3B1 CRIB 2009 P. ROBERTSON

1.(a)

Radiation resistance, R_r: Power radiated $P_r = \frac{1}{2} I^2 R_r$ ½ as $I_{pk} \rightarrow$ rms value

Radiation efficiency, e : $e = \frac{P_r}{P_{in}}$ where $P_{in} = \frac{1}{2} I^2 (R_r + R_{ohmic})$

Gain, G : $G = \frac{\text{max. power radiated / unit area}}{\text{power / unit area from isotropic antenna}} = \frac{P/\text{unit area max.}}{P_{in}/4\pi r^2}$

Directivity, D : $D = \frac{\text{Gain}}{\text{Radn efficiency}} = \frac{G}{e}$ (gives an indication of how directional an antenna is)

Effective Aperture (Area), A_e : Power delivered into a matched load by an antenna $= A_e \times$ power density in incident radio wave

Note: * $G = \frac{4\pi A_e}{\lambda^2}$ * ANTENNA EQN.

(b)

Power density at range, R $= \frac{10 \times 10^{-3}}{4\pi R^2}$

Effective aperture, A_e of receive antenna $= \frac{30 \times \lambda^2}{4\pi}$ m^2 (where $\lambda = \frac{3 \times 10^8}{433 \times 10^6} = 0.693_m$)

$\therefore A_e = 1.15 m^2$

$\therefore$ Power into receiver $= \frac{11.5 \times 10^{-3}}{4\pi R^2} = \frac{v^2}{r} = \frac{(10 \times 10^{-6})^2}{75}$

$\therefore$ Max range, $R = \sqrt{\frac{75 \times 11.5 \times 10^{-3}}{4\pi \times 10^{-10}}} = 26.2$ km

1(c) $\frac{1}{4}$ wavelength $= \frac{0.693}{4}$ m $= \underline{17.3 \text{ cm}}$

Gain of $\lambda/4$ dipole is 1.5 $\therefore$ range will increase by $\sqrt{1.5} \Rightarrow$ $\underline{32.1 \text{ km}}$

However, there is no radiation in the direction of the antenna axis (max. radiation is $\perp$ to wire), so if the aircraft were overhead, then the signal may be weaker than expected.

(d) Antenna radiation efficiency $= \frac{R_r}{R_r + R_{ohm}}$

For a simple dipole antenna $R_r = 20\pi^2\left(\frac{\Delta z}{\lambda}\right)^2 \ \Omega$

Hence for 433 MHz: $R_r = \frac{20\pi^2}{4} = 49.3 \ \Omega$

(Δz is $\lambda/2$ as $\lambda/4$ wire is placed above a reflecting ground plane, which effectively doubles its length)

$\therefore 0.90 = \frac{49.3}{49.3 + R_{ohm}}$ $\therefore R_{ohm} = 5.48 \ \Omega$ at 433 MHz

Assuming the antenna is a thick wire, the current carrying area is prop. to the skin depth, $\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$

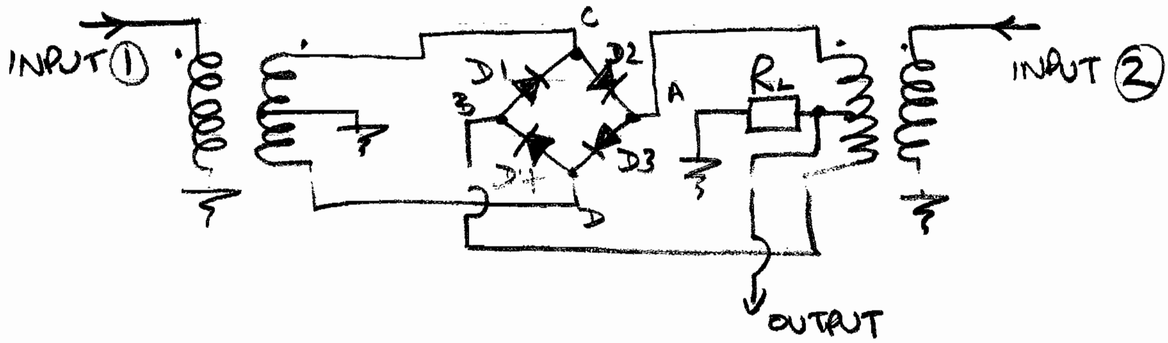
$\therefore R_{ohm}$ @ 175 MHz $= 5.48 \times \sqrt{\frac{175}{433}} = 3.48 \ \Omega$

and R_r @ 175 MHz, where $\lambda = 1.717$ m; $R_r = 20\pi^2\left(\frac{0.346}{1.717}\right)^2$

$R_r = 8.01 \ \Omega$

$\therefore e = \frac{8.01}{8.01 + 3.48} = 0.70$ or $\underline{70\%}$ [and will not be matched]

2. a)



- Mixer selectively inverts, or not, the signal on one input (② in this case) depending on the polarity of the other input (① in this case).

- Hence 2 sine waves in phase will result in a full-wave rectified signal at the output - the components of which are -ve d.c. and 2f mainly.

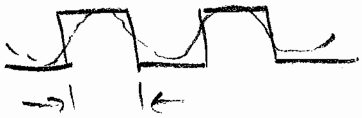
- Consider the circuit above, if ① and ② swing +ve, then diodes D2 & D3 conduct as C goes positive and D negative by the same amount. Hence, point A is a virtual ground and so the output swings -ve.

- As ① and ② swing -ve, then diodes D3 and D4 conduct causing B to be a virtual ground and so the output again swings -ve. Thus the output signal is a full-wave rectified version of the signal at ②.

- with diode switching/ 2 sine waves, the transistion is soft, so the higher harmonics are reduced over a true full-wave rectified signal and the major harmonics are just of (d.c.) and 2f.

- To ensure minimal d.c. in the output, the 2 input waves should be 90° apart i.e: sine and cosine - or the output could be ac coupled through a capacitor.

2(b) Choose a Bessel filter to maintain the underlying square wave shape – without ringing.



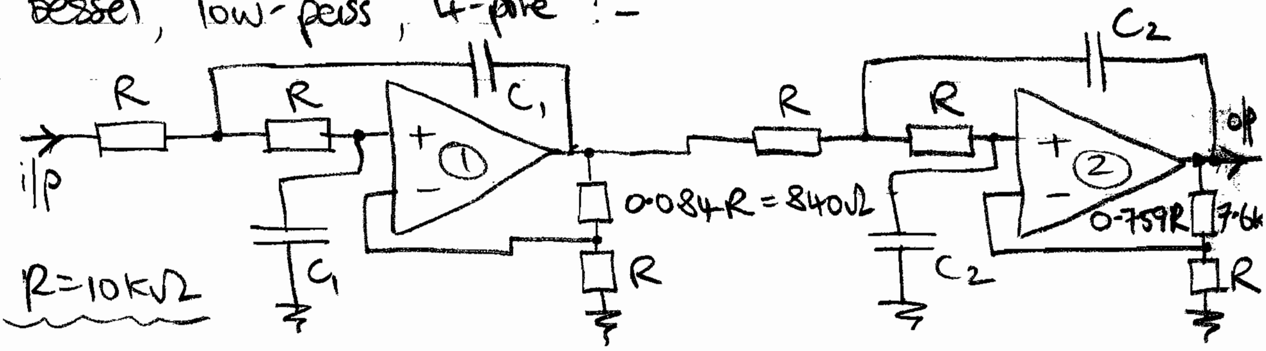
$\frac{1}{4800}$ s

4800 bit/s

∴ fundamental @ 2400 Hz

allow 1st & 3rd harmonic before roll-off ∴ roll-off low pass filter at say $4 \times 2400\text{ Hz} = 9600\text{ Hz}$ (-3dB).

Bessel, low-pass, 4-pole :-

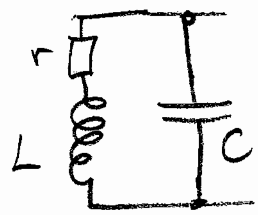


$R = 10\text{k}\Omega$

for stage (1) $\quad 9600 = \dfrac{1}{1{\cdot}432 . C_1 . 10^4 . 2\pi} \quad \therefore \; C_1 = 1{\cdot}16\text{ nF}$

for stage (2) $\quad 9600 = \dfrac{1}{1{\cdot}606 . C_2 . 10^4 . 2\pi} \quad \therefore \; C_2 = 1{\cdot}03\text{ nF}$

2(c)

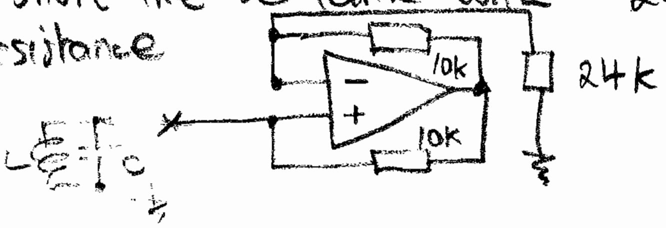


$L = 10^{-5}\text{ H}$, $C = 3{\cdot}3 \times 10^{-10}\text{ F}$ $\quad \therefore \omega_0 = \dfrac{1}{\sqrt{LC}}$

$\therefore f_0 = 2{\cdot}77\text{ MHz}$ $\quad (17{\cdot}4 \times 10^6\text{ rad/s})$

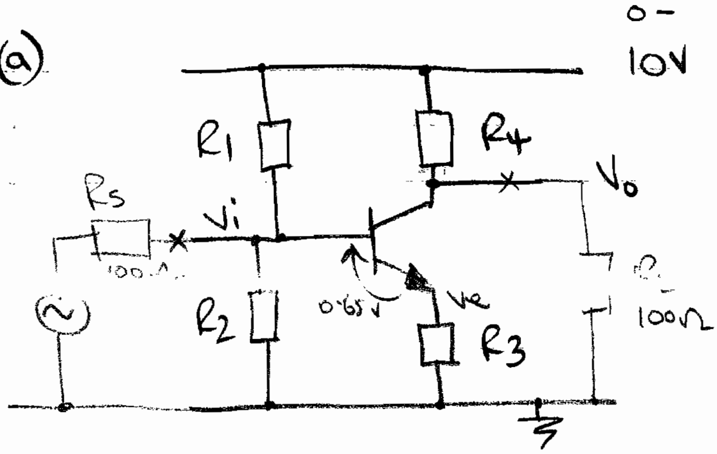
$Q = \dfrac{\omega L}{r} = \dfrac{174}{3} = 58 = \dfrac{R'}{\omega L}$ $\quad \therefore$ equiv. parallel $R' = 10{\cdot}1\text{ k}\Omega$

For $Q = 100$, we need $R' = 17{\cdot}4\text{ k}\Omega$ – hence we need to shunt the LC tank with $-24\text{ k}\Omega$ using a negative resistance



N.I.C.

3(a)



For 100Ω o/p impedance $R_4 = 100\,\Omega$

For 10dB gain, we want a linear gain of ×6.5, includes coupling loss of 1 stage. $(2\times 10^{0.5} \simeq 6.5)$ ∴ ×3.2 when in cct.

$$\therefore \frac{R_4}{R_3 + r_e} = 6.5$$

For $V_o = 5V$ dc then $I_c = 50mA$

$$\therefore r_e = \frac{0.025}{0.05} = \left(\frac{kT/q}{I_c}\right) = 0.5$$

$\therefore R_3 \doteq 15\,\Omega$

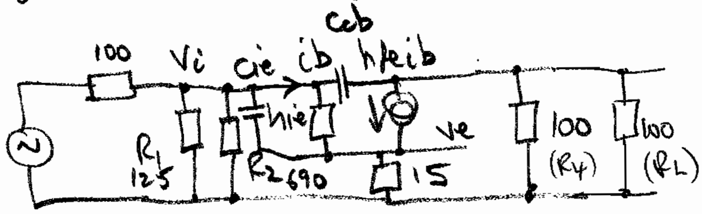
Then $V_e = 0.75V$ dc. ∴ set base @ $0.75+0.65 = 1.4V$ dc.

Choose $R_2 = 200\,\Omega$ [OR 125Ω] then $R_1 \Rightarrow \frac{200}{R_1+200} \cdot 10 = 1.4 \times 1.1$ allow 10% extra for base load

$\therefore R_1 = 1100\,\Omega$ [OR 690Ω]

Check i/p impedance $= 200 \| 1100 \| 200(15.5) = 160\,\Omega$ which is ok, but could drop R_2 and R_1 by $(\times \frac{1}{1.6})$ to 125Ω and 690Ω to give 102Ω i/p impedance

(b)



$$f_t = \frac{1}{2\pi C_{ie}\, r_e} = 22\times 10^9$$

r_e = 0.5

$\therefore C_{ie} = 14.5\,pF$

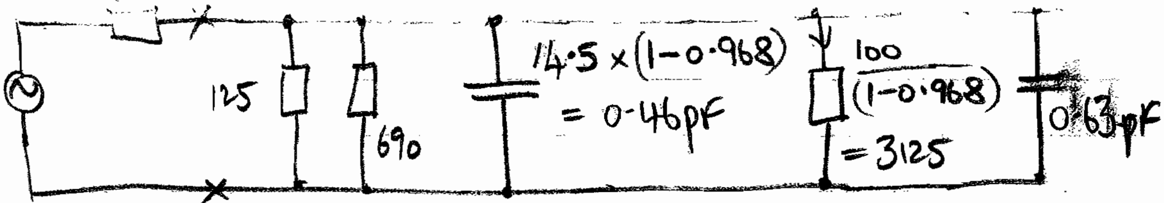
$C_{cb}' = 0.15\,pF \times (1+3.2)$
$= 0.63\,pF$

$h_{ie} = h_{fe} \cdot r_e = 100\,\Omega$

$$V_e = \frac{15}{15+0.5} \cdot V_i = 0.968\, V_i$$

3(b) cont'd.

SSM @ input



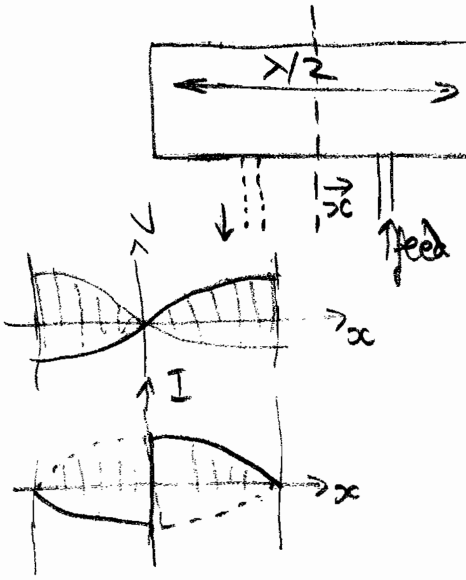
$$\frac{1}{2\pi R'C'} = 1.43\,\text{GHz}$$

or 2.8 GHz
incl. source imped.

$R' = 125 \| 690 \| 3125 (\| 100)$
$= 102\,\Omega$
or $50\,\Omega$ inc. source imped.

$C' = 0.63 + 0.46 = 1.09\,\text{pF}$

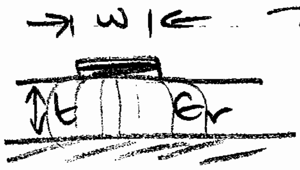
(c) Microstrip patch is $\lambda/2$ long and resonates end to end with a standing wave :-



for $f = 1.5 \times 10^9$ Hz
and $\epsilon_r = 3$, $\lambda = \frac{3 \times 10^8}{\sqrt{3} \times 1.5 \times 10^9}$
$= 11.5\,\text{cm}$

$\therefore \lambda/2 = 5.77\,\text{cm}$

(d) Amplifier inverts, hence so must patch at resonance, so have 2 'feed' lines - equally spaced each side of the centre-line. Adjust distance ($\pm x$) to get $100\,\Omega$ impedance. One feed connects to amp. input, the other to output - through at least 1 d.c. block capacitor to avoid upsetting the bias. Feed lines must be v. short (phases)

3(e) 

$\Rightarrow$ effective width $(w+2t) = A$ /unit length
due to fringing

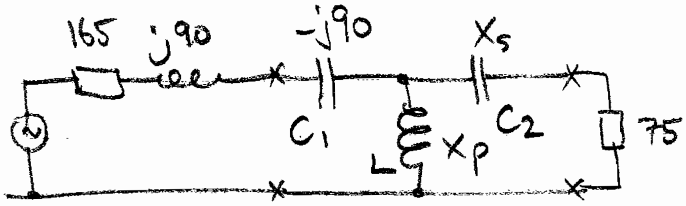
$$C = \frac{A\epsilon_0\epsilon_r}{t} \qquad Z_0 = \sqrt{\frac{L}{C}} \qquad v = \frac{1}{\sqrt{LC}}$$

$$\therefore Z_0 = \frac{\sqrt{L}}{\sqrt{C}} = \frac{1/v\sqrt{C}}{\sqrt{C}} = \frac{1}{vC}$$

$$\therefore Z_0 = \frac{t}{A\epsilon_0\sqrt{\epsilon_r}}\cdot\frac{\sqrt{\epsilon_r}}{c_0} = 100 = \frac{1.6\times10^{-3}}{3\times10^{8}\cdot(w+3.2\times10^{-3})\cdot 8.85\times10^{-12}\cdot\sqrt{3}}$$

$$\therefore w = 0.28\,\text{mm}$$

4(a)



$\omega = 2\pi\, 500 \times 10^6$
$= \pi \times 10^9$ rad/s

Firstly cancel reactive part with $-j90 = \frac{1}{j\omega C_1}$

$\therefore C_1 = 3.54\,pF$ $\qquad R_{hi} = 165, \quad R_{lo} = 75$

Then $Q = \sqrt{\frac{165}{75} - 1} = 1.095 = \frac{165}{X_p} = \frac{X_s}{75}$

$\therefore X_p = 150 = \omega L \quad \therefore L = 4.77 \times 10^{-8}\,H \quad = 48\,nH$

$X_s = 82.1 = \frac{1}{\omega C_2} \quad \therefore C_2 = 3.88 \times 10^{-12}\,F \quad = 3.9\,pF$

(b) Normalise $\frac{165 + j90}{75} = 2.2 + j1.2$ plot point 'A'

LC

Admittance is point 'B' on circle ①.

Plot circle ② to find point 'C' where 'C-O-D' gives impedance point 'D' where Re part is unity

B → C is a parallel inductor $j(0.47 - 0.19) = j0.28$ Susceptance or $j\frac{1}{0.28}$ reactance $= \frac{75}{j0.28} = j268 = j\omega L \quad \therefore L = 85.3\,nH$

D → O is a series capacitor $-j1.4 = -j105 = \frac{1}{j\omega C} \quad \therefore C = 3.03\,pF$

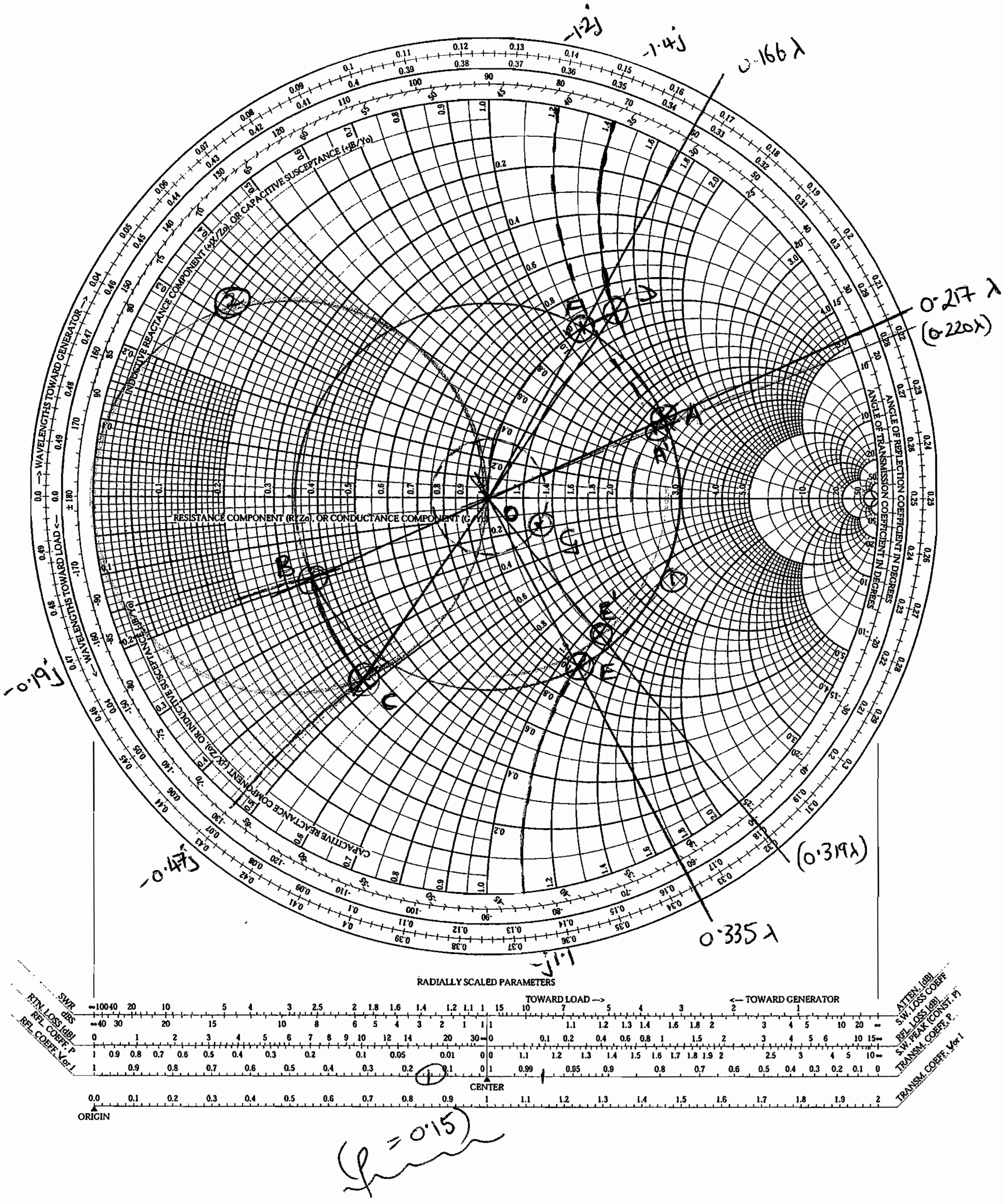
coax. + L

on circle ①
A → E use $(0.335 - 0.217)\lambda = 0.118\lambda$ then E → O
use series inductor to cancel $-j1.1 \quad \therefore \omega L = 1.1 \times 75 = 82.5$
$L = 26.3\,nH$

coax. + C

on circle ①
A → F use $(0.5 - (0.217 - 0.166))\lambda = 0.449\lambda$ then F → O
use series capacitor to cancel $j1.12 \quad \therefore \frac{1}{\omega C} = 1.12 \times 75 = 84$
$C = 3.79\,pF$

Chart for question 4; to be detached and handed in with script.



4(c) If $\epsilon_r = 2.2$ then $v = \frac{3 \times 10^8}{\sqrt{2.2}} = 2.02 \times 10^8$ m/s

@ 500 MHz, $\lambda = 0.405$ m

(L+C) costs = 10+2 = 12 p

(coax. + L) cost = $10 + 0.118 \times 0.405 \times 20 = 11$p

(coax. + C) cost = $2 + 0.449 \times 0.405 \times 20 =$ 5.6p = cheapest.

(d) For f: 500MHz → 420MHz

output impedance falls from $165 + j90$ to $165 + j76$: point 'A'

Then, length of line is $\frac{420}{500} \times 0.118\lambda = 0.099\lambda$: point 'E'

Then, inductor of normalised impedance $1.1 \to 1.1 \times \frac{420}{500} = 0.92$ only ∴ -0.176 reactance is left.

So, impedance is point 'G'. Reading radius off Ref. Coeff. scale gives $\rho = 0.15$.

3B1 – 2009 Numerical answers

1 (b)	26.2 km (1.33 pW)
1 (c)	17.3 cm each half. Range increases to 32.1 km
1(d)	70%
2 (b)	Use a low pass Bessel filter (for pulse shape) @ 9600 Hz. C1 = 1.16 nF, C2 = 1.03 nF
2(c)	Q = 58 with equiv. R = 10.1 kΩ. For Q=100, R' = 17.4 kΩ, hence shunt with –24 kΩ
3 (a)	R4 = 100 Ω, R3 = 15 Ω, R2 = 120 Ω, R1 = 680 Ω
3 (b)	1.46 GHz (or 2.9 GHz incl. source impedance of 100 Ω)
3 (c)	57.7 mm
3 (e)	0.28 mm
4 (a)	Cseries = 3.54 pF, C = 3.9 pF, L = 48 nH
4 (b)	(i) series 3.03 pF, parallel 85.3 nH
	(ii) 26.3 nH and 0.118 λ
	(iii) 3.79 pF and 0.449 λ
4 (c)	coax. + C = 5.6 pence
4 (d)	Voltage refl. coeff. = 0.15