Department of Microtechnology and Nanoscience

Wireless and Photonic System Engineering SSY085

2013-01-17, 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: Contact Christian or Magnus as above.

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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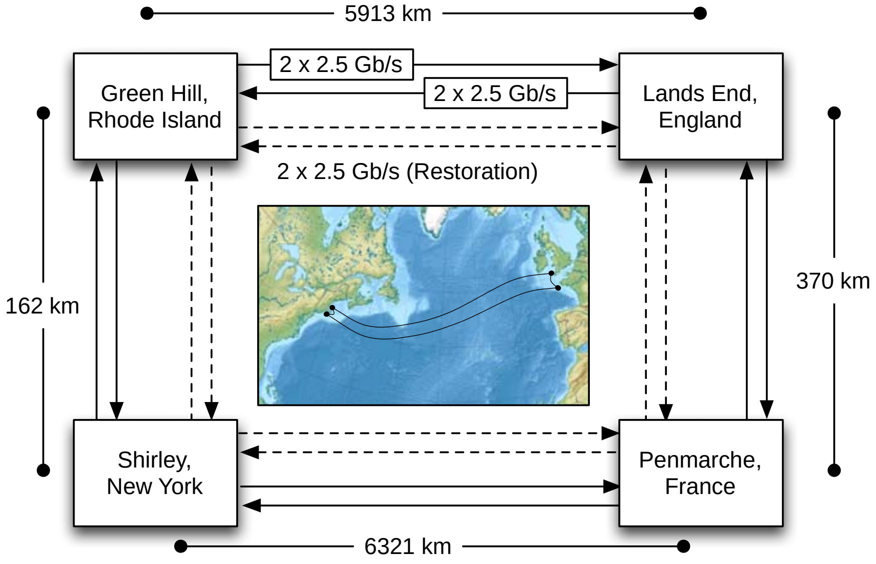
1. The TAT 12/13 Network

In 1995 the first transatlantic cable using optical amplifiers, the TAT 12/13, was designed. It consisted of two Atlantic crossings (hence the double numeral name) in order to provide ring network protection among the four nodes (Green Hill, Lands End, Penmarche, Shirley); i.e. if a cable break occurred between any two nodes, the communication between them could quickly be restored by switching on the normally unused "restoration" fibers (dashed in the figure). The network carried 2 wavelengths of 2.5 Gb/s OOK data each per fiber. Each cable consisted of four fibers, two lit fibers (one for each direction) and two dark fibers for the restoration backup, as shown in the figure.



Problem 1: The transatlantic telephone (TAT) 12/13 ring. The system was in use from 1996 to 2008.

Your tasks are to:

(a) Design this system, (specify all relevant parameters, e.g. lasers, detectors, amplifiers, amplifier spacing, wavelengths etc.) assuming realistic values, and verify that your selected design works. Note that in 1995 fibers had around 10 % higher loss coefficients than today, and the EDFAs had slightly higher noise figures (6 dB), and lower gain (<15 dB). Also allocate 8 dB in system SNR margin for safety, and to enable future upgradability to higher data rates.

(24 points)

(b) Discuss how such a future upgrade to higher data rates can be carried out.

(3 points)

(c) Estimate the cost of this system, assuming that one Atlantic cable crossing (including submerging with a cable ship) costs 200 M$, one amplifier costs 0.1 M$, and the terminal equipment for each wavelength in a node is 0.5 M$.
Given that the main income is telephony at 0.1 $/minute, and on average 10 % of the available transmission capacity is used for telephony, how long did it take to pay off this system? Compare this to its 12 years of use.

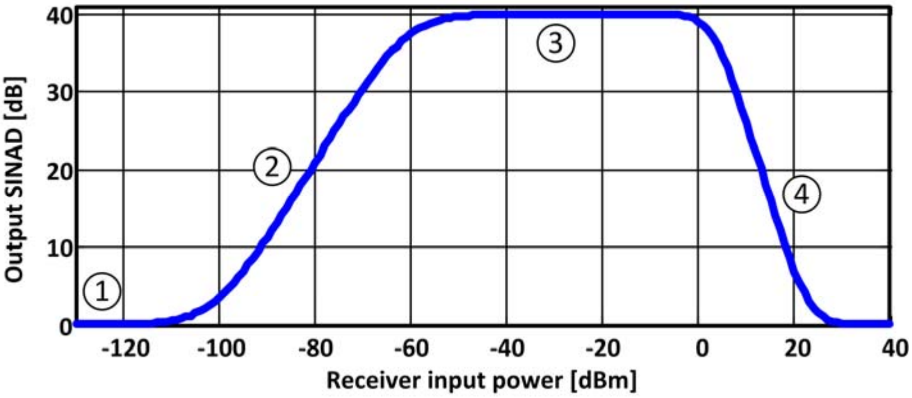
(3 points)

2. SINAD

Receivers are sometimes characterized by their *signal-to-noise and distortion ratio* (SINAD) which is defined as:

$$SINAD = \frac{P_{signal} + P_{noise} + P_{distortion}}{P_{noise} + P_{distortion}}$$

The figure below shows an example of how SINAD behaves versus input power for a receiver with a bandwidth of 10 MHz:



a) Which is the dominant noise/distortion mechanism in each of the four operating areas indicated in the figure? (4p)
b) Calculate the input third order intercept point. (2p)
c) Calculate the phase noise. (2p)
d) Calculate the noise figure. (2p)

(10 points)

3. Point-to-point link

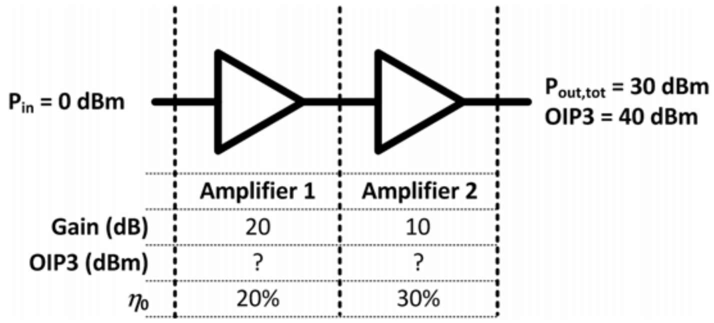
A 23 GHz point-to-point link mounted with line-of-sight between two rooftops in a city has an output power of 10 dBm, has a receiver with noise figure of 5 dB, and uses parabolic antennas with 0.4m diameter. The link should be designed considering Rician fading (K = 10 dB), outage probability of $<10^{-4}$, and a maximum rain attenuation of 5dB/km.

Calculate the maximum range for 100 Mb/s communication at BER = 10^{-5}.

(10 points)

4. Transmitter design

Transmitter design is typically about managing contradicting linearity and power consumption constraints in the final power amplifiers (PAs). The power consumption of a PA may be approximated by: $P_{dc} = P_{1dB}/\eta_0$, where η_0 is related to the PA design. Consider now the following two-stage PA design:



	Amplifier 1	Amplifier 2
Gain (dB)	20	10
OIP3 (dBm)	?	?
η_0	20%	30%

Your task is to determine how the linearity (OIP3) of the two PAs should be selected such that the total OIP3 = 40 dBm and that the total power consumption is minimized. What is the resulting minimum power consumption for the complete two-stage PA?

(10 points)

Solutions

Problem 1:

Problem 2:

a) 1: Thermal noise (ambient noise dominating over the signal),
2: Thermal noise (signal is now larger than noise floor, but thermal noise is still the dominating effect),
3: Phase noise (proportional to signal power → Flat SINAD),
4: Intermodulation distortion (dominates at high power)

b) Input third-order intercept point (IIP3):
Signal and distortion power is for a two tone signal related to OIP3 through (3.106) in Pozar: Pdist = $(Pout)^3/OIP3^2$. To get the total distortion power, twice the power needs to be considered for both distortion and signal. Further, from the graph we only know the input power and we are looking for IIP3 = OIP3/Gain. In the resulting expression, the gain cancels, and we get the following IIP3 expression:

IIP3 = sqrt(Pin^3/4/Pdist)

Pdist can be calculated from the figure and SINAD definition, considering that Pnoise is negligible in part 4 of the diagram.
This yields: IIP3 = 20 dBm.

c) Phase noise:
This is extracted from region 3 in the diagram, where distortion and thermal noise are both negligible. Phase noise is proportional to signal power:

$P_{phasenoise}$ = L*B*Psignal = L*B*Pin*Gain → L = $P_{phasenoise}$/(B*Pin*Gain)

$P_{phasenoise}$/Gain can then be extracted from the SINAD expression with numbers from the graph in region 3. The result is: L = -110 dBc/Hz.

d) Thermal noise:
Thermal noise is dominating in regions 1 and 2. Pnoise is in this case given by Pnoise = k*(Te+T0)*B*Gain. Like for the other cases, the gain will cancel when using the SINAD expression with the graph given. The Te obtained is 289K, which can be converted to
F = 1 + Te/290 = 3 dB.

Problem 3:

First of all, we choose to consider QPSK modulation since it (and BPSK) requires less energy per transmitted bit for a given SNR and hence longest range. QPSK at BER = 10^{-5} corresponds to S/N = 12.6 dB

The outage probability given can be converted into a corresponding fading margin using the plots for Rician fading in the lecture slides. For K = 10 dB and an outage probability, the fading margin is according to the plot approximately 13 dB.

Finally, to overcome the internal noise of the receiver, we also need to overcome the receiver noise figure of 5 dB. The overall required S/N that we need to design for at the receiver input is therefore:
S/N = 12.6 + 13 + 5 = 30.6 dB.

Furthermore, the given antenna sizes can be converted to corresponding antenna gains of
$Gr = Gt = (\pi * d_{Parab}/\lambda)^2 = 9280 = 39.7$ dBi.

Since the system is placed between two rooftops we may assume free space propagation for the main path. However, in order to compensate for the possible 5 dB/km rain loss, we get the following relation between received and transmitted power:

$Pr = Pt*[Gr*Gt*\lambda^2/(4*pi*R)^2]*10^{-(R/1000)*(5/10)}$
where the latter term is related to the rain loss.

Considering that the received power should exceed the ambient noise power with 30.6 dB, as calculated above, we get:

$Pr = k*T0*B*10^{30.6/10} = Pt*[Gr*Gt*\lambda^2/(4*pi*R)^2]*10^{-(R/1000)*(5/10)}$, where all information except for R is given in the problem statement (B = bitrate/2 for QPSK). Inserting numbers yields the following equation: $2.2975*10^{-10} = 0.93*10^{-R/2000}/R^2$, which has to be solved numerically for R (simply trying with your calculators).

The maximum range found is: <u>R = 4411m</u>

Problem 4:
The expression for cascaded OIP3 (P3) is: 1/P3tot = 1/(P31*G2) + 1/(P32)
Where G2 is gain of second stage and P31 and P32 are the OIP3 for the two stages.
Thus, for a given total P3tot, the following relationship is established:
P32 = P31*G2*P3tot/(P31*G2-P3tot)

Now, the total DC power consumption is given by: Pdc = P31/(10*η1)+P32/(10*η2)
where it has been used that P3 = 10*P1_dB (approximately).

Pdc is minimized when its derivative is equal to zero. The resulting derivative, replacing P32 with the expression above, yields:

d(Pdc)/d(P31) = 0 =
1/(10 η1)-(G2^2 P31 P3tot)/(10(G2 P31-P3tot)^2 η2)+(G2 P3tot)/(10(G2 P31-P3tot) η2)

Solving for P31 results in a second degree equation with the following solution, of which only one gives a positive (and thus physical) intercept point power.

P31 = (P3tot sqrt(η_2) +/- sqrt(G2) P3tot sqrt(η_1))/(G2 sqrt(η_2))

Inserting numbers: G2=10, η1=0.20, η2=0.40, P3tot=10 yields
P31 = 3.6 W = 35.5 dBm and from the relation above, P32 = 13.9 W = 41.4 dBm.
Finally, inserting these numbers into the Pdc expression yields:
The total dc power consumption Pdc = 6.4 W.