Department of Microtechnology and Nanoscience

Wireless and Photonic System Engineering SSY085

2015-10-27, 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: Tue. Nov. 17th, 12-13 in room A703 "Donatorn", MC2 floor 7.

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

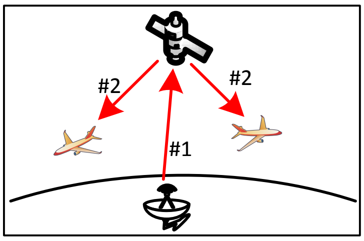
1. A future Stockholm-Göteborg link

Since the demand for broadband access keeps increasing, so does the demand for trunk network capacity. The Swedish University Network (SUNET):s next generation Stockholm-Gothenburg link (600 km) will likely use coherent transponders at 100 Gb/s (with 28 GHz of signal bandwidth) per wavelength channel and operate at an accumulated data rate of 10 Tb/s in the EDFA C-band. Thanks to the use of forward error correction and other digital signal processing algorithms, the required Q for such a channel is reduced from the conventional 6 to 3.

Design the link including necessary hardware, and consider as a design goal that you want to minimize the number of in-line amplifiers for cost reasons. Describe the link with block diagrams for the hardware and show with supporting calculations that it will work. Make reasonable and realistic assumptions for all ingoing system parameters.

(30 points)

2. Earth-to-satellite-to-aircraft link



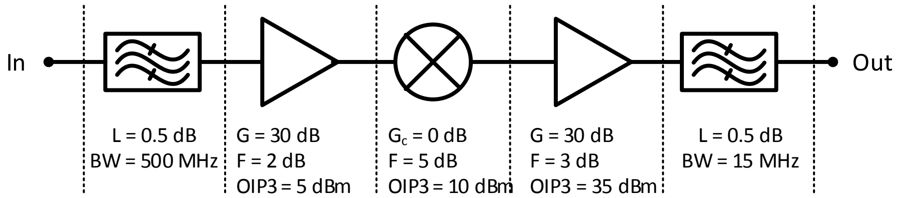
A telecom operator uses a geostationary satellite (G/T = 3 dB/K), supporting the 10.35 – 10.45 GHz frequency band, to provide on-board internet to aircraft passengers. The earth station uses a 5m diameter parabolic antenna and BPSK to reach a total capacity of 20 Mbit/s in the #1 link.

a) Calculate the minimum output power from the earth station, assuming BER<10^{-5}.
b) Describe which possibilities the operator have to increase the #1 link capacity.
c) Present a complete RF block diagram for a homodyne earth station transmitter (<u>no numbers needed</u>) and describe in detail <u>which</u> and <u>how</u> the components would have to be replaced to increase the link capacity.

(10 points)

3. Receiver dynamic range

The receiver below will be used at room temperature for 30 Mbit/s communication using QPSK modulation

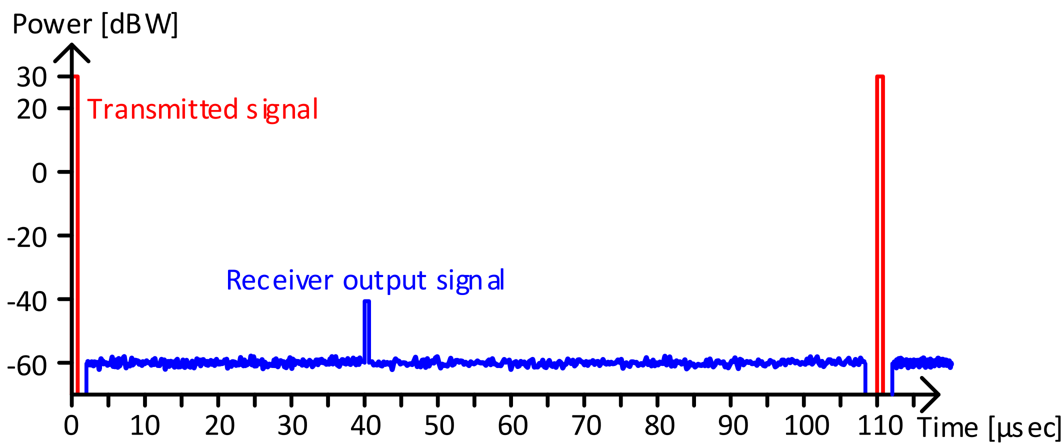


a) What is the linear dynamic range of the receiver?
b) We are going to use this amplifier in an urban area where there is no direct path between the transmitter and the receiver. The outage probability should be <10 %. What is ratio between the maximum and the minimum distance (R_{max}/R_{min}) if the required BER = 10^{-4}.

(10 points)

4. Pulsed radar system

Consider an ground-based aircraft surveillance radar (free space conditions). The radar transmits a pulsed 10 GHz RF signal after which it switches to receive mode to listen for possible radar echoes. The figure below shows an example of the transmitted and measured receiver output power versus time. The radar uses a parabolic antenna with 0.4m diameter (e_{rad} = 80%) and a receiver with 80 dB of gain and 1 MHz bandwidth.



a) What is the noise figure of the radar receiver?
b) What is the distance to the object in front of the radar?
c) What is the radar cross section of the object?
d) Assuming an object with radar cross section 1m^2, what is the maximum range for this radar?

(10 points)

Solutions

1.

2. **Earth-to-satellite-to-aircraft link**

a) Output power

```
% Matlab solution
f = 10.4e9; % Frequency in the middle of the band
lambda = 3e8/f;
G_T = 10^(3/10);
d = 5;
Ap = pi*d^2/4; % Physical antenna area
Gt = 4*pi*Ap/lambda^2; % Physical area and antenna area is similar
k = 1.38e-23; % Boltzmann constant
R = 36000e3; % Geostationary satellite = 36000km
Rb = 20e6;
B = Rb; % Spectral efficiency = 1 for BPSK
S_N = 10^(9.6/10); % Lecture Modulation, slide 29

% Non-fading lecture, slide 22
Pt = S_N/(G_T*Gt*lambda^2)*(k*B*(4*pi*R)^2);
Pt_dBm = 10*log10(Pt/1e-3);
```

Minimum transmit power = 1 W = 30 dBm

b) Improvement of capacity

- Increase the bandwidth utilization with the same modulation (it is not fully utilized now)
- Increase the modulation order
- (More antennas / but MIMO is probably not an option in satellite links)
- More satellites, so that each can serve fewer aircraft.

c)

- Bandwidth: Filters need to be replaced, A/D and D/A converters may need to be changed. Transmit power need to be increased kTB, or antennas replaced.
- Higher modulation order, same bandwidth: Transmit power increased (higher SNR requirement) (larger antenna or larger PA), new algorithms.
- More satellites…

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3. **Receiver dynamic range**

a) Two equations are used:

(1) $T = T_{antenna} + T_{amplifier}$

(2) $$\frac{1}{P3} = \frac{1}{Gc\,.\,Gb\,.\,P3a} + \frac{1}{Gc\,.\,P3b} + \frac{1}{P3c}$$

DR_L (dB) = (P3 (dBm)-10-No (dBm)),   No=G*k*B*T

G = -0.5+30+0+30-0.5=59 dB

$T_{amplifier}$ (input) ≈ $(10^{0.05}-1)$ x290+ $(10^{0.2}-1)$x290/$10^{-0.05}$ = 225 K →

T_{sys} = 290+225=515 K (mixer noise can be neglected since the LNA gain is high)

→ No=$10^{5.9}$ x1.38x10^{-23}x15x10^{6}x515=8.47e-8 = -40.7 dBm

P_3 from (2) → P_3 = 31.35 dBm

DR_L (dB) = 31.35-10+40.7 = 62.05 dB, where it has been used that

P_{1dB} ~ P_3 dBm – 10 dB

b) SNR = Eb/n0 x Rb/B

For BER = 1e-4 (QPSK) {Lecture Modulation, curves slide 29) → Eb/n0 @ BER = 10^{-4} = ca 8 dB → SNR = 11 dB

Since there is no direct path between the transmitter and the receiver, we have a Rayleigh fading situation. From the figures in lecture notes (Lecture 8, p.32), Fading margin, Fd = 11 dB is needed for a 10% outage probability.

So the new DR_f can be find as
DR_L = (P3 (dBm)-10 dB -No (dBm)- SNR (dB) - Fd (dB)) = (31.35-10+40.7-11-11) dB =40.05 dB

So $(R_{max}/R_{min})^n = 10^{4.005}$ and for the urban area n = 3 → $(R_{max}/R_{min}) = 21.63$

As a remark, in real systems e.g. mobile communication, power control is used so that the base station or mobile phone adjusts its transmit power depending on the distance. Variable gain amplifiers are also used in the receiver to keep a constant power level to the demodulator / analog-to-digital converter.

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4. **Pulsed radar system**

```
%% Matlab solution
clear;
clc
f = 10e9;
lambda = 3e8/f;
```

a) Receiver noise figure

```
erad = 0.8; % Radiation efficiency
B = 1e6;
k = 1.38e-23;
Tb = 50; % Brightness temperature, approximately from Lecture Non-
fading systems, slide 18.
TA = erad*Tb + (1-erad)*290; % Same lecture slide 20
Nout = 10^(-60/10); % The output noise is read to be -60 dBW (note,
not dBm) in the graph in the problem.
GRX = 10^(80/10); % The receiver gain is 80 dB
Nin = Nout/GRX; % Referring from output to input noise

Te = Nin/(B*k)- TA; % Equivalent receiver noise, subtracting the
antenna noise
F = 1+Te/290; % Noise figure
F_dB = 10*log10(F)
```

Total receiver noise figure = 5 dB.

b) Distance

```
% According to the figure, the received pulse arrives 40 µsec after
the transmit pulse. Having traveled twice the distance yields
t = 40e-6;
R = t*3e8/2
```

Distance = 6 km.

c) Radar cross section

```
d = .4; % Antenna diameter
Ae = pi*d^2/4; % Antenna area
D = 4*pi*Ae/lambda^2; % Directivity
Gt = erad*D; % Antenna gain
Pt = 10^(30/10); % Transmit power, from graph
```

```
Pr_out_dBW = -40; % Radar echo power, dBW from graph
Pr = 10^((Pr_out_dBW-80)/10); % Convert to W, subtract receiver gain
RCS = Pr*(4*pi)^3*R^4/(Pt*Gt^2*lambda^2) % Radar equation
```

Radar cross section (RCS) = 1.45 m^2.

d) Max range

```
Pr = Nin; % Max distance is when the radar echo level is the same as
the noise floor (Nin, see problem 4a)
RCS = 1; % According to problem
Rmax_noise = (RCS*Pt*Gt^2*lambda^2/(Pr*(4*pi)^3))^(1/4) % Radar
equation, another way around
```

Max noise-limited range (Rmax_noise) = 17.3 km.

But, we also have to check if the echo arrives before the next pulse is transmitted.
t_{max} = 108µsec → $R_{max,time}$ = t_{max}*3e8/2 = 16.2 km < Rmax_noise.

The maximum range is limited by the time between the pulses in this case.

The maximum range is therefore 16.2 km for an object with 1m^2 radar cross section.