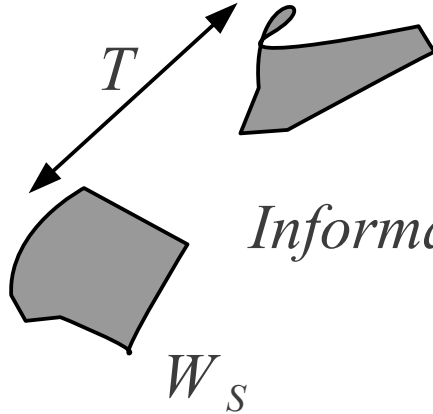
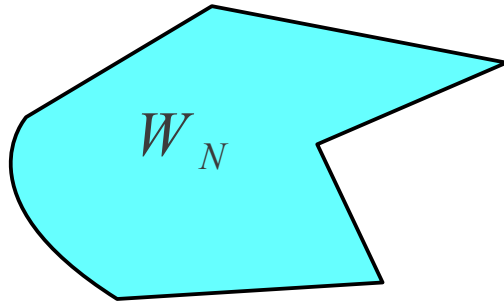


# Optične komunikacije

## Predavanje 1:

Zmogljivost in domet  
vrvičnih in brezvrvičnih zvez

*Claude Shannon 1948*



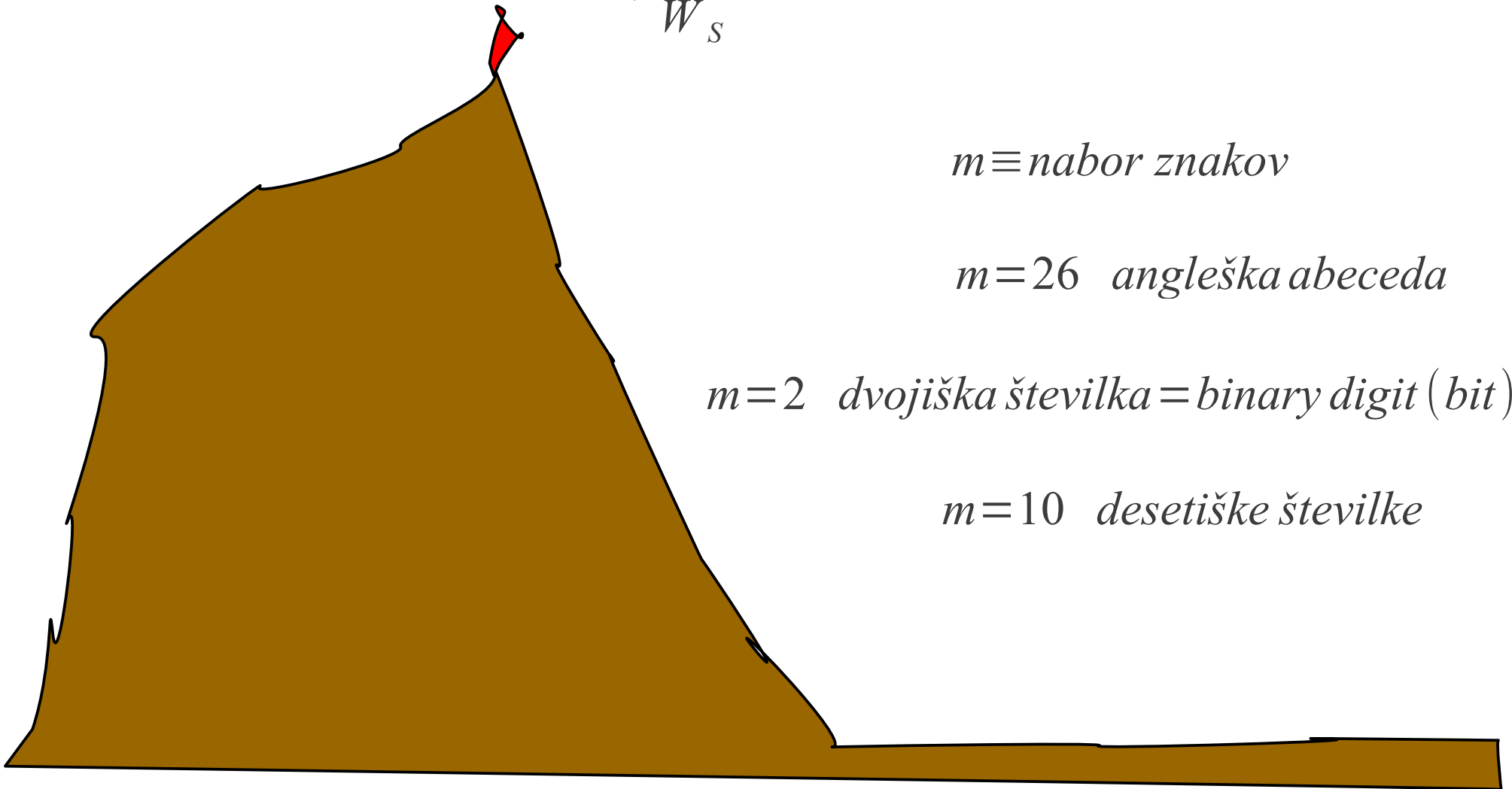
$$\text{Informacija} \equiv I \leq \frac{1}{2} \log_m \left( 1 + \frac{W_S}{W_N} \right) \quad [\text{znaki}]$$

*m*  $\equiv$  nabor znakov

*m* = 26 angleška abeceda

*m* = 2 dvojiška številka = binary digit (*bit*)

*m* = 10 desetiške številke



$$\text{Zmogljivost} \equiv C = \frac{dI}{dt}$$

$$C = \frac{1}{2T} \log_m \left( 1 + \frac{W_S}{W_N} \right) \quad [\text{znaki/s}]$$

$$\text{Pasovna širina} \equiv B = \frac{1}{2T}$$

$$C = B \cdot \log_m \left( 1 + \frac{W_S}{W_N} \right) \quad [\text{znaki/s}]$$

$$\text{Moč} \equiv P = \frac{dW}{dt}$$

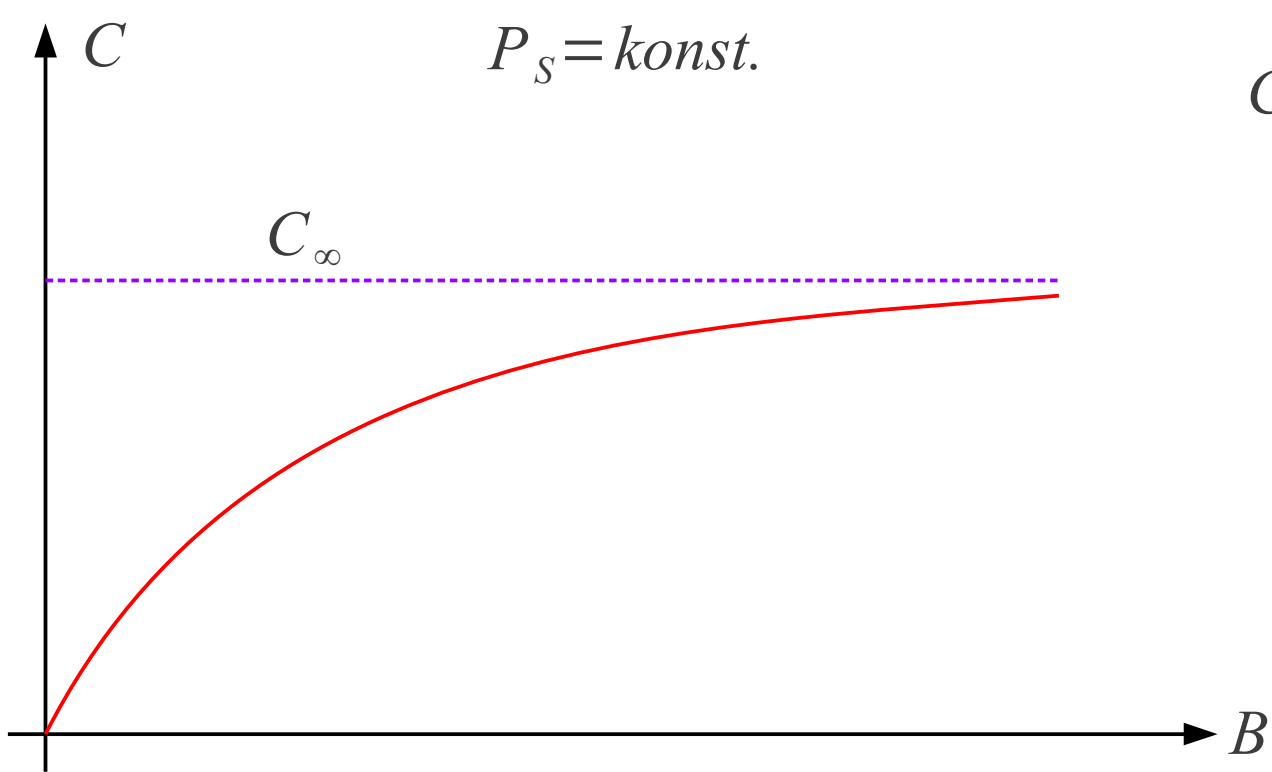
$$C = B \cdot \log_m \left( 1 + \frac{P_S}{P_N} \right) \quad [\text{znaki/s}]$$

$$C = B \cdot \log_2 \left( 1 + \frac{P_S}{P_N} \right) \quad [\text{bit/s}]$$

$$\text{Moč šuma} \equiv P_N = B \cdot N_0$$

$$N_0 \equiv \text{spektralna gostota šuma} [W / \text{Hz} = J]$$

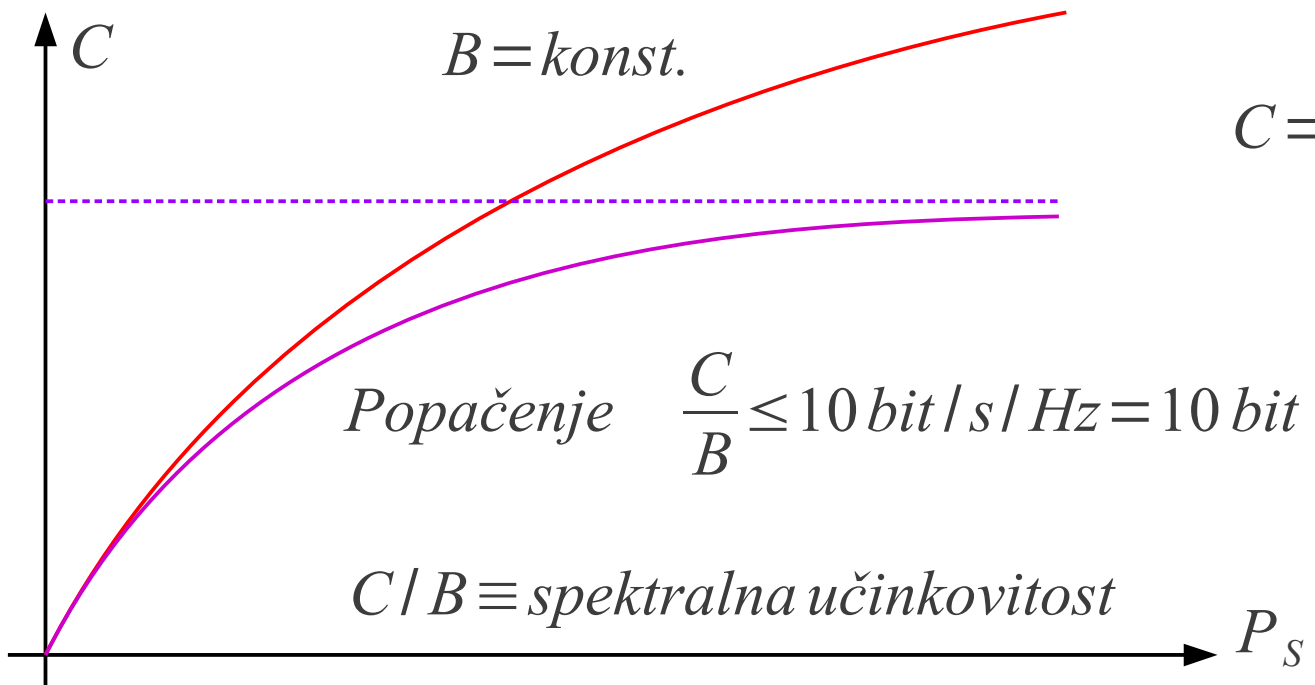
$$C = B \cdot \log_2 \left( 1 + \frac{P_S}{B \cdot N_0} \right) \quad [\text{bit/s}]$$



$$C = B \cdot \log_2 \left( 1 + \frac{P_s}{B \cdot N_0} \right) \quad [bit/s]$$

$$C \leq \lim_{B \rightarrow \infty} C = C_\infty = \frac{P_s}{N_0 \ln 2}$$

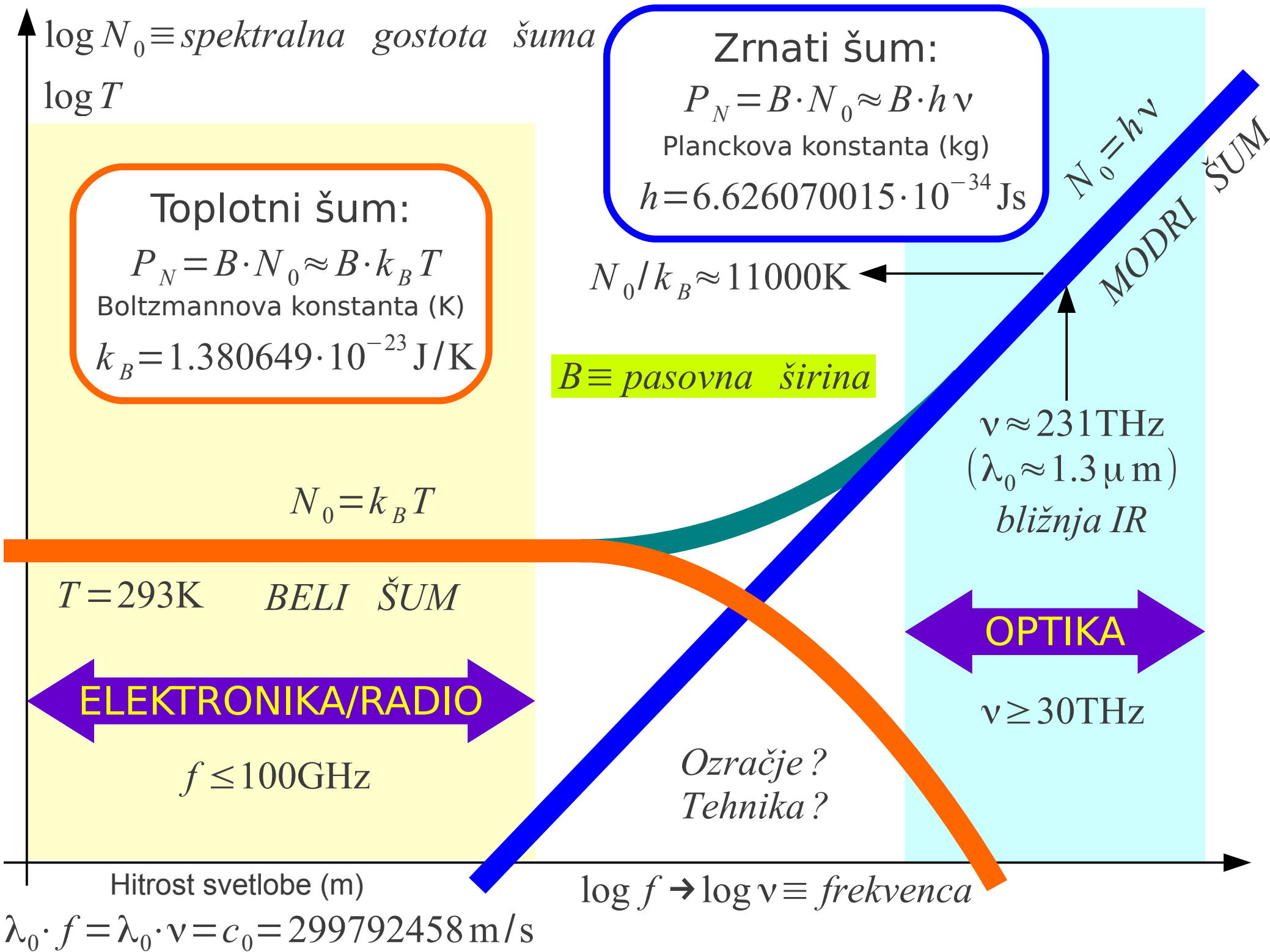
*Stroga teroetična meja!*



$$C = B \cdot \log_2 \left( 1 + \frac{P_s}{B \cdot N_0} \right) \quad [bit/s]$$

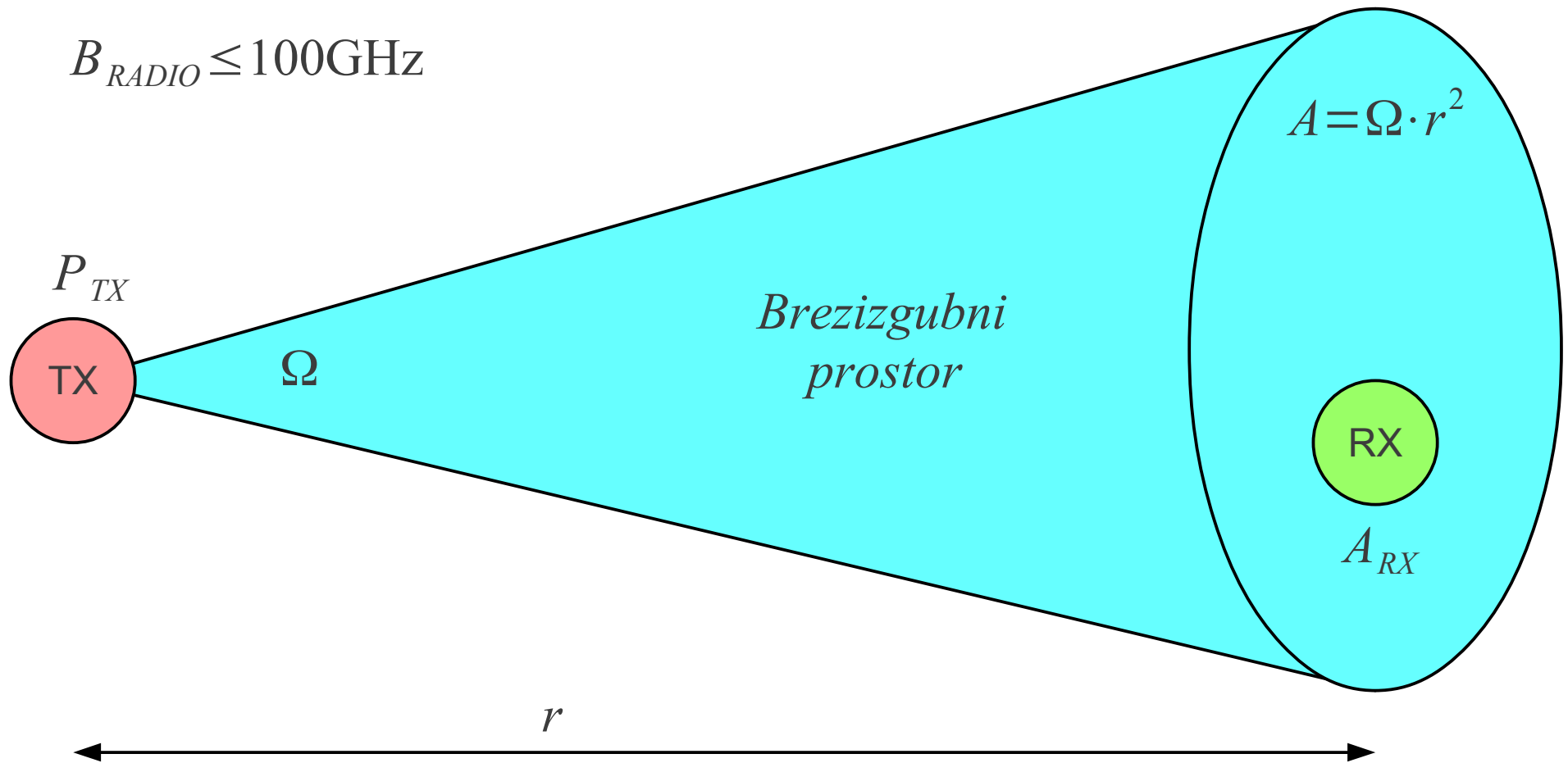
*Popačenje*  $\frac{C}{B} \leq 10 \text{ bit/s/Hz} = 10 \text{ bit}$

*Praktična meja!*



*Brezvrvična zveza  $\equiv$  razširjanje valovanja*

$$B_{RADIO} \leq 100\text{GHz}$$



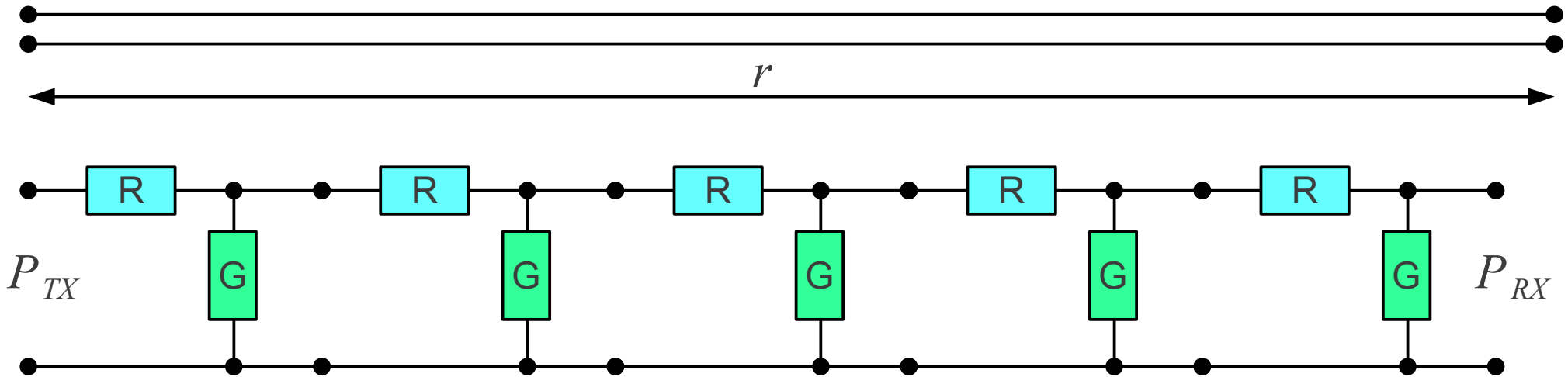
$$S = \frac{P_{TX}}{A} = \frac{P_{TX}}{\Omega \cdot r^2}$$

$$P_{RX} = S \cdot A_{RX} = P_{TX} \frac{A_{RX}}{\Omega \cdot r^2} = \alpha \cdot r^{-2}$$

*Razširjanje z ovirami  $P_{RX} = \alpha \cdot r^{-N}$*

*Vrvična zveza ≡ vodenje valovanja*

*Žični dvovod*



$$P_{RX} = P_{TX} \cdot e^{-2\alpha \cdot r}$$

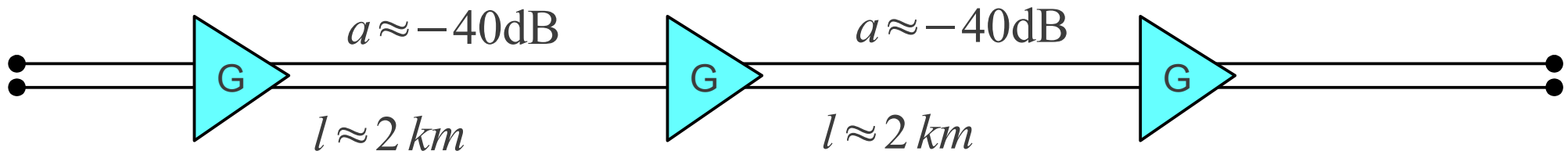
$$B_{RODOVI} \rightarrow B_{KOAKS} \approx \frac{c_0}{\pi \cdot (r_{\text{žile}} + r_{\text{oklopa}}) \cdot \sqrt{\epsilon_r}} \approx 10 \text{ GHz}$$

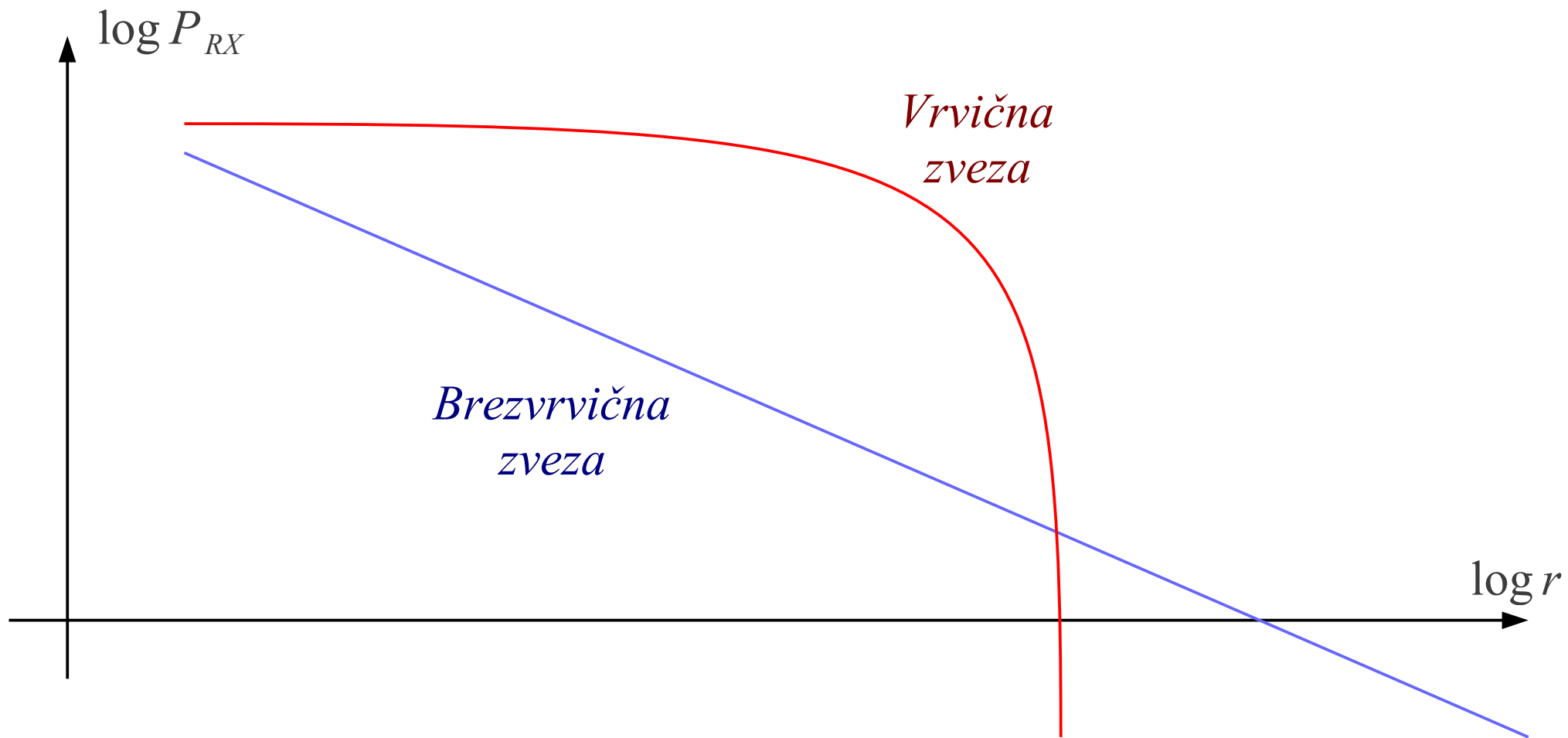
*Kabelska TV ali telefonija*

*Številski telefonski mux  $C = 140 \text{ Mbit/s}$*

*$a/l \approx -20 \text{ dB/km}$*

*Analogni telefonski mux  $B = 60 \text{ MHz}$  (10800 pogovorov)*

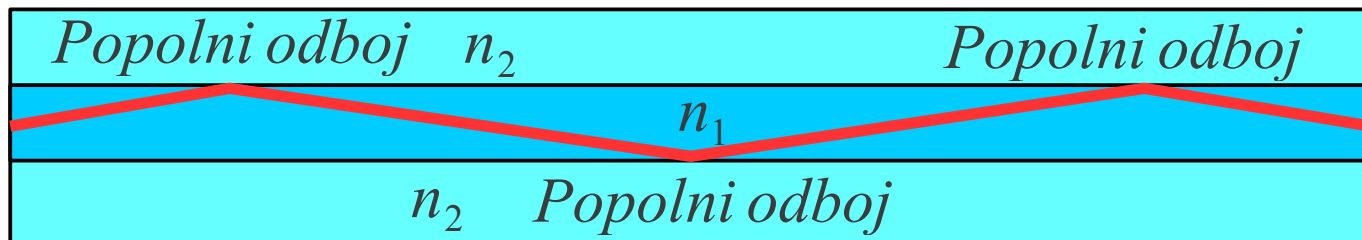
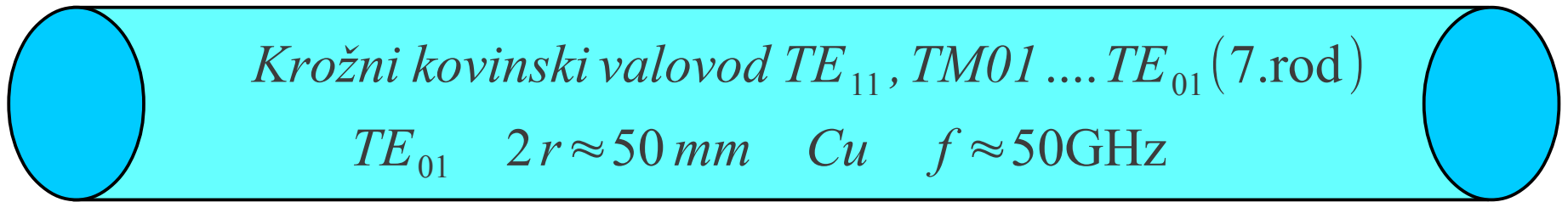
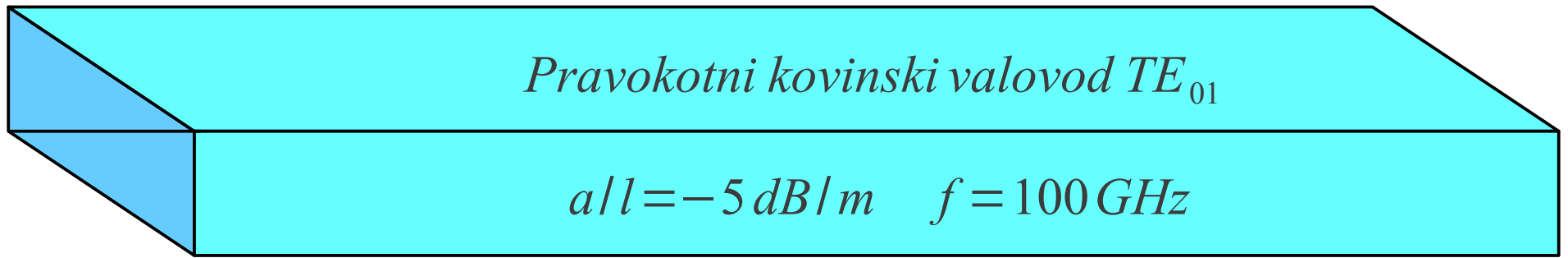




$N$  vzporednih vrvic  $\rightarrow N \cdot C_{\text{vrvična}}$   $N$  zelo velik ! (1000)

$N$  rodov  $\rightarrow N \cdot C_{\text{brezvrvična}}$   $N = 2$  dve polarizaciji ,  $N \approx 4$  sistem MIMO



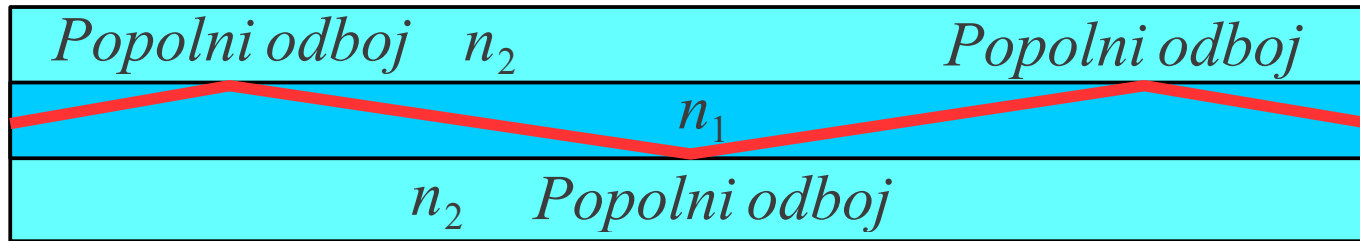


*Dielektrični valovod  $\equiv$  svetlobno vlakno*

1960  
 $a/l \approx -1 \text{ dB/m}$   
 $a/l \approx -1000 \text{ dB/km}$

Dielektrični valovod  $\equiv$  svetlobno vlakno

$$n_1 > n_2$$



Popolni odboj  
 $|\Gamma| = 1$

1960  $a/l \approx -1000 \text{ dB/km}$

Plastika  $a/l \approx -150 \text{ dB/km}$

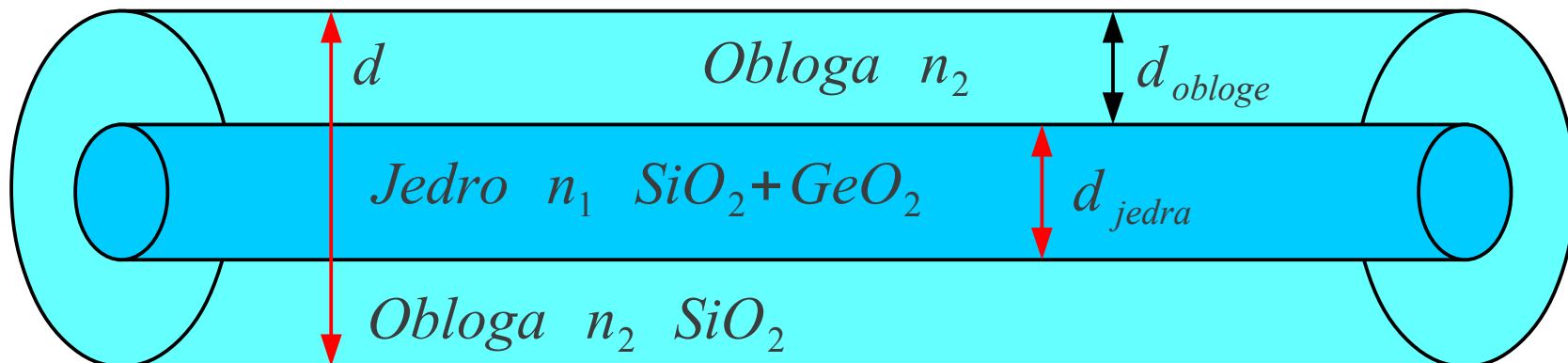
1970  $a/l \approx -17 \text{ dB/km}$  Corning čiste kemikalije za polprevodnike!

1977  $a/l \approx -0.2 \text{ dB/km}$  Japonci teoretska meja za steklo  $\text{SiO}_2$

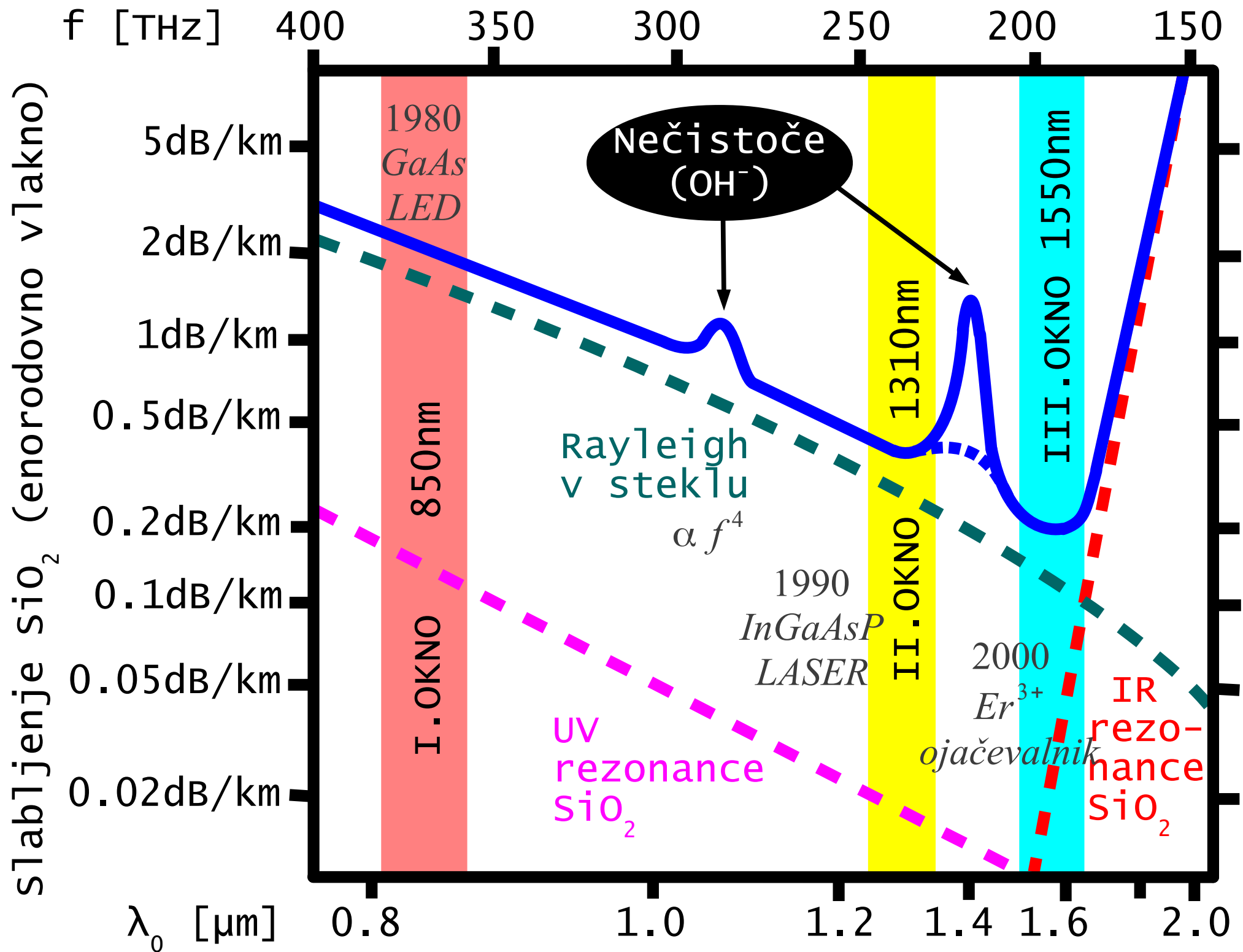
$\text{TlCl}_4$  ??? (strup za miši)  $a/l \approx 0.001 \text{ dB/km} \rightarrow 1 \text{ dB/m}$   $\lambda \approx 3 \mu\text{m}$

$d = 250 \mu\text{m} \dots 80 \mu\text{m} \rightarrow 125 \mu\text{m}$

$d_{\text{obloge}} > 30 \mu\text{m} \gg \lambda$

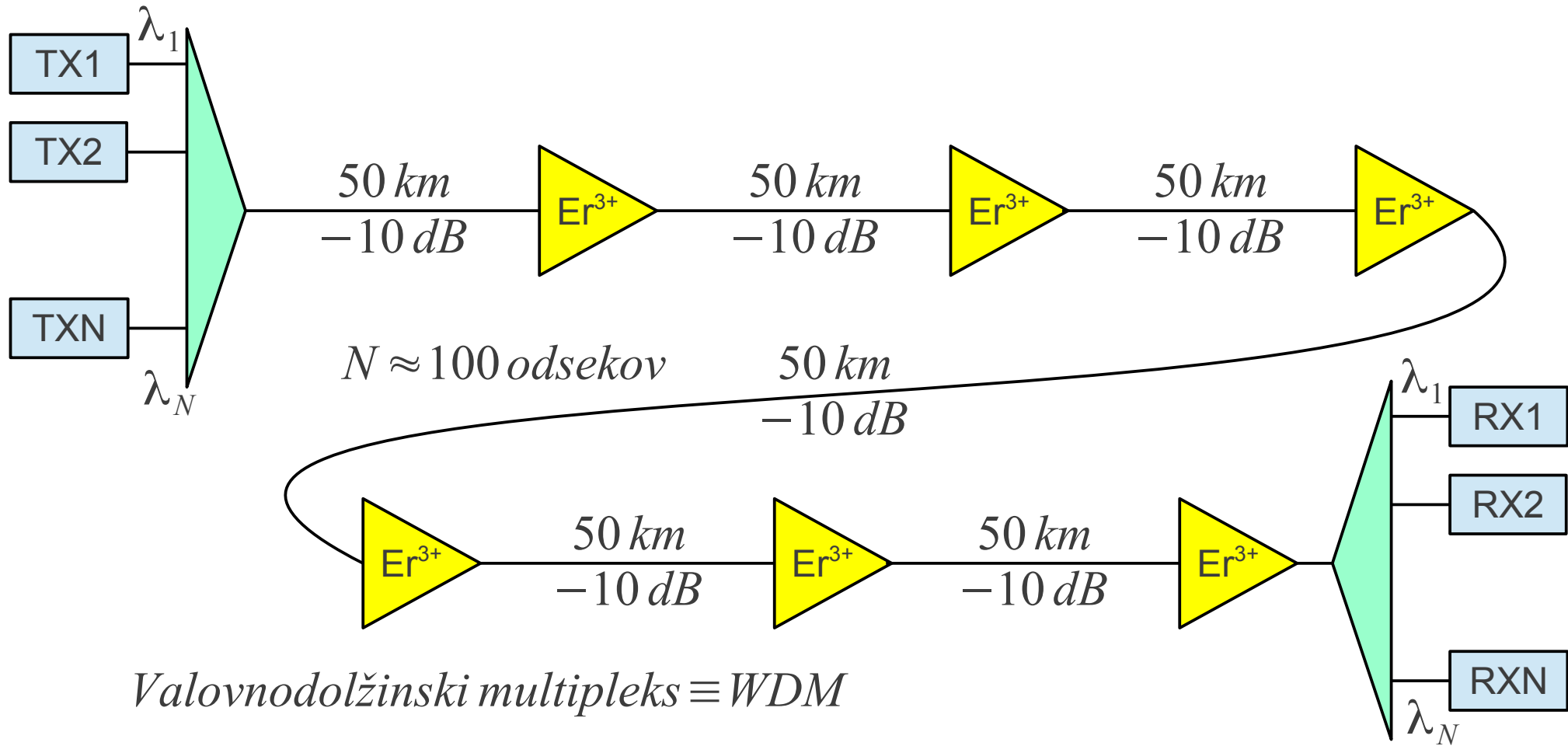


Enorodovno vlakno  $\lambda_0 \approx 1.55 \mu\text{m}$  (bližnja IR)  $\rightarrow d \approx 9 \mu\text{m} \rightarrow$  spajanje?



# Razvoj tehnike danes?

$B \approx 4 \text{ THz}$  ( $\text{Er}^{3+}$  ojačevalnik)  $\rightarrow$  prekooceanski kabel  $C \approx 10 \text{ Tbit/s}$



Modulacija QAM16  $\times$  2 polarizaciji  $\rightarrow$  100 Gbit/s kanal

Sodobna cenena tehnika: modulacija ON/OFF  $C = 10 \text{ Gbit/s}$  (SFP modul)