# สูตร การวิเคราะห์วงจรอิเล็กทรอนิกส์ความถี่สูง

## บทนำ

$$q = 1.60 \times 10^{-19}\,\mathrm{C}$$

$$T = \left(273 + \ ^{\circ}\mathrm{C}\right)$$

$$k_B = \ 1.38 \times 10^{-23}\ \mathrm{J/K}$$

## บทที่ 1 คุณสมบัติทางไฟฟ้าและพารามิเตอร์ย่านความถี่สูง

$$r_d = \frac{\left(k_B T/q\right)}{I_D} \tag{1.1}$$

$$C_D(V_R) = \frac{C_D(0)}{\left(1 + \left|\frac{V_R}{V_F}\right|\right)^{\mathrm{n}}} \tag{1.2}$$

$$P_D = I_C V_{CE} \tag{1.3}$$

$$P_D = \frac{T_j - T_A}{(R_{\theta JC} + R_{\theta CS} + R_{\theta SA})} \tag{1.4}$$

$$\begin{aligned} F_T &= F_\beta \beta_F \\ \beta_{o(F_\beta)} &= 0.707 \beta_F \end{aligned} \tag{1.5}$$

$$NF = 10 \log_{10}\left(\frac{P_{si}}{P_{ni}} \times \frac{P_{no}}{P_{so}}\right)\ (\mathrm{dB}) \tag{1.6}$$

$$\left|\ \mathrm{S_{21e}}\right|^2_{(\mathrm{dB})} = 10 \log \left|\ \mathrm{S_{21e}}\right|^2_{(\mathrm{W})} \tag{1.7}$$

$$\left|\ \mathrm{S_{21e}}\right|^2_{(\mathrm{W})} = 10^{\frac{\left|\ \mathrm{S_{21e}}\ \right|^2_{(\mathrm{dB})}}{10}} \tag{1.8}$$

$$g_m = \frac{I_{C(dc)}}{V_T} = \frac{I_{C(dc)}}{\left(k_B T/q\right)} \tag{1.9}$$

$$r_{b'e} = \frac{\beta_o}{g_m} \tag{1.10}$$

$$r_{bb'} = \frac{V_{be}}{I_b} - r_{b'e} \tag{1.11}$$

$$I_c = g_m V_{b'e} \tag{1.12}$$

$$I_c = \frac{g_m I_b \beta_o}{g_m} = I_b \beta_o \tag{1.13}$$

$$I_c = g_m V_{b'e} = \beta_o I_b \tag{1.14}$$

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$$C_{b'e} + C_{b'c} = \frac{g_m}{2\pi F_\beta \beta_o}$$

$$C_{b'c} \cong C_{ob} \tag{1.15}$$

$$C_{b'e} = \frac{g_m}{2\pi F_T} - C_{ob} \tag{1.16}$$

$$P_D = I_D V_{DS} \tag{1.17}$$

$$g_{m0} = \frac{2I_{DSS}}{|V_P|} \tag{1.18}$$

$$g_m = g_{m0}\left(1 - \frac{V_{GS}}{V_P}\right) \tag{1.19}$$

$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right) \tag{1.20}$$

$$C_T = C_{iss} + C_{rss} g_m R_{out} \tag{1.21}$$

บทที่ 2 วงจรขยายย่านความถี่สูง

$$V_{TH} = \frac{V_{CC} R_{B2}}{(R_{B1} + R_{B2})} \tag{2.1}$$

$$R_{TH} = (R_{B1} \,||\, R_{B2}) = \frac{R_{B1} R_{B2}}{(R_{B1} + R_{B2})} \tag{2.2}$$

$$V_{TH} = I_B R_{TH} + V_{BE} + I_E R_E \tag{2.2a}$$

$$I_B = \frac{(V_{TH} - V_{BE})}{R_{TH} + (\beta_F + 1) R_E} \tag{2.3}$$

$$I_C = \beta_F I_B \tag{2.4}$$

$$V_{CE} = V_{CC} - \{I_C R_C + (\beta_F + 1) I_B R_E\} \tag{2.5}$$

$$Z_i = r_{bb'} + r_{b'e} \tag{2.6}$$

$$Z_{in} = (R_{BB} \,||\, Z_i) = \frac{R_{BB} Z_i}{(R_{BB} + Z_i)} = \frac{R_{BB}(r_{bb'} + r_{b'e})}{(R_{BB} + r_{bb'} + r_{b'e})} \tag{2.7}$$

$$Z_o = \infty \tag{2.8}$$

$$Z_{out} = R_{out} = (R_C \,||\, R_L) = \frac{R_C R_L}{(R_C + R_L)} \tag{2.9}$$

$$A_{V(F_{Mid})} = -\frac{V_o}{E_i} = -\frac{g_m r_{b'e} Z_{out}}{Z_i} = -\frac{g_m r_{b'e} R_C R_L}{(r_{bb'} + r_{b'e})(R_C + R_L)} \tag{2.10}$$

$$A_{V(F_{Mid})} = -\frac{V_o}{E_g} = -\frac{V_o}{E_i} \times \frac{Z_{in}}{(R_g + Z_{in})} = -\frac{g_m r_{b'e} Z_{out}}{Z_i} \times \frac{Z_{in}}{(R_g + Z_{in})} \tag{2.11}$$

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$$A_{i(F_{Mid})} = \frac{I_{R_L}}{I_b} = \frac{g_m r_{b'e} R_C}{\left(R_C + R_L\right)} \tag{2.12}$$

$$P_G = \frac{V_o}{E_g} \times \frac{I_{R_L}}{I_b} = \frac{\left(g_m r_{b'e} R_C\right)^2 R_L}{Z_i \left(R_C + R_L\right)^2} \times \frac{Z_{in}}{\left(R_g + Z_{in}\right)} \tag{2.12a}$$

$$P_G = \frac{V_o}{E_i} \times \frac{I_{R_L}}{I_b} = \frac{\left(g_m r_{b'e} R_C\right)^2 R_L}{Z_i \left(R_C + R_L\right)^2} \tag{2.12b}$$

$$F_{L(C_B)} = \frac{1}{2\pi R_{FLCB} C_B} \tag{2.13}$$

$$F_{L(C_E)} = \frac{1}{2\pi R_{FLCE} C_E} = \frac{1}{\left(2 \times \pi \times R_{FLCE} \times C_E\right)} \tag{2.14}$$

$$F_{L(C_C)} = \frac{1}{2\pi R_{FLCC} C_C} = \frac{1}{\left(2 \times \pi \times R_{FLCC} \times C_C\right)} \tag{2.15}$$

$$A_{V(F_L)} = -\frac{V_o}{E_g} = 0.707 A_{V(F_{Mid})} \tag{2.16}$$

$$F_H = \frac{1}{2\pi R_{FH} C_T} \tag{2.17}$$

$$A_{V(F_H)} = -\frac{V_o}{E_g} = \left(0.707\right) A_{V(F_{Mid})} \angle -45^\circ \tag{2.18}$$

$$B_W = F_H - F_L \tag{2.19}$$

$$I_{C(dc)} = \frac{F_T \left(k_B T / q\right)}{R_{FH} F_H \left(2\pi F_T C_{b'c} R_{out} + 1\right)} \tag{2.20}$$

$$V_{CE} = 0.5 V_{CC} \tag{2.21}$$

$$V_{RC} = 0.35 V_{CC} \tag{2.22}$$

$$V_{RE} = 0.15 V_{CC} \tag{2.23}$$

$$R_C = \frac{0.35 V_{CC}}{I_C} \tag{2.24}$$

$$R_E = \frac{0.15 V_{CC}}{\left(\beta_F + 1\right) I_B} \tag{2.25}$$

$$R_{TH} = 15 R_E \tag{2.26}$$

$$V_{TH} = I_B R_{TH} + V_{BE} + \left(\beta_F + 1\right) I_B R_E \tag{2.27}$$

$$R_{B1} = \frac{V_{CC} R_{TH}}{V_{TH}}, R_{B2} = \frac{V_{CC} R_{TH}}{\left(V_{CC} - V_{TH}\right)}; \tag{2.28}$$

$$C_B = \frac{1}{2\pi R_{FLCB} F_{L(C_B)}} \tag{2.29}$$

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$$C_E = \frac{1}{2\pi R_{FLCE} F_{L(C_E)}} \tag{2.30}$$

$$C_C = \frac{1}{2\pi R_{FLCC} F_{L(C_C)}} \tag{2.31}$$

$$V_{CC} \le V_{CEO} \tag{2.32}$$

$$I_C < 0.5 I_{C(\mathrm{MAX})} \tag{2.33}$$

$$V_{CE} I_C < P_D \tag{2.34}$$

$$P_{R_C} = \frac{2\left(0.35V_{CC}\right)^2}{R_C} \tag{2.35}$$

$$P_{R_E} = \frac{2\left(0.15V_{CC}\right)^2}{R_E} \tag{2.36}$$

$$P_{R_{B1}} = \frac{2\left(V_{R_{B1}}\right)^2}{R_{B1}} = \frac{2\left\{V_{CC} - \left(V_{BE} + V_{R_E}\right)\right\}^2}{R_{B1}} \tag{2.37}$$

$$P_{R_{B2}} = \frac{2\left(V_{R_{B2}}\right)^2}{R_{B2}} = \frac{2\left(V_{BE} + V_{R_E}\right)^2}{R_{B2}} \tag{2.38}$$

$$V_{C_C} = 2\left(0.5V_{CC} + 0.15V_{CC}\right) = 2\left(0.65V_{CC}\right) \tag{2.39}$$

$$V_{C_E} = 2\left(0.15V_{CC}\right) \tag{2.40}$$

$$V_{C_B} = 2\left(0.15V_{CC} + V_{BE}\right) \tag{2.41}$$

$$V_G = V_{GS} + V_{RS} \tag{2.42}$$

$$V_{GS} = V_P\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right) \tag{2.43}$$

$$V_{R_{G2}} = V_G = \frac{V_{DD} R_{G2}}{\left(R_{G1} + R_{G2}\right)} \tag{2.44}$$

$$V_{DD} = I_D R_D + V_{DS} + I_D R_S \tag{2.45}$$

$$I_{DSS} = \frac{V_{DD}}{R_D + R_S} \tag{2.45a}$$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 \tag{2.46}$$

$$0 = \frac{I_{DSS} R_S V^2{}_{GS}}{\left(V_P\right)^2} + \left(1 - \frac{2I_{DSS} R_S}{V_P}\right) V_{GS} + I_{DSS} R_S - V_G \tag{2.47}$$

$$a = \frac{I_{DSS} R_S}{\left(V_P\right)^2}$$

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$$b=\left(1-\frac{2I_{DSS}R_S}{V_P}\right)$$

$$c=I_{DSS}R_S-V_G$$

$$V_{GS}=\frac{-b\pm\sqrt{b^2-4ac}}{2a} \quad (2.48)$$

$Z_i=\infty$ หรือ $Z_i=$ วงจรเปิด (2.49)

$$Z_{in}=R_{GG}=\frac{R_{G1}R_{G2}}{\left(R_{G1}+R_{G2}\right)} \quad (2.50)$$

$$Z_o=\infty \quad (2.51)$$

$$Z_{out}=R_{out}=\left(R_D\parallel R_L\right)=\frac{R_DR_L}{\left(R_D+R_L\right)} \quad (2.52)$$

$$A_{V(F_{Mid})}=-\frac{V_o}{E_i}=-g_mZ_{out} \quad (2.53)$$

$$A_{V(F_{Mid})}=-\frac{V_o}{E_g}=-\frac{V_o}{E_i}\times\frac{Z_{in}}{\left(R_g+Z_{in}\right)}=-g_mZ_{out}\times\frac{Z_{in}}{\left(R_g+Z_{in}\right)} \quad (2.53a)$$

$$F_{L(C_G)}=\frac{1}{2\pi R_{FLCG}C_G} \quad (2.54)$$

$$F_{L(C_S)}=\frac{1}{2\pi R_{FLCS}C_S} \quad (2.55)$$

$$R_o=\frac{1}{g_m} \quad (2.55a)$$

$$F_{L(C_D)}=\frac{1}{2\pi R_{FLCD}C_D} \quad (2.56)$$

$$A_{V(F_L)}=-\frac{V_o}{E_g}=0.707A_{V(F_{Mid})}\angle 45^\circ \quad (2.57)$$

$$F_H=\frac{1}{2\pi R_{FH}C_T} \quad (2.58)$$

$$A_{V(F_H)}=-\frac{V_o}{E_g}=0.707A_{V(F_{Mid})}\angle -45^\circ \quad (2.58a)$$

$g_m=\frac{1.414I_{DSS}}{\left|V_P\right|}$ เมื่อ $\left(I_D=0.5I_{DSS},V_{GS}=0.293V_P;\right)$ (2.60)

$$V_{R_S}=0.586\left|V_P\right| \quad (2.61)$$

$$V_{DS}=0.5V_{DD} \quad (2.62)$$

$$V_{R_D}=V_{DD}-\left(V_{DS}+V_{R_S}\right) \quad (2.63)$$

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$$R_D = \frac{V_{R_D}}{I_D} \quad (2.64)$$

$$R_S = \frac{V_{R_S}}{I_D} = \frac{0.586|V_P|}{I_D} \quad (2.65)$$

$V_{R_{G2}} = V_G = 0.293V_P + 0.586|V_P|$ เมื่อ เฟตช่องเอ็น (2.65a)

$V_{R_{G2}} = V_G = 0.293V_P - 0.586V_P$ เมื่อ เฟตช่องพี (2.65b)

$$R_{G1} = \frac{\left(V_{DD} - V_{R_{G2}}\right) R_{G2}}{V_{R_{G2}}} \quad (2.66)$$

$$C_G = \frac{1}{2\pi R_{FLCG} F_{L(C_G)}} \quad (2.67)$$

$$C_D = \frac{1}{2\pi R_{FLCD} F_{L(C_D)}} \quad (2.69)$$

$$\left.\begin{array}{r} V_{DD} < BV_{GSS} \\ V_{DS} I_D < P_D \end{array}\right\} \quad (2.70)$$

$$P_{R_D} = \frac{2\left(V_{R_D}\right)^2}{R_D} \quad (2.71a)$$

$$P_{R_S} = \frac{2\left(V_{R_S}\right)^2}{R_S} \quad (2.71b)$$

$$P_{R_{G1}} = \frac{2\left(V_{R_{G1}}\right)^2}{R_{G1}} \quad (2.71c)$$

$$P_{R_{G2}} = \frac{2\left(V_{R_{G2}}\right)^2}{R_{G2}} \quad (2.71d)$$

$$V_{C_D} = 2\left(V_{DS} + V_{R_S}\right) \quad (2.72a)$$

$$V_{C_S} = 2\left(V_{R_S}\right) \quad (2.72b)$$

$$V_{C_G} = 2\left(V_{R_{G2}}\right) \quad (2.72c)$$

บทที่ 3 วงจรขยายจูน

$$Z = \frac{1}{G + \frac{1}{J\omega L} + J\omega C} \quad (3.1)$$

$$Z_{F_R} = \frac{1}{G} = R_L \quad (3.1a)$$

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$$F_R = \frac{1}{2\pi\sqrt{LC}} \quad (3.1b)$$

$$Z_{F_H} = 0.707R_L \angle -45^\circ \quad (3.1c)$$

$$Z_{F_L} = 0.707R_L \angle 45^\circ \quad (3.1d)$$

$$Q = \frac{E^2{}_S / X_L}{E^2{}_S / R} = \frac{E^2{}_S}{X_L} \times \frac{R}{E^2{}_S} = \frac{R}{X_L} = \frac{R}{\omega L} \quad (3.1e)$$

$$Q = \frac{E^2{}_S / X_C}{E^2{}_S / R} = \frac{E^2{}_S}{X_C} \times \frac{R}{E^2{}_S} = \frac{R}{X_C} = \omega CR$$
$$R = \frac{R_g R_L}{\left(R_g + R_L\right)} \quad (3.1f)$$

$$B_W = \frac{F_R}{Q} = \frac{F_R}{\omega CR} = \frac{1}{2\pi CR} \quad (3.2)$$

$$F_H = F_R + \frac{B_W}{2} = \frac{1}{2\pi}\left(\frac{1}{\sqrt{LC}} + \frac{1}{2RC}\right) \quad (3.2a)$$

$$F_L = F_R - \frac{B_W}{2} = \frac{1}{2\pi}\left(\frac{1}{\sqrt{LC}} - \frac{1}{2RC}\right) \quad (3.2b)$$

$$Q_S = \frac{\left(I_S\right)^2 X_{L_S}}{\left(I_S\right)^2 R_S} = \frac{X_{L_S}}{R_S} = \frac{\omega L_S}{R_S} \quad (3.3)$$

$$Q_P = \frac{\left(E_S\right)^2 / X_{L_P}}{\left(E_S\right)^2 / R_P} = \frac{R_P}{X_{L_P}} = \frac{R_P}{\omega L_P} \quad (3.4)$$

$$QR_S = \frac{R_P}{Q},\ R_S = \frac{R_P}{Q^2},\ R_P = Q^2 R_S; \quad (3.5)$$

$$Q_L = \frac{\left(R \| R_P\right)}{\omega L_P} = \frac{RR_P}{\left(R + R_P\right)\omega L_P} \quad (3.5a)$$

$$L = C\mu N^2 \quad (3.6)$$

$$\frac{L_P}{L_S} = \frac{C\mu N^2{}_P}{C\mu N^2{}_S} \text{ หรือ } \frac{L_P}{L_S} = \frac{N^2{}_P}{N^2{}_S} \quad (3.7)$$

$$\frac{E_P}{N_P} = \frac{E_S}{N_S} \quad (3.8)$$

$$I_P N_P = I_S N_S \quad (3.9)$$

$$\frac{Z_P}{N^2{}_P} = \frac{Z_S}{N^2{}_S},\ Z_P = \frac{Z_S N^2{}_P}{N^2{}_S}; \quad (3.10)$$

$$C_P N^2{}_P = C_S N^2{}_S \quad (3.11)$$

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$$V_{CE} = V_{CC} - (\beta_F + 1) I_B R_E \quad (3.12)$$

$$F_{R(L_{21})} = \frac{1}{2\pi\sqrt{L_{21}(C_{BT} + C_{b'e})}} \quad (3.13)$$

$$F_{R(L_{12})} = \frac{1}{2\pi\sqrt{L_{12} C_{CT(\text{ab})}}} \quad (3.14)$$

$$C_{CT(\text{ab})} = \frac{C_{CT} N^2_{22}}{N^2_{12}} \quad (3.15)$$

$$R_{L(\text{ab})} = \frac{R_L N^2_{12}}{N^2_{32}} \quad (3.16)$$

$$B_{W(L_{21})} = \frac{1}{2\pi R(C_{BT} + C_{b'e})} \quad (3.17)$$

$$B_{W(L_{12})} = \frac{1}{2\pi C_{CT(\text{ab})} R_{L(\text{ab})}} \quad (3.18)$$

$$E_S = V_{b'e} = \frac{E_g r_{b'ep}}{R_g + r_{b'ep}} \times \frac{N_{21}}{N_{11}} \quad (3.19)$$

$$r_{b'ep} = \frac{r_{b'e} N^2_{11}}{N^2_{21}}$$

$$A_{V(F_R)} = \frac{V_o}{E_g} = \frac{g_m R_L N_{12}}{N_{32}} \times \frac{r_{b'ep}}{R_g + r_{b'ep}} \times \frac{N_{21}}{N_{11}} \quad (3.20)$$

$$C_n = (n) C_{b'c} \quad (3.21)$$

$$R_n = \frac{r_{bb'}(C_{b'e} + C_{b'c})}{(n) C_{b'c}} \quad (3.22)$$

$$V_{CE} = 0.5V_{CC}, V_{RE} = 0.5V_{CC}; \quad (3.23)$$

$$R_E = \frac{0.5V_{CC}}{(\beta_F + 1) I_B} \quad (3.24)$$

$$C_{b'ep} = \frac{C_{b'e} N^2_{21}}{N^2_{11}} \quad (3.25)$$

$$C_{BT} = \frac{1}{L_{11}\left(2\pi F_{R(L_{11})}\right)^2} - C_{b'ep} \quad (3.26)$$

$$C_{CT} = \frac{1}{L_{22}\left(2\pi F_{R(L_{22})}\right)^2} \quad (3.27)$$

$$B_{W(L_{11})} = \frac{1}{2\pi R\left(C_{BT} + C_{b'ep}\right)} \quad (3.27a)$$

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$$F_{R(L_{11})} = \frac{1}{2\pi\sqrt{L_{11}\left(C_{BT} + C_{b'ep}\right)}} \tag{3.28}$$

$$Z_{in} = R_{CF1} + Z_{icf} \tag{3.29}$$

$$Z_{incf} = R_{CF2} + \frac{R_{BB}\left(r_{bb'} + r_{b'e}\right)}{\left(R_{BB} + r_{bb'} + r_{b'e}\right)} \tag{3.30}$$

$$A_{V(F_R)} = -\frac{V_o}{E_{i_1}} = -\frac{(0.5)\, g_m Z_{out} r_{b'e} R_{BB}}{R_{CF2}\left(R_{BB} + r_{bb'} + r_{b'e}\right) + R_{BB}\left(r_{bb'} + r_{b'e}\right)} \tag{3.31}$$

$$A_{V(F_H)} = -\frac{V_o}{E_{i_1}} = (0.707)\, A_{V(F_R)} \angle -45^\circ \tag{3.32}$$

$$I_{C(dc)} = \frac{\beta_o V_T}{\left(Z_{incf} - R_{CF2} + r_{bb'}\right)} \tag{3.33}$$

บทที่ 4 วงจรทวีความถี่

$$V_1 = \frac{E_i N_{23}}{N_{13}}, V_1 = V_2; \tag{4.1}$$

$$I_{D_1} = \frac{E_i N_{23}}{\left(R_1 + R_L\right) N_{13}} - \frac{V_{FD_1}}{\left(R_1 + R_L\right)} \tag{4.2}$$

$$E_i = \frac{I_{D_1}\left(R_1 + R_L\right) N_{13} + V_{FD_1} N_{13}}{N_{23}} \tag{4.2a}$$

$$I_{D_2} = \frac{E_i N_{33}}{\left(R_2 + R_L\right) N_{13}} - \frac{V_{FD_2}}{\left(R_2 + R_L\right)} \tag{4.3}$$

$$L_{43} = \frac{L_{13}\left(N_{23} + N_{33}\right)^2}{N^2{}_{13}} \tag{4.4}$$

$$F_{R(L_{43})} = \frac{1}{2\pi\sqrt{L_{43} C_{CM}}} \tag{4.5}$$

$$C_{CM} = \frac{1}{L_{43}\left(2\pi F_{R(L_{43})}\right)^2} \tag{4.5a}$$

$$r_{d_1} = r_d = \frac{\left(k_B T / q\right)}{I_D} \tag{4.5b}$$

$$R_{g(L_{23})} = \frac{R_g N^2{}_{23}}{N^2{}_{13}}$$

$$R_{BW} = \frac{R_{g(L_{23})}\left(r_{d_1} + R_1 + R_L\right)}{\left(R_{g(L_{23})} + r_{d_1} + R_1 + R_L\right)} \times \frac{\left(N_{23} + N_{33}\right)^2}{N^2{}_{23}} \tag{4.5c}$$

$$B_{W(L_{43})} = \frac{1}{2\pi C_{CM} R_{BW}} \quad (4.5d)$$

$$V_{o(0-\pi)} = I_{D_1} R_L = R_L \left\{ \frac{E_i N_{23}}{(R_1 + R_L) N_{13}} - \frac{V_{FD_1}}{(R_1 + R_L)} \right\} \quad (4.6)$$

$$V_{o(\pi\text{-}2\pi)} = I_{D_2} R_L = R_L \left\{ \frac{E_i N_{33}}{(R_2 + R_L) N_{13}} - \frac{V_{FD_2}}{(R_2 + R_L)} \right\} \quad (4.7)$$

$$R_{1x} = \frac{R_L}{V_{ox}} \left( \frac{E_i N_{23}}{N_{13}} - V_{FD_1} \right) - R_L \quad (4.8)$$

$$R_{2x} = \frac{R_L}{V_{ox}} \left( \frac{E_i N_{33}}{N_{13}} - V_{FD_2} \right) - R_L \quad (4.9)$$

$$I_{D_1} = \frac{(V_{CC} - V_{FD_1})}{(R_1 + 2R_L)}, I_{D_1} = I_{D_2}; \quad (4.10)$$

$$R_{i(0\text{-}\pi)} = r_{bb'} + r_{b'e} + (\beta_F + 1) R_{EP} \quad (4.11a)$$

$$R_{in(0\text{-}\pi)} = \frac{R_{BB} R_{i(0\text{-}\pi)}}{R_{BB} + R_{i(0\text{-}\pi)}} \quad (4.11b)$$

$$I_{d_2} = \frac{E_i g_m r_{b'e} R_E}{R_{i(0\text{-}\pi)} (R_E + r_{d_2} + R_L)} \quad (4.12)$$

$$V_{o(0\text{-}\pi)} = I_{d_2} R_L \quad (4.13)$$

$$R_{i(\pi\text{-}2\pi)} = r_{bb'} + r_{b'e} + (\beta_F + 1) R_{EP1} \quad (4.14)$$

$$R_{in(\pi\text{-}2\pi)} = \frac{R_{BB} R_{i(\pi\text{-}2\pi)}}{R_{BB} + R_{i(\pi\text{-}2\pi)}} \quad (4.15)$$

$$I_{d_1} = \frac{E_i g_m r_{b'e} R_C}{R_{i(\pi\text{-}2\pi)} (R_C + r_{d_1} + R_L)} \quad (4.16)$$

$$V_{o(\pi\text{-}2\pi)} = I_{d_1} R_L \quad (4.17)$$

$$F_{L(C_B)} = \frac{1}{2\pi R_{FLCB} C_B} \quad (4.18)$$

$$F_{L(C_E)} = \frac{1}{2\pi R_{FLCE} C_E} \quad (4.19)$$

$$F_{L(C_C)} = \frac{1}{2\pi R_{FLCC} C_C} \quad (4.20)$$

$$F_H = \frac{1}{2\pi R_{FH} C_T} \quad (4.21)$$

$$V_{CE} = 0.5V_{CC}, V_{RC} = 0.25V_{CC}, V_{RE} = 0.25V_{CC}; \quad (4.22)$$

*สูตรการวิเคราะห์วงจรอิเล็กทรอนิกส์ความถี่สูง*

$$R_C = \frac{0.25V_{CC}}{I_C} \tag{4.23}$$

$$R_E = \frac{0.25V_{CC}}{(\beta_F + 1)I_B} \approx \frac{0.25V_{CC}}{I_C} \tag{4.24}$$

$$C_B = \frac{1}{2\pi F_{L(C_B)} R_{FLCB}} \tag{4.25}$$

$$C_E = C_C = \frac{1}{2\pi F_{L(C_E)} R_{FLCE}} \tag{4.26}$$

$$P_{R_C} = \frac{2(0.25V_{CC})^2}{R_C} \tag{4.27}$$

$$P_{R_E} = \frac{2(0.25V_{CC})^2}{R_E} \tag{4.28}$$

$$P_{R_{B1}} = \frac{2(V_{R_{B1}})^2}{R_{B1}} = \frac{2\{V_{CC} - (V_{BE} + V_{R_E})\}^2}{R_{B1}} \tag{4.29}$$

$$P_{R_{B2}} = \frac{2(V_{R_{B2}})^2}{R_{B2}} = \frac{2(V_{BE} + V_{R_E})^2}{R_{B2}} \tag{4.30}$$

$$P_{R_1} = \frac{2(V_{R_1})^2}{R_1} = \frac{2\{V_{CC} - (V_{FD_1} + 2I_{D_1}R_L)\}^2}{R_1} \tag{4.30a}$$

$$P_{R_2} = \frac{2(V_{R_2})^2}{R_2} = \frac{2\{V_{CC} - (V_{FD_2} + 2I_{D_2}R_L)\}^2}{R_2} \tag{4.30b}$$

$$V_{C_C} = 2(0.5V_{CC} + 0.25V_{CC}) = 2(0.75V_{CC}) \tag{4.31}$$

$$V_{C_E} = 2(0.25V_{CC}) \tag{4.32}$$

$$V_{C_B} = 2(0.25V_{CC} + 0.6\ \mathrm{V}) \tag{4.33}$$

บทที่ 5 วงจรออสซิลเลเตอร์ย่านความถี่สูง

$$0 = I_b(r_{b'e} + Z_1) - I_z Z_1 \tag{5.1}$$

$$0 = I_b(g_m r_{b'e} Z_2 - Z_1) + I_z(Z_1 + Z_2 + Z_3) \tag{5.2}$$

$$0 = r_{b'e}(Z_1 + Z_2 + Z_3) + Z_1(Z_2 + Z_3 + g_m r_{b'e} Z_2) \tag{5.3}$$

$$0 = Jr_{b'e}(X_1 + X_2 + X_3) - X_1\{X_2(1 + g_m r_{b'e}) + X_3\} \tag{5.4}$$

$$0 = X_1 + X_2 + X_3 \tag{5.4a}$$

$$0 = X_2(1 + g_m r_{b'e}) + X_3 \tag{5.4b}$$

*สูตรการวิเคราะห์วงจรอิเล็กทรอนิกส์ความถี่สูง*

$$X_2 = -\frac{X_3}{(1+g_m r_{b'e})} \quad (5.5)$$

$$X_1 = -\frac{X_3 (g_m r_{b'e})}{(1+g_m r_{b'e})} \quad (5.6)$$

$$\beta_o = \frac{X_1}{X_2} \quad (5.7)$$

$$F_o = \frac{1}{2\pi\sqrt{(L_1+L_2)C_3}} \quad (5.7a)$$

$$L_T = (L_1+L_2) + 2\sqrt{L_1 L_2} \quad (5.8)$$

$$F_o = \frac{1}{2\pi\sqrt{L_T C_3}} \quad (5.9)$$

$$C_T = \frac{C_1 C_2}{C_2 + C_1} \quad (5.10a)$$

$$F_o = \frac{1}{2\pi\sqrt{C_T L_3}} \quad (5.10b)$$

$$0 = I_d (Z_2 + r_d) + I_z (Z_2 - g_m Z_1 r_d) \quad (5.11)$$

$$0 = I_d Z_2 + I_z (Z_1 + Z_2 + Z_3) \quad (5.12)$$

$$0 = r_d (Z_1 + Z_2 + Z_3) + Z_2 \{Z_1 (1+g_m r_d) + Z_3\} \quad (5.13)$$

$$0 = Jr_d (X_1 + X_2 + X_3) - X_2 \{X_1 (1+g_m r_d) + X_3\} \quad (5.14)$$

$$0 = X_1 + X_2 + X_3 \quad (5.15a)$$

$$0 = X_1 (1+g_m r_d) + X_3 \quad (5.15b)$$

$$X_1 = -\frac{X_3}{(1+g_m r_d)} \quad (5.16)$$

$$X_2 = -\frac{X_3 (g_m r_d)}{(1+g_m r_d)} \quad (5.17)$$

$$\frac{X_2}{X_1} = g_m r_d \quad (5.18)$$

$$F_{OS} = \frac{1}{2\pi\sqrt{L_S C_S}} \quad (5.19)$$

$$F_{OP} = \frac{1}{2\pi\sqrt{L_S \dfrac{C_S C_P}{C_S + C_P}}} \quad (5.20)$$

$$L_1 = nL_2 \quad (5.21)$$

$$L_2 = \frac{L_T}{(n+1) + 2\sqrt{n}} \quad (5.22)$$

*สูตรการวิเคราะห์วงจรอิเล็กทรอนิกส์ความถี่สูง*

$$L_T = \frac{1}{C_3 \left(2\pi F_o\right)^2} \quad (5.23)$$

$$C_4 = \frac{1}{2\pi F_o X_{C_4}} \quad (5.24)$$

$$C_1 = nC_2 \quad (5.25)$$

$$C_2 = \frac{C_T \left(n+1\right)}{n} \quad (5.26)$$

$$C_T = \frac{1}{L_3 \left(2\pi F_o\right)^2} \quad (5.27)$$

$$R_S = \frac{-0.293 V_P}{0.5 I_{DSS}} \quad (5.28)$$

$$R_D = \frac{V_{R_D}}{0.5 I_{DSS}} \quad (5.29)$$

$$C_4 = \frac{1}{2\pi F_o X_{C_4}} \quad (5.30)$$

$$C_3 = \frac{C_2}{10} \quad (5.31)$$

$$F_o = \frac{1}{2\pi \sqrt{L_1 C_3}} \quad (5.32)$$

$$C_E = \frac{C_2}{10} \quad (5.33)$$

$$F_o = \frac{1}{2\pi \sqrt{L_1 C_T}} \quad (5.34)$$

บทที่ 6 วงจรแมตช์และฟิลเตอร์

$$P_{in} = E_S I_s = \frac{\left(E_S\right)^2}{\left(R_S + R_{in}\right)} \quad (6.1)$$

$$P_{out} = \left(I_s\right)^2 R_{in} = \frac{\left(E_S\right)^2 R_{in}}{\left(R_S + R_{in}\right)^2} \quad (6.2)$$

$$P_G = \frac{R_{in}}{\left(R_S + R_{in}\right)} \quad (6.3)$$

$$V_o = \frac{I_c R_{out} R_L}{\left(R_{out} + R_L\right)} \quad (6.4)$$

$$P_{in} = I_c V_o = \frac{\left(I_c\right)^2 R_{out} R_L}{\left(R_{out} + R_L\right)} \quad (6.5)$$

*สูตรการวิเคราะห์วงจรอิเล็กทรอนิกส์ความถี่สูง*

$$P_{out} = \frac{(V_o)^2}{R_L} = \frac{(I_c R_{out} R_L)^2}{(R_{out} + R_L)^2 R_L} \quad (6.6)$$

$$P_G = \frac{R_{out}}{(R_{out} + R_L)} \quad (6.7)$$

$$Z_{in} = \frac{(r_{bb'} + r_{b'e}) + J\omega C_T r_{bb'} r_{b'e}}{1 + J\omega C_T r_{b'e}} \quad (6.8)$$

$$R_{ip} = \frac{r}{\cos\theta}, X_{ip} = \frac{r}{\sin\theta}; \text{ เมื่อ } (-X_{ip} = X_{C_{ip}}) \quad (6.9a)$$

$$R_{is} = r\cos\theta, X_{is} = r\sin\theta; \text{ เมื่อ } (-X_{is} = X_{C_{is}}) \quad (6.9b)$$

$$F_R = \frac{1}{2\pi\sqrt{L_{mi} C_{ip}}} \quad (6.10)$$

$$L_{mi} = \frac{1}{(2\pi F_R)^2 C_{ip}} \quad (6.11)$$

$$F_R = \frac{1}{2\pi\sqrt{L_{mo} C_{ce}}} \quad (6.12)$$

$$L_{mo} = \frac{1}{(2\pi F_R)^2 C_{ce}} \quad (6.13)$$

$$R_{bwi} = (R_{ip} \,||\, R_S) = \frac{R_{ip} R_S}{(R_{ip} + R_S)} \quad (6.14)$$

$$B_{Win} = \frac{1}{2\pi R_{bwi} C_{ip}} \quad (6.15)$$

$$R_{bwo} = (R_{out} \,||\, R_L) = \frac{R_{out} R_L}{(R_{out} + R_L)} \quad (6.16)$$

$$B_{Wout} = \frac{1}{2\pi R_{bwo} C_{ce}} \quad (6.17)$$

$$C_{ipx} = \frac{1}{2\pi R_{bwi}(B_{Win})} \quad (6.18)$$

$$C_{ipp} = C_{ipx} - C_{ip} \quad (6.19)$$

$$L'_{mi} = \frac{1}{(2\pi F_R)^2 (C_{ip} + C_{ipp})} \quad (6.20)$$

$$Q_m = \sqrt{\left(\frac{R_{m4} - R_{m1}}{R_{m1}}\right)}, Q_m = \frac{F_R}{B_W}; \quad (6.21a)$$

$$L_{m2} = \frac{Q_m R_{m1}}{\omega} \quad (6.21b)$$

*สูตรการวิเคราะห์วงจรอิเล็กทรอนิกส์ความถี่สูง*

$$C_{m3} = \frac{L_{m2}}{R^2{}_{m1} + \left(\omega L_{m2}\right)^2} \tag{6.21c}$$

$$Q_m = \sqrt{a\left(\frac{R_{m5} - R_{m1}}{R_{m1}}\right)} \tag{6.22a}$$

$$L_{m2} = \frac{Q_m R_{m1}}{\omega} \tag{6.22b}$$

$$C_{m3} = \frac{1}{\omega R_{m1}\left(1 + Q^2{}_m\right)}\left(Q_m - \sqrt{\frac{R_{m1}\left(1 + Q^2{}_m\right)}{R_{m5}} + 1}\right) \tag{6.22c}$$

$$C_{m4} = \frac{\sqrt{R_{m5}}}{\omega R_{m5}\sqrt{R_{m1}\left(1 + Q^2{}_m\right) - R_{m5}}} \tag{6.22d}$$

$$C_{m3} = \frac{1}{\omega Q_m R_{m1}} \tag{6.23a}$$

$$C_{m4} = \frac{1}{\omega R_{m5}\sqrt{\left(\frac{R_{m1}}{R_{m5} - R_{m1}}\right)}} \tag{6.23b}$$

$$L_{m2} = \frac{1}{\omega^2 C_{m3}} + R_{m1}R_{m5}C_{m4} \tag{6.23c}$$

$$L_{m5} = \frac{Q_{m2}R_{m6}}{\omega} \tag{6.24a}$$

$$C_{m3} = \frac{1}{\omega Q_{m1}R_{m1}} \tag{6.24b}$$

$$C_{m4} = \frac{Q_{m2}}{\omega\left(1 + Q^2{}_{m2}\right)}\left(\frac{R_{m6} + R_{m1}}{R_{m6}R_{m1}}\right) \tag{6.24c}$$

$$L_{m2} = \frac{1 + \left(\omega C_{m3}R_{m1}Q_{m2}\right)}{\omega^2 C_{m3}} \tag{6.24d}$$

$C_m$ ขนาน $C_x$ จะได้ $C_{m(new)} = C_m - C_x$ (6.25a)

$C_m$ ขนาน $L_x$ จะได้ $C_{m(new)} = \dfrac{\left(\omega^2 C_m L_x + 1\right)}{\omega^2 L_x}$ (6.25b)

$L_m$ อนุกรม $L_x$ จะได้ $L_{m(new)} = L_m - L_x$ (6.25c)

$L_m$ อนุกรม $C_x$ จะได้ $L_{m(new)} = \dfrac{\omega^2 L_m C_x + 1}{\omega^2 C_x}$ (6.25d)

$C_m$ อนุกรม $C_x$ จะได้ $C_{m(new)} = C_m - C_x$ (6.25e)

$C_m$ อนุกรม $L_x$ จะได้ $C_{m(new)} = \dfrac{C_m}{1 + \omega^2 C_m L_x}$ (6.25f)

*สูตรการวิเคราะห์วงจรอิเล็กทรอนิกส์ความถี่สูง*

$$R_S = \frac{R_P}{1+\left(\omega C_P R_P\right)^2}, C_S = \frac{1+\left(\omega C_P R_P\right)^2}{\left(\omega R_P\right)^2 C_P}; \quad (6.26a)$$

$$R_P = \frac{1+\left(\omega C_S R_S\right)^2}{R_S\left(\omega C_S\right)^2}, C_P = \frac{C_S}{1+\left(\omega C_S R_S\right)^2}; \quad (6.26b)$$

$$R_S = \frac{R_P\left(\omega L_P\right)^2}{R^2{}_P+\left(\omega L_P\right)^2}, L_S = \frac{R^2{}_P L_P}{R^2{}_P+\left(\omega L_P\right)^2}; \quad (6.27a)$$

$$R_P = \frac{R^2{}_S+\left(\omega L_S\right)^2}{R_S}, L_P = \frac{R^2{}_S+\left(\omega L_S\right)^2}{\omega^2 L_S}; \quad (6.27b)$$

$$L = \frac{R_L L_n}{2\pi F_H} \quad (6.28)$$

$$C = \frac{C_n}{2\pi F_H R_L} \quad (6.29)$$