Department of Microtechnology and Nanoscience

Wireless and Photonic System Engineering SSY085

2013-10-21, 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. 11, 12-13 in room A604, ("Acceptorn", MC2, 6th floor).

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. Rhino surveillance using unmanned aerial vehicles (UAVs)

UAVs (i.e. remote controlled small airplanes) are used increasingly in civilian applications. Your task is to develop a wireless system for UAV-based video surveillance of rhinos (noshörningar) in the Kruger National Park in South Africa.

Kruger National Park Map

Each UAV is equipped with a high resolution camera (IR or daylight) generating 2 Mbit/s of video data that should be sent to the control central in Shingwedzi through a number of base stations that will be installed in the park. The same base station installations should also be used to send 100 kbit/s flight control data to each UAV. The system should support communication with up to 10 UAVs in the park at the same time.

We want information concerning the number of base stations needed, as well as RF system design of the UAV and base station transmitters and receivers including block diagrams, modulation formats, antennas, output power, frequencies, etc. All assumptions made should be clearly motivated. Focus on low cost solutions where applicable.

The interconnection between the base stations and communication with central station in Shingwedzi will be made with optical fiber and is not part of your task.

(30 points)

2. Phase noise

A simplified graph illustrating the phase noise characteristics of a 19 GHz phase locked oscillator is shown below.

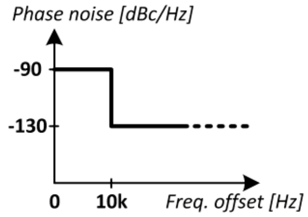


Figure 1. 19 GHz oscillator phase noise specification.

This oscillator will be used in combination with a ×3 multiplier as a 57 GHz local oscillator in both the transmitter and receiver of a 60 GHz wireless system. The system is designed for BER = 10^{-5} using 256-QAM modulation, corresponding to max tolerable RMS phase error of θ_{RMS} = 1.5°. What is the maximum system bitrate that can be obtained with this oscillator?

(10 points)

3. An MMF link

A multimode fiber is used for a low-cost, intensity modulated transmission over short distances at the wavelength 850 nm. The fiber is made of a polymer, with core and cladding indices of 1.1 and 1.6, respectively. Since the core radius is as large as 1 mm, the fiber is prone to bend losses, and an estimated loss of 1 dB/m is therefore used in the design. A directly modulated laser with output power 0.5 mW and rise time 50 ps is used as transmitter, and a Si photodiode with a Gaussian-shaped transfer function of 5 GHz of FWHM bandwidth is used as receiver. Assume 5 dB coupling losses in and out from the fiber. Make additional reasonable design assumptions and state them clearly.

a) What is the highest data rate you can transmit over 10 meters?
b) How long can you transmit 100 Mbit/s?

(10 points)

4. A ring network

A wavelength routed metro ring network consists of 4 nodes, each capable of transmitting and receiving 10 wavelengths of 10 Gb/s each in *both* directions, i.e., 10x10 Gb/s clockwise (CW) *and* 10x10 Gb/s counterclockwise (CCW). Enumerate the nodes clockwise from 1 to 4, and assume that the following matrix for the data traffic from (row node number) and to (column node number) is to be fulfilled:

Node nbr	To 1	To 2	To 3	To 4
From 1	-	50 Gb/s	0 Gb/s	80 Gb/s
From 2	10 Gb/s	-	60 Gb/s	x Gb/s
From 3	50 Gb/s	0 Gb/s	-	0 Gb/s
From 4	70 Gb/s	0 Gb/s	30 Gb/s	-

Assign wavelengths to meet this traffic demand! You can make use of both CW and CCW traffic to meet the required demand. What is the highest data rate that can be accommodated from node 2 to node 4 (marked x in the table)

a) if the ring works as specified?
b) if there is a cable break between nodes 3 and 4? (10 points)

Solutions

Problem 1:

Problem 2:

The RMS phase error is in general related to phase noise by:

$$P_{noise,SSB}/P_{carrier} = \int_0^{B/2} L(\Delta f)\, d\Delta f = \frac{\theta_{RMS}^2}{2}$$

Since a ×3 multiplier is used with the oscillator the max RMS phase error needs to be converted: $\theta_{RMS,57GHz} = 3\times\theta_{RMS,19GHz}$.

Furthermore, the phase noise at the transmitter and receiver will add up. Since they can be assumed to be independent processes their phase noise powers will add and we therefore have:

$$\frac{\theta_{RMS,57GHz,tot}^2}{2} = \frac{\theta_{RMS,57GHz,TX}^2}{2} + \frac{\theta_{RMS,57GHz,RX}^2}{2} = \frac{\left(3\theta_{RMS,19GHz,TX}\right)^2}{2} + \frac{\left(3\theta_{RMS,19GHz,RX}\right)^2}{2} = 9\theta_{RMS,19GHz}^2$$

where $\theta_{RMS,19GHz}$ relates to the phase error in one of the 19 GHz VCOs (transmitter or receiver). The total tolerated phase error at 57 GHz is specified as $\theta_{RMS,57GHz,tot}$ = 1.5° = 26.2×10^{-3} rad, which according to the expression above leads to $\theta_{RMS,19GHz}$ = 6.2×10^{-3} rad.

Hence, we need to solve the following equation for the bandwidth, *B*, using the phase noise data from the graph, i.e. $L(\Delta f)$.

$$\int_0^{B/2} L_{19GHz}(\Delta f)\, d\Delta f = \frac{\theta_{RMS,19GHz}^2}{2} = 1.9\cdot 10^{-5}$$

This yields: $10^4 * 10^{-90/10} + (B/2 - 10^4) * 10^{-130/10} = 1.9 * 10^{-5}$ → *B* = 181 MHz.
Using the spectral efficiency of 256-QAM yields the max bitrate:
<u>$R_{b,max}$ = 8*181 MHz = 1.448 Gbit/s</u>.

Problem 3:

Assume OOK modulation and that thermal noise limits the receiver (it does for received signal power less than around 1 mW). Obviously we need to make power and risetime budgets to evaluate the performance.
For Q>6 (BER<10^{-9}) we have $Q=(I_1-I_0)/2\sigma_T = RP_{rec}/\sqrt{4\,kT\,\Delta f/R_L} > 6$, where P_{rec} is the average received power R the responsivity, and Δf the detection bandwidth, which we assume equal to the datarate B. The responsivity is R=q/hv (assume 100 % quantum efficiency) which is 0.69 A/W at 850 nm.

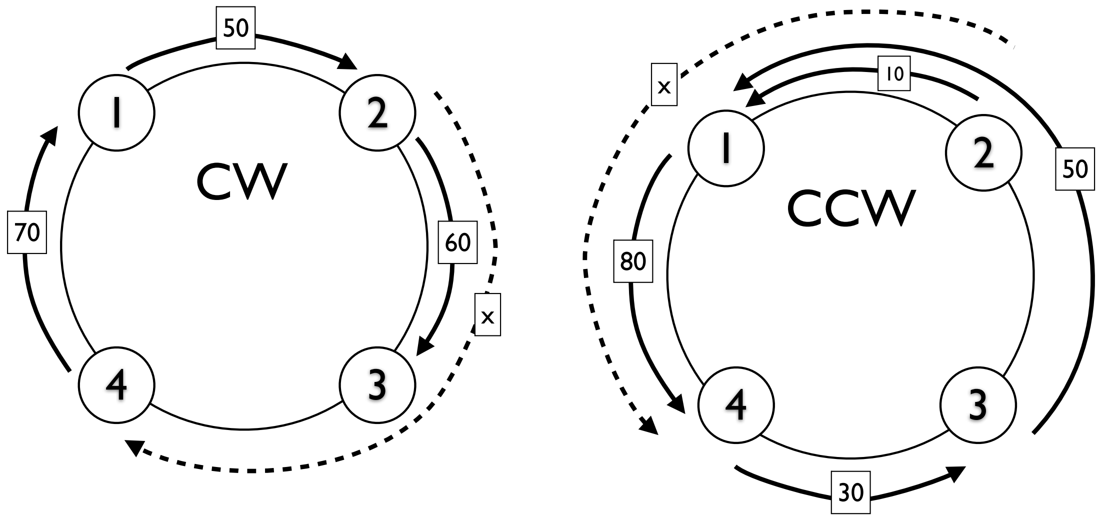
For the risetime budget we need the MMF pulse broadening ΔT, which is per unit length L: $\Delta T/L = n_1^2\,\Delta/(c\, n_2)$ where Δ is the index difference, which is $(n_1-n_2)/n_1$ =(1.6-1.1)/1.6=0.3125, so that ΔT/L=2.4 ns/m.

a) For 10m we find ΔT=25 ns; way larger than the laser and detector risetimes (5 GHz corresponds to around 0.2 ns) which can be neglected. Selecting a bit period of twice the fiber risetime, 50 ns, leads to a data rate of B=20 Mbit/s. We need to check the power budget; at this data rate the thermal noise variance is receiver sensitivity is $P_{rec}=6\sigma_T/R$=-31 dBm, and the allowed losses are -3-(-31)=28 dB, which would correspond to 18 dB fiber loss, or 18 m of fiber, so it is clearly limited by the fiber dispersion.

b) At 100 Mbit/s (a bit period of 10 ns), i.e., Δf=100 MHz, the receiver sensitivity is 5 times (7 dB) lower than in the a)-problem, hence the allowed fiber length given by the loss budget is 18-7=11 dB, or 11m. However the fiber dispersion allowing for a bit period of 10 ns is only 5 ns which corresponds to a fiber length of 5/2.4=2.1 m. Also here the system is limited by dispersion, rather than attenuation.

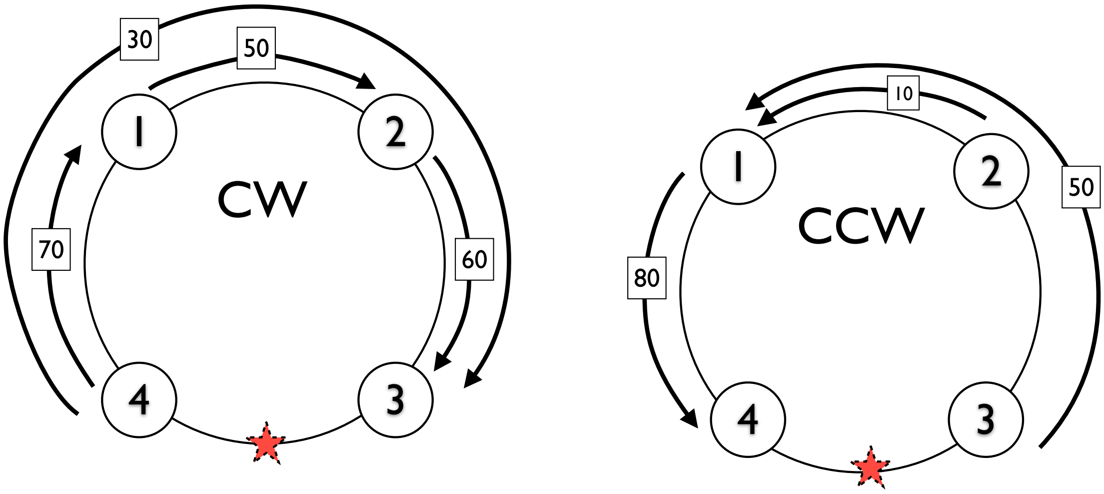
Problem 4:

a) It is straightforward to obtain the following traffic flows from the matrix, where we have two alternatives for the 2-4 data x (dashed); either in the CW or the CCW direction:



Since the sum of all traffic in any direction and over any path must be ≤100 Gb/s, we see that x in the CCW direction is ≤ 20 Gb/s (limited by the 1-4 path), whereas in the CW direction it is limited to ≤ 40 Gb/s (by the 2-3 path). Thus the answer is 40 Gb/s in the CW direction.

b) If the connection between 3 and 4 is broken, the CCW 4-3 data of 30 Gb/s must be redirected to the CW direction, obtaining the diagram



from which we can see that the 4-2 connection must go in the CW direction. However since the CW 4-1 path is filled with 100 Gb/s data, no data from 4-2 is possible, i.e., x=0 in this case.