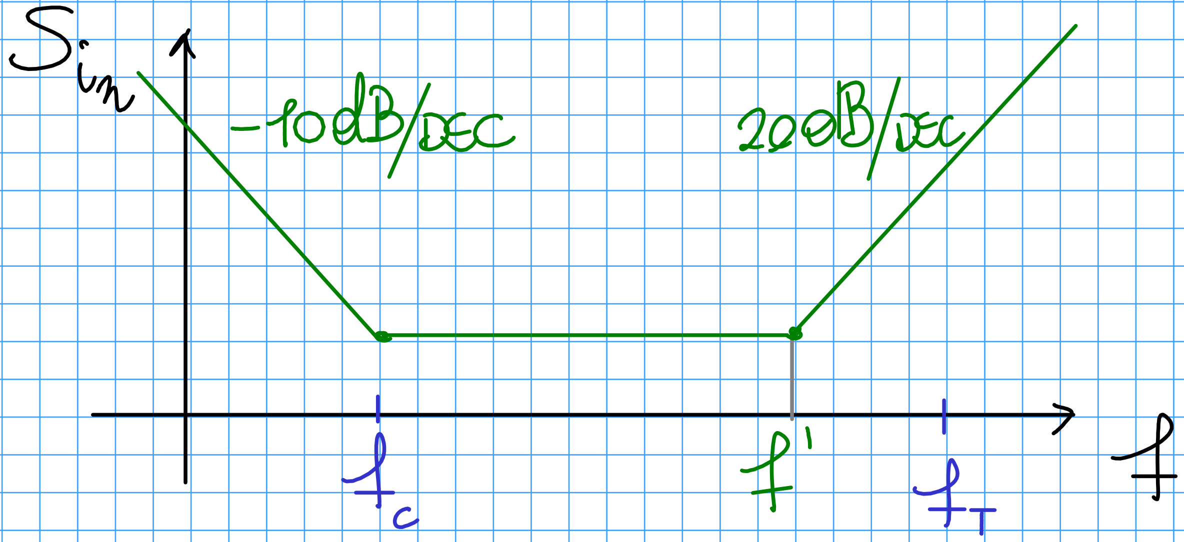
SHOT I_B FLICKER I_B SHOT I_C

CORRENTE NON PORTA RUMORE FLICKER → CORRENTE IN CASCATA, NON SI MODIFICA CON QUESTA CON

CON Hp $I_C = h_{FE} I_B$

TERMINE $\frac{2qI_C}{h_{FE}^2} = \frac{2qI_B}{h_{FE}} \ll 2qI_B$ (CON $h_{FE} > 100$)

$$\boxed{S_{i_n} = 2qI_B + 2qI_B\left(\frac{f_c}{f}\right)^1 + 2qI_B h_{FE}\left(\frac{\omega}{\omega_T}\right)^2}$$



$$2qI_B = 2qI_B h_{FE}\left(\frac{\omega}{\omega_T}\right)^2$$

$$\frac{\omega}{\omega_T} = \frac{1}{\sqrt{h_{FE}}}$$

$$\omega' = \frac{\omega_T}{\sqrt{h_{FE}}}$$

CALCOLO V_{01} CON V_{02} APERTO E IMPONGO UGUAGLIANZA

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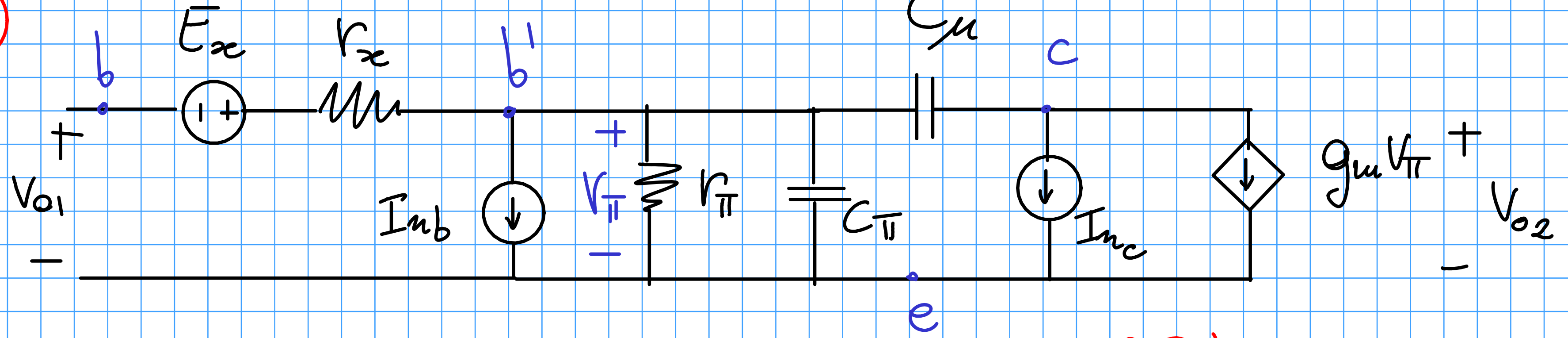

EQUIVALENZA

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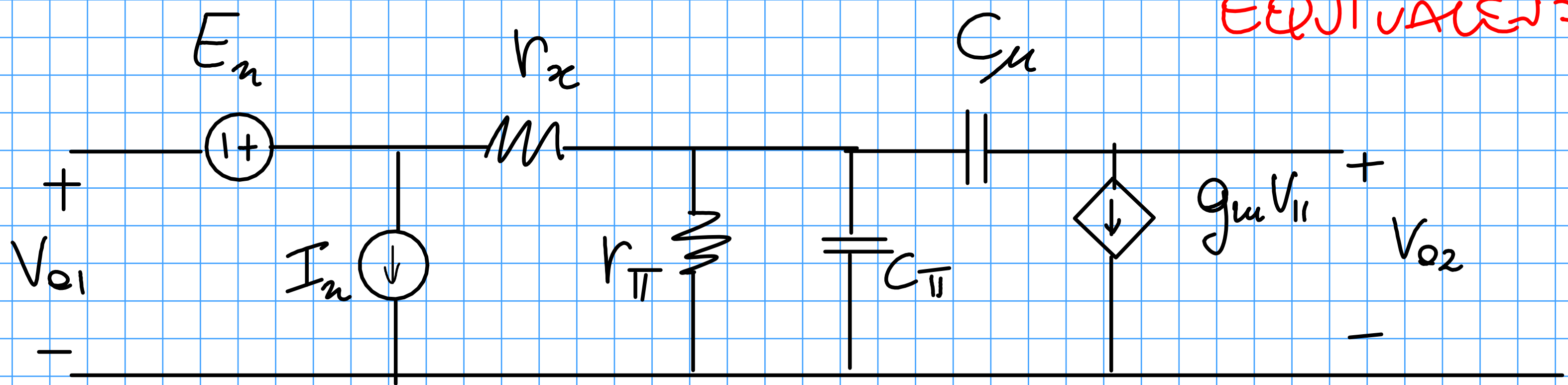

$$1 \rightarrow \quad V_{01} = E_x + V_\pi = E_x - \frac{Z_\pi}{1 + g_m Z_\pi}\left[I_{nb} + I_{nc}\right]$$

$$2 \rightarrow \quad V_{01} = E_n + V_\pi - I_n r_x = E_n + \frac{Z_\pi}{1 + g_m Z_\pi} I_n - I_n r_x$$

1 + 2

$$E_n - E_x = -\frac{Z_\pi}{1+g_m Z_\pi}\left[I_{nb} + I_{nc}\right] + \frac{Z_\pi}{1+g_m Z_\pi} I_n + I_n r_x$$

$$E_n - E_x = \frac{Z_\pi}{1+g_m Z_\pi}\left[I_n - I_{nb} - I_{nc}\right] + I_n r_x$$

SOSTITUISCO ESPRESSIONE TROVATA NEI CONTI PRECEDENTI

$$I_n = I_{nb} + I_{nc}\left[\frac{Z_\pi j\omega C_\mu + 1}{Z_\pi (j\omega C_\mu - g_m)}\right]$$

SVOLGO CONTI:

$$E_n - E_x = \frac{Z_\pi}{1+g_m Z_\pi}\left[\frac{1 + \cancel{j\omega C_\mu Z_\pi} - \cancel{j\omega C_\mu Z_\pi} + g_m Z_\pi}{(j\omega C_\mu - g_m) Z_\pi}\right] I_{nc} + I_n r_x$$

$$E_n - E_x = \frac{\cancel{Z_\pi}}{\cancel{1+g_m Z_\pi}} \frac{\cancel{1+g_m Z_\pi}}{(j\omega C_\mu - g_m)\cancel{Z_\pi}} I_{nc} + I_n r_x$$

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$$E_n - E_x = I_n r_x + \frac{I_{nc}}{(\cancel{j\omega C_\mu} - g_m)}$$

CON STESSA Hp SUL CIRCUITO DI GIACOLETTO

$$f \ll f_T/3$$

$$\hookrightarrow j\omega C_\mu \ll g_m$$

$$E_n - E_x \cong I_n r_x - \frac{I_{nc}}{g_m}$$

$$E_n \cong E_x + I_n r_x - \frac{I_{nc}}{g_m}$$

SI TRASCURA CORRELAZIONE TRA I_n E I_{nc} (COMPLICA CONTI)

$$S_{E_n} = \underbrace{4KTr_x}_{S_{E_x}} + \underbrace{\frac{2qI_C}{g_m^2}}_{I_{nc}/g_m} + \frac{r_x^2\left[2qI_C\left(\frac{f}{f_T}\right)^2 + 2qI_B\left(1+\left(\frac{f}{f_C}\right)^\gamma\right)\right]}{I_n r_x}$$

$$S_{E_n 0} = 4KTr_x + 2qI_C r_e^2 + 2qI_B r_x^2$$

$$r_{b'e} = \frac{V_T}{I_C} h_{fe}$$

$$\frac{1}{g_m} = \frac{r_{b'e}}{h_{fe}} \triangleq r_e$$

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$$S_{E_n\phi} = 4KT r_x + 2qI_c r_e^2 + 2 r_x^2 \cancel{q} \frac{KT}{\cancel{q} r_\pi}$$

$$I_B = \frac{V_T}{R_\pi}$$

$$S_{E_n\phi} = 2KT\left[2r_x + \cancel{\frac{r_x^2}{r_\pi}}\right] + 2qI_c r_e^2$$

CON $r_\pi \gg r_x$ IN GENERALE

$$S_{E_n\phi} = 4KT r_x + 2qI_c r_e^2 \Longrightarrow \boxed{S_{E_n\phi} = 4KT r_{bb'} + 2qI_c \frac{r_{b'e}}{h_{fe}}}$$

SOLUZIONE CON MINOR APPROSSIMAZIONE (CON $r_x \ll r_\pi$ VALIDA) :

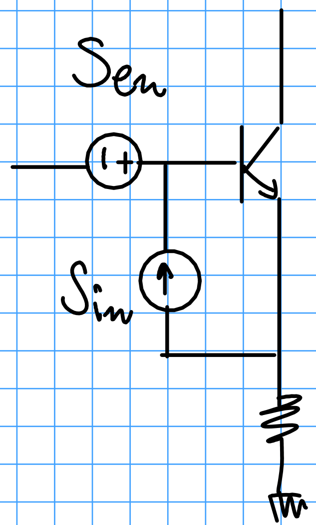
$$S_{E_n} = 4KT r_x + 2qI_c\left[\frac{r_\pi}{h_{fe}} + r_x j\frac{\omega}{\omega_T}\right]^2 + r_x^2\, 2qI_{nb}\left[1+\left(\frac{f}{f_c}\right)^\gamma\right]$$

OSSERVAZIONI

→ È PREFERIBILE USARE TRANSISTORI CON BASSA r_π, CHE COMPORTA ALTA I_C DI POLARIZZAZIONE

$$\frac{V_T}{I_C} = \frac{r_\pi}{h_{fe}}$$

SE SORGENTE HA ALTA IMPEDENZA, CERCO DI LIMITARE LA S_{in} LEGATA ALLE CORRENTI DI POLARIZZAZIONE



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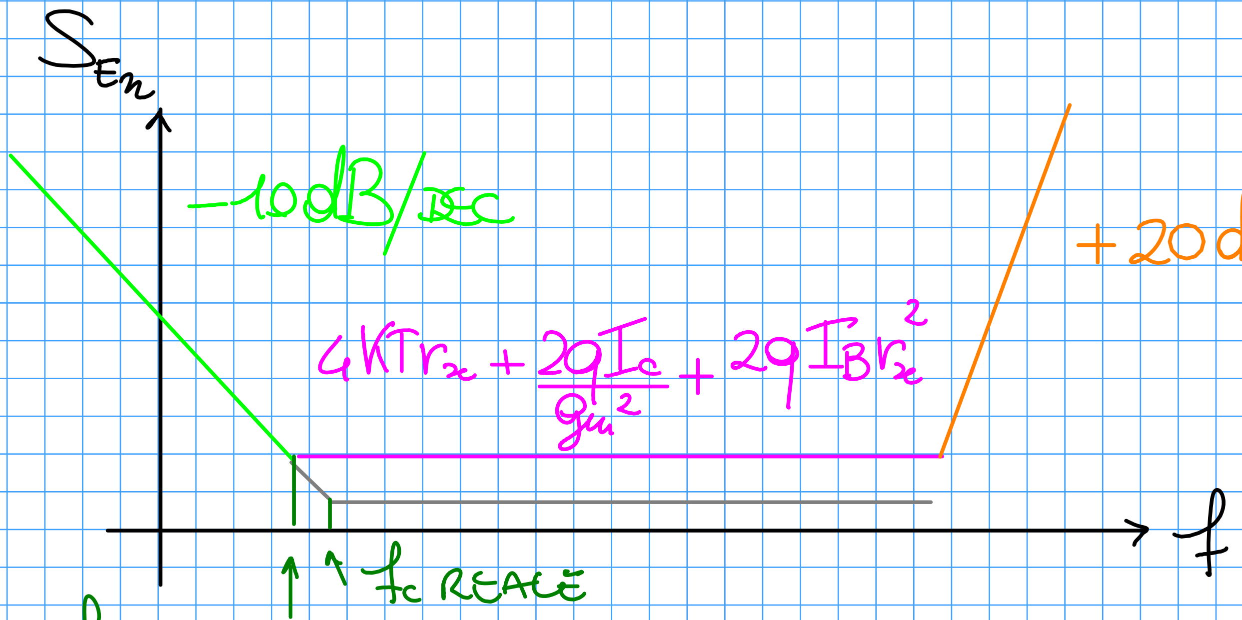
ANDAMENTO IN FREQUENZA S_{E_n}

$$S_{E_n} = 4KTr_x + 2qI_c\left[\frac{r_\pi}{h_{fe}} + r_x j\frac{\omega}{\omega_T}\right]^2 + r_x^2\, 2qI_{nb}\left[1+\left(\frac{f}{f_c}\right)^\gamma\right]$$



f_c CALCOLATA DA FORMULE NON COINCIDE A f_c REALE, PERCHÉ IN QUESTO CASO, SI CONSIDERA SOLO IL RUMORE SHOT COME CONTRIBUTO ALLA ZONA PIATTA