Ultra Wide Band Communications

Maria-Gabriella Di Benedetto

University of Rome La Sapienza

School of Engineering

Lesson 2

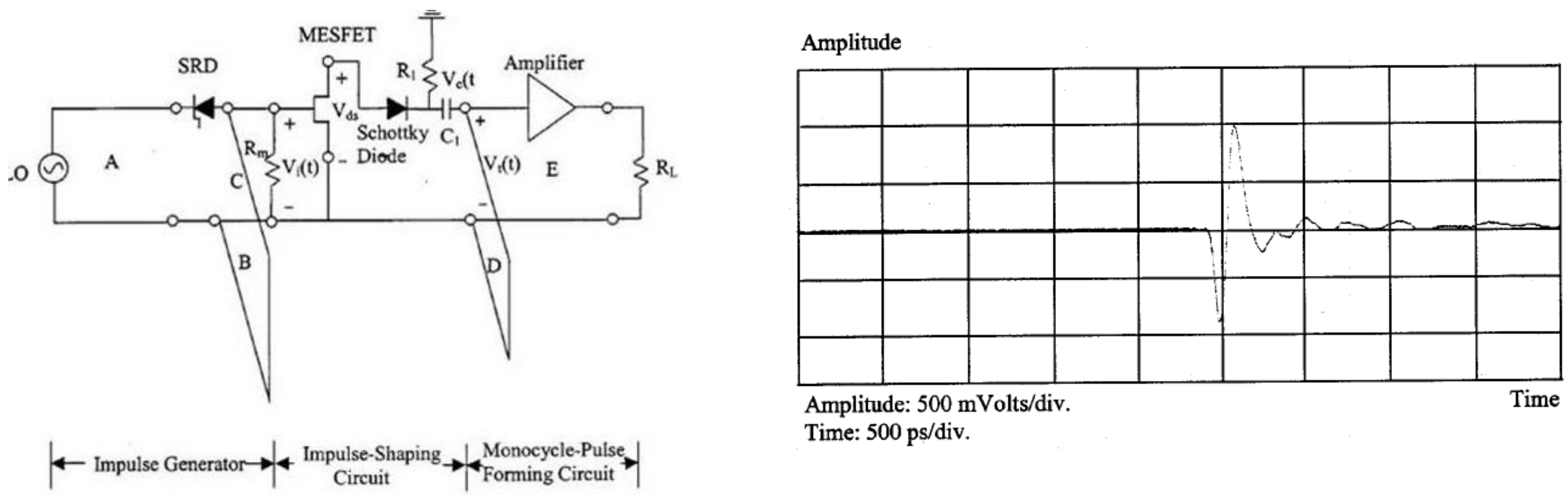
Generation of UWB radio signals

Outline

- The UWB radio signal
- Generation of TH-UWB signals
- Generation of DS-UWB signals
- Generation of MB-UWB signals

The UWB radio signal (1/4)

- A traditional way of emitting an UWB signal is by radiating pulses that are very short in time.
- This transmission technique goes under the name of Impulse Radio (IR).

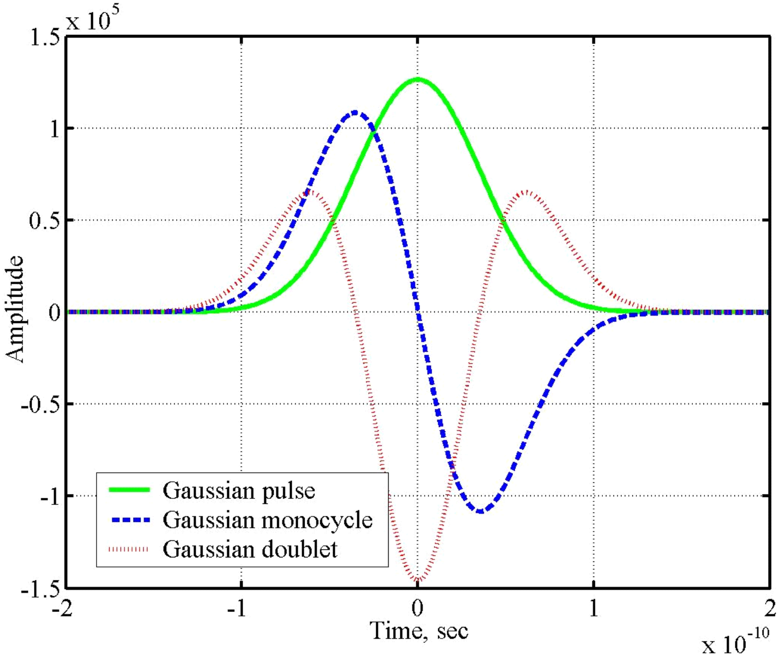


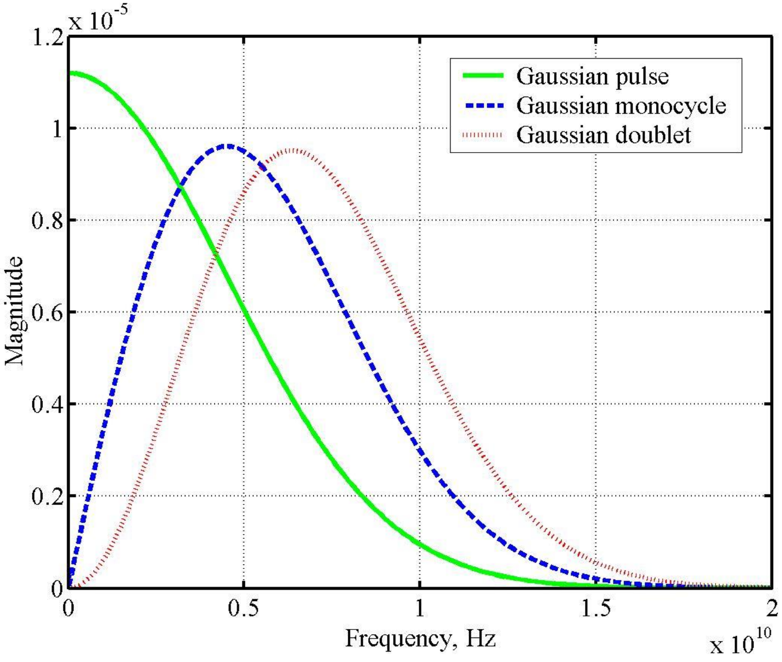
Schematic of an UWB ultra-short-pulse transmitter (left) and measured output (right)

[Lee and Nguyen,"*Novel low-cost ultra-wideband, ultra-short-pulse transmitter with MESFET impulse-shaping circuitry for reduced distortion and improved pulse repetition rate*," IEEE Microwave and Wireless Components Letters, Volume: 11 , Issue: 5 , 2001]

The UWB radio signal (2/4)

- The most currently adopted pulse shape is modelled as the first derivative or the second derivative of a **Gaussian function**
  - Such pulse shapes are easy to generate and have zero DC offset so that they can be radiated in an efficient way



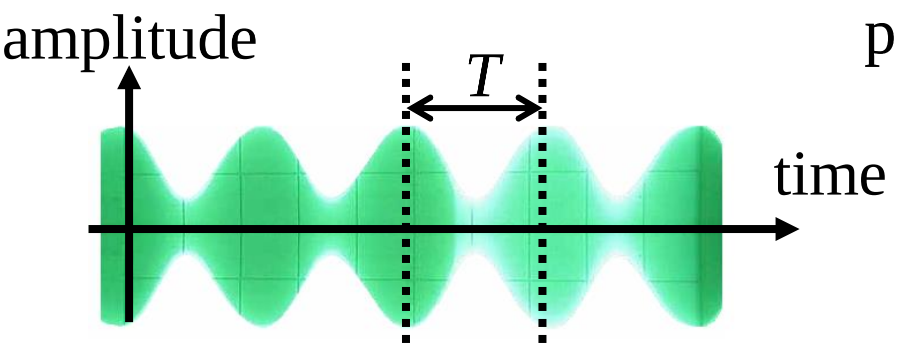


The UWB radio signal (3/4)

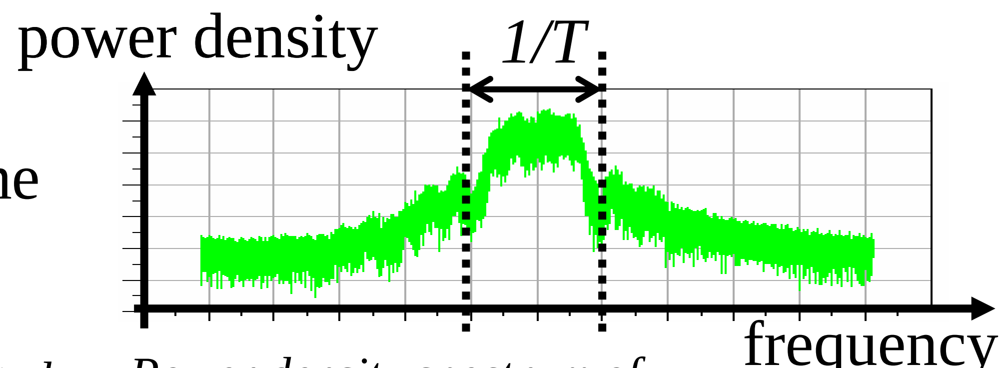
- The way by which the information data symbols modulate the pulses may vary
  - **Pulse Position Modulation** (PPM) and **Pulse Amplitude Modulation** (PAM) are commonly adopted modulation schemes
- In addition to modulation and in order to shape the spectrum of the generated signal, the data symbols are encoded using pseudorandom or pseudo noise (PN) codes.

The UWB radio signal (4/4)

- The UWB definition released by the FCC as mentioned in the previous lecture, does not limit, however, the generation of UWB signals to IR.
- According to the FCC definition, the UWB concept can be extended to continuous-like transmission techniques, provided that the occupied bandwidth of the transmitted signal is greater than 500 MHz.

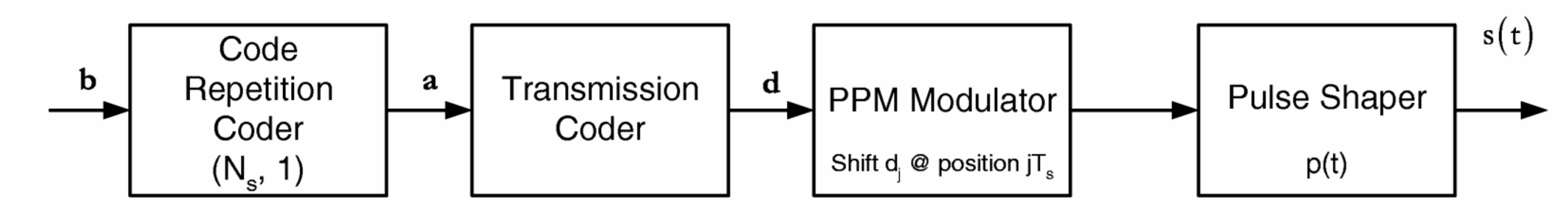


Example of continuous-time, RF modulated digital signal with pulse rate 1/T



Power density spectrum of the transmitted signal

Transmission scheme for a PPM-TH-UWB signal



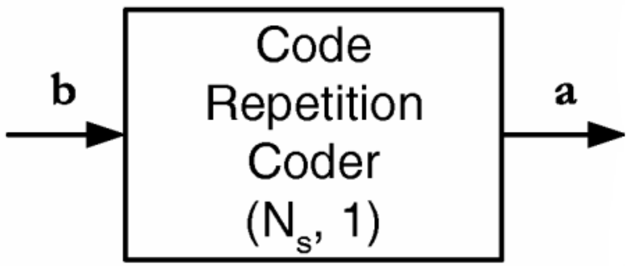
Introduces redundancy

Modulates and encodes the signal

Shapes the spectrum

Generation of TH-UWB signals (2/8)

The Code Repetition Coder



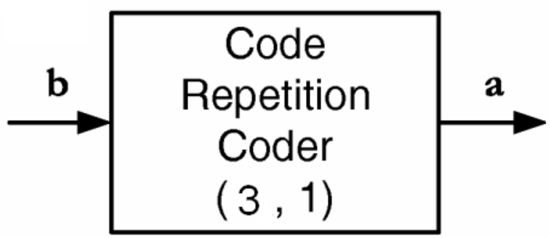
$$R_b = \frac{1}{T_b} \quad (bits/s) \qquad R_{cb} = \frac{N_s}{T_b} = \frac{1}{T_s} \quad (bits/s)$$

T_S : frame time, or average pulse repetition period

- Given the binary sequence **b**, generated at a rate of $R_b = 1/T_b$, a first system repeats each bit N_s times and generates a binary sequence **a** at a rate of $R_{cb} = N_s/T_b = 1/T_s$
- This system introduces redundancy and is denoted as a $(N_s,1)$ code repetition coder.

Original binary sequence

001010

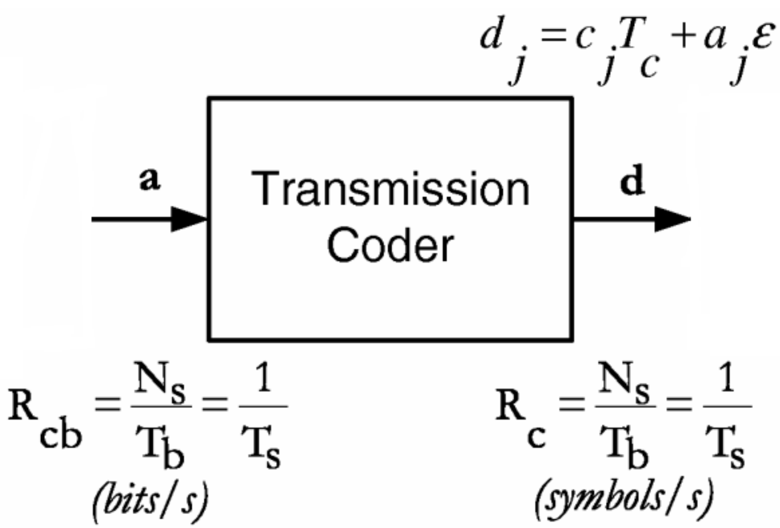


Code repeated binary sequence

000000111000111000

Generation of TH-UWB signals (3/8)

The Transmission Coder



T_c : chip time

ε : PPM shift

- A second block called a transmission coder applies an integer-valued code **c** to the binary sequence **a** and generates a new sequence **d**.
  - The generic element *j* of the sequence **d** is expressed as indicated in the figure, where T_c and ε are constant terms that satisfy the condition $c_j T_c + \varepsilon < T_s$ for all c_j. One also has, in general, $\varepsilon < T_c$.
  - Code **c** might be periodic, and in that case, its period is N_P

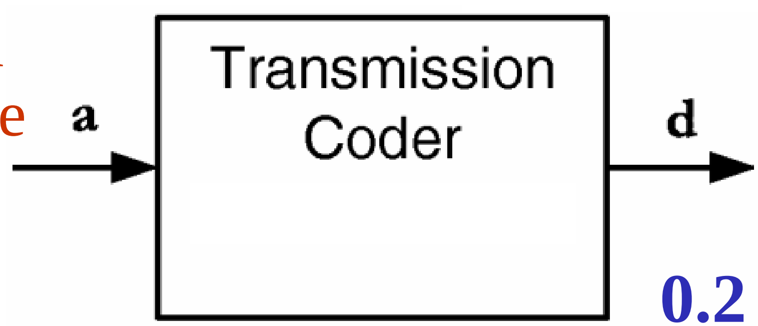
Generation of TH-UWB signals (4/8)

Original binary sequence

1 0

Code repeated binary sequence

1 1 1 0 0 0



Coded real valued sequence

$$d_j = c_j T_c + a_j \varepsilon$$

0.2 , 3.2 , 1.2 , 2.0 , 0.0 , 3.0

values in nanoseconds ?

Time Hopping code **c** ($N_P = 4$)

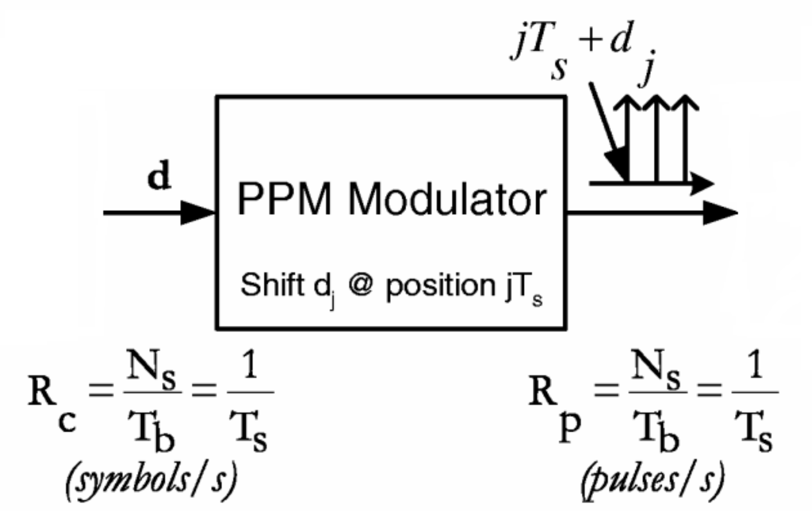
0 3 1 2

chip time T_c = 1 ns

PPM shift ε = 0.2 ns

Generation of TH-UWB signals (5/8)

The PPM modulator

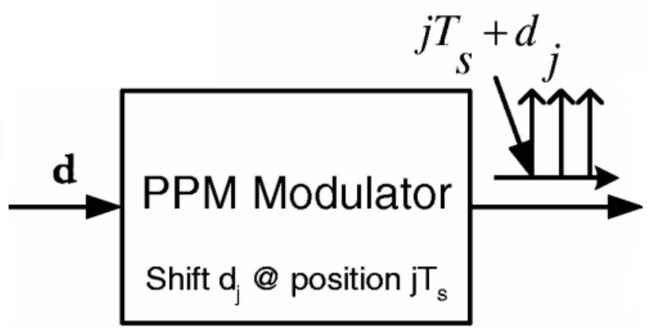


- The coded real-valued sequence **d** enters a third system, the PPM modulator, which generates a sequence of unit pulses (Dirac pulses $\delta(t)$) at a rate of $R_p = N_s / T_b = 1/T_s$.
  - These pulses are located at times jT_s+d_j, and are therefore shifted in time from nominal positions jT_s by d_j. Pulses occur at times $(jT_s+c_jT_c+a_j\varepsilon)$.

Generation of TH-UWB signals (6/8)

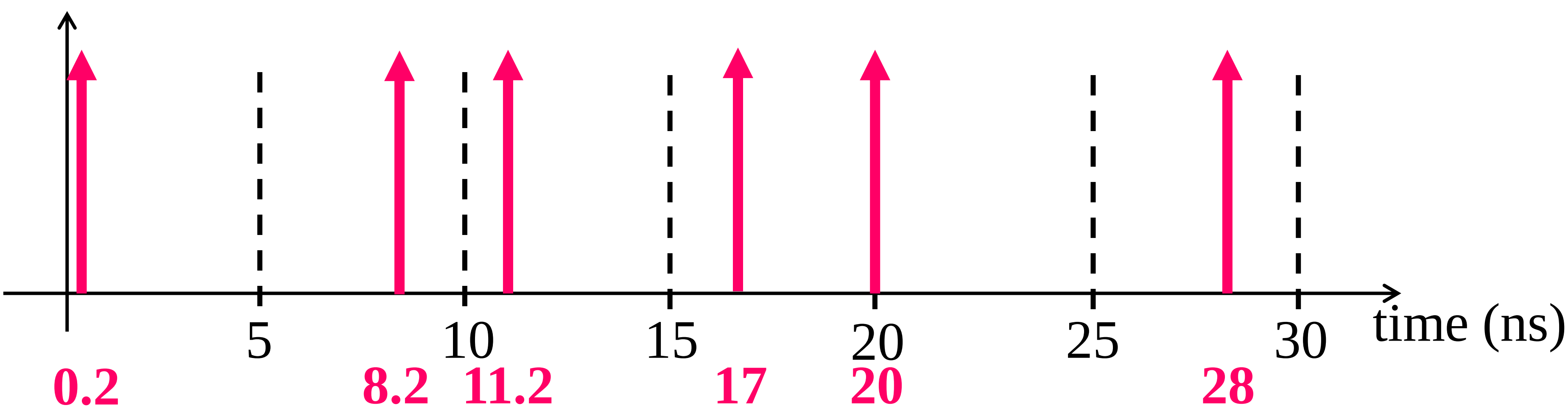
Original binary sequence	Code repeated binary sequence	Coded real valued sequence
1 0	**1 1 1 0 0 0**	**0.2 , 3.2 , 1.2 , 2.0 , 0.0 , 3.0**
		values in nanoseconds

0.2 , 3.2 , 1.2 , 2.0 , 0.0 , 3.0
values in nanoseconds



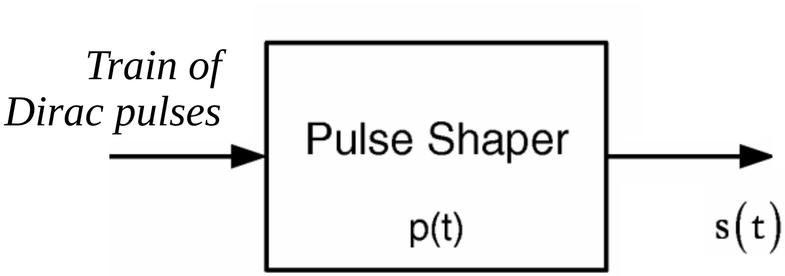
Dirac pulses, with average pulse repetition period T_S = 5 ns

$$s(t) = \sum_{j=-\infty}^{+\infty} \delta\left(t - jT_S - c_j T_C - a_j \varepsilon\right)$$



Generation of TH-UWB signals (7/8)

The pulse shaper



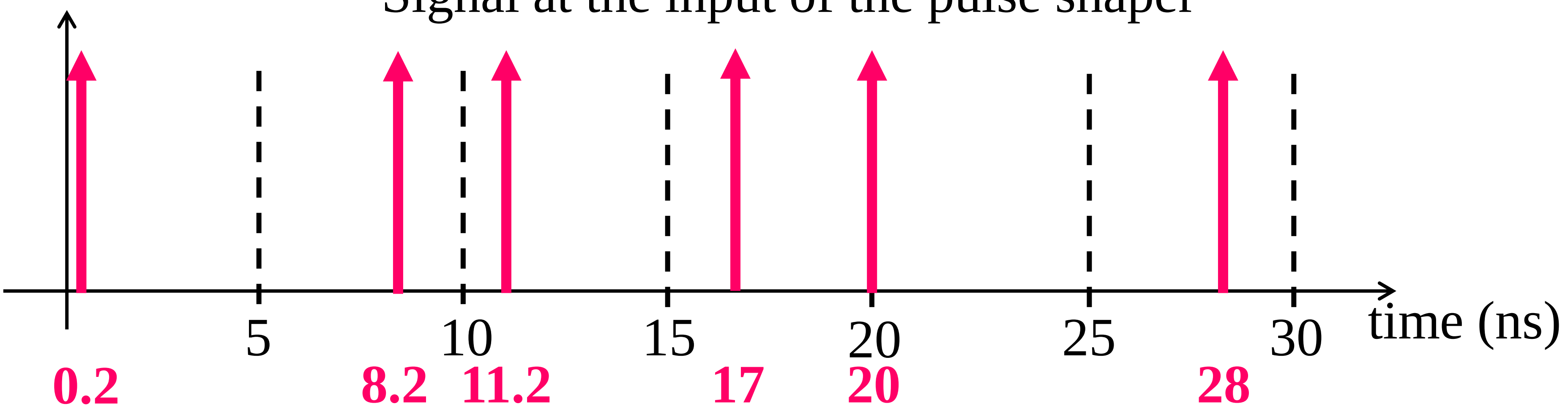
$$R_p = \frac{N_s}{T_b} = \frac{1}{T_s}$$
(pulses/s)

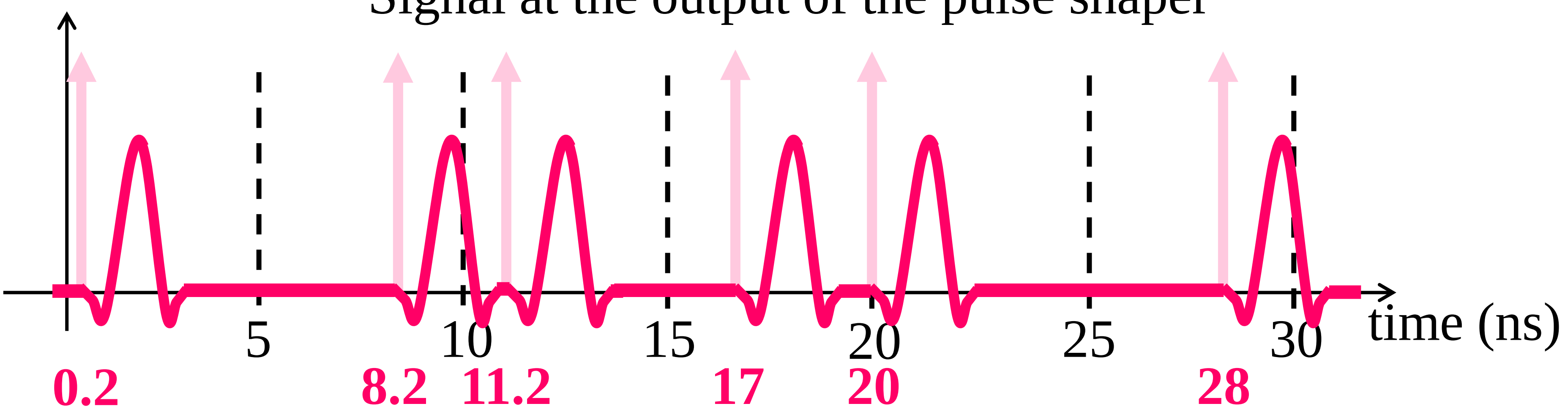
- The last system is the pulse shaper filter with impulse response *p(t)*. The impulse response *p(t)* must be such that the signal at the output of the pulse shaper filter is a sequence of strictly non-overlapping pulses

$$s(t) = \sum_{j=-\infty}^{+\infty} p\left(t - jT_s - c_j T_c - a_j \varepsilon\right)$$

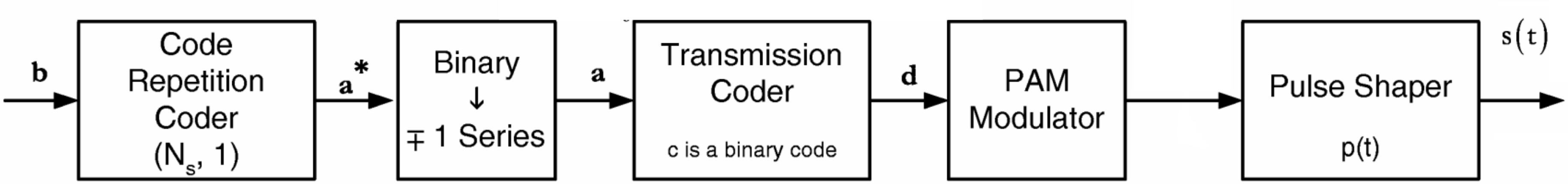
Analytical expression for a PPM-TH-UWB signal

Generation of TH-UWB signals (8/8)





Transmission scheme for a PAM-DS-UWB signal



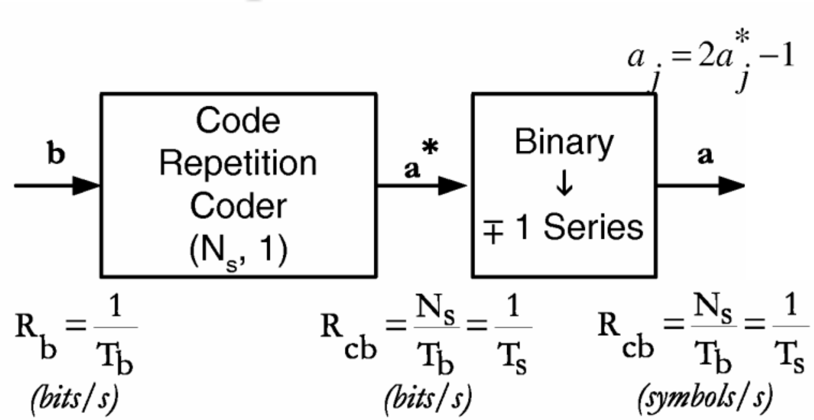
Introduces redundancy

Modulates and encodes the signal

Shapes the spectrum

Generation of DS-UWB signals (2/6)

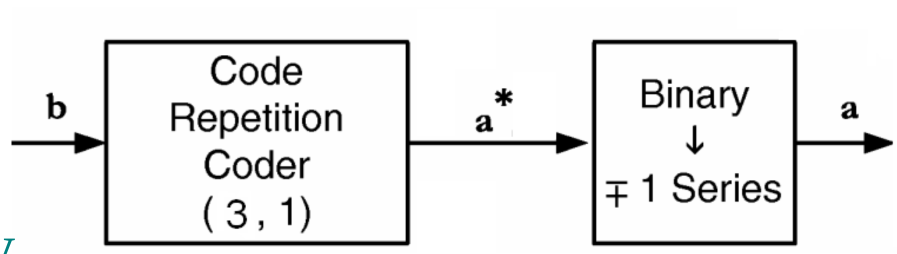
The Code Repetition Coder



- Given the binary sequence **b** generated at a rate of $R_b = 1/T_b$, a first system repeats each bit Ns times and generates a binary sequence **a*** at a rate of $R_{cb} = N_s/T_b = 1/T_s$ bits/s.
- A second system transforms the **a*** sequence into **a**, which is composed by binary antipodal symbols (±1).

1 0

Original binary sequence



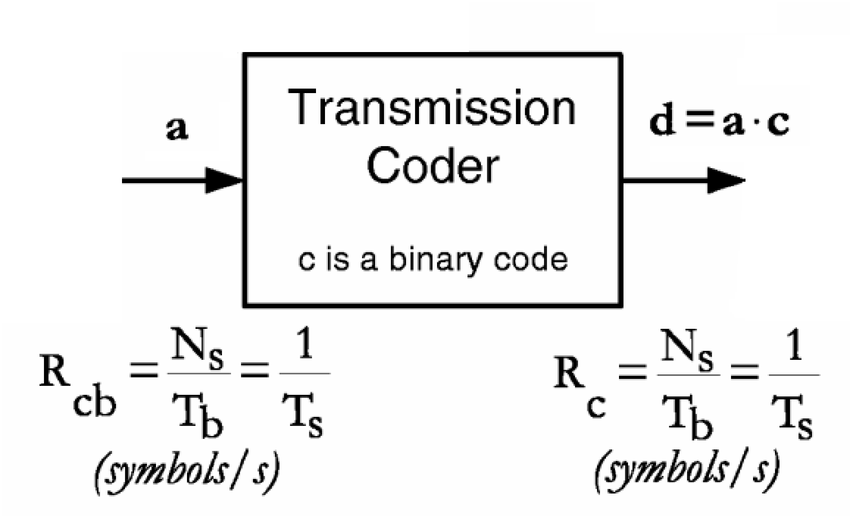
1 1 1 0 0 0

+1 +1 +1 -1 -1 -1

Code repeated binary sequence

Generation of DS-UWB signals (3/6)

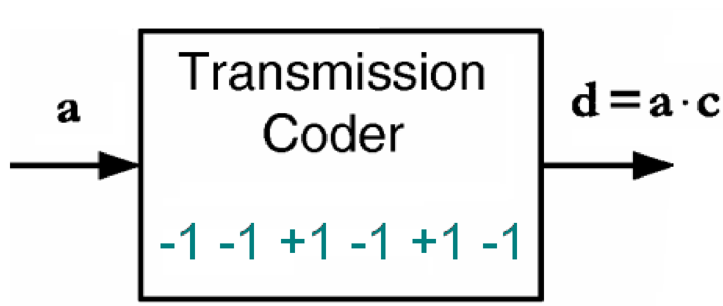
The Transmission Coder



- The transmission coder applies a binary code **c** composed of ±1's and period N_p to the sequence **a** and generates a new sequence **d** = **a** · **c** composed of elements $d_j = a_j c_j$. N_p is commonly assumed to be a multiple of N_s.

+1 +1 +1 -1 -1 -1

Code repeated binary sequence



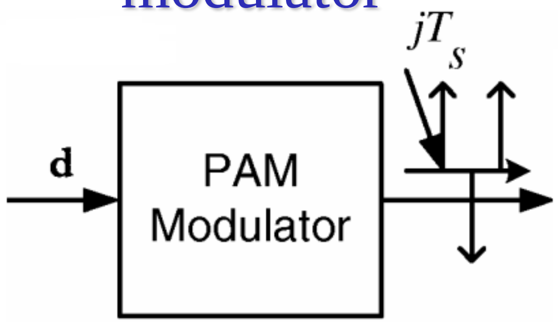
Direct Sequence code **c** ($N_p = 6$)

-1 -1 +1 +1 -1 +1

Coded binary sequence

Generation of DS-UWB signals (4/6)

The PAM modulator



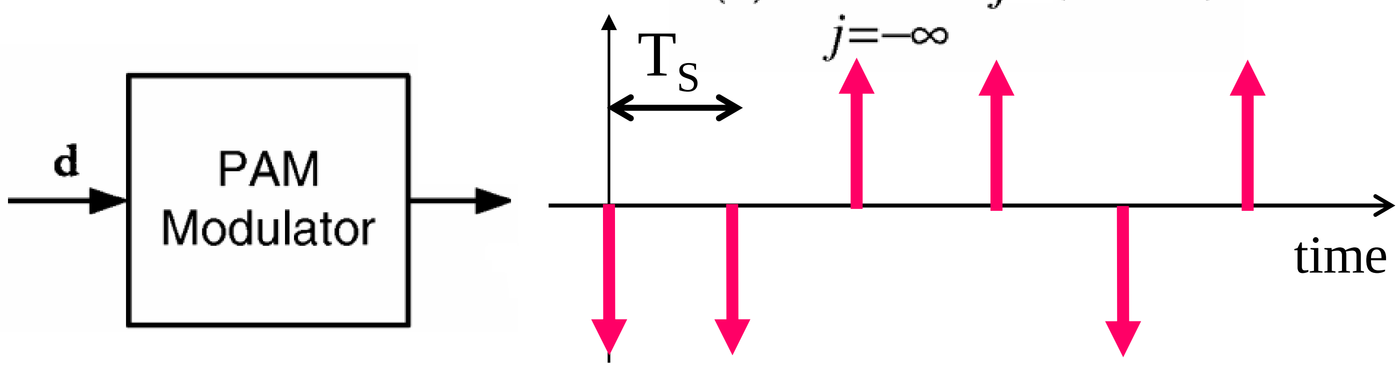
$$R_c = \frac{N_s}{T_b} = \frac{1}{T_s} \qquad R_p = \frac{N_s}{T_b} = \frac{1}{T_s}$$

- Sequence **d** enters a third system, the PAM modulator, which generates a sequence of Dirac pulses $\delta(t)$ at a rate of $R_p = N_s/T_b = 1/T_s$.
- These pulses are located at times jT_s.

$$s(t) = \sum_{j=-\infty}^{+\infty} d_j \, \delta(t - jT_s)$$

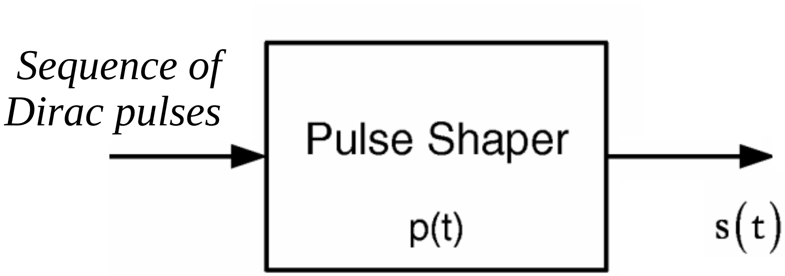
-1 -1 +1 +1 -1 +1

Coded binary sequence



Generation of DS-UWB signals (5/6)

The pulse shaper



$$R_p = \frac{N_s}{T_b} = \frac{1}{T_s}$$

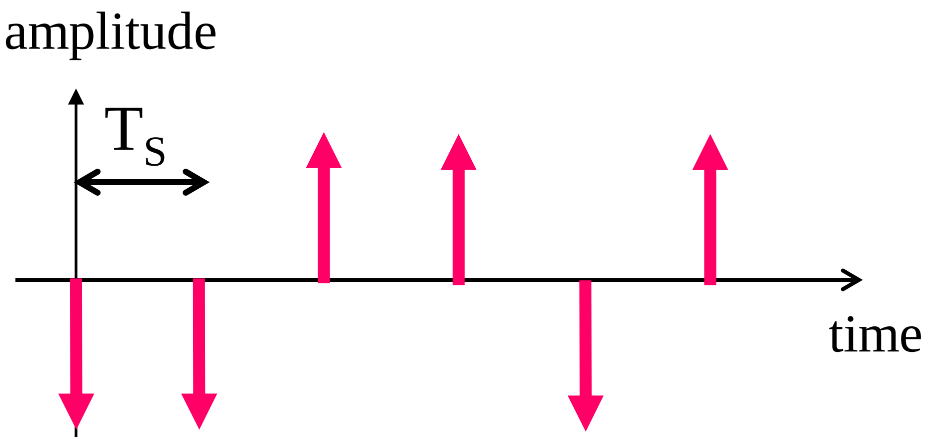
(pulses/s)

- The last system is the pulse shaper filter with impulse response *p(t)*. The impulse response *p(t)* must be such that the signal at the output of the pulse shaper filter is a sequence of strictly non-overlapping pulses

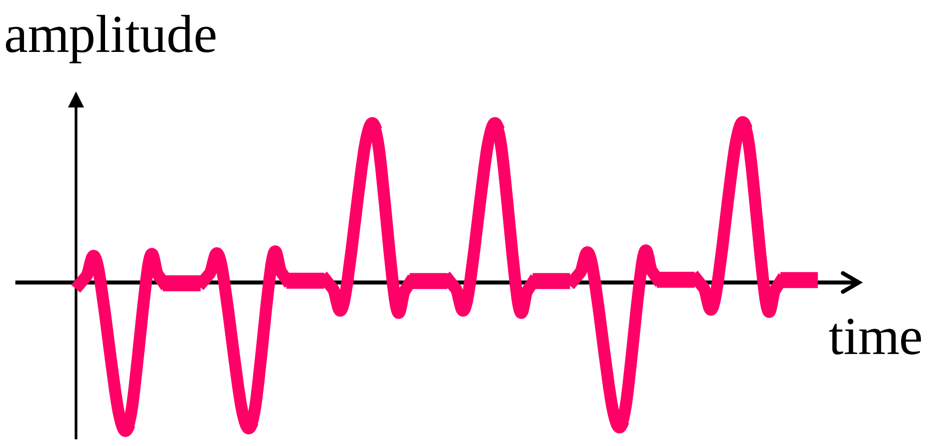
$$s(t) = \sum_{j=-\infty}^{+\infty} d_j p(t - jT_s)$$

Analytical expression for a PAM-DS-UWB signal

Generation of DS-UWB signals (6/6)



Signal at the input of the pulse shaper



Signal at the output of the pulse shaper

PPM vs. PAM

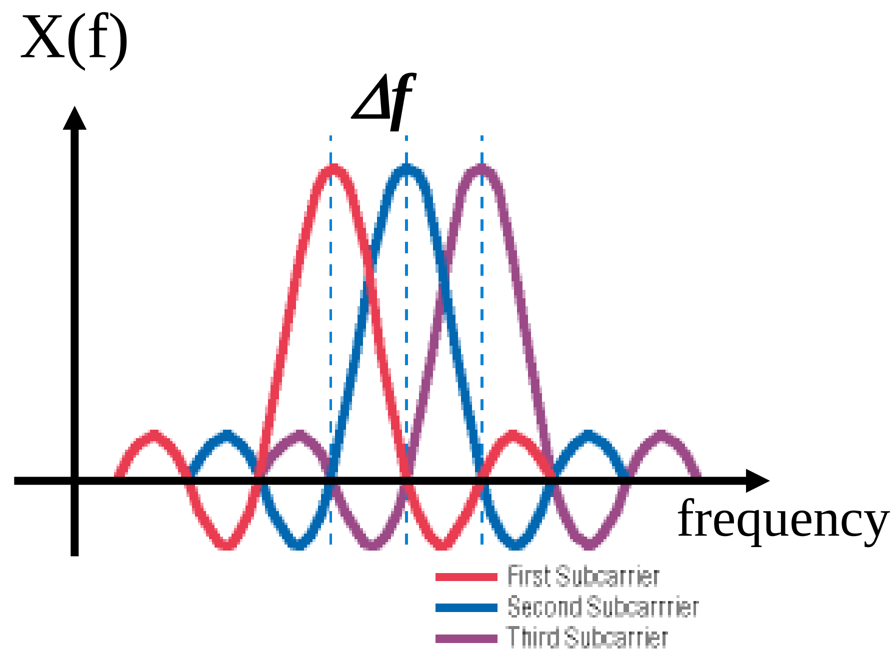
- Modulation efficiency of both PPM and PAM can be determined in terms of inter-symbol distance as a function of the energy per bit.
- The symbol constellations for PPM and PAM indicates that binary PAM leads to a greater inter-symbol distance than PPM, which results in a 3 dB advantage in efficiency: <u>PPM requires twice as much energy as PAM to achieve the same bit error rate</u>.
- On the other side, PPM requires only a single polarity for the generated pulses, so the transceiver structure may be simpler than that for PAM.

Generation of Multi Band UWB signals (1/4)

- The Multi Band (MB) approach moves away from the Impulse Radio (IR) principle.
- In particular, based on the UWB definition released by the FCC, the overall bandwidth is split into smaller frequency bands of at least 500 MHz each.
- The transmission of data for a given user occurs on different sub-bands in subsequent periods of time.
- Different types of modulation can be adopted for data modulation within each sub-band. The most popular criterion is based on the well-known Orthogonal Frequency Division Multiplexing (OFDM)

Generation of Multi Band UWB signals (2/4)

- An OFDM-modulated signal consists of the parallel transmission of several signals that are modulated at different carrier frequencies f_m. These carriers are equally spaced by Δf in the frequency domain.



$$\underline{x}(t) = g_T(t) \sum_{m=0}^{N-1} c_m e^{j 2\pi f_m t}$$

Analytical expression of the complex envelope of a single OFDM symbol

- According to the MB-OFDM approach, different OFDM symbols may be transmitted by using different carriers, that is, by adopting a Frequency Hopping (FH) scheme.

Generation of Multi Band UWB signals (3/4)

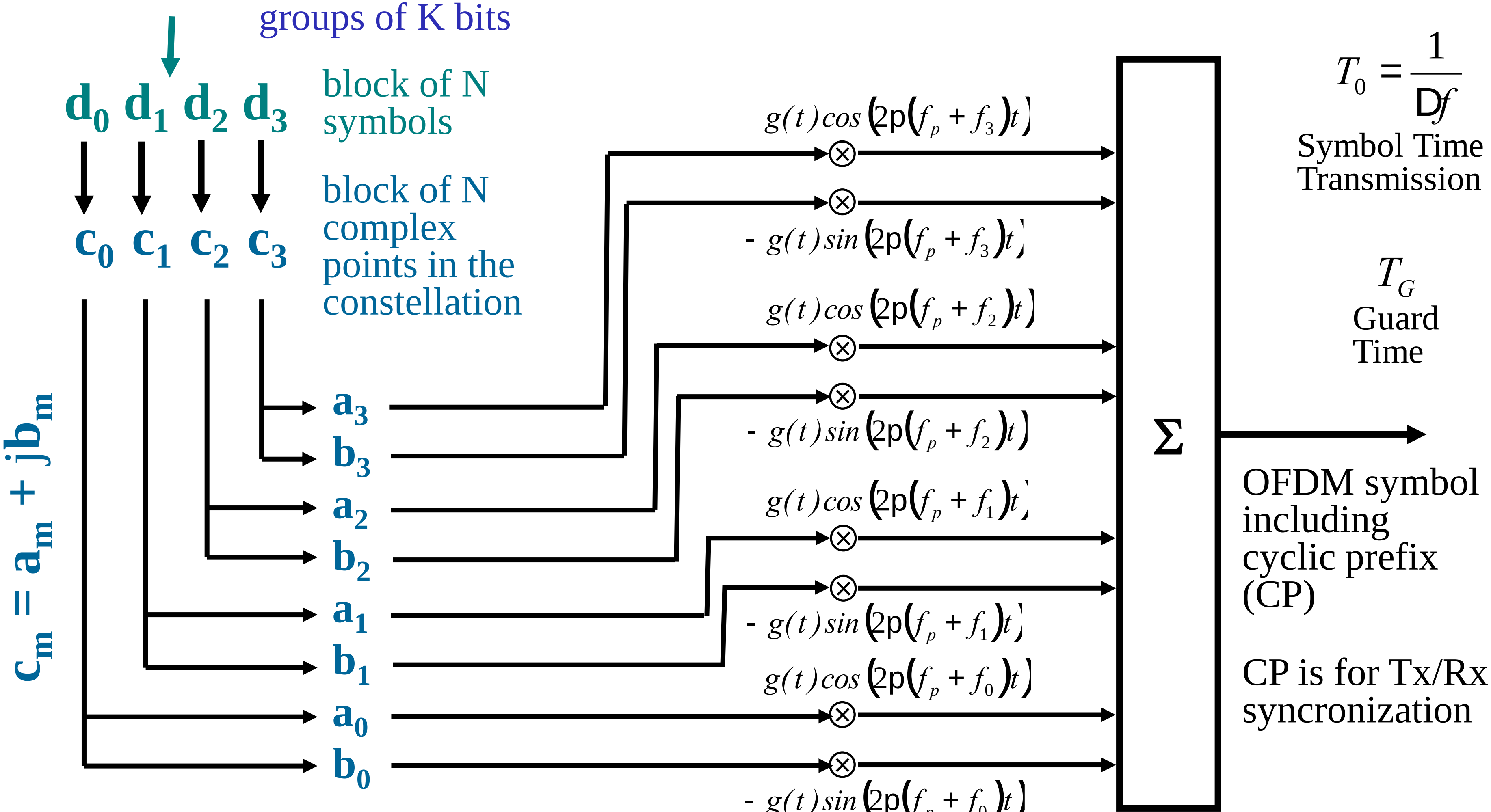
original binary stream

Reference architecture of an OFDM transmitter

… 1 0 0 1 1 0 1 0 1 1 …

groups of K bits

$$f_m = m\Delta f - \frac{N}{2}\Delta f \qquad g(t) = \frac{1}{\sqrt{T_G + T_0}} \quad with \ t \in [-T_G, T_0]$$



Generation of Multi Band UWB signals (4/4)

"All digital" implementation of an OFDM transmitter

original binary stream

$$\ldots\ \underbrace{1\ 0\ 0\ 1\ 1}\ \underbrace{0\ 1\ 0\ 1\ 1}\ \ldots$$

groups of K bits

$\mathbf{d_0\ d_1\ d_2\ d_3}$ block of N symbols

$\mathbf{c_0\ c_1\ c_2\ c_3}$ block of N complex points in the constellation

IDFT

$$C_n = \sum_{m=0}^{N-1} c_m e^{j\frac{2\pi mn}{N}}$$

$\mathbf{C_0\ C_1\ C_2\ C_3} \rightarrow \mathbf{C_2\ C_3\ C_0\ C_1\ C_2\ C_3} \rightarrow \square \rightarrow \mathbf{x_2\ x_3\ x_0\ x_1\ x_2\ x_3}$

Cyclic prefix

$$x_n = \sqrt{1/T}\,(-1)^n C_n$$

OFDM symbol ready for RF transmission