SOLUTIONS MANUAL

MICROWAVE TRANSISTOR AMPLIFIERS

Analysis and Design

SECOND EDITION

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5.1) $\beta(j\omega) A_{vo} = 1$ OR $[\beta_r(j\omega) + j\beta_i(j\omega)] A_{vo} = 1$

$\therefore \; A_{vo} = \dfrac{1}{\beta_r(\omega)}$ AND $\beta_i(j\omega) = 0$

$$\beta(j\omega) = \frac{10^{-5}}{1+(\omega-10^3)^2} - j\,\frac{10^{-5}(\omega-10^3)}{1+(\omega-10^3)^2}$$

$\beta_i(j\omega) = 0$ WHEN $\omega = 10^3$ rad/s

AT $\omega = \omega_o = 10^3$ rad/s : $\beta_r(j\omega_o) = 10^{-5}$

THEN, $A_{vo} = \dfrac{1}{10^{-5}} = 10^5$

5.2) $X_L(j\omega_o) = j\omega_o L + \dfrac{1}{j\omega_o C} = 0$ OR $\omega_o = \dfrac{1}{\sqrt{LC}}$

$$f_o = \frac{1}{2\pi\sqrt{50\,10^{-9}\,10\,10^{-12}}} = 225 \text{ MHz}$$

$$R_L = \frac{R_o}{3} = \frac{30}{3} = 10\,\Omega$$

5.3) $B_L(j\omega_o) = j\omega_o C + \dfrac{1}{j\omega_o L} = 0$ OR $\omega_o = \dfrac{1}{\sqrt{LC}}$

$$f_o = \frac{1}{2\pi\sqrt{25\,10^{-9}\,5\,10^{-12}}} = 450 \text{ MHz}$$

$$G_L = \frac{G_o}{3} = \frac{40\,10^{-3}}{3} = 13.3 \text{ mS}$$

5.4)(a) $Z_{IN}(A',\omega) = \dfrac{1}{G(A') + j\omega C} = \dfrac{G(A')}{G^2(A') + \omega^2 C^2} + j\,\dfrac{-\omega C}{G^2(A') + \omega^2 C^2}$

$\therefore \; R_{IN}(A',\omega) = \dfrac{G(A')}{G^2(A') + \omega^2 C^2}$ AND $X_{IN}(A',\omega) = \dfrac{-\omega C}{G^2(A') + \omega^2 C^2}$

FROM (5.2.16), (5.2.17), AND (5.2.20), A STABLE OSCILLATION OCCURS

$$R_L = -R_{IN}(A',\omega) = \frac{-G(A')}{G^2(A') + \omega^2 C^2}$$

$$X_L = -X_{IN}(A',\omega) = \frac{\omega C}{G^2(A') + \omega^2 C^2}$$

AND

$$\left.\frac{\partial R_{IN}}{\partial A'}\right|_{A'=A_o} \left.\frac{\partial X_L}{\partial \omega}\right|_{\omega=\omega_o} > 0$$

(b) $P = \frac{1}{2}|V|^2 |G(A')| = \frac{1}{2} A'^2 G_o (1 - A'/A'_m)$, $\dfrac{\partial P}{\partial A'} = \dfrac{G_o}{2}\left(2A' - \dfrac{3A'^2}{A'_m}\right) = 0$

OR $A' \equiv A'_{o,max} = \frac{2}{3} A'_M$. AT $A' = A'_{o,max}$ THE VALUE OF $G_{IN}(A')$ IS:

$G_{IN}(A_{o,max}) = -G_o/3$. THEREFORE: $G_L = G_o/3$.

5.5) $K = -0.505$, $\Delta = 0.933 \angle 141.9^\circ$ $\therefore$ POTENTIALLY UNSTABLE

INPUT STABILITY CIRCLE: $C_{in} = 1.56 \angle 2.55^\circ$, $r_{in} = 0.789$

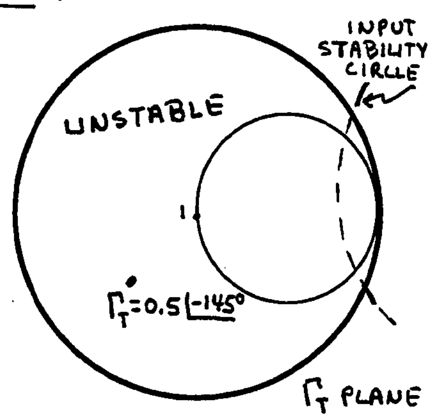
OUTPUT STABILITY CIRCLE: $C_L = 0.89 \angle -155.2^\circ$, $r_L = 0.295$

SELECT THE GATE TO SOURCE AS THE TERMINATING PORT. THE VALUE FOR Γ_T SELECTED IS $\Gamma_T = 0.5 \angle -145^\circ$.

THEN, $\Gamma_{IN} = 1.116 \angle 173^\circ$

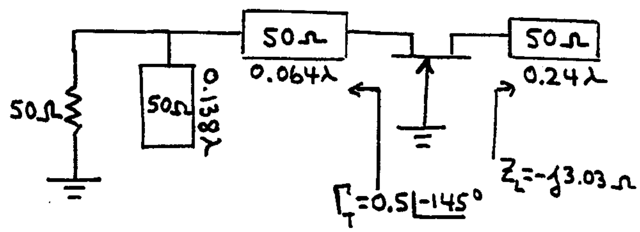
$$Z_{IN} = -2.74 + j3.03 \ \Omega$$

LET $Z_L = \frac{2.74}{3} - j3.03 = 0.91 - j3.03 \Omega$



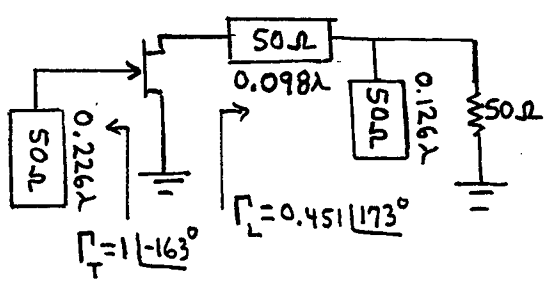
NEGLECTING THE 0.91Ω, Z_L CAN BE IMPLEMENTED WITH AN OPEN-CIRCUITED LINE OF LENGTH 0.24λ.

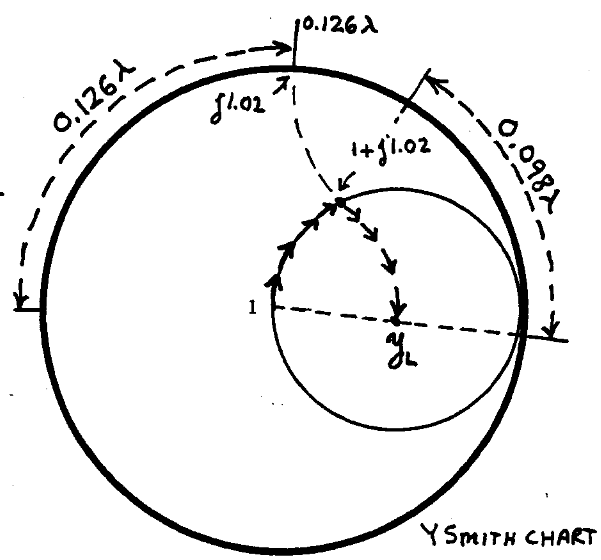
A DESIGN FOR THE OSCILLATOR IS:



5.6) $Z_L = 19 + j2.6 \ \Omega$, $z_L = 0.38 + j0.052$, $\Gamma_L = 0.451 \angle 173^\circ$

$y_L = \frac{1}{z_L} = 2.58 - j0.353$





5.7) WITH $L = 0.5\,nH$: $K = -0.834$, $\Delta = 1.02\angle 157^\circ$ ∴ POTENTIALLY UNSTABLE

INPUT STABILITY CIRCLE : $C_s = 1.38\angle -50.9^\circ$, $r_s = 2.1$

OUTPUT STABILITY CIRCLE : $C_L = 0.78\angle 119.7^\circ$, $r_L = 1.39$

SELECTING THE OUTPUT PORT (i.e., BASE TO COLLECTOR) AS THE TERMINATING PORT WITH:

$$\Gamma_T = 0.5\angle 30^\circ$$

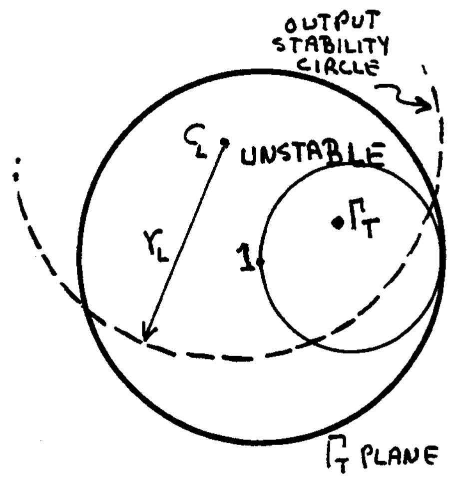
THEN: $\Gamma_{IN} = 1.126\angle 172.4^\circ$

$$Z_{IN} = -2.98 + j3.31\ \Omega$$

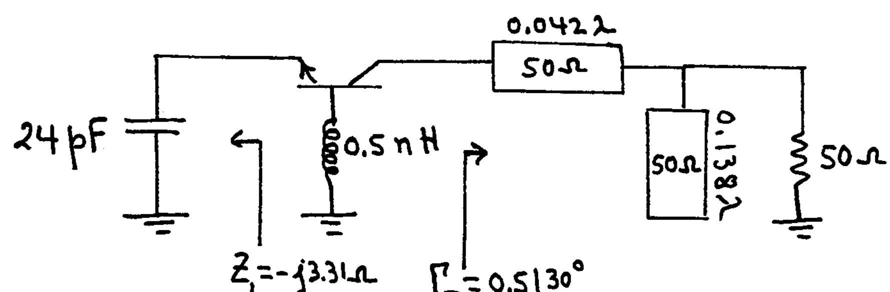
LET $Z_L = \dfrac{2.98}{3} - j3.31 = 0.99 - j3.31\ \Omega$

NEGLECTING THE $0.99\,\Omega$ WE CAN DESIGN THE LOAD CIRCUIT WITH A CAPACITOR, NAMELY

$$-j3.31 = \frac{-j}{\omega C} \text{ OR } C = \frac{1}{2\pi(2\cdot 10^9)3.31} = 24\,pF$$



A DESIGN FOR THE OSCILLATOR IS:



5.8) $K = 0.654$, $\Delta = 0.812\angle -59.8^\circ$ ∴ POTENTIALLY UNSTABLE

FROM (5.4.4) AND (5.4.5): $C_{IN} = 0.78\angle -162^\circ$, $r_{IN} = 0.842$

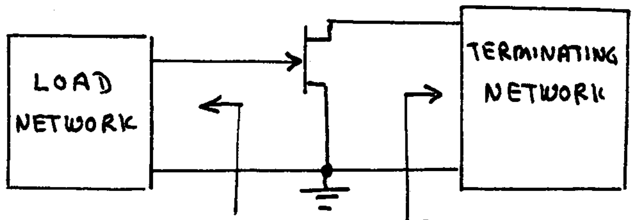
FROM (5.4.6) : $\Gamma_{IN,max} = (0.78 + 0.842)\angle -162^\circ = 1.622\angle -162^\circ$

FROM (5.4.7): $\Gamma_{T,o} = 1\angle -174^\circ$, $Z_{T,o} = -j2.62\ \Omega$

$$Z_{IN,max} = -12.1 - j7.5\,\Omega$$

THE LARGE-SIGNAL CHARACTERISTICS SHOW THAT A POWER OF 150 mW IS POSSIBLE WITH $Z_L = 50(0.2 - j0.35) = 10 - j17.5\ \Omega$

THE BLOCK DIAGRAM OF THE OSCILLATOR IS:



$Z_L = 10 - j17.5\,\Omega$ $\quad Z_{T,0} = -j2.62\,\Omega$

$(\Gamma_{T,0} = 1\angle -174^\circ)$

5.9) $$\Gamma_{IN} = \frac{S_{11} - \Delta\Gamma_T}{1 - S_{22}\Gamma_T} = \frac{S_{11}(1-|S_{22}|^2) - \Delta\Gamma_T(1-|S_{22}|^2)}{(1-S_{22}\Gamma_T)(1-|S_{22}|^2)}$$

$$\Gamma_{IN} = \frac{S_{11} - S_{11}S_{22}S_{22}^* - S_{11}S_{22}\Gamma_T + S_{21}S_{12}\Gamma_T + \Delta\Gamma_T\, S_{22}S_{22}^*}{(1-S_{22}\Gamma_T)(1-|S_{22}|^2)}$$

ADDING AND SUBTRACTING IN THE NUMERATOR THE TERM $S_{21}S_{12}S_{22}^*$ GIVES

$$\Gamma_{IN} = \frac{S_{11} - \Delta S_{22}^* - S_{11}S_{22}\Gamma_T + \Delta\Gamma_T S_{22}S_{22}^* + S_{21}S_{12}(\Gamma_T - S_{22}^*)}{(1-S_{22}\Gamma_T)(1-|S_{22}|^2}$$

$$\Gamma_{IN} = \frac{S_{11}(1-S_{22}\Gamma_T) - \Delta S_{22}^*(1-S_{22}\Gamma_T) + S_{21}S_{12}(\Gamma_T - S_{22}^*)}{(1-S_{22}\Gamma_T)(1-|S_{22}|^2)}$$

$$\Gamma_{IN} = \frac{S_{11} - \Delta S_{22}^*}{1-|S_{22}|^2} + \frac{S_{12}S_{21}}{1-|S_{22}|^2}\;\frac{\Gamma_T - S_{22}^*}{1-S_{22}\Gamma_T} = \Gamma_{IN,0} + \alpha\Gamma_T'$$

WHERE $\Gamma_{IN,0} = \dfrac{S_{11}-\Delta S_{22}^*}{1-|S_{22}|^2}$ AND $\alpha\Gamma_T' = \dfrac{S_{12}S_{21}}{1-|S_{22}|^2}\;\dfrac{\Gamma_T - S_{22}^*}{1-S_{22}\Gamma_T}$

IF α IS DEFINED AS: $\alpha = \dfrac{S_{12}S_{21}}{1-|S_{22}|^2}\;\dfrac{1-S_{22}^*}{1-S_{22}}$, THEN

$\Gamma_T' = \dfrac{\Gamma_T - S_{22}^*}{1-S_{22}\Gamma_T}\;\dfrac{1-S_{22}}{1-S_{22}^*}$. LETTING $\Gamma_T = \dfrac{Z_T - Z_0}{Z_T+Z_0}$ AND $S_{22} = \dfrac{Z_{22}-Z_0}{Z_{22}+Z_0}$

$$\therefore\ \Gamma_T' = \frac{\left(\frac{Z_T-Z_0}{Z_T+Z_0}\right) - \left(\frac{Z_{22}^*-Z_0}{Z_{22}^*+Z_0}\right)}{1 - \left(\frac{Z_{22}-Z_0}{Z_{22}+Z_0}\right)\left(\frac{Z_T-Z_0}{Z_T+Z_0}\right)}\left(\frac{Z_{22}^*+Z_0}{Z_{22}+Z_0}\right) = \frac{Z_T - Z_{22}^*}{Z_T + Z_{22}}$$

$\Gamma_{IN,max}$ (SEE FIG. 5.4.3) OCCURS WHEN $|\Gamma_T'| = 1$ AND $\angle\alpha = \angle\Gamma_{IN,0}$. HENCE,

$$\Gamma_{IN,max} = \Gamma_{IN,0} + |\alpha|\,\hat{u}_{IN,0} \qquad (1)$$

WHERE $\hat{u}_{IN,0}$ IS A UNIT VECTOR IN THE DIRECTION OF $\Gamma_{IN,0}$.

(b) (1) IS IDENTICAL TO (5.4.6) BECAUSE $\Gamma_{IN,0} = C_{IN}$, $|\alpha| = |r_{IN}|$, AND $\hat{u}_{IN,0} = \angle C_{IN}$. (1) CAN ALSO BE WRITTEN AS

$$\Gamma_{IN,max} = (|\Gamma_{IN,0}| + |\alpha|)\angle\Gamma_{IN,0}$$

WHICH IS THE SAME AS (5.4.6).

5.10) THE S PARAMETERS OF A SERIES IMPEDANCE Z IN A Z_0 SYSTEM WERE DERIVED IN EXAMPLE 1.6.1. IN THE CASE OF A DRO THE VALUE OF Z IS GIVEN BY 5.5.6, NAMELY

$$Z = \frac{R}{1+j2Q_u\delta} = \frac{2\beta Z_0}{1+j2Q_u\delta}$$

USING (1.6.24) AND (1.6.25) WE OBTAIN:

$$S_{11} = S_{22} = \frac{Z}{Z+2Z_0} = \frac{\beta}{\beta+1+j2Q_u\delta}$$

$$S_{21} = S_{12} = \frac{2Z_0}{Z+2Z_0} = \frac{1+j2Q_u\delta}{\beta+1+j2Q_u\delta}$$

5.11) AT 12 GHz: $K = 1.36$ AND $\Delta = 0.41\angle 139.8^\circ$, $\therefore$ UNCONDITIONALLY STABLE.

THE S PARAMETERS ARE CLOSE TO THOSE USED IN EXAMPLE 5.5.1. HENCE, THE DESIGN PROCEDURE IS SIMILAR TO THE ONE USED IN EXAMPLE 5.5.1.

USING A SERIES FEEDBACK CAPACITOR (SEE FIG. 5.5.12a) WITH $Z = -j120\,\Omega$ RESULTS IN A POTENTIALLY UNSTABLE CONFIGURATION WITH: $S_{11} = 1.255\angle 117^\circ$, $S_{12} = 1.65\angle -78.4^\circ$, $S_{21} = 1.87\angle -23.2^\circ$, AND $S_{22} = 0.9\angle 102^\circ$.

THE GATE TO GROUND PORT IS SELECTED AS THE TERMINATING PORT. THE STABILITY CIRCLE AT THE TERMINATING PORT IS SIMILAR TO THE ONE DRAWN IN FIG. 5.5.12b (i.e., $C_\Omega = 0.773\angle 26.5^\circ$ AND $r_\Omega = 0.805$).

WITH $\beta = 10$: $R = 10\,(2\times 50) = 1000\,\Omega$ AND $\Gamma_T = \frac{10}{10+1} e^{-j2\theta} = \frac{10}{11} e^{-j2\theta}$

LETTING $l_1 = \lambda/4$ (i.e., $\theta = \pi/2$), THEN $\Gamma_T = 0.909\angle -180^\circ$, $\Gamma_{IN} = 2.68\angle 33.4^\circ$ (OR $Z_{IN} = -83.4 + j39.8\,\Omega$), AND Z_L IS SELECTED AS: $Z_L = 27.8 - j39.8\,\Omega$

THE DRO CIRCUIT IS SHOWN IN FIG. 5.5.12c.

5.12) FROM THE RESULTS IN EXAMPLE 5.2.2 A STABLE OSCILLATION OCCURS AT

$$\omega_0 = \frac{1}{\sqrt{L_0 C_0}}$$

AT THE AMPLITUDE $A' = A'_0$, DETERMINED BY

$$G_{IN}(A'_0) + G_0 = 0$$

THE OSCILLATION IS STABLE (SEE EXAMPLE 5.2.2) BECAUSE

$$\left.\frac{\partial G_{IN}(A')}{\partial A'}\right|_{A'=A'_0} \left.\frac{dB_0(\omega)}{d\omega}\right|_{\omega=\omega_0} > 0$$

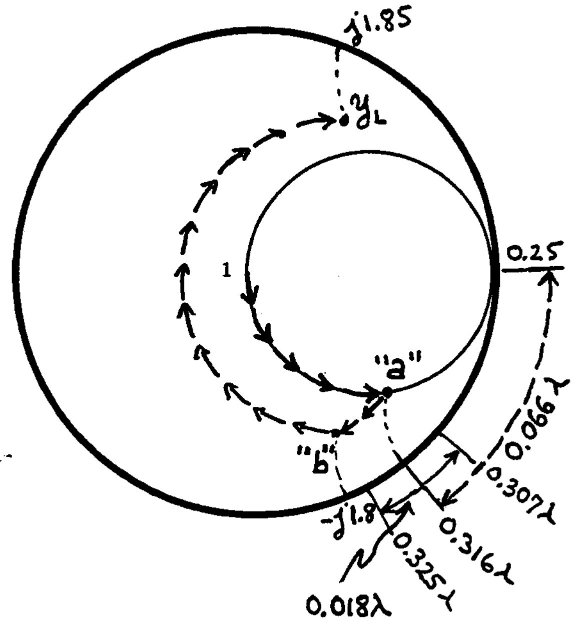
WHERE $B_0(\omega) = j\omega C_0 + \frac{1}{j\omega L_0}$

THE START OF OSCILLATION CONDITION REQUIRES THAT

$$|G_{IN}(0)| + G_0 > 0$$

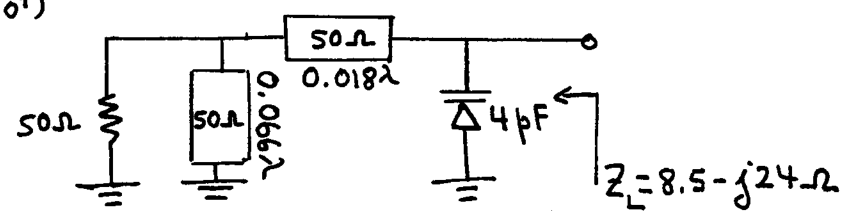
5.13) $Z_L = 8.5 - j24\,\Omega$, $z_L = \frac{Z_L}{50} = 0.17 - j0.48$, $y_L = 0.656 + j1.85$

THE MATCHING USED IS SHOWN IN THE Y SMITH CHART. THE MOTION FROM THE ORIGIN TO "a" IS IMPLEMENTED WITH A SHORT-CIRCUITED SHUNT STUB. THE MOTION FROM "a" TO "b" IS IMPLEMENTED WITH A SERIES TRANSMISSION LINE OF LENGTH 0.018λ. THE MOTION FROM "b" TO y_L (i.e., ALONG A CONSTANT CONDUCTANCE CIRCLE) IS IMPLEMENTED WITH A CAPACITOR IN SHUNT. THIS CAPACITOR CAN BE OBTAINED USING A VARACTOR DIODE. THE VALUE OF THE CAPACITOR IS:



$$y_c = j1.85 - (-j1.8) = j3.65$$

$$\therefore C = \frac{3.65/50}{2\pi(2.75\,10^9)} = 4\ \text{pF}$$



5.14) IT IS A POTENTIALLY UNSTABLE TRANSISTOR

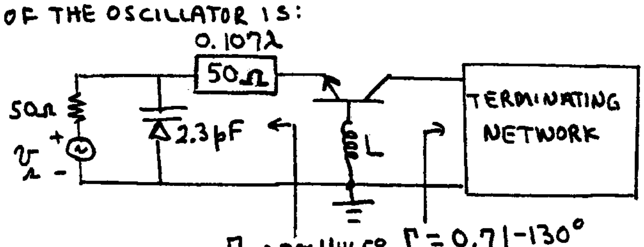
OUTPUT STABILITY CIRCLE: $C_L = 0.921\angle{-76.1^\circ}$, $r_L = 0.858$

SEVERAL VALUES OF Γ_T IN THE UNSTABLE REGION SHOULD BE TRIED, AND THE ASSOCIATED Γ_{IN} CALCULATED. FOR THIS DESIGN WE USED $\Gamma_T = 0.7\angle{-130^\circ}$, THEN $\Gamma_{IN} = 2.09\angle{-136^\circ}$ AND $Z_{IN} = -20 - j17.2\,\Omega$.

LET $Z_L = \frac{20}{3} + j17.2 = 6.7 + j17.2$ OR $\Gamma_L = 0.786\angle{141.5^\circ}$

AN IMPLEMENTATION OF THE OSCILLATOR IS:

THE CAPACITOR (C = 2.3pF) IS IMPLEMENTED WITH A VARACTOR DIODE).



5.15) (a) $P_{OUT} = P_{sat}\left(1 - e^{-G_o P_{IN}/P_{sat}}\right)$ (1)

MAXIMUM OSCILLATOR POWER OCCURS WHEN $P_{OUT} - P_{IN}$ IS A MAXIMUM, OR $\frac{\partial P_{OUT}}{\partial P_{IN}} = 1$. SINCE

$$\frac{\partial P_{OUT}}{\partial P_{IN}} = P_{sat}\left(-\frac{G_o}{P_{sat}}\right)\left(e^{-G_o P_{IN}/P_{sat}}\right) = G_o e^{-G_o P_{IN}/P_{sat}} = 1$$

THEN, $e^{-G_o P_{IN}/P_{sat}} = \frac{1}{G_o}$ OR $P_{IN} = P_{sat}\frac{\ln G_o}{G_o}$ (2)

SUBSTITUTING (2) INTO (1), P_{OUT} CAN BE EXPRESSED AS:

$$P_{OUT} = P_{sat}\left(1 - \frac{1}{G_o}\right) \quad (3)$$

FROM (3) AND (2), THE MAXIMUM OSCILLATOR POWER ($P_{osc}(\text{max})$) IS

$$P_{osc}(\text{max}) = P_{OUT} - P_{IN} = P_{sat}\left(1 - \frac{1}{G_o} - \frac{\ln G_o}{G_o}\right)$$

(b) $G_o = 7.5\text{ dB}$ OR 5.623

$P_{sat} = 1\text{ W}$

$$P_{osc}(\text{max}) = 1\left(1 - \frac{1}{5.623} - \frac{\ln 5.623}{5.623}\right) = 0.515\text{ W}$$

(c)