Practice #4 – October 08, 2021

Ultra Wide Band Radio Fundamentals

Generation of UWB Signals

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Outline

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The UWB radio signal: an overview

UWB TXs

UWB radio signals

Generation of a UWB signal:

1. **IR-UWB**: very short pulse width + spreading code
   - TH (Time-Hopping),
   - DS (Direct-Sequence);
2. **non IR-UWB**: very high data rate
   - OFDM,
   - MC-CDMA.

In the following, analysis of the IR-case.

The UWB pulse shape

A suitable shape for UWB signals is the **monocycle** (= 1st derivative of a gaussian).

The classical gaussian shape is:

$$g(t) := \mathcal{N}(0, \sigma^2)(t) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{t^2}{2\sigma^2}\right)$$

Who is in general the ***n***-th order derivative?

It can be shown by means of mathematical induction principle that:

$$\frac{d^n}{dt^n} g(t) = \frac{(-1)^n}{\sigma^n} \mathrm{H}_n\left(\frac{t}{\sigma}\right) g(t), \quad n \in \mathbb{N}$$

where $\mathrm{H}_n(\cdot)$ is the ***n***-order Hermite polynomial, defined recursively as follows:

$$\begin{cases} \mathrm{H}_0(x) = 1, \\ \mathrm{H}_1(x) = x, \\ \mathrm{H}_{n+1}(x) = x\,\mathrm{H}_n(x) - n\,\mathrm{H}_{n-1}(x). \end{cases}$$

Let be $\sigma^2 = \tau^2/(4\pi)$: then,

- the **monocycle** is $g'(t)$;
- the **doublet** is $g''(t)$.

Exercise 1 (Pulse Shape Generator)

Write the module

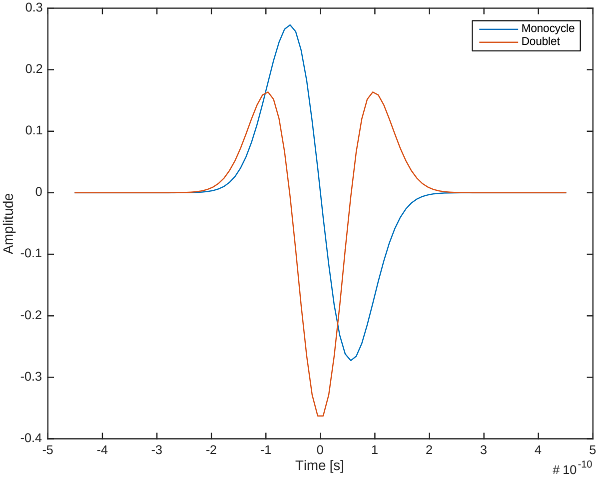
```
p = gaussian_wf(sample_freq, duration, tau, n)
```

that returns the *n*-th derivative **p** of a gaussian pulse with shape-parameter **tau**, at least for cases *n*=1,2.

Settings:

```
fc   = 10e10;      % Sampling Frequency [Hz]
Tm   = 0.9e-9;     % Pulse Duration [s]
tau  = 0.2e-9;     % Shape Factor
n    = 1,2;        % Order of derivative
```

Figure 1: n=1 (monocycle) vs. n=2 (doublet)



Outline

2PPM-TH-UWB

CHECKPOINT 2–1

Provide an implementation of a 2PPM-TH-UWB TX:

Exercise 2 (PPM-TH)

```
[data, c, signal, TH_signal] = TX_BPPM_TH(...
                      num_bits, Ns, smp_freq, Tc, Ts, ...
                      Np, Nh, dPPM, IR_d, tau, powdBm),
```

with:

- num_bits: bitstream length,
- Ns: channel coder rep factor,
- smp_freq: sampling freq,
- Tc: chip time,
- Ts: frame time,
- Np: TH code length,
- Nh: code max value,
- dPPM: PPM dither,
- IR_d: gaussian pulse duration,
- tau: shape-parameter,
- powdBm: avg tx power.

2PPM-TH-UWB

CHECKPOINT 2–1

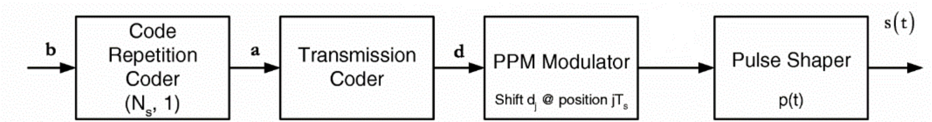
Provide an implementation of a 2PPM-TH-UWB TX:

Exercise 2 (PPM-TH)

```
[data, c, signal, TH_signal] = TX_BPPM_TH(...
                    num_bits, Ns, smp_freq, Tc, Ts, ...
                    Np, Nh, dPPM, IR_d, tau, powdBm),
```

```
numbits  = 2;          % bitstream length
Ns = 3;                % channel coder repetition factor
Np = 3;                % Time Hopping code length
Nh = 3;                % code max value
Tc = 1e-9;             % Chip time
Ts = 5e-9;             % frame time
dPPM = 0.2e-9;         % PPM shift
IR_d=Tm = 0.9e-9;      % Pulse Duration [s]
powdBm = -30;          % avg Tx Power [dBm]
```

Remind:Transmission scheme for a PPM-TH-UWB signal



Modulates and encodes the signal

Introduces redundancy

Shapes the spectrum

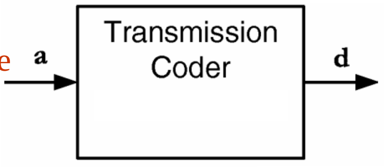
Remind:Transmission scheme for a PPM-TH-UWB signal

Original binary sequence

1 0

Code repeated binary sequence

1 1 1 0 0 0



Coded real valued sequence

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

values in nanoseconds

0.2 , 3.2 , 1.2 , 2.0 , 0.0 , 3.0

Time Hopping code c ($N_P = 4$)

0 3 1 2

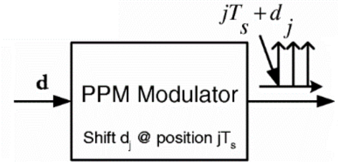
chip time T_c = 1 ns

PPM shift ε = 0.2 ns

Remind:Transmission scheme for a PPM-TH-UWB signal

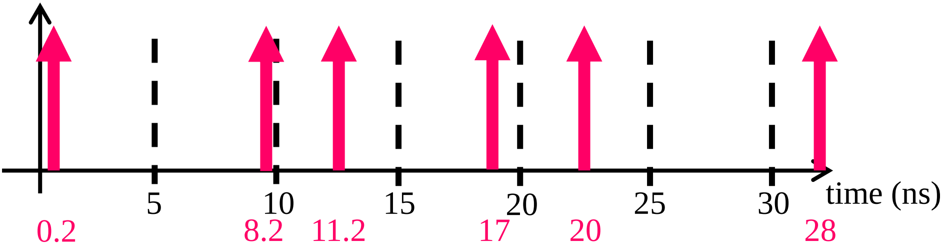
Original binary sequence	Code repeated binary sequence	Coded real valued sequence
1 0	1 1 1 0 0 0	0.2 , 3.2 , 1.2 , 2.0 , 0.0 , 3.0
		values in nanoseconds

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

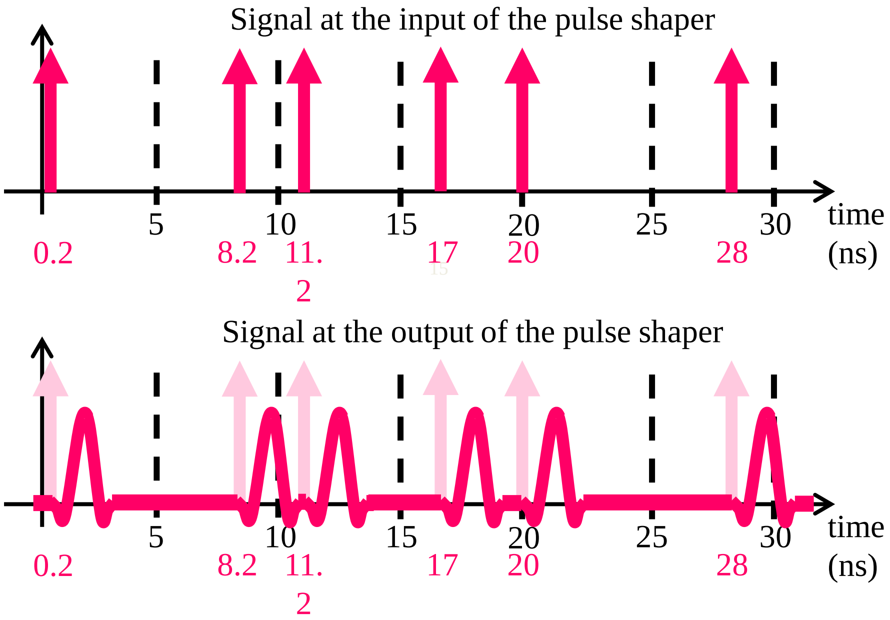


Dirac pulses, with average pulse repetition period T_S = 5 ns

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



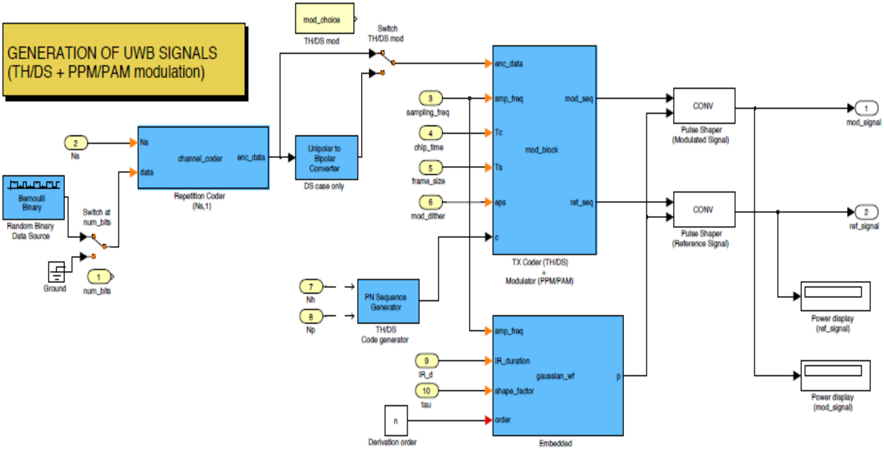
Remind:Transmission scheme for a PPM-TH-UWB signal



Split the TX in the following parts:

- `data = binary_source(num_bits)`,
- `rep_data = channel_coder(Ns,data)`,
- `c = TH_code_generator(Nh,Np)`,
- `[PPM_TH_seq, TH_seq] = BPPM_TH_mod(... rep_data,smp_freq,Tc,Ts,dPPM,c)`,
- `p = gaussian_wf(smp_freq,duration,tau,order)`.

The following scheme is useful in the 2PAM-DS-UWB case too.


GENERATION OF UWB SIGNALS
(TH/DS + PPM/PAM modulation)
mod_choice
TH/DS mod
Switch
TH/DS mod
2
Ns
Ns
data
channel_coder
enc_data
Repetition Coder
(Ns,1)
Unipolar to
Bipolar
Converter
DS case only
Bernoulli
Binary
Random Binary
Data Source
Switch at
num_bits
Ground
1
num_bits
3
sampling_freq
4
chip_time
5
frame_size
6
mod_dither
enc_data
smp_freq
Tc
Ts
eps
c
mod_seq
mod_block
ref_seq
TX Coder (TH/DS)
+
Modulator (PPM/PAM)
7
Nh
8
Np
PN Sequence
Generator
TH/DS
Code generator
smp_freq
IR_duration
gaussian_wf
shape_factor
order
p
9
IR_d
10
tau
n
Derivation order
Embedded
CONV
Pulse Shaper
(Modulated Signal)
CONV
Pulse Shaper
(Reference Signal)
1
mod_signal
2
ref_signal
Power display
(ref_signal)
Power display
(mod_signal)

2PAM-DS-UWB

CHECKPOINT 2–2

Provide an implementation of a 2PAM-DS-UWB TX:

Exercise 3 (PAM-DS)

```
[data, ac, signal, DS_signal] = TX_BPAM_DS(...
                        num_bits, Ns, smp_freq, Ts, ...
                        Np, Nh, IR_d, tau, powdBm),
```

There are few differences with respect to the TH-UWB case.

- `ac = DS_code_generator(Nh,Np)`,
- `[PAM_DS_seq, DS_seq] = BPAM_DS_mod(a,smp_freq,Ts,c)`.