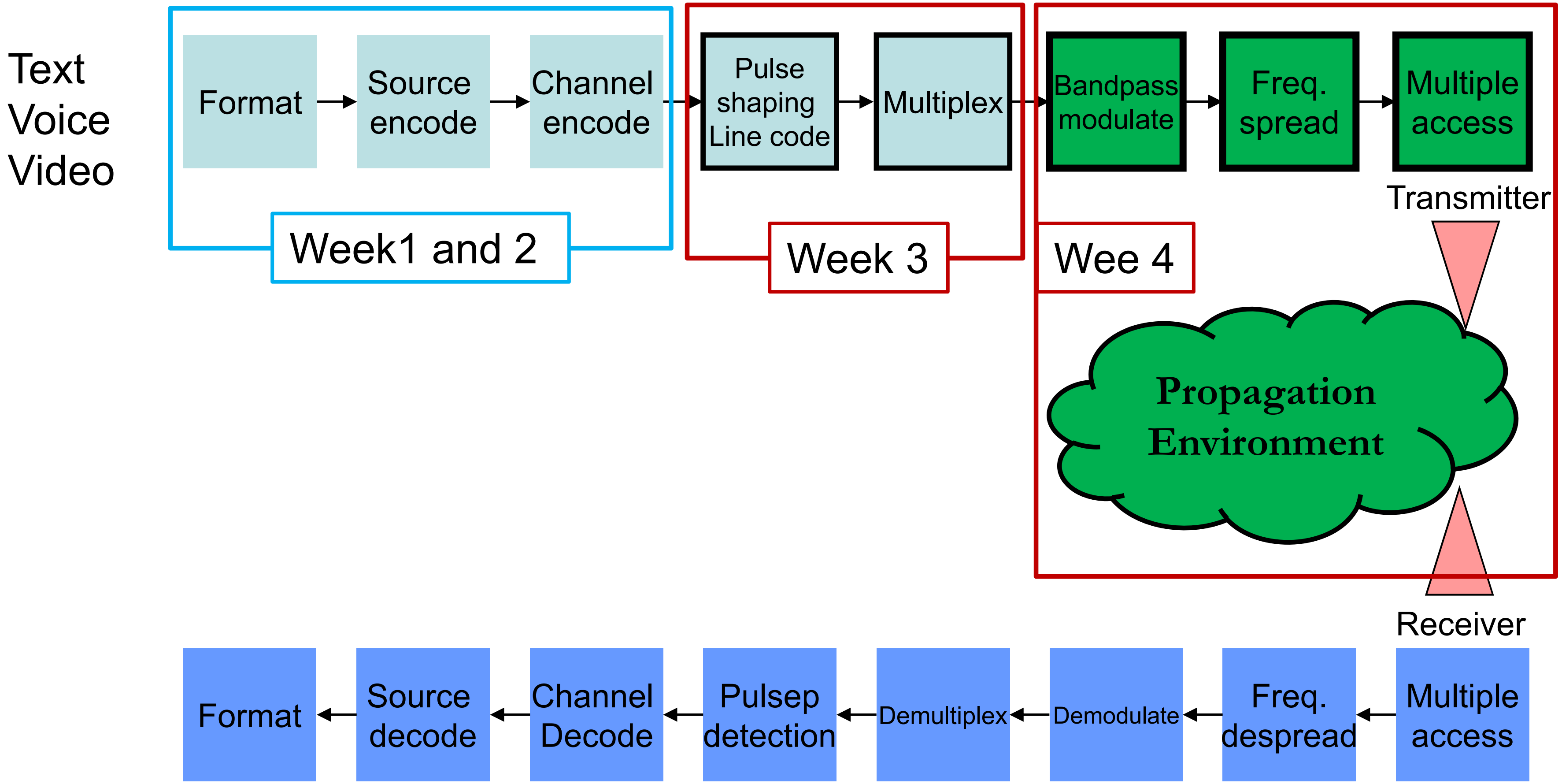
Telecom Systems (Revision)

Dr Cindy SUN

Queen Mary
University of London

Overview of Wireless Communication System

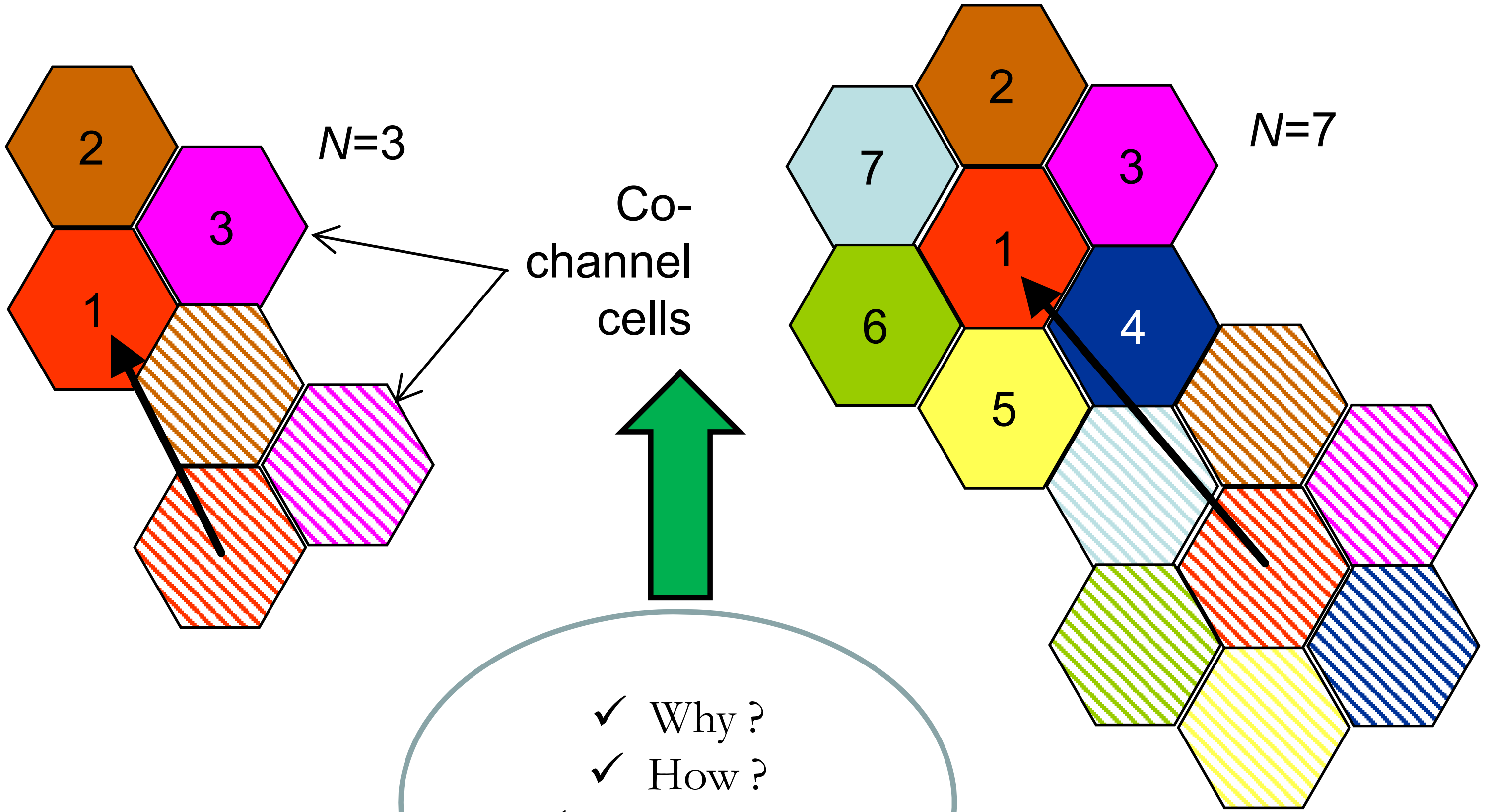


LOS Wireless Transmission Impairments

- Attenuation and Distortion
- Noise
- Multipath
- Thermal noise
- ….

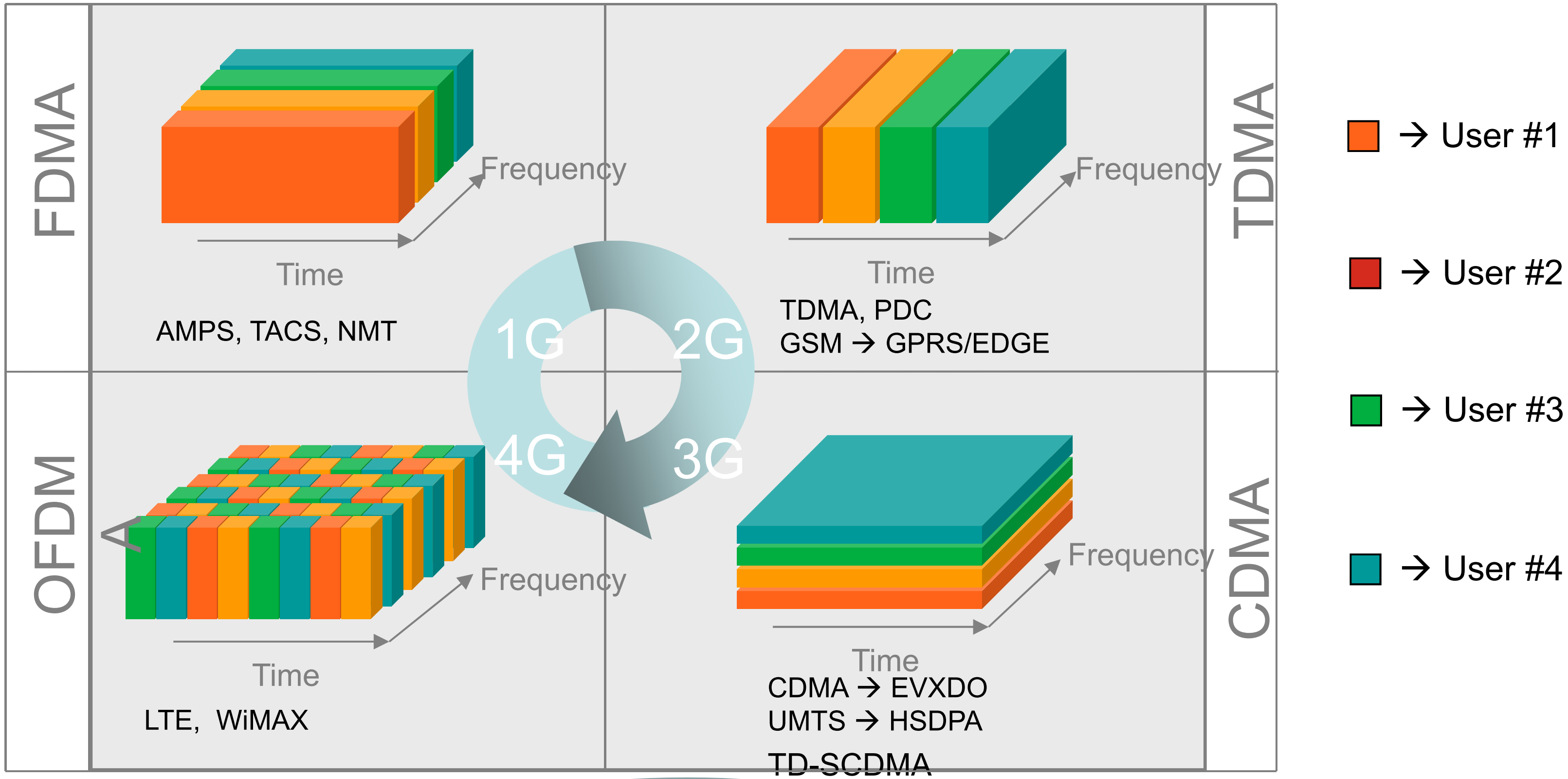
- ✓ Cause?
- ✓ Consequence?
- ✓ Potential Solution?

Cellular Concept and Frequency Reuse



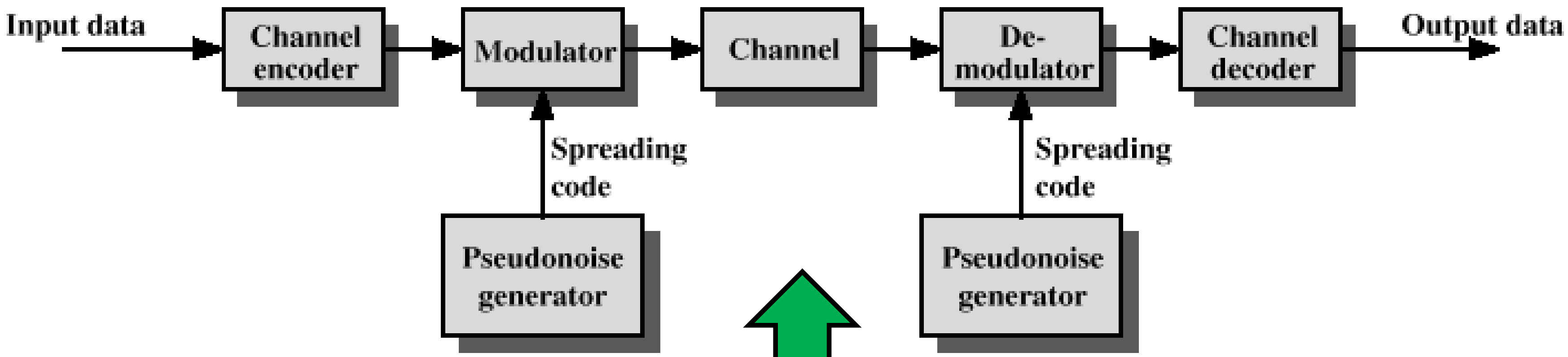
- ✓ Why ?
- ✓ How ?
- ✓ Cluster Size?
- ✓ Distance?

Multiple Access



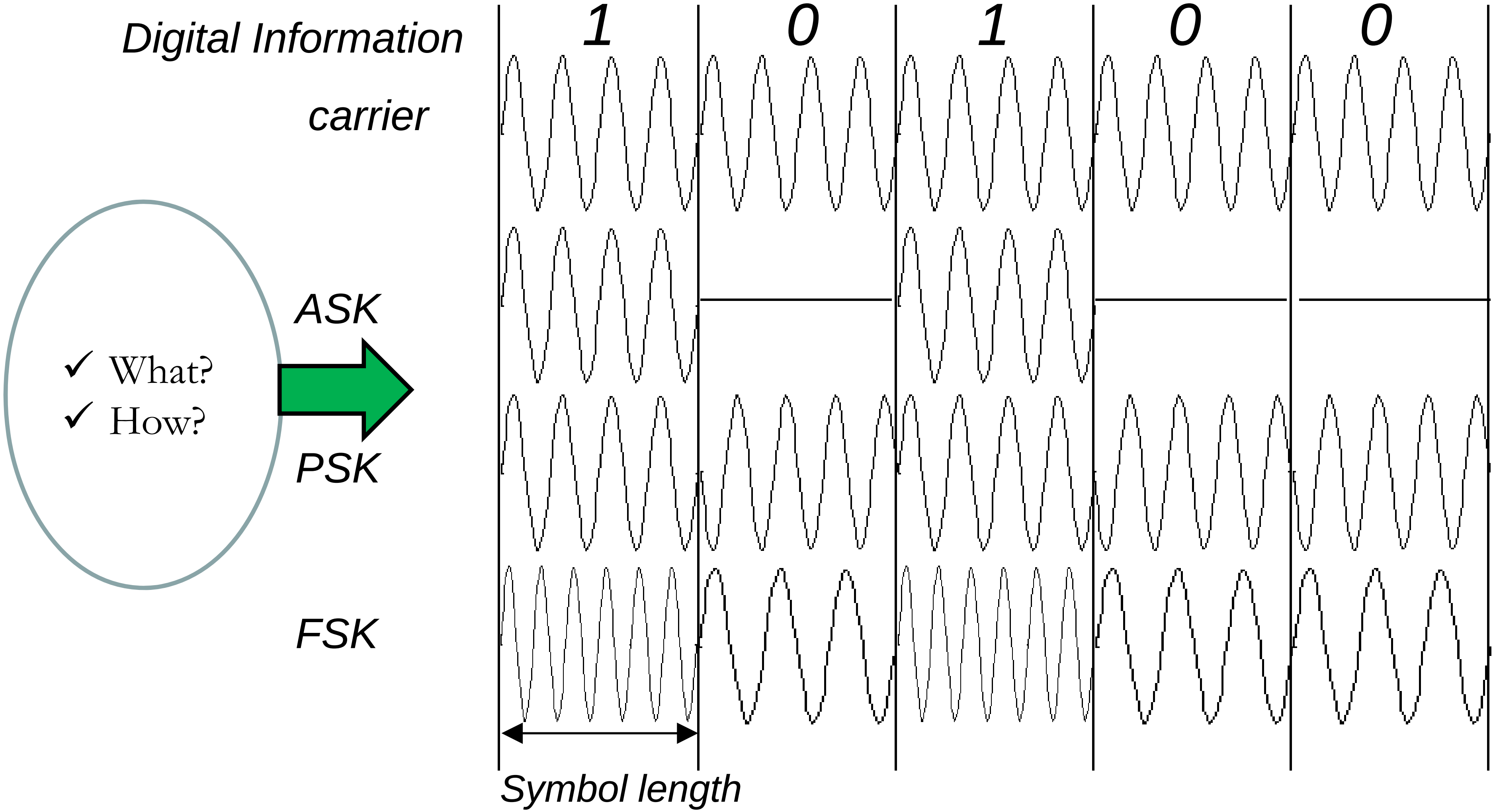
- ✓ Principle ?
- ✓ Interference source ?
- ✓ Potential Solution?

Spread Spectrum

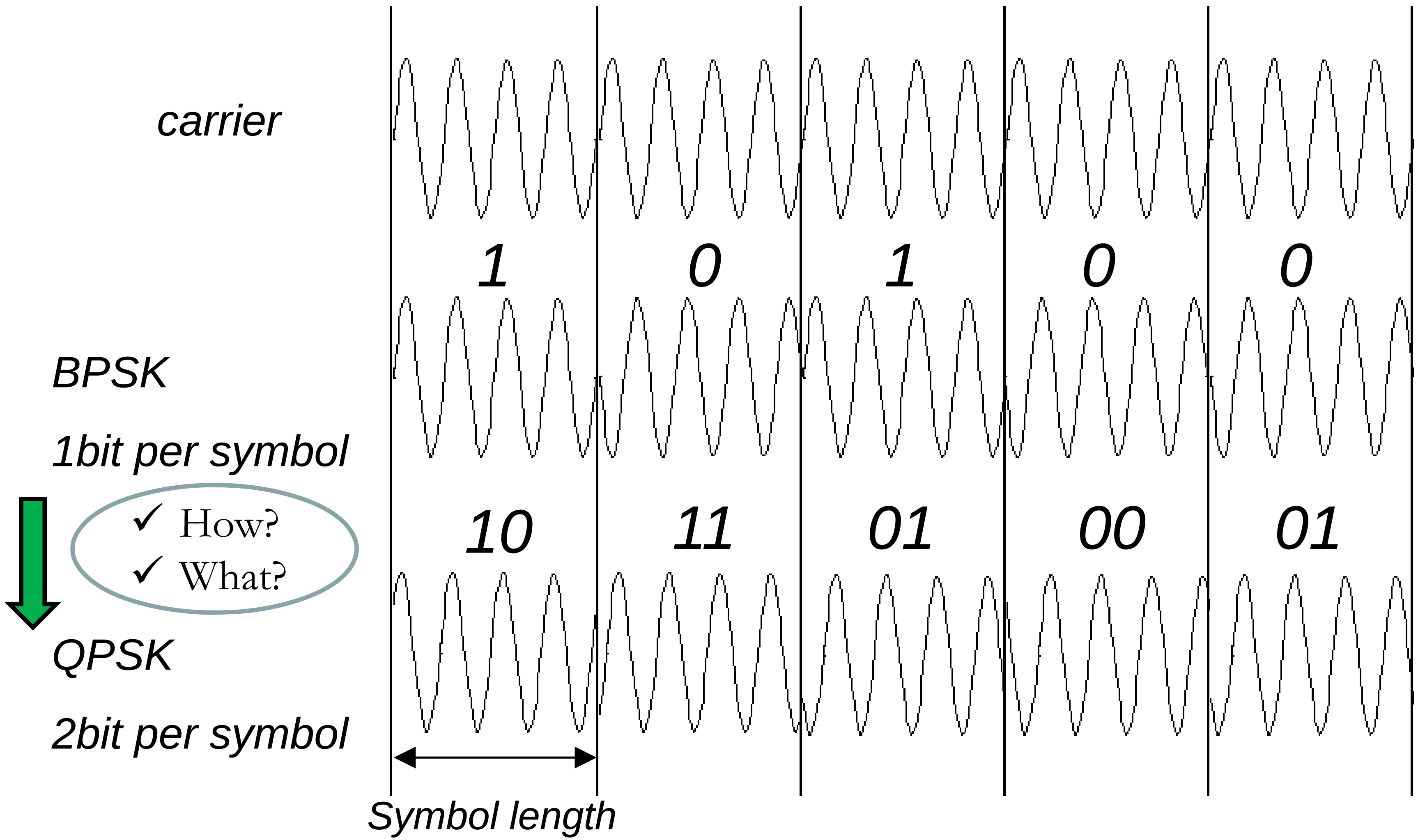


- ✓ How FHSS works?
- ✓ Slow or Fast FHSS?
- ✓ How DSSS works?
- ✓ DSSS in CDMA?

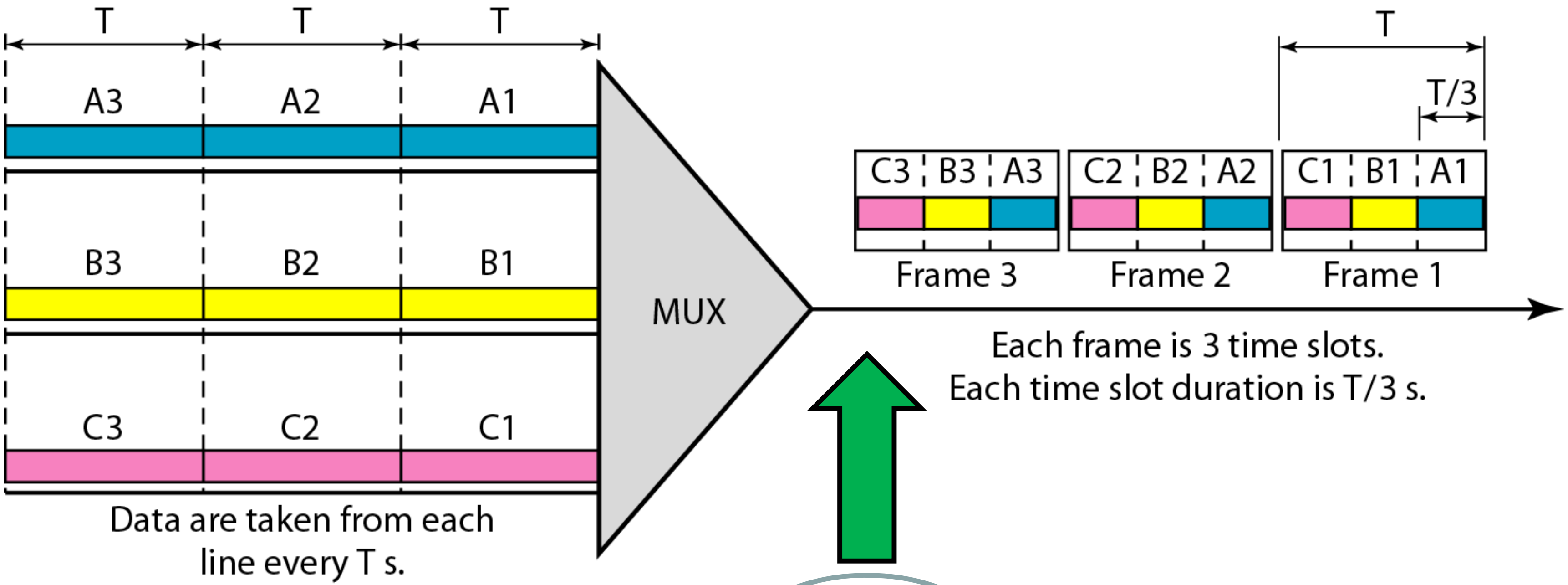
Basic Modulation Techniques



Multi bit modulation



Time-Division Multiplexing

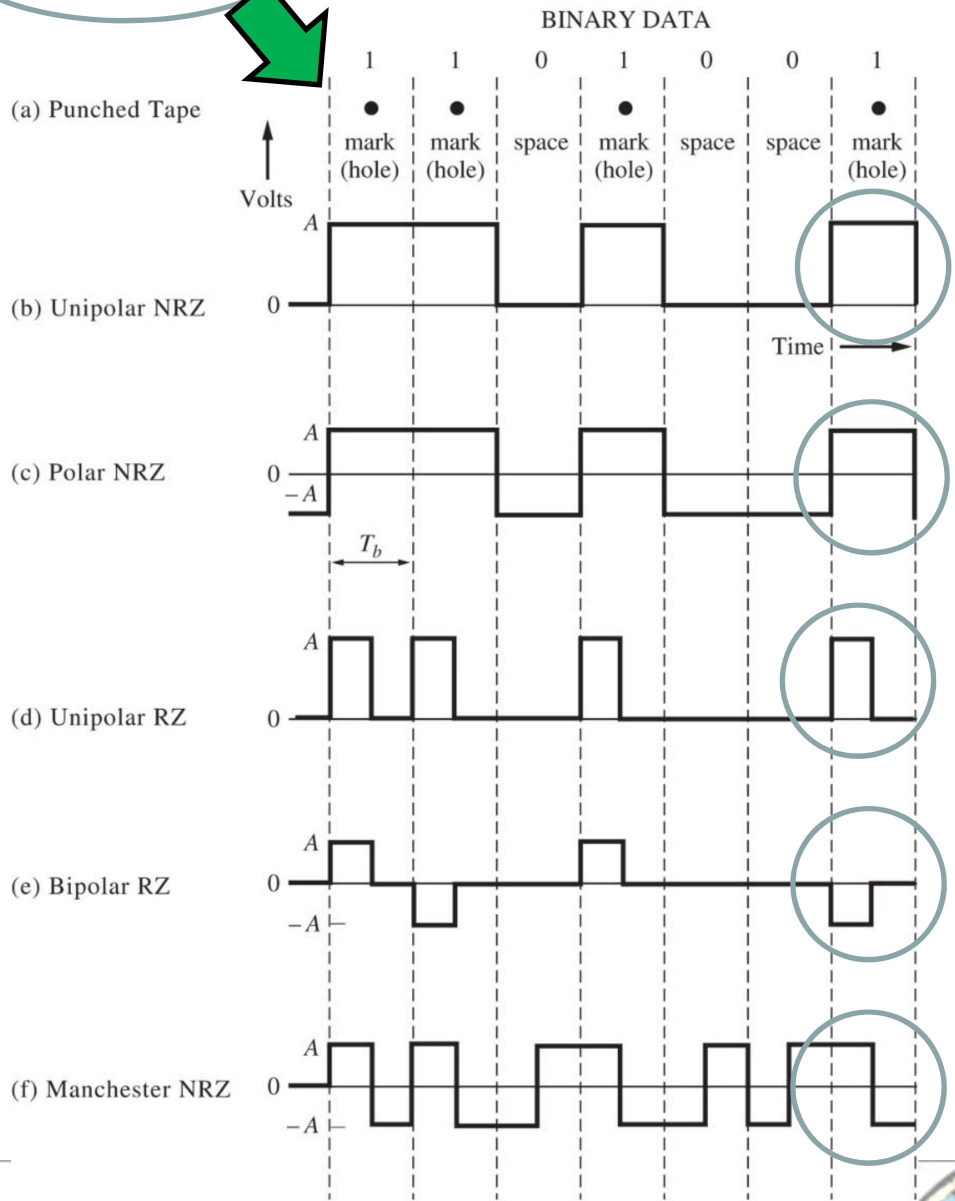


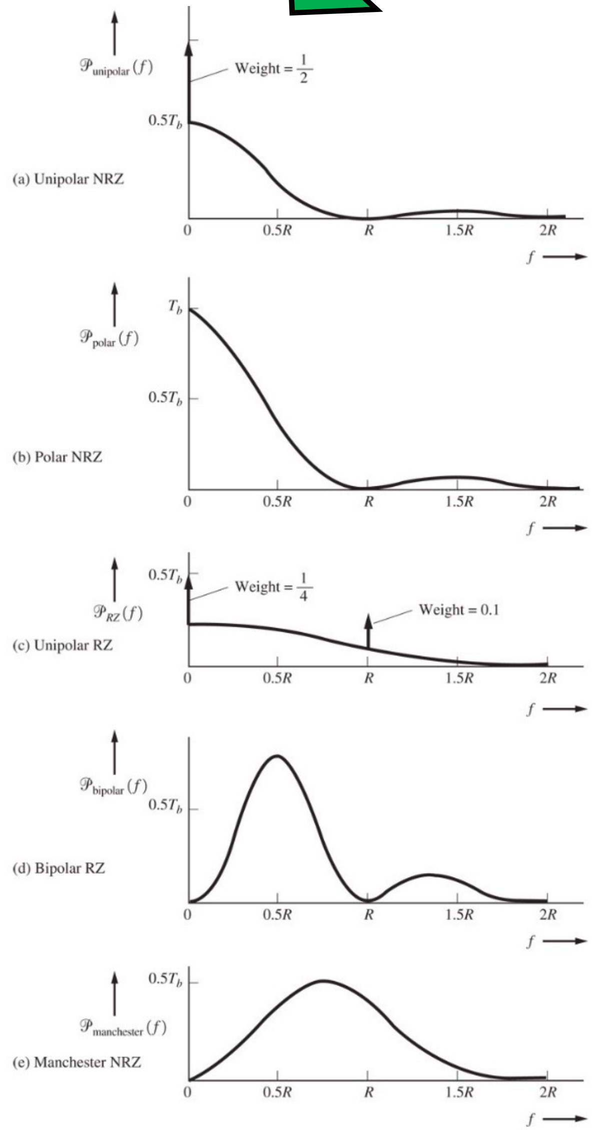
- ✓ How?
- ✓ What?

PSD for different line codes

✓ What?

✓ How?





General expression for the PSD of a digital signal

- The general expression for the PSD of a digital signal can be expressed by:

$$P(f) = \frac{|F(f)|^2}{T_s} \sum_{k=-\infty}^{\infty} R(k) e^{j2\pi k f T_s} \qquad (3\text{-}6a)$$

where F(f) is the Fourier transform of the pulse shape f(t).

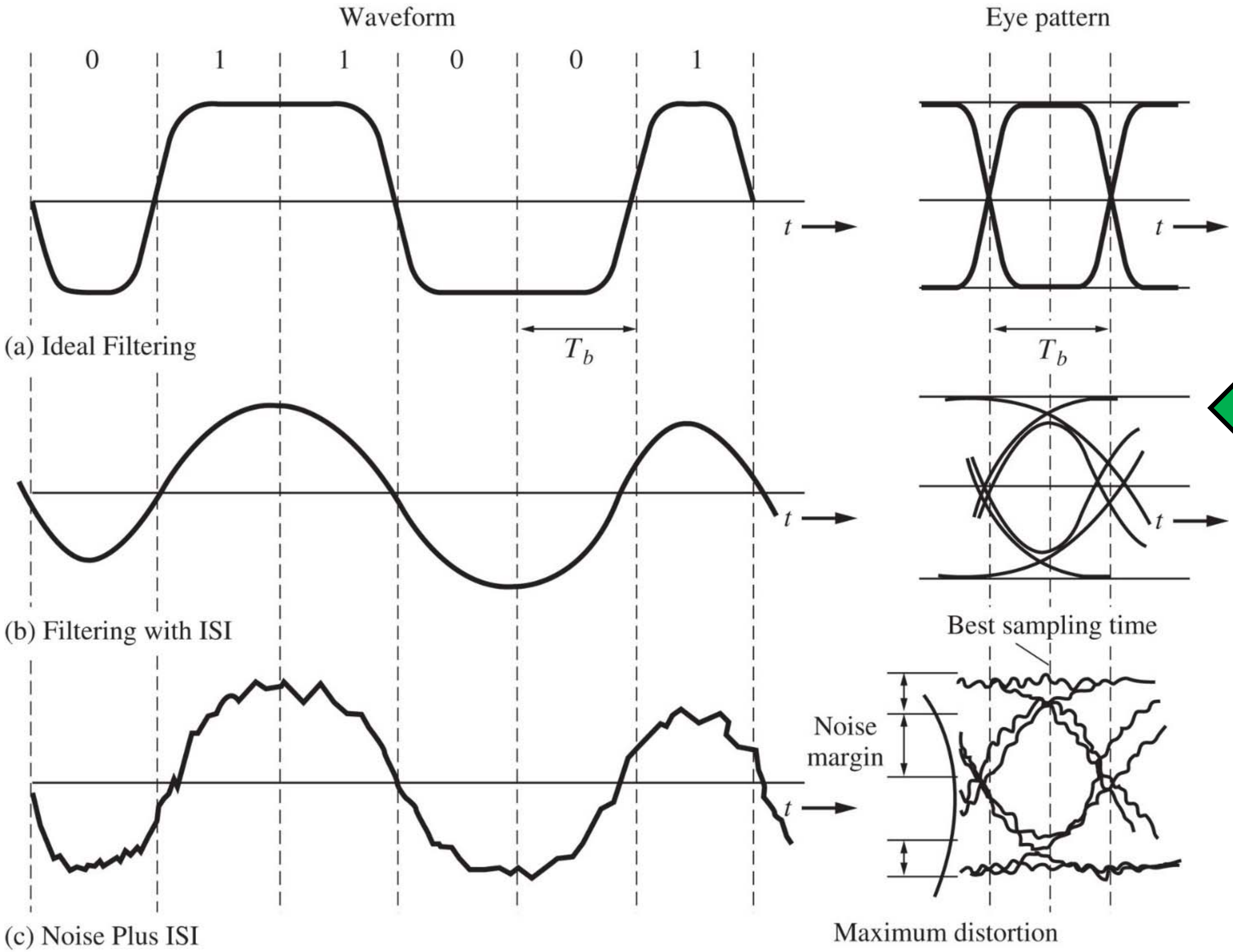
R(k) is the autocorrelation of the data. The autocorrelation is given by

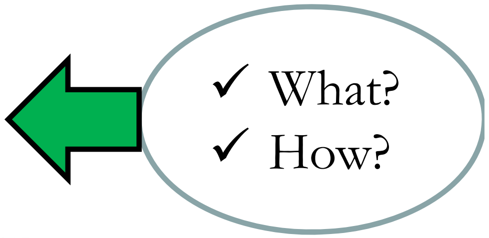
$$\mathrm{R}(k) = \sum_{i=1}^{l} (a_n a_{n+k})_i \, P_i \qquad (3\text{-}6b)$$

where a_n and a_{n+k} are the (voltage) levels of the data pulses at the nth and (n+k)th symbol positions, respectively. Pi is the probability of having the ith $a_n a_{n+k}$ product.

- Note that equation (3-6a) shows that the spectrum of the digital signal depends on two things:
  - The pulse shape used
  - Statistical properties of the data

Distorted polar NRZ waveform and corresponding eye pattern





Raised cosine-rolloff Nyquist filtering

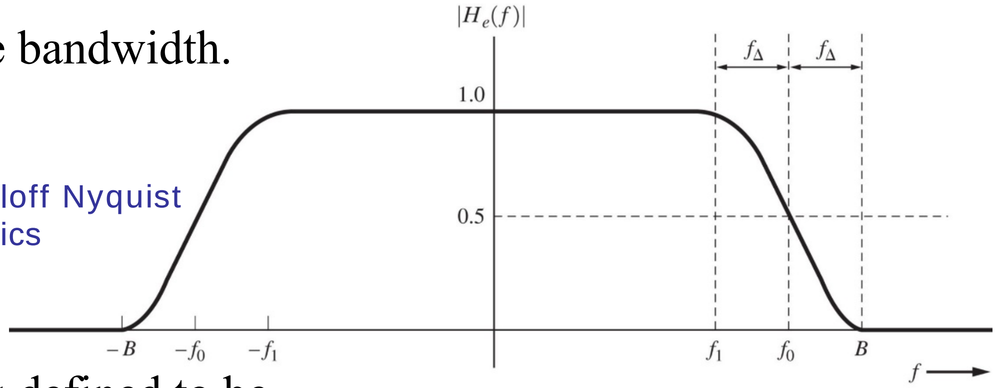
- Why?
- How?

- The raised cosine-rolloff Nyquist filter has the transfer function

$$H_e(f) = \begin{cases} 1, & |f| < f_1 \\ \frac{1}{2}\left\{1 + cos\left[\frac{\pi(|f| - f_1)}{2f_\Delta}\right]\right\}, & f_1 < |f| > B \\ 0 & |f| > B \end{cases} \qquad (3\text{-}29)$$

where B is the absolute bandwidth.

Raised cosine-rolloff Nyquist filter characteristics



- This rolloff factor is defined to be

$$r = \frac{f_\Delta}{f_0} \qquad (3\text{-}30)$$

- The impulse response is

$$h_e(t) = F^{-1}[H_e(f)] = 2f_0\left(\frac{sin2\pi f_0 t}{2\pi f_0 t}\right)\left\{\frac{cos2\pi f_\Delta t}{1 - (4f_\Delta t)^2}\right\}$$

Information theory and Entropy

- ✓ What?
- ✓ Why?

- p is the probability of the event and I is the information content.

$$I = \log_2(1/p)$$

- If a source emits a number of symbols, the entropy (H) is the average information content per symbol:

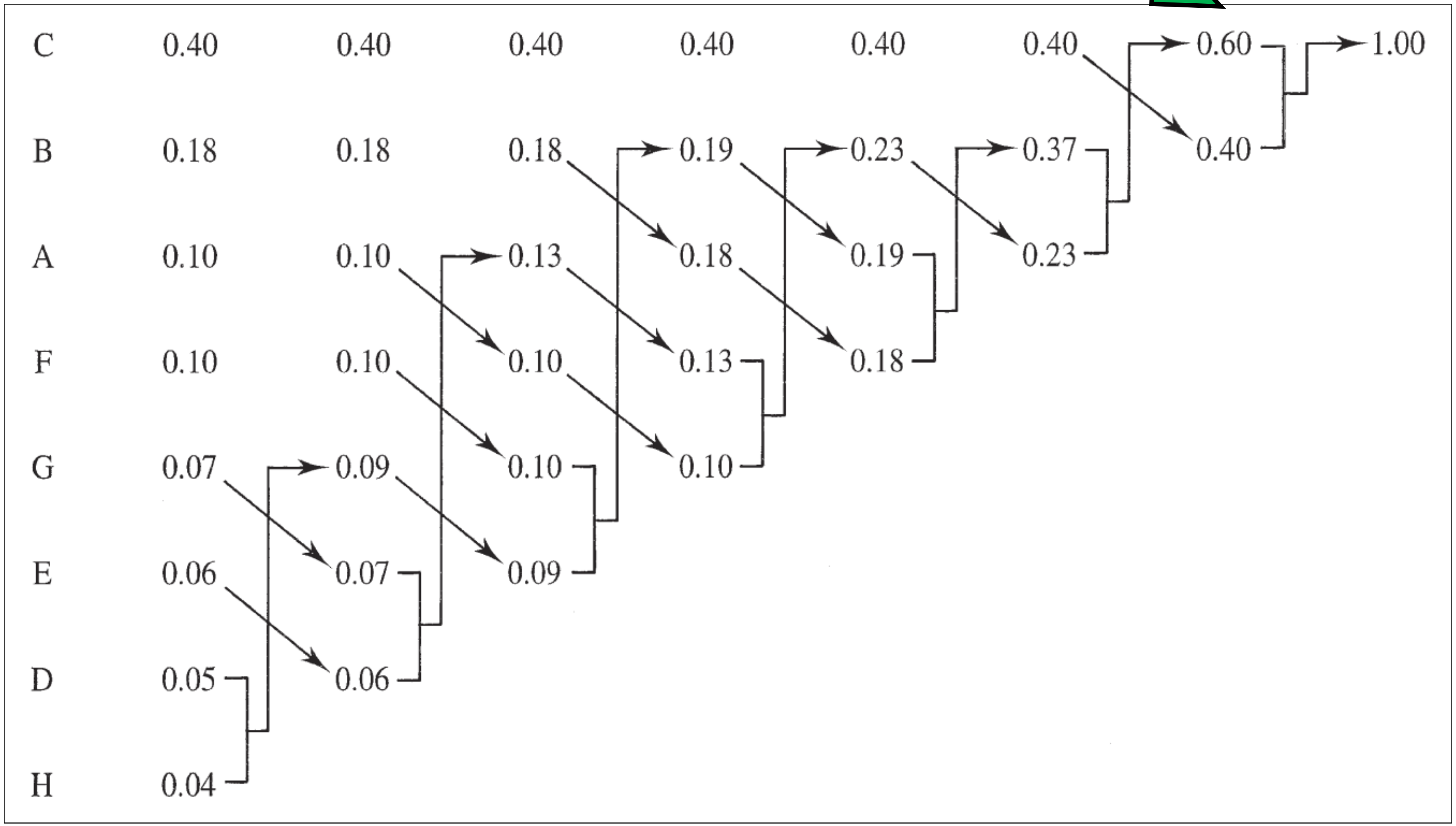
$$H = \sum_i p_i \, log_2(1/p_i)$$

- p_i is the probability of the i'th event occurring

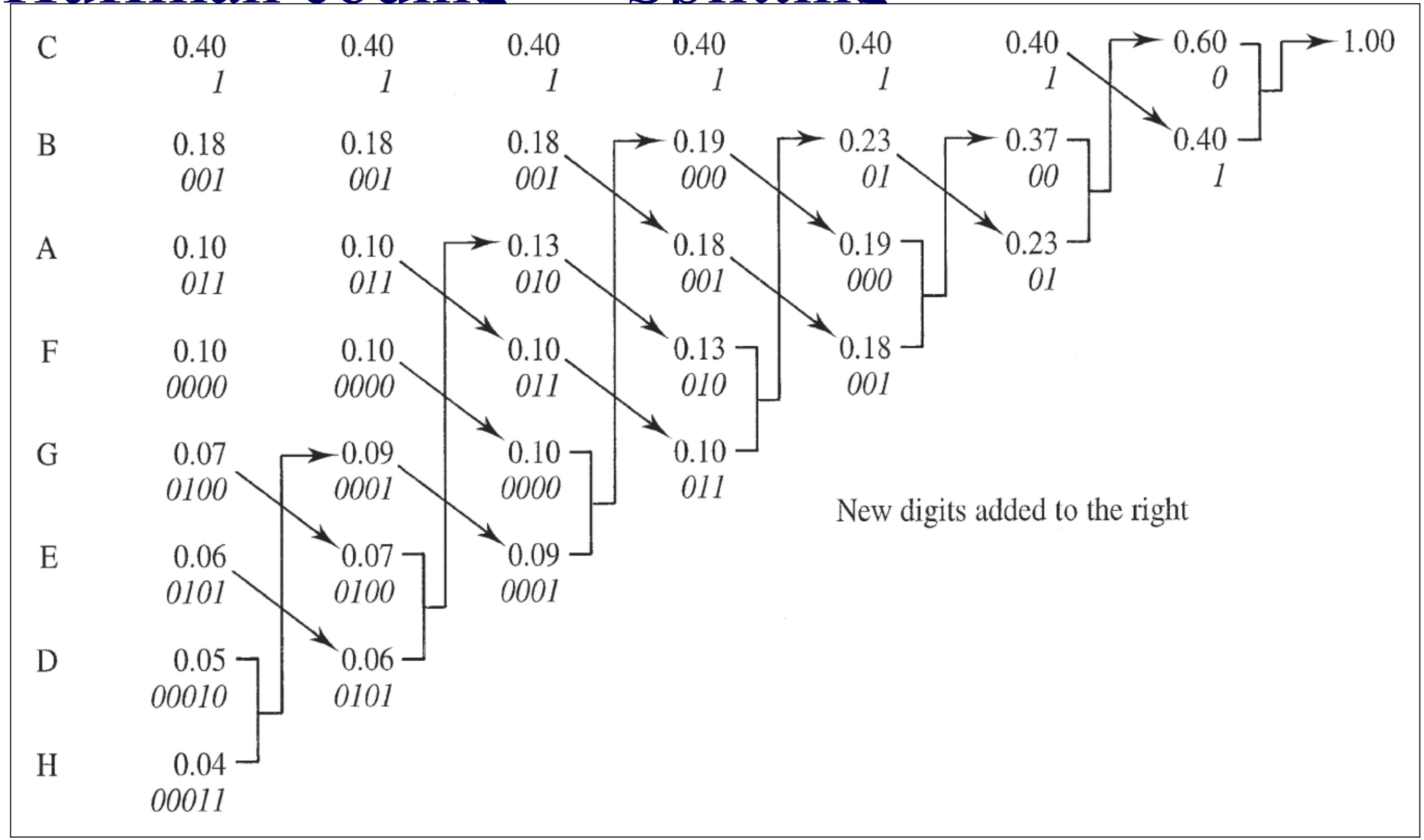
$$\sum_i p_i = 1$$

- ✓ What?
- ✓ How?

Huffman coding – Reduction



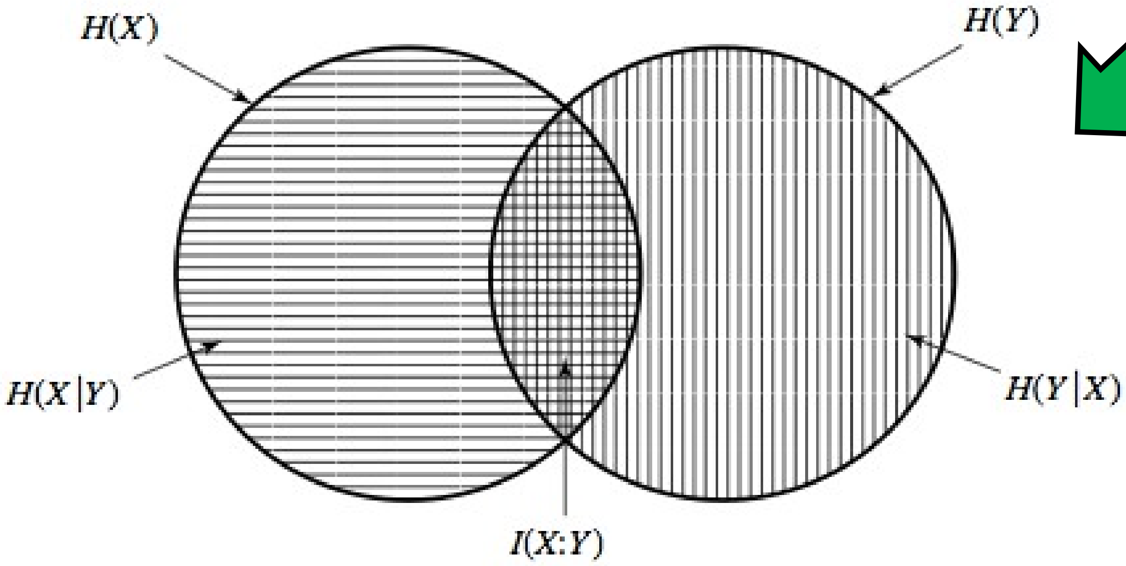
Huffman coding — Splitting



Information-theory analysis of the digital channel

Information theory quantities $H(X)$, $H(Y)$, $H(X|Y)$, $H(Y|X)$ and $I(X;Y)$ can be represented as follows:

- ✓ What?
- ✓ How?



$$H(X|Y) = -\sum_{x,y} P(x,y)\log p(x|y)$$

$$\begin{aligned} I(X;Y) &= H(X) - H(X|Y) \\ &= H(Y) - H(Y|X). \end{aligned}$$

The Noisy Channel Coding Theorem

- The capacity of a digital memoryless channel is given by

$$C = \max_{p(x)} I(X;Y)$$

✓ What?
✓ How
✓ Why?

$$I(X;Y) = \sum_{x,y} p(x,y) \log\left(\frac{p(x,y)}{p(x)p(y)}\right)$$

- The **binary symmetric channel capacity** :

$C = 1 - H_b(\varepsilon)$ bits/transmission

Shannon's formula - Capacity of AWGN Channel

- $C_{bit/s} = Wlog(1 + SNR) = Wlog\left(1 + \frac{P}{N_0 W}\right) bit/\mathrm{sec}$
- $C_{bit/sym} = \frac{C_{bit/s}}{2W} = \frac{1}{2}\log(1 + SNR) = \frac{1}{2}log\left(1 + \frac{P}{N_0 W}\right) bits/symbol$
- $\eta_{max} = \frac{C_{bit/s}}{W} = \log\left(1 + \frac{P}{N_0 W}\right) bps/Hz$
- $C_{bit/s} = Wlog(1 + \eta\frac{E_B}{N_0})$ bit/sec.

✓ What?
✓ How?

Channel coding and redundancy

- **Channel coding** is to protect information against errors and for that **introducing redundancy**, producing longer sequences of symbols.
- Code rate R_C as

$$R_C = \frac{k}{n}$$

- **Definition of** *Hamming distance* between two code words $\mathbf{c}_i$ and $\mathbf{c}_j$, $d(\mathbf{c}_i, \mathbf{c}_j$
- **Definition** of the *minimum distance* of a code d_{min}.
- **Definition of** the *Hamming weight*, or the *weight* of a code word $\mathbf{c}_{i,}$ $w(\mathbf{c}_i)$
- **Definition** of *the minimum weight of a code*

✓ What?
✓ How?

Generator and Parity check matrix of Systematic codes

- Generator matrix has the form

✓ What?
✓ How?

$$\mathbf{G} = [\,\mathbf{I}_k \mid \mathbf{P}\,]$$

where $\mathbf{I}_k$ is the $k \times k$ identity matrix and $\mathbf{P}$ is the parity matrix.

- Parity check matrix can be obtained as

$$\mathbf{H} = [\,\mathbf{P}^t \mid \mathbf{I}_{n\text{-}k}\,]$$

where t denotes transposition. In the binary case, $-\mathbf{P}^t = \mathbf{P}^t$. Hence, parity check matrices allow us to detect errors by determining whether a given received sequence is a code word or not.

Block decoding algorithm: syndrome decoding

✓ What?
✓ How?

Let us denote by **e** the error binary sequence. The output sequence y that we obtain when code word c is transmitted can be expressed as

$$y = c + e.$$

If there are no errors during transmission, e = 0, if there is an error in the first bit, e = (10 . . . 0), if there is an error in the first and third bite = (1010 . . . 0), and so on.

If we apply the parity check to y, we get:

$$y\boldsymbol{H}^{\boldsymbol{t}} = c\boldsymbol{H}^{\boldsymbol{t}} + e\boldsymbol{H}^{\boldsymbol{t}} = e\boldsymbol{H}^{\boldsymbol{t}}$$

Notice that the result of this operation **depends on the error sequence e and not on the code word c that we have transmitted.**

Aliasing (ideal sampling)

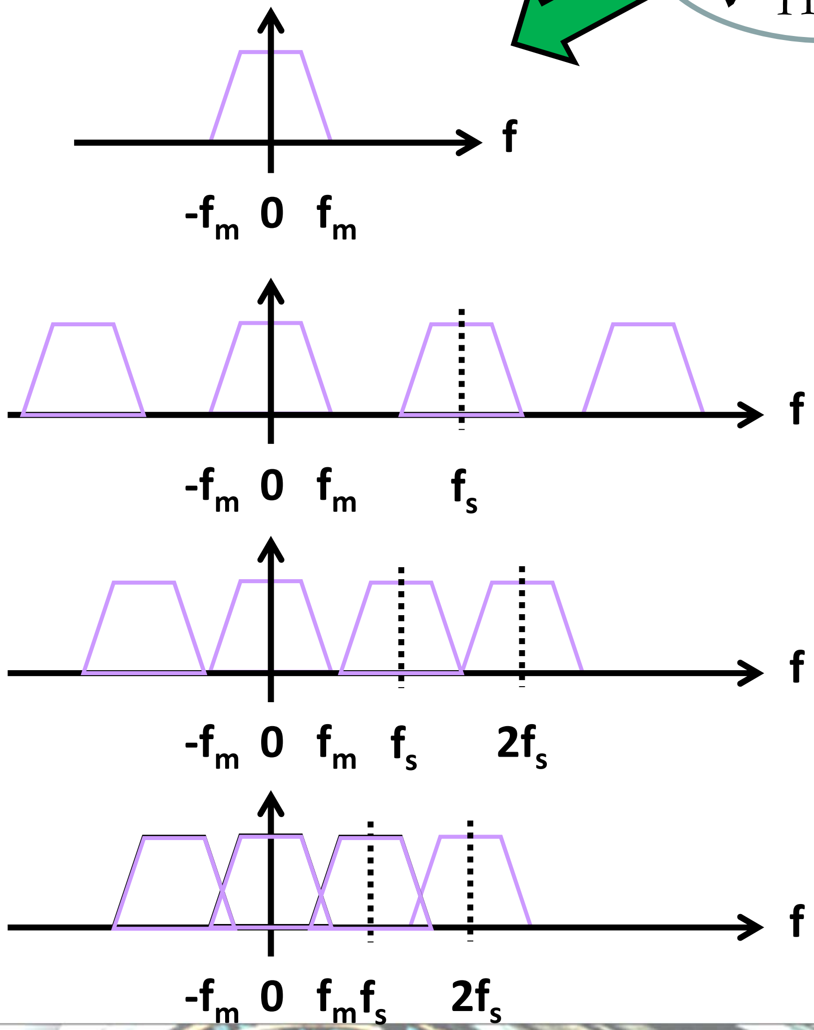
✓ What?
✓ Why?
✓ How?

original signal

signal sampled with $f_s > 2\,f_m$

signal sampled with $f_s = 2\,f_m$

signal sampled with $f_s < 2\,f_m$
aliasing occurs



Quantising distortion

✓ What?
✓ Why?
✓ How?