POLYTECHNIC UNIVERSITY
EL501: WIRELESS PERSONAL COMMUNICATIONS

# INTRODUCTION TO SPREAD SPECTRUM COMMUNICATIONS

# WIRELESS COMMUNICATIONS SIGNALS

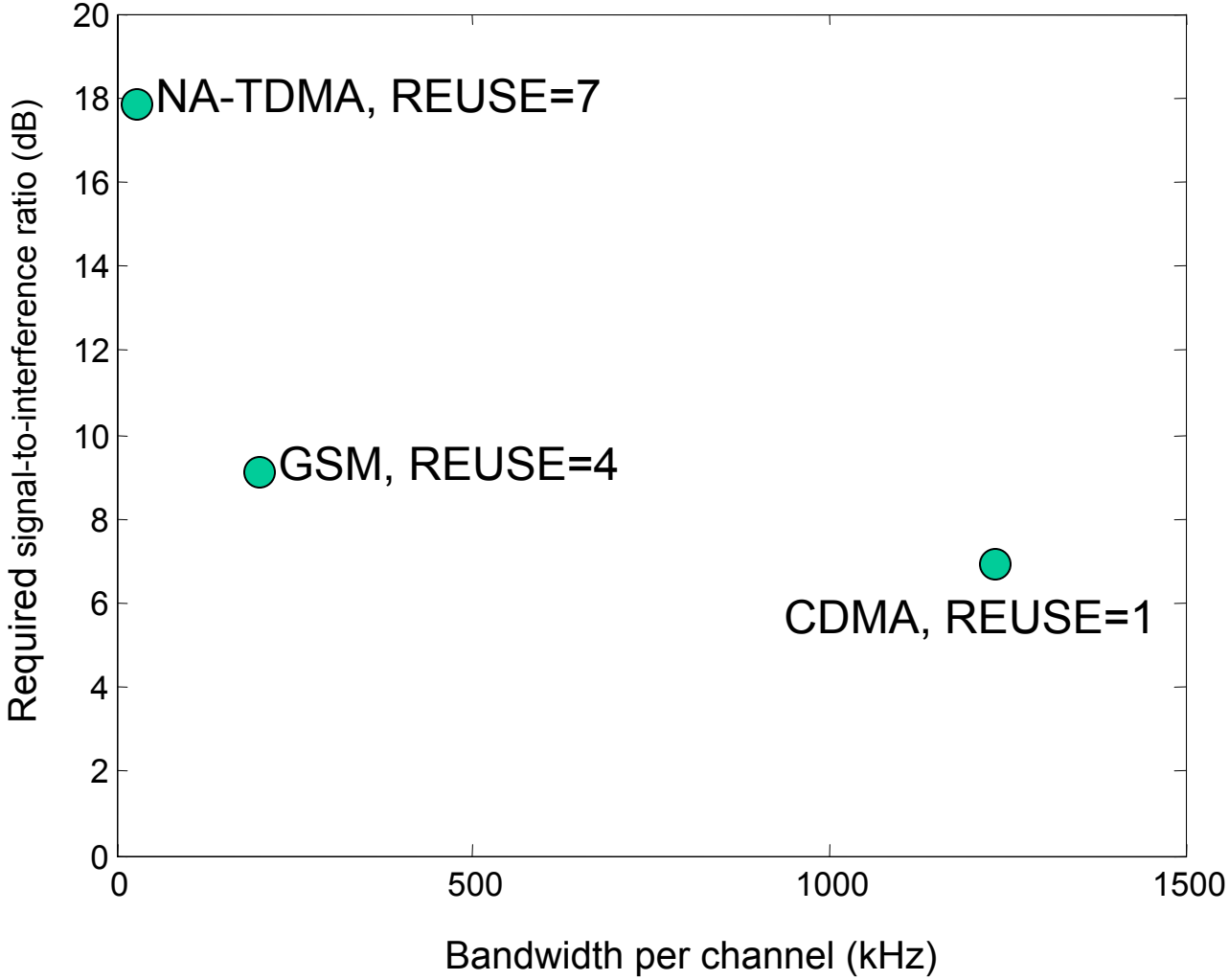
- IMPORTANT PROPERTIES ARE:
  - BANDWIDTH, W (Hz)
  - IMMUNITY TO INTERFERENCE $10\log(\gamma_{req})$(dB)

- IN CELLULAR, IMMUNITY TO INTERFERENCE AND BANDWIDTH TOGETHER DETERMINE EFFICIENCY
  - AMPS, NA-TDMA: W=30 kHz $\gamma_{req}$=18 dB
  - GSM W=200 kHz $\gamma_{req}$= 9 dB

# SPREAD SPECTRUM SIGNALS

- SPREAD SPECTRUM SYSTEMS HAVE HIGH W AND LOW $\gamma_{req}$
  - CDMA: W=1.25 MHz $\gamma_{req}$= 7 dB

# BANDWIDTH AND IMMUNITY TO INTERFERENCE

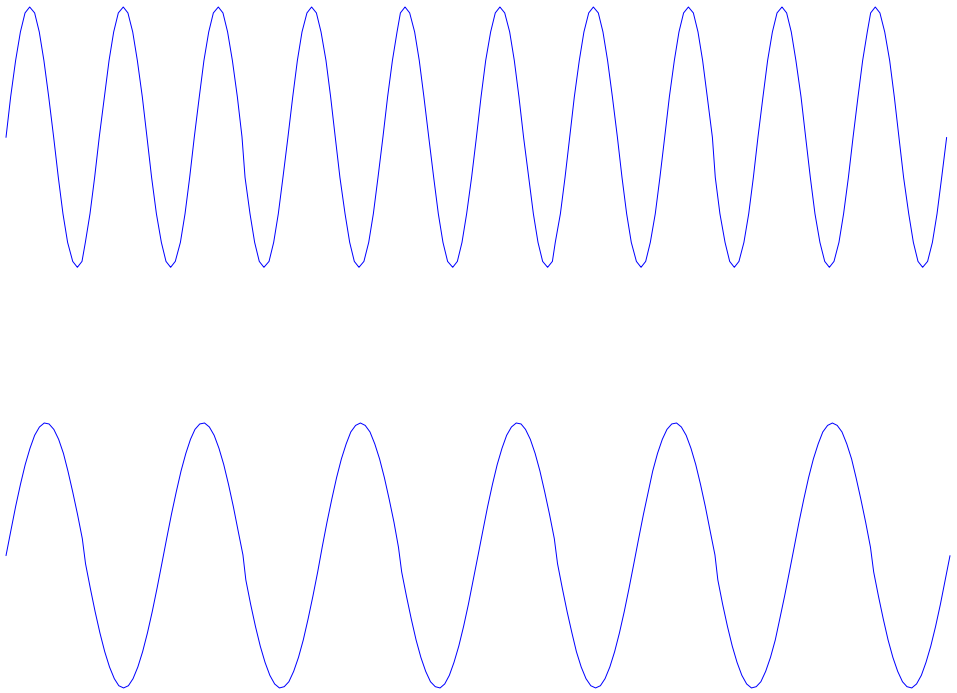


# MULTIPLE ACCESS/MULTIPLEX & MODULATION

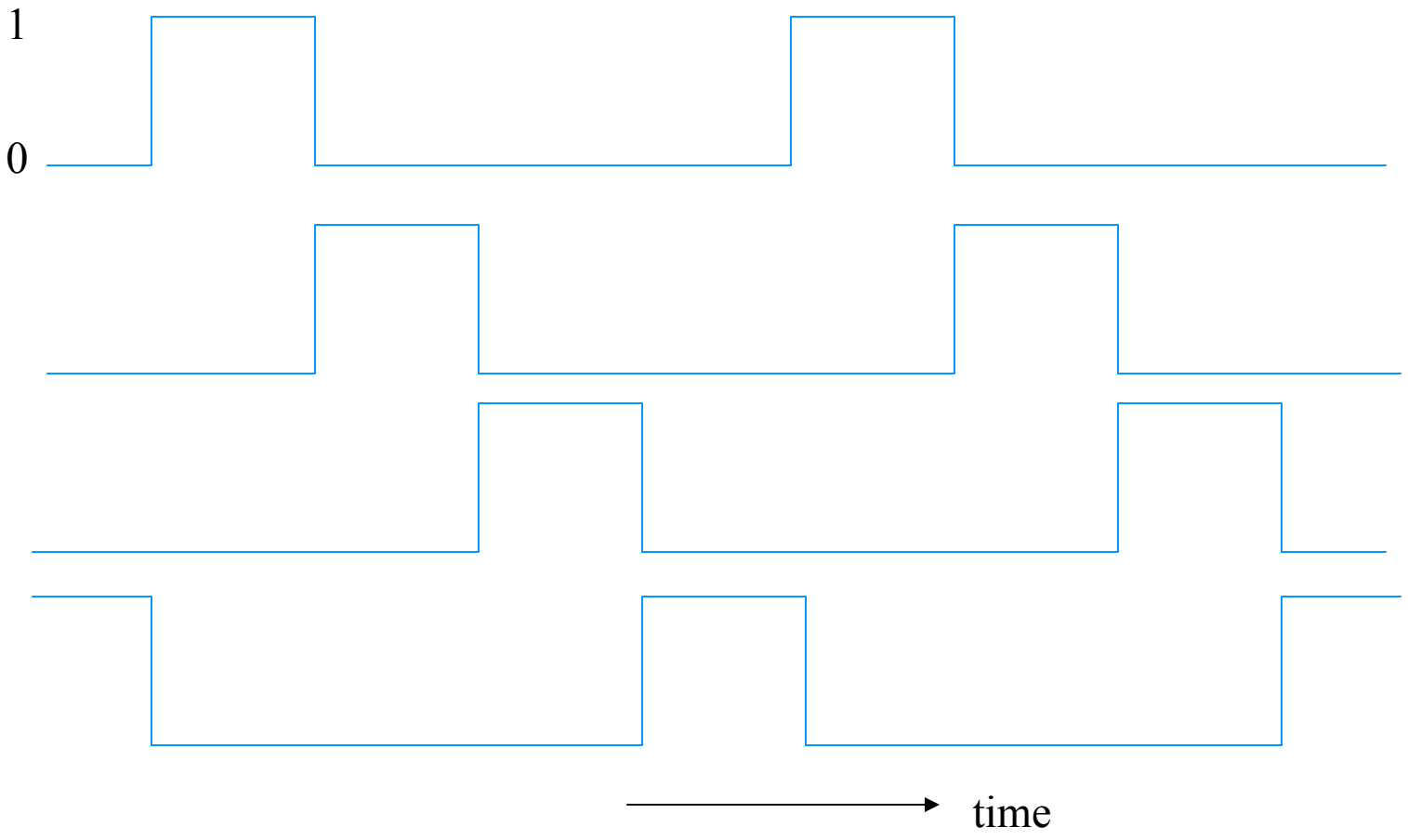
- MULTIPLE ACCESS/MULITIPLEXING: EACH COMMUNICATION HAS ITS OWN **CARRIER**
  - CARRIERS CAN BE ORTHOGONAL OR NOT

- MODULATION: MODIFY A CARRIER ACCORDING TO THE INFORMATION TO BE SENT

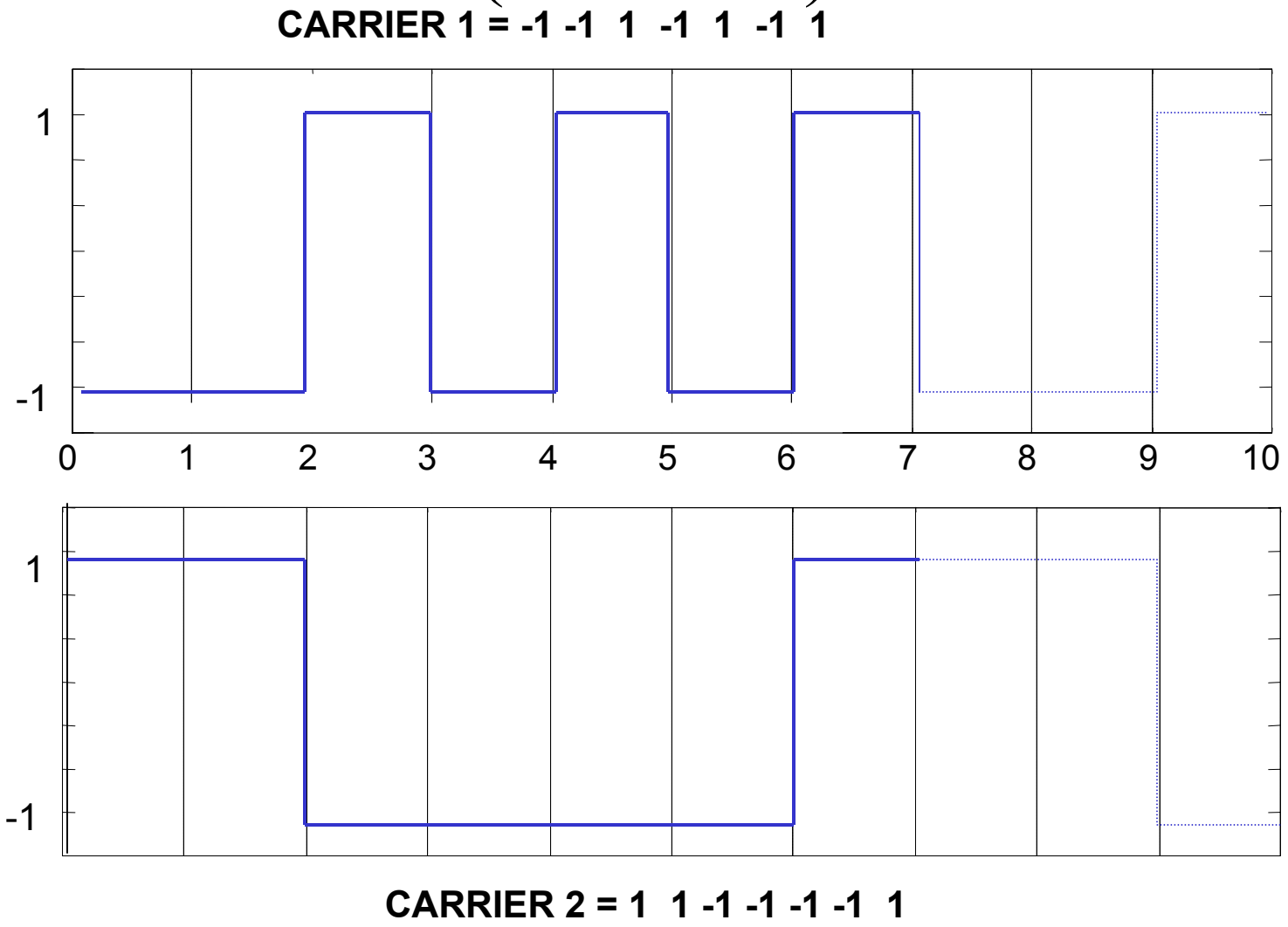
# SINE WAVE CARRIERS (FREQUENCY DIVISION)



# ON-OFF CARRIERS (TIME DIVISION)

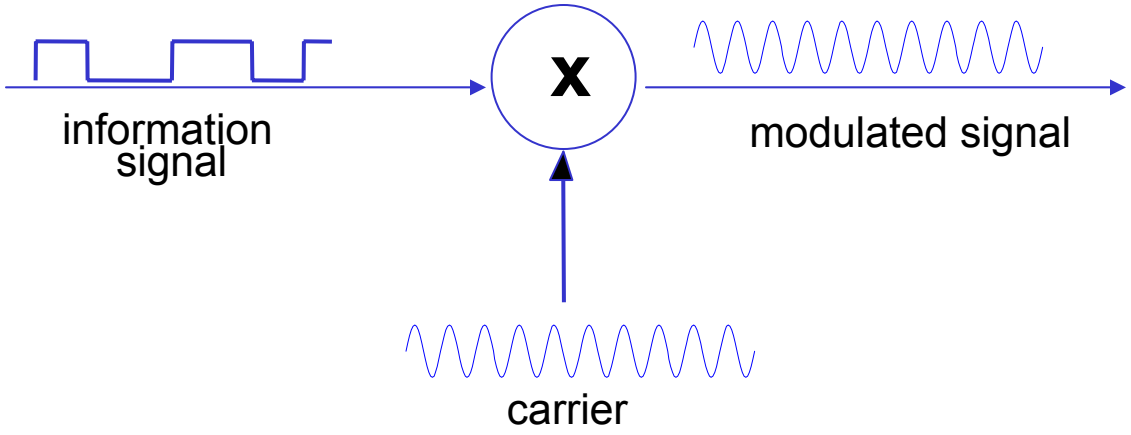


# DIRECT SEQUENCE CARRIERS (7 CHIPS)

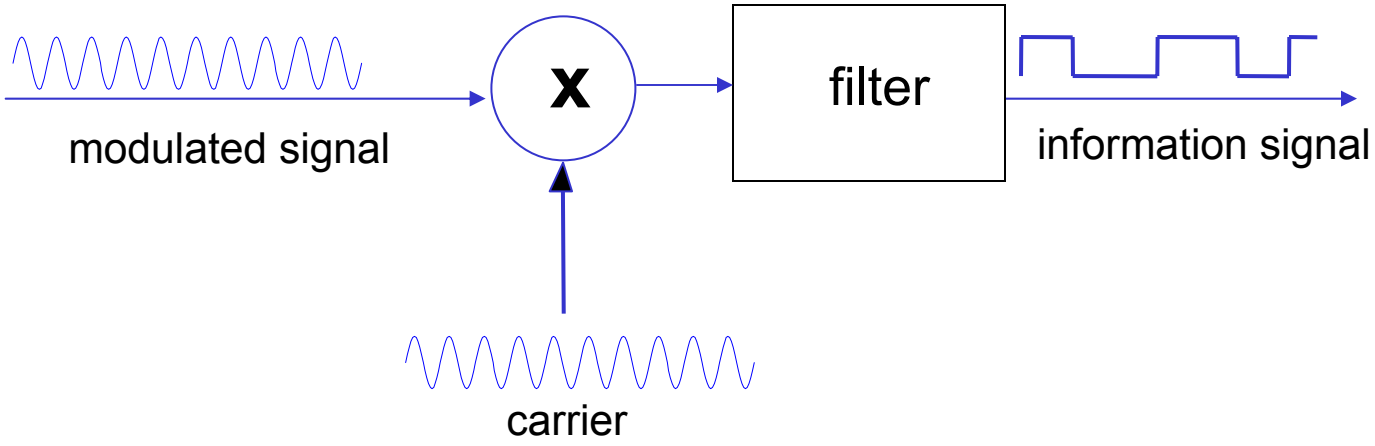


# MODULATION & DEMODULATION

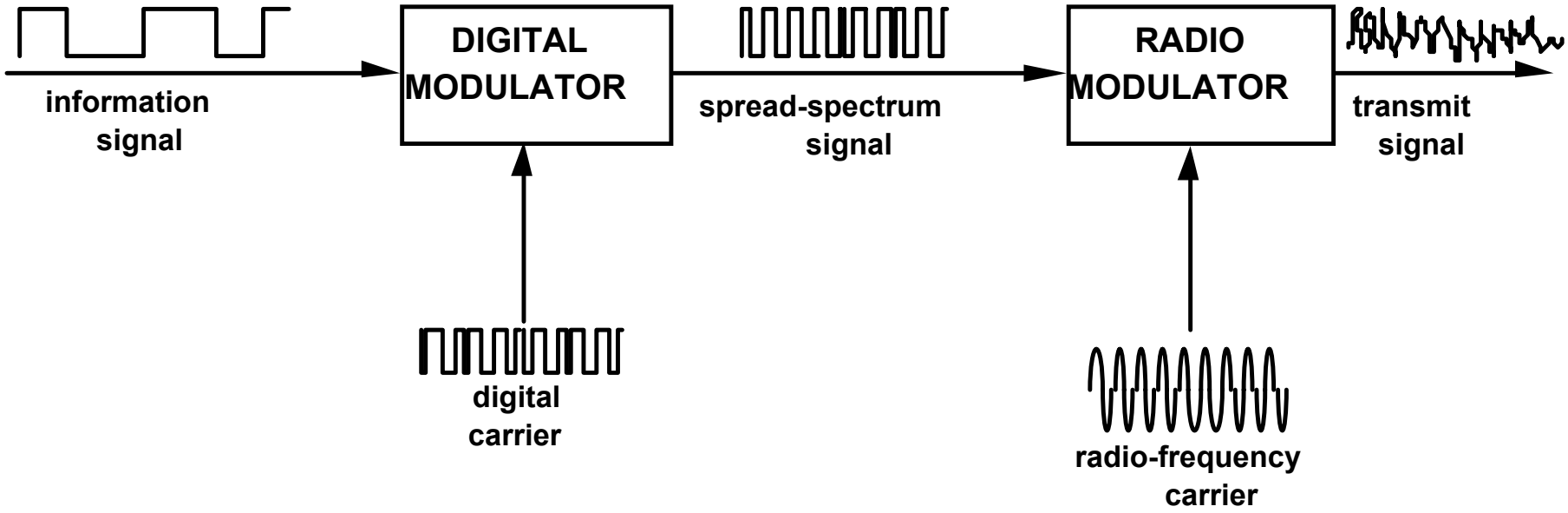
MO




DEM



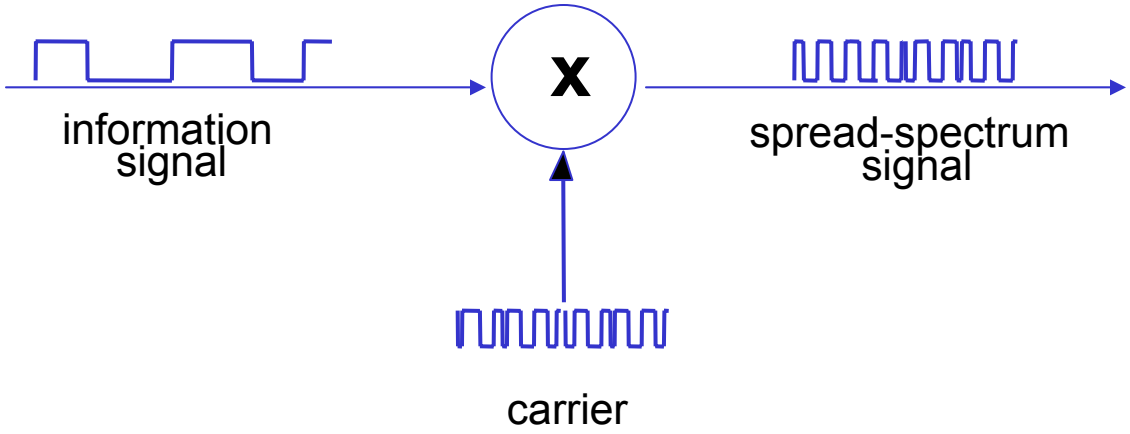
# DIGITAL MODULATOR & RADIO MODULATOR




MODULATION AND MULTIPLE ACCESS

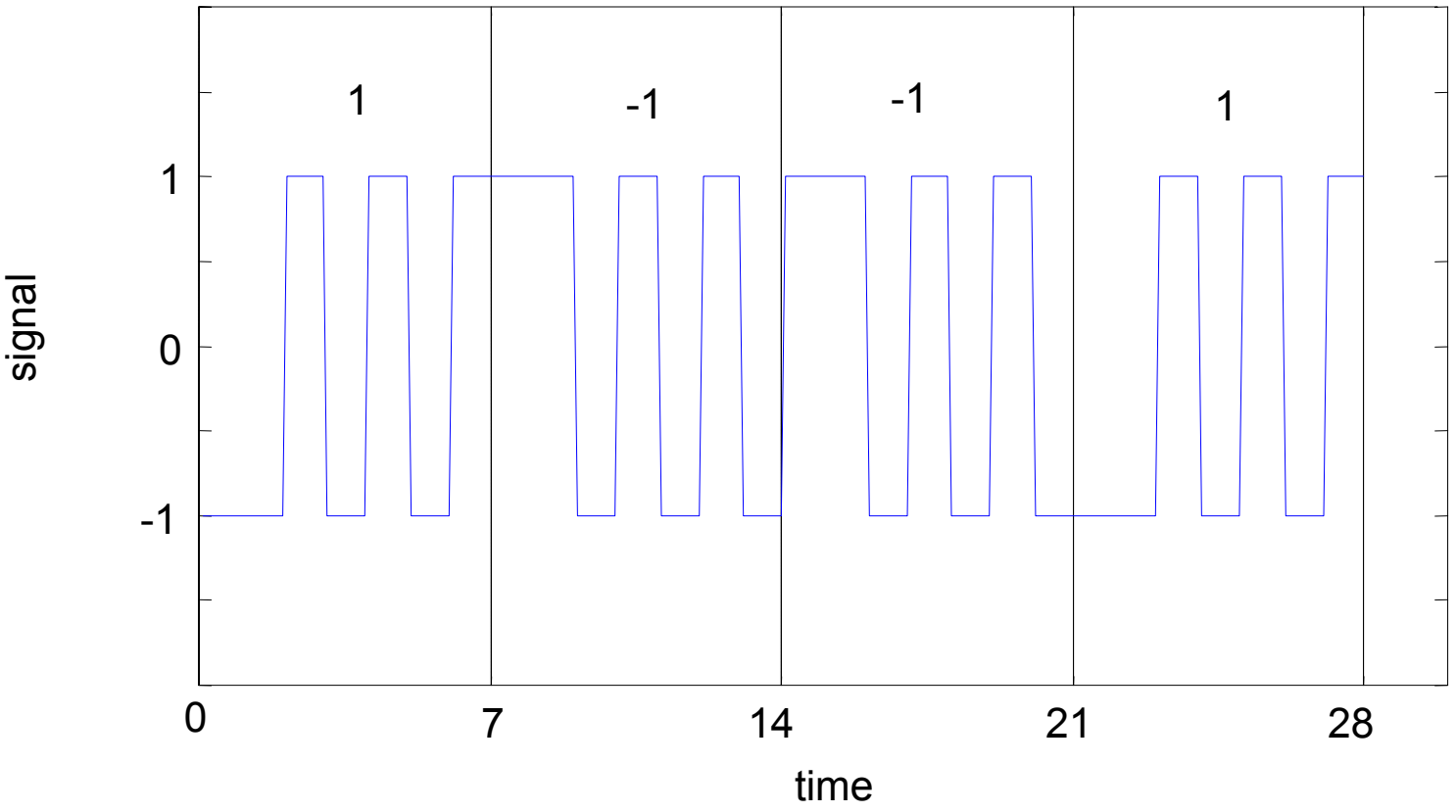
MODULATION AND FREQUENCY TRANSLATION

# SPREAD SPECTRUM MODULATION

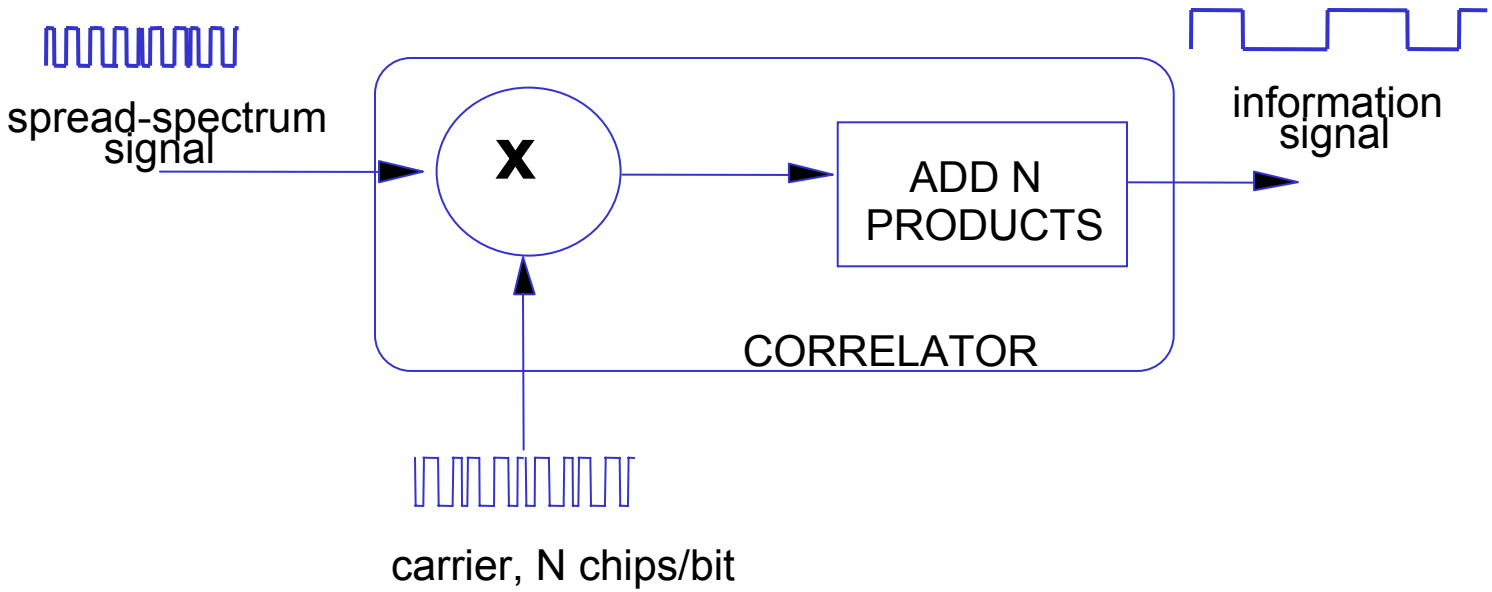


# TRANSMIT 4 BITS

## CARRIER 1 X [1 –1 –1 1]

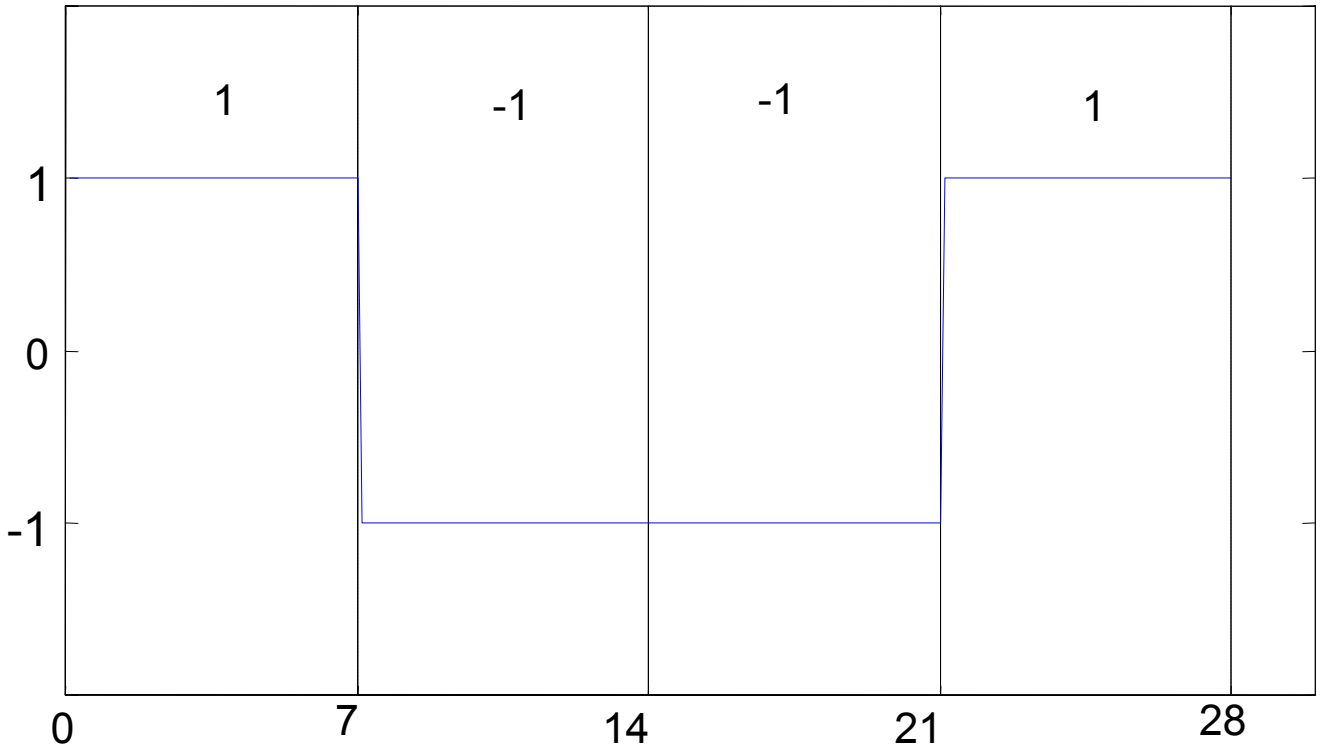


# DEMODULATION
# DIGITAL MATCHED FILTER



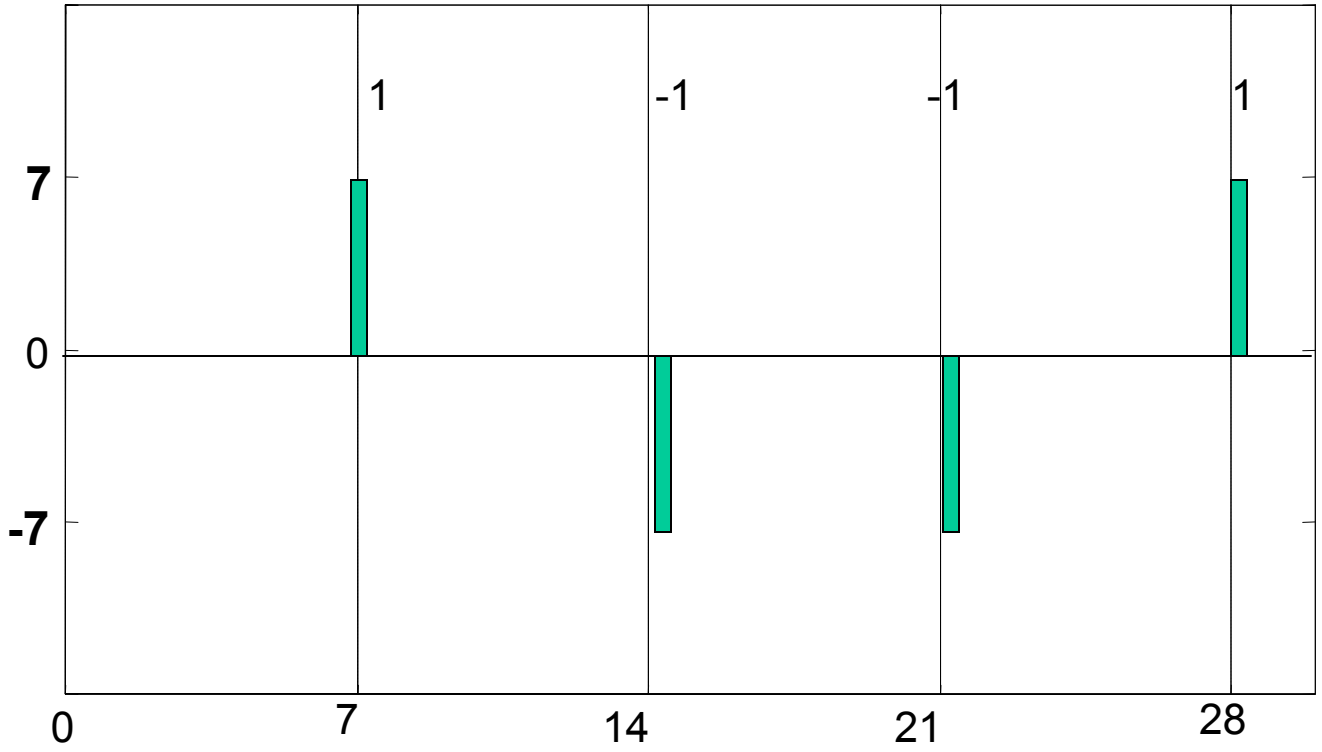
# MULTIPLIER OUTPUT

## (CARRIER 1 X SS SIGNAL)



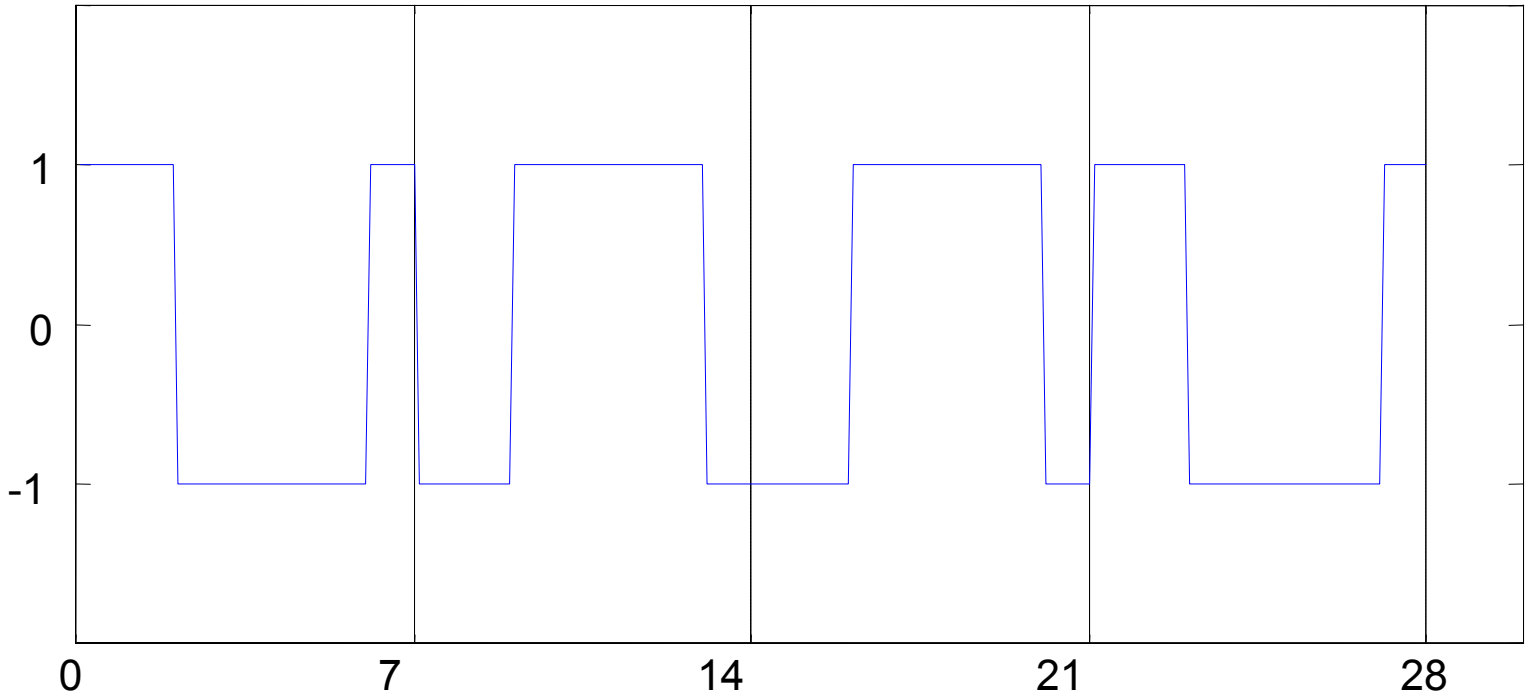
# CORRELATOR OUTPUT AFTER ADDING 7 PRODUCTS

## (PROCESSING GAIN = 7)

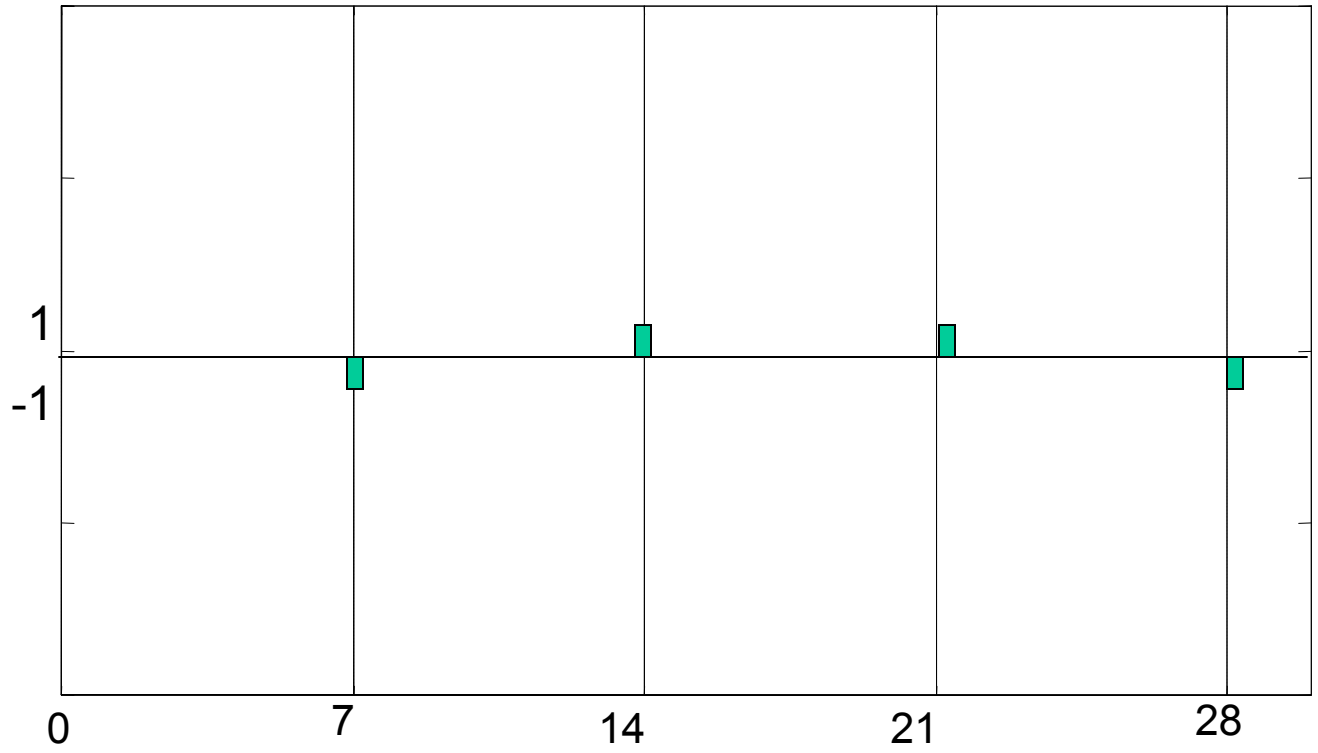


# MULTIPLY SS SIGNAL BY CARRIER 2

## (INTERFERENCE IN A DIFFERENT RECEIVER)



# CORRELATOR OUTPUT IN SECOND RECEIVER



# Probability of error

- Reference user has a code with G chips, all +1.
- Transmitted bit is +1
- At the receiver the reference user contributes G to the correlator output
- Other users have codes G chips each is +1 or –1 selected randomly
- Interfering users transmit +1 or –1 at random

# Probability of error

- At the receiver each interfering user contributes the sum of G random variables to the correlator output.

- Each random variable x is +1 or –1 with probability ½.
- E[X]=0;  var[X]=1

- With K-1 interfering users, the interference is the sum of G(K-1) independent identically distributed random variables.

# Probability of error

- The expected value of the sum of G(K-1) iid random variables, each with E[X] = 0, is G(K-1)E[X]=0

- The variance of the sum of G(K-1) iid random variables, each with Var[X] = 1, is G(K-1)Var[X]=G(K-1)

- An error (-1 received) occurs when the signal + interference < 0.

- Because the signal part of the output is G, an error occurs when interference < -G.

# Probability of error

- The interference I is a random variable with
  - E[I]=0 and Var[I]=G(K-1).

- The probability of error $P_e$ is the probability I<-G:

$$P_e = \int_{-\infty}^{-G} f_I(x)dx$$

- I is related to a binomial random variable and it is not hard to write the formula for its probability density (actually it is a probability mass function).

# Probability of error

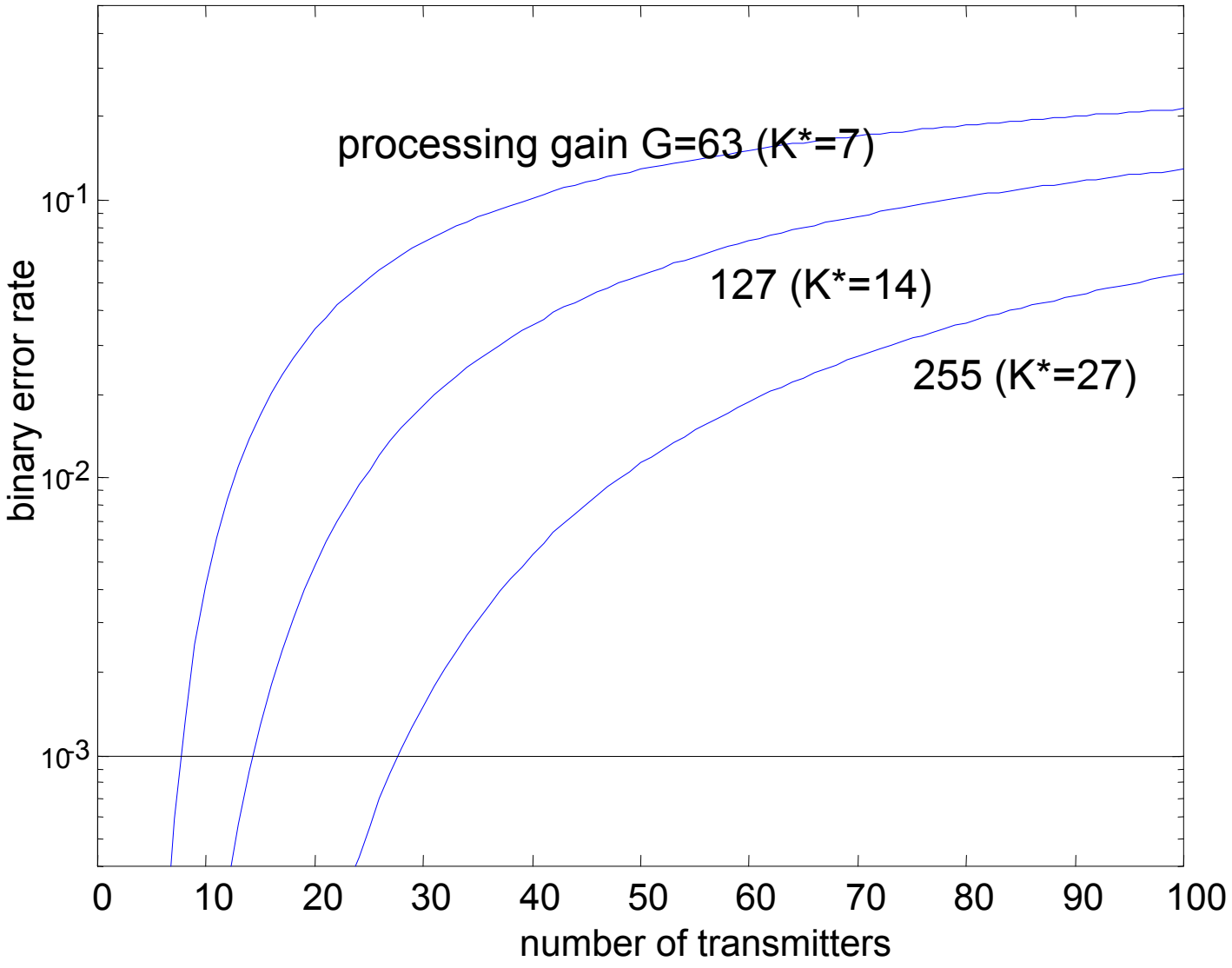
•However, it is more convenient to use the Gaussian approximation to $f_I(x)$:

$$f_I(x) = \frac{1}{\sqrt{2\pi Var[I]}} \exp\left( -\frac{(x - E[I])^2}{2Var[I]} \right)$$

•With this approximation

$$P_e = \int_{-\infty}^{-G} f_I(x)dx = \frac{1}{\sqrt{2\pi}} \int_{\sqrt{\frac{G}{K-1}}}^{\infty} \exp(-\frac{u^2}{2})du = Q\left( \sqrt{\frac{G}{K-1}} \right)$$

# Soft capacity



# Additional considerations in practical systems

- Signals from different terminals do not arrive in synchronism at base station
- Signals from different terminals arrive with different strength at base station
- Error correcting and error detecting codes
- Channel conditions: interference from other cells, fading, multipath, etc.

**Use "top down" approach to estimate capacity**