Department of Microtechnology and Nanoscience

Wireless and Photonic System Engineering SSY085

2011-10-17, 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: Monday Nov. 7^{th} at $12^{00} – 12^{30}$ in room A604/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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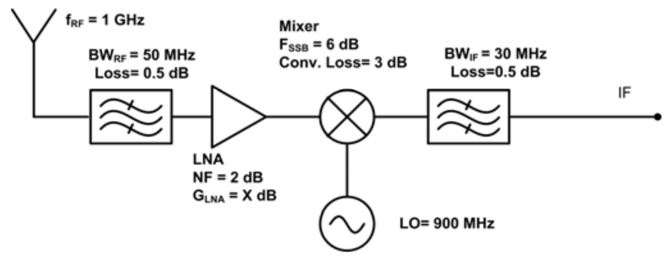
1. Design a fiber link connecting Perth (in western) with Sydney (in eastern) Australia. The operator wants 1 Tbit/s data capacity in both directions, but with capability to upgrade the capacity over a number of years, up to 3 Tbit/s at a later time. Describe all system components, the layout of the system and verify with calculations that it will work as intended. Also describe how the upgrade from 1 to 3 Tbit/s is to be carried out. Make (and state) reasonable parameter assumptions for the ingoing components. Fiber nonlinearities limit the total transmitted power into a fiber to less than 50 mW at any place along the line. To your disposal you also have forward error correction (FEC) circuits, capable of reducing a $BER=10^{-3}$ to less than 10^{-12}, provided 10 % increased data rate is allocated for the extra control bits.

Fig.1: Map over Australia

(30 points)

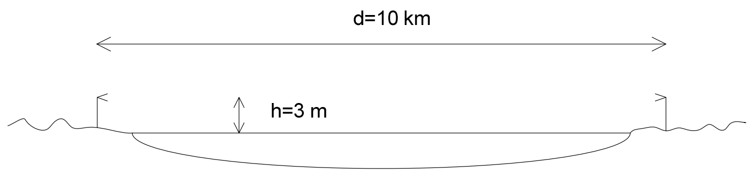
2.



a) The diagram above depicts a receiver in a microwave link. To achieve low noise in the receiver at a reasonable cost, you are asked to calculate the minimum LNA gain (X dB) required to make the noise contribution from the mixer 10 times smaller than the one from the LNA at the receiver output. (6p)

b) Calculate the equivalent noise temperature of the receiver. (2p)

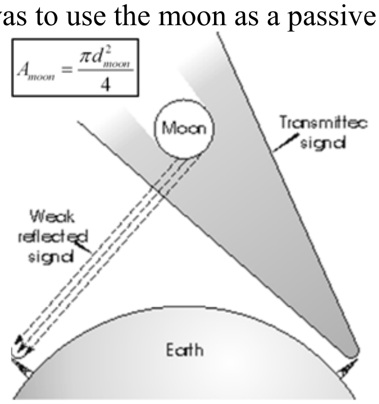
c) The receiver is placed in a link like the one depicted below. The modulation is QPSK at 10 Mb/s. List five fundamentally different things you can change in order to improve the datarate without increasing the bit error rate. Look at both the receiver and the whole system. You don't need to make any calculations. (2p)



(10 points)

3.

Before communication satellites were available for cross Atlantic communication, one idea was to use the moon as a passive reflector (see below).



Frequency	1296 MHz
Transmit power	300 W
Antenna diameter (TX)	5 m
Radiation efficiency (TX)	50%
Receiver G/T	14 dB/K
Modulation format	unspecified
BER	$<10^{-5}$
Distance earth-moon	$3.8*10^{8}$ m
Moon diameter (d_{moon})	$3.476*10^{6}$ m
Moon radar cross section	$7\%*A_{moon}$

Given the system specifications above, calculate the minimum time needed to transfer a typical MP3 file (3e7 bits). Comment on the results obtained.

(10 points)

4.

A 60 GHz point-to-point link with a transmitter output power of 10 mW is designed for a maximum range of 1 km when using QPSK modulation at BER = 10^{-5}.

a) Calculate how much output power is needed if the BER requirement is relaxed to 10^{-3} (4p)

b) Calculate how much output power is needed to extend the range to 2 km with BER = 10^{-5}. (6p)

(10 points)

Solutions

Problem 1:

The distance is 3300 km.
The simplest solution assumes OOK, at e.g. 40 Gb/s at 25 and later 75 wavelength channels, equally spaced in the EDFA band. One could also play with the TDM data rates.
The birdirectionality adds nothing of value; the system must be essentially be doubled in both directions. Possibly the DCF could be reused with help of circulators but that would be expensive as well.
DCF (dispersion of -170 ps/nm km, loss of 0.6 dB/km is state of the art) is reasonably inserted at each amplifier and will add a few dBs of loss.
Average transmitted power comes from the Q=6=sqrt(P_t/(N hv G F_n B)), where by using G=15 dB F_n=3, B=40 GHz, N=66 we obtain P_t=0.38 mW which for 75 channels gives a total power of 29 mW, well below the nonlinear limit.

Full solutions should be more detailed, including component choices (laser type, detector type, bandwidths, modulation formats, wavelength allocation, all noise sources, SNR calculations, block diagrams etc.)

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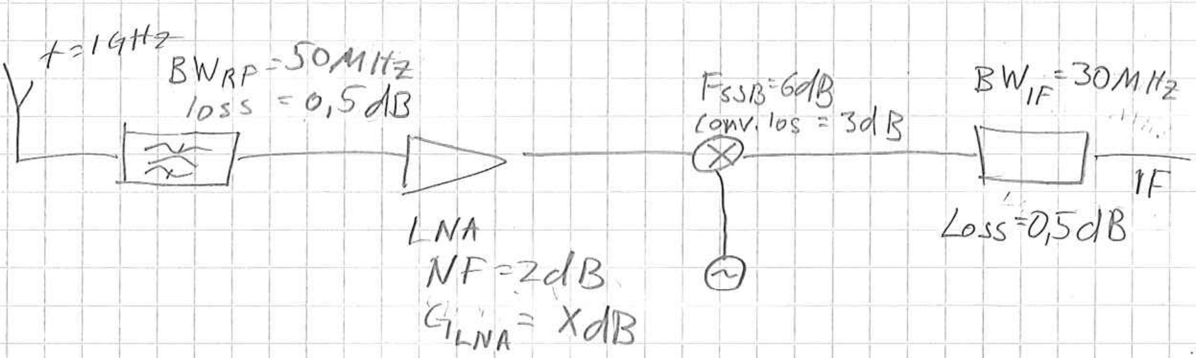
2,a)



Find X that makes the noise contrib. from T_{SSB} 10 times smaller than the one from T_{LNA}

RF-filter reflective at image freq. $\Rightarrow T_f = 0$ @ f_{IF}

In-band: $T_f = \left\{ \begin{matrix} \text{assume } 290K \\ \text{as phys. temp} \end{matrix} \right\} = (1-10^{-0,05}) \cdot 290 = 32\ K$

$T_{SSB} = (4-2) \cdot 290 = 580K$, $T_{LNA} = (1,58-1)290 = 168K$

$G_f = -0,5dB = 10^{-0,05} = 0,89$

$G_M = -3dB = 0,5$

$$N_{out} = kB\Big[T_f \cdot G_f \cdot G_{LNA} \cdot G_M \cdot G_f + T_{LNA} \cdot G_{LNA} \cdot G_M \cdot G_f + T_{SSB} \cdot G_M \cdot G_f + \underbrace{T_{LNA} \cdot G_{LNA} \cdot G_M \cdot G_f}_{\text{image freq.}} + T_f G_f \Big]$$

$N_{0,T_{LNA}} = 2 \cdot T_{LNA} G_{LNA} G_M \cdot G_f$

$N_{0,T_{SSB}} = T_{SSB} \cdot G_M \cdot G_f$

$N_{0,T_{LNA}} = 10 \cdot N_{0,T_{SSB}}$

$2 \cdot T_{LNA} G_{LNA} G_M \cdot G_f = 10 \cdot T_{SSB} \cdot G_M \cdot G_f$

$$G_{LNA} = \frac{10 \cdot T_{SSB} \cdot \cancel{G_M} \cancel{G_f}}{2 T_{LNA} \cdot \cancel{G_M} \cancel{G_f}} = \frac{10 \cdot 580}{2 \cdot 168} = 17,26 \approx 12,4dB$$

b)

$$T_{e,out} = T_f \cdot G_f \cdot G_{LNA} \cdot G_M \cdot G_F + T_{LNA} \cdot G_{LNA} \cdot G_M \cdot G_f + T_{SSB} G_M \cdot G_f + T_{LNA} \cdot G_{LNA} \cdot G_M \cdot G_f + T_f G_f = 3086\ K$$

$$T_{e,in} = \frac{T_{e,out}}{G_{tot}} = \frac{T_{e,out}}{G_f G_{LNA} G_M G_f} = 451\ K$$

c)

Increase LNA gain

Higher gain antennas

Increase transmit power

Raise antennas

Increase modulation

Increase power transmitted

Use filters with lower loss

Use LNA with lower NF

etc...

Problem 3:

```
%% settings
f = 1296e6; lambda = 3e8/f;
Pt = 300; dParab = 5;
d = 3.476e6; r = 3.8e8;
erad = 0.55; eta = 0.07;
GT = 10^(14/10); %Converted from dB/K

%% TX
Gtx = erad*(pi*dParab/lambda)^2;
EIRP = Pt*Gtx;

%% Path loss
% The radar equation when using the moon cross section area * eta as
the radar cross section
PL = 1/(eta*d^2*lambda^2/((16*pi)^2*r^4));

%% SNR
% Receiver SNR according to (4.30) in Pozar: SNR = GT*EIRP/(PL*k*B).
% SNR = Eb/n0*(Rb/B) which allows Rb to be solved for.
% Rb = EIRP*GT/(PL*1.38e-23*(Eb/n0)) where GT is G/T for receiver.
% Rb is maximized for modulation with minimum Eb/n0 @ BER = 1e-5.
% According to Pozar binary PSK and QPSK have equal minimum Eb/n0 =
9.6 dB, which yields
Eb_n0 = 10^0.96;
Rb = EIRP*GT/(PL*1.38e-23*Eb_n0);

%% Time
time = 3e7 / Rb
% time = 2.29e5 seconds = 2.65 days. Actually quicker to transfer the
file using USB memory on an airplane!
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Problem 4:

4a) From BER vs. Eb/n0 graphs, for example on Lecture 4 (Modulation) page 29, it can be estimated that E_b/n_0 decreases from 9.6 dB @ BER = 10^{-5} to approximately 6.5 dB @ BER = 10^{-3}. Hence, the signal level at the receiver can be reduced with 3.1 dB. Starting from an output power of 10mW = 10 dBm @ BER = 10^{-5}, it will therefore be sufficient with 6.9 dBm = **4.9 mW** to get BER = 10^{-3}.

4b) Here we need to consider both free space propagation, and an atmospheric loss. According to Lecture 8 (Fading), slide 17 the attenuation is approximately 15 dB/km @ 60 GHz. This loss should be added on top of the free space loss. The expression for the received power is thus: $Pr = Pt*Gt*Gr*\lambda^2/(4\pi R)^2 * 10^{-15/10*R/1000}$

Assuming fixed Pr, Gt, Gr, λ, results in the following: $Pt_{2R} / Pt_R = 4 / 10^{-15/10*R/1000}$
Inserting Pt_R = 10 mW yields $Pt_{2R} = 4*10^{-2} / 10^{-1.5}$ = **1.26 W**