

Strokovno izobraževanje

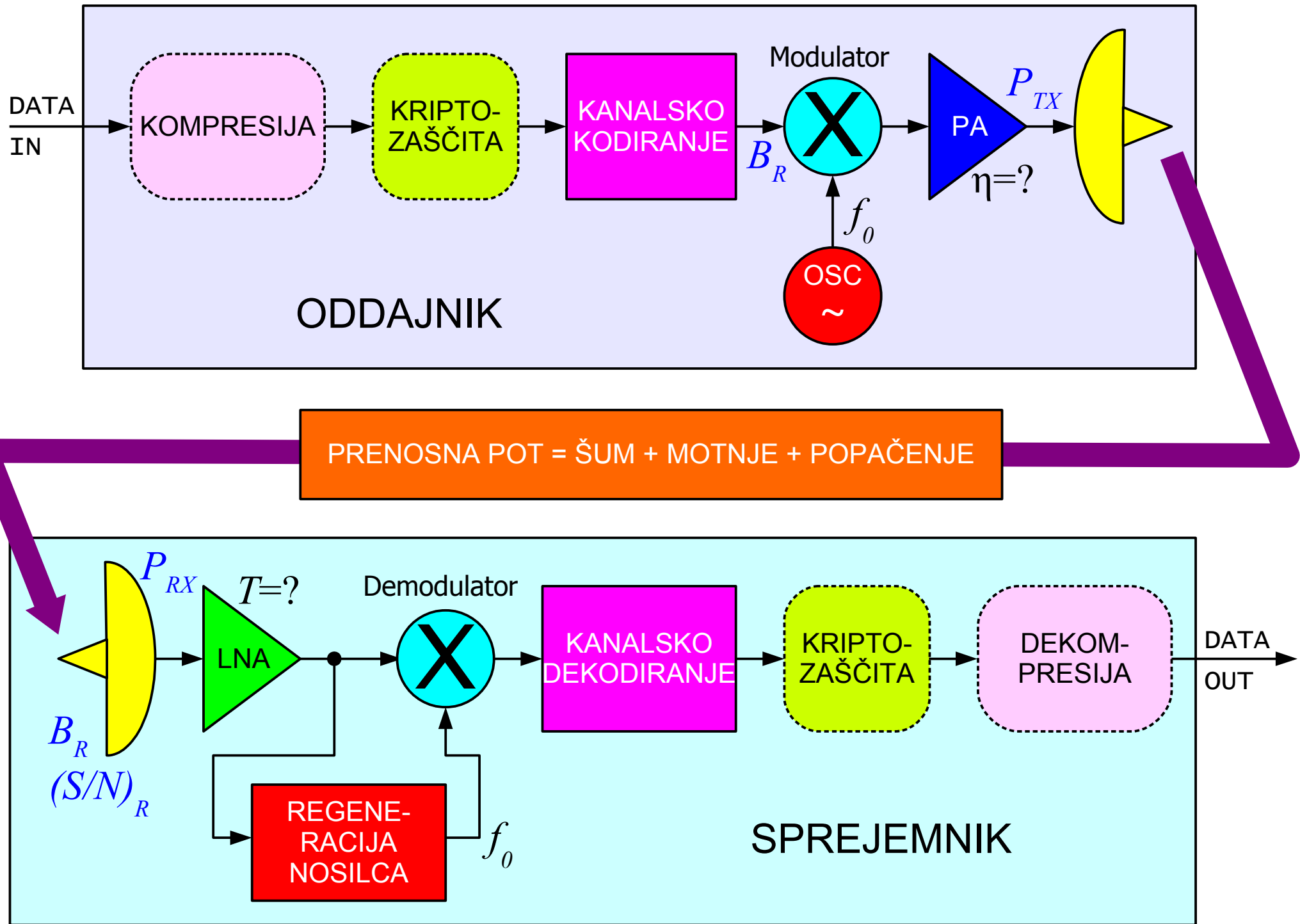
# MODULACIJA IN KODIRANJE

Matjaž Vidmar

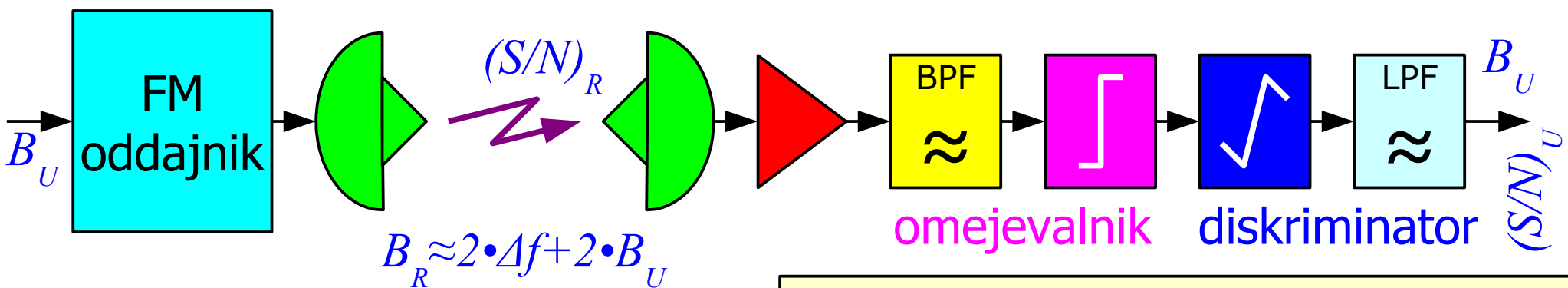
AKOS, Ljubljana, 22.5.2015

## Seznam prosojnic predavanja: MODULACIJA IN KODIRANJE

- 1 - Obdelava signalov v radijski zvezi
- 2 - Analogna zveza
- 3 - Modemska številna zveza
- 4 - Nabor kazalcev številne zveze
- 5 - Bi-Phase Shift Keying (BPSK)
- 6 - Quadri-Phase Shift keying (QPSK)
- 7 - Kvadratura amplitudna modulacija (QAM)
- 8 - Izračun pogostnosti napak BPSK
- 9 - Pogostnost napak (BER) različnih modulacij
- 10 - Različice PSK in QAM
- 11 - Vektorska napaka (EVM in MER)
- 12 - Oblikovanje spektra PSK/QAM oddaje
- 13 - FSK inačici MSK in GMSK
- 14 - Vnaprejšnje popraviljanje napak FEC (Forward Error Correction)
- 15 - Samodejno ponavljanje ARQ (Automatic Repeat reQuest)
- 16 - Kanalsko kodiranje in dekodiranje



1 - Obdelava signalov v radijski zvezi



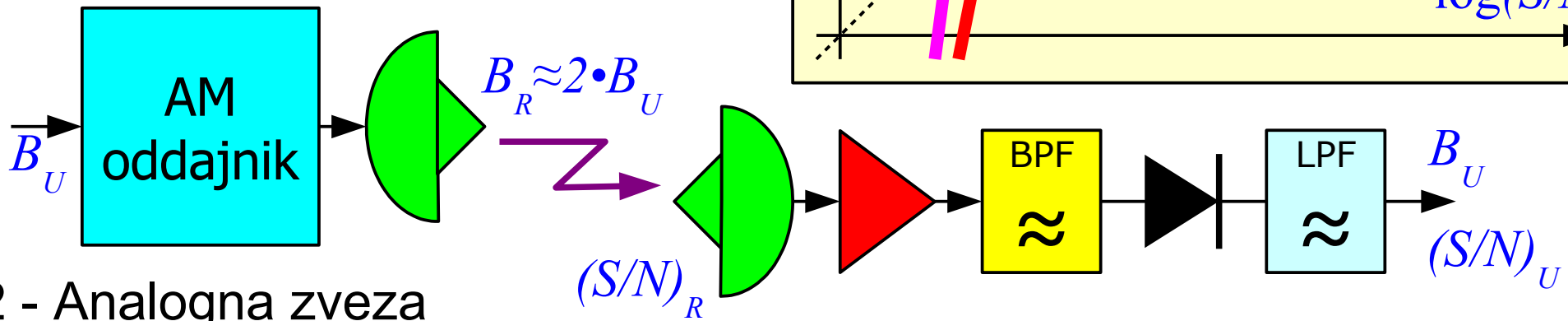
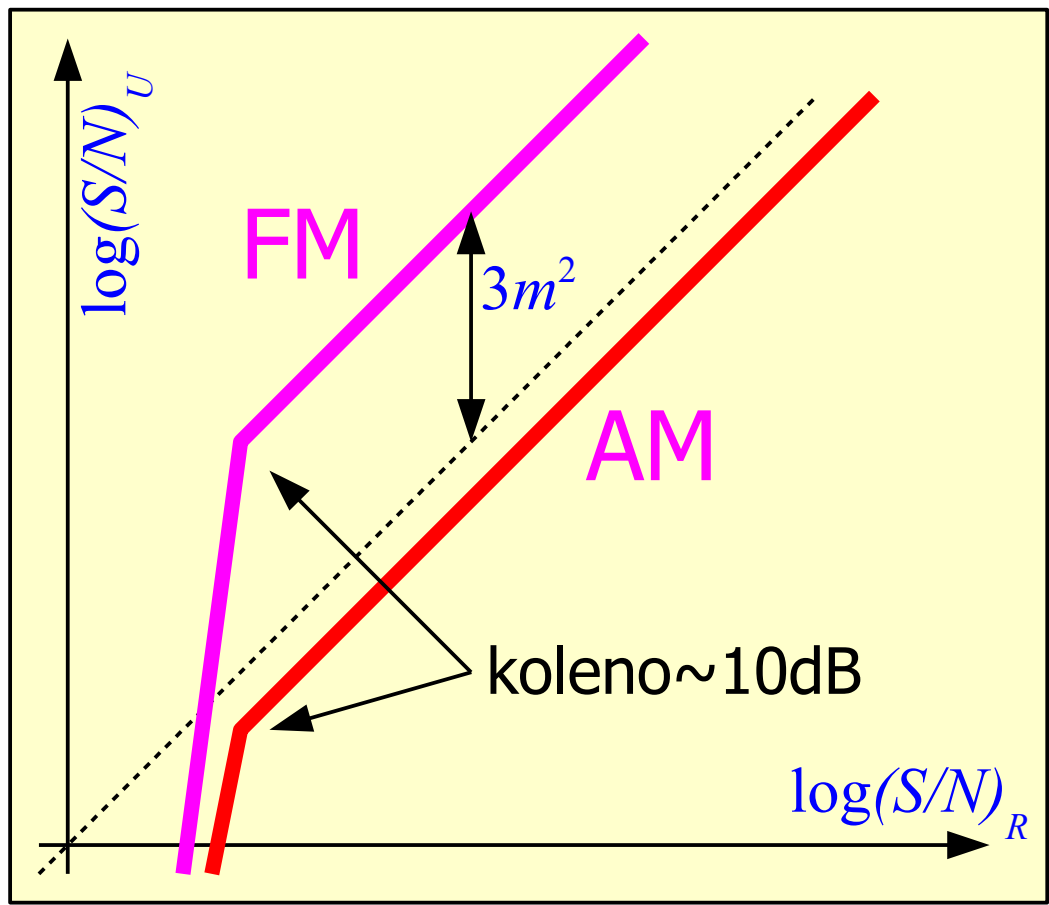
**Razmerje  $S/N$  pri AM in FM**

$B_U$  [Hz]  $\equiv$  širina uporabnika

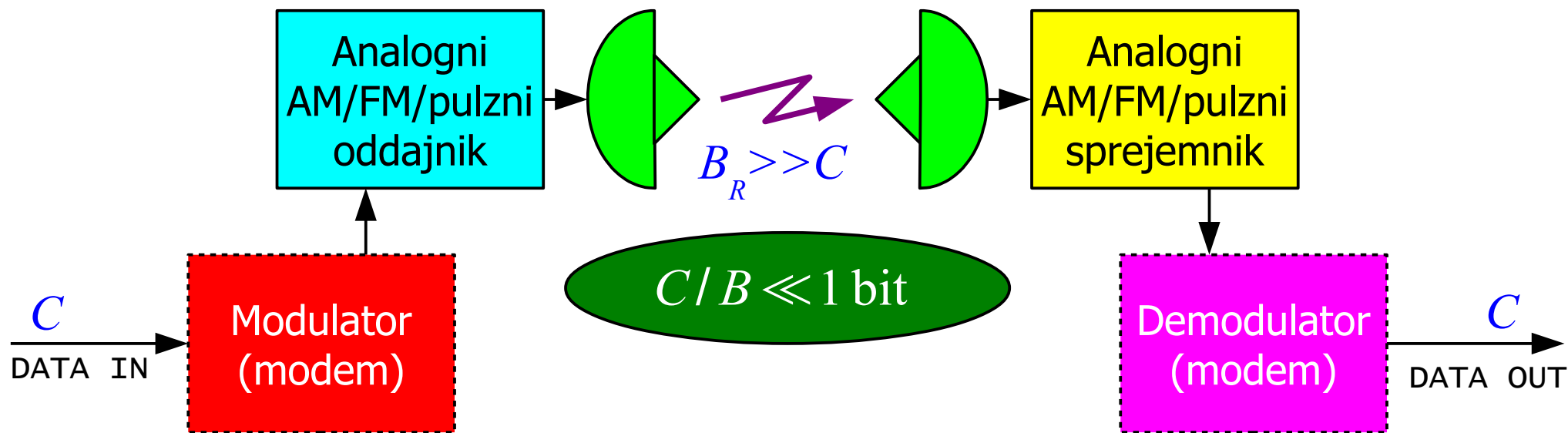
$\Delta f$  [Hz]  $\equiv$   $\pm$ FM koleb

$m = \Delta f / B_U$

$B_R$  [Hz]  $\equiv$  radijska širina



2 - Analogna zveza



ASK  $\equiv$  Amplitude Shift Keying  
 FSK  $\equiv$  Frequency Shift Keying  
 AASK  $\equiv$  Audio Amplitude Shift Keying  
 AFSK  $\equiv$  Audio Frequency Shift Keying  
 OOK  $\equiv$  On-Off Keying  
 PAM  $\equiv$  Pulse-Amplitude Modulation  
 PPM  $\equiv$  Pulse-Position Modulation

Velika radijska pasovna širina  $B_R \gg C$

Zelo nizka spektralna učinkovitost  $C/B$

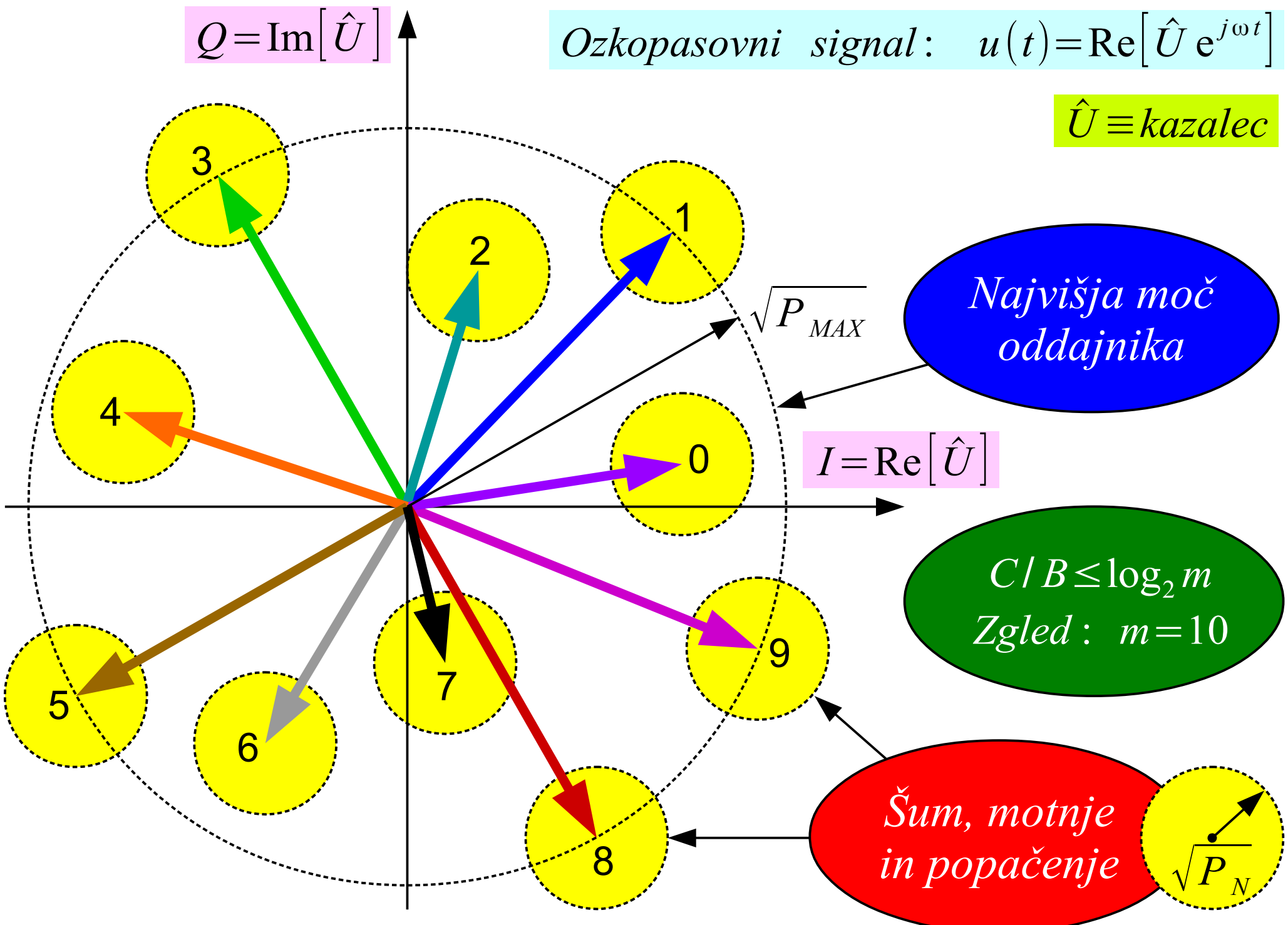
Nekoherenten sprejemnik

20dB...50dB slabše od Shannon-ove  
zmogljivosti

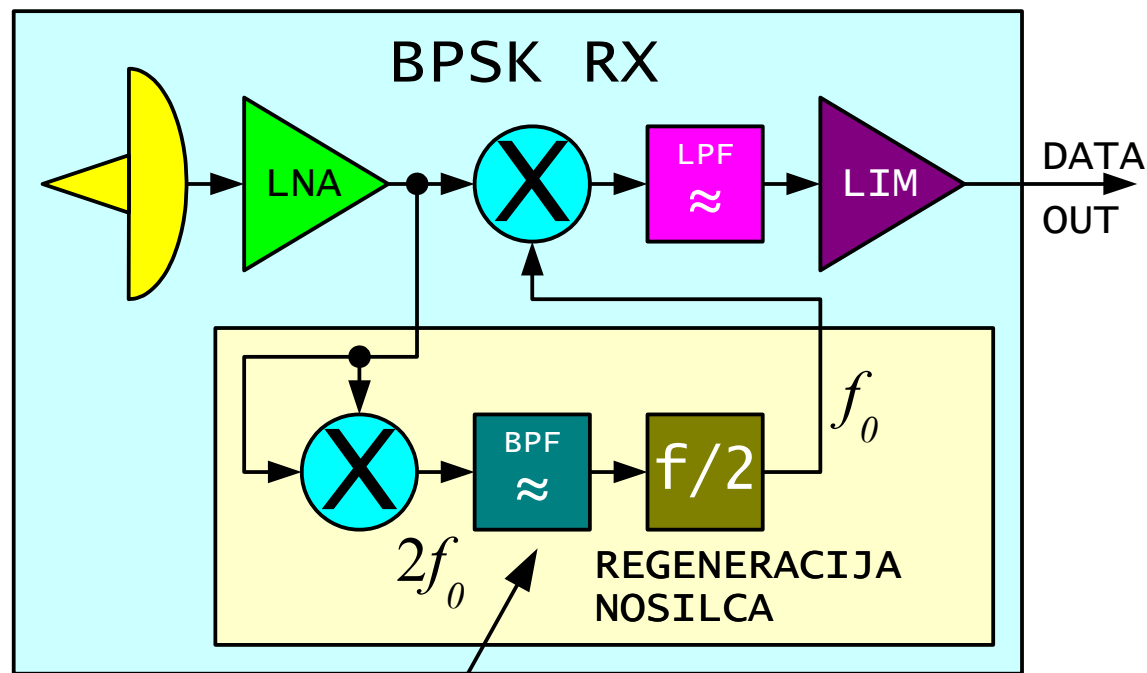
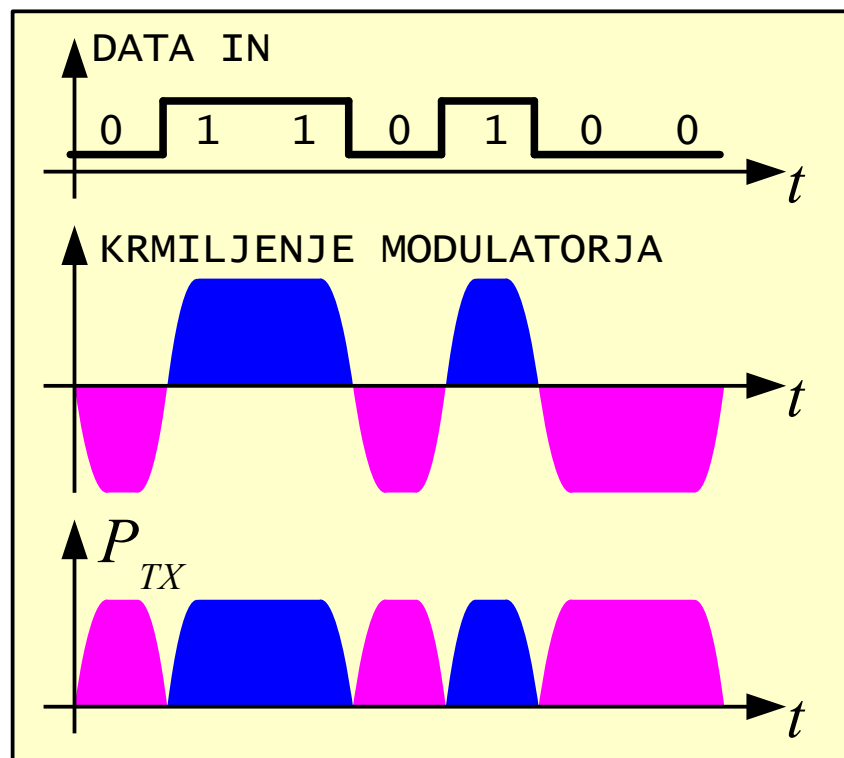
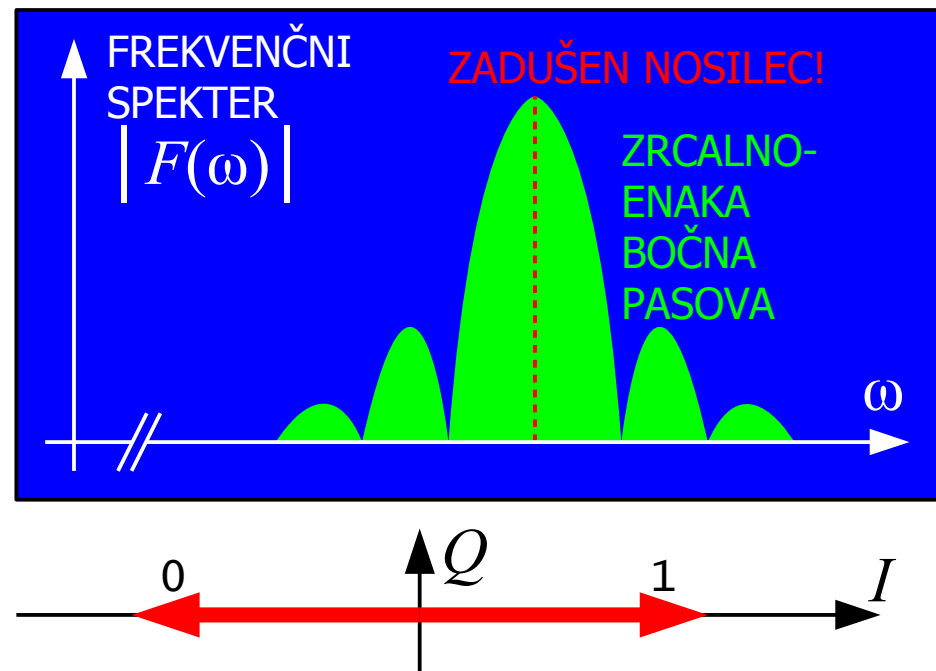
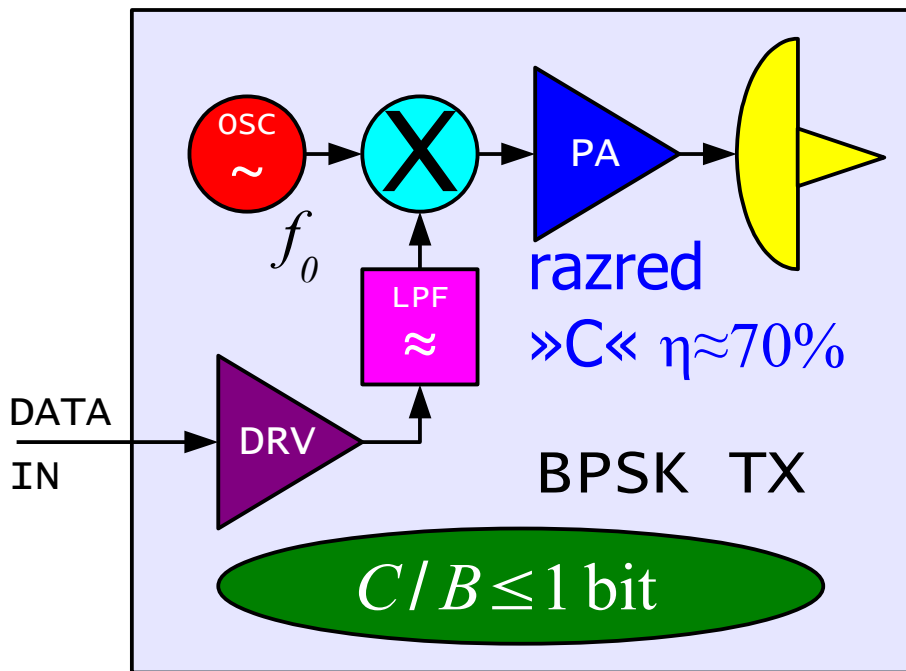
ZGODOVNSKO  
KRPANJE!

Preprosta oddajnik in sprejemnik

Neobčutljivo na odstopanje frekvence  
nosilca oddajnika/sprejemnika



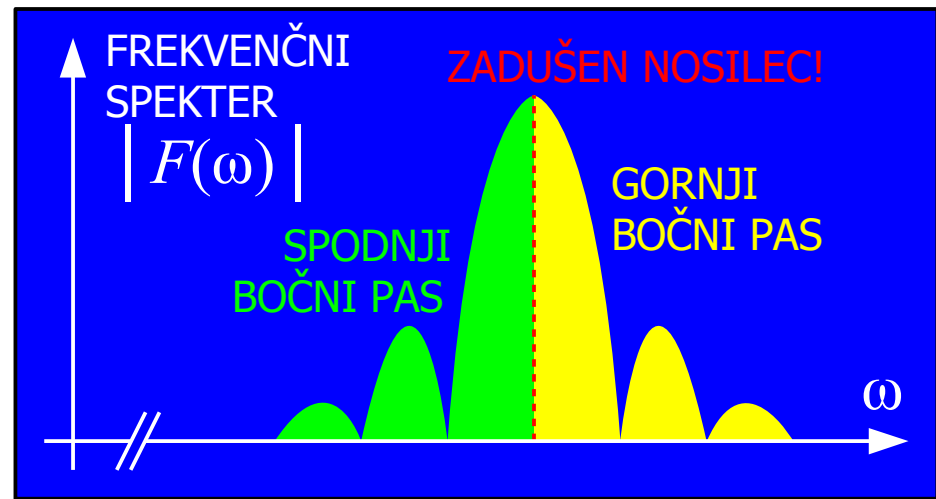
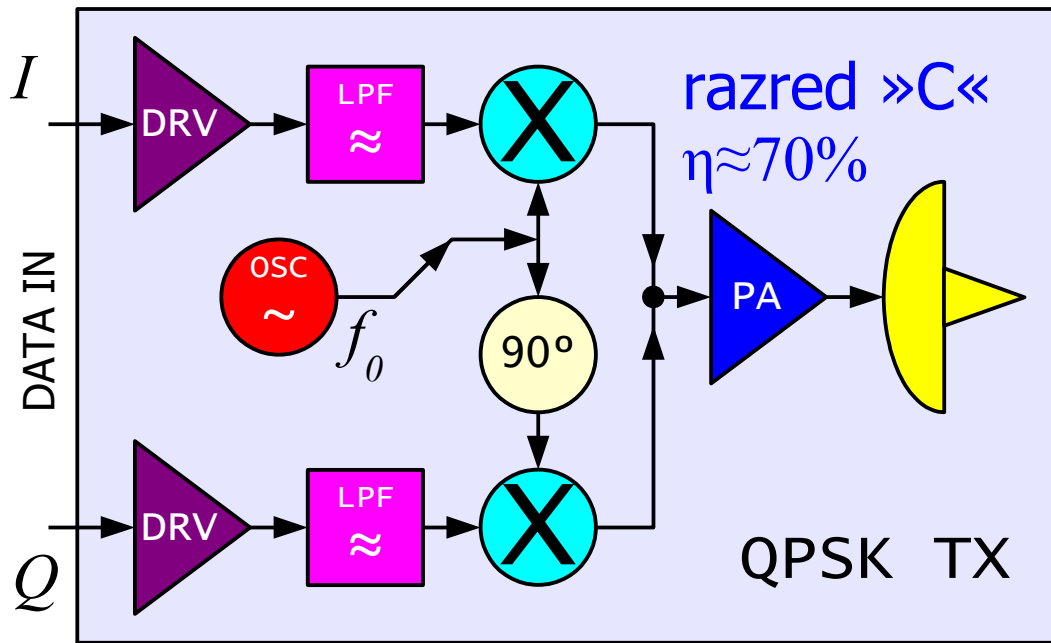
4 - Nabor kazalcev številske zveze



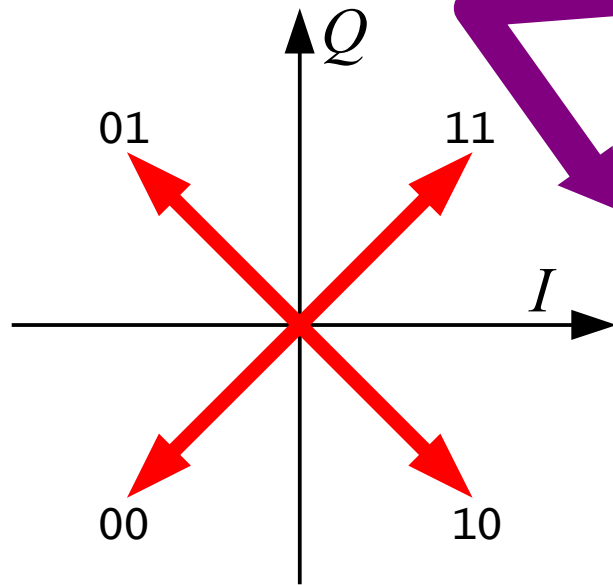
5 - Bi-Phase Shift Keying (BPSK)

$\Delta f \leq 10\% C$

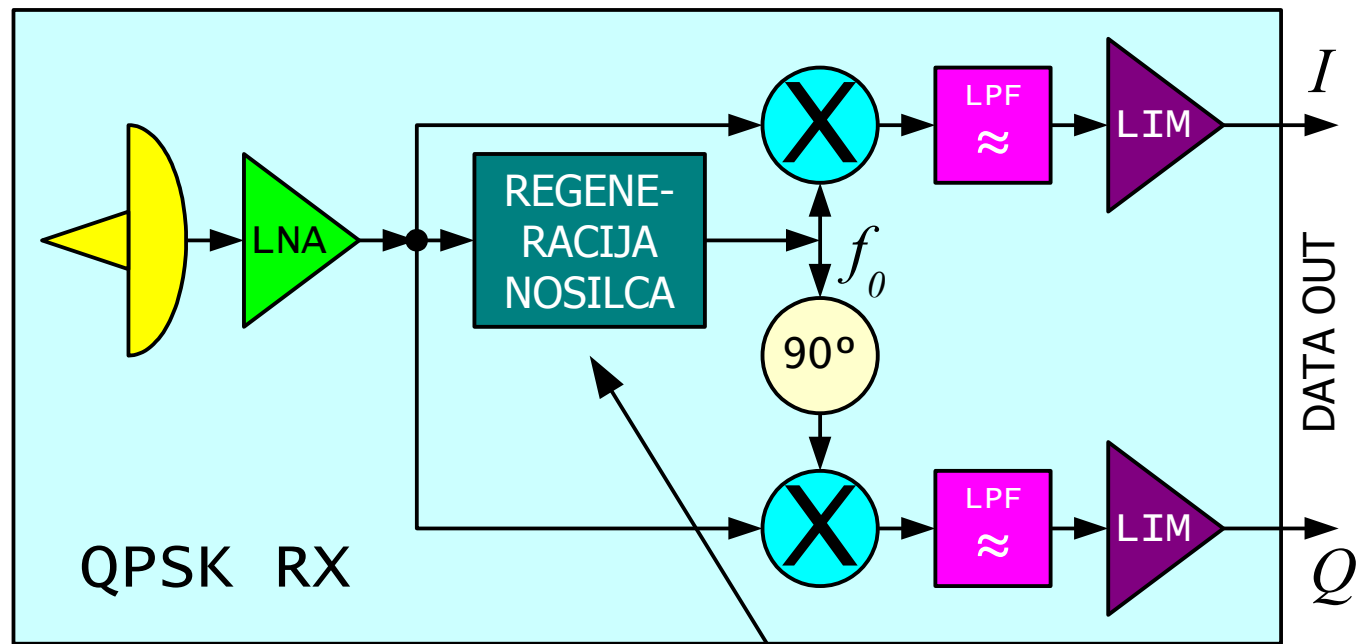
PREPROSTO!



$C/B \leq 2 \text{ bit}$



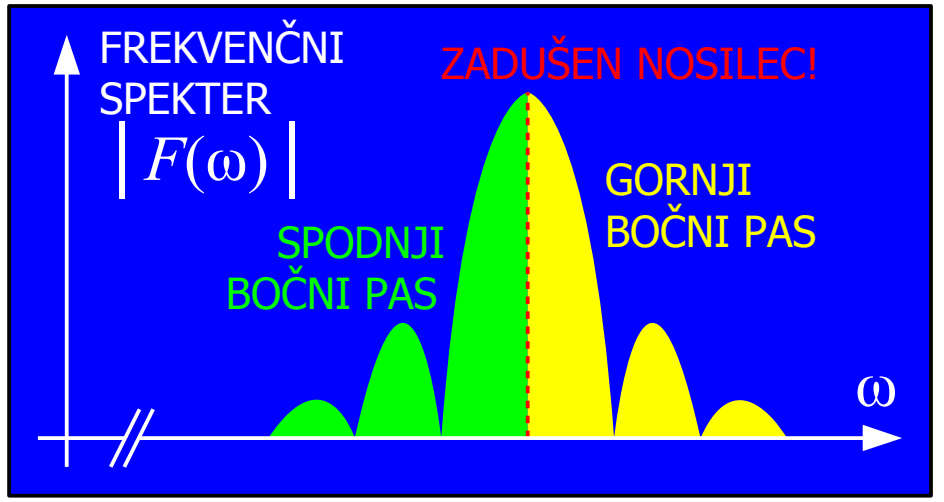
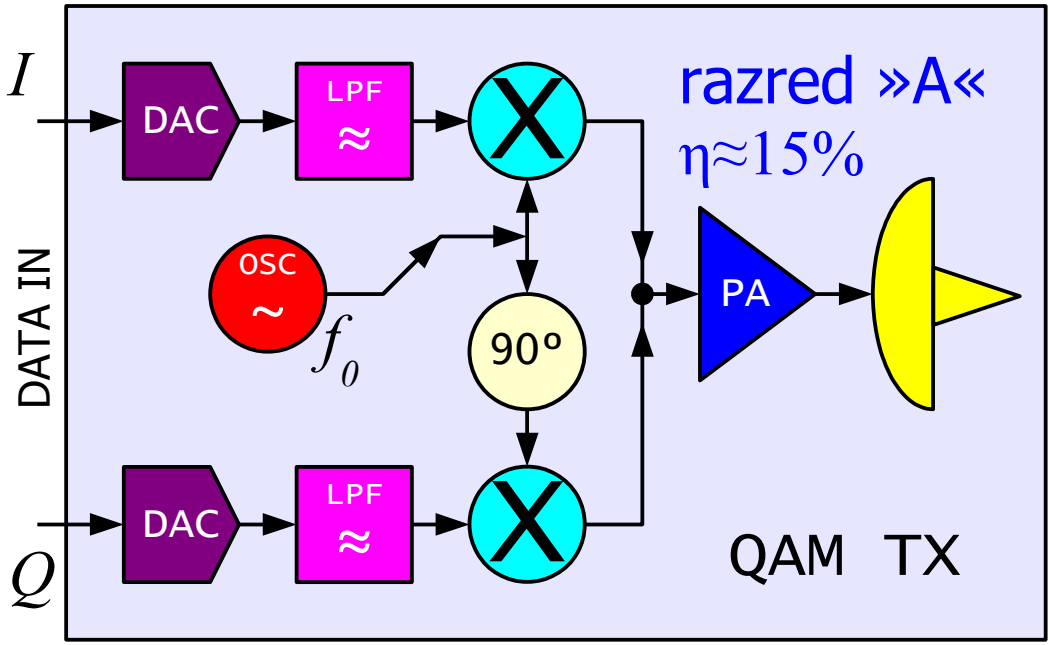
VESOLJE, GSM



$\Delta f \leq 10\% R$

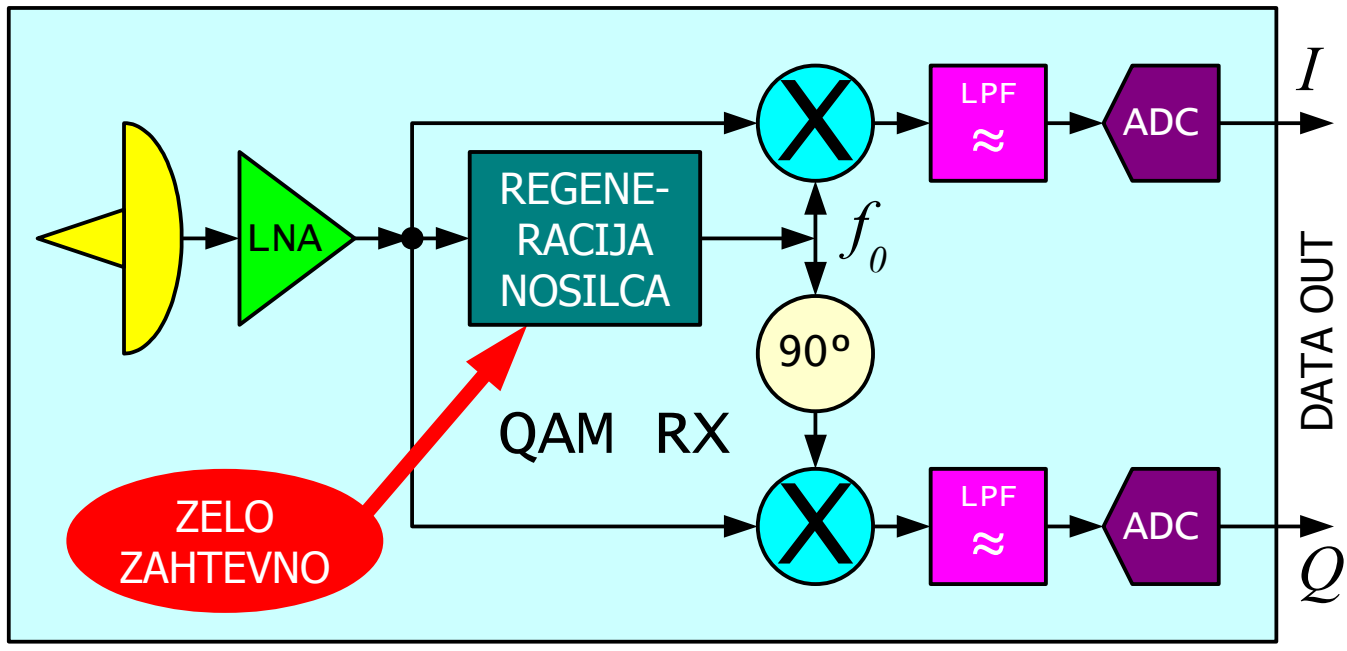
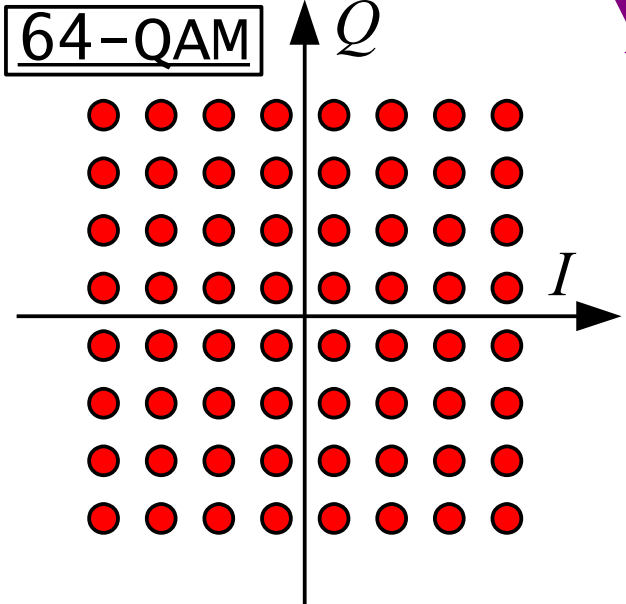
6 - Quadri-Phase Shift Keying (QPSK)





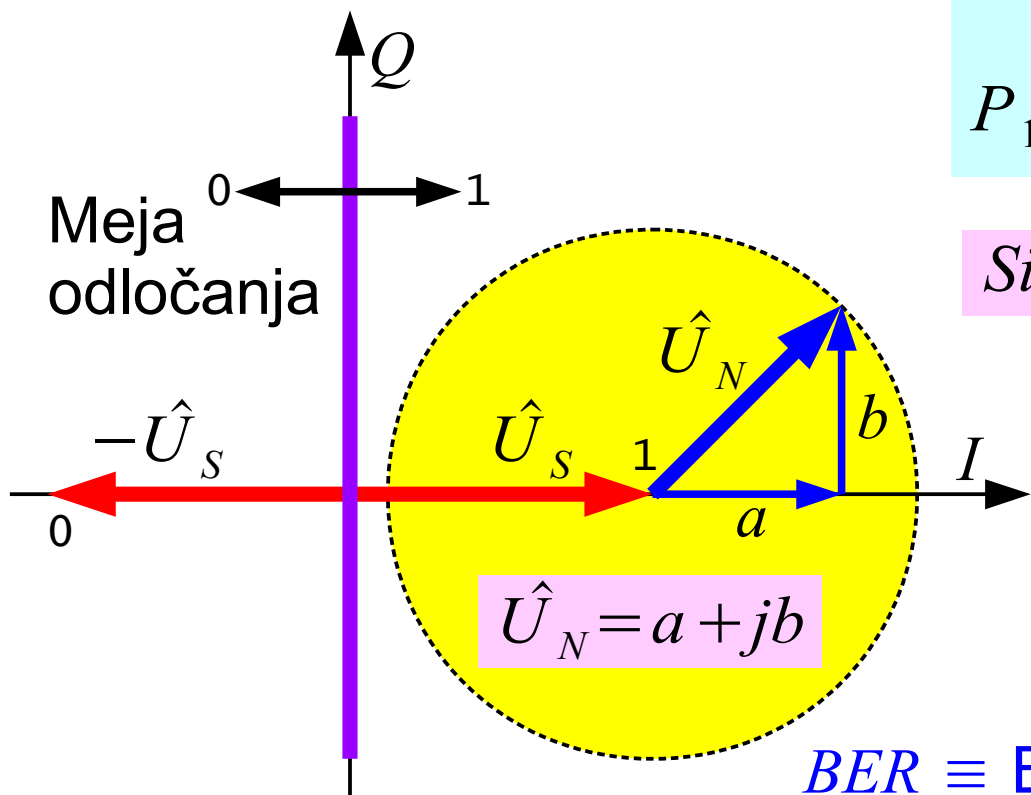
OBČUTLJIV NA ODBOJE (VEČPOTJE)

$C/B \leq 6$  bit



TOČKA-TOČKA

7 - Kvadraturna amplitudna modulacija (QAM)



$$P_{1 \rightarrow 0} = \int_{-\infty}^{-|\hat{U}_s|} p(a) da$$

$$P_{0 \rightarrow 1} = \int_{|\hat{U}_s|}^{\infty} p(a) da$$

Simetrična meja:  $P_{1 \rightarrow 0} = P_{0 \rightarrow 1} = BER$

$$BER = \int_{|\hat{U}_s|}^{\infty} \frac{1}{\sqrt{\pi \langle |\hat{U}_N|^2 \rangle}} e^{-\frac{a^2}{\langle |\hat{U}_N|^2 \rangle}} da$$

$$\text{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-u^2} du$$

$BER \equiv$  Bit-Error Rate

Gaussova porazdelitev gostote verjetnosti sofazne  $a$  in kvadraturene  $b$  komponente šuma

$$p(a) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{a^2}{2\sigma^2}}$$

$$p(b) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{b^2}{2\sigma^2}}$$

$$BER = \frac{1}{2} \text{erfc} \left( \frac{|\hat{U}_s|}{\sqrt{\langle |\hat{U}_N|^2 \rangle}} \right)$$

$$P_S = \alpha |\hat{U}_s|^2$$

$$P_N = \alpha \langle |\hat{U}_N|^2 \rangle$$

$$\langle |\hat{U}_N|^2 \rangle = \langle a^2 \rangle + \langle b^2 \rangle = 2\sigma^2$$

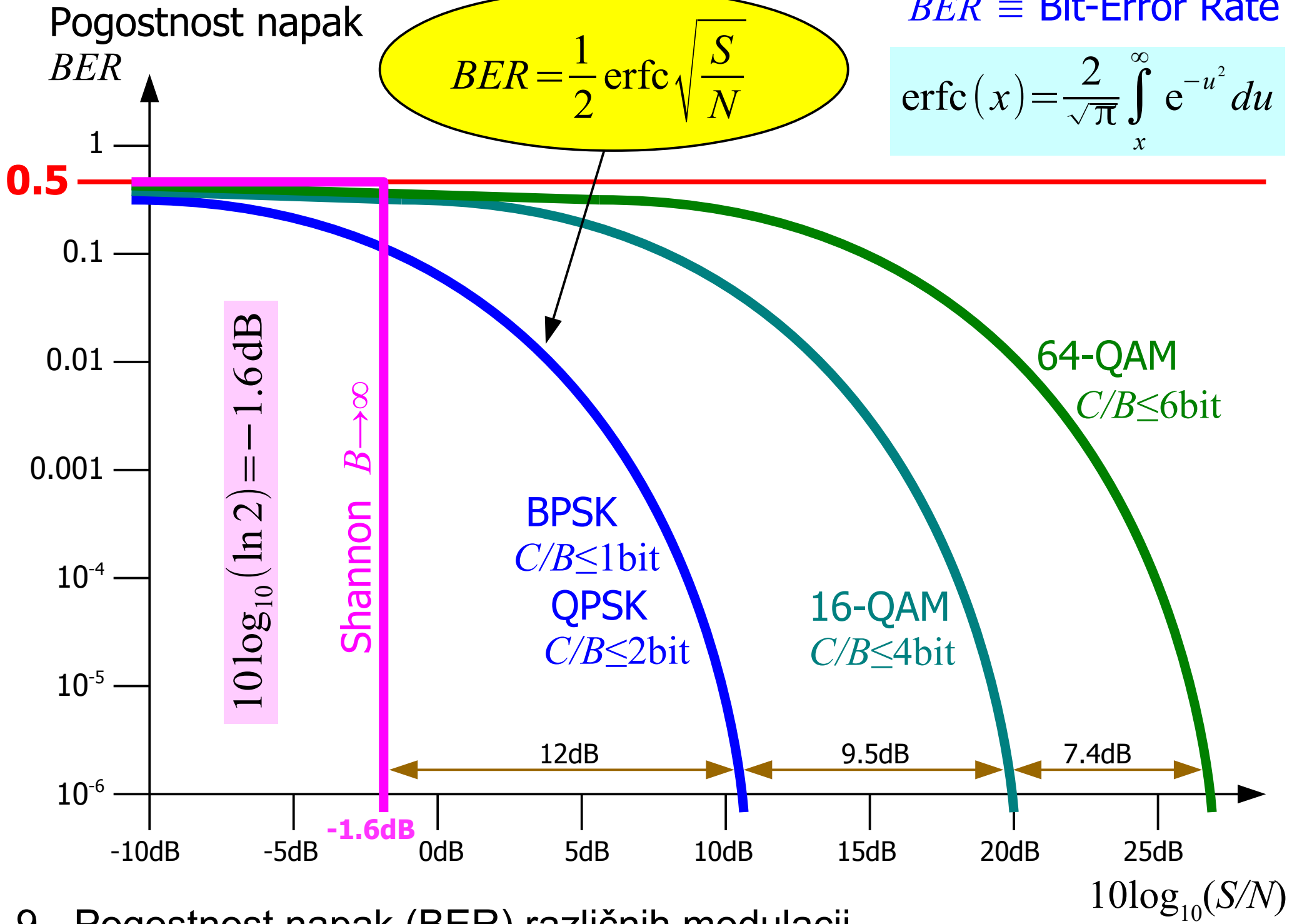
$$BER = \frac{1}{2} \text{erfc} \left( \sqrt{\frac{P_S}{P_N}} \right)$$

8 - Izračun pogostnosti napak BPSK

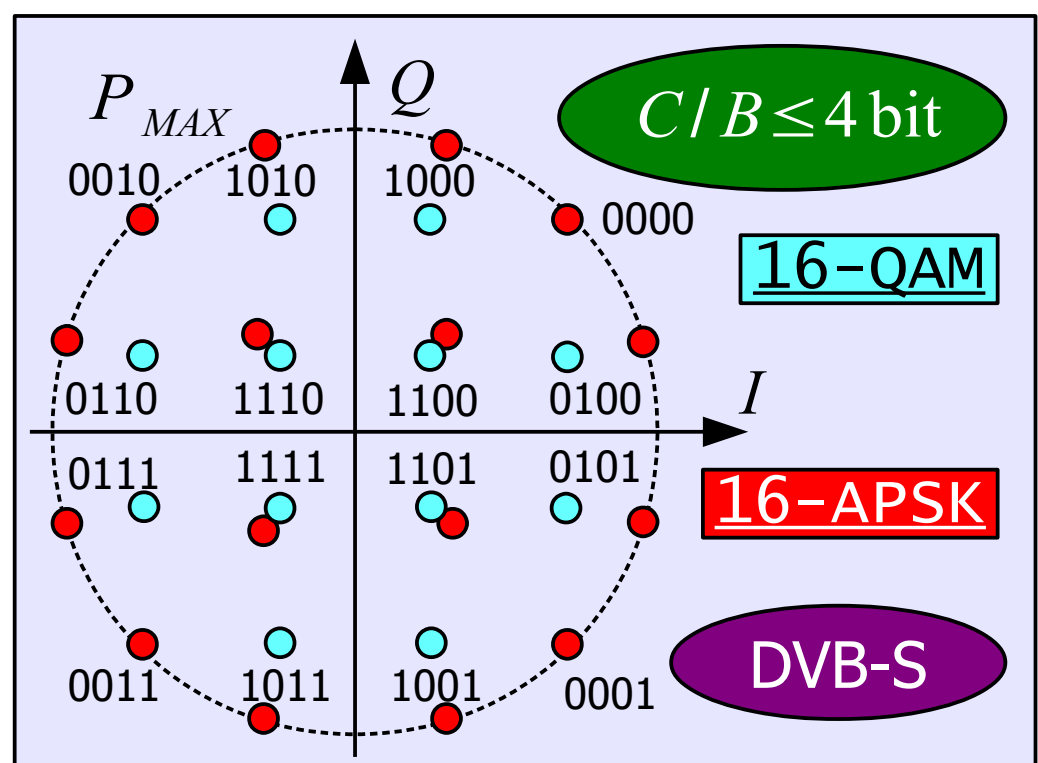
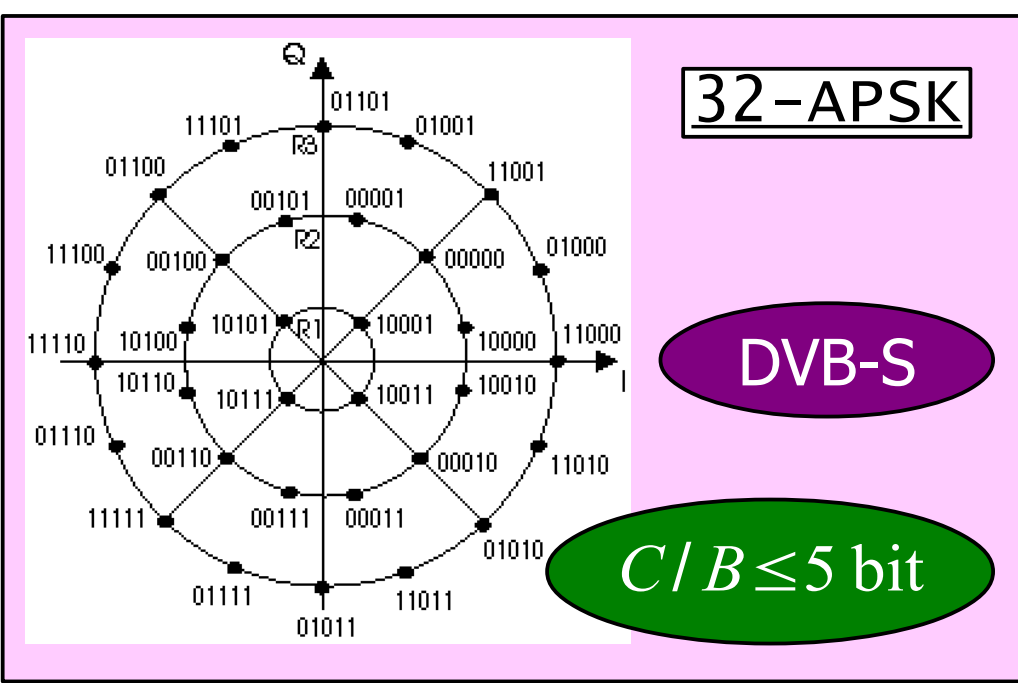
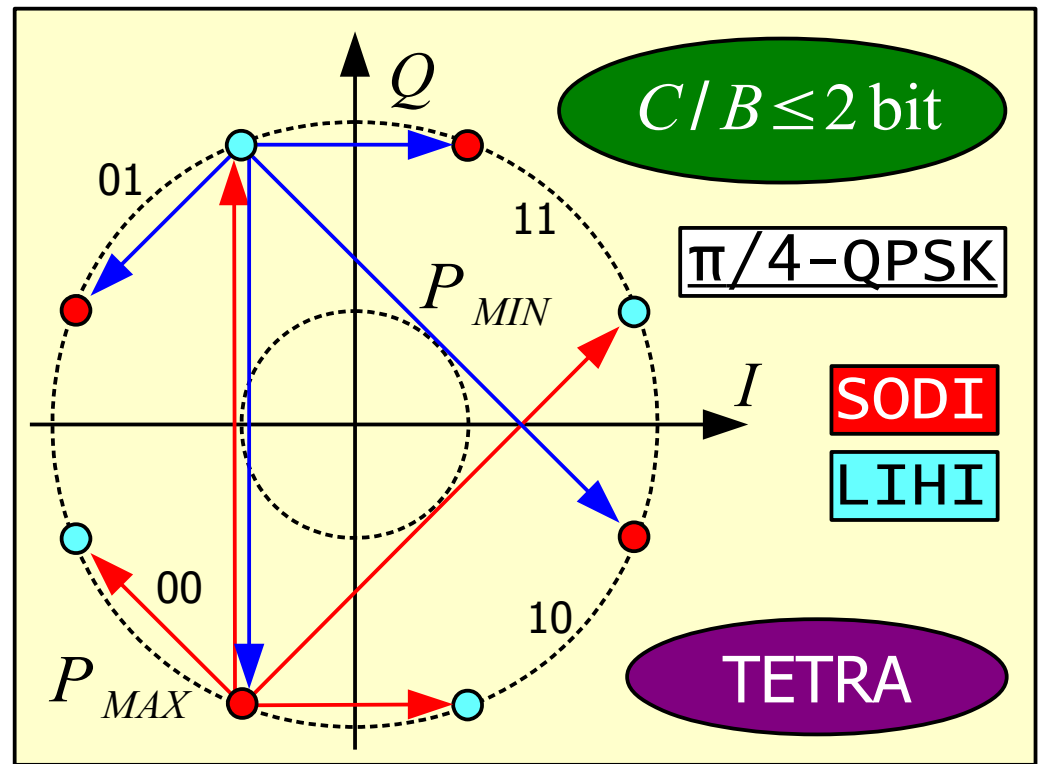
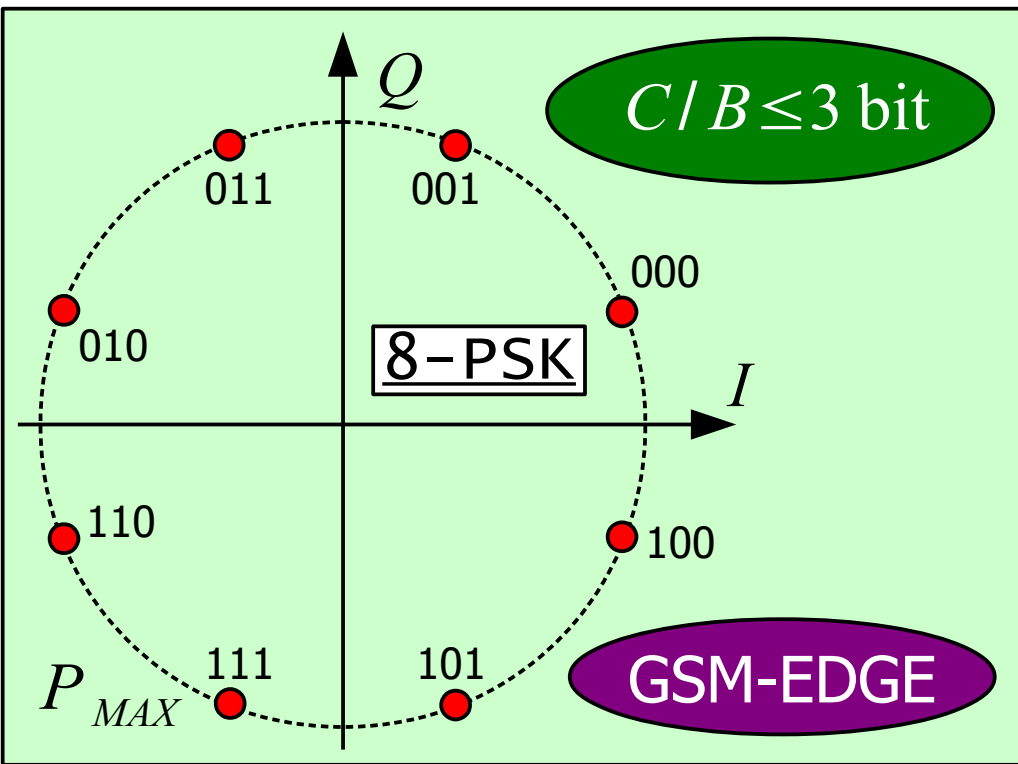
$BER \equiv$  Bit-Error Rate

$$\text{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-u^2} du$$

$$BER = \frac{1}{2} \text{erfc} \sqrt{\frac{S}{N}}$$



9 - Pogostnost napak (BER) različnih modulacij

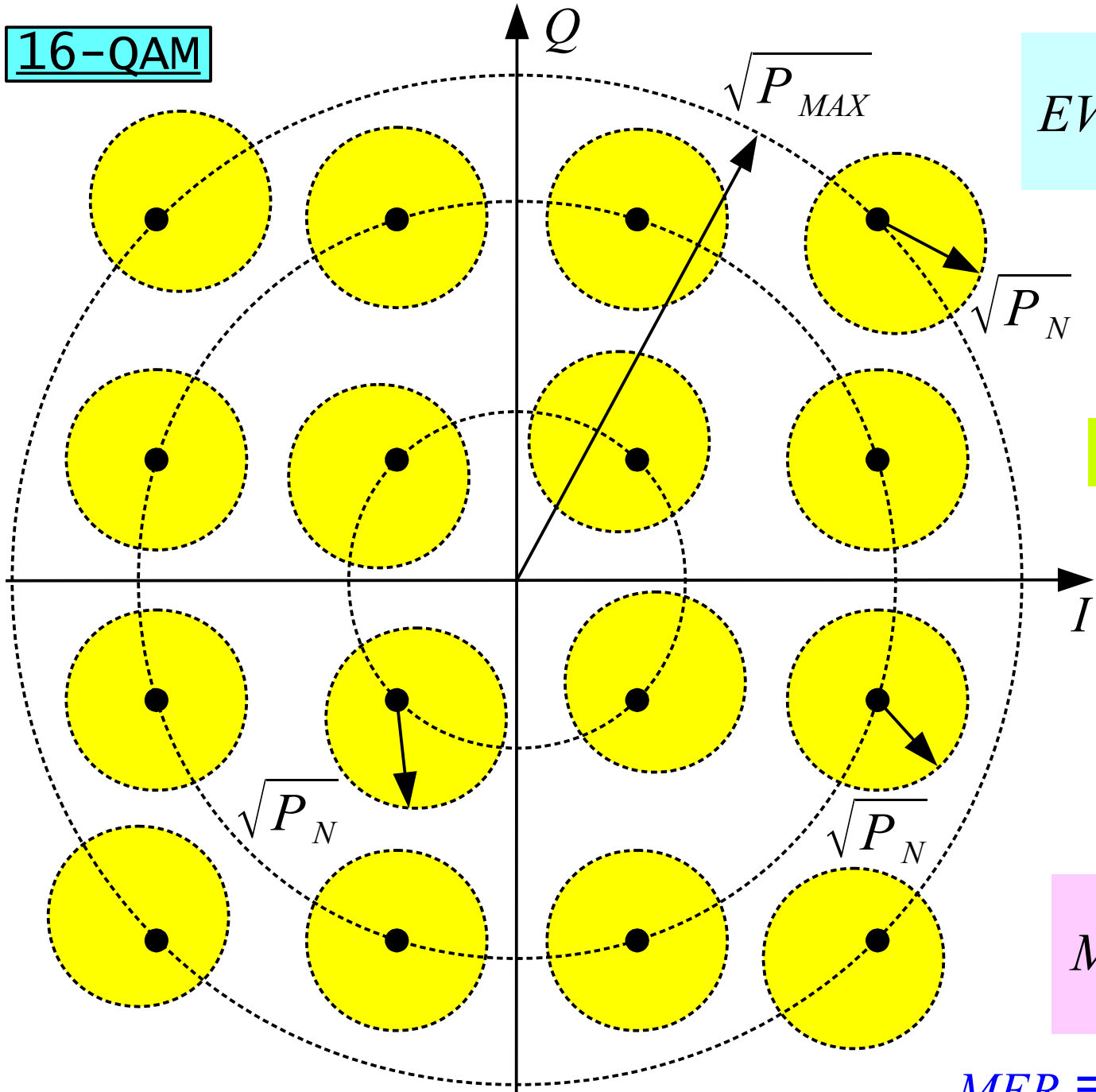


10 - Različice PSK in QAM

AM/φM → medsebojni zasuk ozvezdij!

$EVM \equiv$  Error Vector Magnitude

16-QAM



$$EVM = \sqrt{\frac{\langle P_N \rangle}{P_{MAX}}} \quad [\%]$$

?ali?  $EVM = \sqrt{\frac{\langle P_N \rangle}{\langle P_S \rangle}}$

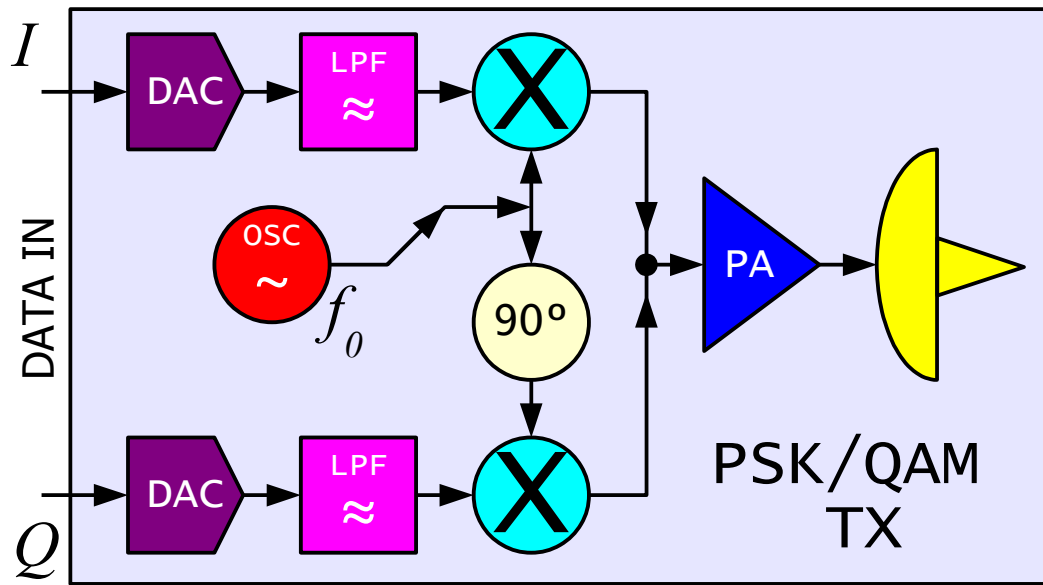
$$EVM_{dB} = 20 \log_{10} EVM$$

*EVM* in *MER*  
vsebuja šum,  
motnje in  
popačenje!

$$MER_{dB} = 10 \log_{10} \left( \frac{\langle P_S \rangle}{\langle P_N \rangle} \right)$$

$MER \equiv$  Modulation Error Ratio

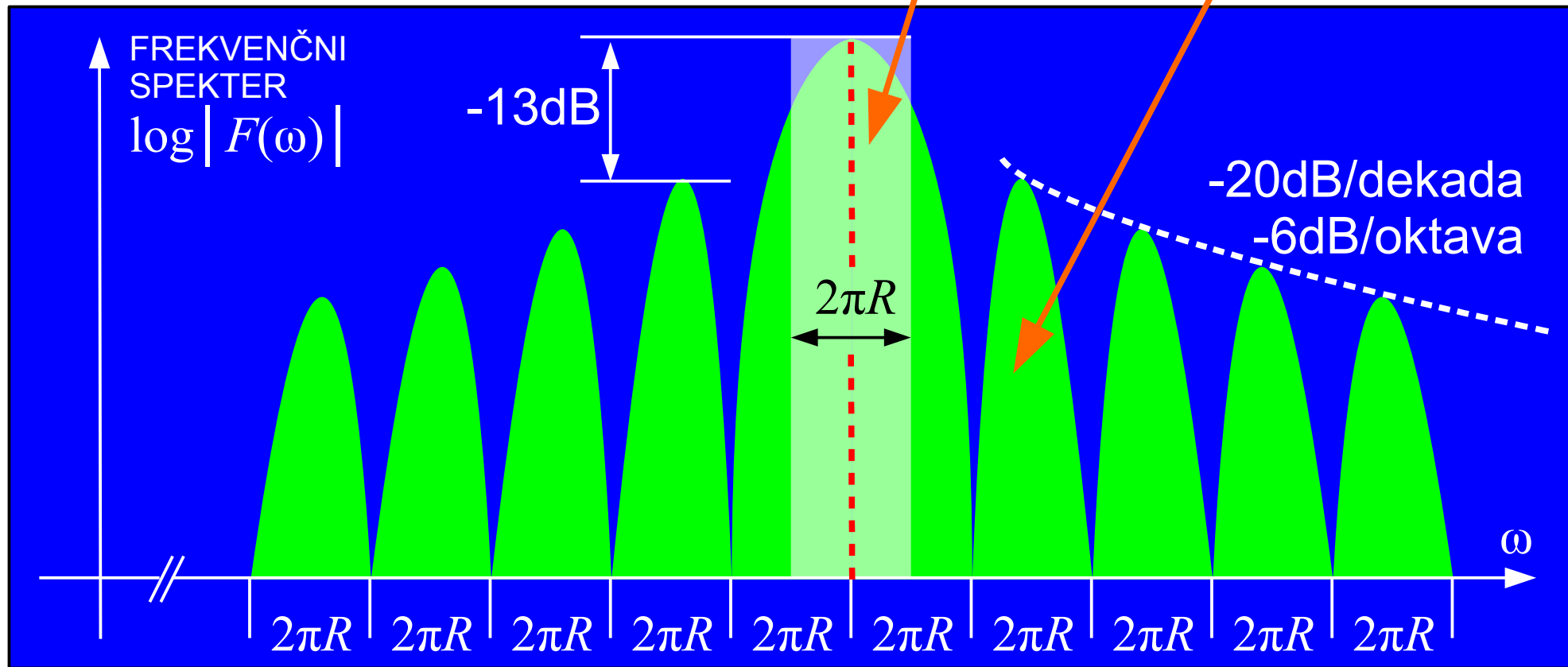
11 - Vektorska napaka (EVM in MER)



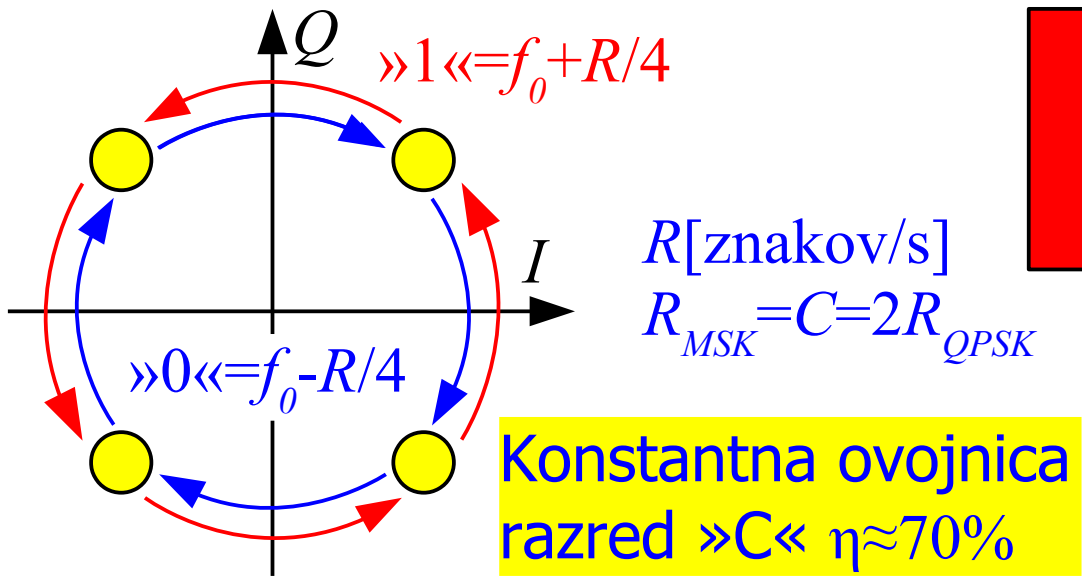
Nyquist  $B=R$   
 razred »A«  $\eta \approx 15\%$

$R$  [znakov/s]  
 $R_{BPSK} = C$   
 $R_{QPSK} = C/2$

Brez sita  $B \rightarrow \infty$   
 razred »C«  $\eta \approx 70\%$

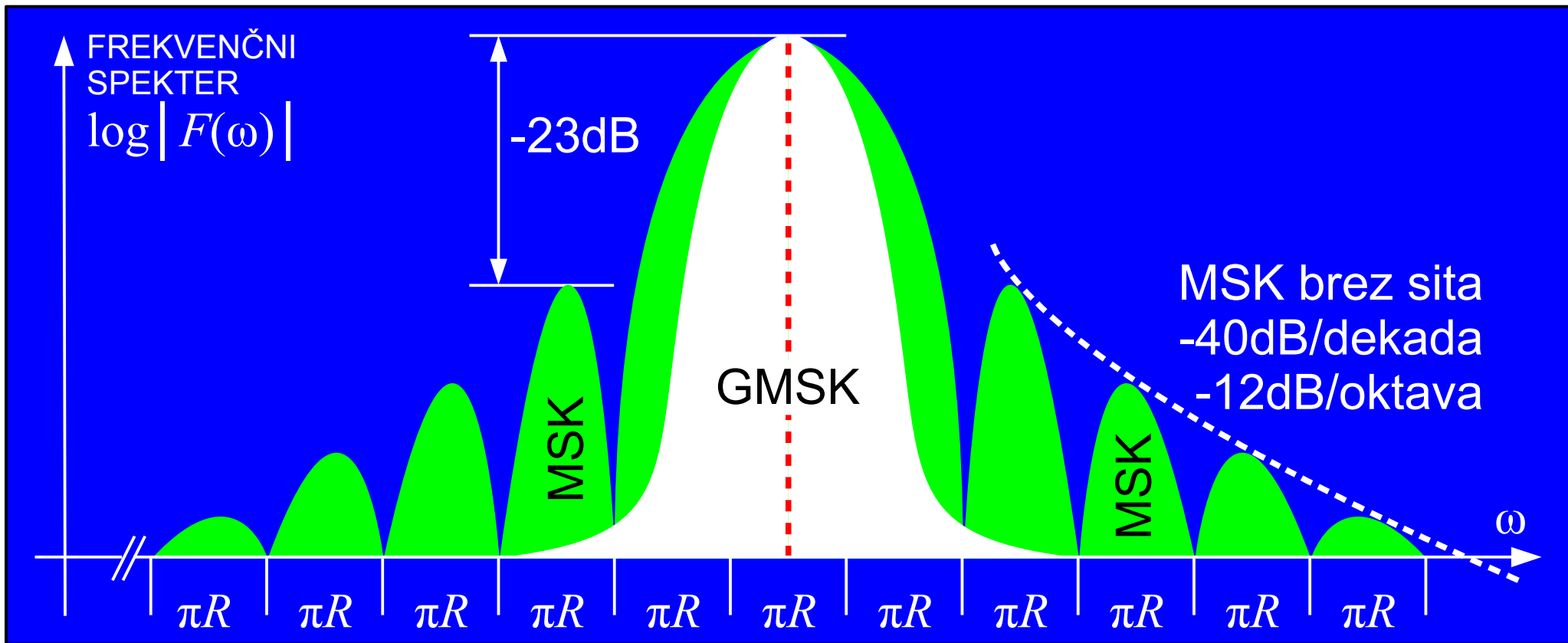


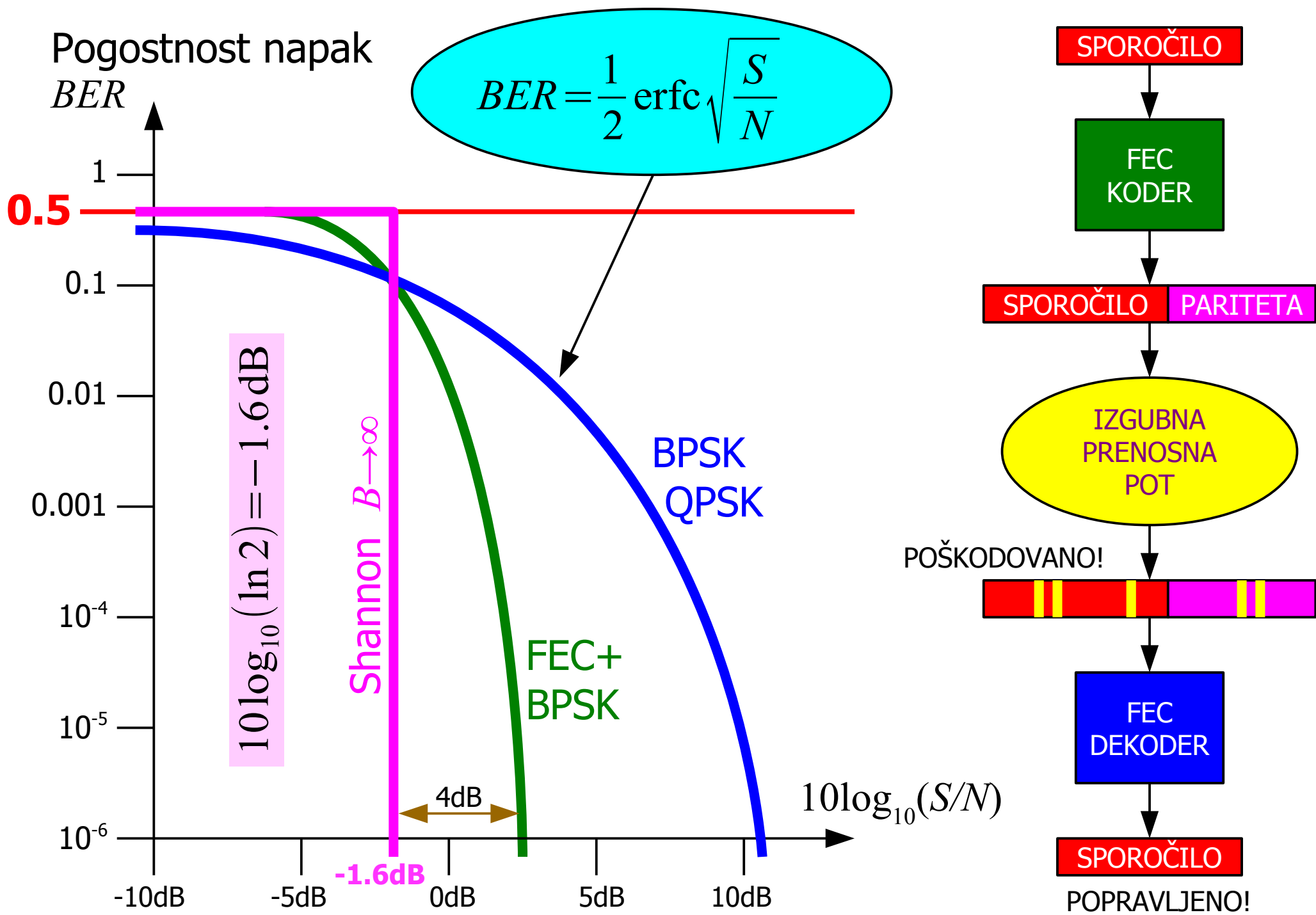
12 - Oblikovanje spektra PSK/QAM oddaje



Nekoherenten (G)MSK:  $f \approx f_0 \pm R/4$   
 Neposredno moduliran VCO  
 Uporaba: DECT

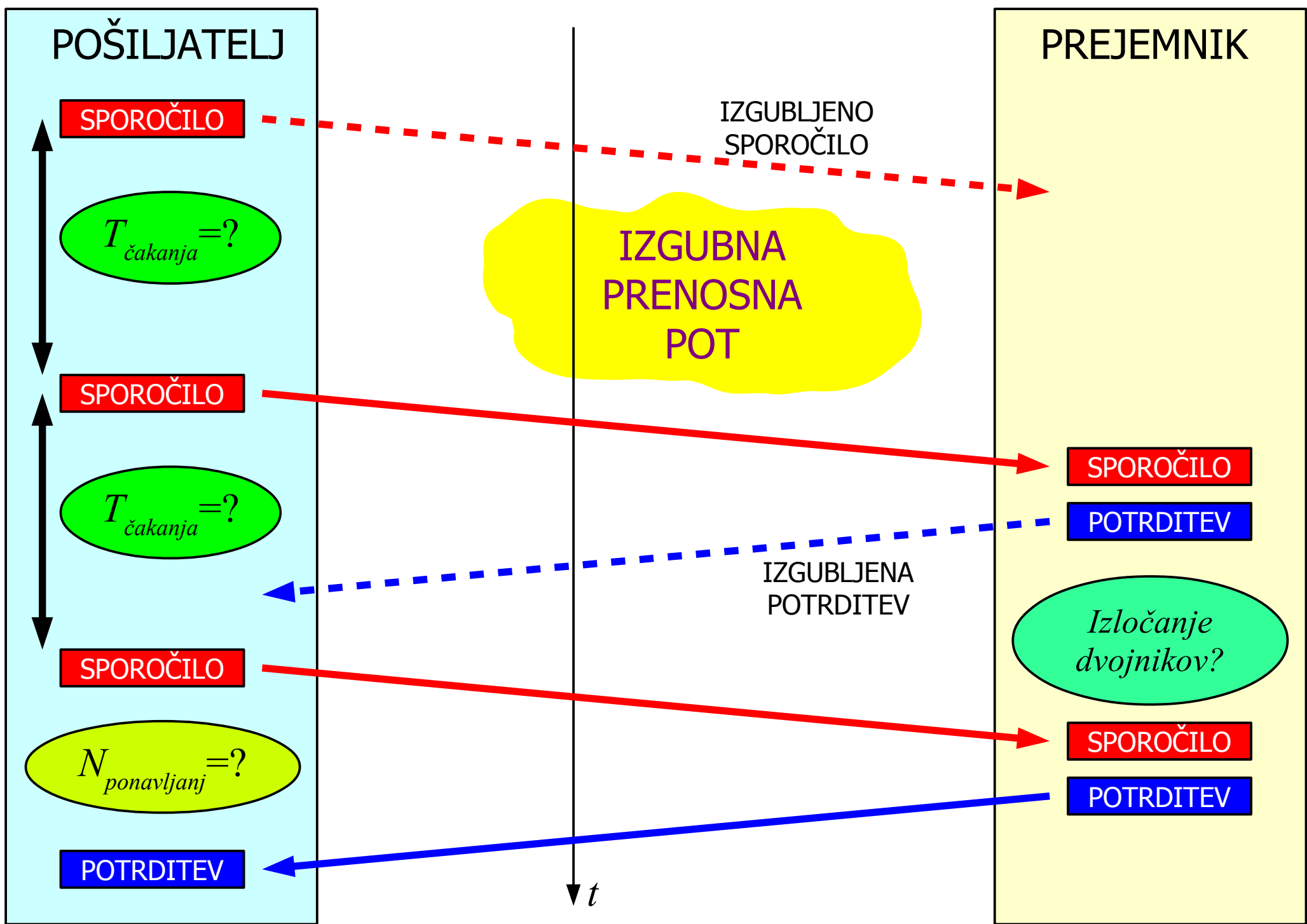
Koherenten (G)MSK:  $f = f_0 \pm R/4$   
 Kvadraturni modulator  
 Uporaba: GSM



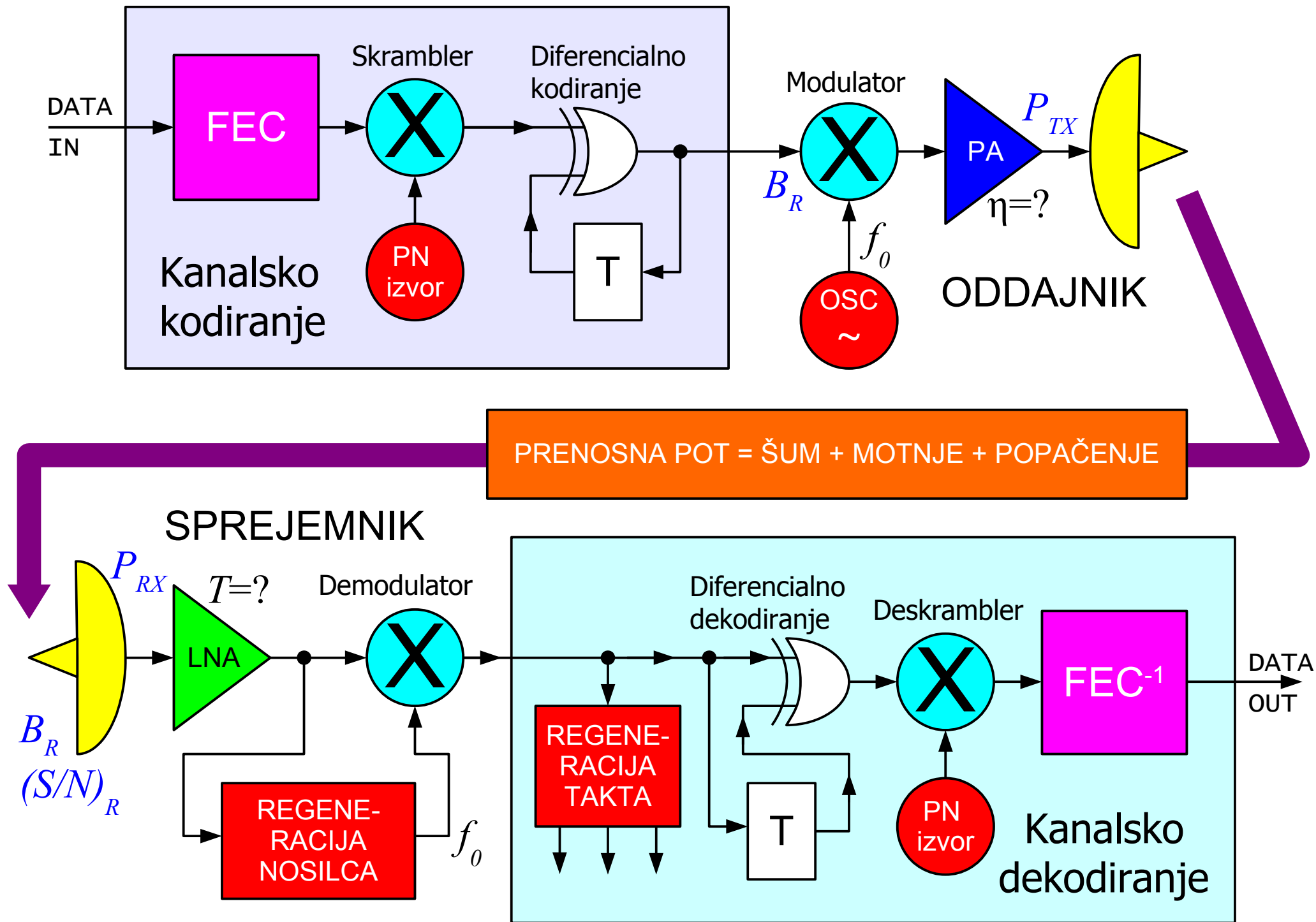


14 - Vnaprejšnje popravljanje napak FEC (Forward Error Correction)





15 - Samodejno ponavljanje ARQ (Automatic Repeat reQuest)



16 - Kanalsko kodiranje in dekodiranje