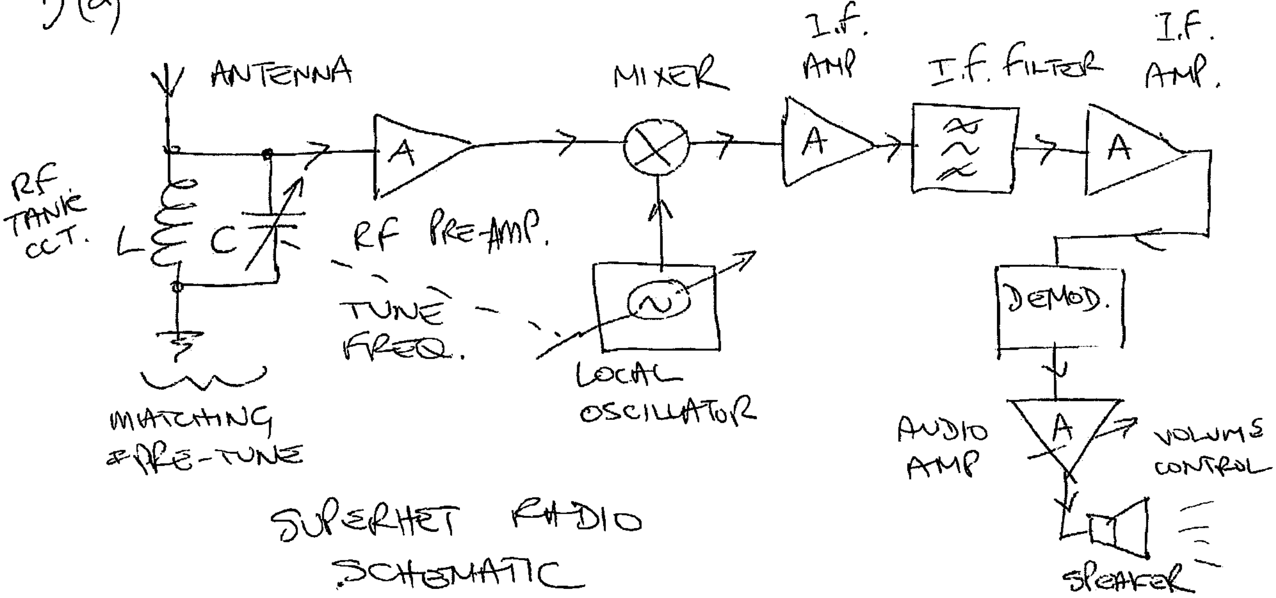
1) (a)



SUPERHET RADIO SCHEMATIC

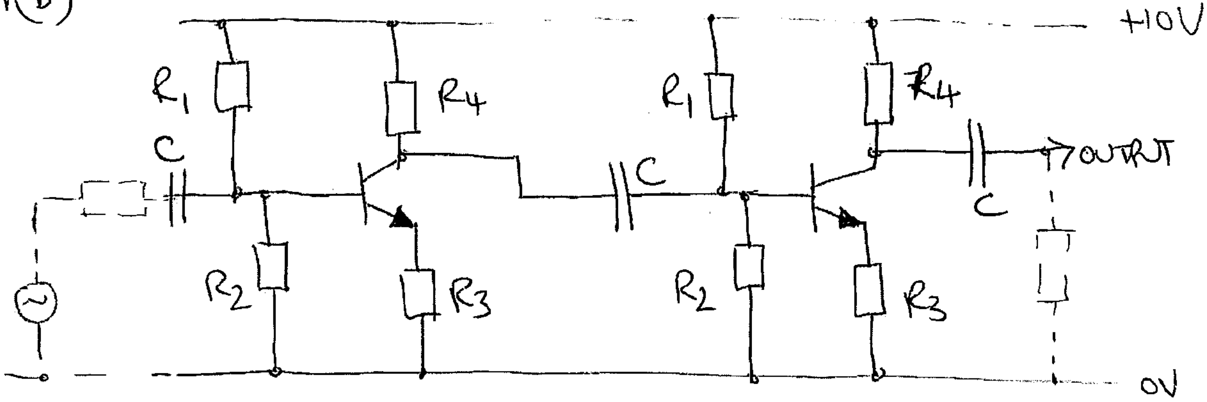
- The incoming radio signal is coupled via the antenna into a pre-tune LC resonant circuit, after which it is amplified by a low noise, RF amplifier.

- The signal (at carrier RF freq.) is mixed with that from a local oscillator to produce the Intermediate Frequency (I.F.) The action of the mixer (multiplier) is to produce sum and difference frequencies of the inputs, at the output. Hence, for a given I.F., there are 2 possible R.F. frequencies ie: $f_{LO} \pm f_{I.F.}$. The choice between these is made by the pre-tune section (image rejection).

- The I.F. signal carries the same modulation as the R.F. carrier (AM or FM), hence demodulation of the I.F. signal, after amplification, yields the required audio signal – which is output via a loudspeaker for example.

- "Tracking" is the term given to the frequency alignment of the L.O. and R.F. tank frequencies – they should differ by a fixed frequency (I.F.) over the tuning range. [30%]

1(b)



- Same values of $R_1 - R_4$ for each circuit with 12 dB net gain per stage for 24dB total.

- $R_4 = 75\,\Omega$ matched to i/p & o/p impedance
- $R_2 = 120\,\Omega$ approx. 2x i/p, o/p impedance
- Gain $= 24\text{dB} = \times 16 \times \underbrace{2^2}_{\text{extra coupling losses over 3 stages}} = \times 64 \Rightarrow \underbrace{\sqrt{64} \text{ per stage}}_{= 8}$
- $r_e + R_3 = 75 / 8 = 9.4\,\Omega$
- $V_{base} = 6.6\,\Omega \times 0.06\text{A} + 0.65 = 1.05\text{V}$ + 10% for base loading
- $r_e = \left(\frac{0.06}{0.025}\right)^{-1} = \left(\frac{I_c}{V_t}\right)^{-1} = 0.42\,\Omega$ ∴ say 1.15V for R_1, R_2 potential divider
- $1.15 = 10 \cdot \frac{R_2}{R_1 + R_2}$ ← 120 ∴ $R_1 = 920\,\Omega$

check i/p impedance: $R_{in} \approx R_1 \| R_2 \| h_{fe}(R_3 + r_e) = 99\,\Omega$

- ∴ $R_3 = 9\,\Omega$ just about o.k., close to $75\,\Omega$
- Choose C's large eg: 10nF for RF coupling

[30%]

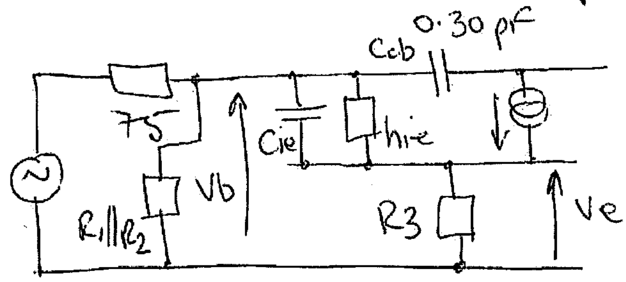
1(c) $f_t = 24\text{GHz} = \frac{1}{2\pi C_{ie} r_e}$ ← $0.42\,\Omega$

∴ $C_{ie} = 15.8\text{pF}$

Small signal model: $V_e = \frac{9}{9 + 0.42} \cdot V_b = 0.955 V_b$

1(c) contd.

Small signal model for input :-



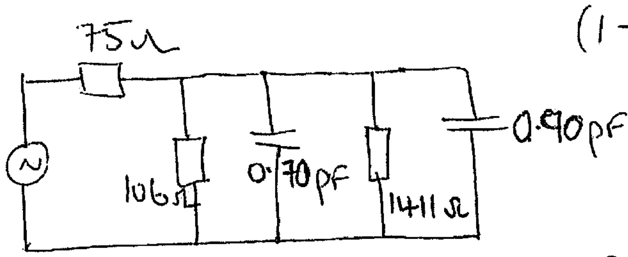
$h_{ie} = r_e \times h_{fe}$
$= 0.42 \times 150$
$= 63\ \Omega$

So, refering Cie & hie to ground and Ccb to ground.

$\div 22.4$ $\quad \times 22.4$ $\quad \times\left(1 + \frac{8}{2^2}\right) = \times 3$

(1 + Gain)

Revised SSM :-



$R' = 75 \| 106 \| 1411 = 43\ \Omega$

$C' = 1.6\ pF$

So, $f_{-3dB} \simeq \dfrac{1}{2\pi \cdot 43 \cdot 1.60 \times 10^{-12}}$

$\simeq 2.31\ GHz$

But 2 stages will roll-off a bit earlier ie. $-6dB$ @ 2.3GHz

So, ok at ~ 500MHz.

(Lower end $(2\pi \cdot 10nF \cdot 96\Omega)^{-1} = 1.66 \times 10^5$ Hz)

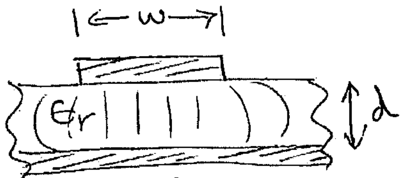
[40%]

2 (a)

- Impedance mismatch will give reflections and distort the signal.
- Maximum power matching when source & load impedances are the same $\therefore$ better signal/noise

[15%]

(b)



(assuming fringe fields extend track width by d each side)

$$C \simeq \frac{(w+2d)\,\epsilon_r\,\epsilon_0}{d}$$

per unit length

$$c = \frac{c_0}{\sqrt{\epsilon_r}}$$ velocity of light in dielectric

$$Z_0 = \sqrt{\frac{L}{C}}\,, \quad c = \frac{1}{\sqrt{LC}}$$

$$\therefore \sqrt{L} = \frac{1}{c\sqrt{C}} \qquad \therefore Z_0 = \frac{1}{cC} = \frac{\sqrt{\epsilon_r}}{c_0 C}$$

where $$Z_0 = \frac{\cancel{\sqrt{\epsilon_r}}\,.\,d}{c_0\,(w+2d)\sqrt{\epsilon_r}\,\epsilon_0}$$

$\therefore$ $d = 1.6$ mm

$\epsilon_r = 4.2$

$c_0 = 3 \times 10^8$ m/s

$\epsilon_0 = 8.854 \times 10^{-12}$ F/m

$$Z_0 = 75 = \frac{1.6}{3\times10^8\,.\,(w+3.2)\,.\,\sqrt{4.2}\,.\,8.854\times10^{-12}}$$

$\therefore$ $w = 0.72$ mm

[25%]

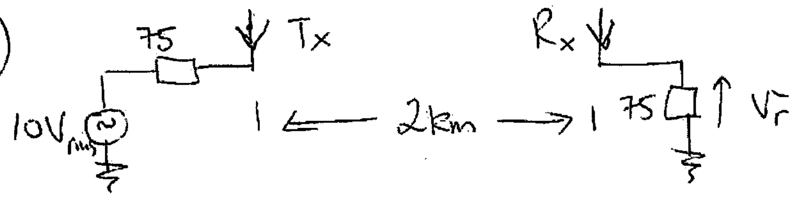
(c) For efficient, resonant antenna the patch length should be $\lambda/2$. $\lambda_0 = \dfrac{3\times10^8}{468\times10^6} = 0.641$ m in free space

$$\therefore \lambda_{PCB} = \frac{0.641}{\sqrt{4.2}} = 0.313 \text{ m} \quad \therefore \lambda/2 = 15.6 \text{ cm}$$

For 'see-saw' patch resonance, the feedpoint has low impedance at the patch centre (low V, high I) and increases towards the edge. So, feedpoint position is selected for 75Ω

[15%]

2(d)



Assume patch antenna gain = 3 (same as dipole, but radiation into ½ hemi-sphere only - due to ground plane of patch).

$$G = \frac{4\pi A_e}{\lambda^2} = 3 \quad \text{with } \lambda = 0.641 \text{ m}$$

$\therefore A_e = 0.098 \text{ m}^2$

$$\therefore P_{trans.} = \frac{10^2}{(75 \times 2)} = 0.667 \text{ W}$$

$$\therefore P_{rec} = \frac{0.667 \cdot 3 \cdot 0.098}{4\pi\, 2000^2} = \frac{P_{trans} \cdot G \cdot A_e}{4\pi R^2} = 3.9 \text{ nW} = \frac{V_r^2}{75}$$

$\therefore V_r = 0.54 \text{ mV}_{rms}$

(e) $\eta_{radn.} = \dfrac{R_{radn.}}{R_{radn} + R_{ohmic}}$ ← radiation resistance = 75Ω say. [25%]

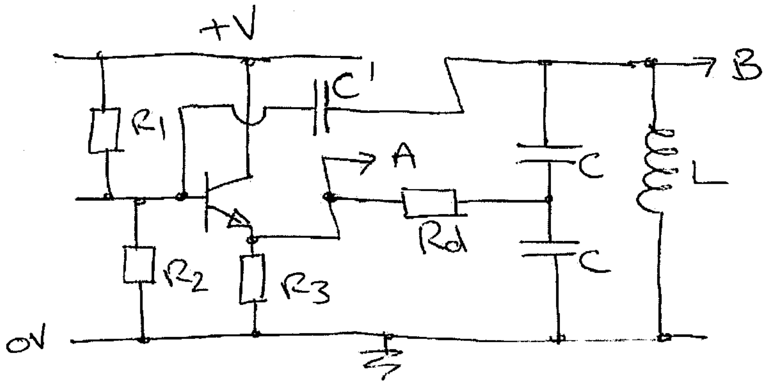
$$= \frac{75}{75 + \left(\frac{\rho L}{A}\right)} \leftarrow 7.8$$

$\rho = 3 \times 10^{-5}$ Ωm
$L = 0.156$ m
$A = 20 \times 10^{-6} \times 30 \times 10^{-3}$ m²

$\eta_{radn.} \simeq 90\%$

[20%]

3(a)



- R_1 & R_2 are base bias resistors for transistor buffer/ emitter follower : gain $\simeq 1$
- R_3 is emitter load resistor
- Rd is drive resistor for LC's tank circuit
- LC's provide resonant cct $f_{res} \simeq \frac{1}{2\pi\sqrt{L\,C/2}}$
- C' is feedback d.c. block capacitor
- LC's tank gives x2 voltage gain @ resonance from centre tap ∴ with x1 buffer gives x2 loop gain - so oscillations start up, limited by transistor voltage swing
- take o/p from A for low impedance + small load effect
  B for better harmonic purity by loads will pull freq./amplitude

[25%]

(b) $$468 \times 10^6 = \frac{1}{2\pi\sqrt{10\times10^{-9}\cdot C/2}} \quad \therefore C = 23.1\text{ pF}$$

for L = 10nH

75Ω load - take from point A as low impedance

7 dBm = 5mW into 75Ω $\quad 0.005 = \frac{v^2}{75}$

$\therefore v = 0.61$ Vrms

(1.73 Vpp) ok.

choose $R_3 = 75\times2 = 150\Omega$

bias to 2.5 Vdc. ∴ base voltage ≐ 3.2V d.c.

and Rd = 1kΩ $\quad$ ∴ $R_2 = 18k\Omega$ and $R_1 = 10k\Omega$

i.e. less than $(R_1 \| R_2)/4$ $\quad$ (with $R_1, R_2 \sim h_{fe} \times R_3 \lesssim 10$'s k)

3(b) contd.

with $R_3 = 150\Omega$ and $V_E = 2.5V$

$I_C = 16.7\ mA$

and base bias $\simeq 0.2\ mA$

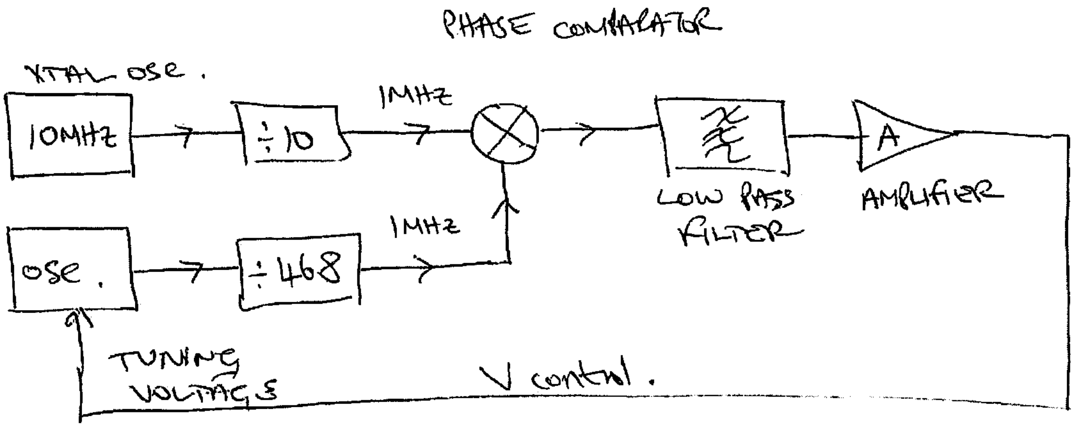
D.C. $P_{IN} = 5 \times 16.9\ mW \simeq 85\ mW$

RF. $P_{OUT} = 5\ mW$

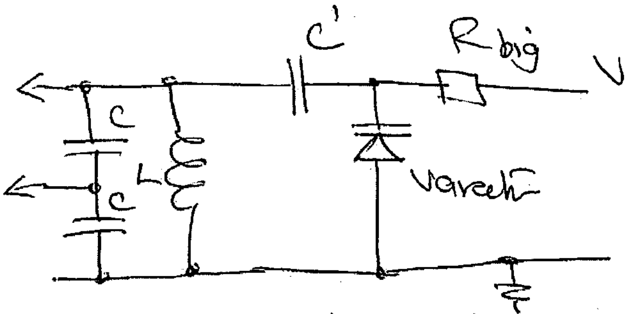
$\therefore \eta \simeq \frac{5}{85} \times 100\% \simeq 6\%$

[40%]

(c)



Colpitts must be freq. tuneable by putting varactor across LC tank cct. Varactor capacitance is tuned by low pass filtered output from phase comparator. Digital freq. counter/dividers bring each oscillator o/p to a common 1MHz freq. for phase comparison.



parallel varactor with C' d.c. blocking capacitor & Rbig bias resistor.

(d) $Q = \underbrace{\sqrt{\frac{300}{75} - 1}}_{1.73} = \frac{X_S}{75} = \frac{300}{X_P}$

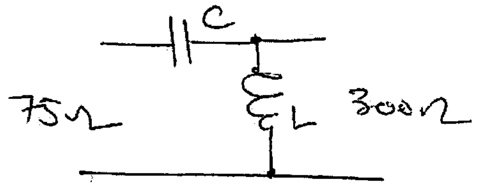
$\therefore |X_S| = 130\ \Omega \quad |X_P| = 173\ \Omega$

[20%]

3(d) cont.

Let $X_s = \dfrac{1}{2\pi f C} = 130$ $\qquad$ $X_p = 2\pi f L = 173$

capacitor $\qquad$ inductor.



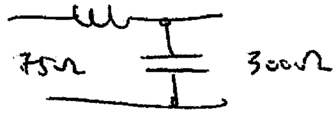
$2\pi f = 2.94 \times 10^9$ rad/s

$\therefore L = 59\ nH$

$\underline{C = 2.6\ pF}$

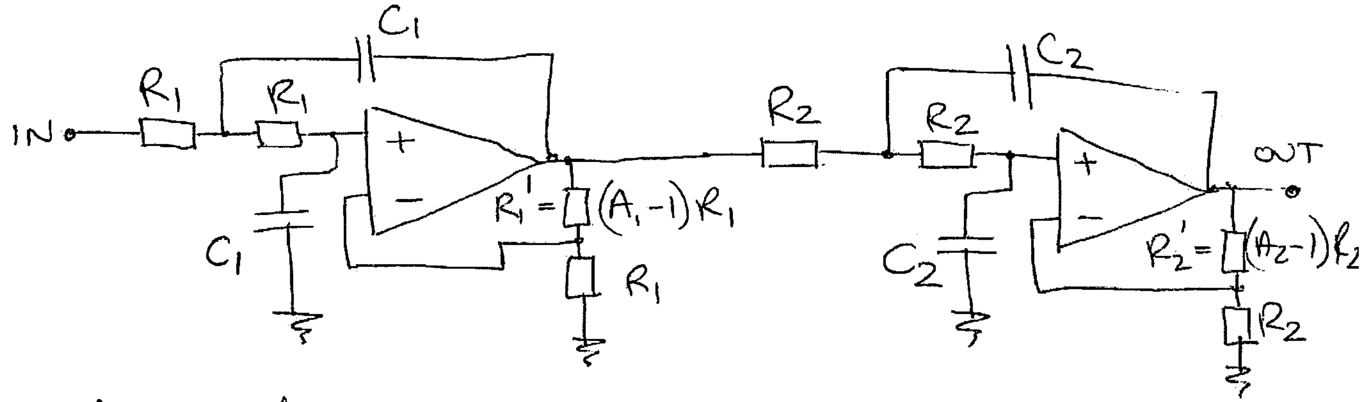
OR $1.97\ pF$ X_p for

$44\ nH$ X_s



[15%]

4(a) Select Bessel filter, with 1kHz roll-off, as this retains waveform shape well in the time domain (at the expense of frequency cut-off steepness)



$$f_{3dB} = \frac{f_n \, 1}{2\pi RC f_n}$$

Set $R_1 = R_2 = 10k\Omega$ $\quad\therefore\ R_1' = 840\Omega$: stage 1

$R_2' = 7590\Omega$: stage 2

For stage 1: $10^3 = \dfrac{1}{2\pi . 10^4 . C_1 . 1.432}$ $\Rightarrow C_1 = 11\,nF$

stage 2: $10^3 = \dfrac{1}{2\pi . 10^4 . C_2 . 1.606}$ $\Rightarrow C_2 = 9.9\,nF$

[35%]

(b) see Smith chart:

length of t/line $= 0.446\lambda$, series capacitor impedance $= -j0.95$ (normalised to 75Ω)

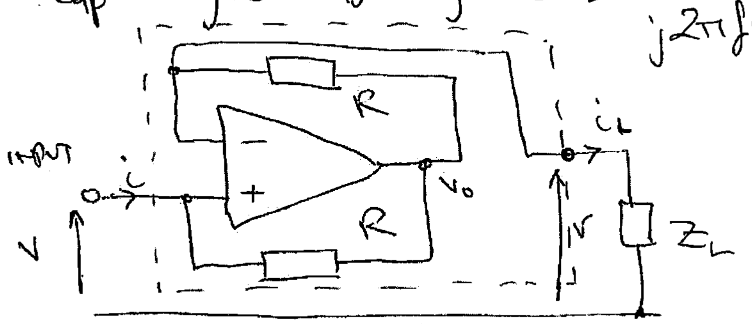
$$\therefore\ \lambda_g = \frac{3 \times 10^8}{468 \times 10^6 . \sqrt{1.5}} = 0.523\,m$$

$\therefore$ length of t/line $= 0.523 \times 0.446 = 0.233\,m$

[35%]

$$Z_{cap} = -j75 \times 0.95 = -j71.3\,\Omega = \frac{1}{j2\pi f C} \quad \therefore\ C = 4.8\,pF$$

(c)

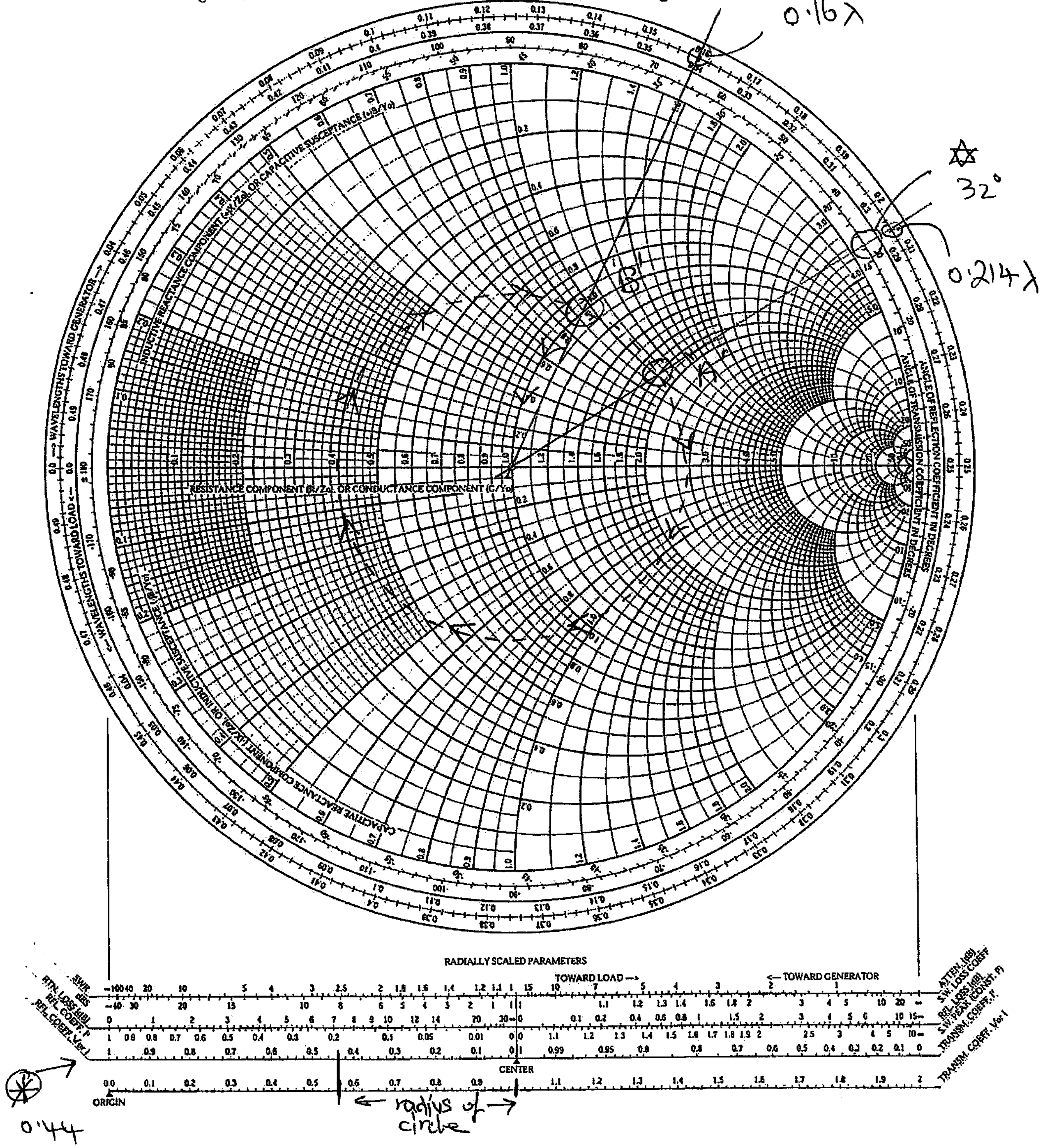


Use Negative Impedance Converter (N.I.C.)

4(b) • Measure of 0·44 on ⊛ Refl. coeff. scale and 32° ✡ on refl. coeff angle and plot point 'A'

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

• Track around transmission line c/wise from 'A' to 'B' to meet Re = 1 circle: $B = 1 + j0{\cdot}95$.



• Cancel $j0{\cdot}95$ with series capacitor of $-j0{\cdot}95$ impedance.

• Length of trans. line $= 0{\cdot}5\lambda - (0{\cdot}214 - 0{\cdot}16)\lambda = 0{\cdot}446\lambda$

4(c) contd.

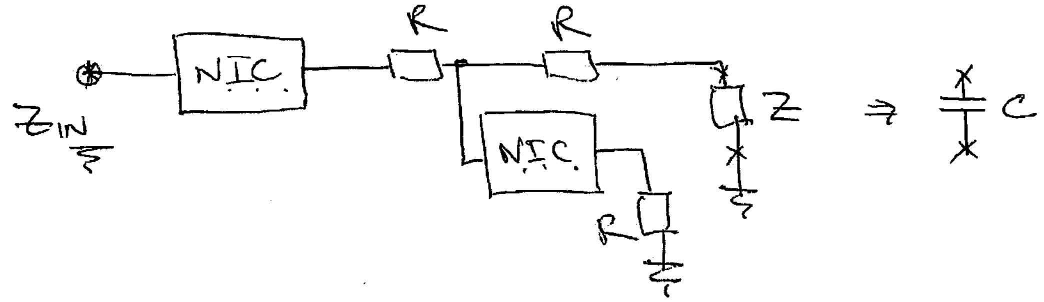
$$i = \frac{V - V_0}{R} \quad @ \text{ + node}$$

$$i_L = \frac{V_0 - V}{R} \quad @ \text{ − node}$$

and $V_+ = V_-$ in ideal opamp $\therefore i_L = -i$

So, at input Z_L appears as $-Z_L$

To create an inductor, 2 of these must be used.



$$Z_{in} = -\left[R + \frac{-R(R+Z)}{Z}\right] = -\left[\frac{RZ - R^2 - RZ}{Z}\right]$$

$$= \frac{R^2}{Z}$$

So if $Z = \frac{1}{j2\pi f C}$ then $Z_{IN} = j2\pi f \underbrace{R^2 C}_{\equiv L}$

So, for $L = 0.01$ H with $R = 10^4 \Omega$, $C = \frac{L}{R^2} = 100pF$

- Synthesised inductors can be large in value, but only over the freq. range where the op-amps work well and stray impedances do not impinge too much: this tends to mean low frequencies. A real inductor stores energy, synthetic inductors only appear to as regards the signals. Real inductors can also have large common mode voltages, large signals and currents, but are sources of electromagnetic interference + coupling.

[30%]

3B1 Radio Frequency Electronics 2011 – Numerical Answers

1(b) R1 = 920 Ω, R2 = 120 Ω, R3 = 9 Ω, R4 = 75 Ω, C = 10 nF

1(c) R' = 43 Ω, C' = 1.6 pF, f_{3dB} = 2.31 GHz / stage

2(b) w = 0.72 mm

2(c) $\lambda/2$ = 15.6 cm

2(d) Pr = 3.9 nW, Vr = 0.54 mVrms

2(e) η = 90 %

3(b) C = 23.1 pF, R3 = 150 Ω, R2 = 18 kΩ, R1 = 10 kΩ, Rd = 1 kΩ, η = 6 %

3(d) Xs = 130 Ω, Xp = 173 Ω so, L = 59 nH & C = 2.6 pF OR L = 44 nH, C = 2 pF

4(a) Bessel, C1 = 11 nF, R1' = 840 Ω, C2 = 9.9 nF, R2' = 7590 Ω with R = 10 kΩ

4(b) T/line length = 0.233 m (= 0.446 λ), C = 4.8 pF

4(c) $L = CR^2$ hence for R = 10 kΩ, C = 100 pF