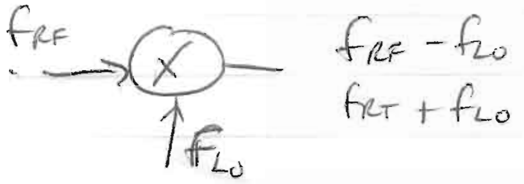
Q1 a) In the superhet there is no way of discriminating between +ve & −ve freq, hence there are multiple combinations of freqs that mix to the same IF



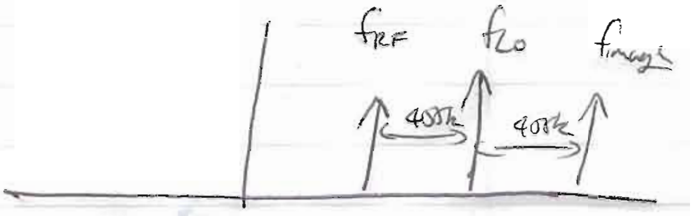
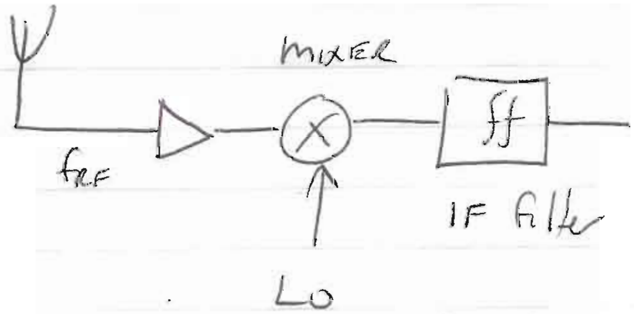


Image rejection is any technique that prevents these unwanted freqs from getting into the IF filter.

eg f_{LO} 1.5MHz $f_{IF} = 455\text{kHz}$ $f_{RF} = f_{LO} - 455\text{kHz} = 1.045\text{ MHz}$

Assume we take $f_{IF} = f_{LO} - f_{RF}$ $f_{imag} = f_{LO} + 455\text{kHz} = 1.955\text{MHz}$

b) Superhet AM

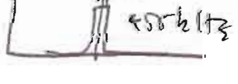


Tuning is formed by the combination of the LO frequency + the mixer. Mixer forms the product of the two input freq

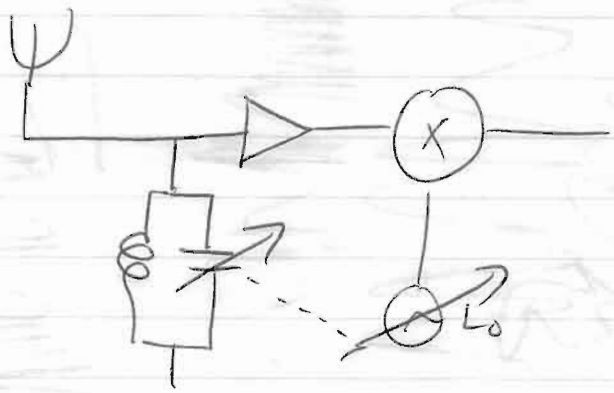
ie $A \rightarrow \otimes \rightarrow A.B$, with B into the mixer

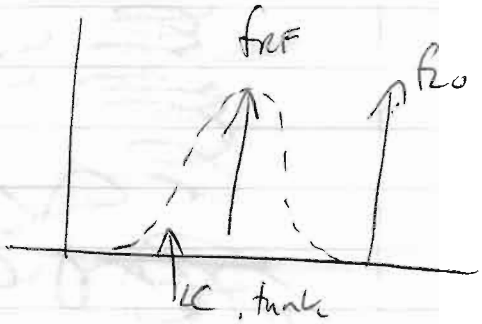
$$= A\sin(\omega_1 t) \times B\sin(\omega_2 t)$$
$$= \tfrac{1}{2}AB\left(\sin(\omega_1+\omega_2)t + \sin(\omega_1-\omega_2)t\right)$$

We take $\omega_1 = LO$ $\omega_2 = RF$ ⇒ tune by filtering out the $\omega_1 - \omega_2$ freq with the IF filter. IF filter is very narrow band to allow only the desired RF band to pass thru.



~~Thevenin~~ Tuning can be modified to include image rejection by adding a tuneable LC tank at the input to the mixer

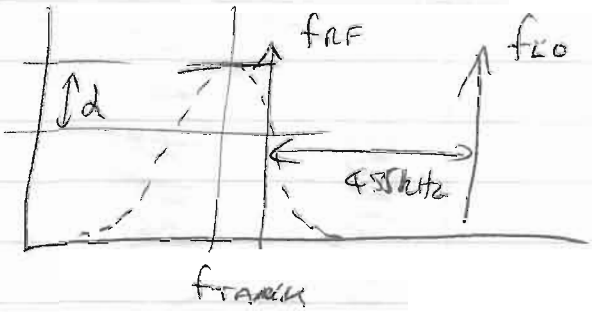




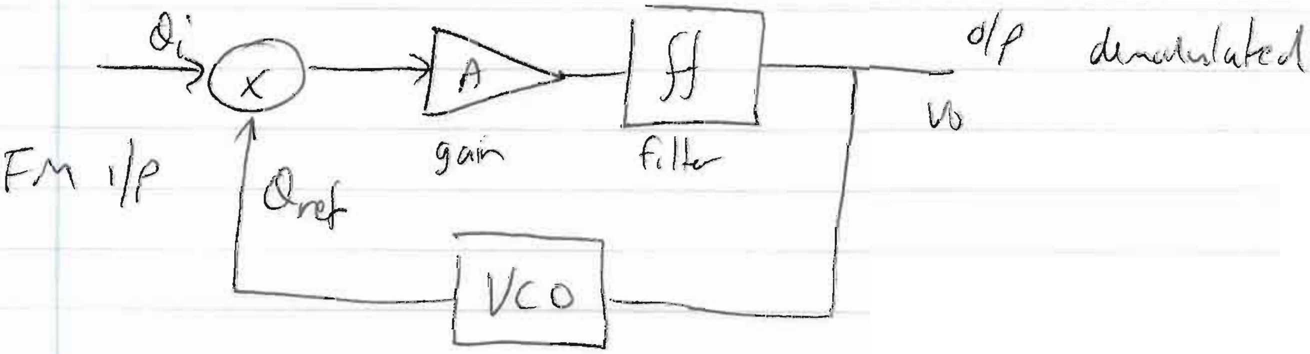
LC tank pre-filters the RF + removes image freq. It requires a good Q tank filter and must track with the tuning of the LO. (tracking)

Tracking depends on LC Q.

If tracking is not set to 455kHz then there will be a loss of signal (α).

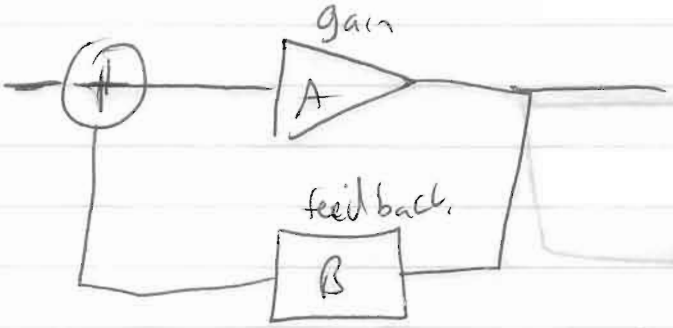


c) FM demodulator can be made from PLL



PLL sets VCO so that $\theta_i - \theta_{ref} = 0$. Hence the control voltage to the VCO is proportional to the freq of the input signal. If the PLL response time is fast enough, then V_0 will track the freq difference ~~&~~ give a demodulated output.

2 a)

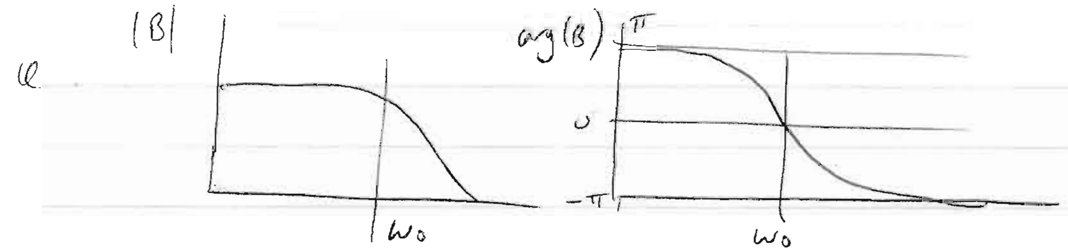


Oscillation condition

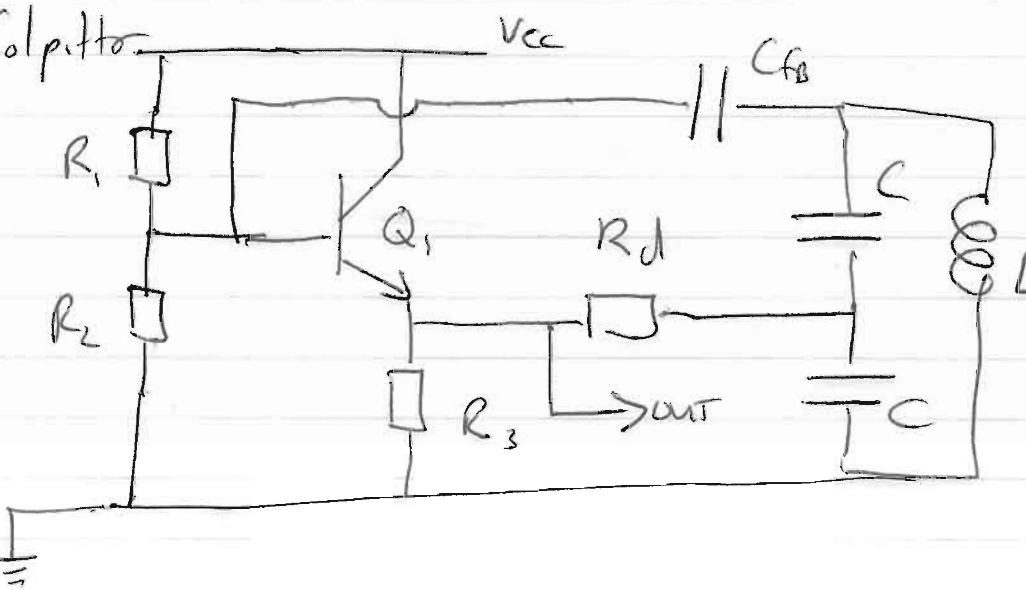
$|A \cdot B| \geq 1$ (loop gain > 1)

$\angle AB = 0$ or $360°$ (loop phase) for positive feed back.

Oscillator is designed by making B a freq dependant network which only satisfies the above condition at a single freq.



b) Colpitts



$f_0 = \dfrac{1}{2\pi\sqrt{LC/2}}$

R_1 + R_2 - base bias Rs

R_3 emitter load

Cfb feed back decoupling capacitor

LCs → resonant tank cct (gain of 2)

Rd → tank drive resistance

LCs provide resonant feedback cct. Split C gives effective gain of x2. Q is emitter follower amplifier.

b) $3\ dBm = 10 \log_{10}\left(\frac{P}{1mW}\right) \Rightarrow P = 2mW$

$= V^2/R$

with 400Ω load $\Rightarrow V = 0.80\ rms$

$V_{p-p} = 2.25V \Rightarrow 5V\ V_{cc}$ is ok.

$f_{osc} = 1.5MHz = \frac{1}{2\pi\sqrt{LC/2}}$ $\quad f_T = 200MHz \gg f_{osc}$ ok

$L = 15\mu H \Rightarrow \frac{C}{2} = \frac{1}{(1.5\times10^6 \times 2\pi)^2 \times 15\times10^{-6}} \Rightarrow \frac{C}{2} = 7.5\times10^{-10} F$

$C = 1.5nF$

to bias emitter at $V_{cc}/2 = 2.5V$ set base at $3.25V$

$\Rightarrow \frac{R_2 \times 5}{R_1 + R_2} = 3.25V$ $\quad$ Choose $R_2 = 100k\Omega$

$\Rightarrow R_1 = 54k\Omega\ (56k\Omega)$

n.b./ or could use $R_1 // R_2 \approx h_{fe}(R_3 // R_L)$ to give similar value

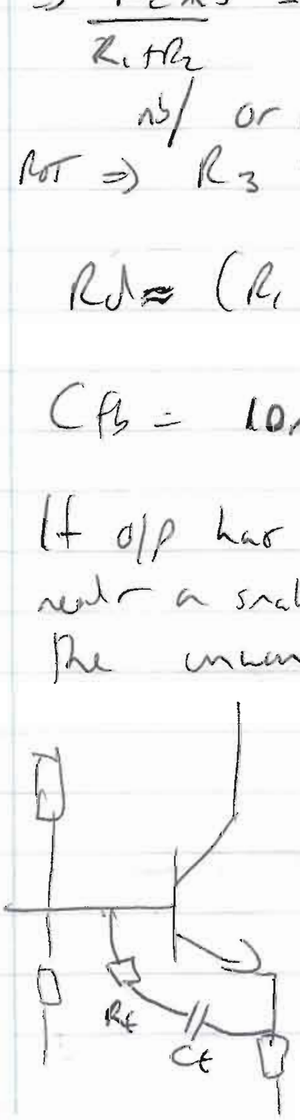
RoT $\Rightarrow R_3 \approx 1.5 \times R_{load} = 1.5 \times 400 = 600\Omega\ (580\Omega)$

$// Q\omega L\ (Q \approx 50)$

$R_d \approx (R_1 // R_2 // h_{fe}R_3 // h_{fe}R_{load})/5 = 4.1\times10^3\Omega \approx 4.7k\Omega$

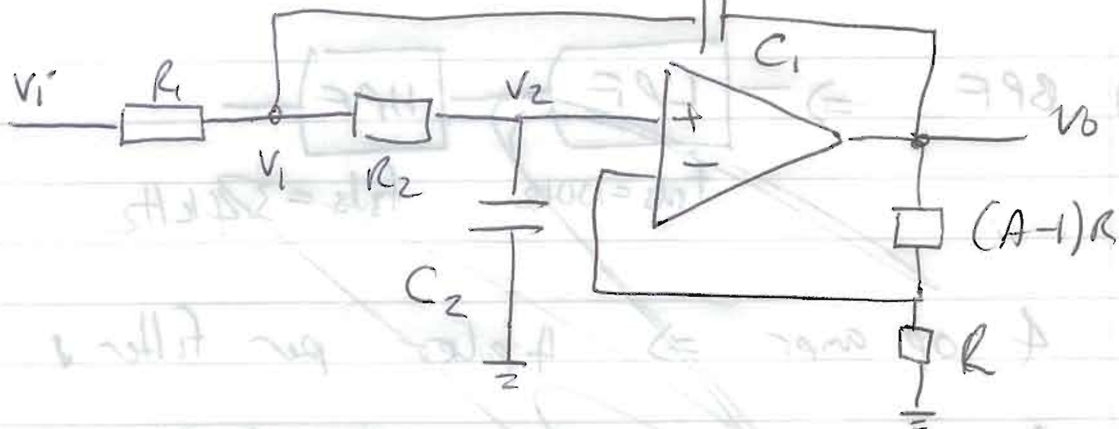
$C_{fb} = 10nF$ (large value so low impedance at $1.5MHz$)

c) If o/p has harmonic distortion, then the emitter follower needs a small amount of -ve feed back to help remove the unwanted harmonics in the cct



$R_f + C_f$ form a simple f/b network. The exact values of $R_f + C_f$ could be calculated based on the value of R_d & the 3rd harmonic freq, but a simpler method is to try different values to see what improves the o/p quality.

3 a)



Assume $R_1 = R_2$ + $C_1 = C_2$ + opamp is ideal.

$\Rightarrow V_0 = AV_1$ (1) Pdivider $\Rightarrow$ $V_2 = \dfrac{1/j\omega C\, V_1}{R_2 + 1/j\omega C} = \dfrac{V_1}{1+j\omega CR}$ (2)

Summing currents at the V_1 node we have:

$$\frac{V_i - V_1}{R} = \frac{V_1 - V_0}{1/j\omega C} + \frac{V_1 - V_2}{R} \Rightarrow V_i = V_1(2+j\omega CR) - V_0 j\omega CR - V_2$$

Sub for V_1 + V_2 from (1) + (2)

$$\Rightarrow V_i = \left(\frac{1+j\omega CR}{A}\right) V_0 (2+j\omega CR) - V_0 j\omega CR - V_0/A$$

$$= \frac{V_0}{A}\left[1 - (\omega CR)^2 + j\omega CR(3-A)\right]$$

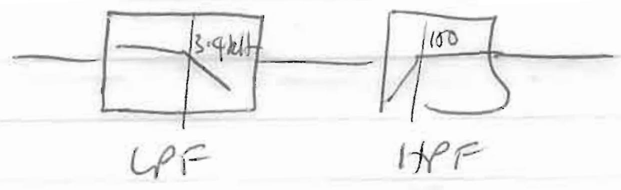
$$\Rightarrow \left|\frac{V_0}{V_i}\right| = A\left[\left(1-(\omega CR)^2\right)^2 + (\omega CR)^2(3-A)^2\right]^{-1/2}$$

$$= A\left[1 + (\omega CR)^2\left[(3-A)^2 - 2\right] + (\omega CR)^4\right]^{-1/2}$$

$$= A\left[1 + \left(\frac{\omega}{\omega_n}\right)^2 B + \left(\frac{\omega}{\omega_n}\right)^4\right]^{-1/2}$$

where $\omega_n = \dfrac{1}{RC}$ + $B = (3-A)^2 - 2$

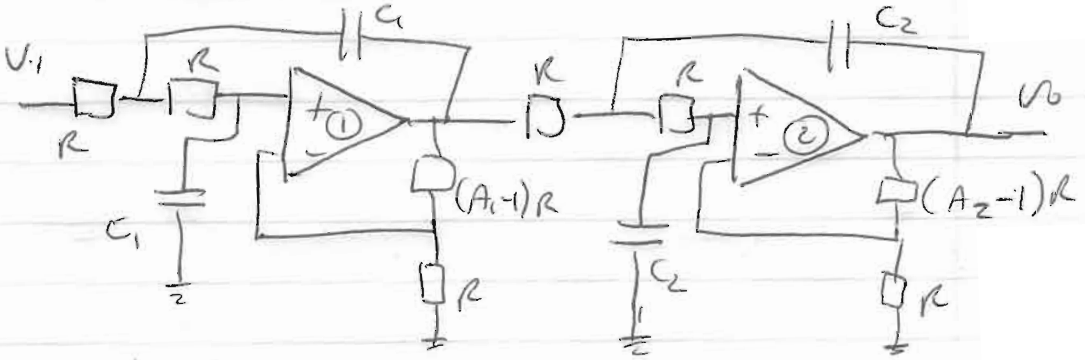
b) BPF



4 op amps
$\Rightarrow$ 4 poles/filter

No ripple in passband $\Rightarrow$ Bessel filter 4 poles.

LPF stage



Choose $R = 10k\Omega$

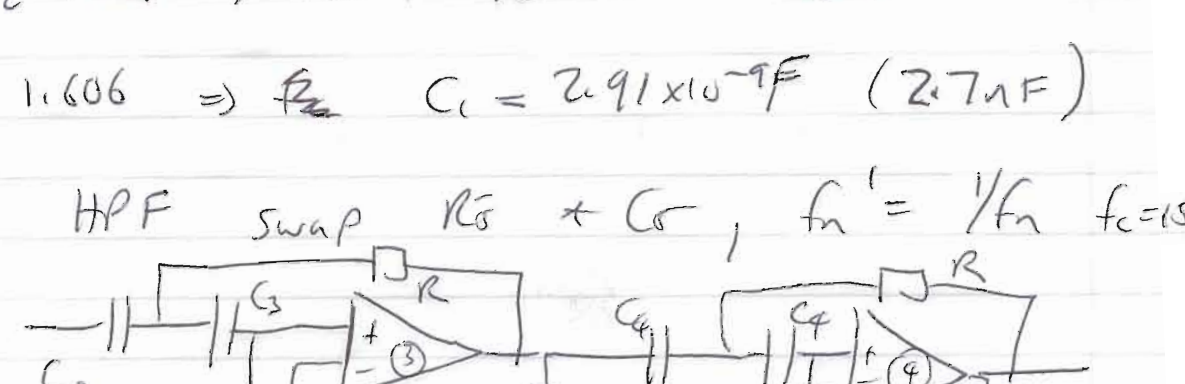
(1) $A_1 = 1.084 \Rightarrow (A_1-1)R = 840\Omega$ (820Ω)

$f_n = 1.432$ $f_c = \dfrac{1}{2\pi R C_1 f_n}$ $f_c = 3.4kHz \Rightarrow C_1 = 3.27\times10^{-9}F$
$(3.3nF)$

(2) $A_2 = 1.759 \Rightarrow (A_2-1)R = 7.6\times10^3\Omega$ $(8.2k\Omega)$

$f_n = 1.606 \Rightarrow$ $C_1 = 2.91\times10^{-9}F$ $(2.7nF)$

For HPF swap R's + C's, $f_n' = 1/f_n$ $f_c = 150Hz$



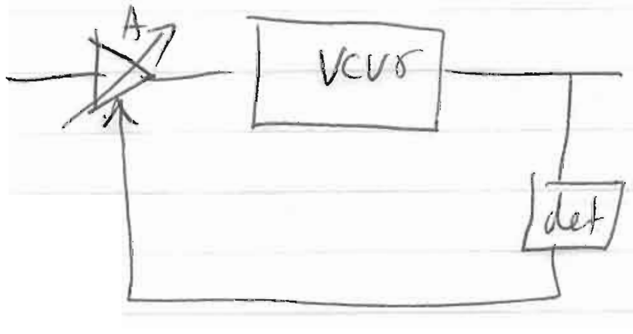
(3) $A_3 = 1.084 \Rightarrow (A_3-1)R = 840\Omega$ (820Ω)

$f_n' = \frac{1}{1.432} = 0.698 \Rightarrow C_3 = 1.15\times10^{-7}F$ $(150nF)$

$A_4 = 1.759$ $(A_4-1)R = 7.6k\Omega$ $(8.2k\Omega)$

$f_n' = \frac{1}{1.606} = 0.622$ $C_4 = 1.7\times10^{-7}F$ $(180nF)$

c) The pass band could be flattened further by adding some sort of AGC system to the filter. The simplest method would be to add a variable gain element before the VCVS & then control the gain via a MOSFET or a variable R.

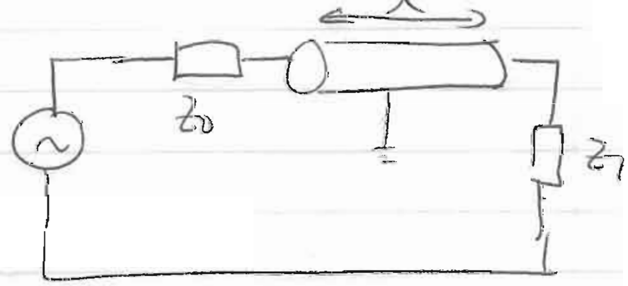


The detection cct must be very sensitive (possibly a differential system) to control the gain very accurately.

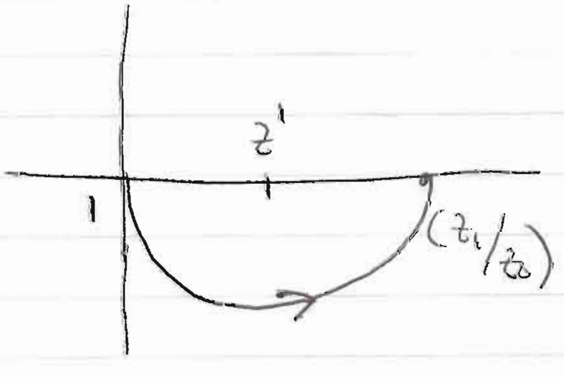
It is also possible to tweak the gains of the VCVS itself by a small amount.

Q4 a) Quarter-wave match

$$Z' = \sqrt{Z_0 Z_1}$$

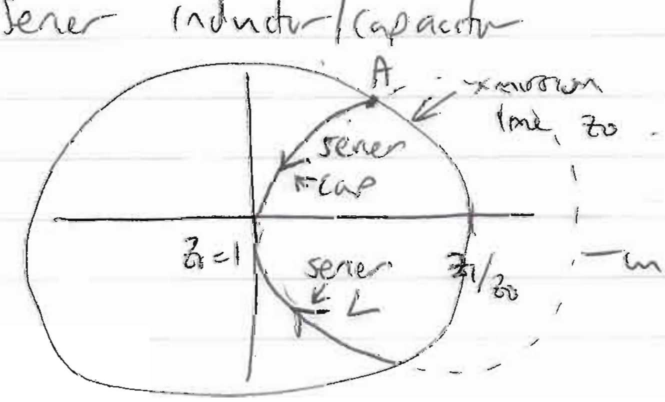


$Z_1 > Z_0$



Xmission line length plots a circle on the Smith chart from Z_0 (1) to Z_1/Z_0. This will be $l = \lambda/4$ of xmission line ~~[illegible]~~ with char impedance of Z'

ii) Series inductor/capacitor



Point A is the intersection of the Z_0 Xmission line with the unit circle. This defines series ~~inductor~~ cap or capacitor to get to the unity point. Lower intersection point defines a series inductor. Clockwise gives length of Xmission line required.

b) Capacitance $C = \frac{A\epsilon}{d} = \frac{(w+2d)\epsilon_0\epsilon_r}{d}$

The 2d component allows for the effects of fringing fields.

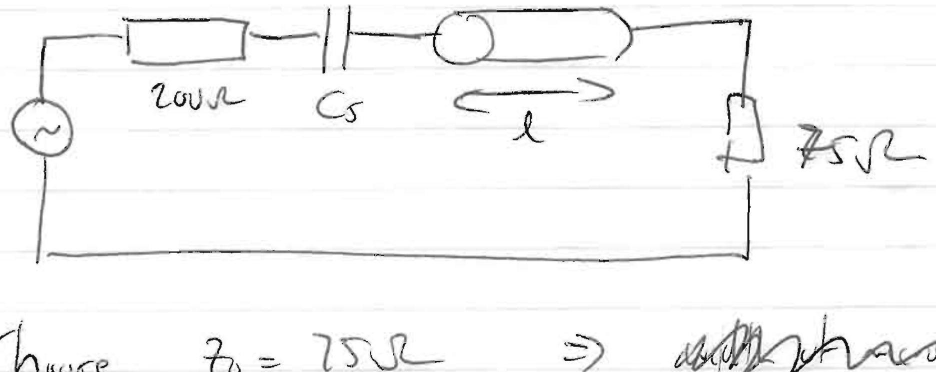
$Z_0 = \sqrt{\frac{L}{C}}$ $\qquad v = \frac{1}{\sqrt{LC}}$ $\qquad c_0 = \frac{1}{\sqrt{\mu_0\epsilon_0}}$

$\Rightarrow$ velocity $v = \frac{1}{\sqrt{\epsilon_0\epsilon_r\mu_0}} = \frac{c_0}{\sqrt{\epsilon_r}}$ $\quad (\mu_r = 1)$

$$Z_0 = \sqrt{\frac{L}{C}} = \frac{1}{vC} = \frac{d}{\epsilon_0\epsilon_r(w+2d)} \times \frac{\sqrt{\epsilon_r}}{c_0}$$

$$= \frac{d}{(w+2d)c_0\epsilon_0\sqrt{\epsilon_r}}$$

c)



Choose $Z_0 = 75\Omega$ $\Rightarrow$

$$75 = \frac{d}{(2d + 0.5\times10^{-3})\,3\times10^{8}\times 8.85\times10^{-12}\times\sqrt{3.7}}$$

Thickness of PCB $\Rightarrow d = 0.82\,mm$

Choose $Z_0 = 200\,\Omega$ * $\Rightarrow Z_L = 75\,\Omega$

*see smith chart. normalised $= 0.375$

For series cap $X_S = 1.58 \times 200 = 316 = \frac{1}{\omega C_S}$

$\Rightarrow C_S = \frac{1}{\omega X_S} = \frac{1}{2\times\pi\times1.8\times10^9\times318} = 0.28\,pF$

length of μstrip $l_C = 0.178\lambda$ $\quad \lambda = \frac{v}{f} = \frac{c_0}{f\sqrt{\varepsilon_r}} = \frac{3\times10^8}{1.8\times10^9\sqrt{3.7}}$

$= 86.6\,mm$

$l_C = 0.178\lambda = 15.4\,mm$

length is ok, but series cap is very small & difficult to fabricate

c) DC power $\Rightarrow$ need series inductance (point B)

$\Rightarrow X_L = 1.58 \times 200 = 316\,\Omega = \omega L_S$

$\Rightarrow L_S = 316/\omega = 316/2\pi\times1.8\times10^9 = 28\,nH.$

$l_L = 0.315\lambda = 0.315 \times 86.6 = 27.3\,mm$

* nb also could choose $Z_0 = 75\,\Omega \Rightarrow$ normalised to give 2.67. This gives a similar plot on the smith chart, but be careful of the direction to source / generator

From chart get cap path $1.05j$

$\Rightarrow C = 1.12\,pF$

Length $= 0.413\lambda \Rightarrow l = 35.8\,mm$

The Complete Smith Chart

Black Magic Design

Series Cap = -1.58j