Department of Microtechnology and Nanoscience

Wireless and Photonic System Engineering SSY085

2014-10-28, 14:00-18.00

Teachers in charge:
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Aids: Open book examination. Any printed material and calculator of choice is allowed. Communication devices (computers, mobile phones etc.) are *not* allowed.

Examination checking: Nov. 18, 12-13 in room A402, ("Gaten", just next to Café Canyon, MC2).

Convince yourself that you have understood the problem before you get started. Constructive and valuable gambits will also give points. If information is lacking in the description of the task, you must yourself introduce technical plausible assumptions. Make sure you clearly state such assumptions.
Grades: 3: ≥ 24, 4: ≥ 36, 5: ≥ 48

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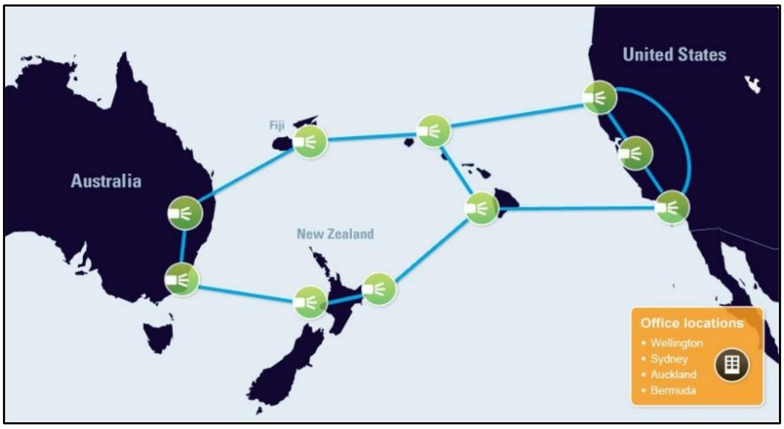
1. The "Southern cross" submarine link

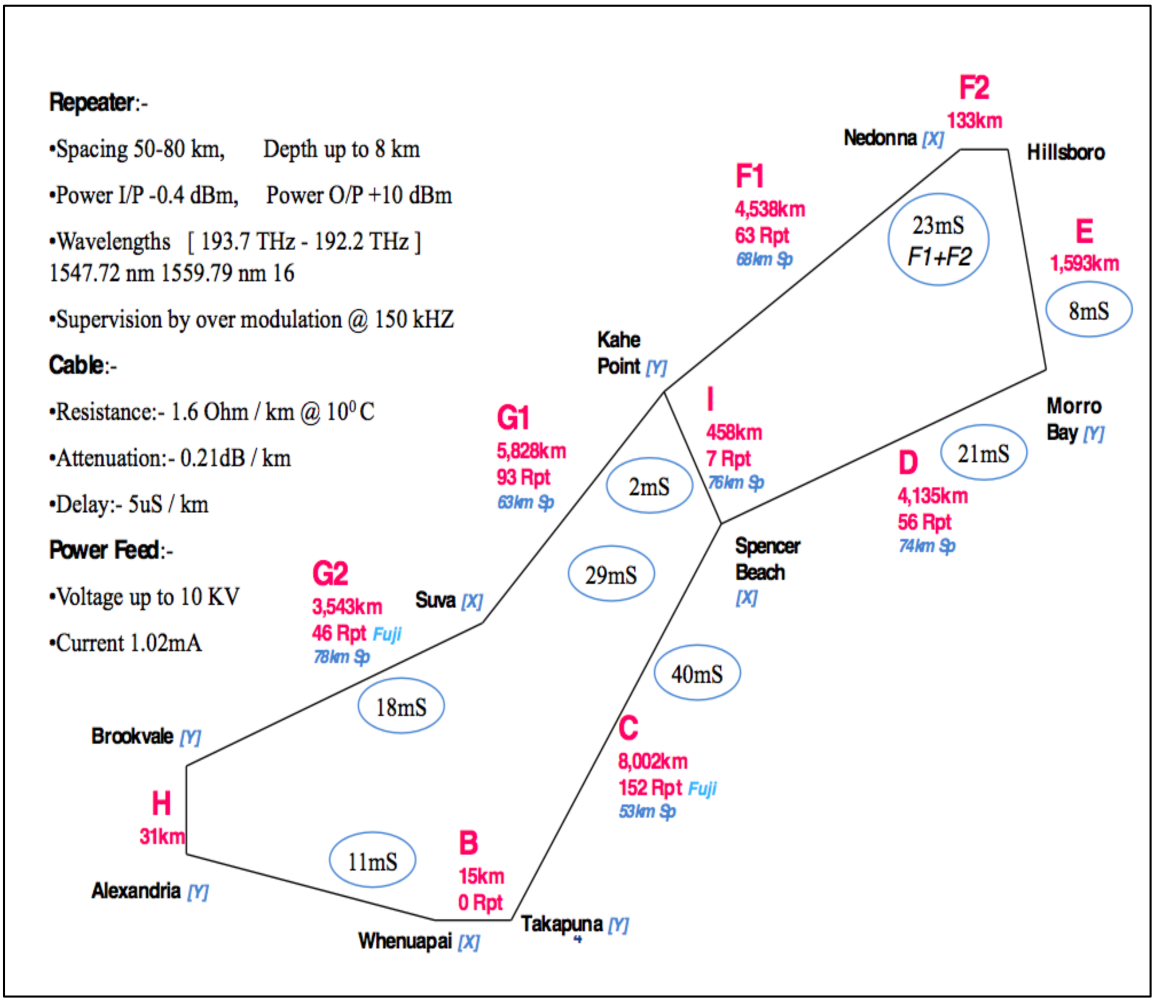
The "Southern cross cable" is an undersea ring connecting Australia, New Zealand, Fiji, Hawaii and mainland US as shown in the below maps. The distances and number of repeaters (i.e. optical amplifiers, marked "Rpt" in the map) are shown in the second figure, taken from the project website. The link was originally installed with 16 wavelengths at 2.5 Gb/s (40 Gb/s in total) in 2001, but already in 2004 it was upgraded to 480 Gb/s by replacing the 2.5 Gb/s with 10 Gb/s transmitters/receivers, but without changing any wet plant (i.e. submarine) equipment.

a) Discuss and implement the 2004 upgrade! Determine what components are needed, what are the wavelength and channel separation requirements, the SNR requirements, modulation format, dispersion etc. Check noise sources. It is enough to design the longest leg (marked leg C in the map). Make realistic parameter and system assumptions unless given in the map. (26 points)

b) In 2012 the link was *further* upgraded, to 1.6 Tb/s in total. Discuss ways to accomplish this (again without affecting the wet plant). (4 points)



Problem 1. Overview of the Southern Cross Link



Problem 1. Distances and amplifier ('Rpt') numbers and spacings ('Sp') for the Southern cross link.

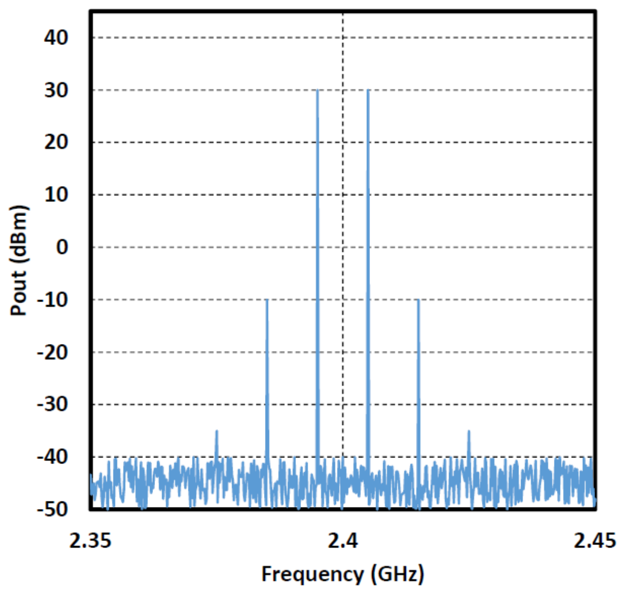
2. Radar
A ground based air-surveillance radar operating at 1.3 GHz is designed to detect a target with a radar cross section of 1 m^2 at a maximum range of 400 km. The rectangular antenna is 14 m wide and 4.2 m high, with an aperture efficiency of 65%. The sensitivity of the receiver is -100 dBm. Determine the following,

a) Antenna effective aperture area and antenna gain (dB).
b) Peak transmitter power.
c) Pulse repetition frequency for a maximum unambiguous range of 400 km.

(10 points)

3. Intermodulation
Output spectrum for a power amplifier excited with a two tone signal (15 dBm each) with a center frequency of 2.4 GHz and 10 MHz spacing is shown below.

a) Determine the amplifier power gain.
b) Draw a figure of the resulting spectrum if each input signal is increased 5 dB.
c) Determine the third order intercept point referred to the output.
d) Estimate the 1 dB compression point.



(10 points)

4. Multistage amplifier design
Using the transistors listed below, you should design a 2.0 GHz multistage amplifier with a power gain of 20 dB and output power of 18 dBm. The listed characteristics are for an operating frequency f=2.0 GHz.

a) Determine the number of stages, and motivate the choice of transistor and gain ($G \leq G_{max}$) for each stage.
b) Estimate the total amplifier noise figure F_{tot} and third-order intercept point $OIP3_{tot}$ of the amplifier.

Transistor	G_{max} (dB)	F (dB)	$P_{out,1\,dB}$ (dBm)	OIP3 (dBm)
BFG505	10	1.9	4	10
BFG520	8	1.9	17	26
BFG540	7	2.1	21	34

(10 points)

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CHALMERS	Anonymous code / Anonym kod SSY085-12	Points for question (to be filled in by teacher) / Poäng på uppgiften (ifylles av lärare) 30	Consecutive page no. / Löpande sid nr 1 / Question no. / Uppgift nr 1

1, Optical communication system over 194 THz or 1550 nm Longest Tx distance is 8002 km and what I will considere here: System parameters:

SMF, $\alpha = 0,21$ dB/km
OOK ⇒ SE = 1, ~~Assume~~ nyqvist BW ⇒ Bitrate = BW.

WDM system ⇒ we separate channels in Frequency domain. Typical channel spacing required is 2-10 times signal BW

Each WDM channel forms a separate data channel and requires an own transmitter and receiver. Multiple such channels are later combined via a MUX, transmitted over the fiber and then splitted via a DEMUX on the receiver side.

EDFA is used in the undersea cable and they perform amplification over a large band around 1550 nm so all WDM channels will be amplified. We will assume that the amplification is constant over the spectrum

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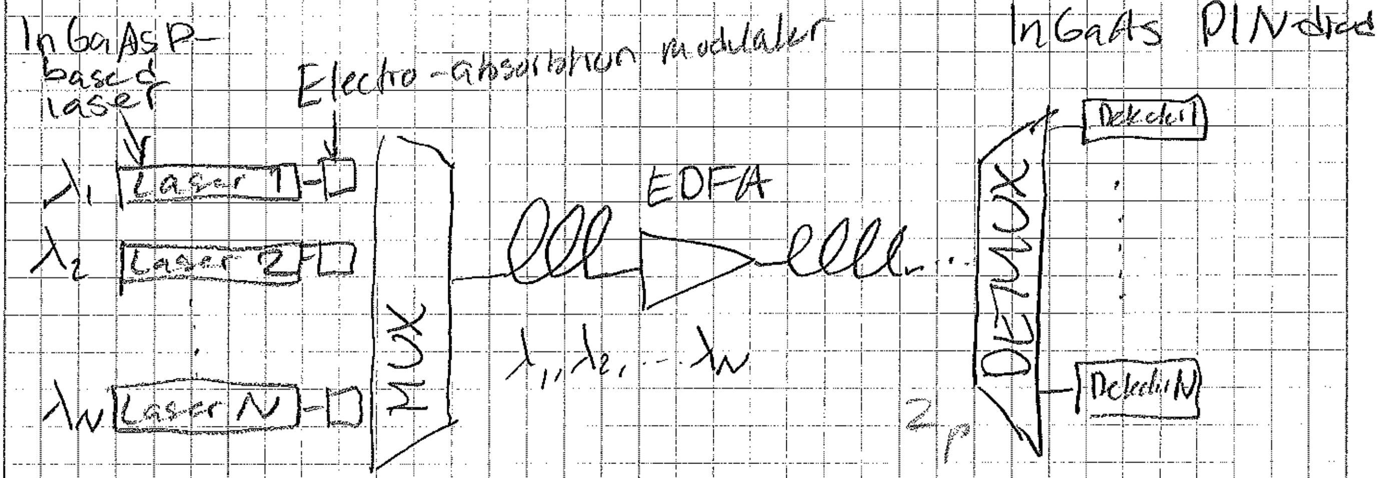
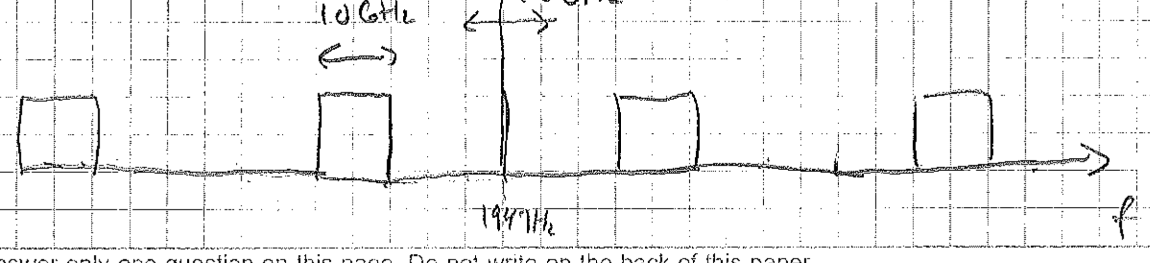
OOK is detected using energy detection via a single photo-diod which performs square-law operation; Lets Assume:

PIN-diod made from InGaAs semiconductor material η is then ≈0,8 ⇒ R ≅ 1 A/W

Sketch over system design: 1550nm WDM sys



Spectrum allocation: Have around 4,4THz available in C-band. For each channel we need 10 Gbps ⇒ 10GHz. In total we need 48 channels. Assume 3 channel BW between + side margin.
Total BW = 48 · 40 Gbps = 1920 Gbps ⇒ 1,92THz, which is within the available BW.
In frequencies channels are spaced:



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Receiver performance:

Assume we want a BER of 10^{-9} ⇒
Q = 6 and no forward error correction (FEC). The main noise source is (will be validated later)
Signal spontaneous noise from the amplifiers:

$\sigma_{s-sp}^2 = 4R^2 P_{in} S_{sp} \Delta F$, where the

PSD $S_{sp} = \frac{E_n}{2} G h\nu \cdot N$

The Q is defined as:

$$Q = \frac{I_1 - I_0}{\sigma_0 + \sigma_1}$$

For OOK, when σ_{s-sp}^2 dominates

$$Q = \frac{I_1}{\sigma_1} = \frac{R P_{in}}{\sqrt{\sigma_{s-sp}^2}}$$

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Fiber: Since system already is implemented and operational, I assume that it has sufficient amount of DCF layed out.
In this case it's already dispersion compensated and I only need to focus on power and Noise

Total distance = 8002 km
152 amplifiers ⇒ 52,6 km / span.

Over this distance the power loss is 11,05 dB, since $\alpha = 0,21$ dB/km

We also have coupling losses, which can be included in the 0,21 dB/km but I add 2 dB extra to account for this.

⇒ $G = 13,05\,dB = 20,2$ Required
$F = 4\,dB = 2,5$, Assumed.
We have 152 amplifiers along the path
⇒

$$Q = \sqrt{\frac{P_{in}}{2F_n G h \nu \Delta f \cdot N}}$$

$P_{in} = 0\,dBm$
$F = 2,5$
$G = 20,2$
h = planks const
$\nu = 194\,THz$
$\Delta f = 10\,GHz$
$N = 152$

2

⇒ $Q = 7,15 > 6$:)

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For current setup I get Q = 7 which is good. Then I have some margin for my target at Q = 6

For example, system a bit older. Here we can afford much higher noise Figures.

Noise sources: Validation of prior assumption.

Thermal noise

$\sigma_{th}^2 = \frac{4kT\Delta f}{R_L}$, $R_L = 50, T = 300 \Rightarrow 3{,}31 \cdot 10^{-12}$

Shot-noise

$\sigma_{shot}^2 = 2qRP_m\Delta f = 3{,}2 \cdot 10^{-12}$

Signal-spontaneous beat noise

$\sigma_{s-sp}^2 = 4R^2 P_m \cdot \frac{F_n}{2} \cdot G \cdot h \cdot \nu \cdot \Delta f \cdot N = 1{,}97 \cdot 10^{-5}$

$\sigma_{sp-sp}^2 = 4R^2 \left(\frac{F_n}{2} G \cdot h\nu \cdot N\right)^2 \Delta\nu \cdot \Delta f$. Assume

$\Delta\nu \approx 2\Delta f \Rightarrow \sigma_{sp-sp}^2 = 1{,}1 \cdot 10^{-8}$

Clearly σ_{s-sp}^2 dominates and the above calculation holds.

Answer only one question on this page. Do not write on the back of this paper
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1.b: Upgrade to 1.6 Tbps in total.

One way is to use the same principle again and stack a lot of channels next to each other. WDM will be part of most such implementations. Superfast electronics could be used to push the bitrate per WDM carrier to around 40 Gbps. Clever pulse shaping can be used to minimize the distance between carriers but care to NL effects must be done. The procedure is analog to 1a.

1

It could also be possible to implement a coherent receiver and transmitter for each WDM channel. This enables the use of QAM modulation formats and ex. PSK. This means that modulation formats with spectral efficiency >1 can be used to push in the direction of Shannon capacity. However the receiver (and transmitter) is much more complicated.

1

It leads to higher data rates but system complexity grows alot!

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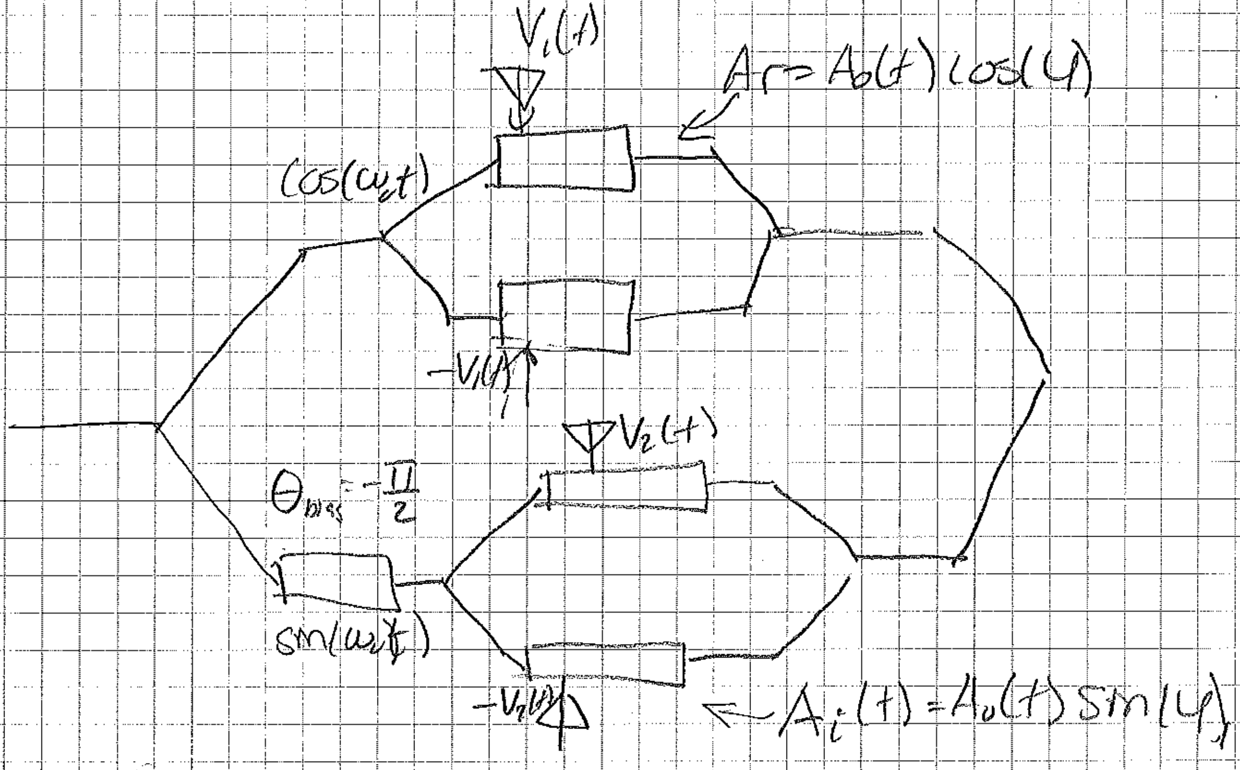
For a coherent Tx: Two MZM can be used. Principle sketch:

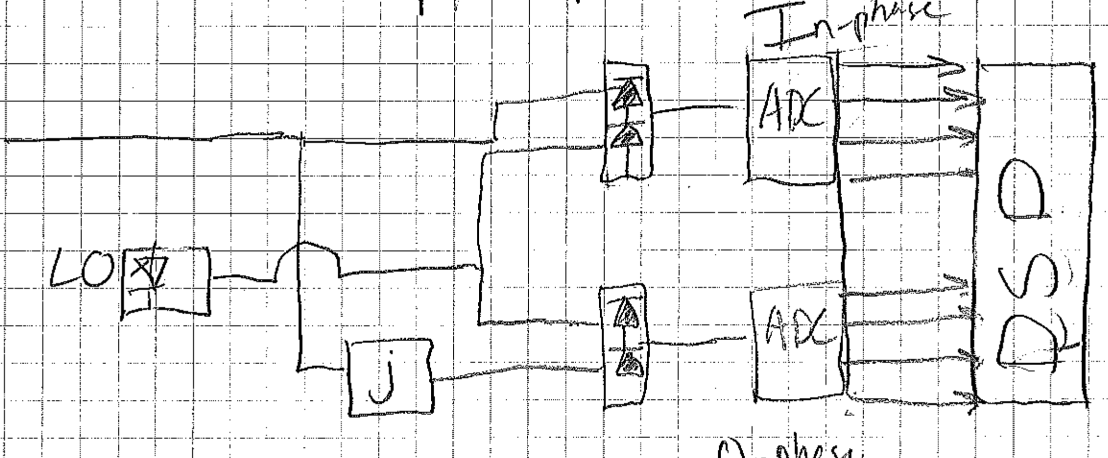


Output: $E(t) = A_0(t)\left(\cos(\omega_0 t)\cos(\varphi) - \sin(\omega_0 t)\sin(\varphi)\right) =$

2 $\quad = \mathrm{Re}\{A(t)\cdot e^{j\omega_0 t}\}$

Modulate inphase data on In-phase and Q-phase data on the other.

Receiver principle sketch:



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From the principle sketches on the last page it's clear that coherent Tx and Rx is way more complicated than using a directly modulated laser or externally modulated OOK with simple direct detection.

We already have good Q-margin but higher order modulation formats requires higher SNR. FEC could also be used to lower the Q/SNR requirements.

Comment on a-part. If all dispersion is compensated in receiver we need to add DCF prior to that to compensate this. This would increase the losses and thereby the amplifier gain required. For DCF the following relation is essential:

$$D_{SMF} \cdot L_{SMF} + D_{DCF} \cdot L_{DCF} = 0$$

$D_{SMF} \approx 17$ ps/nm·ns

$D_{DCF} \approx -100$ ps/nm·km

2)

a) The antenna physical area is $14 \times 4.2\ m^2 = 58.8\ m^2$.

With an aperture efficiency of 65%, the effective aperture area becomes.

$A_e = 0.65 \cdot 58.8\ m^2 = \underline{38\ m^2}$

The corresponding antenna gain,

$$G = \frac{4\pi \cdot A_e}{\lambda^2}$$

where $\lambda = \frac{c}{f} = \frac{3 \cdot 10^8}{1.3 \cdot 10^9} = 0.23\ m$

$\Rightarrow G = 9079 = \underline{\underline{40\ dB}}$

b) Radar equation

$$P_r = P_t \frac{G^2 \cdot \lambda^2}{(4\pi)^3 \cdot R^4} \sigma$$

$$\Rightarrow P_t = P_r \frac{(4\pi)^3 \cdot R^4}{G^2 \cdot \lambda^2 \sigma} =$$

$$= 10^{-13} \frac{(4\pi)^3 \cdot (4 \cdot 10^5)^4}{(9079)^2 \cdot (0.23)^2 \cdot 1} = \underline{1.2\ MW}$$

The pulse reflected from a target 400 km away should be received before we send the next pulse.

$$T_p = \frac{2R}{c} = \frac{2 \cdot 4 \cdot 10^5}{3 \cdot 10^8} = 2.67\,ms$$

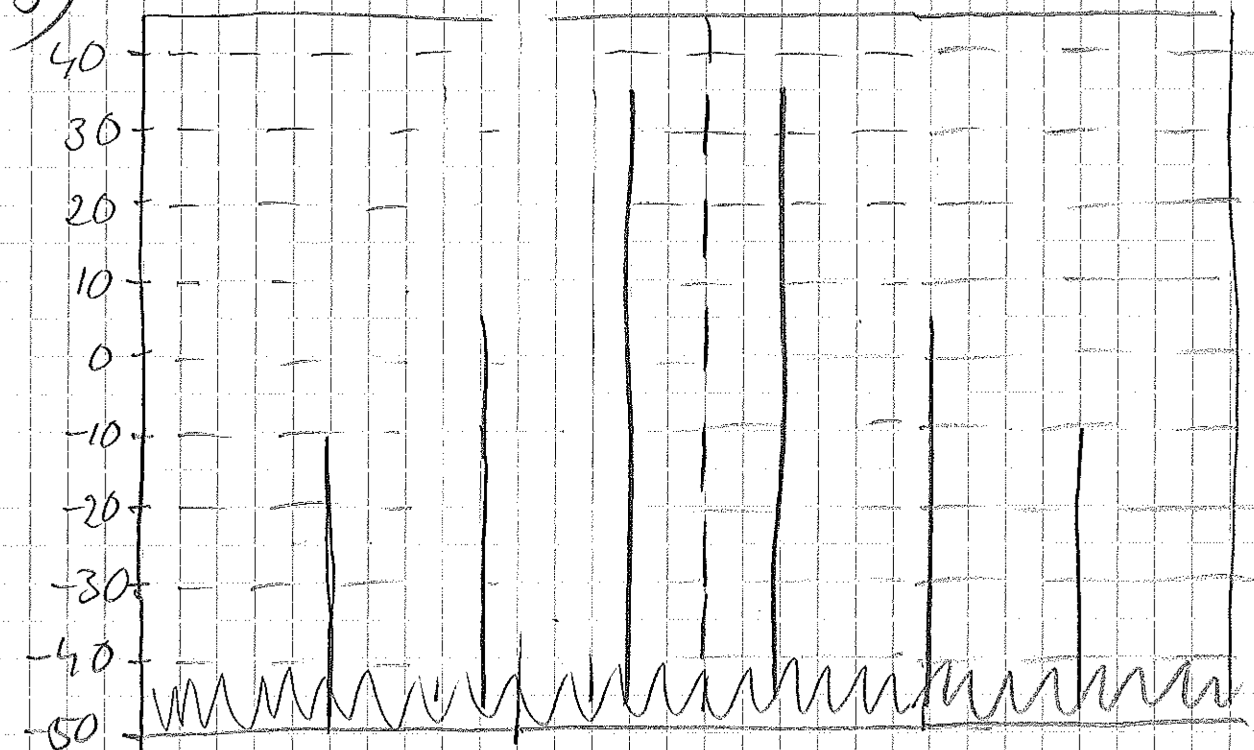
$$\Rightarrow f_p = \frac{1}{T_p} = 375\,Hz$$

3)

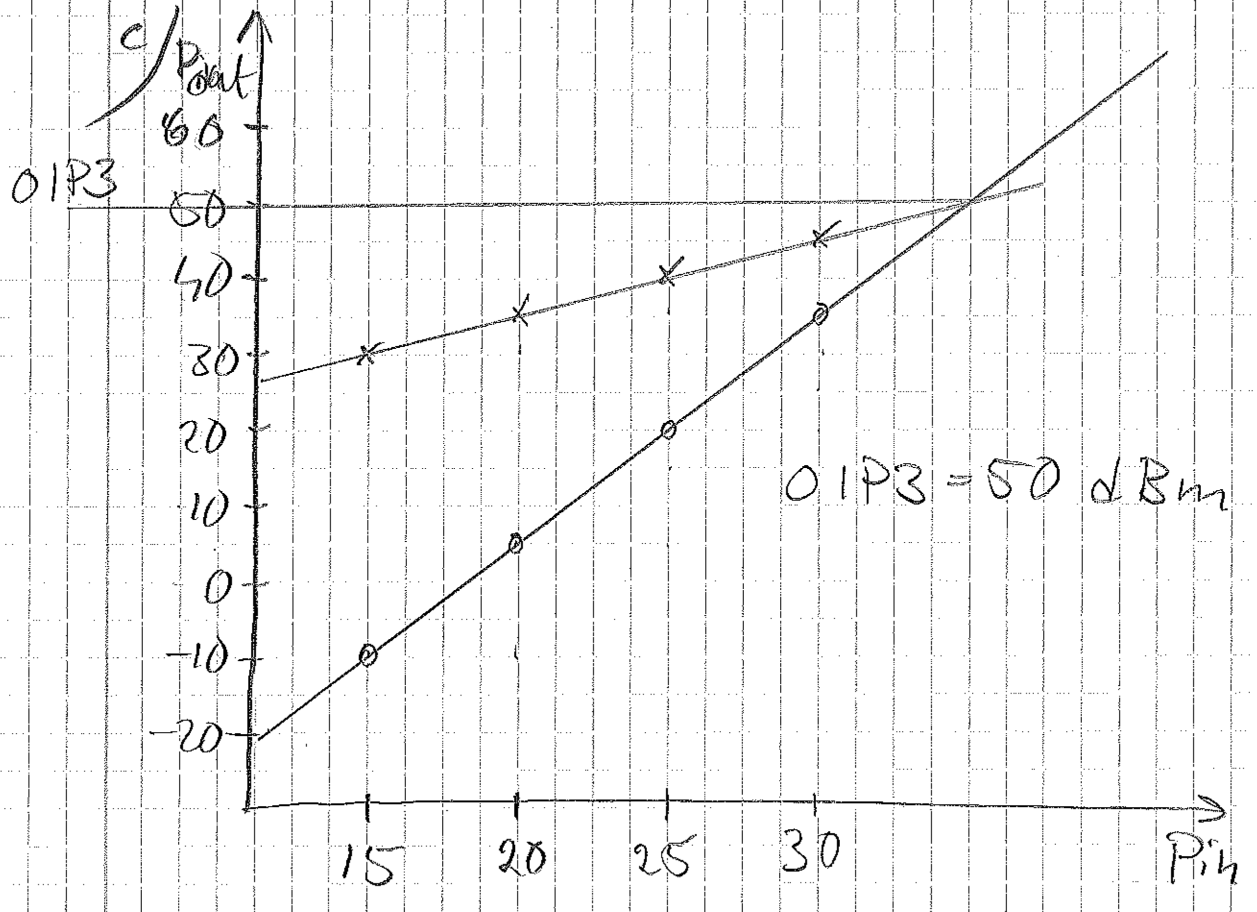
a) $P_{out} = 30$ dBm, $P_{in} = 15$ dBm

$\Rightarrow G = P_{out} - P_{in} = 30 - 15 = \underline{\underline{15 \text{ dB}}}$

b)



c)



OIP3 = 50 dBm

OIP3 can also be estimated from, 2(a)

$OIP3 = P_{\omega_1} + \frac{1}{2}\Delta P = 30\,dBm + \frac{1}{2}(30-(-10))$

$= \underline{30 + 20\ dBm}$

d) $P_{1dB} \simeq OIP3 - 10 = \underline{40\ dBm}$

4) There are several possible solutions, but 1(3)

1. The output power from each transistor stage should have some margin to the 1 dB compression point. Let's use $P_{out,x} \leq P_{1dB,x} - 3\,dB$ where x denotes the transistor stage.

2. The first transistor should have a large gain in order to reduce the impact of noise from the following stages.

3. There is no point in using larger devices than necessary.

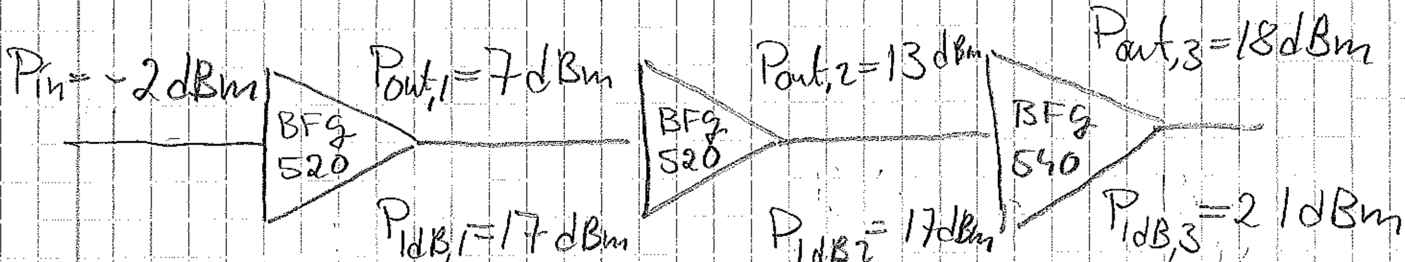
a) We need three stages in order to get a total gain of 20 dB. The third stage has to be a BFG540 since it is the only one that can deliver 18 dBm output power.

With a total gain of 20 dB and 18 dBm output power the input power to the first stage

$$P_{in,1} = 18 - 20 = -2\,dBm$$

If we chose BFG505 for the first stage, we can only use a gain of 3 dB (-2+3=1 which gives a margin of 3 dB to the P_{1dB}. Hence for the first stage we choose BFG520 in order to have a higher gain on the first stage. 2(3)

For the second stage, BFG520 is large enough. The power levels, gains, and P_{1dB} are shown below.



$g_1 = 9$ $\qquad g_2 = 6$ $\qquad g_3 = 5$

c) With solution shown above we get

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

$$= 1{,}55 + \frac{1{,}55 - 1}{7{,}94} + \frac{1{,}62 - 1}{7{,}94 \cdot 3{,}98} = \underline{\underline{1{,}64}} = \underline{\underline{2{,}15 \text{ dB}}}$$

$$OIP3 = \left[\frac{1}{OIP3_1 \cdot G_2 \cdot G_3} + \frac{1}{OIP3_2 \cdot G_3} + \frac{1}{OIP3_3}\right]^{-1} =$$

$$= \left[\frac{1}{398 \cdot 3.98 \cdot 3.16} + \frac{1}{398 \cdot 3.16} + \frac{1}{2512}\right]^{-1} =$$

$$= 717 = \underline{\underline{28.6\ dBm}}$$