Department of Microtechnology and Nanoscience

Wireless and Photonic System Engineering SSY085

2010-01-12 14.00-18.00

Teachers in charge:
Magnus Karlsson, phone 772 1590, email: magnus.karlsson@chalmers.se
Christian Fager, phone 772 5047, email: christian.fager@chalmers.se

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

Examination checking: On Feb. 2^{nd}, 12-13 in room A604 at 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

---

1. You should design a system for live HDTV broadcasting from the 2010 Winter Olympic Games. All cameramen should be equipped with portable transmitters allowing wireless connection to a fixed central station, where one TV-stream is selected and re-transmitted to a geo-stationary broadcasting satellite (h = 36000km). The central station should be able to simultaneously receive TV-streams from up to 10 cameras. The maximum allowed distance between the camera and central station is 2000 m.

To get full marks you must present block diagrams for both the portable transmitters and the central station. Component parameters, antennas, frequencies, bandwidths, modulation formats etc. should be motivated considering signal and noise power levels, propagation effects, BER, portability, power consumption etc. Use realistic assumptions where applicable.

The bitrate of a compressed HDTV channel is 10 Mbit/s. The broadcast satellite receiver is centered at 12.5 GHz and has a G/T of 7 dB/K.

(30 points)

2. The relationship between the input voltage (V_{in}) and output voltage (V_{out}) of a microwave amplifier can be approximated by the following relationship:

$$V_{out} = 20 \cdot \arctan\left(5 \cdot V_{in}\right)$$

a. Calculate the small signal gain in dB (4p)
b. Calculate the input and output third order intercept points in dBm (4p)
c. Calculate the 1-dB compression point in dBm (2p)

Assume a load impedance of 50 Ω. Approximations may be used where applicable.

(10 points)

3. When characterizing an optical receiver with 1 GHz bandwidth, the following table of average received optical power vs SNR is obtained:

P_{rec} [dBm]	SNR [dB]
-30	3.6
-28	7.6
-26	11.6
-24	15.6
-22	19.6
-20	23.6
-18	27.6

a. What noise source is limiting this receiver? Motivate your answer! (3p)
b. What will be (approximately) the bit error rate at a received average power of -24 dBm, assuming OOK is used? (4p)
c. How many photons per bit is required for a BER of 10^{-9}? (3p)

(10 points)

4. The backbone optical link for a 3G mobile base station should provide 10 Gb/s over a passive SMF which has attenuation 0.2 dB/km and dispersion D=17 [ps/(nm km)]. The transmitter provides 1 mW of power at the wavelength 1550 nm, and the receiver consists of a single p-i-n diode with a responsivity of 1 A/W and a load impedance of 50 Ohms. The transmitter and receiver rise times are 10 ps each, and the optical bandwidth of the signal is 0.07 nm.

a. Make rise-time and SNR budgets for this link to determine how long it can be, i.e. how far from the central office can the base station be located? Assume the allowable rise time and SNR to be, respectively, 50% of the bit period and 16 dB. (8p)
b. What can be done to increase the length of this link beyond the limits calculated in item a) above? (2p)

(10 points)

Problem 2: Solution

Input - output voltage relationship:

$$V_{out} = 20 \arctan(5 \cdot V_{in})$$

a) Calculate small signal gain in dB. (4p)

For small signals, we may approximate $V_{out}(V_{in})$ with its Taylor series expansion around $V_{in} = 0$.

$$V_{out} \approx a_1 \cdot V_{in} + a_2 V_{in}^2 + a_3 \cdot V_{in}^3 + \ldots \quad (1)$$

The coefficients are given by:

$$a_1 = \left.\frac{dV_{out}}{dV_{in}}\right|_{V_{in}=0} = \left\{\frac{d}{dx}\arctan(x) = \frac{1}{1+x^2}\right\} = \frac{100}{1+25 \cdot V_{in}^2} = 100$$

$$a_2 = \frac{1}{2} \cdot \left.\frac{d^2 V_{out}}{dV_{in}^2}\right|_{V_{in}=0} = -\frac{2500 \cdot V_{in}}{(1+25V_{in}^2)^2} = \{V_{in}=0\} = 0$$

$$a_3 = \frac{1}{6} \cdot \left.\frac{d^3 V_{out}}{dV_{in}^3}\right|_{V_{in}=0} = \frac{2500(75V_{in}^2 - 1)}{3(1+25V_{in}^2)^3} = \{V_{in}=0\} = -\frac{2500}{3}$$

At small signals, only the linear term (a_1) remains in (1)

$$\Rightarrow V_{out} = a_1 \cdot V_{in}$$

Hence voltage gain, $G = \frac{V_{out}}{V_{in}} = a_1 = 100$.

The gain in dB: $G_{dB} = 20 \cdot \log_{10}(G) = 20 \cdot 2 = \underline{\underline{40\ dB}}$

where 20 log is used for voltages.

(see (3.98) in Pozar)

Problem 2, continued.

2b) Third order intercept points (4p)

According to Pozar, page 102, the output third order intercept point, P_3, is given by (3.105)

$$P_3 = \frac{1}{2} \cdot a_1^2 \cdot V_{IP}^2 = \frac{2a_1^3}{3a_3}$$

However, in the final step of the derivation, when converting from V_{IP} to P_3, a load resistance of 1Ω is assumed.

In our case, with $R_L = 50\Omega$, we should modify the expression to:

$$(3.105) \Rightarrow P_3 = \frac{a_1^2 \cdot V_{IP}^2}{2 \cdot R_L} = \frac{2a_1^3}{3 \cdot a_3 \cdot R_L}$$

Inserting Taylor series coefficients a_1 & a_3 and $R_L = 50\Omega$ yields:

$$P_3 = \frac{2 \cdot 100^3}{3 \cdot |-2500/3| \cdot 50} = \underline{16\ W}$$

$$P_{3,dBm} = 10 \log_{10}\left(\frac{16W}{100mW}\right) = \underline{42\ dBm}$$

The input intercept point is obtained by subtracting the small signal gain:

$$P_{3,dBm}^{input} = P_{3,dBm} - G_{dB} = 42 - 40 = \underline{2\ dBm}$$

Problem 2, continued

2c) 1-dB compression point. (2p)

In this case we use the approximate expression that $P_{1dB} \approx P_{3,dBm} - 10\,dB$ (see slides & Pozar)

This yields: $P_{1dB} \approx 42 - 10 = 32\ dBm$

Solutions:

3.

a) We see that the SNR increases 2 dB for every dB of optical signal power. Thus the SNR increases with the optical power squared, i.e. SNR ~ P_{rec}^2. The only noise source which has this dependence on power is thermal noise, so this must be dominating.

b) For OOK and thermal noise, we have $Q=(I_1-I_0)/(\sigma_1+\sigma_0)=I_1/(2\sigma_T)=I_{av}/\sigma_T=\sqrt{SNR}$. At a power of -24 dBm, the SNR is 15.6 dB≈36 so that $Q=\sqrt{SNR}\approx 6$ and the BER is then approximately 10^{-9}.

c) A power of -24 dBm is P_{av}=4.0 μW, and using a photon energy of $h\nu = 6.626\ 10^{-34}\ 3\ 10^8/1.55\ 10^{-6}=1.28\bullet 10^{-19}$ [J], we obtain a corresponding photon flow of $n=P_{av}/(h\nu\ B_0)=4\bullet 10^{-6}/(1.28\bullet 10^{-19}\ 10^9)\approx 31\ 000$ photons per bit.

4.

a)

Rise time budget: $t_{sys}^2=t_{tx}^2+t_{rx}^2+t_{fib}^2=50^2$ ps^2. Using $t_{tx}= t_{rx}$ =10 ps we obtain t_{fib}=47.96 ps. Since $t_{fib}=DL\Delta\lambda$, where L is the fiber length and $\Delta\lambda$ the optical bandwidth, we find the dispersion-limited length as L=47.96/(17*0.07)=40.3 km.

SNR budget (thermal and shot noise):

$\sigma_T^2=4kT\Delta f/R_L=3.31\ 10^{-12}$ [A^2],

$\sigma_s^2=2eRP_{rec}\Delta f=3.20\ 10^{-13}$ [A^2] for P_{rec}=0.1 mW, so we can neglect shot noise if the received power is below 0.1 mW.

Since the $SNR=(RP_{rec})^2/\sigma_T^2$=16 dB=40, we get

$P_{rec}=\sigma_T(40)^{1/2}/R=(3.31\bullet 10^{-12}\bullet 40)^{1/2}$=11.5 μW=-19.4 dBm (note that shot noise can be neglcted for this power). An allowable fiber loss of 19.4 dB corresponds to a loss-limited length of 19.4/0.2=97 km.

Thus the link is dispersion limited to 40 km, and attenuation limited to 97 km.

b) To extend the above distances we must use some kind of dispersion compensation, e.g. dispersion compensating fiber, and to overcome the SNR limit we can use e.g. an optical amplifier in the receiver. Optically amplified receivers at 10 Gb/s has a sensitivity of around -34 dBm, enabling distances up to 34/0.2=170 km.