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: Thursday Nov 15, 12-13 in room A 604 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 technically plausible assumptions. Make sure you clearly state such assumptions.
Grades: 3: ≥24, 4: ≥36, 5: ≥48

1. Mars – Earth communication

Your task is to design the next generation Mars – Earth communication system. The system should support up to 50 terminals anywhere on Mars surface (vehicles, bases, astronauts, etc.), each with an up- and down-link capacity of 200 kbit/s.

The Mars terminals communicate with Earth through three relay satellites in equatorial non-stationary orbit around Mars (Fig. 2). The satellites share data using ideal line-of-sight optical links (not part of your design).

The relay satellites communicate with Earth through the NASA Deep Space Network (DSN)[1] whereby at least one of three 34m-diameter antennas sites, located in different parts of the Earth, provide line-of-sight connection to the Mars satellites. DSN Earth transmitters: f = 34.45 GHz, P_{max} = 500W; Receivers: f = 32.05 GHz, T_{sys} = 28K.

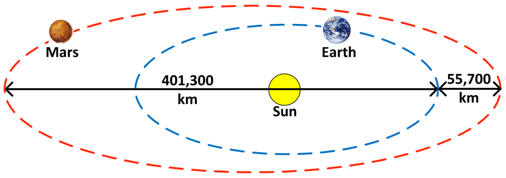

Fig. 1: Earth and Mars solar orbits.

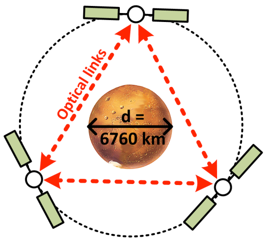

Fig. 2: Top view of Mars relay satellite configuration.

Fig. 3: DSN site in Goldstone/US.

Your solution should include the design of transmitters and receivers for both the Mars terminals and the relay-satellites, including frequencies, modulation format, block diagrams, antennas, output power, etc. Use realistic assumptions where applicable.

(30 points)

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[1] ***deepspace**.jpl.nasa.gov*

2. The near-far problem

Using several channels around 2.14 GHz, an urban area base station is communicating with mobile units in the range 50m – 10000m. To reach the far users, 25W output power is needed, but the power in each channel should be minimized.

Assume that the mobile units have a noise figure of 5 dB and that channel filtering is implemented in digital domain using an IF A/D converter with 48 dB dynamic range (8 bits). 1 Mbit/s QPSK modulation (BER <10^{-5}) and 5dB fading margin is used.

a) What output power should the base station transmit for the near (50m) users?
b) What is the minimum LNA OIP3 required for the mobile terminals?

(10 points)

3. Fiber type selection

Large effective area fibers (LEAFs) are becoming increasingly popular. Their advantage over standard single-mode fibers (SMFs) is that the optical mode area is slightly larger, which means that they have less optical intensity for the same power, and can tolerate 2-3 dB higher transmission power before the nonlinearities distort the signal. A drawback is a slightly higher attenuation.

In the below table, the maximum transmission powers and the attenuation coefficients of the two fibers are compared.

	Max power (per WDM channel) into the fiber	Attenuation
LEAF	2 dBm	0.22 dB/km
SMF	0 dBm	0.18 dB/km

When designing a WDM link between Stockholm and Gothenburg (600 km), we would for cost reasons want to have no more than 8 amplifier spans. We want to transmit 40 Gb/s OOK data at each wavelength. Suggest a way to compare the two transmission fiber types from a system perspective (assume all other properties, such as dispersion, coupling losses and cost are the same)! Which fiber would you select and why?

(10 points)

4. Wireless vs. fiber

A radio-over-fiber (RoF) link that transmits a modulated RF signal e.g. to a base station or other remote location, can be a viable alternative to free-space transmission. Compare an RoF link to a wireless link, given the parameters in Fig. 4. Assuming a modulated optical power of 0.1 mW in the fiber, how much RF transmitted power in the wireless link is required to have the same received RF signal power after 20 km? The RF link uses a 10 GHz carrier and dish antennas with a diameter of 0.5 m. The optical link has a fiber with 0.2 dB/km of loss, and quantum efficiencies in the laser and detector of 0.8 and 0.99 respectively.

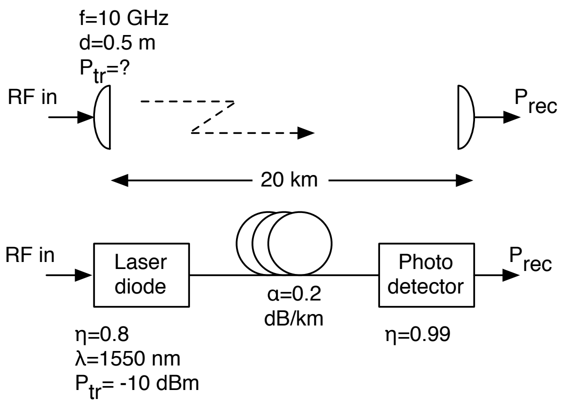


Fig. 4. The 20 km RF link vs. the 20 km RoF link.

(10 points)

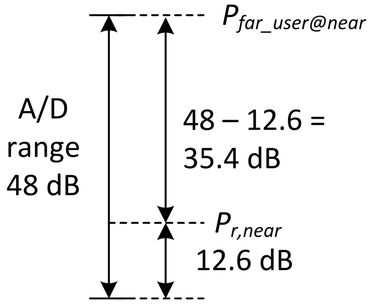
Solutions

Problem 1:

See detailed solution at http://chrislee.dhs.org/projects/satcom/mars/. Note that they have assumed the use of error correcting codes, which allows low BER operation at lower SNR. We have not discussed this in our lectures, which is the reason why I have relaxed the bit rate from 1.5 Mbit/s to 200 kbit/s in this case.

Problem 2:

a) The near users will experience strong adjacent signals from the base station communicating with far users. These must be filtered at IF, since RF filters would be too narrowband. For the digital IF filtering to work, the A/D converter must be operated within its dynamic range. The receiver needs a SNR of 12.6 dB for the signal itself (QPSK @ BER = 1e-5 → S/N = 12.6 dB), which leaves 48 – 12.6 dB = 35.4 dB margin for the A/D converter. Hence, for the digital filtering to work at the near user, its power ($P_{r,near}$) can be max 35.4 dB weaker than the power to the far users at the near location ($P_{far\_user@near}$):



The base station power transmitted to the near users should therefore be larger than: **$P_{t,near}$ = 25W*10$^{-35.4/10}$ = 7.2 mW**, which will be easy to realize and is negligible compared to the 25W needed for the far users.

b) It is reasonable to assume that the system is designed such that the max distance, 10km, is reached when the received power is equal to the receiver sensitivity + fading margin:

Sensitivity = k*T_0*B*F*$(S/N)_{out}$= 1.38e-23*290*0.5e6*10^(5/10)*10^(12.6/10) = 1.15e-13 W = -99.4 dBm.

$P_{r,maxrange}$ = -99.4 dBm + 5 dB fade margin = -94.4 dBm = 3.6e-13 W

The power at the near position distance ($P_{far\_user@near}$ in Fig. above) is therefore given by the receiver sensitivity multiplied by the ratio of the path loss between the near and far distances:

$P_{far\_user@near}$ = 1.15e-13*$(R_{far}/R_{near})^N$ = 3.6e-13*$(10000/50)^3$ = 2.9e-6 W= -25.4 dBm.

According to the 3-dB gain desensitization calculation (see Intermodulation Lecture), this means that P_{1dB} for the LNA must be at least -25.4 dBm - 1.2 dB = -26.6 dBm, or using the rule-of-thumb relation OIP3 = P1dB + 10: **$OIP3_{LNA}$ = -16.6 dBm**.

Problem 3:

A simple approach is to compute the Q-values of the systems, based on the two fibers, and see which is highest.

In an amplified link with N amplifiers, using OOK and with s-sp noise dominating, the Q value is given by

$Q=[\ I_1/\sigma_{s\text{-}sp}]=2RP_{in}/[4\ R^2\ P_{in}\ S_{sp}\ \Delta f]^{1/2}=[P_{in}/S_{sp}\ \Delta f]^{1/2}=[2P_{in}/N\ hv\ G\ F\ \Delta f]^{1/2}$

where Pin is the average input power in to the receiver, N the number of amplifiers, hv the photon energy, G the gain per amplifier, F the noise figure per amplifier and Δf the bandwidth. The two systems will only differ in P_{in} and G, so that it is enough to note that Q is proportional to $[P_{in}/\ G]^{1/2}$.

The gain for the SMF link is obtained from 600/8=75 km SMF, i.e. 0.18*75=13.5 dB, and for the LEAF 0.22*75=16.5 dB.

This means that

$Q_{LEAF}/Q_{SMF}=[P_{LEAF}\ G_{SME}\ /\ P_{SME}\ G_{LEAF}]^{1/2}.=(2+13.5-0-16.5)/2=-0.5$ dB

So the SMF is 0.5 dB or 12 percent (in terms of Q) better than the LEAF. For all practical purposes this is almost negligible, and other effects neglected in the analysis may be as significant. Note, however, that if the number of amplifiers are reduced, or the transmission distance different, this conclusion may change.

Problem 4:

The easiest way is to compare the transmission losses of the two links. First the optical link:

The input/output RF attenuation is given by $(\eta_t\ \eta_r\ \exp(-\alpha z))^2=$ $(0.8\bullet 0.99\bullet \exp(-0.0461\bullet 20))^2=0.099=\ -10.0$ dB

where the linear attenuation is obtained from $\alpha=0.2\ \ln(10)/10=0.0461$ [km^{-1}].

For the RF link we use Friis eq., in terms of the antenna areas A, to obtain a transmission loss of $A^2/(\lambda^2 R^2)=1.07e{-7}=-69.7$ dB,

where we used $A=d^2\pi/4=0.196$ [m^2], $\lambda=3e8/1e10=0.03$ [m], R=20 [km].

In addition we can add the atmosphere attenuation, which (from fig 4.21 in Pozar) is 0.02 dB/km at 10 GHz, i.e. 20*0.02=0.4 dB to get a total loss of 70.1 dB.

Thus the RF link has 60.1 dB more losses than the optical link, and would thus require -10-10.0+70.1=50.1 dBm=102 Watt of transmission power. This is a bit higher than what one would like in a real system, so over those distances the RoF link is probably preferred.