1 (a)(i)

Can do by 2 methods, either direct or break down into 3 elements and multiply.

Directly:

V_1=A V2 with I2=0

V2=(Za/(Za+Zb)V1. A=(Za+Zb)/Za

B = V1/I2 with V2=0 (short).B= Zb

C=I1/V2 with I2 =0. -> 1/(Za/(Za+Zb) *(Za//(Za+Zb))) = (2Za+Zb)/Za^2

D=(Za//Zb)/Za

$$\begin{matrix} \frac{Z_a + Z_b}{Z_a} & Z_b \\ \frac{2Z_a + Z_b}{Z_a^2} & \frac{Z_a + Z_b}{Z_a} \end{matrix}$$

Alternative breakdown method:

$$\begin{bmatrix} 1 & 0 \\ 1/Z_a & 1 \end{bmatrix} \begin{bmatrix} 1 & Z_b \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/Z_a & 1 \end{bmatrix}$$

(ii) ABCD of line:

$$\begin{bmatrix} 0 & jZ_a/2 \\ j\frac{2}{Z_a} & 0 \end{bmatrix}$$

Overall ABDC matrix:

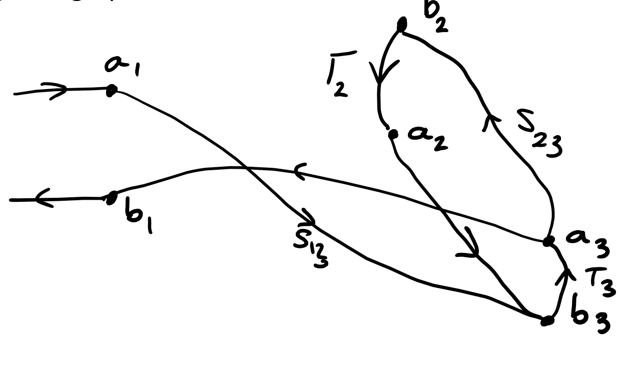
$$\begin{bmatrix} 0 & j75 \\ \frac{j}{75} & 0 \end{bmatrix} \begin{bmatrix} 1+4j & 100j \\ 0.08+0.16j & 1+4j \end{bmatrix} = \begin{matrix} -12+6j & -300+75j \\ -0.05+0.01j & -1.333 \end{matrix}$$

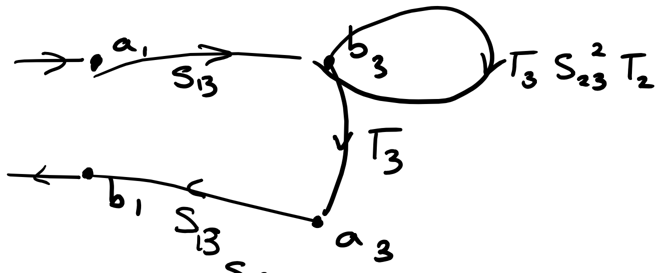
$$S_{21} = \frac{2}{A + \frac{B}{Z_0} + CZ_0 + D}$$

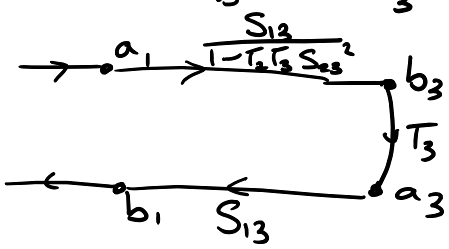
$$S_{21} = 0.0852\angle - 159°$$

(b)

Using sig flow graphs:





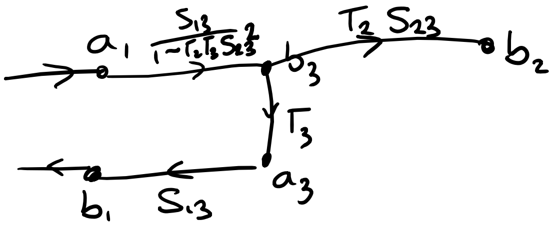


$$b_1 = a_1 \frac{S_{13}}{1-\Gamma_2 \Gamma_3 S_{23}^2} \Gamma_3 S_{13}$$

$$\Gamma_{in} = \frac{b_1}{a_1} = \frac{S_{13}^2 \Gamma_3}{1-\Gamma_2 \Gamma_3 S_{23}^2}$$

ii)

Power into Port 1 $P_1 = a_1^2 - b_1^2$



$$b_2 = a_1 \frac{\Gamma_2 S_{23} S_{13}}{1-\Gamma_2 \Gamma_3 S_{23}^2}$$

$$a_2 = \Gamma_2 b_2$$

$$\frac{P_2}{P_1} = \frac{b_2^2 - a_2^2}{a_1^2 - b_1^2} = \frac{b_2^2(1-|\Gamma_2|^2)}{a_1^2(1-|\Gamma_{in}|^2)} = \frac{a_1^2 \left(\frac{\Gamma_2 S_{23} S_{13}}{1-\Gamma_2\Gamma_3 S_{23}^2}\right)^2 (1-|\Gamma_2|^2)}{a_1^2(1-\left|\frac{S_{13}^2\Gamma_3}{1-\Gamma_2\Gamma_3 S_{23}^2}\right|^2}$$

$$\frac{(\Gamma_2 S_{23} S_{13})^2(1-|\Gamma_2|^2)}{|1-\Gamma_2\Gamma_3 S_{23}^2|^2(1-\left|\frac{S_{13}^2\Gamma_3}{1-\Gamma_2\Gamma_3 S_{23}^2}\right|^2} = \frac{(\Gamma_2 S_{23} S_{13})^2(1-|\Gamma_2|^2)}{|1-\Gamma_2\Gamma_3 S_{23}^2|^2 - |S_{13}^2\Gamma_3|^2}$$

This was generally answered quite well. Common mistakes included an assumption that B=C in the transmission matrix due to the reciprocal network, but this doesn't work due to the current definitions. In b(ii) most did not realise that the a_2 and b_1 terms need subtracting to get the power into the load (and not reflected) and the power into the network (and not reflected).

2 (a)

(i) Wide band implies that harmonics can't be filtered. Since 3*900>2500 don't need to worry about 3rd harmonics, just the 2nd and any intermods. 3rd order levels of both amplifiers are not that different, also 3rd orders will be much smaller at levels below OIP2, so it is B which is preferred.

(ii) Potential spurs
1.5Ghz – 1050MHz (2nd order) out of band not a problem.
1050*2 2nd order in band poss problem.
1.5+1.050 2nd order out of band.
(2nd harmonic of 1.5 also out of band so ignore)

2*1.5-1.050 3rd order in band.
Amplifier B, IIP2 = 35-25=10dBm

2nd order level. 20dB below IIP2 so intermods will be 2*20dB below OIP2 or -20dBm, harmonics are 6dB less still so -26dBm at 2.1GHz
3rd order = 30dB below IIP3, IM product will be 3*30dB below OIP3 or -45dBm at

(iii) Worst case is assuming that all IM products will add in phase (little delay between stages).

$$OIP_3 = \left(\frac{1}{G_2(OIP_3')} + \frac{1}{OIP_3''}\right)^{-1}$$

OIP3_A = 50dBm, OIP3_B = 45dBm
A before B: 44.98 (B dominates)
B before A: 49.95 (A dominates)
Most favourable to put A 1st.
IIP3 is 49.95-(20+25)=5dBm.

Also acceptable to assume random phases:

$$OIP_3 = \left(\frac{1}{G_2^2(OIP_3')^2} + \frac{1}{OIP_3''^2}\right)^{-1/2}$$

(iv) SFDR = 2/3(OIP3 – Noise)
Ref noise to 1Hz BW give -100-10*log(100e3)= -150dBm/Hz
-96.67dB/Hz^(2/3)

(b) (i) $F = 1 + \frac{T_e}{T_0}$

NF = 10*log10(1+350/290)=3.4dB

(ii) Line has NF of 3dB if the temperature is 290K, but we have a physical temp of 310K.

For the line:

F=1+(L-1)T/T0=3.16dB

Noise temp of input :

1e-3*10^(-9.3)/(50e6*1.38e-23)=726K

Noise figure of the cascade

$$F_l + \frac{F_a - 1}{G_l} = 4.48$$

6.5dB

Tc=(Fc-1)(290)=1009K

No = kB(Tc+Ti)BG = 1.38e-23*(726+1009)*50e6*50=-72.22dBm

Examiners comment:

I common mistake was to attempt to use the taylor expansion to find the amplitudes of the components rather than by scaling in dB from the OIP2/OIP3.
In (b) it is important to realise that the lossy line isn't at $T=T_0$ so $F \neq L$

3

a) Assuming short track lengths within the system itself.

min range is 0.5*3e8*20e-9 = 3m
However the dead time occurs after the end of the transmission of 50ns, which gives:

0.5*3e9*70ns = 10.5m

max unambiguous range = 0.5*3e8*1e-6 = 150m

$$\sigma = \frac{\lambda^2 G^2 |\Gamma|^2}{4\pi}$$

For a short $|\Gamma| = 1$ so

$$\sigma = 7.16m^2$$

Assuming alignment of antenna polarisation and gains.

$$P_{rx} = \frac{G_{tx}^2 P_{tx} \lambda^2 \sigma}{(4\pi)^3 R^4}$$

At max range, P_rx = -100dBm

Gives range of 134m, this is inside the unambiguous range so we are power limited and this is the max range.

b) at max range we get -100dBm out of the antenna.

With 10dBi antenna and 1W EIRP the conducted power into the antenna must be 20dBm (100mW).

S11 required would have to be -120dB – (not feasible)

(c) i). 10m gives delay of 2*10/3e8=6.67e-8s

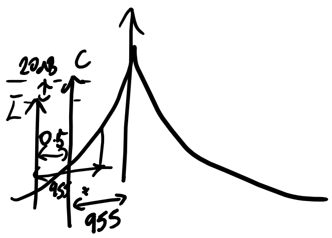
Freq diff will be 100e6/1e-6*6.67e-8 = 6.66Mhz

Max unabigious range. Is when the freq ramp is ½ period out

0.5*1e-6*3e8 = 150m

(ii) cant switch as it is a CW radar. Isolation is through a circulator and good antenna matching. Poor isolation will result in a component with zero freq shift which results in DC after mixing, so require a good DC rejection filter.

(d)



$$L = C - S - I - 10 \log B$$

Interferer is 955+500=1450kHz from LO. Phase noise spec is 500kHz.

-20 -50-10*log10(100e3)=-120dBc/Hz

4. i) Stability.

Need to first convert s-params to linear (10^(S11dB/20) as the s-params are a voltage term:

-0.1445 + 0.7545i   0.0199 + 0.0286i

1.3986 + 2.2010i   0.4913 - 0.7974i

K delta test.

$|\Delta|$=0.6941

K is 0.0793

Abs delta < 1, but K< 1 -> only conditionally stable.

ii)

No matching = Γ_S=0

$$N = \frac{|\Gamma_S - \Gamma_{opt}|^2}{1 - |\Gamma_S|^2} = |\Gamma_{opt}|^2$$

$$|\Gamma_{opt}|^2 = \frac{F - F_{min}}{4R_N/Z_0} |1 + \Gamma_{opt}|^2$$

$$\frac{4R_N/Z_0 |\Gamma_{opt}|^2}{|1 + \Gamma_{opt}|^2} + F_{min} = F$$

F=2.1dB

Output conjugate matched for max gain.

$$G_{L_{max}} = \frac{1}{1 - |S_{22}|^2}$$

=15.77

$$G_{max} = |S_{21}|^2 G_{L_{max}}$$

=20.3dB

iii)

Assume the amplifier is unilateral (it almost is)

Transducer gain – 20.3dB (as calculated above)

Power gain = 24.17 dB (consider power returned due to input reflection (1/1-S11^2)

Available gain – 20.3 (equal transducer gain)

VNA would measure the transducer gain as S21 23 dB.

iv) Using 2.1dB noise figure. (blue construction on Smith chart)

N=0.36

Centre of the NF circle is on the Γ_{opt} line, and we also know that it passes the centre of the Smith chart.

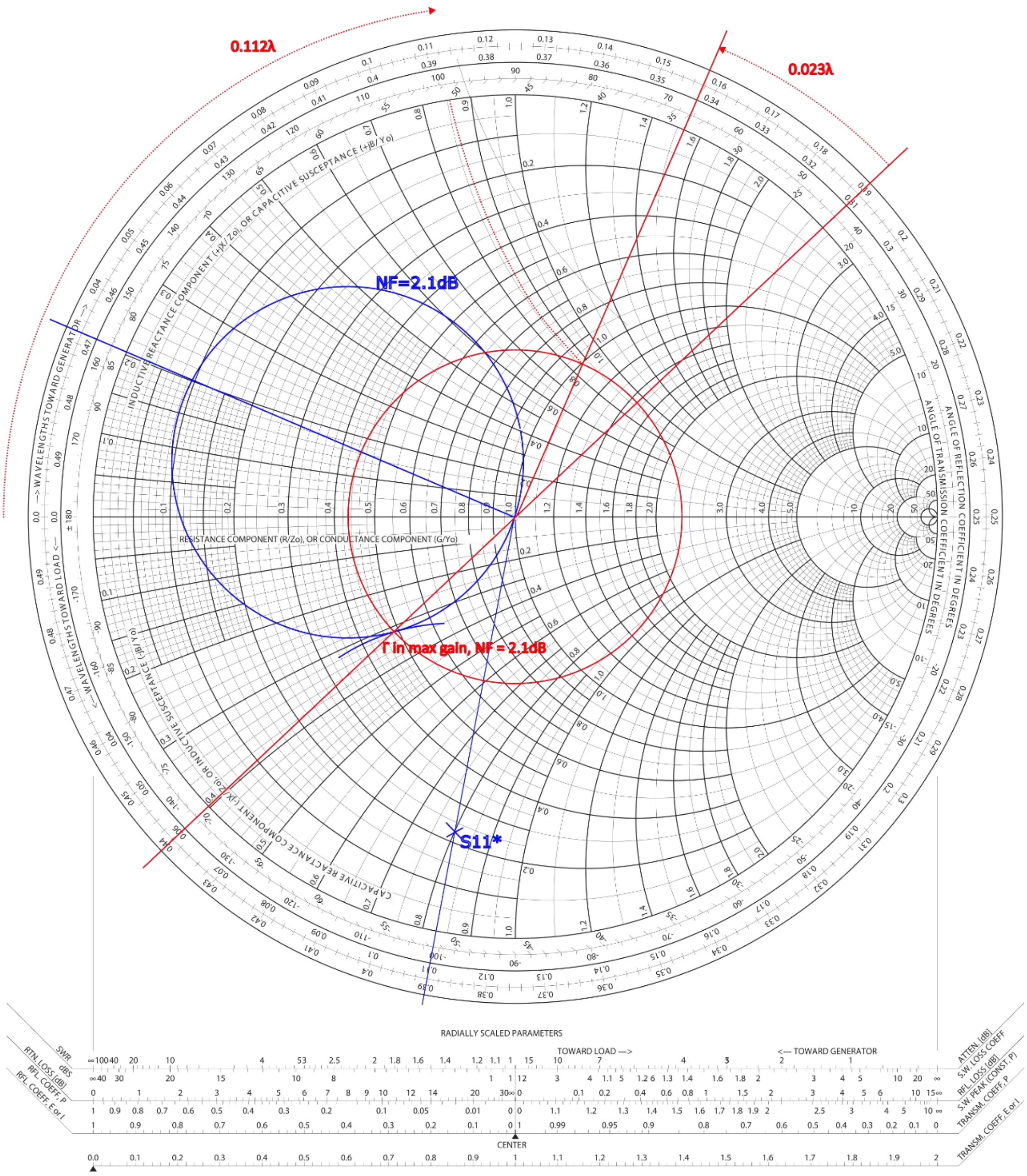
$C_F = \frac{\Gamma_{opt}}{N+1} = 0.4412\angle 156.8$ (blue circle)

Circle defines NF is constant, now need to find max gain.
Plot S11* and find closest approach of noise figure circle (not perfect but a good approximation).

$$\Gamma_{in} = 0.44\angle - 71°$$

$$G_s = \frac{1}{|1 - S_{11}\Gamma_{in}|^2} = 2.01$$

So gain becomes 23.3dB



v)

Starting from Γ_{in} reflect though origin for admittance. Circle around centre to unity R circle. Want wide band so select the first intersection working towards load. Which gives length of 0.023λ. Reactive component required is +0.85j. Shortest method to generate this is an open stub – start at LSH for open in reactance -> 0.112λ

Bandwidth is maximised by using short elements.

b)

For maximum power we should be using conjugate match. So need to match 150 ohm to 25+32.5j.

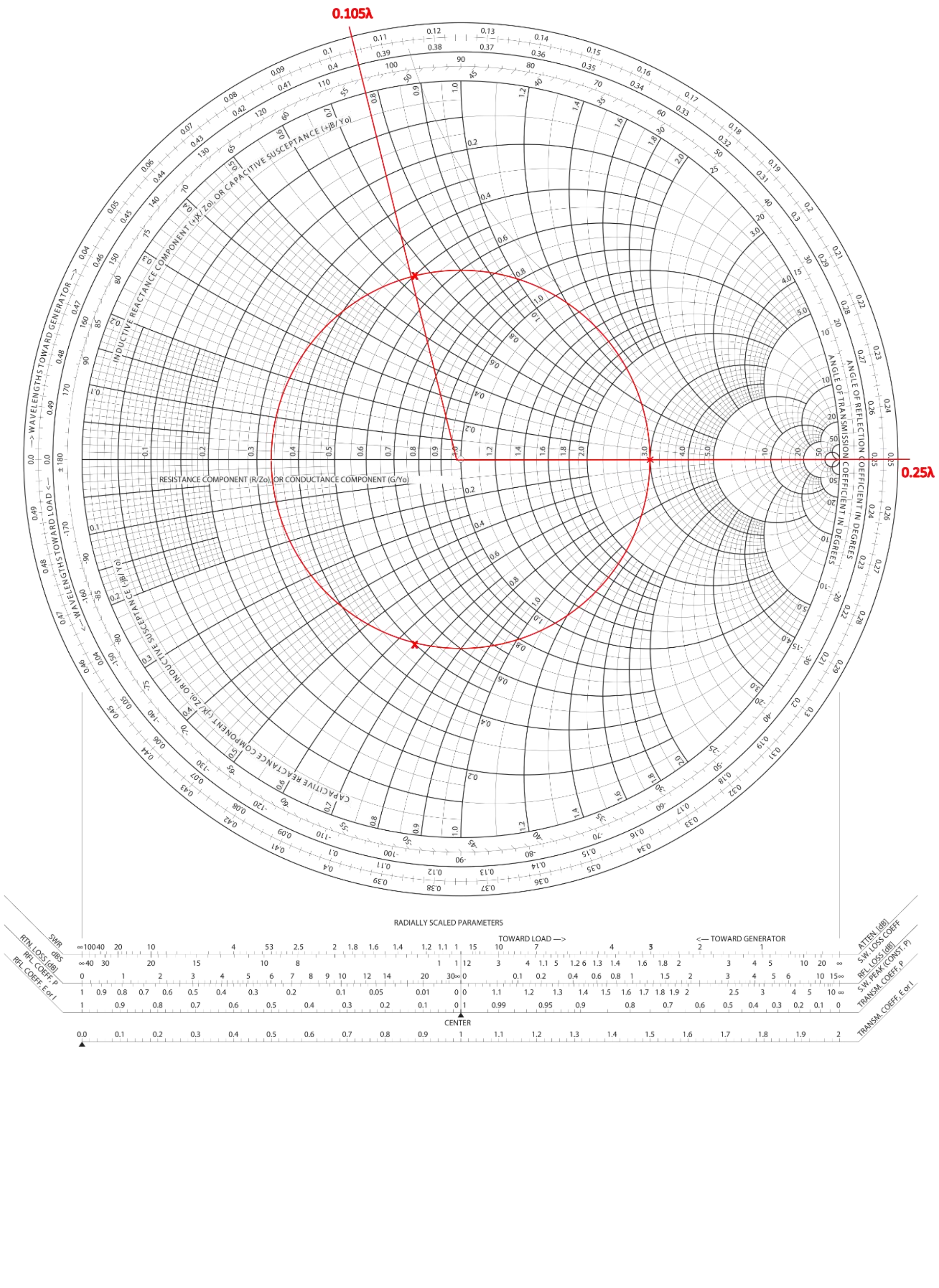
Normalising both we get 3 and 0.5+0.65j

Plotting on smith chart can see that they both line on a circle around origin so the match can be made with a length of line.

Length should be 0.25+0.105 λ = 0.355 λ

Examiners comment:

Not all correctly converted the dB S-parameters to linear (although this was not heavily penalised and the question is still possible with followed through answers). In (a)(iii) many tried to use datasheet equations (which some Γs are hard to find) rather than the definitions of the gains which allow the previous result to be used. In (iv) gain circles can also be used for a more accurate result. (b) can also be solved analytically.



0.105λ
0.25λ
RESISTANCE COMPONENT (R/Zo), OR CONDUCTANCE COMPONENT (G/Yo)
INDUCTIVE REACTANCE COMPONENT (+jX/Zo), OR CAPACITIVE SUSCEPTANCE (+jB/Yo)
CAPACITIVE REACTANCE COMPONENT (-jX/Zo), OR INDUCTIVE SUSCEPTANCE (-jB/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