3B1 CRIB 2014

1 (a) $$\frac{P_t G}{2\pi R^2} = \frac{50\times10^3 \cdot 1.5}{2\pi\,(650\times10^3)^2} = \underline{2.83\times10^{-8}\ \mathrm{W\,m^{-2}}}$$

assuming a transmitter antenna gain of 1.5 radiating into a hemi-sphere.

P_r density $= \frac{1}{2}E^2/\eta = \frac{1}{2}H^2\eta$ where $\eta = 120\pi$, $E = \eta H$

$\therefore E = 4.62\times10^{-3}\ \mathrm{V m^{-1}}$

$H = 1.23\times10^{-5}\ \mathrm{A m^{-1}}$ [15%]

(b) $R_r = 80\pi^2\left(\frac{\Delta z}{\lambda}\right)^2$ for ideal dipole, for short dipole with linear current distr^n $R_r = 20\pi^2\left(\frac{\Delta z}{\lambda}\right)^2$

@ 77.5×10^3 Hz and $c_0 = 3\times10^8$ m/s

$c_0 = f\lambda \Rightarrow \lambda = 3871$ m

$$\therefore R_r = 20\pi^2\left(\frac{0.8}{3871}\right)^2 = \underline{8.43\times10^{-6}\ \Omega}$$

efficiency, $e = \frac{R_r}{R_r + R_{ohmic}}$, $R_{ohmic} = \frac{\rho l}{A}$

check skin depth, $\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = 1.65$ mm $\therefore$ aerial wire is fully filled with current.

$$\therefore R_{ohmic} = \frac{\rho \cdot 0.8}{\pi(2\times10^{-3})^2/4} = 0.21\,\Omega \quad \text{with } \rho = \frac{1}{1.2\times10^6}\ \Omega\mathrm{m}$$

$$\therefore e = \frac{8.43\times10^{-6}}{(0.21 + 8.43\times10^{-6})} = \underline{4\times10^{-5} \text{ or } 0.004\%}$$

very low, as expected from such a short antenna.

[25%]

1(c) $D = G/e = 1.5$ with $e = 4\times10^{-5}$ from (b)

$\therefore G = 6\times10^{-5} = \dfrac{4\pi A_e}{\lambda^2}$ antenna eqn.

$\therefore A_e = 71.5\ m^2$

$\therefore$ $V_r = EL$ into open cct. $\therefore$ into R_m matched load $= \dfrac{EL}{2}$

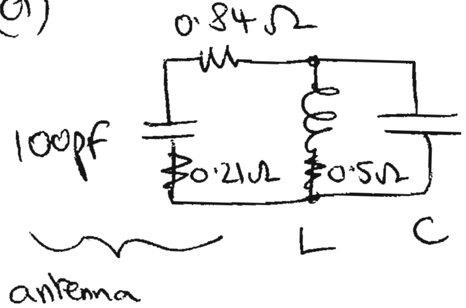
$P_r = \frac{1}{2} A_e E^2/\eta = \dfrac{E^2 L^2}{8R_m}$ $\left(\frac{1}{2}V_r^2/R_m\right)$

$\therefore \dfrac{A_e \cancel{E^2}}{\eta} = \dfrac{\cancel{E^2} L^2}{4R_m}$

$\therefore R_m = \dfrac{\eta L^2}{4A_e} = \dfrac{120\pi\ 0.8^2}{4\times71.5} = 0.84\ \Omega$

Gain $= 6\times10^{-5}$ in dB $= 10\log_{10}(6\times10^{-5}) = -42.2$ dB [40%]

(d)



$L = 100\mu H$

for resonance at 77.5 kHz

$f_{res} = \dfrac{1}{2\pi\sqrt{LC}}$ $\therefore C = 42.2$ nF

$\therefore$ 42.1 nF reqd. Q-factor $= \dfrac{\omega L}{r} = \dfrac{2\pi\ 77.5\times10^3 . 10^{-4}}{0.5}$

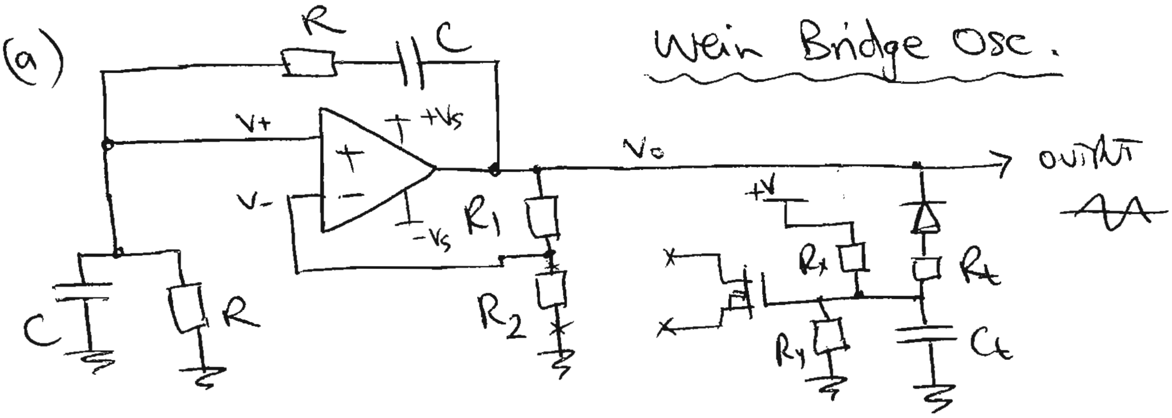
$= 97.4$

(neglecting R_{series} with antenna)
or incl. 0.5% difference → 97 = Q.

Bandwidth $= \dfrac{77.5\times10^3}{97.4} = 796$ Hz

[20%]

2(a) Wein Bridge Osc.



$$V_+ = \frac{\dfrac{V_o R}{1+j\omega CR}}{\dfrac{R}{1+j\omega CR} + R + \dfrac{1}{j\omega C}} = \frac{V_o}{1+\dfrac{R+\frac{1}{j\omega C}}{\frac{R}{1+j\omega CR}}}$$

$$= \frac{V_o}{1+\left(1+\frac{1}{j\omega CR}\right)(1+j\omega CR)} = \frac{V_o}{3+j\omega CR+\frac{1}{j\omega CR}}$$

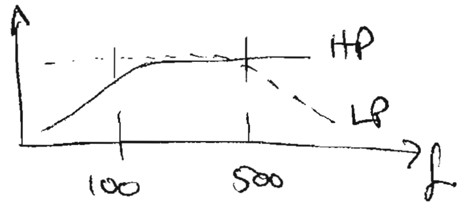
Hence with $\omega = \frac{1}{CR}$ $\quad V_+ = \frac{V_o}{3} = V_- \quad \therefore 1+\frac{R_1}{R_2} = 3$

for stable oscillation and $f = \frac{1}{2\pi RC}$

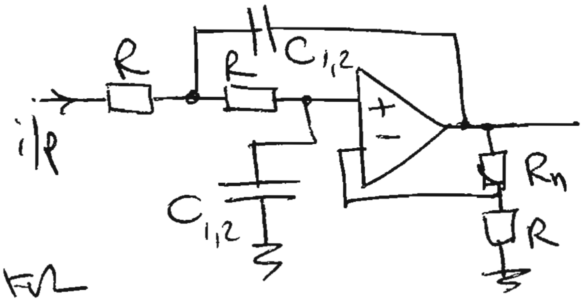
We can use a ntc resistor for R_1 to control gain to limit output, or use a FET/MOSFET as a variable resistance element with amplitude feedback from a diode demodulator. R_x and R_y are bias resistors to set amplitude: initial gain >3 for start-up. Choose R_t and C_t for long time constant to avoid sinewave distortion eg: $R_t = 100k\Omega$, $C_t = 1\mu F$. For 10KHz, $R = 10k\Omega$, $C = 1.59$ nF. Supply ±5V. [35%]

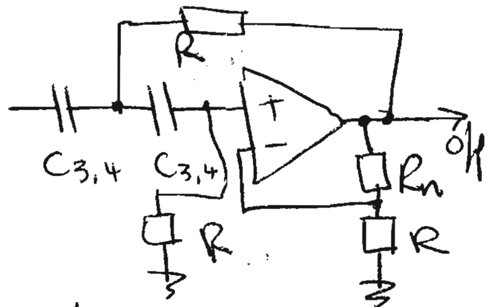
(b) Bandpass filter 100Hz – 500Hz : use Bessel for minimal waveshape distortion (linear phase ≡ constant time delay for all freqs. in pass-band).

HP: 100Hz
LP: 500Hz



2(b)





$R = 10\,k\Omega$

Low Pass High Pass

$R_n = (A-1)R$

Low Pass

stage 1 $\quad 500 = \dfrac{1}{2\pi 10^4 C_1 \, 1.432}$ $\quad \therefore C_1 = 22.2\,nF \quad R_1 = 840$

stage 2 $\quad 500 = \dfrac{1}{2\pi 10^4 C_2 \, 1.606}$ $\quad \therefore C_2 = 19.8\,nF \quad R_2 = 7590$

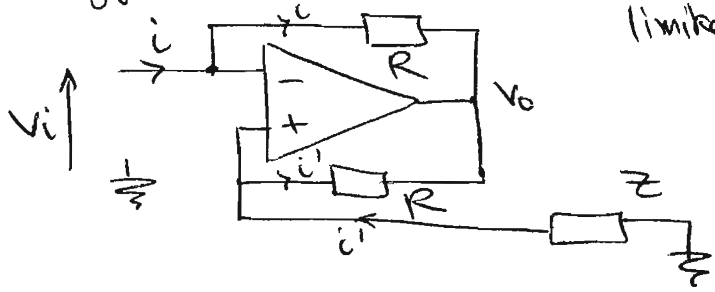
High Pass

stage 3 $\quad 100 = \dfrac{1.432}{2\pi 10^4 C_3}$ $\quad \therefore C_3 = 228\,nF \quad R_3 = 840\,\Omega$

stage 4 $\quad 100 = \dfrac{1.606}{2\pi 10^4 C_4}$ $\quad \therefore C_4 = 256\,nF \quad R_4 = 7590\,\Omega$

[30%]

(c) Negative Impedance Converters (NIC) form the basis of the gyrator circuit to convert a 'C' into 'L'. Inductor synthesis limited by op-amp: slew rate, V limits, freq. response, current limits

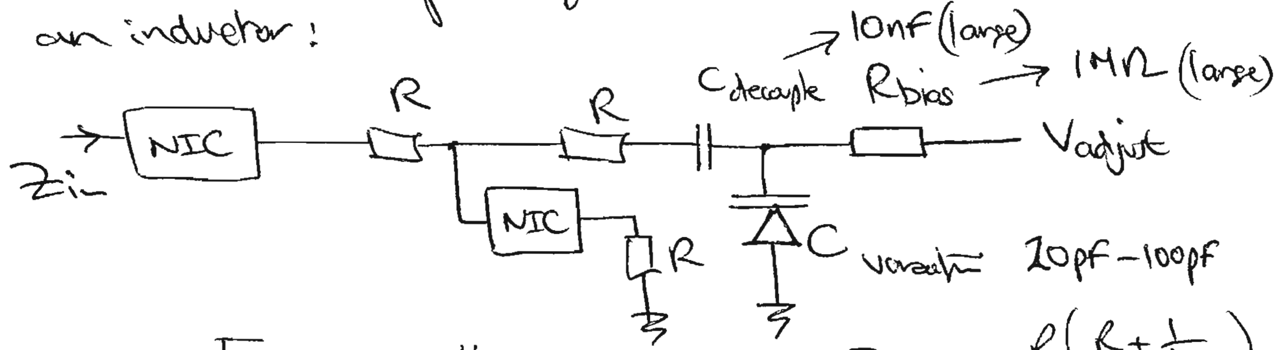


$V_- = V_i = V_+$

$i' = i$

$\therefore Z_{in} = \dfrac{V_i}{i} = -Z$

Interconnect a pair of NICs and R's and C to make an inductor!

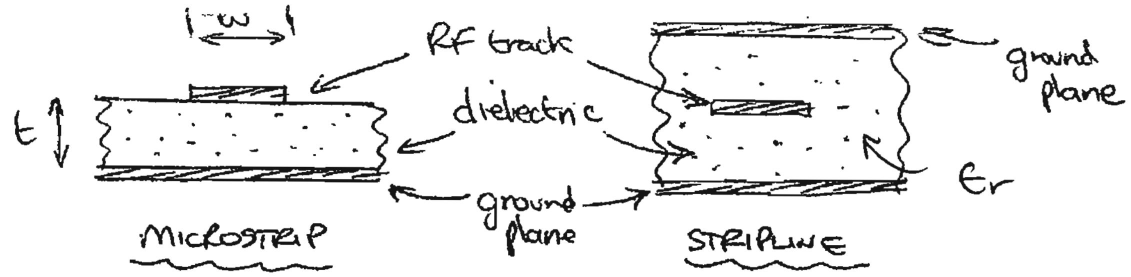


$$Z_{in} = -\left[R + -R \,\|\, R + \frac{1}{j\omega C}\right] = -\left[R + \frac{-R\left(R+\frac{1}{j\omega C}\right)}{-R+R+\frac{1}{j\omega C}}\right]$$

$$= -\left[R - R^2 j\omega C - R\right] = j\omega C R^2 \equiv j\omega L$$

with $L = CR^2$. To vary electronically, use varactor diode for C ...

3(a)



MICROSTRIP	STRIPLINE
• easy to fabricate	• More complex fabrication
• easy for surface mount components / connections	• vias required for connections
• higher radiation losses	• low loss

[10%]

(b) $t = 1.6$ mm $\quad \epsilon_r = 2.3$

Antenna patch $\lambda/2$ for resonance @ 10.6 GHz

$$v = \frac{c_0}{\sqrt{\epsilon_r}} = \frac{3\times10^8}{\sqrt{2.3}} = 1.978\times10^8 \text{ ms}^{-1} = f\lambda$$

$$\therefore \lambda = 0.0187 \text{ m} \qquad \therefore \lambda/2 = 9.33 \text{ mm}$$

square sides

For stripline, C per unit length $= \frac{A\epsilon_0\epsilon_r}{t} = \frac{2(w+2t)\epsilon_0\epsilon_r}{t}$

$$v = 1.978\times10^8 = \frac{1}{\sqrt{LC}} \quad \text{and} \quad Z_0 = \sqrt{\frac{L}{C}} = \frac{1}{vC}$$

$$\therefore Z_0 = \frac{\sqrt{\epsilon_r}\, t}{c_0\, 2(w+2t)\epsilon_0\epsilon_r} = 50\ \Omega$$

with $t = 1.6\times10^{-3}$ $\Rightarrow$ $(w+2t)\,0.4028 = t$

$$\therefore w = 0.77 \text{ mm}$$

[30%]

(c) $0.66\angle{-39^\circ} = (1.4-2j)$ on Smith Chart $\Rightarrow (70-100j)\,\Omega$

(d) length of T-line, $l = (0.196+0.182)\lambda = 0.378\lambda$ [15%]

$$\therefore l = 0.378\times18.7\text{ mm} = 7.07\text{ mm}$$

$j1.75$ to cancel with series capacitor $\equiv -j87.5\ \Omega$

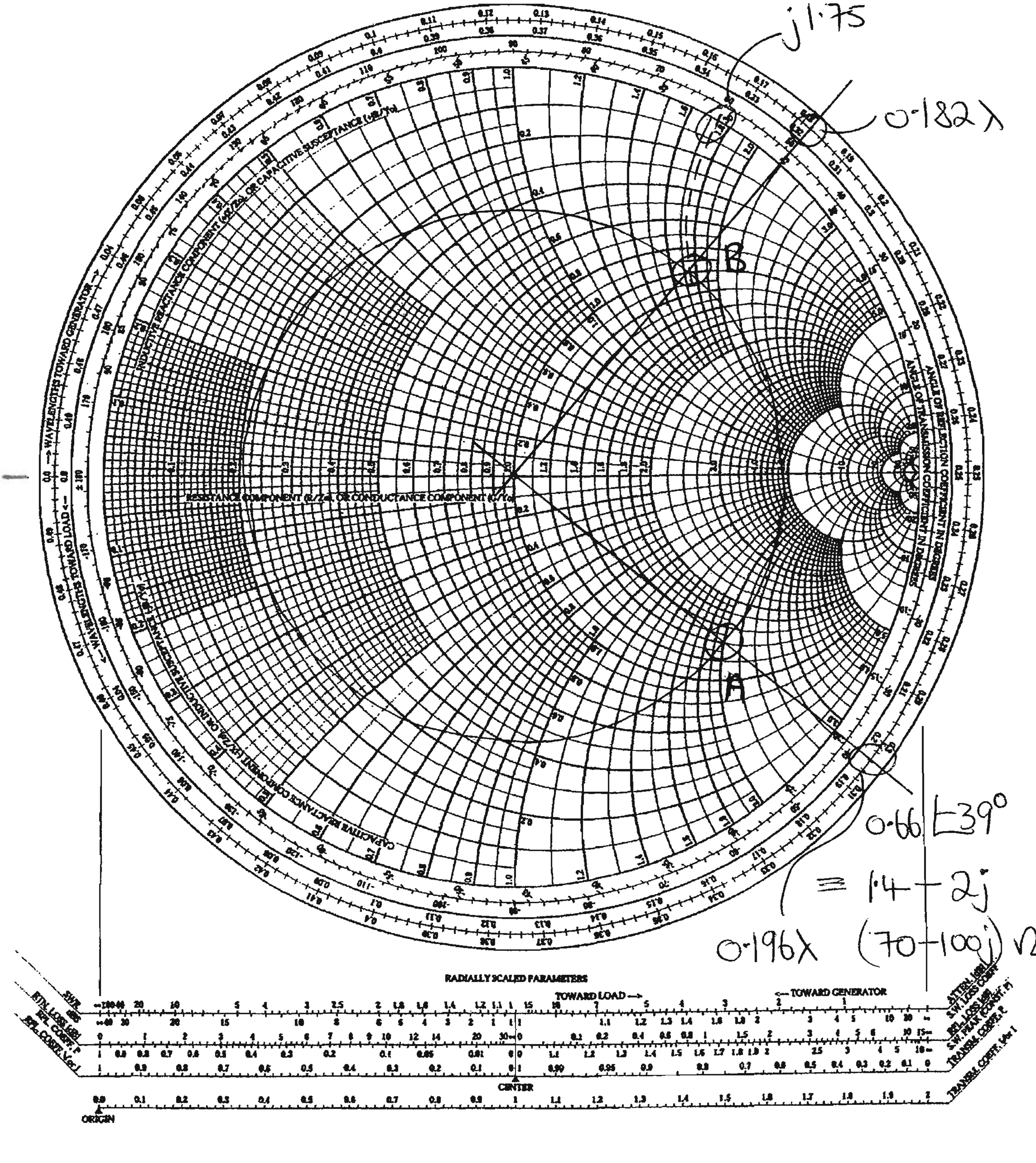
$$87.5 = \frac{1}{2\pi f C} \qquad f = 10.6\times10^9 \text{ Hz}$$

$$\Rightarrow C = 0.172 \text{ pF}$$

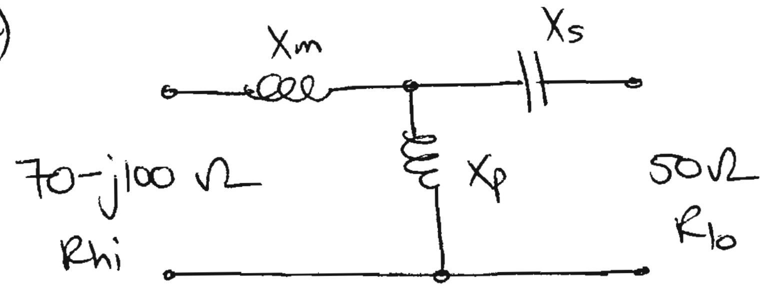
[25%]

3(c)

Chart for question 3; to be detached and handed in with script.



3(e)



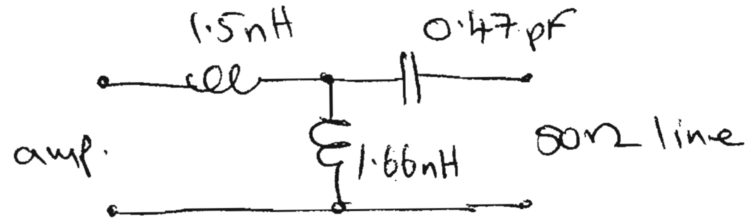
$X_m = j100\ \Omega$ to cancel $-j100\Omega = 2\pi f L_m$

$\therefore \underline{L_m = 1.50\text{ nH}}$

$$Q = \sqrt{\frac{R_{hi}}{R_{lo}} - 1} = 0.632 = \frac{X_s}{\underset{50}{R_{lo}}} = \frac{\overset{70}{R_{hi}}}{X_p}$$

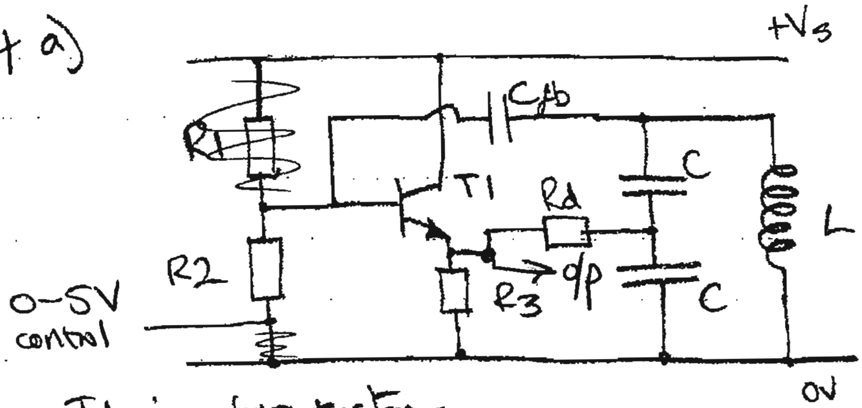
$\therefore X_s = 31.6 = \dfrac{1}{\omega C_s}$ $\qquad \therefore C_s = 0.47\text{ pF}$

$X_p = 110.7 = \omega L_p$ $\qquad \therefore L_p = 1.66\text{ nH}$



[20%]

4 a)



T1 : transistor

R1 + R2 : base bias resistors → can use just R_2 with 0-5V control voltage see (b)

R3 : emitter load resistor

L + C : resonant circuit $f_{res} = \frac{1}{2\pi\sqrt{LC/2}}$

Cfb : feedback capacitor

Rd : drive resistor

LC circuit is maintained in oscillation by transistor buffer. The capacitors mid-point voltage is doubled at resonance and fed back to the transistor base. The buffer has a gain ≈1, hence loop gain is ≈2 (unloaded) - so oscillations start up. The amplitude is limited by the transistor non-linearity at voltage swings approaching the supply rails. The output can be taken from the emitter (low impedance but distorted esp. even harmonics) or the top of L (high impedance loads only - or oscillation will be damped or pulled in frequency).

(b) $27 \times 10^6 = f_{res} = \frac{1}{2\pi\sqrt{LC/2}}$ with $L = 100\,nH,\ C = 695\,pF$

set $R_3 = 300\Omega$ (same as load)

$C_{fb} = 10\,nF$ (large value - appears short cct @ RF.)

with emitter voltage set to $V_S/2 = 4.5V$, then base @ 5.1V for $V_{BE} = 0.6V$. Current through $R_3 = \frac{4.5}{300} = 15\,mA$

$\therefore r_e = \frac{0.025}{0.015} = 1.67\Omega$, as $h_{fe}R_3 \sim 75k\Omega$ so

choose $R_2 = 3.3k\Omega$ say (smaller than $h_{fe}R_3$ but > R_{load})

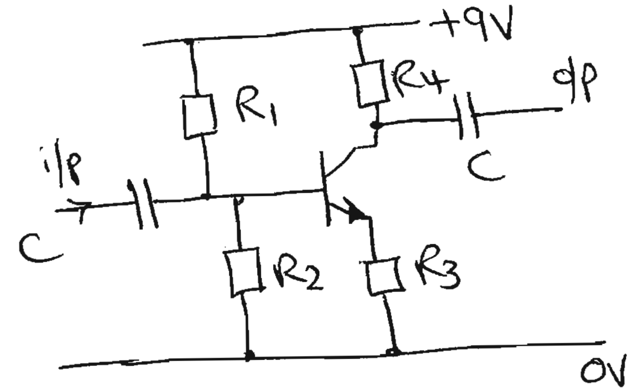
4(b) contd.

So base current $\approx \frac{15\,mA}{250} = 60\,\mu A$, so voltage drop across $R_2 = 60\,\mu A \times 3.3\,k\Omega = 0.2\,V$ ok. ✓

$R_d = \frac{1}{4}\left(3300 \,//\, h_{fe}\frac{R_3}{2} \,/\!/\, \omega L Q\right)$ with $Q = 50$ say

$\approx \frac{664}{4}\,\Omega$. so choose $\underline{150\,\Omega}$

(c)



$R_4 = 300\,\Omega$ to match load

$\underline{C = 1\,nF \text{ (large)}}$

$10\,dB = \times 3.16$ loaded gain $\equiv 6.32$ unloaded

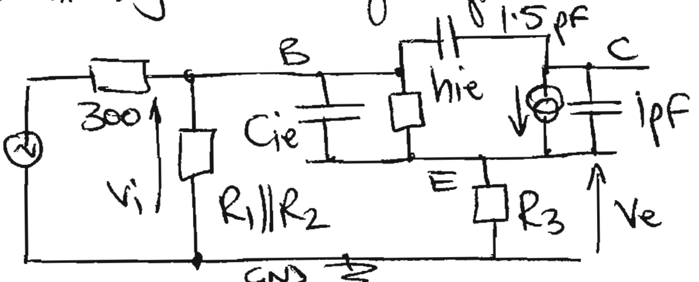
$\therefore \underline{R_3 = 47\,\Omega}$

$r_e = 1.67$ as part (b) with $I_c = 15\,mA$

$\therefore V_E = 0.015 \times 47 = 0.72\,V$ and $V_B = 1.42\,V$ with $V_{BE} = 0.7\,V$

$1.42 = \frac{R_2}{(R_1 + R_2)} \cdot 9$ with $R_2 = 2.2\,k\Omega$ say then $\underline{R_1 = 11\,k\Omega}$

(d) Small sig. model of input cct:

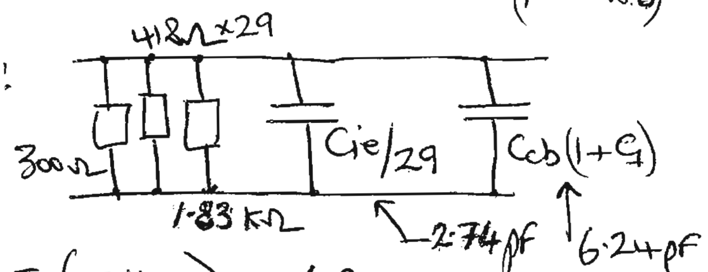


$h_{ie} = h_{fe} r_e = 418\,\Omega$

$\frac{V_e}{V_i} = \frac{R_3}{(R_3 + r_e)} = 0.966$

$\therefore$ impedances B–E referred to B–GND are $\times \frac{1}{(1 - 0.966)} = \times 29$

So input cct. becomes:



Miller effect on $C_{cb} = 1.5\,(3.16 + 1) = 6.24\,pF$

$f_t = \frac{1}{2\pi C_{ie} r_e} = 1.2 \times 10^9 \quad \therefore C_{ie} = 79.4\,pF$ with $r_e = 1.67\,\Omega$

$\therefore f_{-3dB} = \frac{1}{2\pi R' C'}$ with $R' = 252\,\Omega$, $C' = 8.98\,pF$ $\Rightarrow \underline{f_{-3dB} = 70.3\,MHz}$