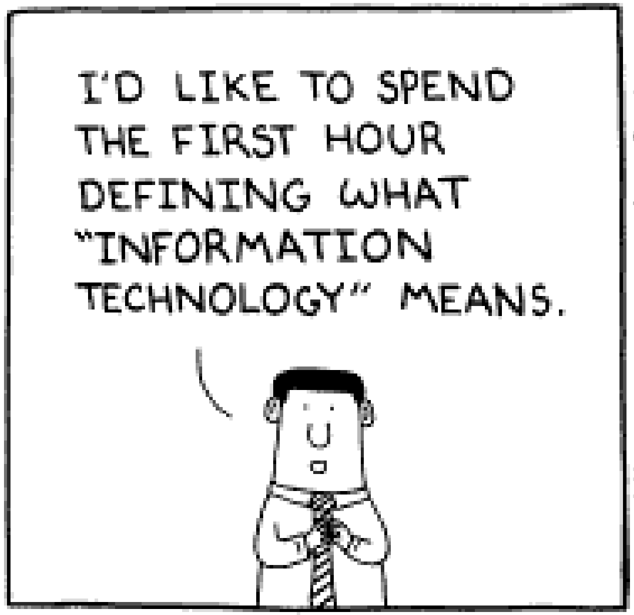


Communication Basics

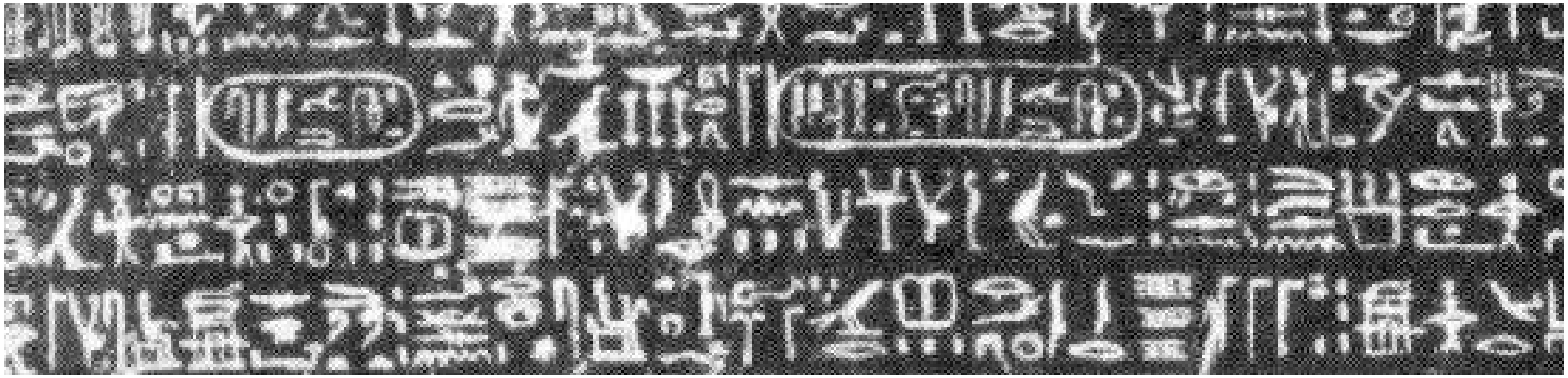
Principles and Dogmas

“Everything
should be made
as simple as possible,
...but not simpler.”

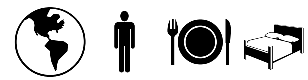
Albert Einstein

Information

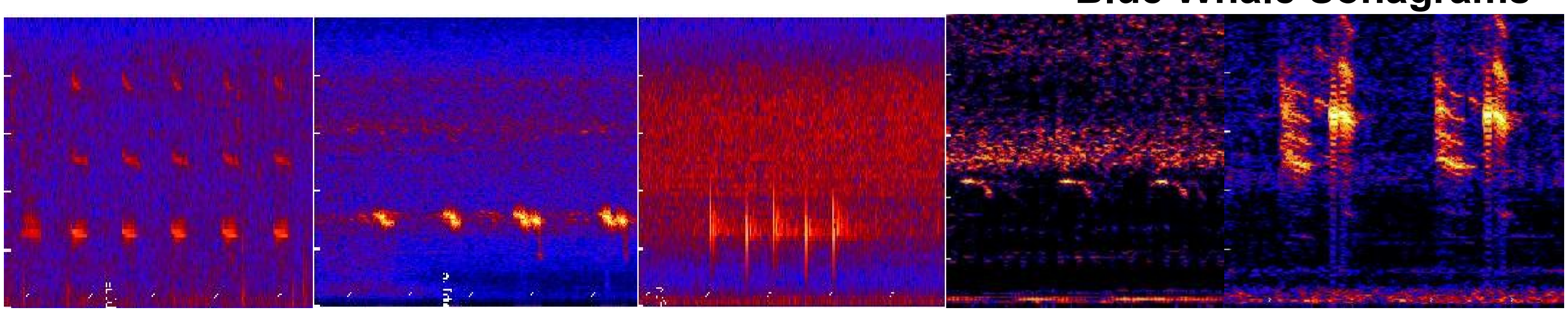
- ***What is*** **information?**
  - **Carried by symbols**
  - **Recognized by receiver (hopefully)**
  - ***Interpretation*** **is the key…**



Symbols

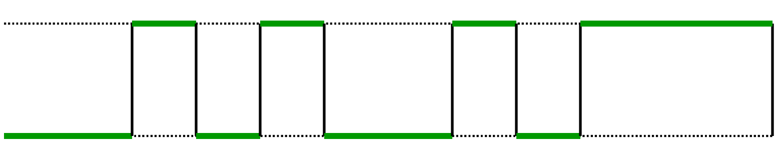
- Symbols (may) represent information
  - Voice patterns (Speech)
  - Sign language, Pictograms 
  - Scripture
  - Voltage levels
  - Light pulses

Blue Whale Sonagrams

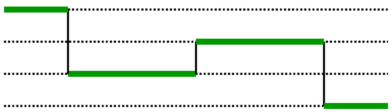


Symbols on Wire

- Discrete voltage levels = "Digital"
  - Resistant against noise
- How many levels?
  - Binary (easiest)
  - M-ary: *More information per time unit!*



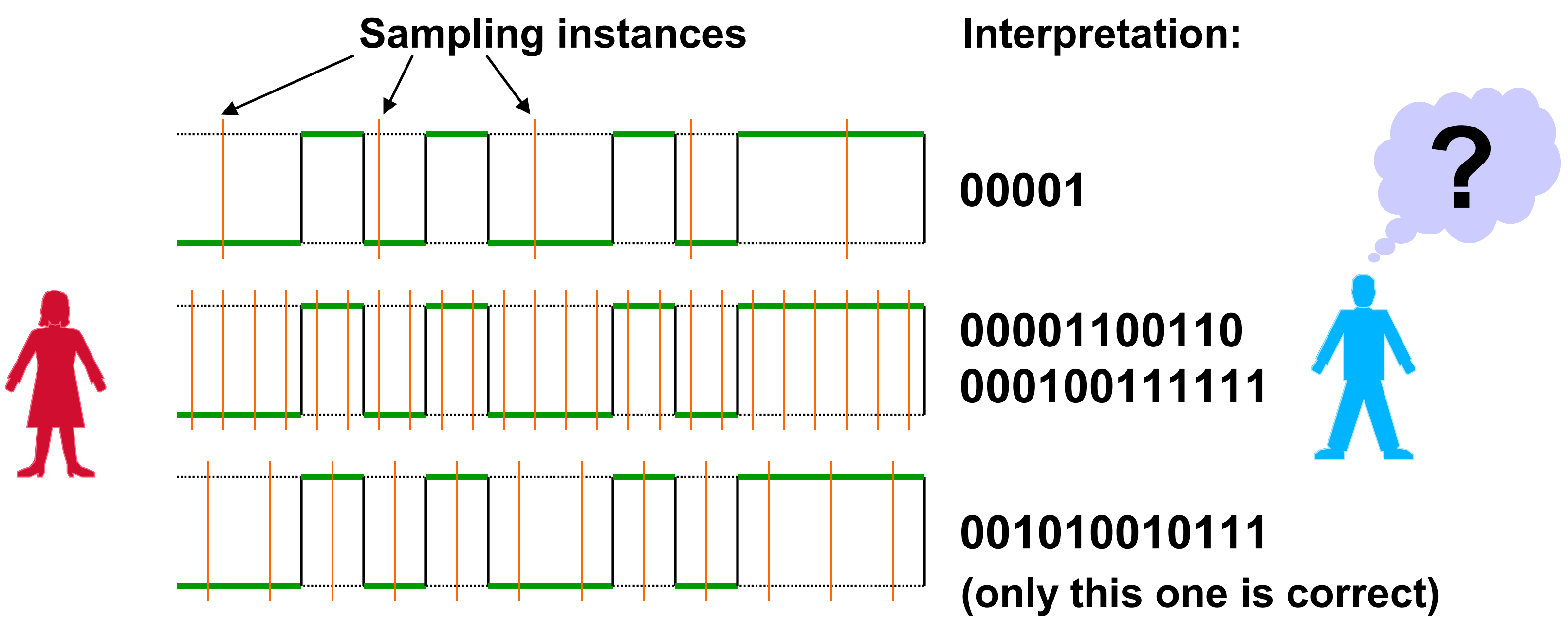
Binary



M-ary
(here 4 levels, e. g. ISDN)

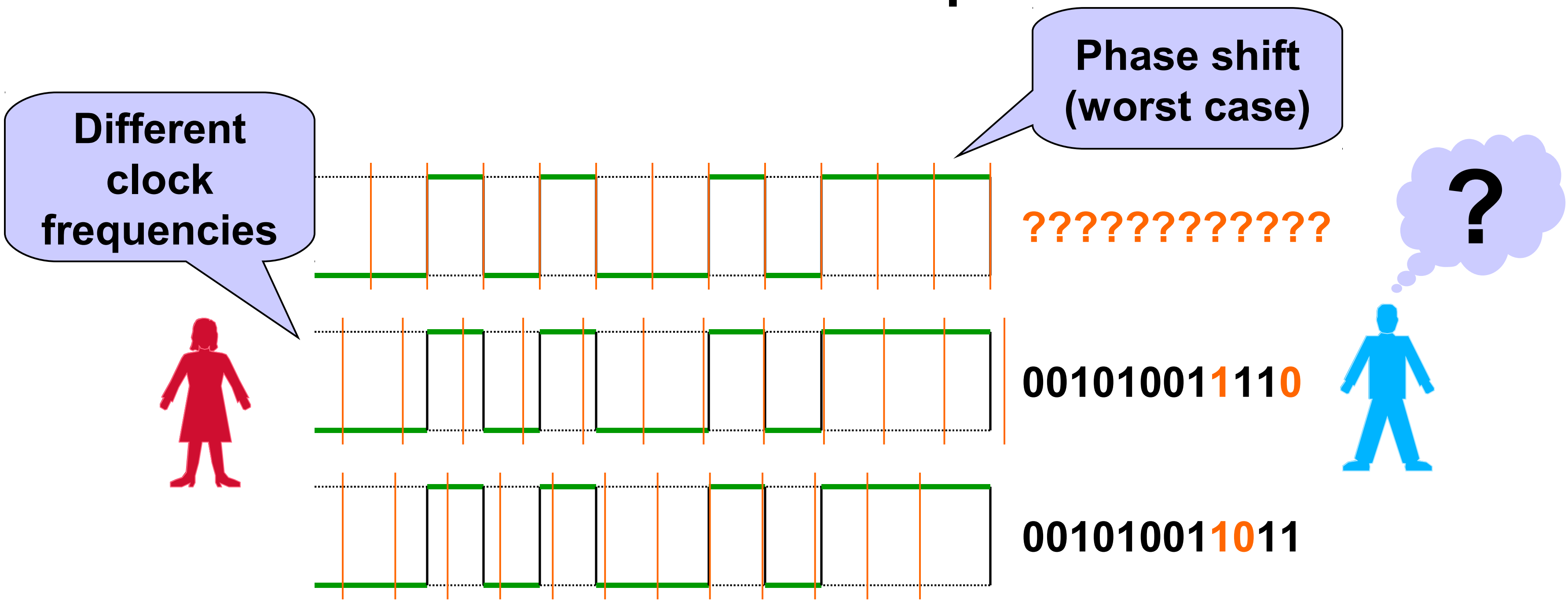
Synchronization

- Sender sends symbol after symbol...
- *When* should receiver pick the signal samples?
  - => Receiver must sync with sender's clock !



Synchronization

- In reality, two independent clocks are NEVER precisely synchronous
  - We always have a frequency shift
  - But we must also care for phase shifts

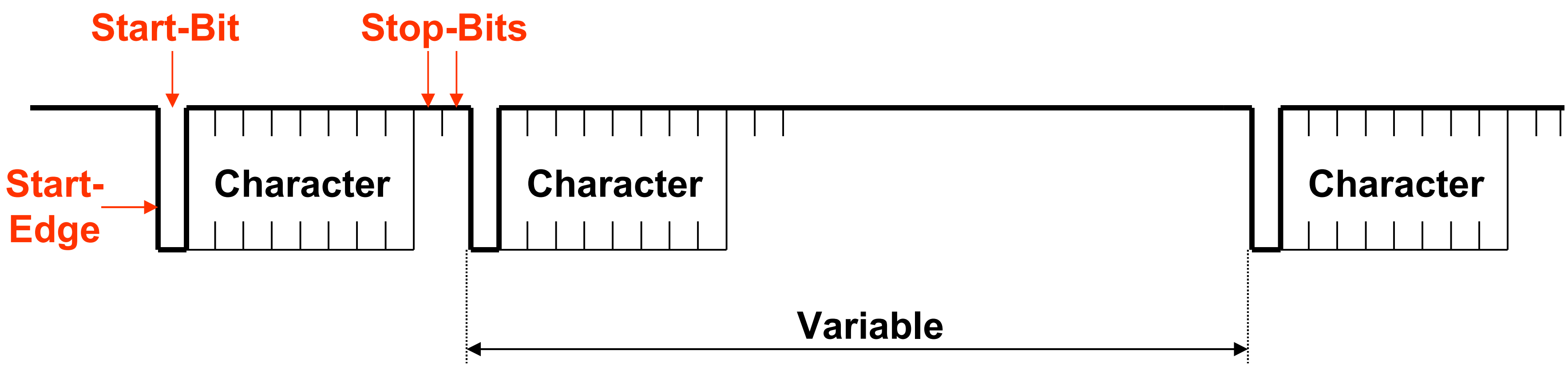


Serial vs Parallel

- Parallel transmission
  - Multiple data wires (fast)
  - Explicit clocking wire
  - Simple Synchronization but not cost-effective
  - Only useful for small distances
- Serial transmission
  - Only one wire (-pair)
  - No clocking wire
  - Most important for data communication

Asynchronous Transmission

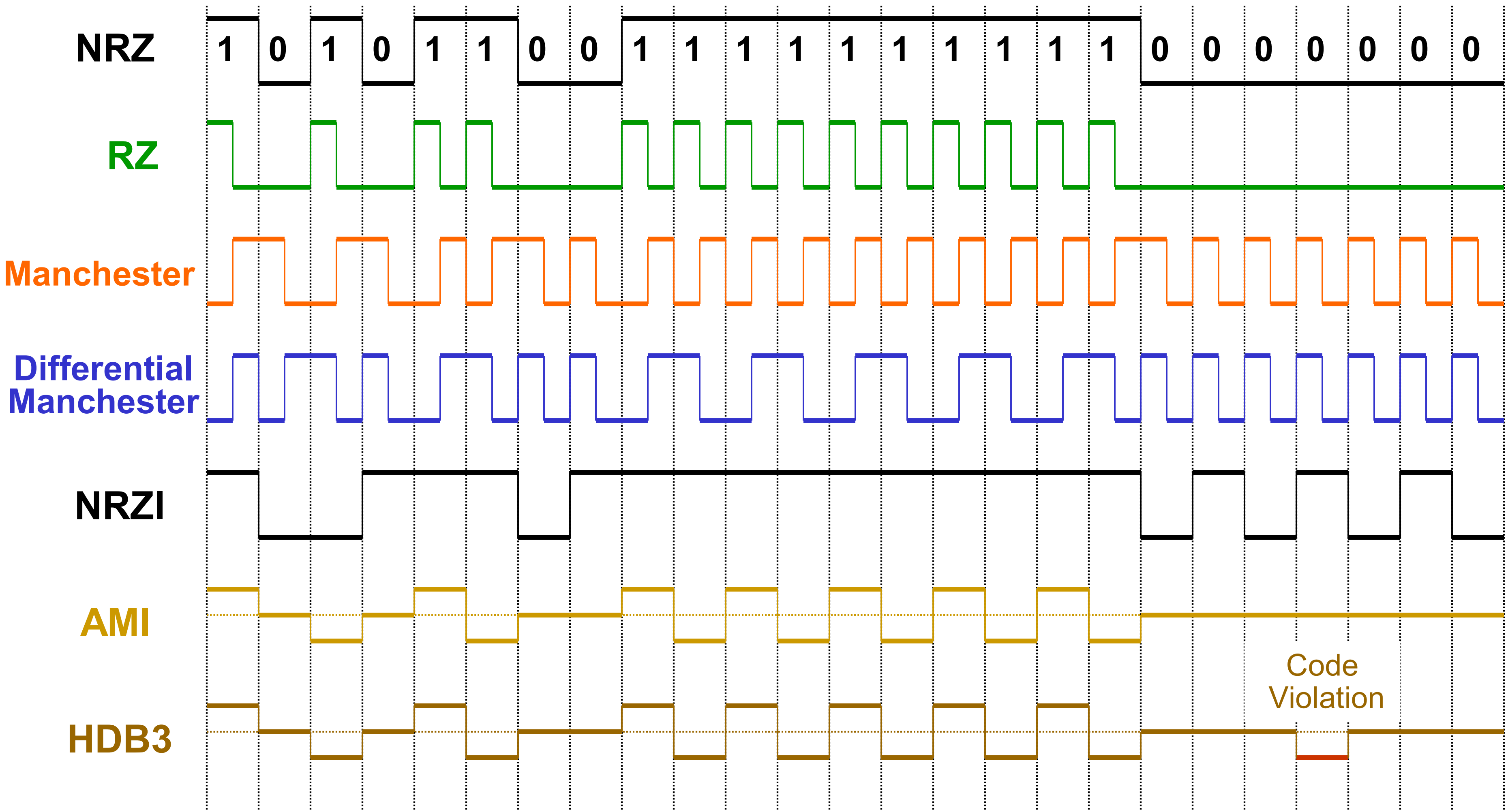
- Independent clocks
  - Oversampling: Much faster than bitrate
- Only phase is synchronized
  - Using Start-bits and Stop-bits
  - Variable intervals between characters
  - Synchronity only during transmission
- Inefficient



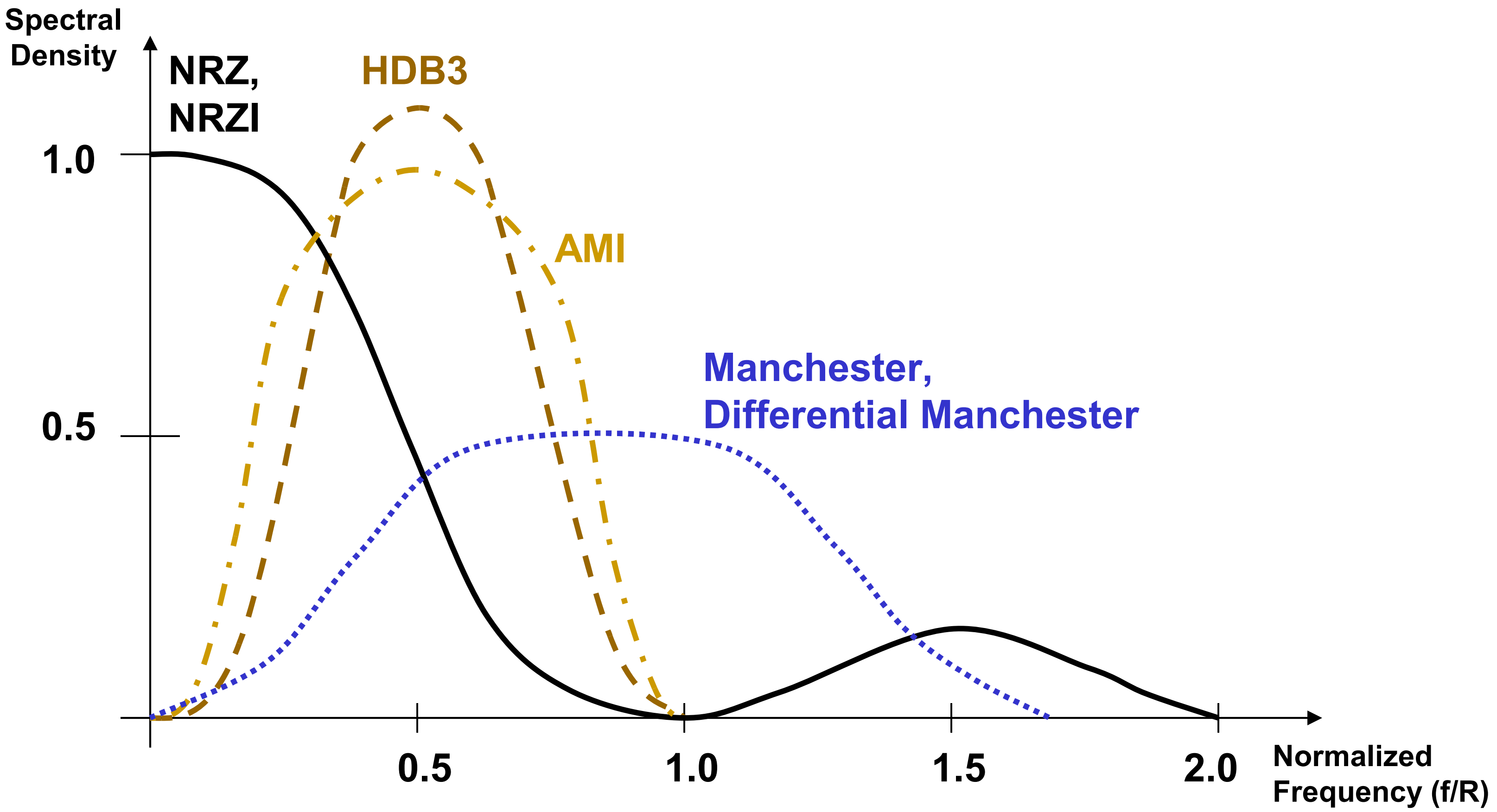
Synchronous Transmission

- Synchronized clocks
  - Most important today!
  - Phase and Frequency synchronized
- Receiver uses a Phased Locked Loop (PLL) control circuit
  - Requires frequent signal changes
  - => *Coding* or *Scrambling* of data necessary to avoid long sequences without signal changes
- Continous data stream possible
  - Large frames possible (theoretically endless)
  - Receiver remains synchronized
  - Typically each frame starts with a short "training sequence" aka "preamble" (e. g. 64 bits)

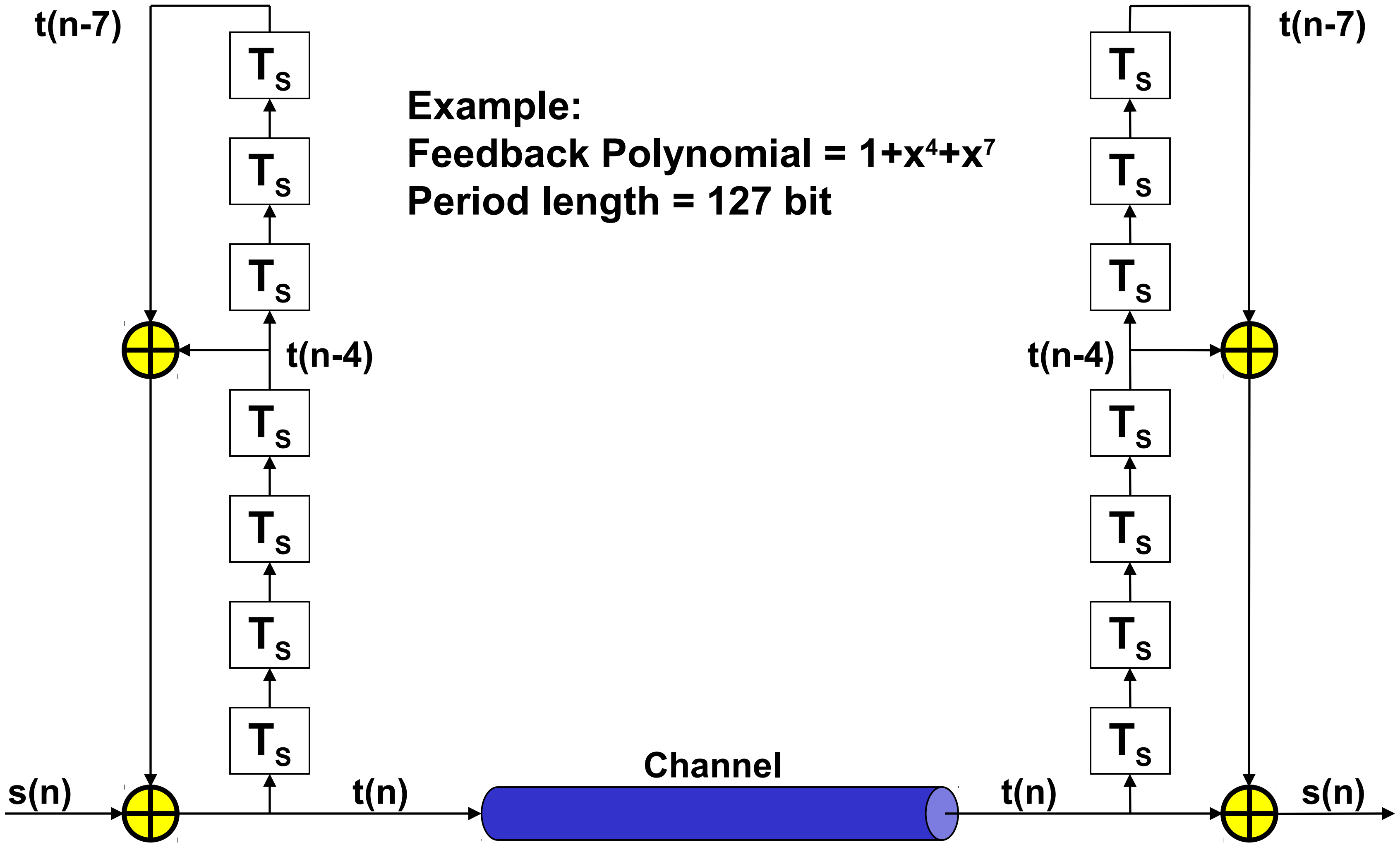
Line Coding


NRZ
1 0 1 0 1 1 0 0 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0
RZ
Manchester
Differential Manchester
NRZI
AMI
Code Violation
HDB3

Power Spectrum Density

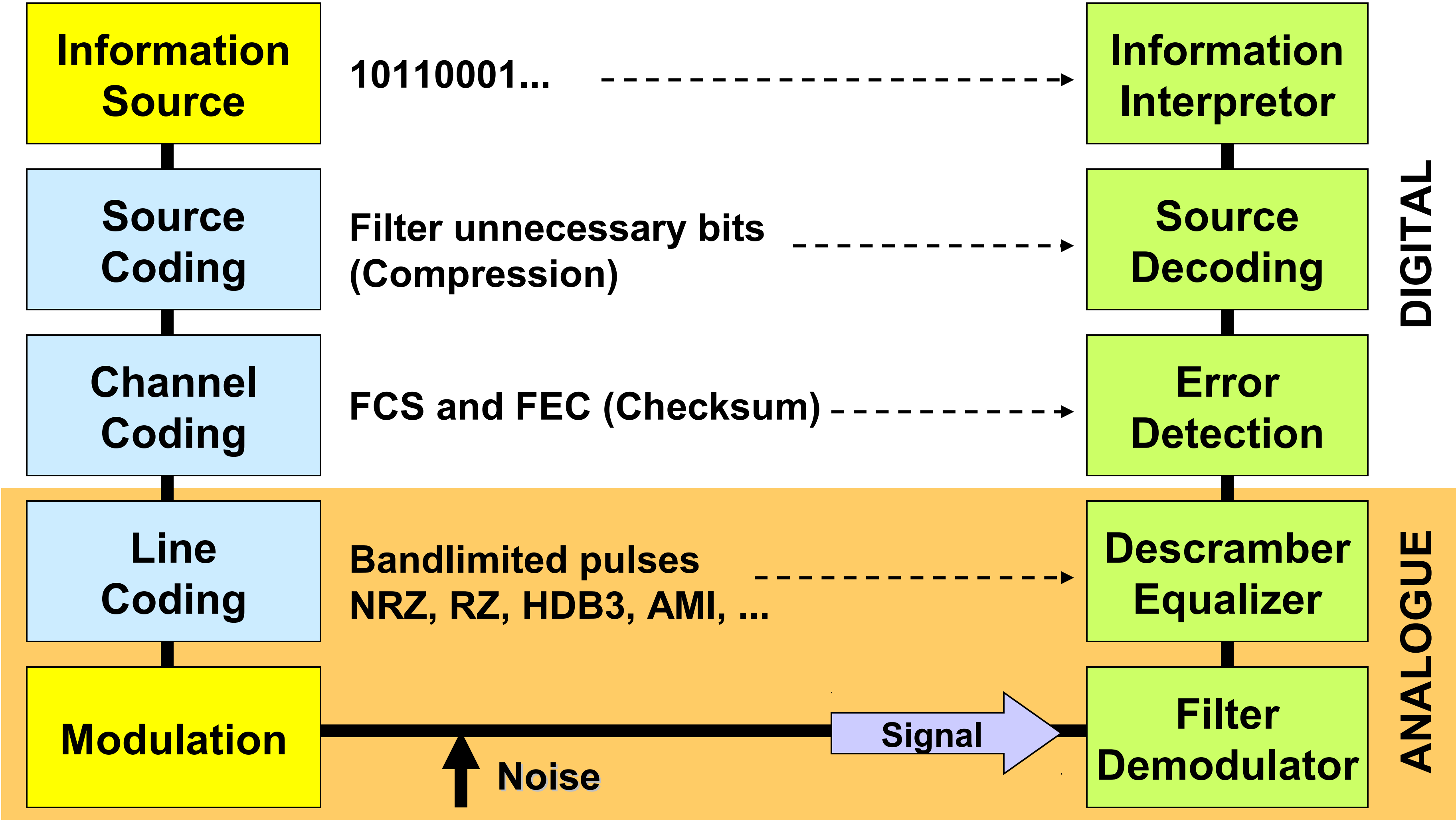


Scrambling Example



Example:
Feedback Polynomial = $1+x^4+x^7$
Period length = 127 bit

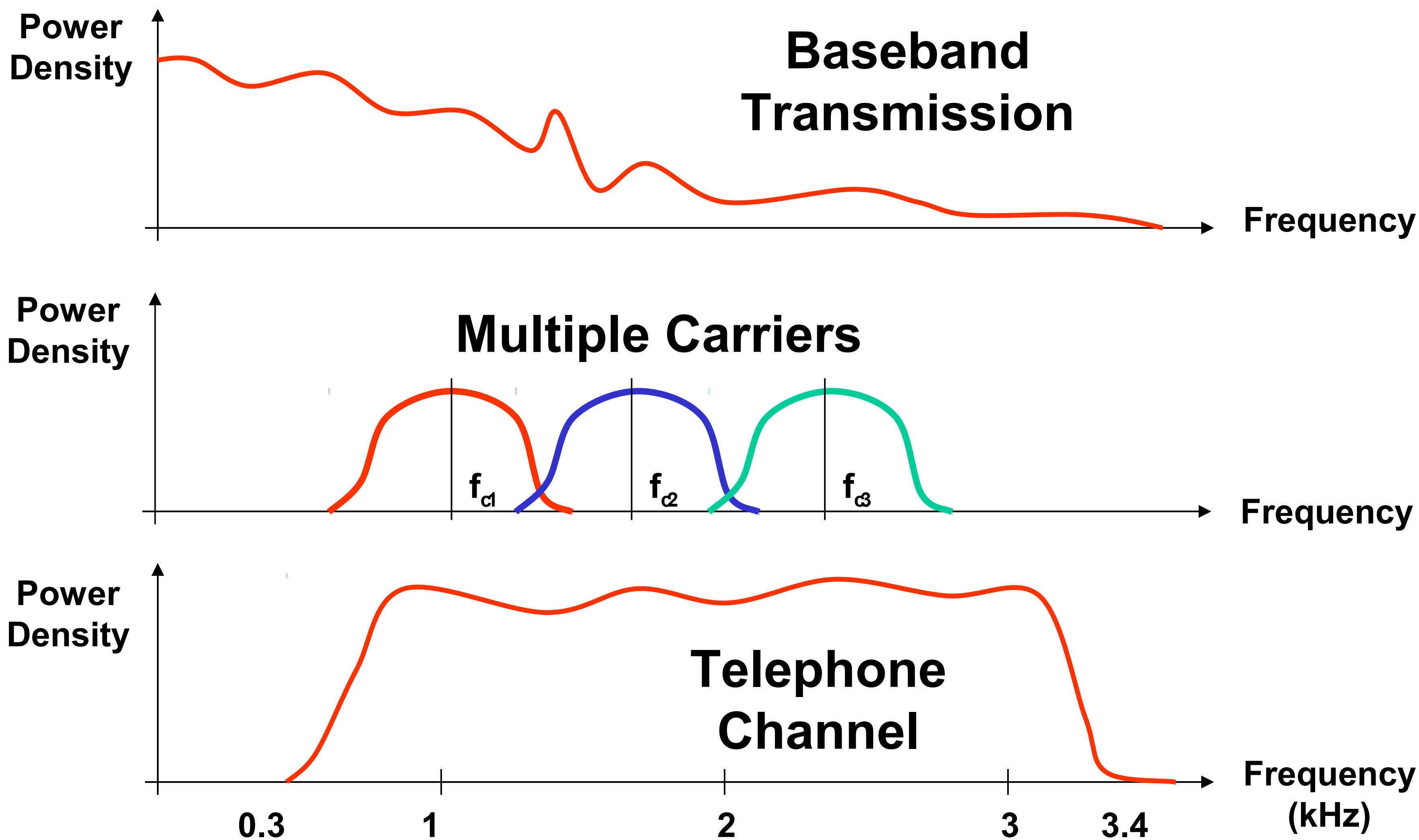
Transmission System Overview



Communication Channels

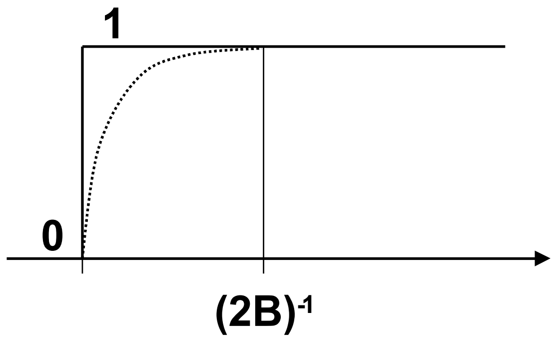
- Usually *Low-Pass* behavior
  - Higher frequencies are more attenuated than lower
- Baseband transmission
  - Signal without a dedicated carrier
  - Example: LAN technologies (Ethernet etc)
- Carrierband transmission
  - The baseband signal modulates a carrier to match special channel properties
  - Medium can be shared for many users (different carriers) – e. g. WLAN

Channel utilization examples



Maximal Signal-Rate

- **Maximal data rate proportional to channel-bandwidth B**
  - **Raise time of Heavyside T=1/(2B)**
  - **So the maximum rate is R=2B, also called the Nyquist Rate**
  - **Note: We assume an ideal channel here – without noise!**
- **Bandwidth decreases with cable length**
  - **As a dirty rule of thumb: BW × Length ≅ const**
  - **But note that the reality is much more complex**
  - **Solitons are remarkable exceptions…**



Maximum signal rate: At least the amplitude must be reached

The Maximum Information Rate

- What about a real channel? What's the maximum achievable information rate in presence of noise?
- Answer by C. E. Shannon in 1948
  - Even when noise is present, information can be transmitted ***without errors*** when the information rate is below the ***channel capacity***
- Channel capacity depends only on channel bandwidth AND SNR
  - Example: AWGN-channel

$$C = B \log (1 + S/N)$$

Bitrate vs Baud

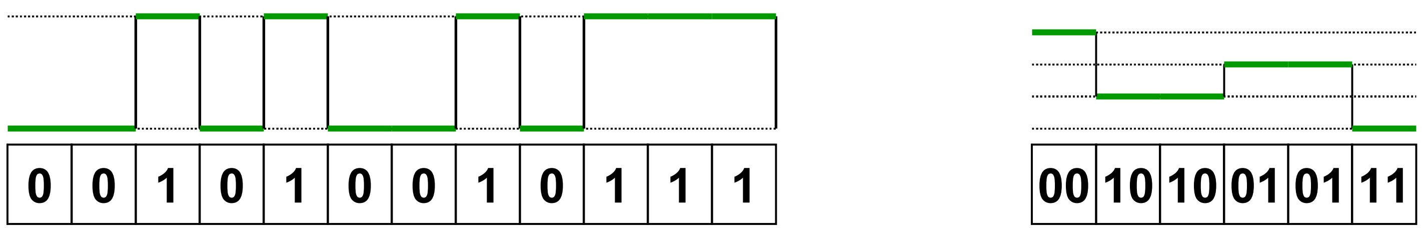
- Information Rate: Bit/s
- Symbol Rate: Baud
- The goal is to send many (=as much as possible) bits per symbol
  - => QAM (see next slides)

N bit/s

N Baud

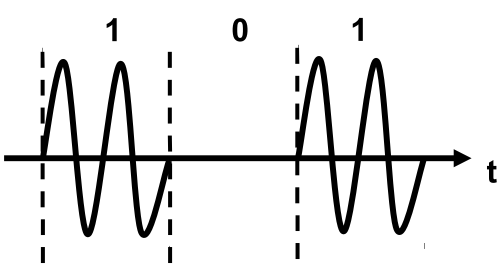
2N bit/s

N Baud

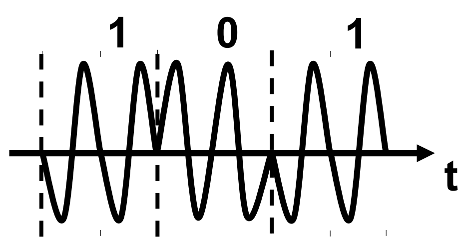


Analogue Modulation Overview

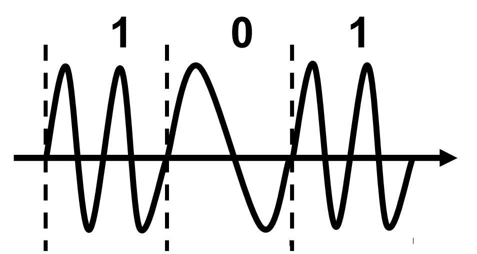
- EVERY transmission is analogue – but there are different methods to put a base-band signal onto a high-frequency carrier
- The most simple (and oldest) is ASK
  - The illustrated ASK method is simple "On-Off-Keying" (OOK)
- FSK and PSK are called "angle-modulation" methods (nonlinear => spectrum shape is changed!)
- For digital transmission, almost always QAM is used
  - The BER of BPSK is 3 dB better than for simple OOK



Amplitude Shift Keying (ASK)



Phase Shift Keying (PSK)



Frequency Shift Keying (FSK)

$$g(t) = A_t \cdot \cos(2\pi f_t t + \varphi_t)$$

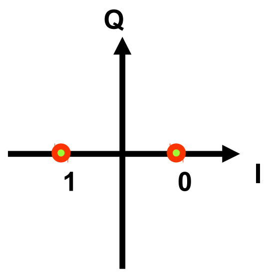
These three parameters can be modulated

QAM: Idea

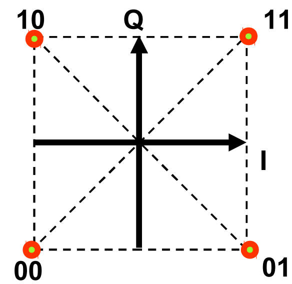
- "Quadrature Amplitude Modulation"
- Idea:
  1. Separate bits in groups of words (e. g. of 6 bits in case of QAM-64)
  2. Assign a dedicated pair of Amplitude and phase to each word (A,φ)
  3. Create the complex amplitude $Ae^{j\varphi}$
  4. Create the signal $\mathrm{Re}\{Ae^{j\varphi}e^{j\omega t}\}$
     $= A(\cos\varphi\cos\omega t - \sin\varphi\sin\omega t)$ which represents one (of the 64) QAM symbols
  5. Receiver can reconstruct (A,φ)

QAM: Symbol Diagrams

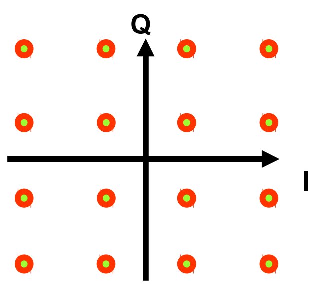
Standard PSK



Quadrature PSK (QPSK)

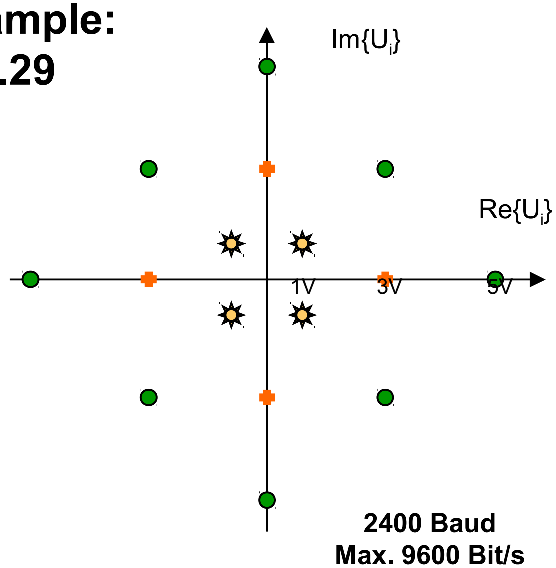


16-QAM



Other example: Modem V.29

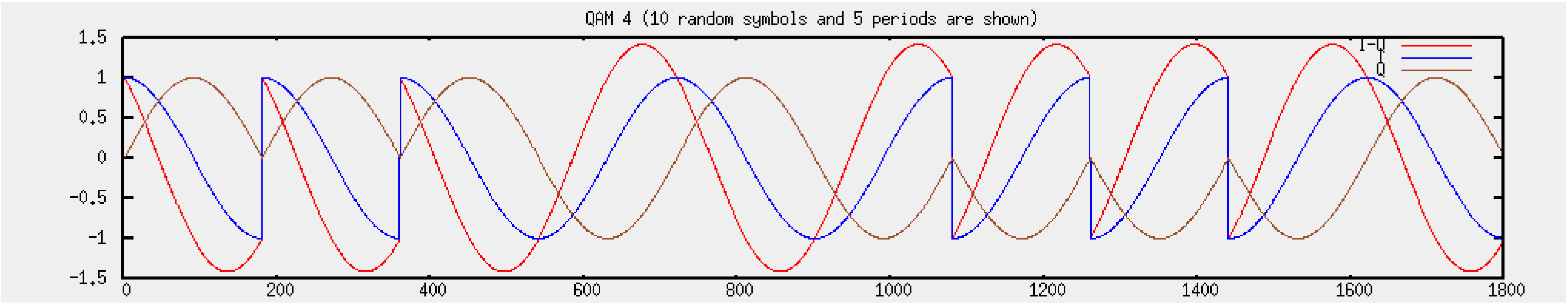
- For noisy and distorted channels 4800 bit/s
- For better channels 7200 bit/s
- For even better channels 9600 bit/s

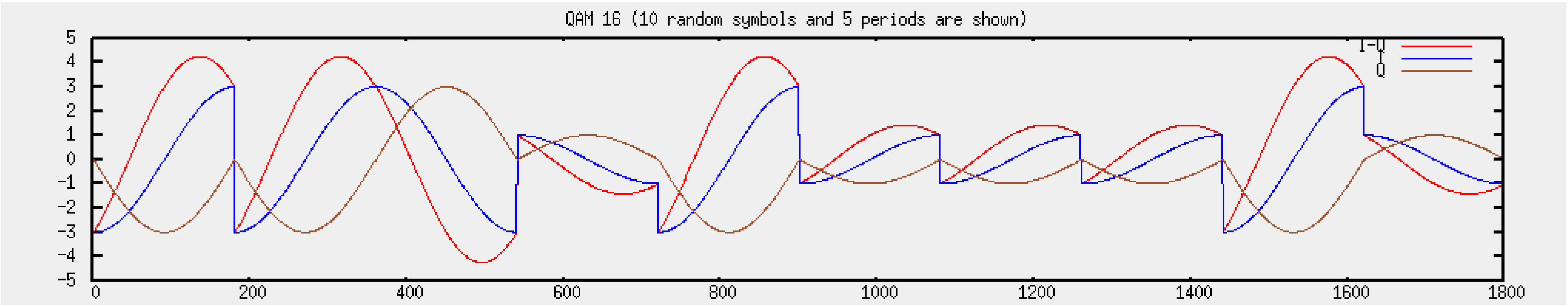


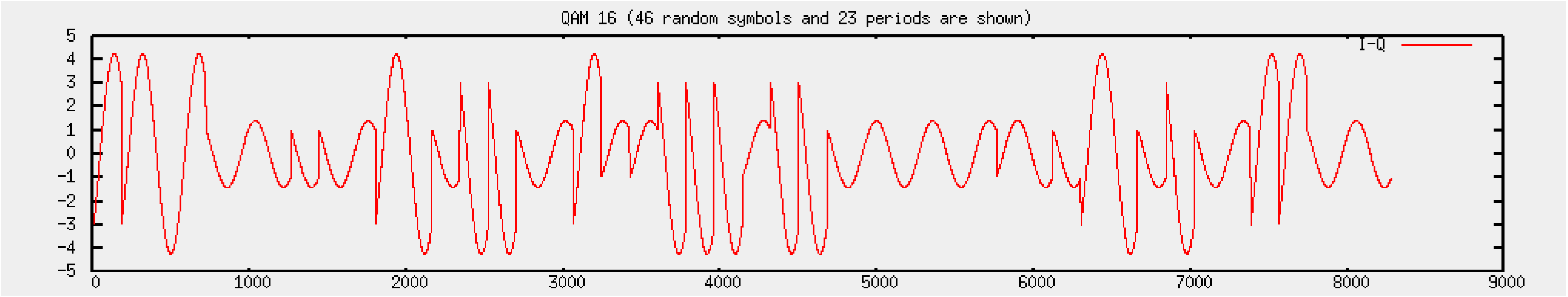
Example QAM Applications

- One symbol represents a bit pattern
  - Given N symbols, each represent ld(N) bits
- Modems, 1000BaseT (Gigabit Ethernet), WiMAX, GSM, …
- WLAN 802.11a and 802.11g:
  - BPSK @ 6 and 9 Mbps
  - QPSK @ 12 and 18 Mbps
  - 16-QAM @ 24 and 36 Mbps
  - 64-QAM @ 48 and 54 Mbps

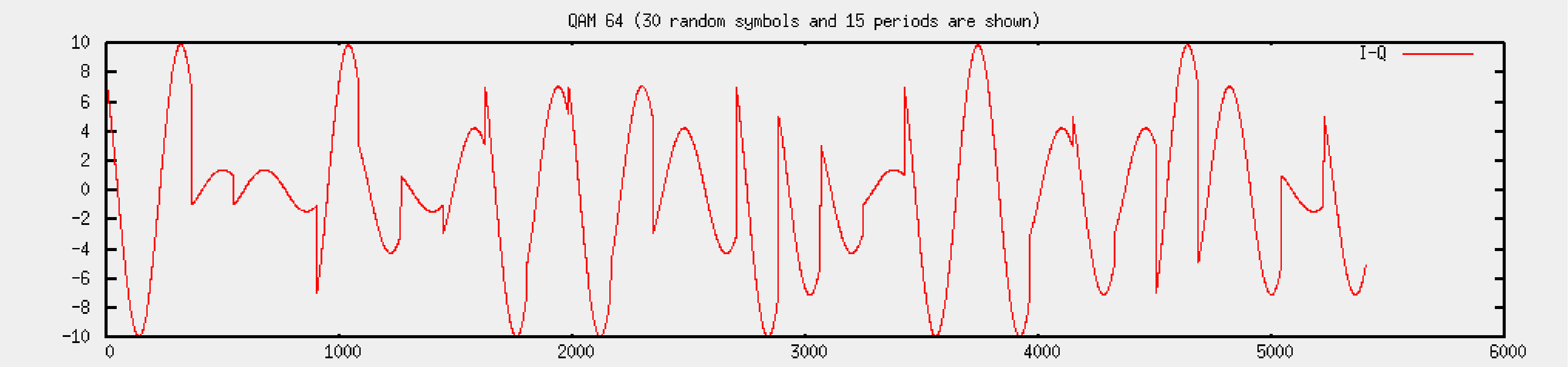
QAM Example Symbols (1)

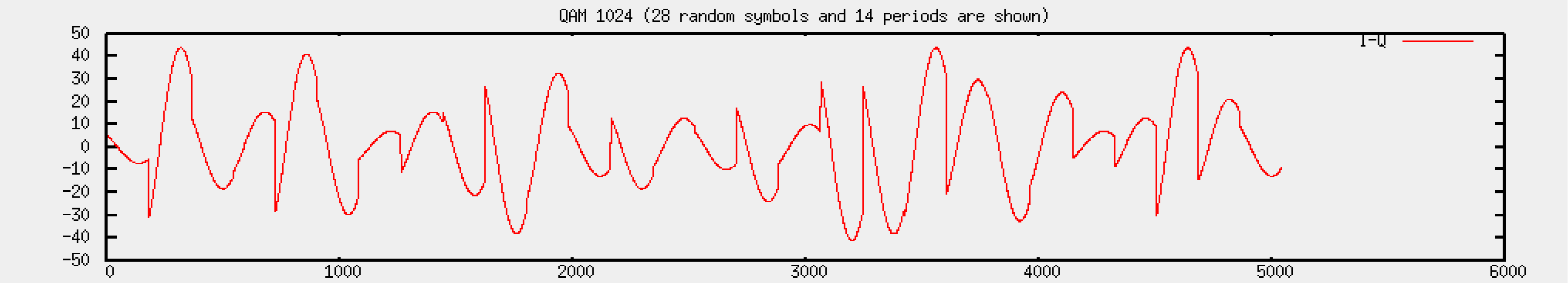


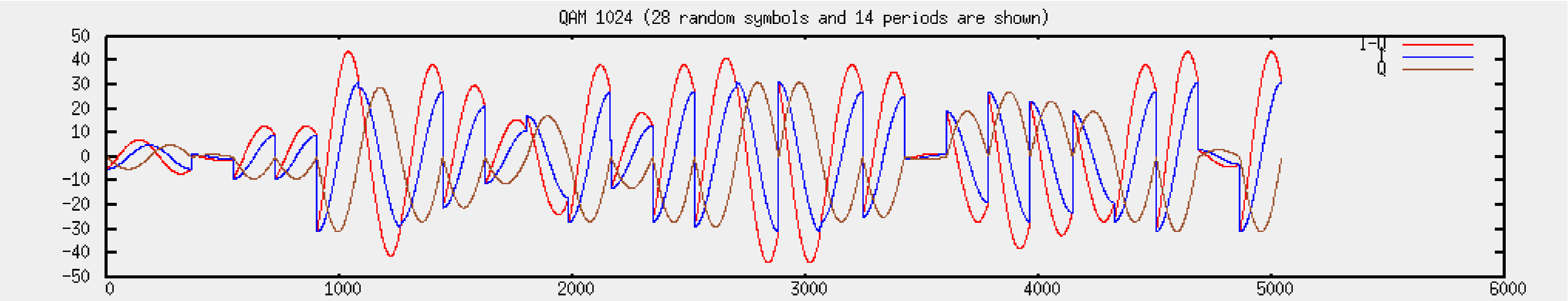




QAM Example Symbols (2)







“The biggest problem with communication is the illusion that it has occured.”

Married?