Department of Microtechnology and Nanoscience

Wireless and Photonic System Engineering SSY085

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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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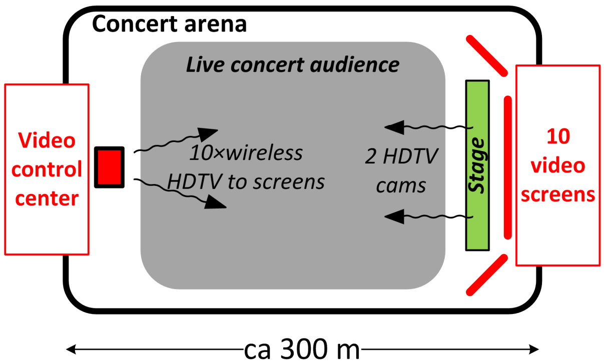
1. Wireless live concert video

The very large video screens and cameras used at live concerts are typically connected to a central video control center using optical fibers, laid down on the ground under the audience. A more flexible and possibly more reliable solution would be to use wireless connections above the heads of the audience, see Figure below.



Your task is to design a system that connects two HDTV (20 Mbit/s) on-stage cameras to the video control center using wireless transmission. The video control should provide wireless feeding of 10 independent HDTV large video displays. The system should operate in the unlicensed 57-63 GHz frequency band.

We want information concerning the RF system design of the camera→control center and control center→display links including block diagrams, modulation formats, antennas, output power, etc. All assumptions made should be clearly motivated.

(30 points)

2. Criticizing wireless receiver design

Your colleague has been assigned the task of designing a low cost super-heterodyne receiver for a 5.0 GHz point-to-point link that uses 20 Mbit/s QPSK modulation. The receiver should have a sensitivity better than -100 dBm at BER<10^{-5}. As a Wireless System Engineering expert, you have been asked to review the solution presented by your colleague, see below.

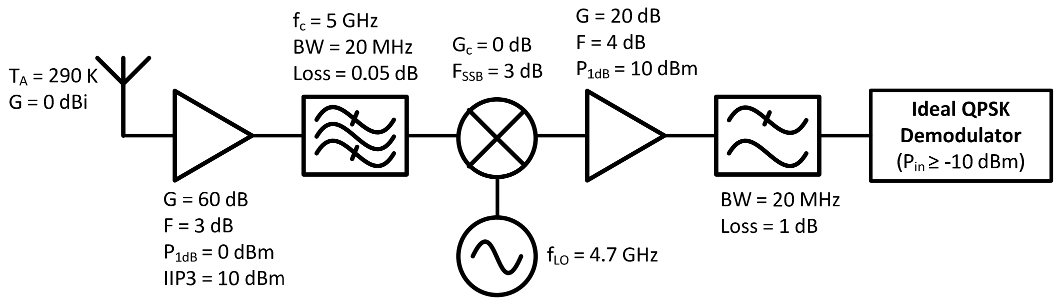


Figure 1. Receiver block diagram proposed by your colleague.

Given the specifications above you should now clearly motivate and list any errors, inconsistencies, or unsuitable design choices that you can find in the receiver block diagram that your colleague has proposed.

(10 points)

3. A multimode fiber link

A MMF link has the fiber properties: a graded index (GRIN) fiber with index difference Δ=0.1, core radius=0.1 mm, core index n_1=1.4, attenuation=3 dB/km, operating wavelength 850 nm. The coupling losses (in to and out from) the fiber is 2 dB per interface. The transmitter is a directly modulated laser diode with bandwidth of 10 GHz and transmitted power of 0.1 mW, and the receiver consists of a p-i-n diode with bandwidth 10 GHz. The link is intended for transmission of on-off-keyed data in a data center over 50m. What is the highest data rate that can be transmitted? Is the link power- or dispersion-limited?

(10 points)

4. A 1 Tb/s link

A 1 Tb/s WDM system consists of 25 channels of 40 Gb/s on-off-keying data. It should be deployed between Göteborg and Malmö (300km) using standard single mode fiber, with attenuation 0.2 dB/km and dispersion D=17 ps/(nm km). For dispersion compensation, dispersion compensating fiber with D=-100 ps/(nm km) and attenuation of 0.5 dB/km is used. For cost reasons the number of inline amplifiers is to be minimized. The used amplifiers have a noise figure of 6 dB and cannot provide more than 5 dBm of average output power (in total, i.e. summed over all wavelengths). What is the minimum number of amplifiers needed to make this system work (with BER<10e-9)? What is the required gain per amplifier?

(10 points)

Solutions

Problem 1:

Problem 2:

1. This is not a super heterodyne reciever. f_{if} should be $\neq 0$ for super-heterodyne recievers, which means that the LPF after the mixer should be a bandpass filter. A homodyne receiver, with fif = 0, needs to receiver chains to demodulate QPSK (one mixing with $\cos(2*\pi*f_{LO}*t)$, and the other mixing with $\sin(2*\pi*f_{LO}*t)$).
2. The first RF filter is too narrowband to be practical. ~5% is minimum bandwidth in practice.
3. No filter before the LNA. Such filter is important to suppress noise/interference/image frequency in receivers.
4. Bandpass filter bandwidth doesn't match the symbolrate. 20 Mbit/s with QPSK results in 10 MHz bandwidth, which is also typically the bandwidth that should be used for the filter before the demodulator.
5. IIP3 and P1dB do not match for the LNA: OIP3 = IIP3+Gain = 70 dBm. As a rule of thumb, OIP3 ≅ P1dB + 10 dB = 0 + 10 = 10 dBm, which is inconsistent.
6. The sensitivity is not sufficient. Sensitivity (without any input filter) = $k*T*B*F_{LNA} = 1.38e\text{-}23*290*10^6*10^{3/10} = -101$ dBm → SNR = 1 dB → too low to be acceptable given the BER requirement. In fact, even with better LNA, it will be impossible to reach the desired sensitivity. The key to solving it would be to increase the antenna gain (see #10)
7. The gain of the RF amplifier is unreasonably high. From both instability and cost reasons, it is better to distribute more gain from the RF to the IF amplifier.
8. The loss of the RF filter placed after the LNA is too low, in particular with the narrow bandwidth specified, and due to the fact that it is placed after the LNA.
9. Gain budget is incorrect. Sensitivity = -100 dBm + total receiver gain = 60 - 0.05 + 0 + 20 - 1 = -19.05 dBm at the demodulator. However, the demodulator requires an input power of -10 dBm to work.
10. It is unrealistic to use an antenna gain of 0 dBi for a point-to-point link (see #6).

Problem 3:

Start by calculating the dispersion-induced broadening for a GRIN fiber:
$\Delta T = L\Delta^2 n_1/(4c) = 50*0.1^2*1.4/(4*3e8) = 0.58$ ns, which is clearly way above the transmitter and receiver bandwidth that corresponds to risetimes on the order of 0.1 ns and which can be neglected. Selecting a bitperiod of 4 ΔT gives a data rate of $B=1/(4\,\Delta T)$=430 Mb/s. Thus the dispersion-limited data rate is 430 Mb/s.
We finally need to check the power budget. The sensitivity can be calculated from $Q=6=RP_{rec}/(4kTB/R_L)^{1/2}$ where we assume a thermal noise limited system. Using a load resistance of R_L =50 Ohm, a responsivity at 850 nm of $R=q/(h\nu)$=0.62 [A/W]. This gives a receiver sensitivity of
$P_{rec}=6*(4kTB/R_L)^{1/2}/R$ = 3.6e-6 [W]=-24.3 dBm. The total losses of 2+2+0.15=4.15 dB and the transmitted power of -10 dBm still leaves almost 10 dB of power margin. Thus the link is dispersion-limited to a maximum bitrate of 430 Mb/s.

Problem 4:

The fiber loss is 0.2*300=60 dB To compensate the dispersion we require 300*17/100 km of DCF which adds 300*17/100*0.5=25.5 dB of losses if we distribute it in the link, i.e. 85.5 dB of losses in total is to be provided by the amplifiers.

Then consider the Q value which, assuming signal-spontaneous noise is limiting, can be expressed as Q=sqrt(P / (2 hv F_n G N Δf)>6 where R is the responsivity (=1.25 A/W at 1550 and unit quantum efficiency), P_t the transmitted average signal power per channel (which is half the peak channel power P for on-off-keying), G is the gain per amplifier, F_n is the noise figure (6 dB=4), N is the number of amplifiers, hv is the photon energy (= 1.28e-19 J) and Δf is the bandwidth (40 GHz). We use the maximum available transmitted power which is 3.162 mW/25=0.126 mW, and obtain a relation between G and N as

GN< P_t/(36 hv F_n Δf)=172.

At the same time we need N*10 log (G)=85.5 to overcome the losses. Clearly N=1 is not possible. Trying increasing values of the integer N to fulfill both equations give that for N=6, and G = 26.6 (14.25 dB) we have GN=160 which is acceptable. Thus 6 amplifiers with 14.25 dB of gain are needed.