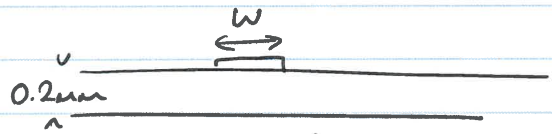
1.a)



$$C = \frac{(w+2d)\varepsilon_0\varepsilon_r}{d} \qquad v = \frac{c_0}{\sqrt{\varepsilon_r}}$$

$$Z = \frac{1}{vC} = \frac{d}{(w+2d)\varepsilon_0\sqrt{\varepsilon_r}\,c_0}$$

$d = 0.2$ mm

$w = 0.4$ mm

$$\sqrt{\varepsilon_r} = \frac{d}{(w+2d)\varepsilon_0 c_0 Z}$$

$\underline{\underline{\varepsilon_r = 3.55}}$

b) with $\varepsilon_r = 3.55$ $v = 1.59 \times 10^8$ m/s $f = 600$ MHz

$v = \lambda f$ so $\lambda = 0.3975$ m

50 mm microstrip is 0.125λ

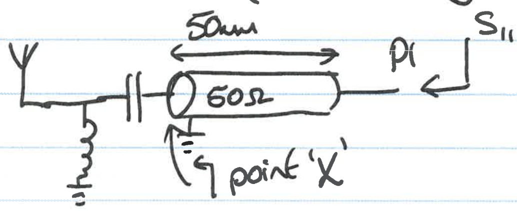
Start at S_{11}, move 0.125λ <u>towards load.</u>

The antenna in this case is the load which produces the mismatch.

Point 'X' $50 \times (1.3 + 0.65j) = 65 + 32.5j$

Question can also be done analytically by thinking purely about the phase shift of the line

c)



Now remove cap. $C = 7.6$ pF $X_c = \frac{1}{j\omega C} = -52.35j\,\Omega$

normalised $x_c = -1.047j$

We need to remove capacitance. Can either use Smith Chart or add impedances in series.
Since we are removing negative reactance imaginary part must have $+1.047j$ <u>added</u>

Move to point 'B' which is $(1.3 + 0.65j) + 1.047j$

Flip to admittance for inductor : B'

Im part is $-0.36j$

$L = 32nH$ $\quad X_L = j\omega L = 80.42j$ $\quad x_L = 1.608j$ $\quad y_L = -0.62j$

Again we are subtracting a negative susceptance so in Smith Chart move in direction of positive susceptance.

This takes us to Ant'

Flip back again to get to impedance.

Marked 'Ant'

$Z_{ant} = 50 \times (2 - 1.8j)$

$= 100 - 90j$

Examiners note: some confusion about directions around Smith Chart. The order of removing components also matters.

Another common error was to attempt to solve by Q-factors - this would only work if the designed match was perfect

Some candidates used the Smith chart but had errors which were impossible to follow through without some labels and working.

iv) for $\lambda/2$ dipole patch need $C = \frac{\lambda}{2}$ in material

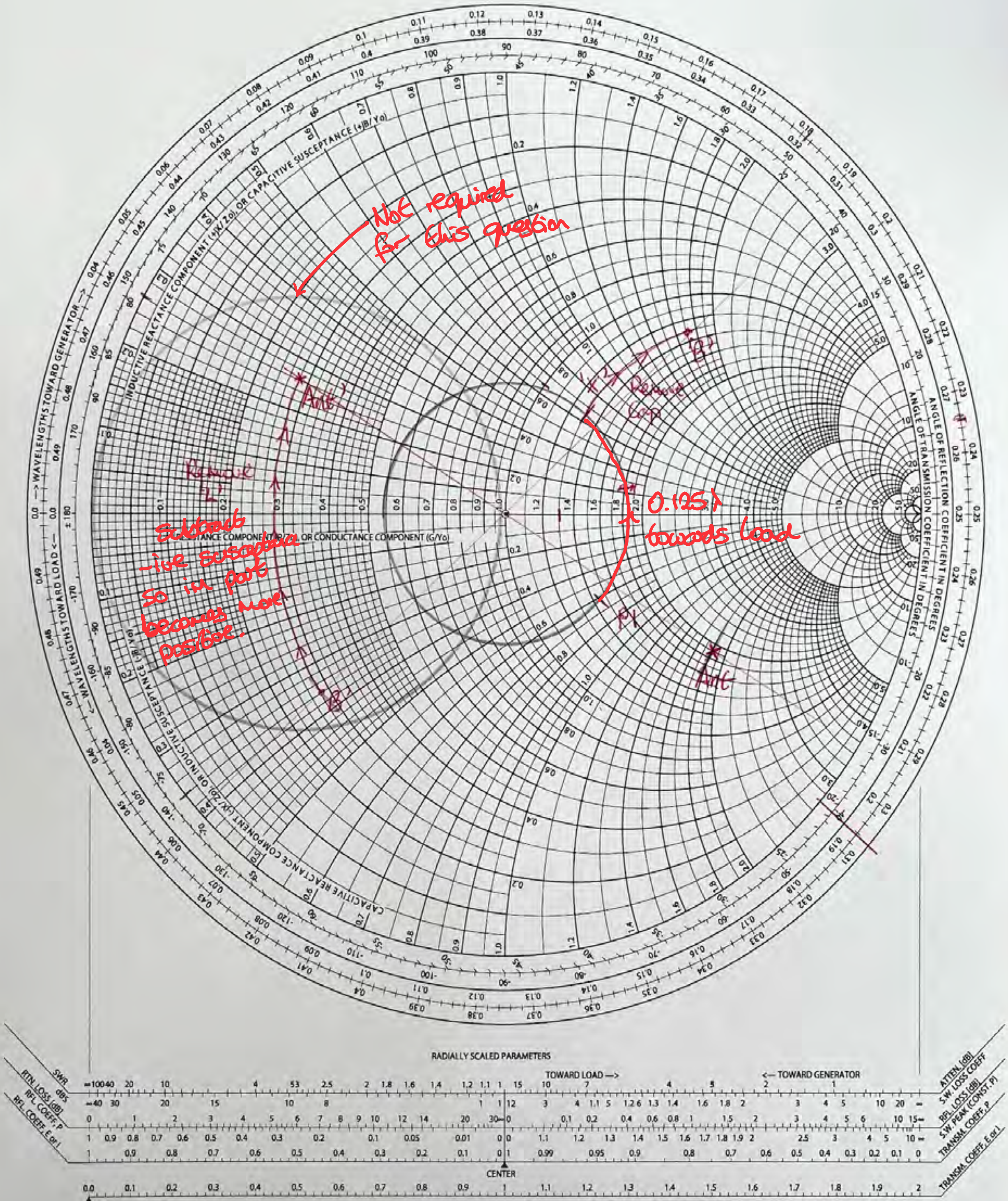
$\lambda = 0.3975$ from above.

$C = 19.8$ cm

Impedance matching can be achieved by moving the feed point.

Since $|Z_{ant}|$ is too high, shifting towards the centre should help. The complex component suggests the antenna is not resonant and the 'C' value used previously is wrong

A common error here and in part (b) was to forget ε_r



Not required for this question
Remove 'L'
Subtract -ive susceptance so im part becomes more positive.
'Ant'
'B'
Remove Cap
0.125λ towards load
Ant
B
INDUCTIVE REACTANCE COMPONENT (+jX/Zo), OR CAPACITIVE SUSCEPTANCE (+jB/Yo)
CAPACITIVE REACTANCE COMPONENT (-jX/Zo), OR INDUCTIVE SUSCEPTANCE (-jB/Yo)
RESISTANCE COMPONENT (R/Zo), OR CONDUCTANCE COMPONENT (G/Yo)
—> WAVELENGTHS TOWARD GENERATOR —>
<— WAVELENGTHS TOWARD LOAD <—
ANGLE OF REFLECTION COEFFICIENT IN DEGREES
ANGLE OF TRANSMISSION COEFFICIENT IN DEGREES
RADIALLY SCALED PARAMETERS
TOWARD LOAD —>
<— TOWARD GENERATOR
SWR
dBS
RTN. LOSS [dB]
RFL. COEFF. P
RFL. COEFF. E or I
ATTEN. [dB]
S.W. LOSS COEFF
RFL. LOSS [dB]
S.W. PEAK (CONST. P)
TRANSM. COEFF. P
TRANSM. COEFF. E or I
CENTER

2. i) gain $= \frac{P_{Max}}{P_{iso}} = 4$

$\eta = \frac{P_{rad}}{P_{IN}} = \frac{R_{rad}}{R_{rad}+R_{ohmic}} = 0.6$

directivity $= \frac{P_{Max}/\eta}{P_{iso}} = 6.67$

$G = \frac{4\pi A_e}{\lambda^2}$ at 2.4GHz $\lambda = 12.5$cm

$A_e = 4.97 \times 10^{-3}$ m^2

Examiners note: This required some careful reading of the question to find the parameters to calculate each quantity.

$P_r = A_e \times S$

$S = 0.05$ W/m^2

ii) For the transmit antenna:

if $S = \frac{P_t}{4\pi R^2} \times G_{tx}$

$P_r = A_e \times S$ ← from (i) – accounts for directivity and efficiency.

$P_r = \frac{A_e P_t}{4\pi R^2} \times G_{tx}$

$R = \sqrt{\frac{A_e P_t G_{tx}}{4\pi P_r}}$

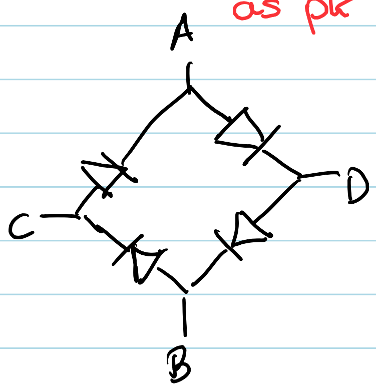
$P_r = \frac{10\mu V^2}{50} = 2 \times 10^{-12}$ W

↖ Input impedance of reciever

$R = 3.4$ km

Reciever sensitivity could be interpeted as pk or RMS, both allowed.

iii)



(all diodes in the oposite orientation also works)

iv) RF isolation via transformer due to centre tap for output each half should balance.

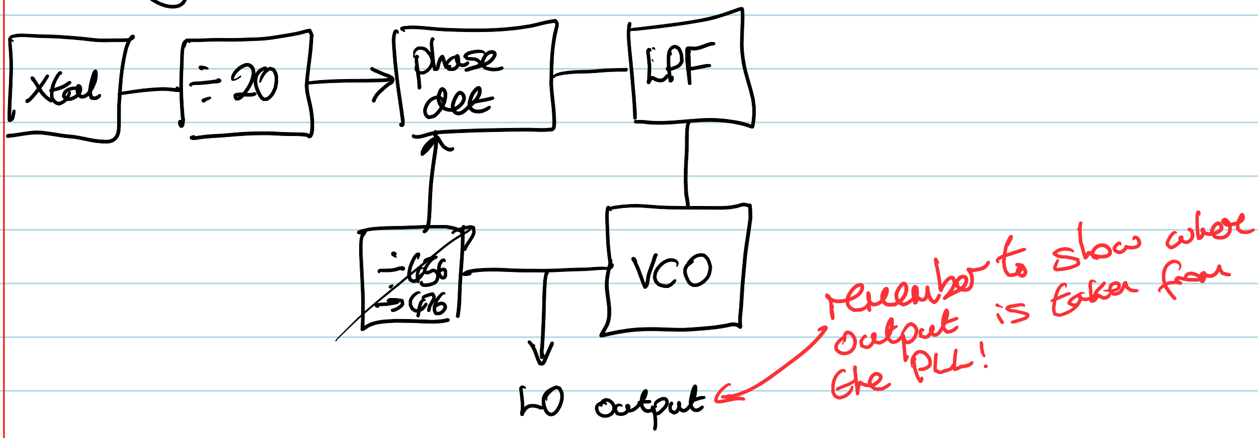
LO isolation since C and D are mid points of pot. divider formed by each diode pair so any LO is common mode at C and D with no pot. difference.

LO isolation reduced by differences in the diodes in the ring.
Good LO isolation prevents potential unwanted transmission of LO from antenna.
RF isolation less important: reduces need for IF filtering

Quite a lot of comments have described operation of the ring as a mixer rather than how isolation is achieved.

c) Since VCO limited to 2.5GHz must have low side LO 2.28 → 2.38 GHz

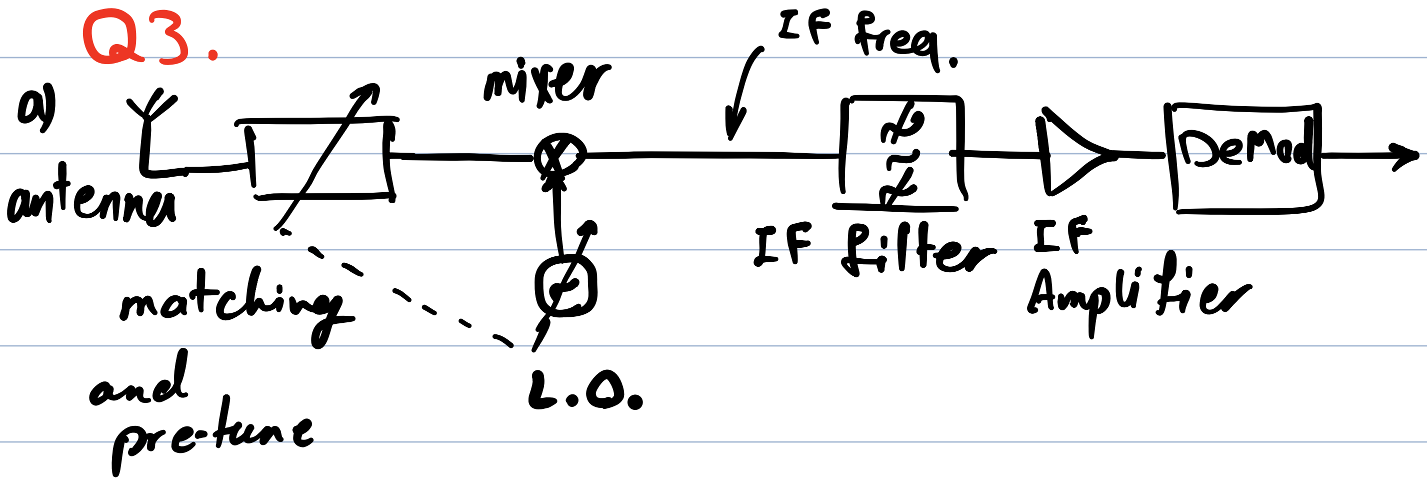
For 5MHz steps phase detector operates at 5MHz.
divide 100 MHz ref by 20
VCO by 456 → 476



A common mistake was to forget to subtract the IF to give the range of LO frequencies required. Many also required fractional dividers!

Q3.

a)

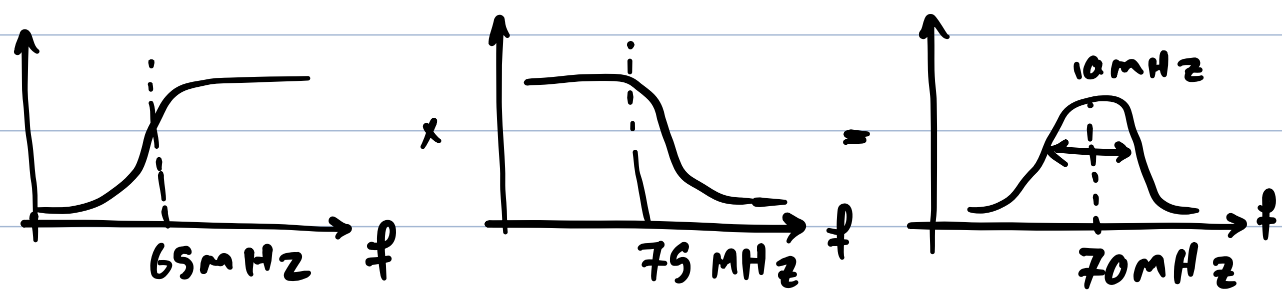


(as in lecture notes)

- L.O. produces a freq. required to move the RF carrier freq down to the IF freq.
- The IF filter selects the IF freq.

- The impact of different recieved signal powers can be controlled using a variable gain amplifier.

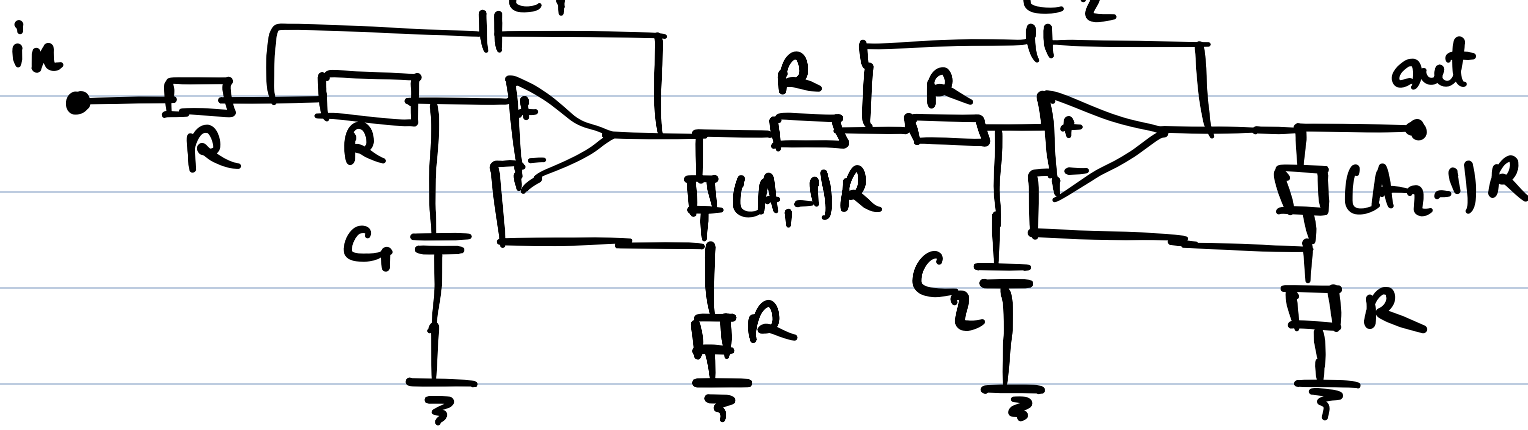
b)



The type of the filter is Bessel.

1st Op-amp

$f_n = 1.432$ $\qquad$ $A_1 = 1.084$



$R = 100\ \Omega$

$(A_1 - 1)R = 8.4\ \Omega$

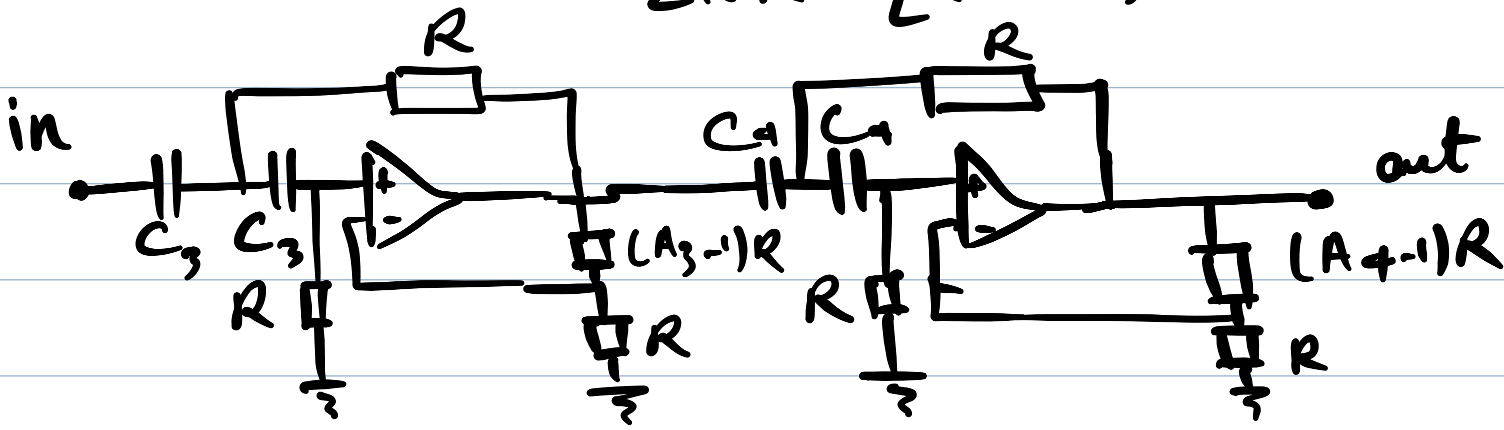
$$75\text{ MHz} = \frac{1}{2\pi R C_1 (1.432)} \Rightarrow C_1 = 14.8\text{ pF}$$

2nd Op-amp

$f_n = 1.606$ $\quad A_2 = 1.759$

$(A_2 - 1)R = 75.9\ \Omega$

$$75\text{ MHz} = \frac{1}{2\pi R C_2 (1.606)} \Rightarrow C_2 = 13.2\text{ pF}$$



Op-amp 3 $\quad \frac{1}{f_n} = 0.6983$ $\quad A_3 = 1.084$

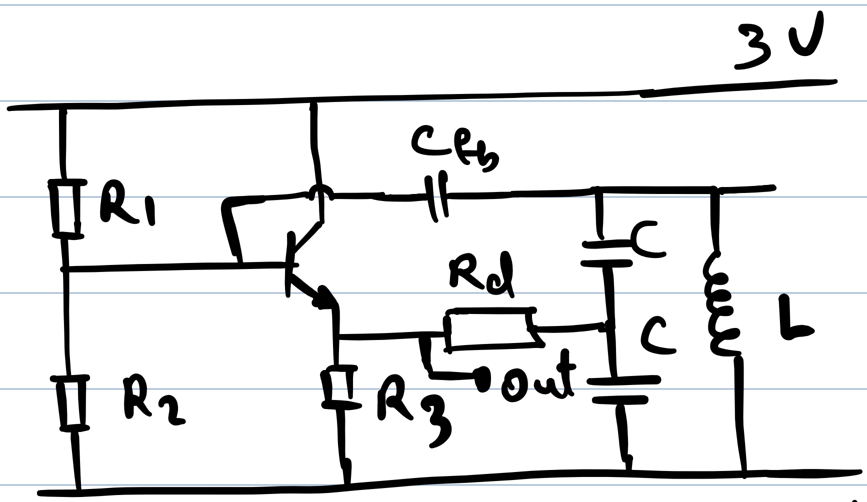
Same resistors

$$65\,\text{MHz} = \frac{1}{2\pi R C_3 (0.6983)} \Rightarrow C_3 = 35\,\text{pF}$$

Op-amp 4 $\quad \frac{1}{f_n} = 0.6227 \quad A_4 = 1.759$

$$65\,\text{MHz} = \frac{1}{2\pi R C_4 (0.6227)} \Rightarrow C_4 = 39\,\text{pF}$$

c)



(one can assume output in parallel with L, hence another solution)

Osc. freq. is 1420 MHz to produce a 70 MHz IF freq.

$$f_0 = 1420\,\text{MHz} = \frac{1}{2\pi\sqrt{L\frac{C}{2}}} \Rightarrow C = 2.5\,\text{pF}$$

10 nH

$$V_{rms}^2 = PR = 0.002 \times 500 \Rightarrow V_{rms} = 1\,V \checkmark \text{OK}$$

$V_{pp} = 2.8\,V$

(ideally we need higher supply)

say $C_{fb} = 10\,nF$ (large value)

inductor resistance : $2\pi f L Q \sim 4k\Omega$

$V_E = 1.5\,V \Rightarrow V_B = 2.1\,V$

choose

$R_3 = \frac{3}{2} \times 500 = 750\,\Omega$ (about $1k\Omega$)

choose R_1 and $R_2 \sim h_{fe} \times (R_3 \parallel \text{load}) \sim 75k\Omega$

and to give $V_B \sim 2.1\,V$

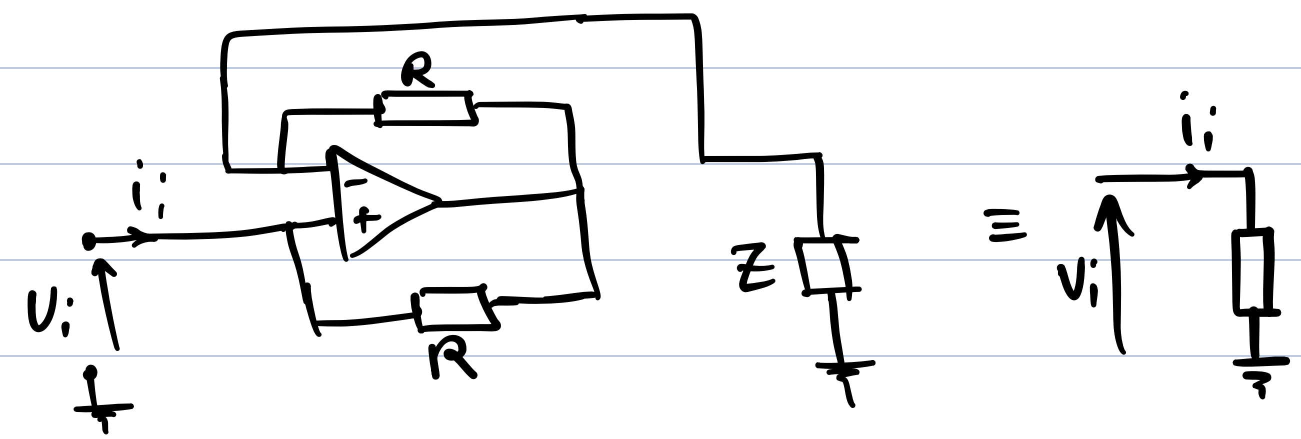
$\Rightarrow R_1 = 36\,k\Omega \quad R_2 = 82\,k\Omega$

$$R_d = \frac{1}{5}\left(R_1 \parallel R_2 \parallel \overset{\omega L Q}{4k\Omega} \parallel h_{fe} R_3 \parallel \text{load} \times h_{fe}\right)$$

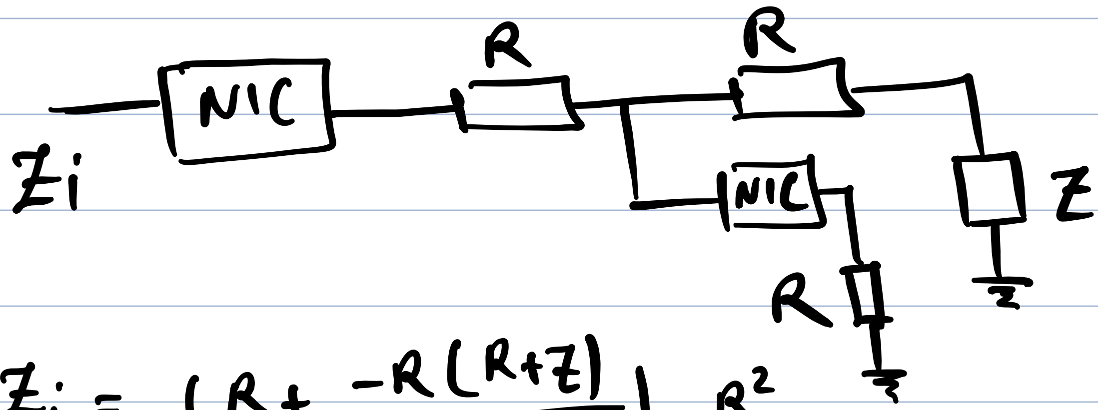
$\simeq 570\,\Omega$

for loop gain >1 *

d)



proof from lecture notes



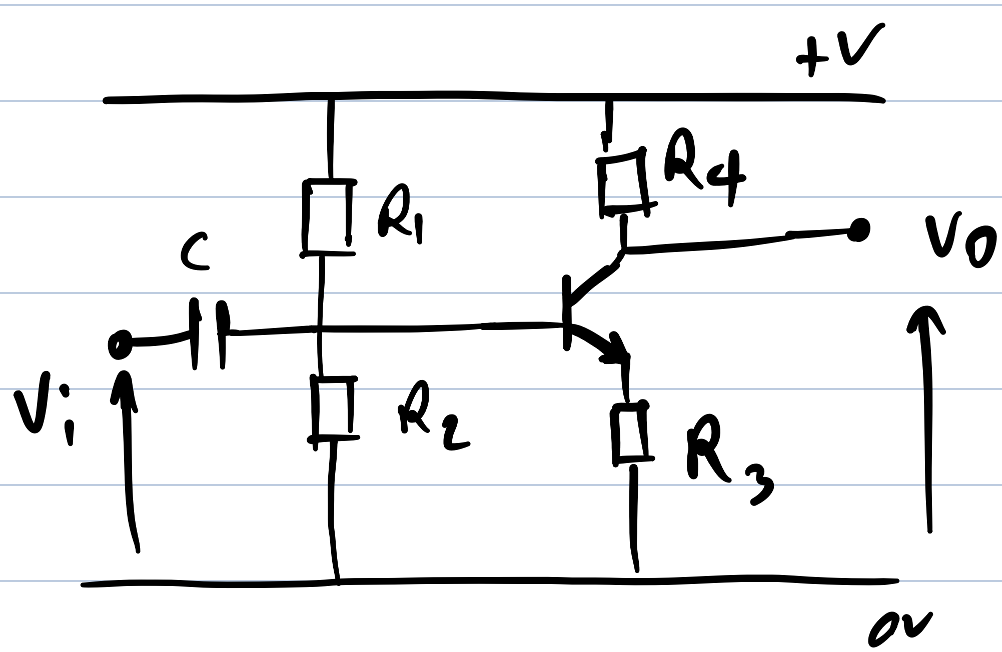
$$Z_i = -\left(R + \frac{-R(R+Z)}{-R+R+Z}\right) = \frac{R^2}{Z}$$

if $Z = \dfrac{1}{j\omega C} \Longrightarrow Z_i = j\omega C R^2 \Rightarrow L = CR^2$

say 10 H 100nF 10 kΩ

Q4

a)



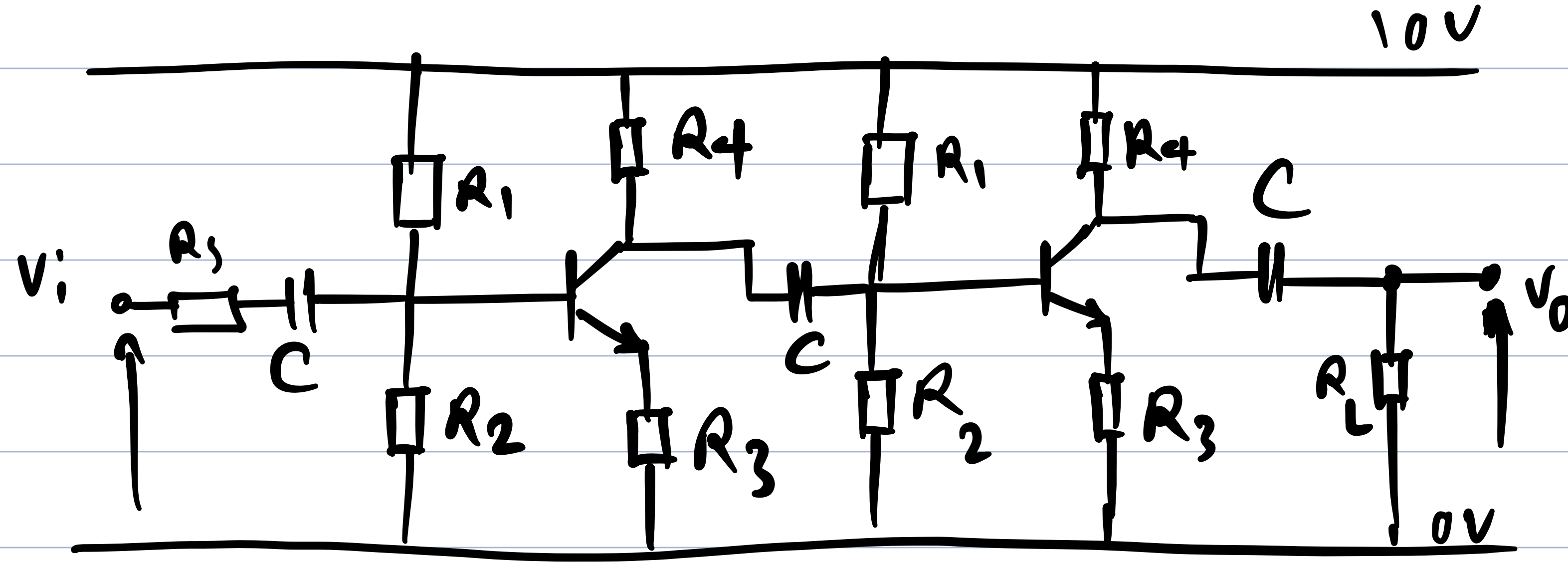
Role of components from lecture notes

R_3: ① improves stability by providing negative feed back, i.e., low current causes lower voltage drop over R_3, resulting in higher V_{BE} (for a fixed V_B), hence stabilizing/increasing current

② Reduces gain as the gain is proportional to $\frac{1}{R_3}$

b)

required gain = 36 dB = 63.1



$R_3 = R_L = 50\ \Omega$

$(0.5)^2 \times (\text{gain per stage})^2 = 63.1$

$\Rightarrow \text{gain per stage} = \sqrt{\dfrac{63.1}{(0.5)^2}}$

$= 16$

(matched stages $\Rightarrow$ same stages)

$R_4 = 50\ \Omega$

$\Rightarrow 16 = \dfrac{50}{R_3 + r_e} \Rightarrow R_3 + r_e = 3.125\ \Omega$

$I_C = \dfrac{10 - V_C}{50}$ ← $\frac{1}{2}$ supply $\rightarrow I_C = 0.1\ A$

$\Rightarrow r_e = \dfrac{0.025}{0.1} = 0.25\ \Omega$

$\Rightarrow R_3 \cong 3\ \Omega$

$V_E = 0.5\ V \Rightarrow V_B = 0.5 + 0.6 = 1.1\ V$

$$10 \frac{R_2}{R_2+R_1} = 1.1\,V + 20\% = 1.3\,V$$

choose $R_2 \approx 75\,\Omega \Rightarrow R_1 = 500\,\Omega$

$R_{in} = R_1 \| R_2 \| R_3 h_{fe} = 60\,\Omega$

OK

choose capacitor $C \sim nF$, eg. $10\,nF$

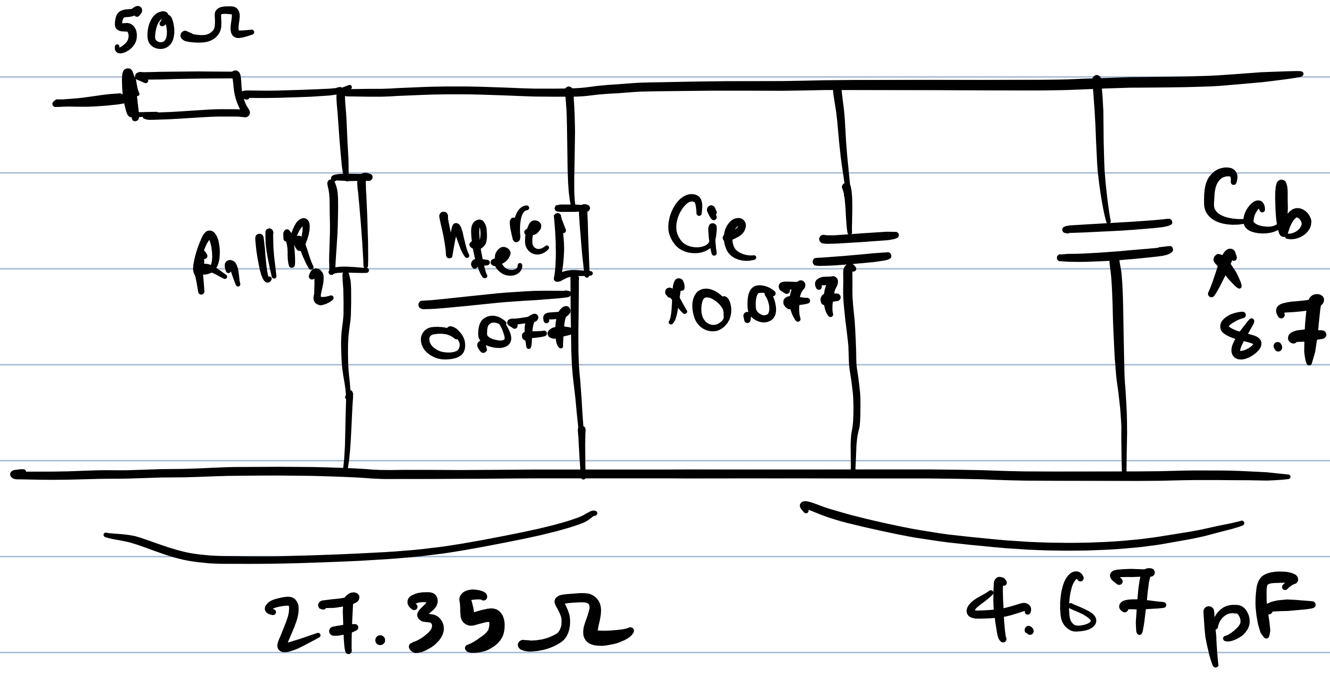
c)

emitter gain : $\frac{R_3}{R_3+r_e} = \frac{3}{3.25} = 0.923$

$0.077 = 1 - 0.923$

$$f_t = \frac{1}{2\pi r_e C_{ie}} \Rightarrow C_{ie} = 31.8\,pF$$

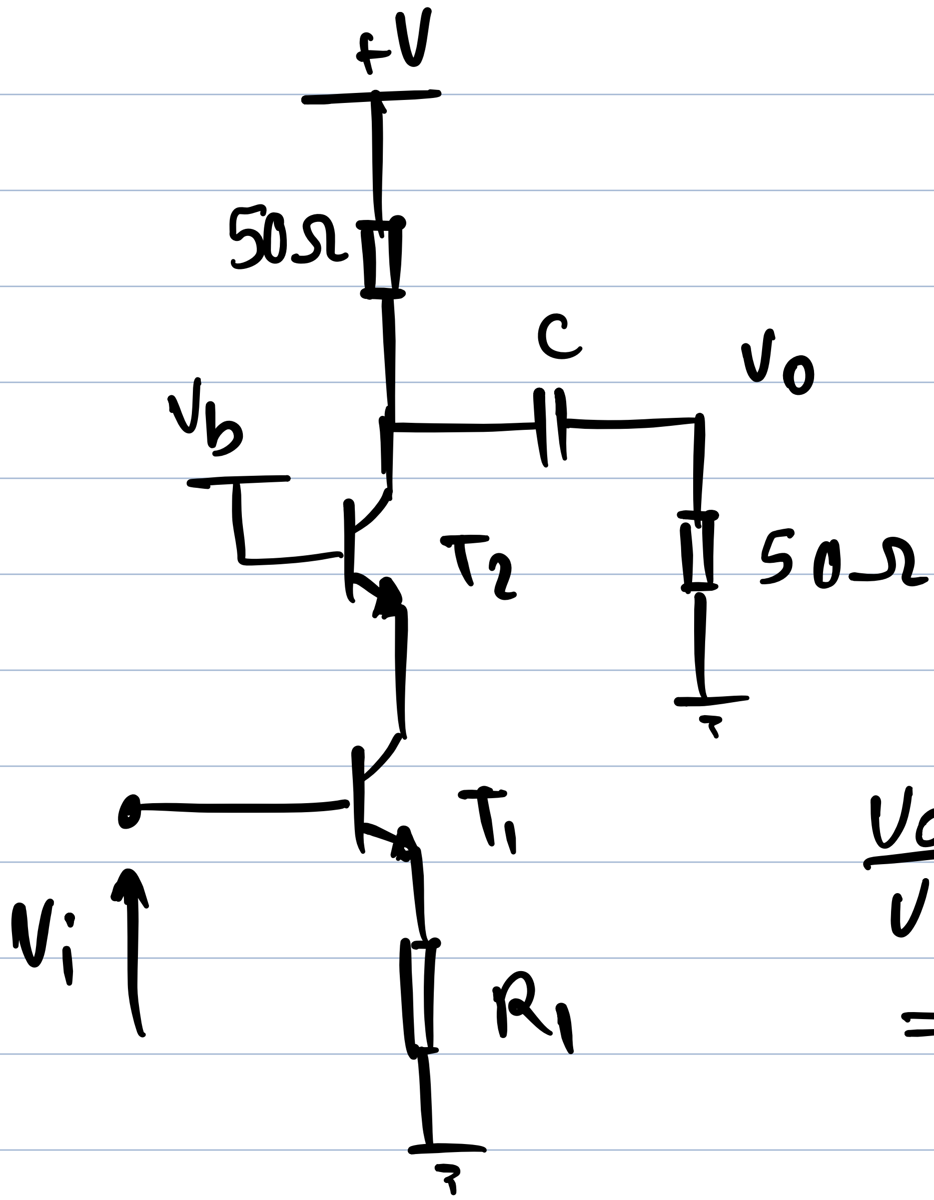
$$\text{Load gain} = \frac{50 \| 50}{R_3 + r_e} = 7.7$$



$$\Rightarrow \quad f_{3dB} = \frac{1}{2\pi \times 27.35 \times 4.67\,pF} = 1.24\,GHz$$

which is marginaly fine for 1GHz
[other assumptions could result in a different conclusion here]

d) The input transistor T_1 has no voltage gain, and thus the Miller effect is not significant. The collector voltage of T_1 is kept constant by the V_{BE} of T_2. The second transistor, T_2, provides the gain, but its base is connected to constant supply, so, due to low resistance, the RC time constant also remains small. Therefore, high bandwidth is expected.



$$\frac{V_o}{V_i} = 16$$

$$\Rightarrow \frac{50 \| 50}{R_1} = 16$$

$$\Rightarrow R_1 = 1.56\,\Omega$$

Q1: 74 Attempts, Mean 11.8/20.

Most could answer the initial part about the microstrip and carry out the initial Smith chart calculation in (b), a common error was rotating the wrong way about the Smith chart. Part (c) really separated those who understand the Smith chart from those trying to apply a known method, here frequent errors were going in the wrong direction when the capacitor and (particularly) inductor are removed. Some students attempted this part using Q-factor analysis, however this is not applicable as it calculates a perfect match, in this case we are considering a poor match. In (b) and (c) some also forgot that the relevant wavelength needs to account for the dielectric constant from part (a)

Q2:31 Attempts, Mean 9.5/20

A disappointing question – a surprising number struggled with (a) (i) which only asked for some fairly basic antenna calculations from the presented information. In (b) most could give the ring configuration, but gave an explanation of the mixing rather than how isolation is achieved. In part (c) there was some confusion over the inclusion of the IF frequency with few realising that this is required to find the range of LO frequencies to be generated.

Q3: 74 Attempts, Mean 11.71/20

Many students answered part (a) on the principles of radio receivers. The answer to part (b) was generally fine, as most students identified the correct filter type, but there were too many errors on the high/low-pass 3dB frequency selection. Only a few students fully answered part (c). The challenge was to first select an output location and then answer accordingly. A number of students, just used some formulas without selecting the output which resulted in wrong answers. Part (d) was quite basic, but it showed only students who carefully studied the course material could answer the question.

Q4: 87 Attempts, Mean 12.28/20

A standard question with an acceptable overall results. Many students did not fully explain the effect of R3 in negative feedback and gain reduction. There were many students who did not calculate the correct gain for single stages for part (b), but the answer to the rest of part (b) was good. Many missed to check the input impendence at the end. In part (c), the impact of effective loaded gain and correct referral of C and R was challenging for many students, leading to incorrect overall answers. Most students drew the cascode circuit but either failed to explain how it works or did not calculate the new R (only a few did).

M. Crisp (Principal Assessor)