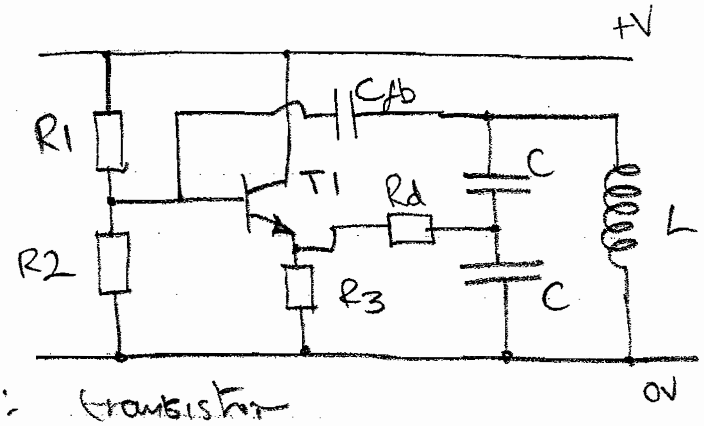
PART IIA 2007
3B1 Radio frequency electronics
Dr P Robertson

1. a)



T1 : transistor
R1 + R2 : base bias resistors
R3 : emitter load resistor
L + C : resonant circuit $\quad f_{res} = \frac{1}{2\pi\sqrt{L\,C/2}}$
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 $\simeq 1$, hence loop gain is $\simeq 2$ (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 oscillations will be damped or pulled in frequency).

b) $\quad f_{res} = 434\,\text{MHz} = \dfrac{1}{2\pi\sqrt{L\,\frac{220\times10^{-12}}{2}}} \quad \therefore L = 1.22\,\text{nH}$

Power level: 2mW into 100Ω, low impedance ∴ take output from the emitter. $\quad P = V^2/R$

$2\times10^{-3} = V^2/100 \quad \therefore V = 0.45\,\text{V}_{rms}$

$\equiv 1.26\,\text{V}_{pp}$ ✓ ok.

as less than 2/3 of supply

1b) cont.

Choose $R_3 = 220\,\Omega$ (twice load resistance)
$C_{fb} = 10\,nF$ (large compared to C)
$C = 220\,pF$

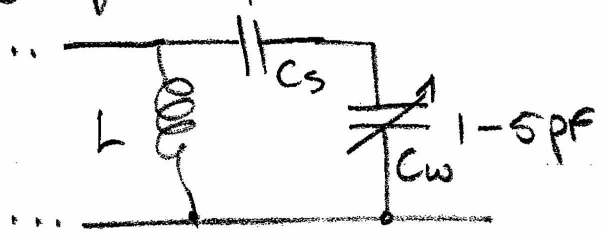
$\omega L = 3.3\,\Omega \Rightarrow$ assuming Q factor of 50, gives a parasitic load of $\simeq 170\,\Omega$. Hence $R_d \lesssim \frac{170}{4} = 33\,\Omega$ say

Choose R1 & R_2 to bias the emitter at $\frac{3.3}{2}V$, taking $V_{BE} = 0.65V \Rightarrow V_B = 2.3V$.

So choose $R_1 = 1\,k\Omega$ & $2.3 = 3.3 \cdot \frac{R_2}{1000 + R_2}$ $\therefore R_2 = 2.3k\Omega$

c) wind speed signal = $1V_{pp}$ @ 10 – 100 Hz : AM
wind dirn. signal = 1 – 5 pF = C_ω : FM

Taking FM case first, we must connect C_ω across the LC tank cct. But for 2MHz FM on a carrier of 434 MHz, $\frac{\Delta f}{f} \simeq 0.5\%$ $\therefore \frac{\Delta C}{C/2} \simeq 1\%$ for correct modulation swing. So, the LC tank must see a capacitance swing of ~1 pF. We achieve this with a series capacitor ...



With a little thought, we can see Cs should be approx. 2pF
2pF in series 1 pF = 0.66pF
2pF in series 5pF = 1.43pF
$\rightarrow$ 0.77pF by guessing or we can solve by eqn.

$$\Delta C = 1 = \left(\frac{1}{C_s} + \frac{1}{5}\right)^{-1} - \left(\frac{1}{C_s} + \frac{1}{1}\right)^{-1}$$

30

1 c) cont.

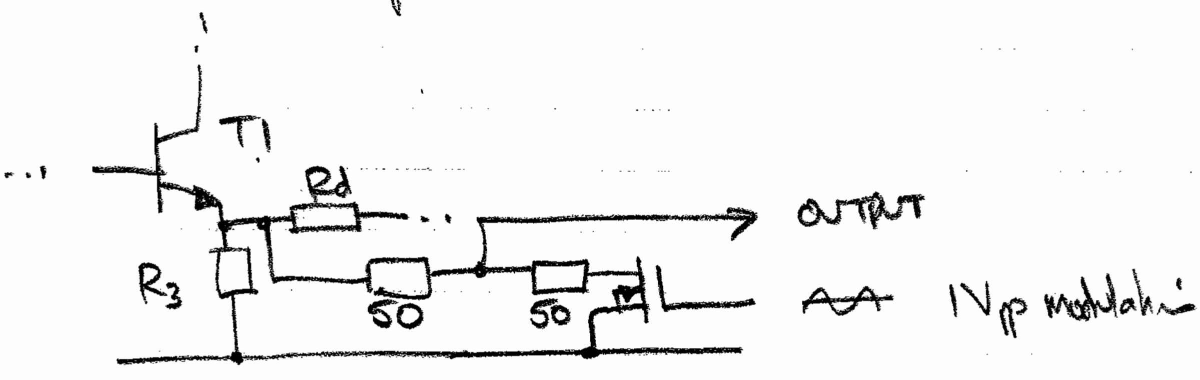
$$1 = \frac{5C_s}{5+C_s} - \frac{C_s}{1+C_s}$$

$$(5+C_s)(1+C_s) = 5C_s(1+C_s) - C_s(5+C_s)$$
$$5 + 6C_s + C_s^2 = \cancel{5C_s} + \cancel{5}\,4C_s^2 - \cancel{5C_s} - C_s^2$$

$$\therefore\ 3C_s^2 - 6C_s - 5 = 0$$
$$\therefore\ C_s = \frac{6 \pm \sqrt{36+60}}{6} \Rightarrow C_s = 2{\cdot}63\ \text{pf}$$

$$\Delta C = 1{\cdot}72\,\text{pf} \rightarrow 0{\cdot}72\,\text{pf} \qquad (1\text{pF}).$$

for the amplitude modulation, we need 1V_{pp} to modulate the output by ~50% ∴ use a (MOS) FET or bipolar transistor potential divider on the output:-



(or, more elegantly, the main oscillator transistor base bias could be modulated through ~1kΩ resistor).

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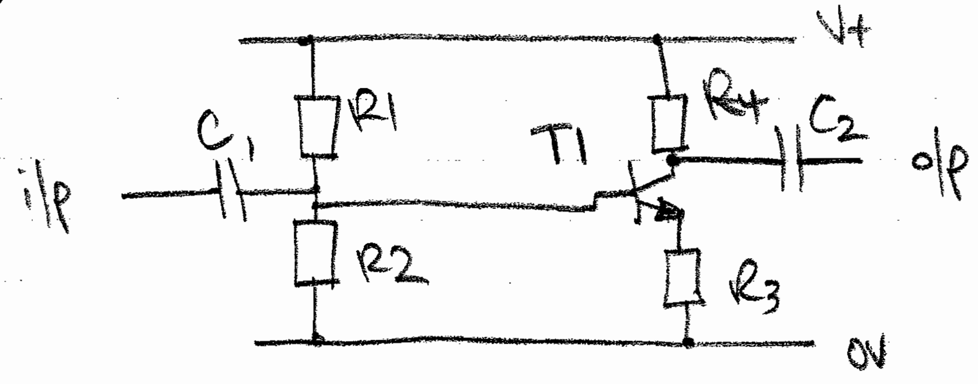
2 a)



R1, R2 base bias resistors : define input impedance and aim to set $V_c \simeq V_{supply}/2$

R3 emitter resistor : to define gain $-R_4/R_3$ and provide -ve feedback for bias stability

R4 collector load resistor : defines output impedance and gain

C1, C2 coupling capacitors : block dc levels from source and/or load from transistor bias point

b) $R_{in} = R_{out} = 100\Omega$
2mW input $\Rightarrow$ 200 mW output for 20dB (×10) gain

$R_4 = 100\Omega$ for output impedance $= 100\Omega$
$R_3 = 2.5\Omega$ for gain of ×40 unloaded = ×10 loaded at output & input

$0.2W = P = V^2/100 \quad \therefore V_{rms} = 4.5V \simeq 13V_{pp}$.
✓ ok for 20V supply

$\therefore$ set $V_c = 10V \quad \therefore V_B = 10.7V$ for $V_{BE} = 0.7V$

$\therefore \frac{R_2}{R_1 + R_2} \times 20V \simeq 12V$ (allowing for base loading)

2b) contd.

$\therefore$ choose $\underline{R_1 = 220\Omega}$ ($\approx 2\times$ input impedance reqd.)

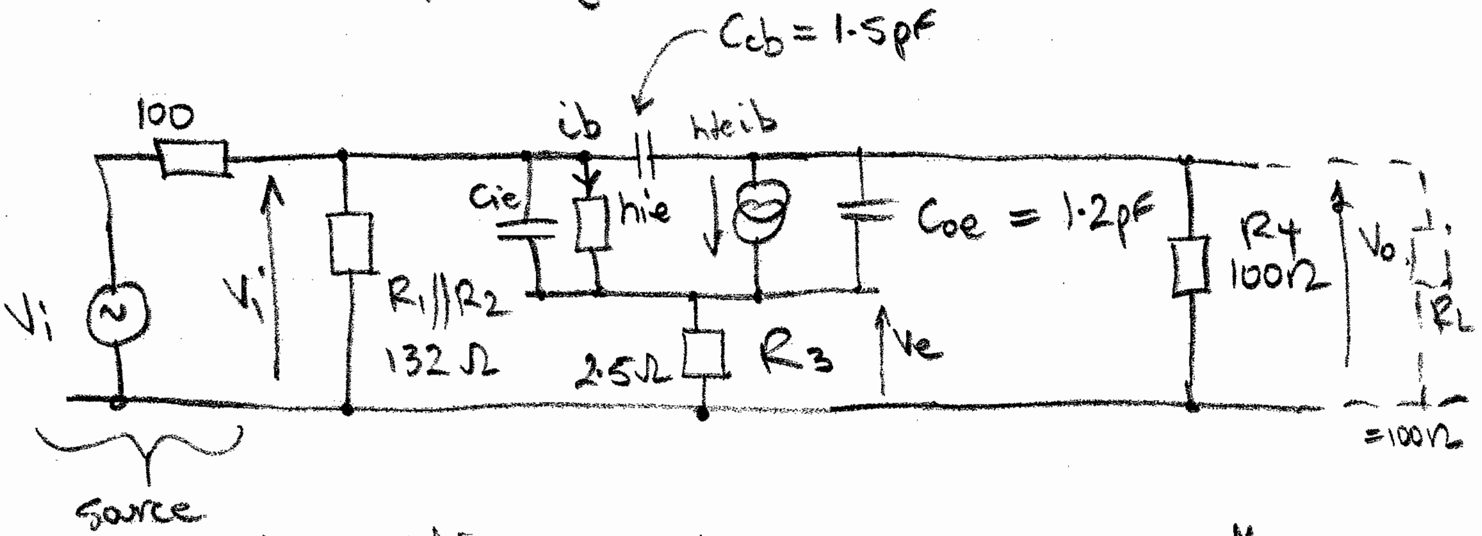
$$0.6 = \frac{R_2}{220 + R_2} \Rightarrow \underline{R_2 \approx 330\Omega}$$

note:- $220 \| 330 \| h_{fe} \cdot R_3 = 120\Omega$ ✓ o.k.
(could reduce $R_1 + R_2$, or shunt with 620Ω for better match to 100Ω).

choose C_1 & C_2 to be small impedance at 400 MHz + eg: $\frac{1}{2\pi f C} \lesssim 1\Omega$ $\quad \underline{\therefore C_{1,2} \sim 1nF}$

note: $I_c = 100\,mA$ $\therefore$ $\underline{r_e = 0.25\Omega}$, so could reduce R_3 to compensate.

c) Now consider small signal model of input to see roll-off frequency:



Net amplifier gain $\frac{V_i}{V_o} = -20$ $\therefore$ Miller effect on

$C_{cb} = 0.25\,pF \times 21 \approx 3.2\,pF$

From $f_T = 18\,GHz = \frac{1}{2\pi C_{ie} r_e}$ ($r_e = 0.25\Omega$)

$\therefore C_{ie} = 35\,pF$ and $h_{ie} = h_{fe} \cdot r_e = 63\Omega$

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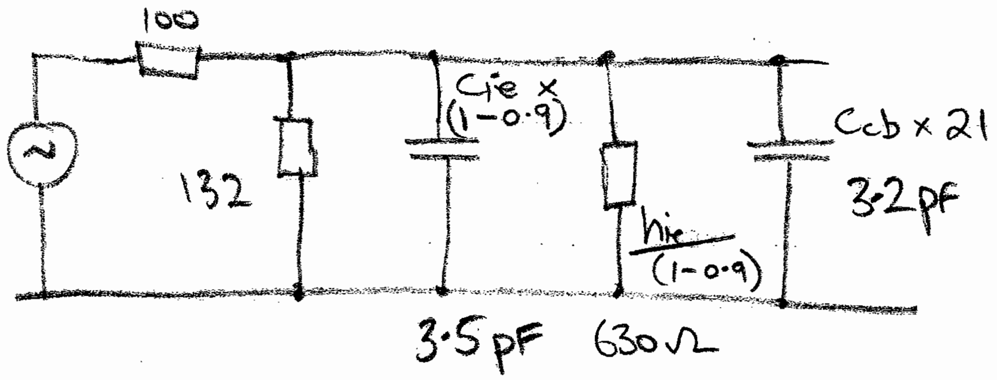
2c) cont'd.

$$V_e \approx \frac{R_3}{R_3 + r_e} V_i = 0.9\, V_i$$ hence small signal model, with components referred to ground ⇒



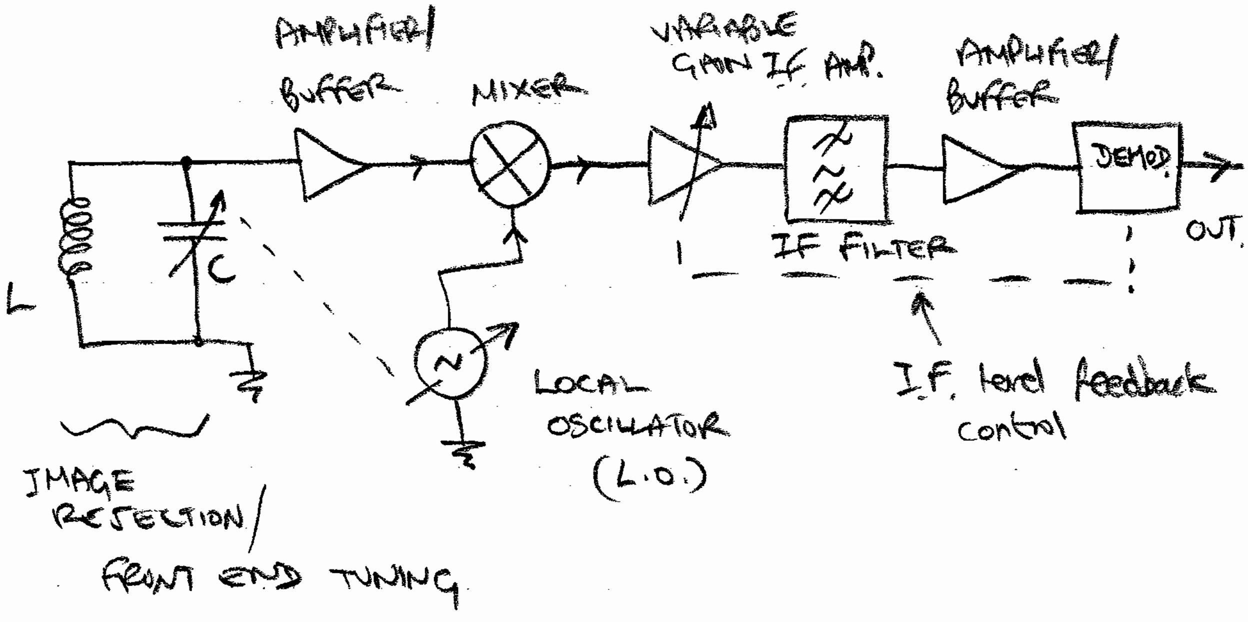
Combining R's & C's we get: $R' = 52\Omega$ $C' = 6.7\text{pF}$

$$f = \frac{1}{2\pi RC} = 457\text{MHz}.$$

Hence, the circuit is only just fast enough for 434 MHz operation and will have < 50% of the required gain at 868 MHz.

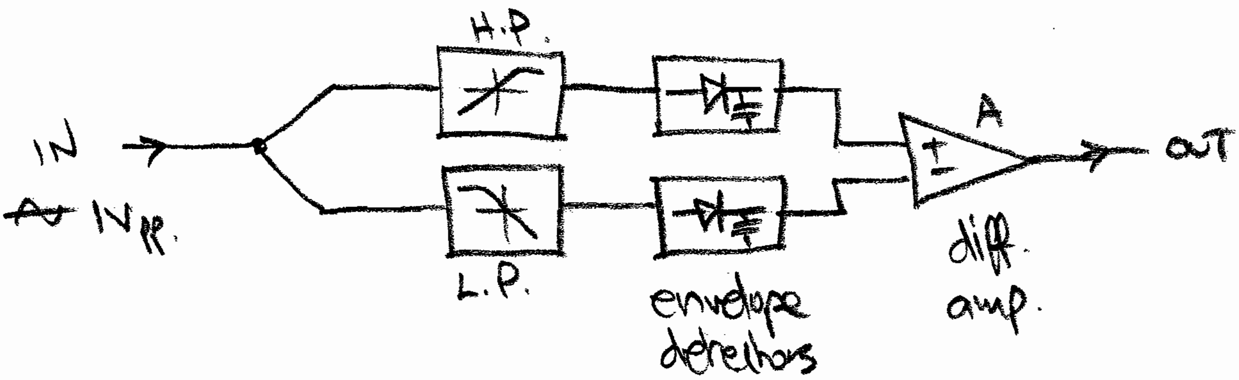
(Even if loaded gain is assumed as x10, then the roll-off is still less than 600 MHz).

3 (a)



- The front-end LC tank selects which of $f_{LO} \pm f_{I.F.}$ is selected for reception
- Controlling the I.F. signal level with an electrically variable gain amplifier gives all received stations similar volumes/ audio levels.
- other details in course notes.

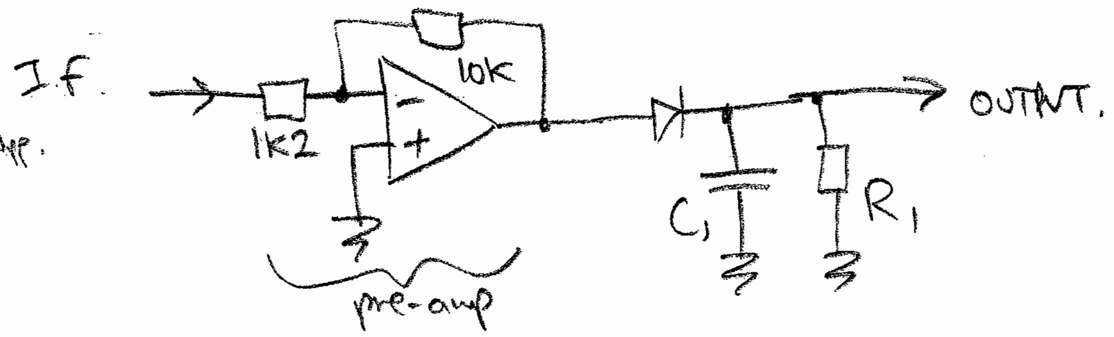
(b) To demodulate an FM signal on the I.F. of 20MHz, we shall use a high-pass and low-pass filter pair and a differential amplifier using the envelopes from the 2 filters. The 2MHz modulation depth gives 10% modulation on the I.F. ie: 19 – 21 MHz



For the filters, we need to be on the roll-off slopes. Choose eg: Butterworth response as good compromise in f and t domains.

3E!

3c) AM demodulation can use diode envelope detector



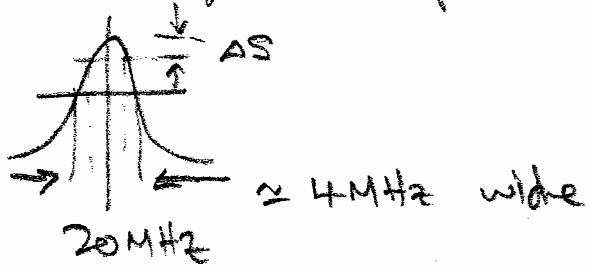
50% of a 1Vpp signal = 0·5Vpp = 0·25Vpk change

∴ gain of $\frac{2}{0{\cdot}25}$ = 8 required for 2Vpp output –

also pre-amp. ensures a large signal for the envelope detector diode.

Choose output time constant = 1ms (for <100Hz signal) R_1 = 10kΩ C_1 = 100nF

d) If the I.F. filter has a peaked response, then as the



frequency is modulated around 20MHz (I.F.), so the amplitude will drop each side – hence the FM signal will be mixed into the AM signal.

For Q=5, the signal drops by 30% (–3dB) for ±2MHz deviation – or perhaps around 10% for ±1MHz, which would be typ. 20% of the AM signal. This could be compensated by combining the 2 output signals to produce a corrected AM signal. Also though, the non-steep band edges of a low Q filter can give poor channel selectivity in a crowded waveband – where the 'stations' are close in frequency.

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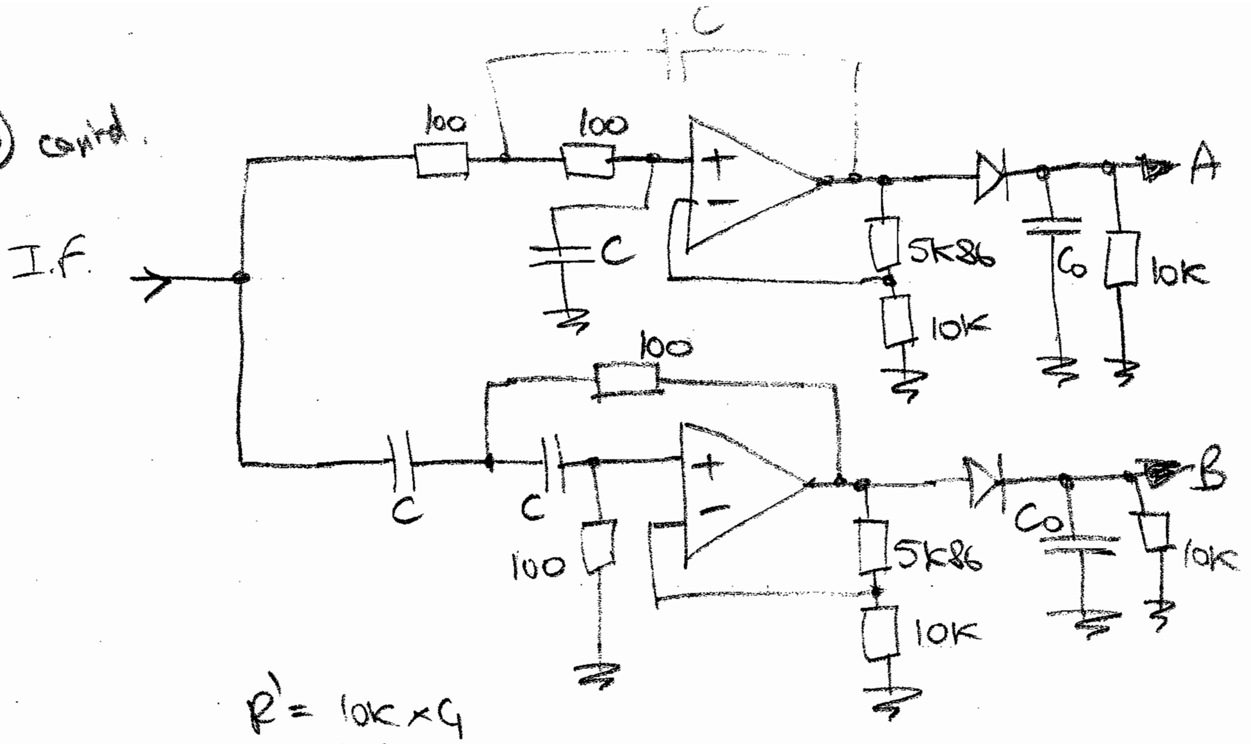
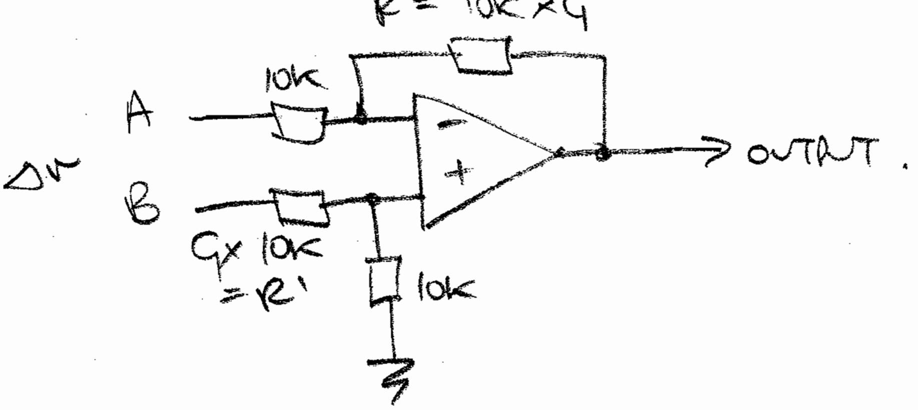
3 b) contd.





Set high-pass $f_0 = 30\text{MHz}$ and for low-pass, $f_0 = 15\text{MHz}$ (so that 20MHz is on roll-off slopes).

Then $\dfrac{1}{2\pi f_n CR}$ = 30 MHz or 15 MHz ; $f_n = 1$, $R = 100\,\Omega$

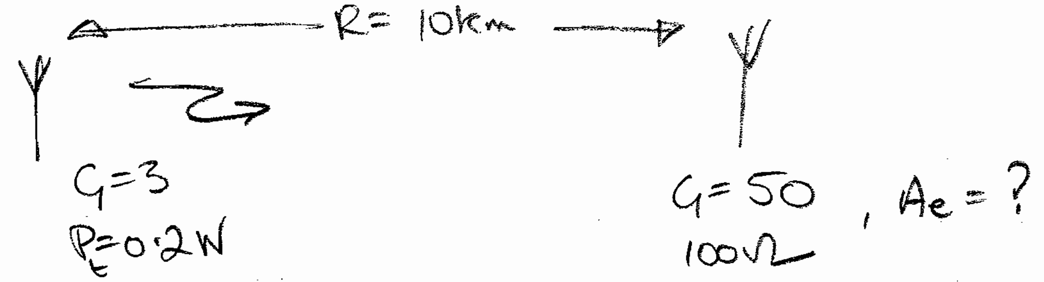
$\downarrow$ $C = 53\text{pF}$ $\qquad$ $\downarrow$ $C = 106\text{pF}$

Set demodulator time constant to 0.1ms $= 10^4 . C_0$ $\therefore C_0 = 10\text{nF}$

Both filters attenuation are approx. $\div 2$ of I.f. and a 10% frequency change will result in 20% amplitude change with a 2-pole filter. $\therefore \Delta V \approx \frac{1}{2} . 0{\cdot}2 = 0{\cdot}1\ \text{V}$

$\therefore$ diff. amp gain $G = \times 10$. $\therefore R' = 100\text{k}\Omega$.

4 (a)



$f = 434\,\text{MHz}$

$$\therefore \lambda = \frac{3\times10^8}{434\times10^6} = 0.691\text{ m}$$

From $G = \dfrac{4\pi A_e}{\lambda^2} = 50$

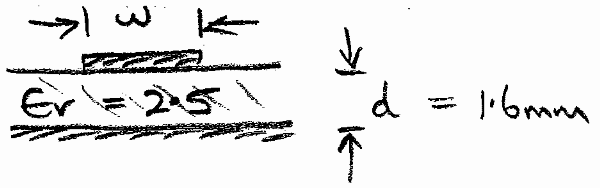
$$\therefore A_e = 1.90\ \text{m}^2$$

So, $P_r = \dfrac{P_t \cdot G \cdot A_e}{4\pi R^2} = \dfrac{0.2\times3\times1.90}{4\pi\,.(10^4)^2} = 0.91\,\text{nW}$

Into a 100Ω matched load, $P_r = \dfrac{v_r^2}{r} = 0.91\times10^{-9} = \dfrac{v_r^2}{100}$

$$\therefore v_r = 0.30\,\text{mV}_{rms} = 0.85\,\text{mV}_{pp}$$

b)



microstrip geometry

Capacitance/m $= C \approx \dfrac{(w+2d).\,\epsilon_0\epsilon_r}{d}$ and $Z_0 = \sqrt{\dfrac{L}{C}}$

also, velocity of e/m wave, $v = \dfrac{1}{\sqrt{LC}} = \dfrac{3\times10^8}{\sqrt{\epsilon_r}}$

$$\therefore \frac{1}{LC} = \frac{(3\times10^8)^2}{\epsilon_r} \Rightarrow L = \frac{\epsilon_r}{C.(3\times10^8)^2}$$

$$\therefore Z_0 = \sqrt{\frac{L}{C}} = \sqrt{\left(\frac{\epsilon_r}{C^2.(3\times10^8)^2}\right)} = \frac{\sqrt{\epsilon_r}}{C.\,3\times10^8} = 100\,\Omega$$

$$\therefore 100 = \frac{\sqrt{2.5}\times1.6}{(w+3.2).\,8.854\times10^{-12}.\,2.5.\,3\times10^8} \Rightarrow w = 0.61\,\text{mm}$$

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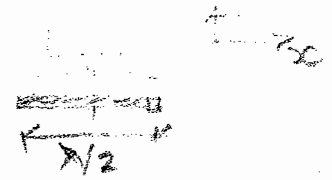
4b) contd.

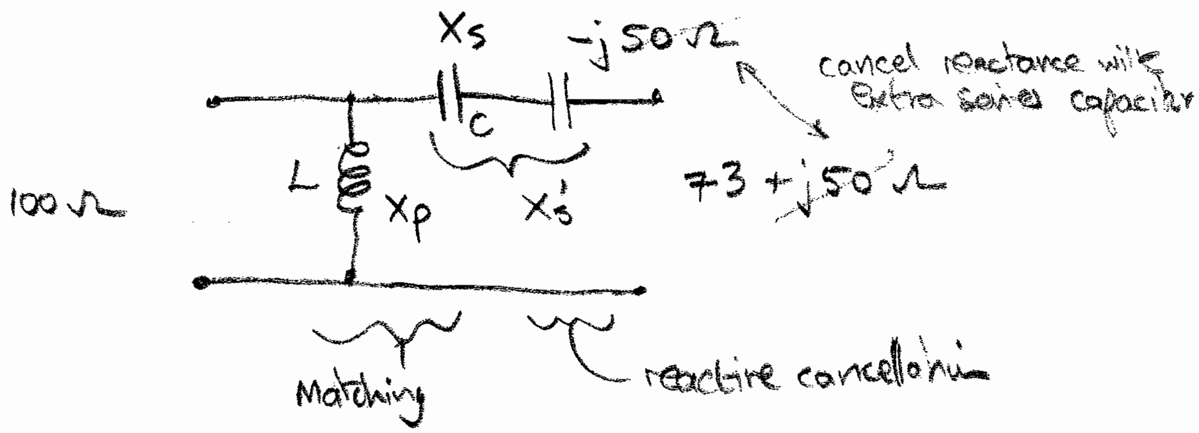


For the patch to be resonant, it should be ½ wavelength long (for the guided wave).

$$\lambda_g = v/f = \frac{3\times10^8}{\sqrt{2.5}\,.\,434\times10^6} = 0.437\,\text{m}$$

∴ the patch should be $\underline{21.9 \text{ cm}}$ long.

c)



$$Q = \sqrt{\frac{100}{73} - 1} = \frac{100}{X_p} = \frac{X_s}{73} = 0.608$$

$$\therefore\ X_p = 164 = \omega L \quad \text{and} \quad X_s = 44 = \frac{1}{\omega C}$$

with $\omega = 2\pi \times 434\times10^6 = 2.73\times10^9$ rad/s

∴ $\underline{L = 60\,\text{nH}}$; for C_s, combine into single C' with

$$X_s' = 44 + 50 = 94 = \frac{1}{\omega C'}$$

∴ $\underline{C' = 3.9\,\text{pF}}$

The resonant standing wave along the patch gives max. voltage swing at the ends and max. current in the centre, hence the feed point impedance, V/I, will increase moving from centre to end.