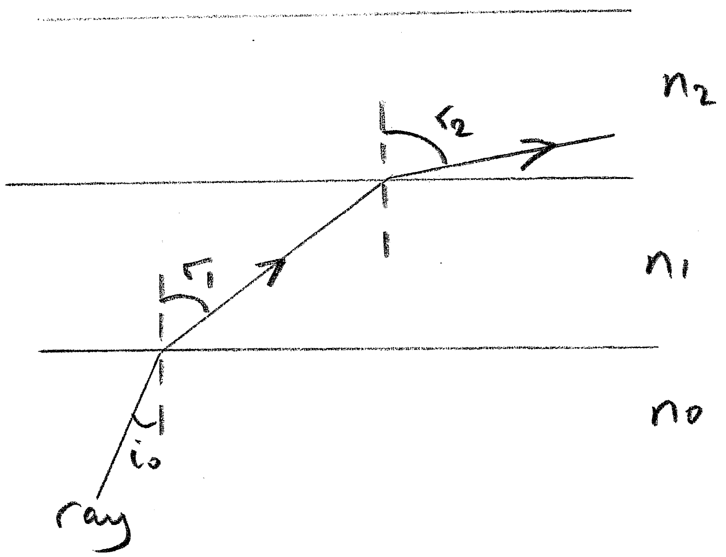
EEE6223 2015 Solutions

Q1)

(a)



2

From Snell's law: 1

$$n_o \sin i_o = n_1 \sin r_1 = n_2 \sin r_2 = \ldots\ldots = n_5 \sin r_5 \text{ (eventually)} \quad (1)$$ 1

but $r_5 = 90^o$ and $n_o \approx 1$ (air) so that 1

$$\sin i_o \approx n_5 \qquad (2)$$ 1

The refractive index of this upper layer is given by

$$n_5 = \sqrt{1 - \left(\frac{\omega_c}{\omega}\right)^2} = \sin i_o \qquad (3)$$ 2

hence

$$\cos i_o = \frac{\omega_c}{\omega} \qquad (4)$$

(ω is the frequency of the radio wave and ω_c the layer *critical frequency*)

(b)

For vertical incidence into the ionosphere,

$$i_o = 0 \quad (5)$$ 1

so

$$\omega = \omega_c \qquad (6)$$ 1

Thus, in this case

$$f_c = 8MHz \approx 9\sqrt{N} \quad (7)$$ 1

where N denotes the electron density of the reflection layer. Hence

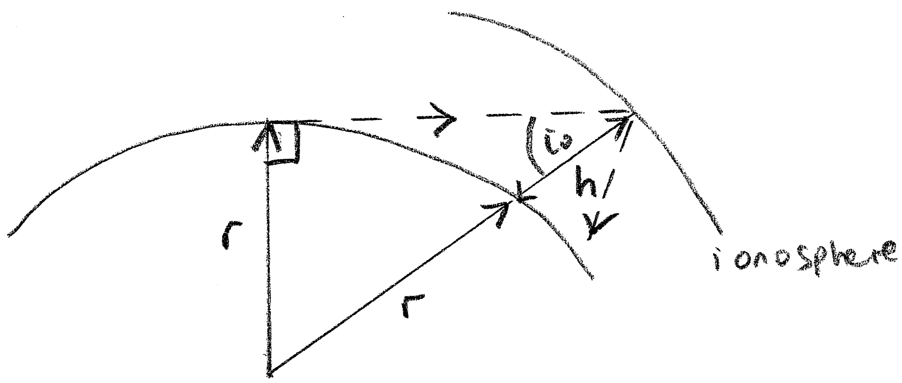
$$N \approx 7.9 \times 10^{11} / m^3 \quad (8)$$ 1

The height of the layer is given by the distance travelled by the signal in half of the round trip time,

$$h = \frac{1}{2} \times 2.5 \times 10^{-3} \times 3 \times 10^{8}\, m = 375km \qquad (9)$$ 1

This therefore identifies the layer as F_2. 1

(c)



1

We need to determine $\cos i_o$. Hence

$$\sin i_o = \frac{r}{r+h} \quad (10)$$ 1

so

$$\cos i_o = \sqrt{1 - \left(\frac{r}{r+h}\right)^2} = 0.3379 \qquad (11)$$ 1

and therefore from (3.4)

$$f = \frac{8}{.3379} = 23.68MHz \qquad (12)$$ 1

A zero elevation launch angle produces the maximum value of i_o, and hence the minimum value of $\cos i_o$ and the longest skip distance. A frequency higher than 23.68MHz would require a lower value of $\cos i_o$ and thus a greater incidence angle into the ionosphere i_o, and therefore could not be reflected by this layer. Conversely, lower frequencies down to 8MHz would require a larger $\cos i_o$ so a non-zero elevation angle giving a smaller i_o would be required and such signals would thus be reflected with shorter skip distances. There would be no reflection below 8MHz. 2

Q2)

(a)

(i) The dipole radiation pattern is the first term in question

$$C\frac{cos(\frac{\pi}{2}cos\theta)}{sin\theta} \qquad (1)$$

1

(ii) The array factor is the second term

$$I\frac{sin(\frac{Nkd}{2}cos\theta)}{sin(\frac{kd}{2}cos\theta)} \qquad (2)$$

1

(iii)

$$I = \frac{I_o}{\sqrt{N}} \qquad (3)$$

1

(iv) Neglecting mutual coupling

$$Z_{in} \approx \frac{73}{N}\Omega \qquad (4)$$

2

(b)

(i) The antenna gain is

$$10log_{10}N = 10.4dBd = 12.6dBi \quad (5)$$

2

(ii) Assuming the dipole pattern changes much more slowly than the array factor, at the first sidelobe

$$\frac{Nkd}{2}cos\theta = \pm\frac{3\pi}{2} \qquad (6)$$

1

so substituting values

$$cos\theta = \pm\frac{3\pi}{11}\times\frac{\lambda}{2\pi}\times\frac{1}{0.7\lambda} = \pm 0.195 \qquad (7)$$

1

so first sidelobe position is at

$$\theta = 78.8^o \, or 101.2^o \qquad (8)$$

2

Height of first sidelobe with respect to main lobe is

$$20\log_{10}\left(\frac{I\left|\sin(\frac{3\pi}{2})\right|}{\sin(\frac{3\pi}{2N})} /(NI) \right) = -13.2 \text{ dB} \qquad (9)$$

2

(iii) Given in question

$$\frac{\sin(11\times 0.127)}{11\times \sin(0.127)} = 0.71 \quad (10).$$

This defines the $-3dB$ point on the radiation pattern, and so we have

$$\frac{kd}{2}\cos\theta = 0.127 \quad (11)$$

2

and therefore the 3dB beamwidth is given by

$$2\times(90^{o} - \theta) = 6.6^{o} \qquad (12).$$

2

(c)

The main beam could be electronically steered by feeding each dipole element with a differential phase shift. This could be achieved by having programmable phase shifters in the transmission lines feeding the elements. An asymmetric sidelobe distribution could be achieved by having non-uniform element spacings. This may be useful for stealth purposes. 2

1

Q3)

(a)

If $L = \lambda$ then

$$\frac{kL}{2} = \pi \qquad (1) \qquad 1$$

so that Equation (1) becomes

$$\left|E_\theta\right| = \frac{2\eta\, I_o}{4\pi r}\left[\frac{cos(\pi cos(\theta)) - cos(\pi)}{sin(\theta)}\right] = \frac{2\eta\, I_o}{4\pi r}\left[\frac{cos(\pi cos(\theta)) + 1}{sin(\theta)}\right] \qquad (2) \qquad 1$$

Now the gain is given by

$$G = \frac{P_r\big|_{\theta=90^o}}{\dfrac{P}{4\pi r^2}} \qquad (3) \qquad 1$$

where P_r denotes radiated power density and P the total radiated power. Now,

$$P_r = \frac{1}{2}\frac{\left|E_\theta\right|^2}{\eta}\, Wm^{-2} \qquad (4) \qquad 1$$

and

$$P = \int_0^{2\pi}\int_0^{\pi} P_r r \sin(\theta) d\phi r d\theta \qquad (5) \qquad 2$$

so that

$$P = 2\pi r^2 \int_0^{\pi} P_r \sin(\theta) d\theta = \frac{I_o^{\,2}\eta}{4\pi}\int_0^{\pi}\frac{(\cos(\pi\cos(\theta)) + 1)^2}{\sin(\theta)} d\theta \qquad (6) \qquad 2$$

Hence from Equation (2)

$$P = \frac{I_o^{\,2}\eta}{4\pi} \times 3.318 \qquad (7) \qquad 1$$

Also from Equation (1) and (4)

$$P_r\big|_{\theta=90^o} = \frac{\eta I_o^{\,2}}{2\pi^2 r^2} \qquad (8) \qquad 1$$

Thus, from (3)

$$G = \frac{8}{3.318} = 2.41 \qquad (9)$$ 1

so

$$10\log_{10} G = 3.8dBi \qquad (10)$$ 1

(b)

Advantage: The gain of a full wave dipole is $1.7dB$ higher than that of a half wave dipole.

Disadvantage: The input impedance of a full wave dipole is very high since it's fed at a current minimum, which makes matching into a transmission line difficult. A half wave dipole however has an input impedance $\sim 73\Omega$ which is commensurate with the characteristic impedance of coaxial cable. A full wave dipole is also twice the length of a half wave dipole of course. 2

(c)

The effective aperture of an antenna is given by

$$A_e = \frac{\lambda^2}{4\pi} G \qquad (11)$$ 1

So from (9),

$$A_e = \frac{0.375^2}{4\pi} \times 2.41 = 0.027m^2 \qquad (12)$$ 1

The power received by the antenna P is then

$$P = A_e \times P_d \qquad (13)$$ 1

where P_d is the power density of the incident plane wave. So

$$P_d = \frac{1}{2\eta} \times (75 \times 10^{-3})^2 = 7.5\mu W / m^2 \qquad (14)$$ 1

Thus,

$$P = 0.2\mu W \qquad (15)$$

(d)

In (11) the aperture is proportional to the wavelength squared. At 1600MHz the wavelength is halved, so the absorbed power in (13) is a quarter i.e. $P = 0.05\mu W$. 2

Q4)

(a) As shown in Fig.1

(b)

The radiated power density is given by

$$P_r = \frac{1}{2}\frac{|E_\theta|^2}{\eta} \qquad (1)$$

1

where $|E_\theta|$ is given in the question, so that

$$P_r = \frac{1}{2\eta}\frac{\eta^2 I_o^2}{4\pi^2 r^2}\frac{\cos^2\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin^2(\theta)} \qquad (2)$$

1

The power radiated into the half space above the ground plane is then

$$P = \int_0^{2\pi}\int_0^{\pi/2} P_r r \sin(\theta) d\phi r d\theta \qquad (3)$$

2

Since the fields are invariant in ϕ, (3) reduces to

$$P = 2\pi \int_0^{\pi/2} P_r r^2 \sin(\theta) d\theta \qquad (4)$$

1

Substituting (2) into (4) then gives

$$P = \frac{\eta I_o^2}{4\pi r^2}\int_0^{\pi/2} \frac{\cos^2\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin(\theta)} r^2 d\theta \qquad (5)$$

1

Substituting the value for the integral given in the question then yields

$$P = \frac{\eta I_o^2}{4\pi} \times 0.61 \qquad (6)$$

1

(i) We now equate this power to that dissipated in a fictitious equivalent circuit 'radiation resistance' R_r thus:

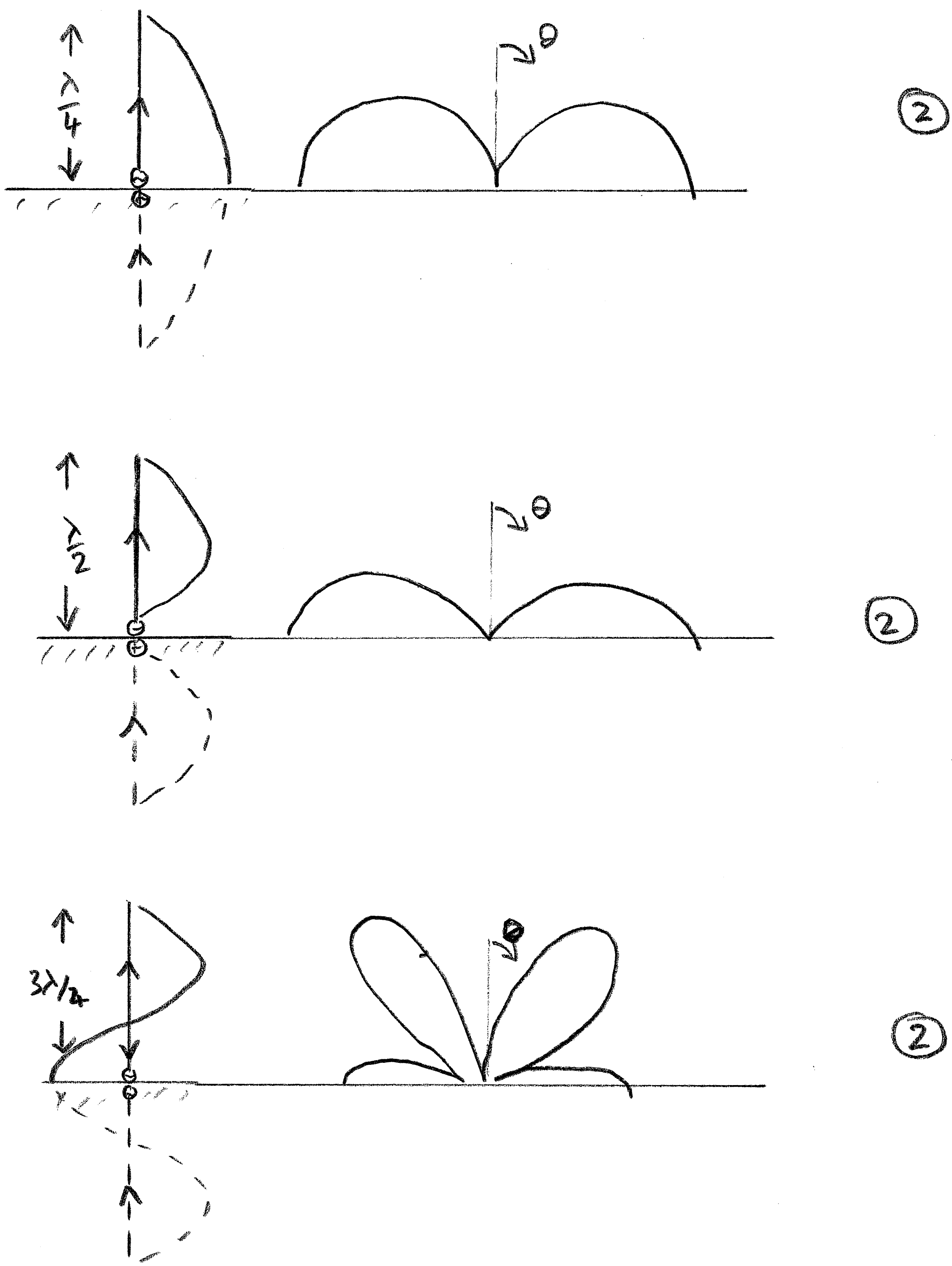


Fig 1.

$$\frac{\eta I_o^2}{4\pi}\times 0.61=\frac{I_o^2}{2}R_r \quad (7)$$ 1

so that

$$\text{(i) } R_r=\frac{377}{2\pi}\times 0.61=36.6\Omega \quad (8)$$ 1

(ii) Gain (=directivity since no losses) at $\theta = 90^o$ is obtained from (2) and (3) as

$$G=\frac{P_r|_{\theta=90^o}}{P/4\pi r^2} \quad (9)$$ 1

hence

$$\text{(ii) } G=\frac{1}{2\eta}\frac{\eta^2 I_o^2}{4\pi^2 r^2}\times\frac{4\pi}{0.61 I_o^2\eta}\times 4\pi r^2=3.28\equiv 5.2dBi \qquad (10)$$ 2

(c) The half wave dipole has (i) $R_r=73.2\Omega$ and $G=5.16-3dBi=2.2dBi$. In other words the radiation resistance is double whilst the gain is half that of the quarter wave monopole. This is because

(i) Constant supplied current: For the same terminal current I_o twice the power is now radiated (over a far field sphere instead of a hemisphere) so R_r in (7) must be doubled. 2

(ii) Constant radiated power: The same radiated power is now distributed over a sphere instead of a hemisphere, so the power density must be half that of a monopole, so the gain in (10) is halved.

Q5)

a) *Discuss the orbits available to satellite system designers and typical uses for each. (6)*

LEO - Low Earth Orbit. Altitude 500-1,500km. Suitable for mobile satellite phones. Small path losses.
MEO – Medium Earth Orbit. Altitude 5,000-15,000km. Suitable for weather and sensing applications.
GEO – Geostationary Earth Orbit. Altitude 36,000km. Suitable for TV broadcast, fixed communications links. High path losses.

6 Marks

b) What advantages do satellite communications have over terrestrial systems and what are the key challenges faced by designers?

Main advantages

- Extended capability of existing terrestrial cellular systems
- Coverage in remote areas
- Large coverage area
- Seamless service to subscriber in any part of the world

Challenges

- Propagation delay
- High signal attenuation with path loss ~200 dB
- Low spectral efficiency
- High costs, >$100M
- Power limited
- Reliability , requiring a lifetime of >10 years in a harsh environment

6 marks

c) Explain the terms: Noise power; Noise factor; Noise figure.

(i) Noise power is expressed in Watts or Watts/Hz but it is more convenient in system design to relate it to a fictitious noise temperature T through the formula P=kTB Wats.
Where
k is the Boltzmann constant = 1.3807×10^{-23}
T is the ambient temperature (K)
B is the system bandwidth (Hz)

(ii) Noise factor F is defined by

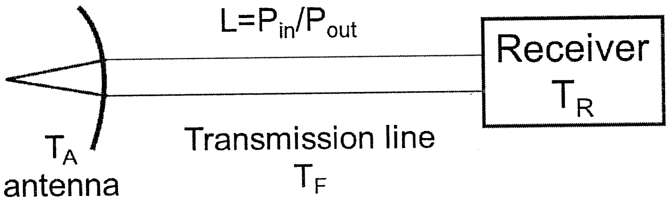
$$F = \frac{C_{in}/N_{in}}{C_{out}/N_{out}} = \frac{output\ noise\ power}{input\ noise\ power}$$

Where C is the carrier power and N is the noise power.

(iii) Noise figure = 10 log (F)

3 marks

a) *An antenna with a noise temperature of 105K is connected to a receiver using a cable with a loss of 2 dB. If the receiver noise figure is 2dB what is the overall noise temperature of the system? Assume the cable temperature is 290 K.*



Noise temperature at the **receiver** is

$$T'_S = \frac{T_A}{L} + (1 - \frac{1}{L})T_0 + T_R$$

As

$T_0 = T_P$

Since noise factor for lossy line = loss L and noise temperature referred to the output is

$T_{eout} = (1 - 1/L)T_F$

Now L=2dB=1.585

For the receiver

$F = 1 + T_e/T_0 = 1.585$

And

$T_R = 170$ K

So

$T'_S = 105/1.585 + 0.585.290/1.585 + 170 = 66.2 + 107 + 170 = 343.2$ K

5 marks

Q6)

a) Describe the challenges facing a communications satellite from launch to life in orbit and how these are alleviated in spacecraft design.

- Satellite components need to be specially "hardened"
- Circuits which work on the ground will fail very rapidly in space
- Temperature is also a problem as the temperature gradient across a satellite can be up to 200C and therefore satellites use electric heaters to keep circuits and other vital parts warmed up. They also need to control the temperature carefully.
- Antennas need to be heat distortion resistant
- Corrosion
- Need to withstand the high levels of G forces and vibrations which occur during launch.
- The environment is a vacuum.

6 marks

b) A satellite receiver operating at 12 GHz has a noise figure of 2 dB. If it is directly connected to an antenna/pre-amplifier with a gain of 7 dB and a noise temperature of 100 K, estimate the overall system noise figure.

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots\ldots\ldots \frac{F_n - 1}{G_1 G_2 .. G_{n-1}}$$

$$F_n = 1 + T_{en} / T_0$$

Antenna amplifier gain G_1=7dB=5

And

F_1=1+100/290=1.345

Recevier

F_2=2dB=1.585

Hence

F = 1.345+(1.585-1)/5 = 1.462 = 1.65 dB

If the antenna/pre-amplifier is now connected to the receiver via a 5m length of coaxial cable with an attenuation of 3dB, estimate the new system noise figure.

Add lossy cable

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}$$

Antenna amplifier gain

G_1 = 5 and F_1 = 1.345

Recevier

F_3=2dB=1.585

Lossy cable

F_2=3dB=2 and G2 = -3dB = 0.5

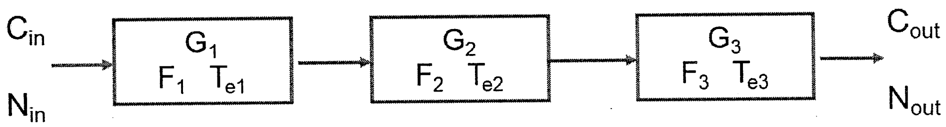
Hence

F = 1.345+(2-1)/5+(1.585-1)/(5*0.5)=1.8

$\therefore$ F = 2.5 dB

7 marks

c) *Derive an expression for the noise figure of a cascade of three amplifier stages in a receiver. Comment on the design of the first amplifier (Pre-amplifier) that would be suitable for use in a satellite receiver.*



Noise generated by each amplifier stage multiplied by gain of next stage and succeeding stages.

3 stage ampifier:

$$C_{out} = C_{in}G_1G_2G_3$$

$$N_{in} = kT_0B, \qquad T_0 = 290K$$

$$N_{out} = kT_0BG_1G_2G_3 + kT_{e1}BG_1G_2G_3 + kT_{e2}BG_2G_3 + kT_{e3}BG_3$$

Now

$$F_n = 1 + T_{en} / T_0$$

Then

$$N_{out} = N_{in}G_1G_2G_3 + N_{in}(F_1 - 1)G_1G_2G_3 + N_{in}(F_2 - 1)G_2G_3 + N_{in}(F_3 - 1)G_3$$

$$F = (C_{in}/N_{in})/(C_{out}/N_{out})$$

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1G_2} + \ldots\ldots\frac{F_n - 1}{G_1G_2..G_{n-1}}$$

Hence it is an advantage to have a first amplifier stage with a low noise factor F_1 and a high gain G_1

7 marks