LASER RADAR SYSTEMS

OPTICAL REMOTE SENSING

(F. Rocadenbosch)

PROBLEM 1: LINK-BUDGET (ELASTIC-BACKSCATTER LIDAR)

Consider an elastic-backscatter lidar defined by the following system parameters:

LASER

• Quantel (Nd:YAG 2ω)		
• Emission wavelength	532 nm	
• Energy, E	160 mJ	
• Pulse-repetition frequency, PRF	20 Hz	
• Beam width, w_0	5×10^{-3} m	(*)
• Divergence (half-width angle), $\theta_{1/2}$	0.5 mrad	(*)

TELESCOPE

• Celestron Schmidt-Cassegrain C-8,	8”	(0.2032 m)
• Shade diameter, d_{sh}	2.7”	(0.06858 m)
• Focal length, f	2 m	
• Transmissivity, T_1	60 %	

OPTO-ELECTRONIC RECEIVER

PHOTODIODE

• APD (EGG C30956E)	
• Active area diameter, D_{APD}	3 mm
• Multiplication factor, M	150
• Excess-noise factor, F	4.5
• Dark surface current, I_{ds}	7.64×10^{-8} A
• Dark bulk current, I_{db}	3.10×10^{-10} A
• Intrinsic responsivity, R_{io}	240 mA/W

INTERFERENCE FILTER

• Bandwidth, $d\lambda$	10 nm
• Transmissivity, T_2	65 %

SIGNAL-CONDITIONING STAGES

• Transimpedance Gain (1st stage), G_t	5750 Ω
• Voltage conditioning Gain (2nd stage), G_{ac}	20.3 V/V
• Noise-equivalent bandwidth, B	10 MHz
• Equivalent input noise (chain input), $\sigma_{th,i}$	$5\ pA\cdot Hz^{-1/2}$

ATMOSPHERE

Aerosol component:

• Visibility margin (532 nm), V_M	39.12 km
• Lidar ratio, $S=\alpha_{Mie}/\beta_{Mie}$	25 sr
• Boundary-layer height, R_{PBL}	3 km

Molecular component (average):

• Rayleigh’s extinction	$0.01\ km^{-1}$
• Rayleigh’s ratio (α_{Ray}/β_{Ray})	$8\pi/3$

Background-radiance component

- Moon's radiance (full Moon), L_{Moon} — 3×10^{-11} W·cm^{-2}·nm^{-1}·sr^{-1}
- Solar radiance, L_{Sun} (typ.) — 3×10^{-6} W·cm^{-2}·nm^{-1}·sr^{-1}

OTHER PARAMETERS

- Full-overlap range, R_{ovf} — 200 m
- Maximum-range criterion — SNR(R_{max}) =1

PHYSICAL CONSTANTS

- Electron charge, q — 1.602×10^{-19} C
- Planck's constant, h — 6.6262×10^{-34} J·s
- Light speed, c — 2.99793×10^{8} m·s^{-1}
- Boltzmann's constant, K — 1.38×10^{-23} J·K^{-1} (*)

(*) Parameter not used.

Questions:

1. Determine the system constant, K(λ) [W·km^3]

2. Estimate the received background power under night-time operation, P_{back}

3. Compute and plot the return power at the following ranges:

   a. P(0.2 km)
   b. P(1 km)
   c. P(2 km)
   d. P(3 km)
   e. P(3^+ km)
   f. P(4 km)

4. Compute the receiver-chain voltage responsivity, R_v, and the net voltage responsivity (i.e., including spectral optical losses), R_v'.

5. a) Compute the range-dependent signal-to-noise ratio (consider the ranges of question 3), SNR(R).

   b) Identify the noise-dominant system-operation mode.

6. Assess the approximate laser-radar maximum range.

7. How many pulses are needed to integrate in order to ensure a SNR_v (voltage signal-to-noise ratio) of 40 dB at 3-km range? What is the resulting observation time of the lidar instrument?

8. Now, consider a Raman system of similar specs. If for Raman systems the return signal is typically 3 orders of magnitude lower than for their elastic system counterparts, discuss on the feasibility of day-time operation.

9. Compute the photodiode NEP and its quantum efficiency (η).

10. Compute the system NEP (NEP_s).

SOLUTIONS

1. K(532 nm)=6.89×10^{-4} W·km^3
2. P_{back} = 1.52×10^{-13} W
3. P(0.2 km)=8.56×10^{-5} W, P(1 km)=2.87×10^{-6} W, P(2 km)=5.76×10^{-7} W, P(3 km)=2.06×10^{-7} W, P(3^+ km)=4.72×10^{-8} W, P(4 km)=2.60×10^{-8} W
4. R_v=4.20×10^6 V/W, R_v'=1.64×10^6 V/W
5. SNR_v(0.2 km)=57.5 dB, SNR_v(1 km)=42.7 dB, SNR_v(2 km)=35.7 dB, SNR_v(3 km)=31.3 dB, SNR_v(3^+ km)=24.9 dB, SNR_v(4 km)=22.3 dB
6. $R_{max} \approx$ 16.9 km
7. n_i=8 pulses, t_{obs}=0.4 s
8. The Raman lidar cannot be operated day-time because P(0.2 km)=8.56×10^{-8} W is progressively comparable to the background component, P_{back}=1.52×10^{-8} W, as we move further in range.
9. NEP=88.2 fW·Hz$^{-1/2}$, η=55.9 %
10. NEP_s=422 fW·Hz$^{-1/2}$