3B1
2015

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1. (a)

Effective Aperture, A_e: Received power into matched load $=$ incident power density $\times A_e$

Gain $=$ $\dfrac{\text{max power density in transmitted wave}}{\text{power density from an isotropic source}}$

Radiation Resistance, R_r: total power radiated given by $P_r = I^2 R_r$

Radiation Efficiency η_{rad}: ratio of radiated power to power supplied to antenna $= \dfrac{I^2 R_r}{I^2(R_r + R_{loss})}$

$G = \dfrac{4\pi A_e}{\lambda^2}$ [20%]

1 (b)

$R = 507 \times 10^9$ m

$f = 10.7 \times 10^9$ Hz, $\lambda = \frac{3\times10^8}{f} = 0.028$ m

$P_t = 750$ W

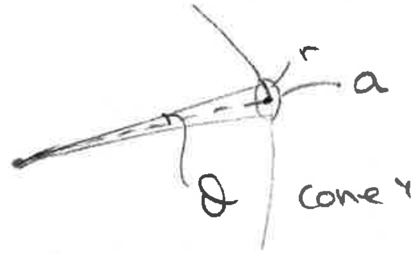
$A_{e_t} = \frac{\pi\, 2.2^2}{4}$ m², $A_{e_r} = \frac{\pi\, 70^2}{4}$

(i) $P_r = \dfrac{V_r^2}{50} = \dfrac{P_t \times G \times A_{er}}{4\pi R^2}$ where $G = \dfrac{A_{et} . 4\pi}{\lambda^2}$

$\therefore P_r = \dfrac{750}{\cancel{4\pi}\,(507\times10^9)^2} . \dfrac{\pi . 2.2^2}{4} . \dfrac{\pi\, 70^2}{4} . \dfrac{\cancel{4\pi}}{0.028^2} = 5.44 \times 10^{-14}$ W

$\therefore V_r = (5.44\times10^{-14} . 50)^{1/2} = \underline{1.65\ \mu V}$ [15%]

(ii) $G = \dfrac{\cancel{4\pi}\ \pi 2.2^2}{\cancel{4}\ 0.028^2} = \underline{60.9\times10^3} = \left(\dfrac{\pi r^2}{4\pi R^2}\right)^{-1}$



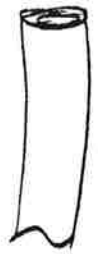
where $r = R\sin\theta$

$= \left(\dfrac{\cancel{\pi} R^2 \sin^2\theta}{4\cancel{\pi} R^2}\right)^{-1}$

$\therefore \sin\theta = \left(\dfrac{60.9\times10^3}{4}\right)^{-1/2}$

$\underline{\therefore \theta = 0.46^\circ}$ [20%]

1(c)



$2.7\,\text{GHz} \Rightarrow \lambda = 0.111\ \text{m}$

$\therefore \lambda/2$ dipole length $= 0.0556\ \text{m} =$

skin depth, $\delta_{s/steel} = \sqrt{\dfrac{2\rho}{\omega\mu_0}} = \sqrt{\dfrac{2\times 72\times10^{-8}}{2\pi\times2.7\times10^{9}\times4\pi\times10^{-7}}}$

$= 8.22\ \mu\text{m}$

$\rho_{s/steel} = 72\times10^{-8}\ \Omega\text{m}$
$\rho_{Cu} = 1.72\times10^{-8}\ \Omega\text{m}$

and for Cu, $\delta_{Cu} = 1.27\ \mu\text{m}$

$R_{ohmic}\begin{cases} \text{s/steel}: & \dfrac{\rho\times L}{\pi\times\delta\times d} : 1.55\ \Omega \\ \text{Cu}: & : 0.240\ \Omega \end{cases}$

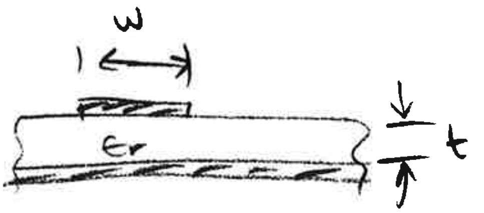
$d = 0.001\ \text{m}$

R_r for $\lambda/2$ dipole $\simeq 75\ \Omega$

$\therefore \eta_{rad\ s/steel\ (Cu)} = \dfrac{R_r}{R_r + R_{ohm}} = \underset{\text{s/steel}}{0.980} \rightarrow \underset{(\text{Cu})}{0.997}$

[20%]

1(d)



capacitance/unit length =

$C = \dfrac{(w+2t)\,\epsilon_r\epsilon_0}{t}$

$v = \dfrac{1}{\sqrt{\epsilon_0\epsilon_r\mu_0}} = 2.12\times10^{8}\ \text{m/s} = \dfrac{1}{\sqrt{LC}}$

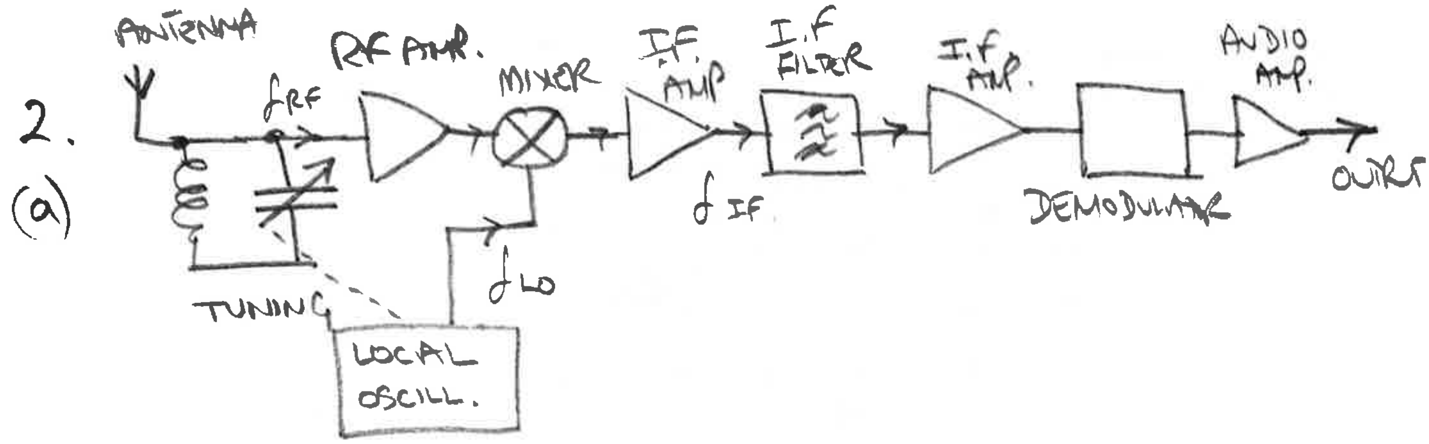
$\therefore \sqrt{L} = \dfrac{1}{v\sqrt{C}}$ and $Z_0 = \dfrac{\sqrt{L}}{\sqrt{C}} = \dfrac{1}{vC}$ $\therefore Z_0 C = \dfrac{1}{v}$

$\therefore \dfrac{50\,(w+2\overset{0.8\times10^{-3}}{t})\,\epsilon_0\overset{2}{\epsilon_r}}{\underset{0.8\times10^{-3}\,\text{m}}{t}} = \dfrac{1}{2.12\times10^{8}}$

$\therefore w + 1.6\times10^{-3} = 4.26\times10^{-3}$ $\therefore w = 2.66\times10^{-3}\ \text{m}$ [25%]

2.

(a)



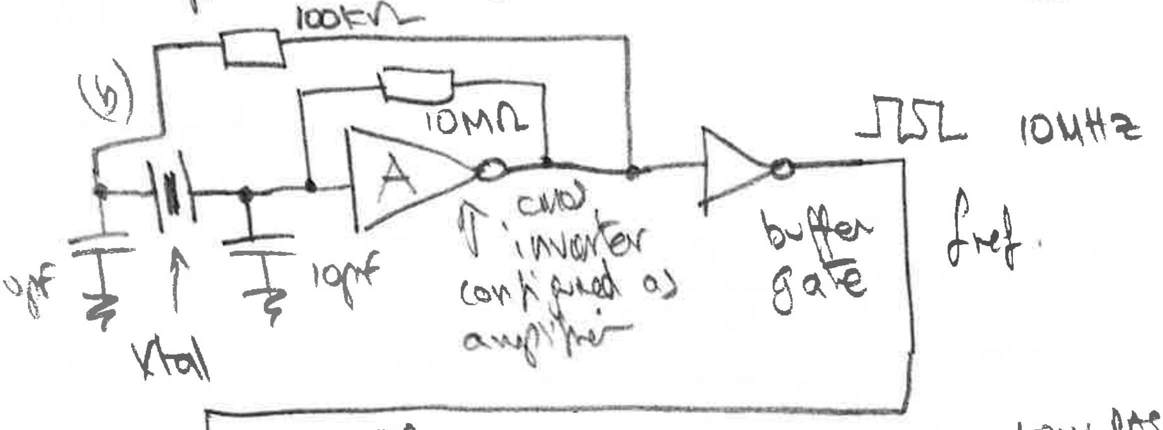
The RF signal is amplified and input to a mixer, which multiplies it by the local oscillator signal. Sum & difference frequencies are produced by the mixer – usually the (lower) difference frequency is selected by the I.F. filter. This is amplified and demodulated to extract the audio information.

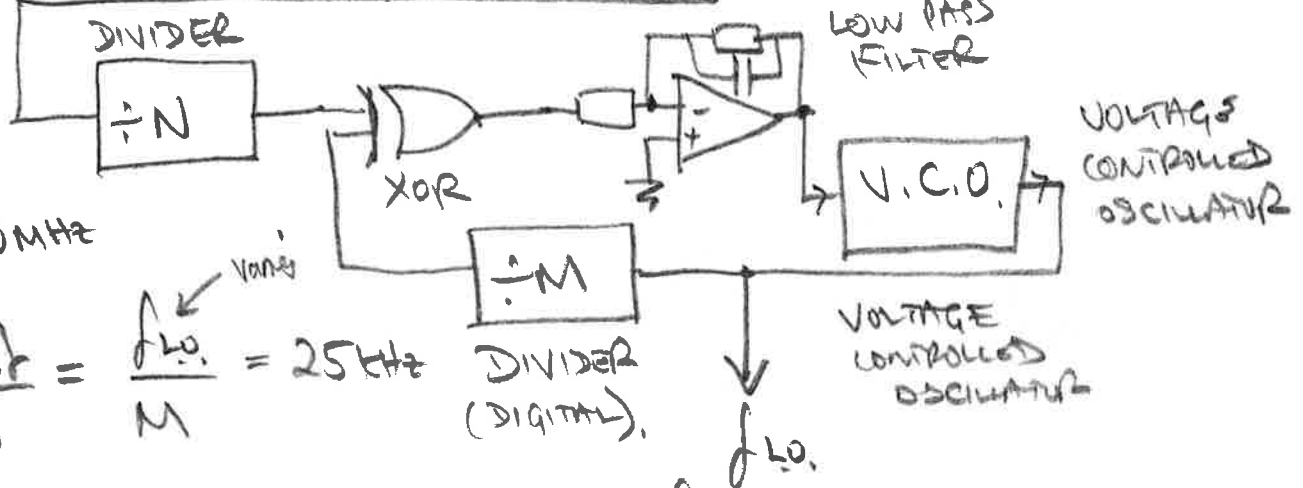
$$f_{IF} = (f_{LO} - f_{RF})$$

To tune the radio, the local oscillator is varied and the 'image rejection' resonant front end resonance is also varied to keep it a fixed (ideally) frequency difference from the local oscillator – this is known as 'tracking'.

[20%]

(b)





10MHz, varies

$$\frac{f_{ref}}{N} = \frac{f_{LO}}{M} = 25\text{kHz}$$

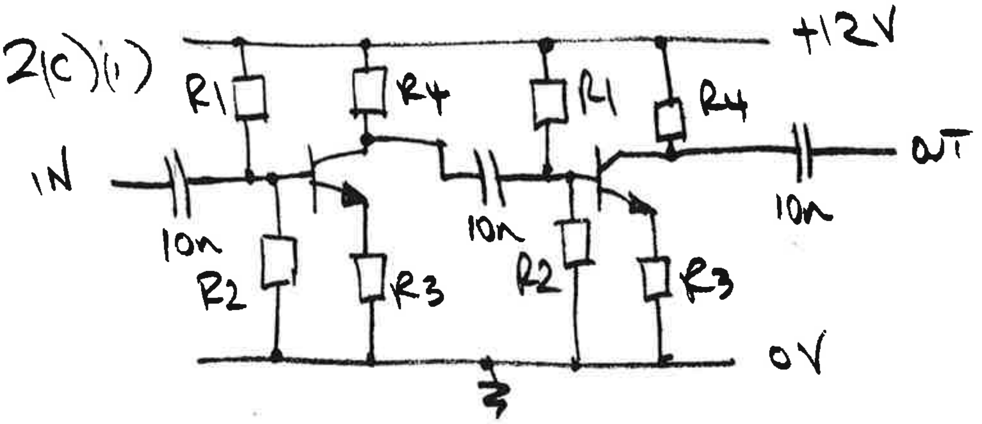
tuning range 120–135MHz ∴ f_{LO} 140–155 MHz

N = 400

M = 5600 – 6200

[20%]

2(c)(i)



cascade 2 identical stages for 30 dB

$\underline{R_4 = 50\,\Omega}$, for 15 dB gain/stage $= \times 5.62$ linear $\times 2$ for loading compensati

$= \times 12$

$\therefore \underline{R_3 = 3.9\,\Omega}$ say $\quad\therefore$ net gain $= \frac{50}{3.9+0.2} = 12.$

$I_c = \frac{50}{12/2} = 0.12\,A \quad \therefore r_e = \frac{0.025}{0.12} = 0.2\,\Omega$

$(\therefore h_{ie} = 50\,\Omega)$.

$\underline{R_2 = 100\,\Omega}$ $(2\times R_i)$.

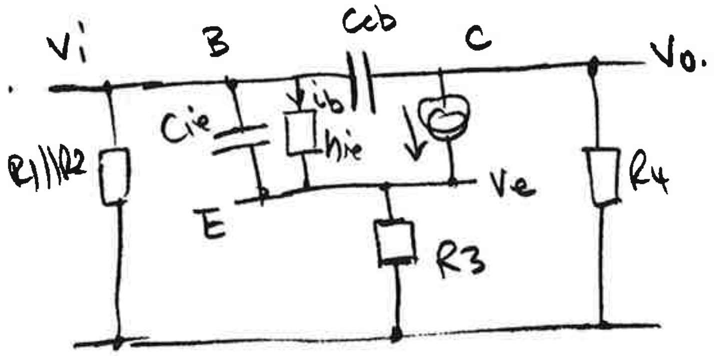
$V_e = 0.12 \times 3.9 = 0.47\,V \quad \therefore +0.65 = 1.1\,V$ for V_{base}.

+10% say for loading

$\therefore \left(\frac{R_2}{R_1+R_2}\right) \times 12 = 1.2 \quad \therefore \underline{R_1 = 910\,\Omega}$

[35%]

(ii) input ssm.



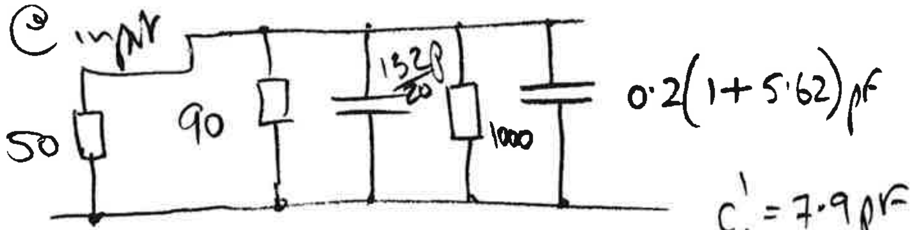
$6 \times 10^9 = \frac{1}{2\pi r_e C_{ie}}$

$\Rightarrow C_{ie} = 132\,pF$

$V_e = V_i \frac{R_3}{R_3 + r_e} = 0.95$

$\therefore$ B-E varies ×20 to grd. for impedance.

@ input



$C' = 7.9\,pF$

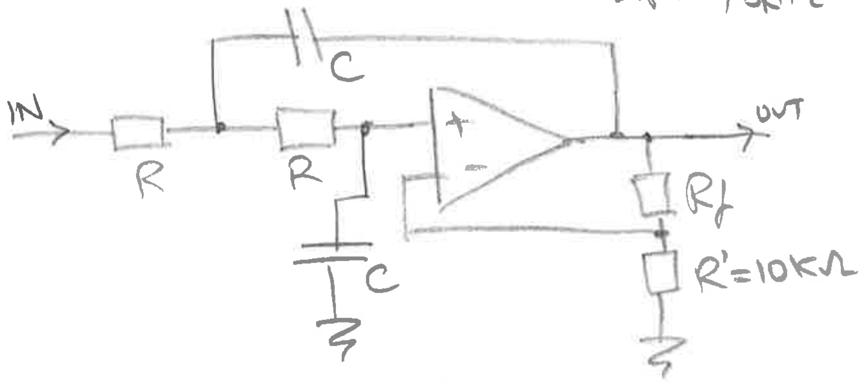
$R' = 31\,\Omega$

$\therefore f_{-3dB} = \frac{1}{2\pi R'C'} = \underline{646\,MHz}$

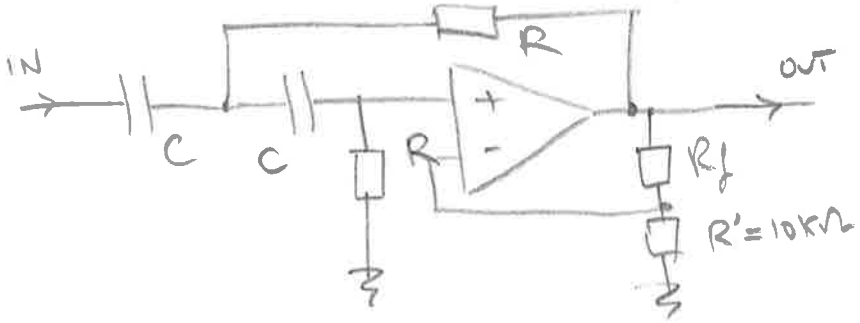
[25%]

✓ o.k.

3(a) Bandpass 0.1–7.5kHz ∴ H.P. 0.1kHz } cascaded.
L.P. 7.5kHz



Low Pass
× 2 stages
(1 & 2)



High Pass
× 2 stages
(3 & 4)

Use <u>Bessel</u> filter for best transient response.

$C = 100\,nF$, for L.P. $7500 = \frac{1}{2\pi f_n RC}$

f_n: 1.432, 1.606

∴ $R =$
148 Ω — ①
132 Ω — ②

for H.P. $100 = \frac{f_n}{2\pi RC}$ ∴ $R =$ 22.8kΩ — ③
25.6kΩ — ④

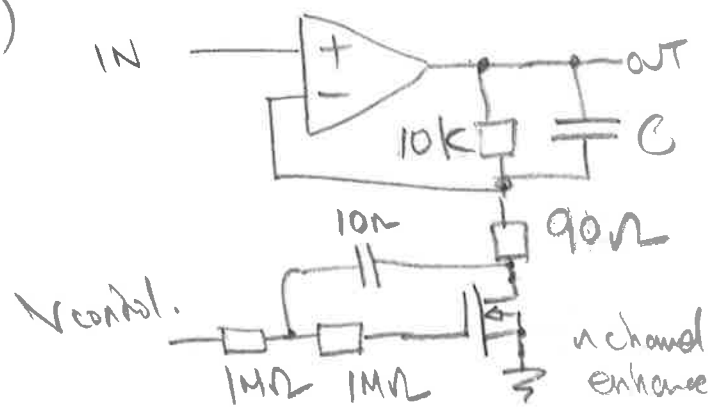
$G = R_f/R' + 1$

①, ③ = 1.084
②, ④ = 1.759

∴ ① R_f = 10 × 0.084 kΩ = 840 Ω
② = 10 × 0.759 kΩ = 7.6 kΩ
③ = 10 × 0.084 kΩ = 840 Ω
④ = 10 × 0.759 kΩ = 7.6 kΩ

[35%]

(b)



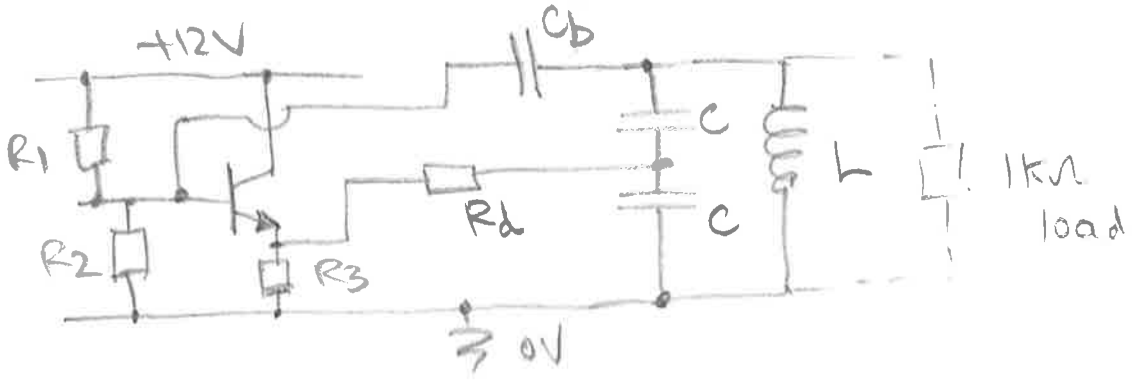
0 – 40 dB = ×1 – ×100 linear gain

- op-amp gain bandwidth >100MHz
- MOSFET $R_{ds\,on} < 10\Omega$ min

n channel enhancement

3(b) contd. $10^6 = \frac{1}{2\pi 10^4 C}$ ∴ $C = 16\,\mathrm{pF}$ [25%]

3(c) more up MOSFET $V_{control} > 2.5\,\mathrm{V}$ for conduction
⇒ higher gain



$C_b = C = 10\,\mathrm{nF}$
∴ for 2 MHz, $f = \frac{1}{2\pi\sqrt{LC/2}}$
∴ $L = 1.27\,\mu\mathrm{H}$

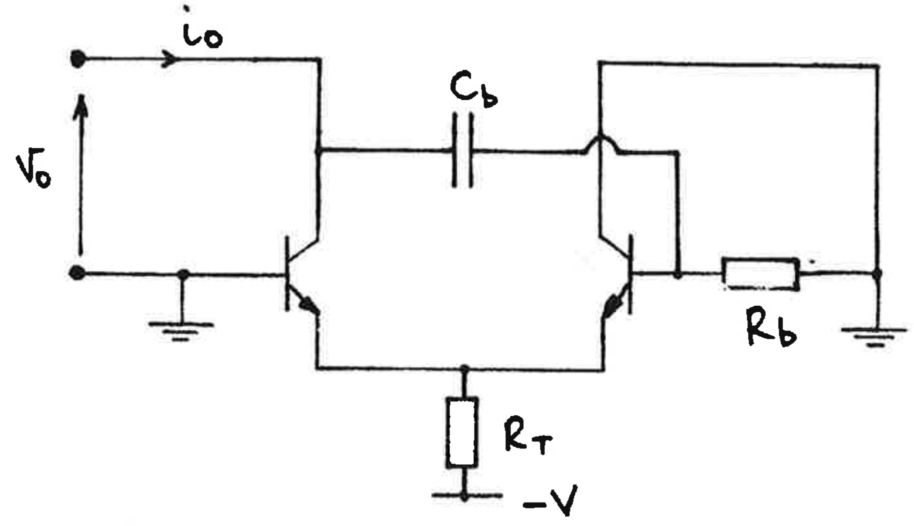
for parasitic losses $R' = \omega L Q \simeq 800\,\Omega \parallel 1\,\mathrm{k}\Omega$ load $\simeq 450\,\Omega$
↑ 50 say.

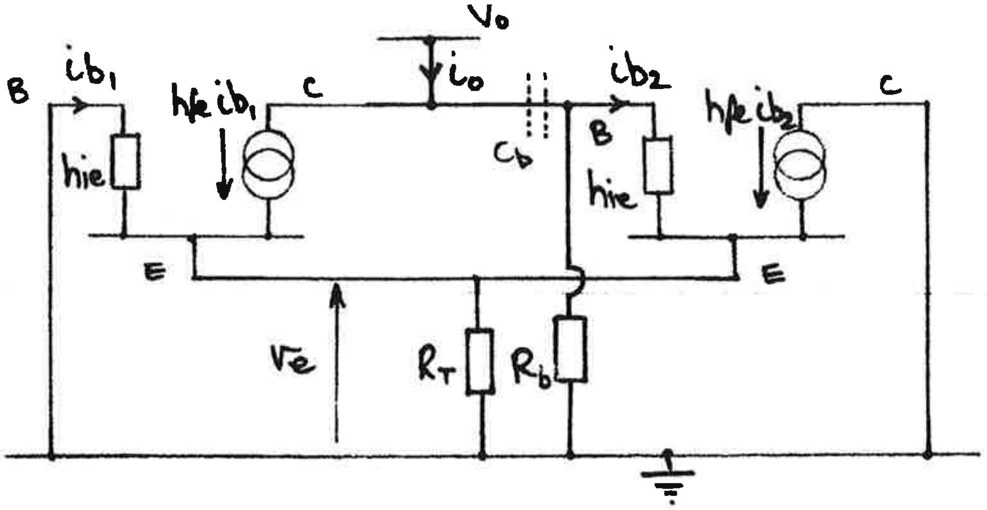
∴ R_1 & R_2 ~ kΩ
$R_3 \sim 450\,\Omega$
$R_d \sim 300\,\Omega$ for loop gain > 1

∴ to set V_e @ ~6V d.c. (½ supply), set $R_1 = R_2$
= 22 kΩ

[20%]

3(d)





① $i_{b1} = \frac{-v_e}{h_{ie}}$, ② $i_{b2} = \frac{V_o - V_e}{h_{ie}}$, ③ $V_e \approx R_T h_{fe}(i_{b1} + i_{b2})$,

④ $i_o = h_{fe} i_{b1} + i_{b2} + V_o/R_b$ Subst. ① and ② into ③:-

$$V_e = -R_T h_{fe} \frac{V_e}{h_{ie}} + R_T h_{fe} \frac{V_o}{h_{ie}} - R_T h_{fe} \frac{V_e}{h_{ie}}$$

small cf. as $R_T \sim h_{ie}$

$$\therefore V_e \left(\cancel{1} + \frac{2 R_T h_{fe}}{h_{ie}} \right) = R_T \frac{h_{fe} V_o}{h_{ie}} \qquad \therefore V_e \approx \frac{V_o}{2} \quad — ⑤$$

subst. ① and ② into ④ and subs. for Ve using ⑤

small cf.

$$\therefore i_o = -\frac{h_{fe} V_o}{2 h_{ie}} + \cancel{\frac{V_o}{2 h_{ie}}} + \frac{V_o}{R_b}$$

$$\therefore i_o = V_o \left(\frac{1}{R_b} - \frac{h_{fe}}{2 h_{ie}} \right)$$ and as $\frac{h_{ie}}{h_{fe}} = r_e$, [20%]

$$Z_o = \frac{V_o}{i_o} = \left(\frac{1}{R_b} + \frac{1}{-2 r_e} \right)^{-1} \Rightarrow Z_o = R_b \| -2 r_e$$

4(a)(i)

$$(2.50 - 2.49)\times10^{9} = \frac{1}{2\pi\sqrt{\underset{100\times10^{-9}}{L}C}}$$

$\therefore C = 2.53\ \text{nf}$ [10%]

(ii) $$Q = \frac{\omega L}{r} = \frac{2\pi \cdot 10\times10^{6} \cdot 100\times10^{-9}}{0.4} = 15.7$$

$$\therefore B/W = \frac{f_0}{Q} = \frac{10\times10^{6}}{15.7} = 637\ \text{kHz}$$ [10%]

3B1 2015 – Assessor's comments

Q1 Antennas & microstrip

The first part on antenna terms was well answered and similarly so for the signal calculation, although some candidates confused the antenna areas or used both the gain and aperture for the same dish. The final part on microstrip design was well attempted by most candidates.

Q2 Superhet, Phase Locked Loop, RF amplifier

The Superhet schematic was known by all candidates and most knew correctly how it was tuned. The phase locked loop presented more of a challenge to some although there were some very good attempts. The final section on amplifier design required a 2 transistor circuit to achieve sufficient gain and bandwidth, which caught out a few people. The bandwidth calculation was nonetheless quite well attempted in general.

Q3 VCVS filter, variable gain amplifier, Colpitts oscillator

Another well answered question in general. Most candidates could design the VCVS filter correctly although a number of candidates did not select the correct type (Bessel). The variable gain amplifier and Colpitts oscillator circuits were also recalled correctly by most, however, the superfluous amplitude feedback components shown in the notes were often included as well.

Q4 Impedance matching, Smith chart

Most attempts correctly evaluated the simple LC resonant circuit values although the Q-factor and bandwidth estimate foxed some people. The Smith chart section was generally well attempted for the first part although the following sections presented more of a challenge and there were only a few correct attempts.

P. A. Robertson (Principal Assessor)