+ Answers.

TEST

Prescription Number:	**ENEL434**
Paper Title:	**Electronics II**

Time Allowed: 50 Minutes

Number of Pages: 5

Formulae Sheet Supplied

Smith Chart Supplied

Department Calculators are supplied

Answer both questions

Each question is worth 20 marks

Q1

Given the transistor amplifier circuit shown in Figure 1 and using the following S parameters taken at Z0 = 50ohms and a frequency of 2GHz

$S_{11} = 0.8\,\underline{/-120}$, $S_{12} = 0.0$, $S_{21} = 2.77\,\underline{/+90}$, $S_{22} = 0.44\underline{/-63}$,

answer the following questions.

a) Using one of the Smith chart supplied, find
   (i) The shortest length of a short circuit input stub D1 and
   (ii) the length of transmission line L1 that conjugate matches the input of the transistor (both answers in wavelengths)

b) Using the second Smith chart, find
   (i) the shortest length of a short circuit output stub D2 and
   (ii) the length of the transmission line L2 that conjugate matches the output of the transistor to the complex load

c) Calculate the transducer gain in dB
   (i) with the two conjugate matching networks and
   (ii) without the two matching networks. (NB I have chosen values to make this calculation easy.)

You must name, label and hand in both Smith charts with your answer book.

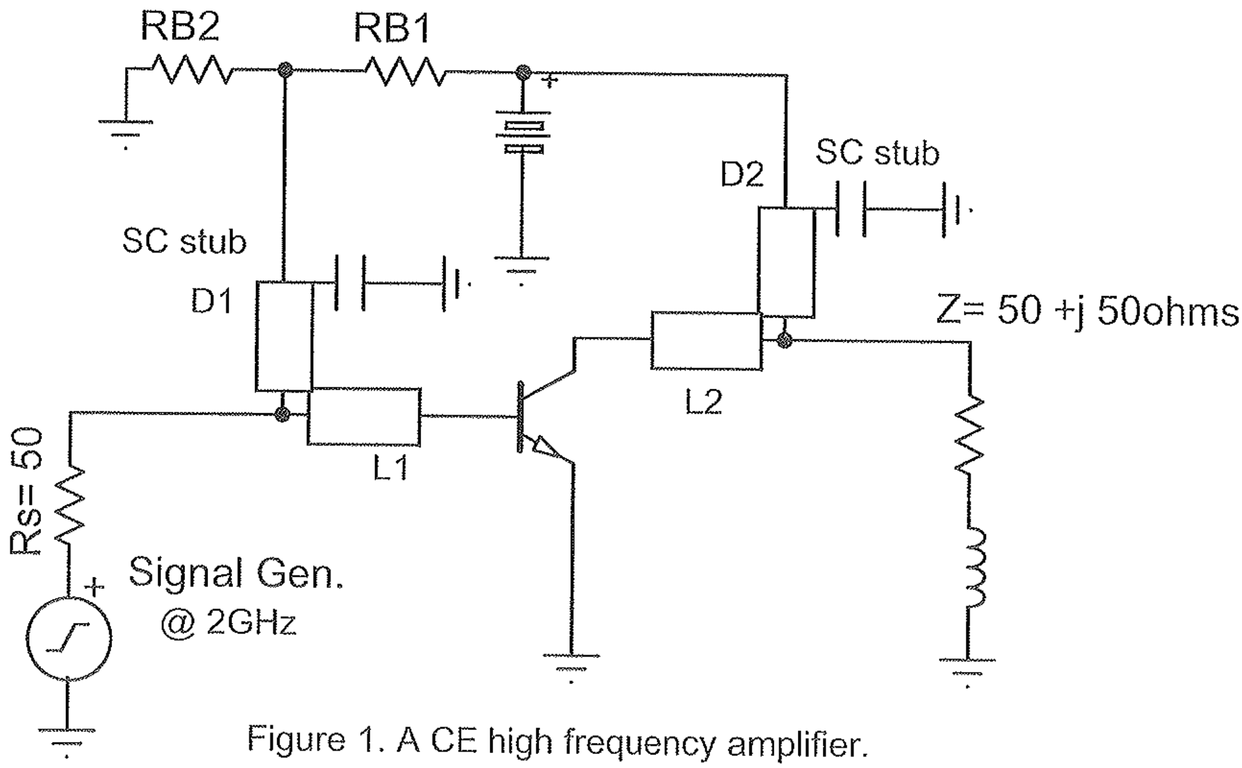

Figure 1. A CE high frequency amplifier.

Q2

Please refer to Figure 2. Assuming the gain is sufficient for oscillation, calculate:

a) the DC biasing conditions specifically
   i) I_C
   ii) V_{CE}
   iii) r_e
b) the resonant frequency ω_0 in rads /s stating any assumptions you make,
c) R_L' the load as seen through the inductive transformer,
d) R_{coil},
e) R_{in}' the input as seen through the capacitive transformer,
f) R_C' the effective ac load on the collector,
g) the ac gain from the emitter to the collector,
h) the feedback ratio β, and
i) if the gain is sufficient for the oscillator to start.

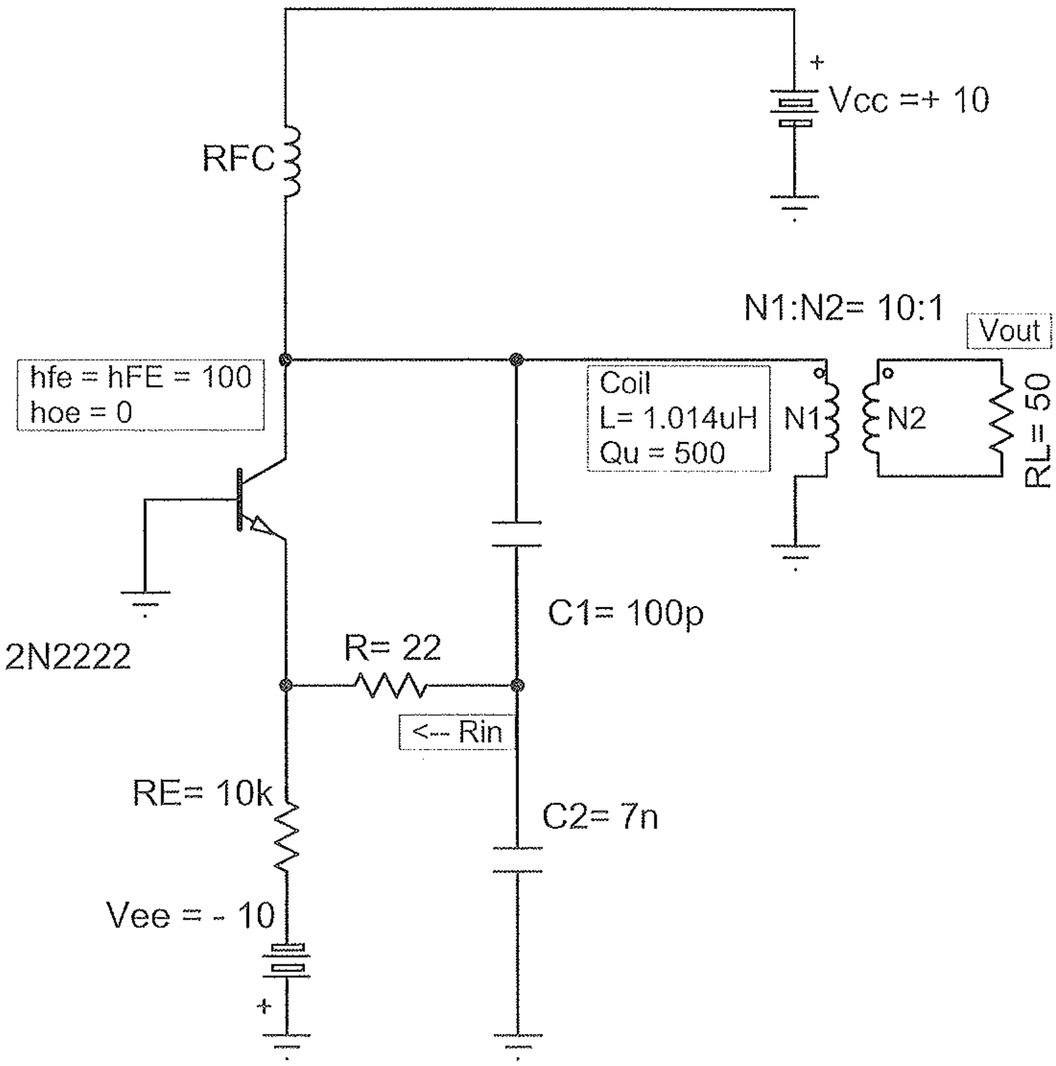

Figure 2 A Colpitts Oscillator

Some useful expansions and maths identities

$2\sin x \sin y = -\cos(x+y) + \cos(x-y)$
$2\cos x \cos y = \cos(x+y) + \cos(x-y)$
$2\sin x \cos y = \sin(x+y) + \sin(x-y)$
$4\cos x \cos^2 y = 2\cos x + \cos(x+2y) + \cos(x-2y)$
$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} \quad \ldots.$
$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \quad \ldots$ and $\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \quad \ldots$

CE, CC and CB transistor amplifiers

Very small signal Voltage Gain
$A_v = -g_m \cdot$ (Resistive load on collector) $= -g_m \cdot (R_c[/\!/ R_L][/\!/ r_o])$ where $g_m = I_C/0.026$ for CE amplifier with emitter resistor bypass capacitor.
A_v for a CB amplifier is the same as that for the CE amplifier but positive.
Without the emitter resistor bypass capacitor, g_m is replaced by $G_m = 1/(r_e + R_E)$

Miller Capacitance for a CE BJT amplifier
$C_{eq} = C_{BC}(1 + |A_v|)$ thus $C_{in} = C_{eq} + C_{BE} + C_{\text{stray}}$

Small signal Voltage Gain for a differential amplifier; $A_v \equiv v_{out1}/v_{in} = -\frac{g_m}{2} \cdot (R_c[/\!/ R_L][/\!/ r_o])$

Small signal Voltage Gain for a differential amplifier; $A_v \equiv v_{out2}/v_{in} = \frac{g_m}{2} \cdot (R_c[/\!/ R_L][/\!/ r_o])$

Small signal Voltage Gain for CC BJT amplifiers; $A_v = \frac{R_E[/\!/ R_L]}{r_e + R_E[/\!/ R_L]}$.

Power gain $A_p = A_v \cdot A_i = A_v^2 R_{in}/R_L$
Power Gain in dB $= 20\log(A_v) + 10\log(R_{in}/R_L)$

Large signal Voltage Gain
For large input voltages ($v_{in} \geq 0.026$V), the gain formulas for small signals are valid but with g_m replaced by $G_m(x)$ where the input signal ratio $x \equiv v_{in}/V_T = v_{in}/0.026$. $G_m(x)/g_m$ is usually read from a graph or tables.

Useful rules of thumb for BJT amplifiers with voltage divider bias.
$V_E \approx 0.1 \cdot V_{cc}$, $\quad I_{R_{B2}} \approx 10 \cdot I_B$ both modifications to increase the stability factor.

For a tuned-load, Class A amplifier, $\quad P_{\text{BJT+load}} \approx 0.90\, V_{cc} \cdot I_c$ watts
and so $P_{\text{load}} \approx 0.5 P_{\text{BJT+load}}$ at max efficiency (i.e., 50% of 90% of the power supplied).

Resonance and tuned load amplifiers

$\omega_0 = \frac{1}{\sqrt{LC}}$ and $Q = \frac{f_0}{\text{BW}} = \frac{R_p}{X_L(@\omega_0)}$ (for parallel) $= \frac{X_L(@\omega_0)}{R_S}$ (for series).

Parallel to series (and the inverse)

$L_{SE} = \frac{Q^2}{(1+Q^2)} L_P$, $C_{SE} = \frac{(1+Q^2)}{Q^2} C_P$ and $R_{SE} = R_P/(1+Q^2)$
so when $Q > 10$, the narrowband case, $\quad L_{SE} \approx L_P, C_{SE} \approx C_P$ and $R_{SE} \approx R_P/Q^2$.

Matching Networks for Two Ports

$\Gamma_s = \frac{Z_s - Z_0}{Z_s + Z_0}$ looking towards the source and $\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$ looking towards the load.
It is easier to use the Smith Chart; i.e., plot Z_s/Z_0 or Z_L/Z_0 and read off Γ_s or Γ_L.

$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} = s_{11} + \frac{s_{12}s_{21}\Gamma_L}{1 - s_{22}\Gamma_L}$
so $\Gamma_{in} = s_{11}$ when $Z_L = Z_0$ or for the unilateral amplifier when $s_{12} = 0$.

$\Gamma_{out} = \frac{Z_{out} - Z_0}{Z_{out} + Z_0} = s_{22} + \frac{s_{12}s_{21}\Gamma_s}{1 - s_{11}\Gamma_s}$
so $\Gamma_{out} = s_{22}$ when $Z_s = Z_0$ or for the unilateral amplifier when $s_{12} = 0$.

Power Gain (i.e., power in the load P_L / power supplied to the input P_{in})

$$G = \frac{P_L}{P_{in}} = \frac{1}{(1 - |\Gamma_{in}|^2)} \cdot |s_{21}|^2 \cdot \frac{(1 - |\Gamma_L|^2)}{|1 - s_{22}\Gamma_L|^2} \quad \text{see Pozar (11.8), page 538.}$$
$$= \quad G_S \quad \cdot \quad G_0 \quad \cdot \quad G_L$$

where G_S = source network gain, G_0 = device gain and G_L = load network gain;

Transducer Power Gain (relative to the max that could be taken from the input)

$$G_T = \frac{P_L}{P_{avs}} = \frac{(1 - |\Gamma_s|^2)}{|1 - \Gamma_{in}\Gamma_s|^2} \cdot |s_{21}|^2 \cdot \frac{(1 - |\Gamma_L|^2)}{|1 - s_{22}\Gamma_L|^2} \quad \text{given that } P_{avs} \equiv P_{in}|_{\Gamma_s = \Gamma_{in}^*} \quad \text{see Pozar (11.9)}$$

Available Power Gain (when source and load are both conjugate matched)

$$G_A = \frac{P_{avn}}{P_{avs}} = \frac{(1 - |\Gamma_s|^2)}{|1 - s_{11}\Gamma_s|^2} \cdot |s_{21}|^2 \cdot \frac{1}{(1 - |\Gamma_{out}|^2)} \quad \text{given } P_{avs} \equiv P_{in}|_{\Gamma_s = \Gamma_{in}^*} \text{ and } P_{avn} = P_L|_{\Gamma_L = \Gamma_{out}^*}$$

Special Cases of Transducer Power Gain

1. Source and load at Characteristic Impedance
(where $\Gamma_s = \Gamma_L = 0$, i.e., $Z_L = Z_0$ and $Z_s = Z_0$)
$G_T = |s_{21}|^2$

2. Unilateral Transducer Power Gain
(where $s_{12} = 0$, so $\Gamma_{in} = s_{11}$ and $\Gamma_{out} = s_{22}$ but Γ_L and Γ_s could be anything)

$$G_{TU} = \frac{(1 - |\Gamma_s|^2)}{|1 - s_{11}\Gamma_s|^2} \cdot |s_{21}|^2 \cdot \frac{(1 - |\Gamma_L|^2)}{|1 - s_{22}\Gamma_L|^2} = G_{S\,(TU)} \cdot G_0 \cdot G_L$$

3. Maximum Unilateral Transducer Power Gain
(for when $s_{12} = 0$ as well as the input and output conjugate matched)

$$G_{TUmax} = \frac{1}{1 - |s_{11}|^2} \cdot |s_{21}|^2 \cdot \frac{1}{1 - |s_{22}|^2} = G_{S\,(TU_{max})} \cdot G_0 \cdot G_{L\,(TU_{max})}$$

Q 1

(a) $\Gamma_{in} = S_{11} = 0.8 \angle -120^\circ$

$\therefore \Gamma_S = \Gamma_{in}^{*} = 0.8 \angle +120^\circ$

$\therefore y_S = 0.42 - j1.65$. This is the aim (or end) point.

$y_{A} = y_0 = 1.0$. This is the start pt.

Add a s.c. stub $= (0.308 - 0.250)\lambda$ long $= 0.058\lambda$.

$y_B = 1.0 - j2.6$.

Now travel down transmission line from B to y_S.

$= (0.333 - 0.302)\lambda = 0.031\lambda$

(i) $\therefore$ $D1 = 0.058\lambda$

(ii) and $L1 = 0.031\lambda$

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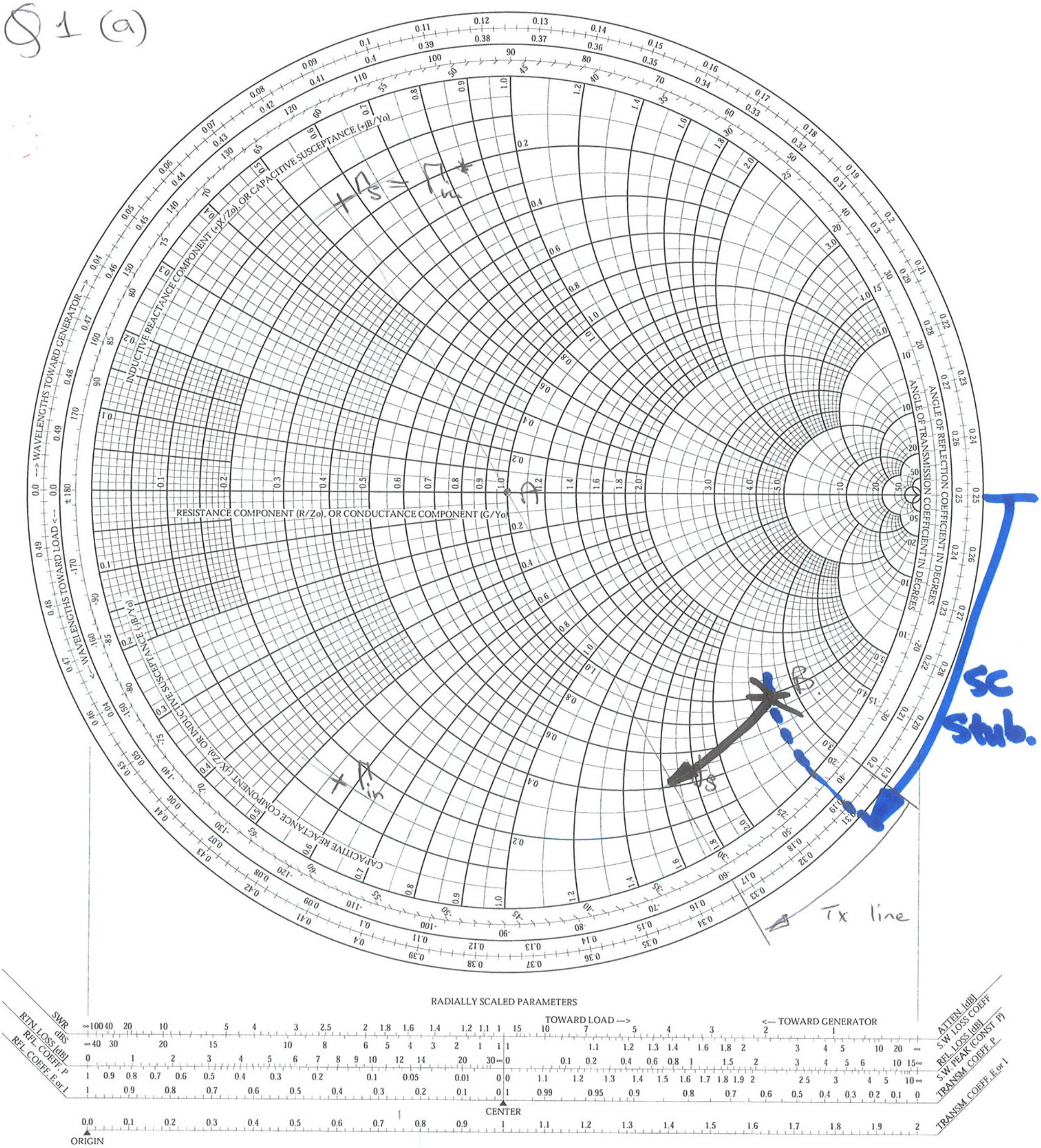
Smith Chart

Q1 (a)



Q1 (b) $Z = 50 + j50$

$\therefore z_n = 1 + 1j$ plot on Smith Chart.

Now turn into an addmittance

$y = 0.5 - j0.5$. this is our start pt.

now $\Gamma_{out} = S_{22} = 0.44\angle{-63^\circ}$.

$\therefore \Gamma_L = \Gamma_{out}^{*} = 0.44 \angle{+63^\circ}$

$\therefore y_e = 0.5 - j0.5$ this is our end pt!

Thus D2 and L2 $= 0\lambda$ and we dont need them at all. the load as specified is the conjugate match.

(c)
(i) $G_{TU} = \frac{1}{1-|S_{11}|^2} \cdot |S_{21}|^2 \cdot \frac{1}{1-|S_{22}|^2}$ $(S_{12} = 0)$

$= \frac{1}{1-0.64} \cdot |2.77|^2 \frac{1}{(1-0.19)}$

$= 2.78 \times 7.67 \times 1.23 = 26.2\times$

$= 4.4\ dB + 8.84\ dB + 0.89\ dB$

$= 14.13\ dB$

(ii) $G = |S_{21}|^2 * \frac{1}{1-|S_{22}|^2} = 9.43$

$= 7.67 \times 1.23 = 9.43 = 9.75\ dB$

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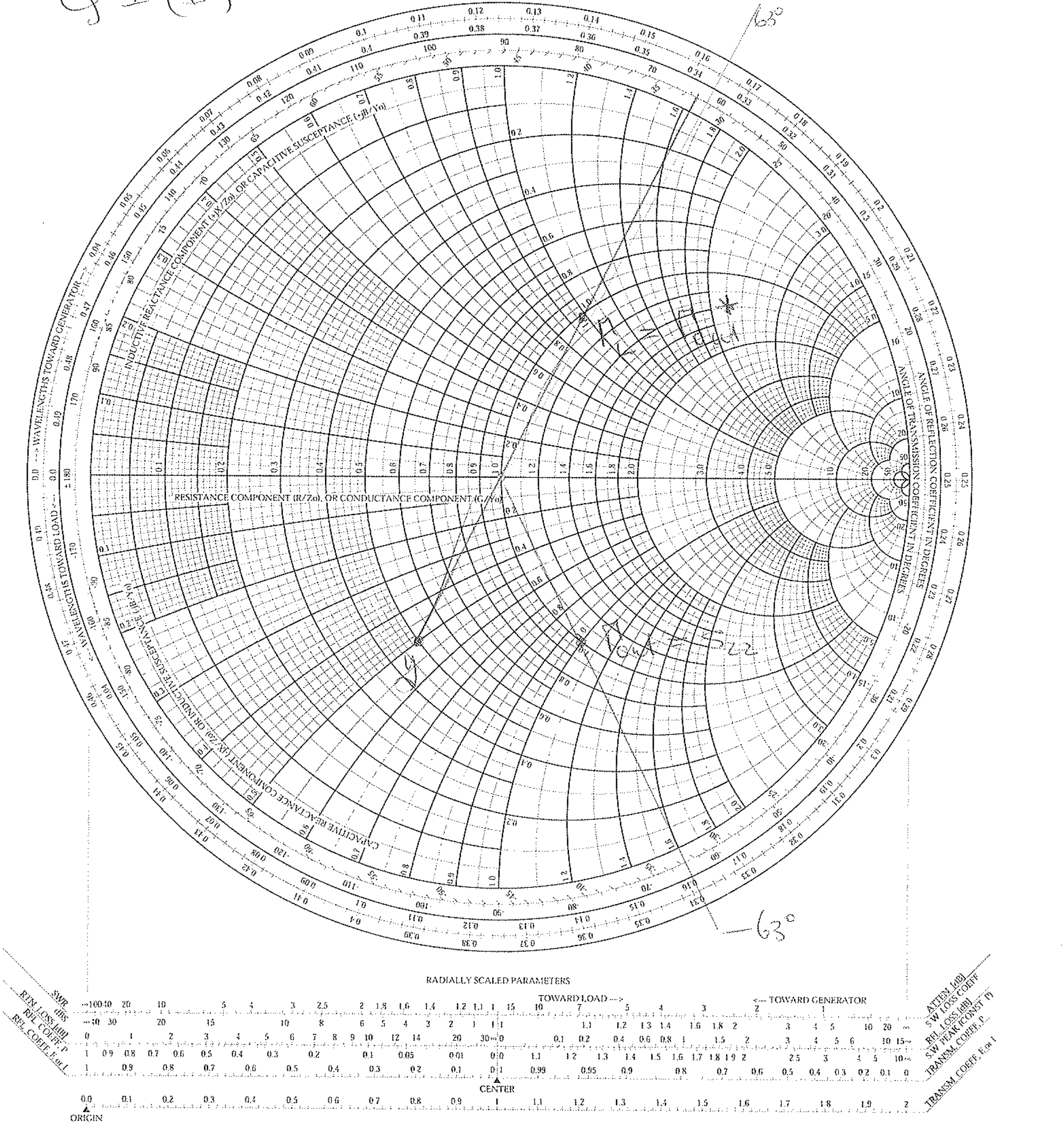
Smith Chart

Q 1 (b)



Answers

2\. (a) (i) $I_C = 0.93\text{mA}$.

(ii) $V_{CE} = 10 + 0.7 = 10.7\text{v}$

(iii) $r_e = 0.026/0.93\text{mA} = 28\Omega$

(b) $C_{eq} = 98.59\text{pF}$.

$L = 1.014\ \mu\text{H}$.

$\omega_0 = 100\text{M rad/sec}$.

Assumes $X_{C2} \ll 50\Omega$.

Checking $X_{C2} @ \omega_0 = 10^8 = 1.43\Omega$

(c) $R_i' = 50 \times 100 = 5\text{k}\Omega$

(e) $R_{in}' = (71)^2 \times \underbrace{50}_{22+28} = 252\text{ k}\Omega$

(d) $R_{coil} = Q \times X_L = 500 \times 101.4$

$= 50.7\text{k}\Omega$

(f) $R_C' = R_i' \,//\, R_{in}' \,//\, R_{coil}$.

$= 5\times10^3 \,//\, 42.2\times10^3$

$= 4.47\text{ k}\Omega$

(g) ac gain $\dfrac{|v_c(t)|}{|v_e(t)|} = 159\times$

$$\beta = \frac{1}{71} \times \frac{28}{50} = \cancel{(0.788)}\ 7.88 \times 10^{-3}$$

$$\text{or } 1/\beta = 129$$

(c) $A\beta = 159 \cancel{\times}/ 129 = 1.23$

So there is just enough gain for the circuit to oscillate.

Note: There is a DC short from the power supply through the RFC and the transformer. To work the transformer would need to be connected to the +ve power supply <u>or</u> a coupling capacitor used.