Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

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Re: [IEEE 802.15.4a Call for Proposals]

Abstract: [This document proposes preliminary proposal for the IEEE 802.15.4a PHY standard based on the UWB direct chaotic communications technology.]

Purpose: [This document proposes preliminary proposal for the IEEE 802.15.4a PHY standard.]

UWB Direct Chaotic Communications Technology

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Outline

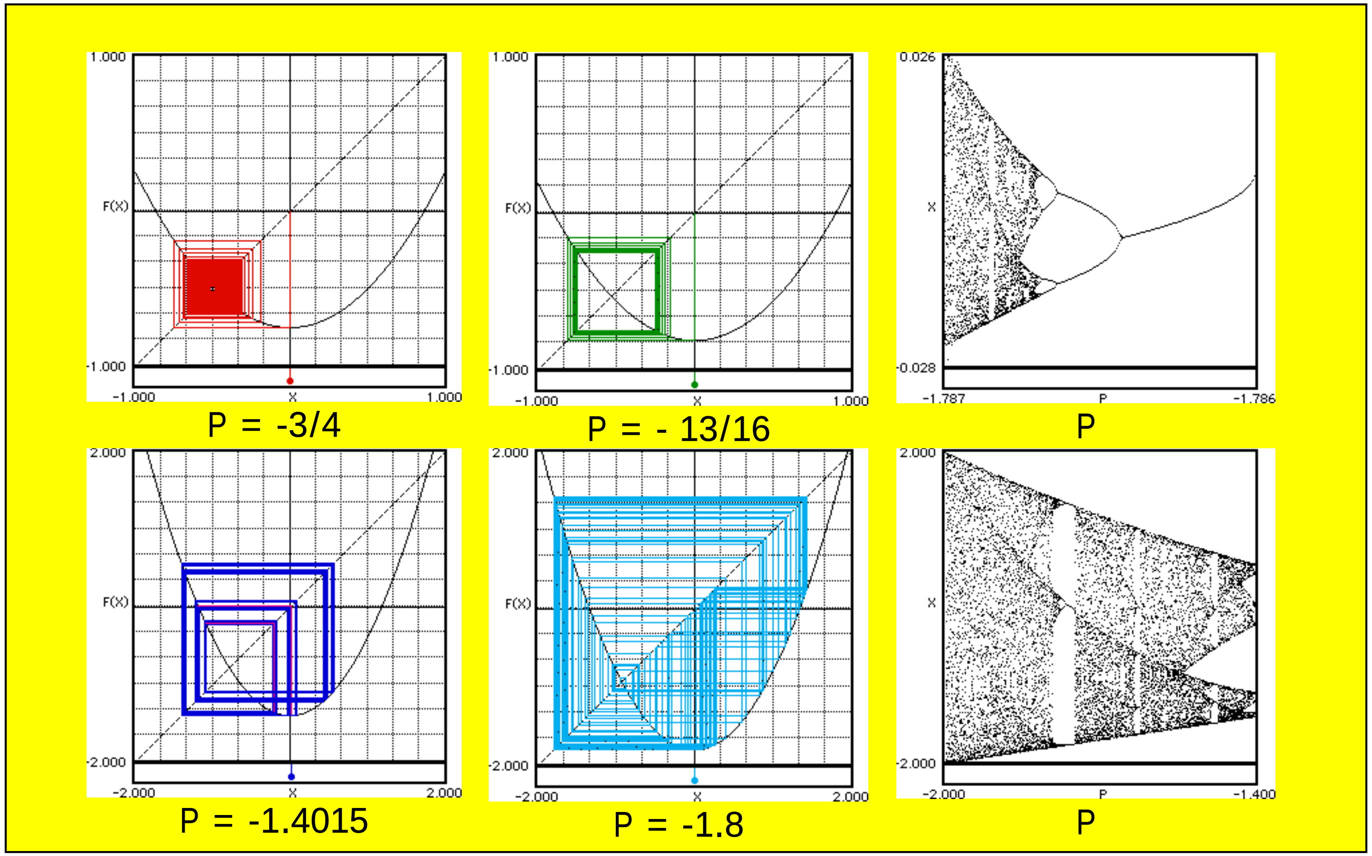
- Introduction to Chaotic Signal
- Principle of Direct Chaotic Communications (DCC)
- Chaotic Modulation Schemes
- System Performance of DC-OOK
- Conclusion

What is Dynamical Chaos?

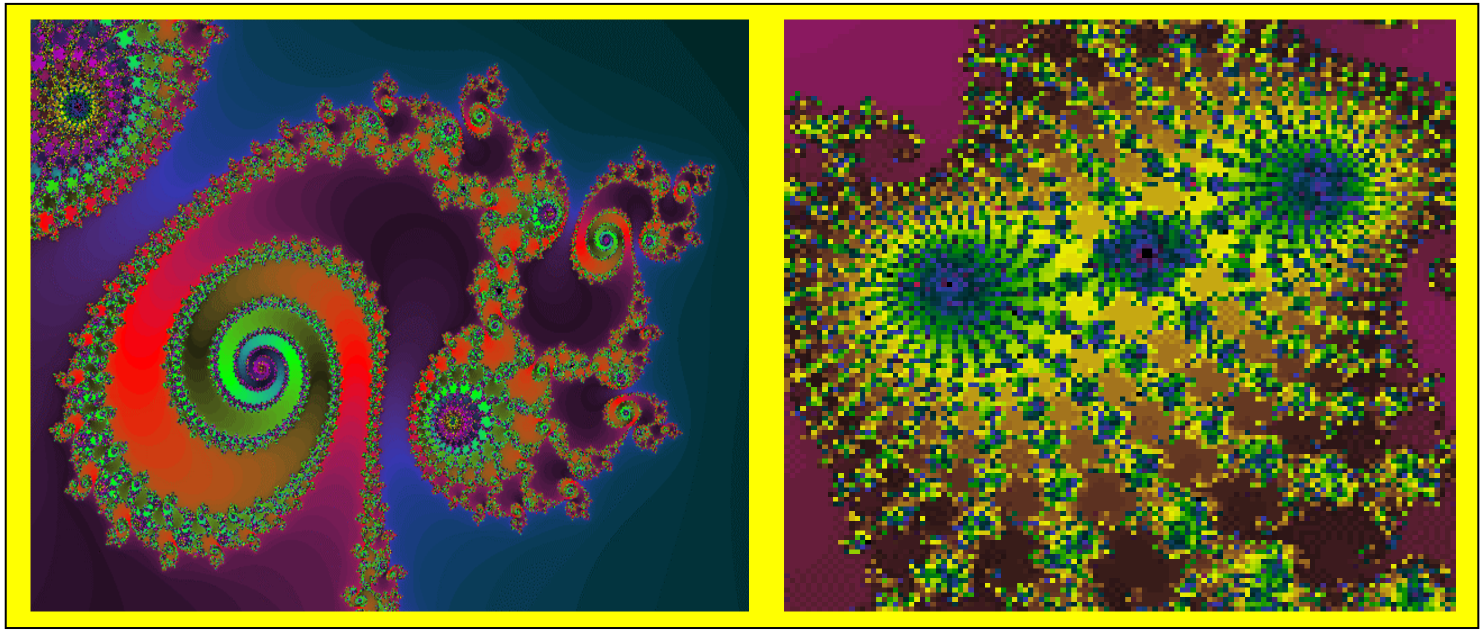
- Dynamical chaos is aperiodic long-term behavior in a deterministic system that exhibits sensitive dependence on initial conditions
- Described by differential equations – dimension $\geq$ 3 for chaotic behavior

Dynamical Chaos

Example Logistic map: $X(n+1) = X^2(n) + P$



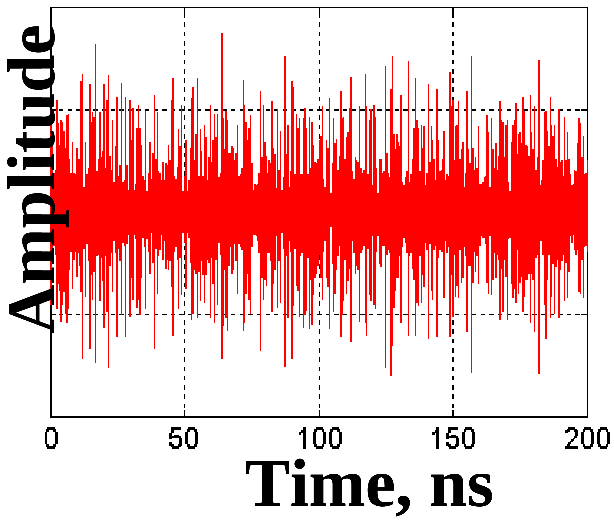
Beauty of Dynamical Chaos

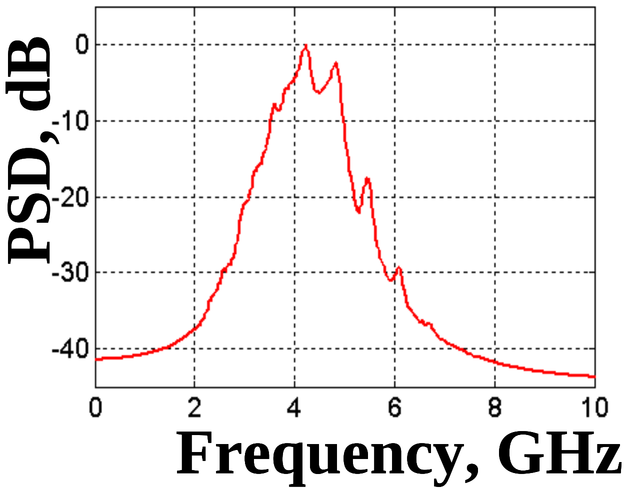


Characteristics of Chaotic Signal (1)

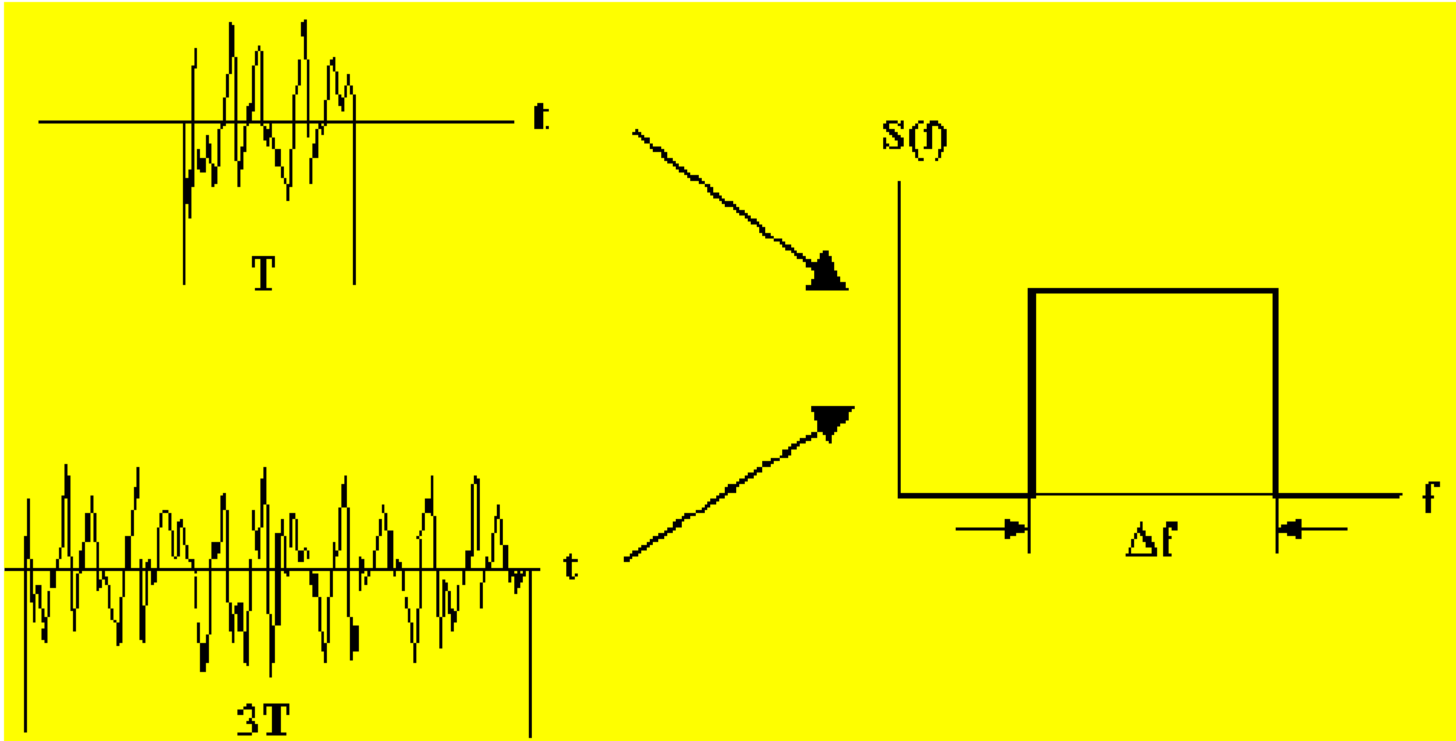
- Low power consumption
  - Chaotic oscillator is a non-linear system → efficiency can be achieved with low power requirement
- Simple circuits
  - Chaotic signal can be generated directly into the desired microwave band by a chaotic generator
- Low cost implementation
  - The low power consumption device leads to low cost product
- Multipath resistance
  - Wideband signal is very immune against multipath fading
- Self-inherent spread spectrum
  - The chaotic signal can be used as the spreading signal for spread spectrum system
- Good spectral properties
  - Non-periodic with a flat (or tailored) spectrum
- Security/Confidentiality
  - Low probability of detection and intercept due to the noise like signal of chaos properties
- Flexibility
  - Chaotic radio pulse with different time duration can have the same bandwidth

Characteristics of Chaotic Signal (2)





Characteristics of Chaotic Signal (3)



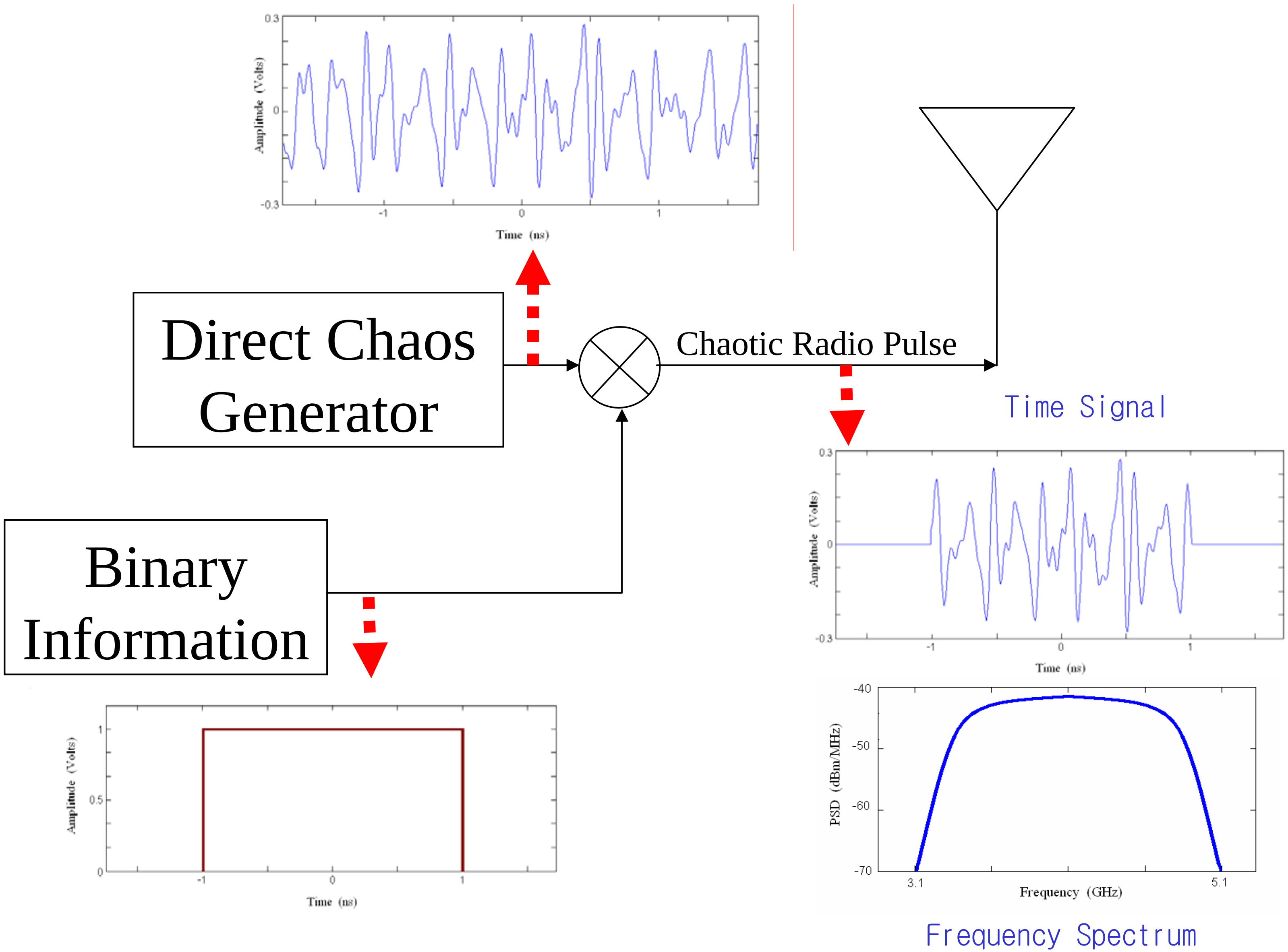
Methods to Generate Chaos

- Chaotic Masking
- Chaotic Shift Keying
- Non-Linear Masking
- Direct-Chaotic Communication

Direct Chaotic Communication (DCC)

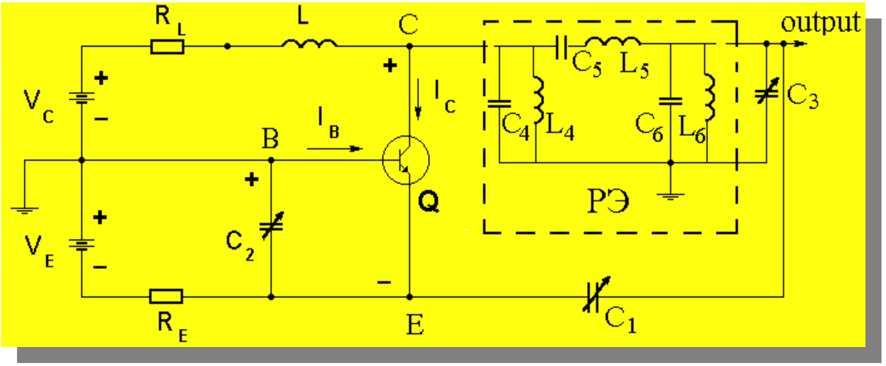
- Chaotic source generates oscillations directly in a specified microwave band.
- Information component is put into the chaotic carrier using the stream chaotic radio pulses.
- Information is retrieved from the chaotic radio pulses without intermediate heterodyning.
- Most simple non-coherent receiver is used.

Direct Chaotic Signal Generation

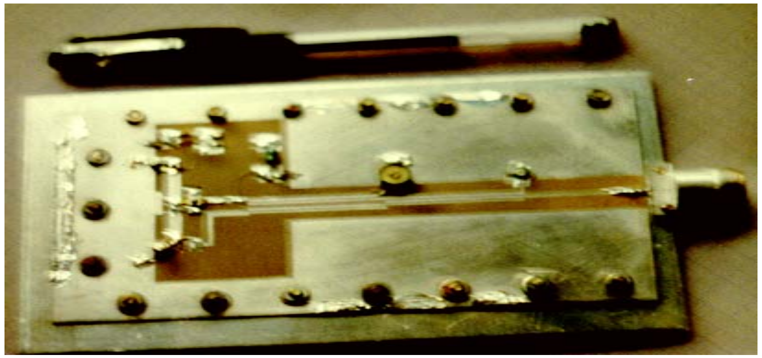


Chaotic Generator Model

Oscillator circuit



Experiment device



Chaotic Mathematical Model

- 2nd order differential equation implemented by ODE with 4.5 freedom

System Equations

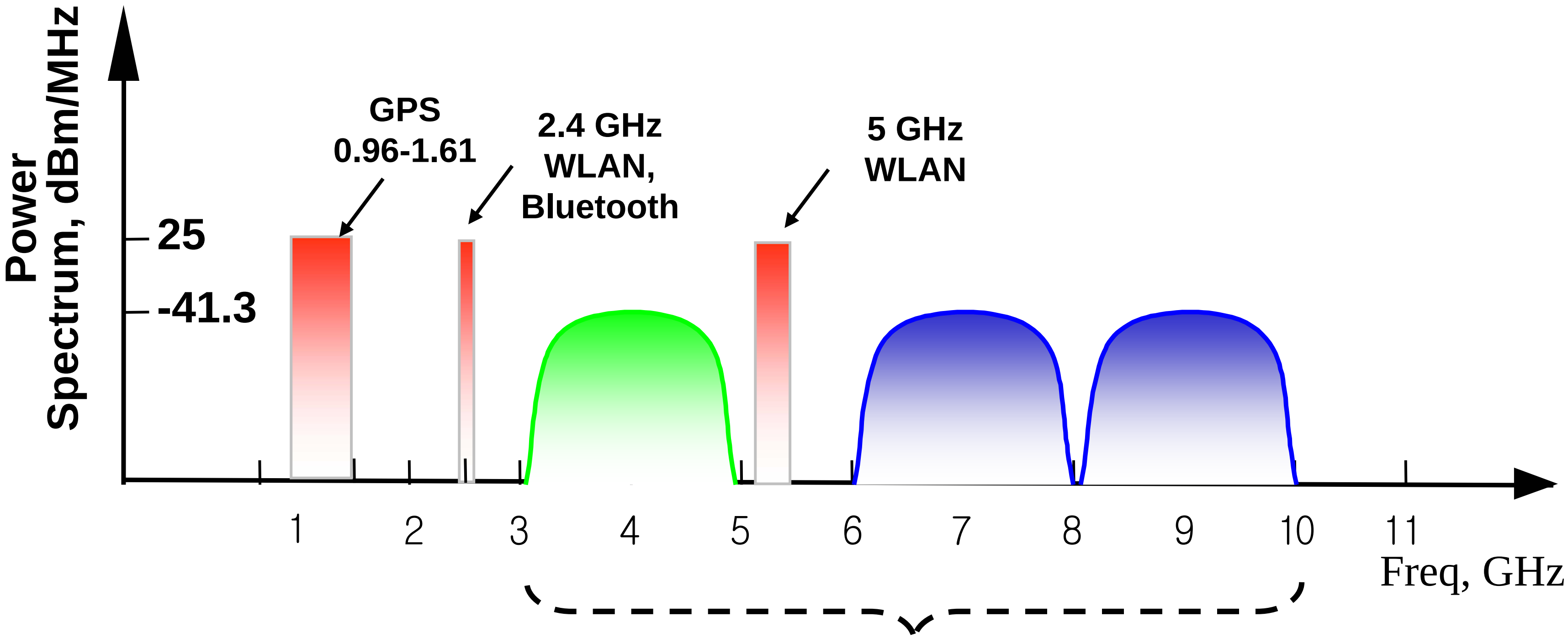
$$T\dot{x}_1 + x_1 = mF(x_5)$$
$$\ddot{x}_2 + \alpha_2\dot{x}_2 + \omega_2^2 x_2 = \omega_2^2 x_1$$
$$\ddot{x}_3 + \alpha_3\dot{x}_3 + \omega_3^2 x_3 = \alpha_3\dot{x}_2$$
$$\ddot{x}_4 + \alpha_4\dot{x}_4 + \omega_4^2 x_4 = \alpha_4\dot{x}_3$$
$$\ddot{x}_5 + \alpha_5\dot{x}_5 + \omega_5^2 x_5 = \alpha_5\dot{x}_4$$

Runge-Kutta Method

y(1) = (m*Fx5 - X1)/T;
y(2) = W1*W1*(X1- X3);
y(3) = X2 - A1*X3;
y(4) = A2*y3-W2*W2*X5;
y(5) = X4 - A2*X5;
y(6) = A3*y(5)-W3*W3*X7;
y(7) = X6 - A3*X7;
y(8) = A4*y(7)-W4*W4*X9;
y(9) = X8 - A4*X9;

Nonlinearity $$F(z) = M\left[|z+e_1| - |z-e_1| + \frac{|z-e_2| - |z+e_2|}{2} \right]$$

Frequency Band Plan (1)

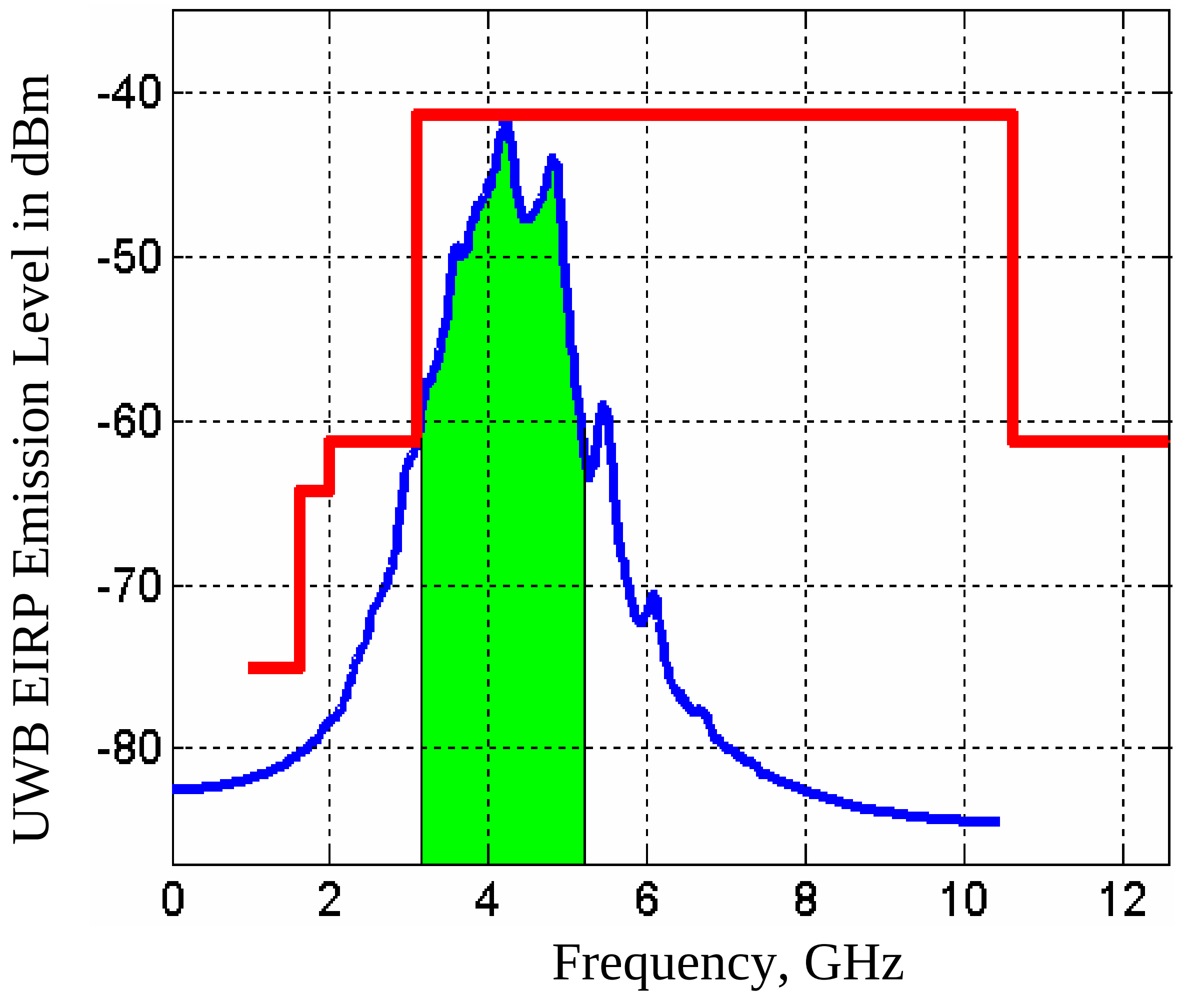


FCC Spectrum Mask for UWB

Frequency Band Plan (2)

- Operating Frequency: 3.1–5.1 GHz
- Why Lower Band?
  - Limitation in the technical capabilities of integrated circuit implementation at higher frequency.
  - Limit of low cost ICs beyond 6 GHz.
  - Prevent coexistence with 5 GHz WLAN band.
  - Use as much bandwidth as possible to maximize the emitted power and follows FCC rules i.e. >500MHz.
- Can be easily change to use higher band if necessary or when cheap technologies available in the future.

FCC Emission Mask



Types of Chaotic Modulation Schemes

<table>
<tr><th>Class</th><th colspan="2">System</th><th>Correlator type detection applicable</th><th>References</th></tr>
<tr><td rowspan="3">Coherent</td><td>Analog</td><td>Chaotic masking</td><td>No</td><td>Kocarev et al.
Cuomo and Oppenhiem.
Milonovic and Zaghloul</td></tr>
<tr><td rowspan="2">Digital</td><td>Generic:
Chaos shift keying (CSK)
CSK (correlation)
Symmetric CSK</td><td>No
Yes
Yes</td><td>Parlitz et al.
Kolumban et al.
Sushchick et al.</td></tr>
<tr><td>DS spread spectrum:
Chaotic spreading sequence
Chaotic digital CDMA
Quantized chaotic spreading sequence</td><td>Yes
Yes
Yes</td><td>Heidari-Bateni and McGillem.
Yang and Chua
Mazzini et al.</td></tr>
<tr><td rowspan="2">Non-Coherent</td><td>Analog</td><td>Chaotic modulation
Signal reconstruction based system</td><td>No
No</td><td>Itoh-Murakami
Feng and Tse</td></tr>
<tr><td>Digital</td><td>Differential CSK (DCSK)
FM-DCSK
Chaotic On-Off Keying (COOK)
CSK (bit-energy)
CSK (optimal)
CSK (regression)
Correlation delay shift keying
Quadrature CSK</td><td>Yes
Yes
No
No
No
No
Yes
Yes</td><td>Kolumban et al.
Kolumban et al.
Kolumban et al.
Kolumban et al.
Hasler and Schimming
Tse et al.
Sushchick et al.
Galias and Maggio</td></tr>
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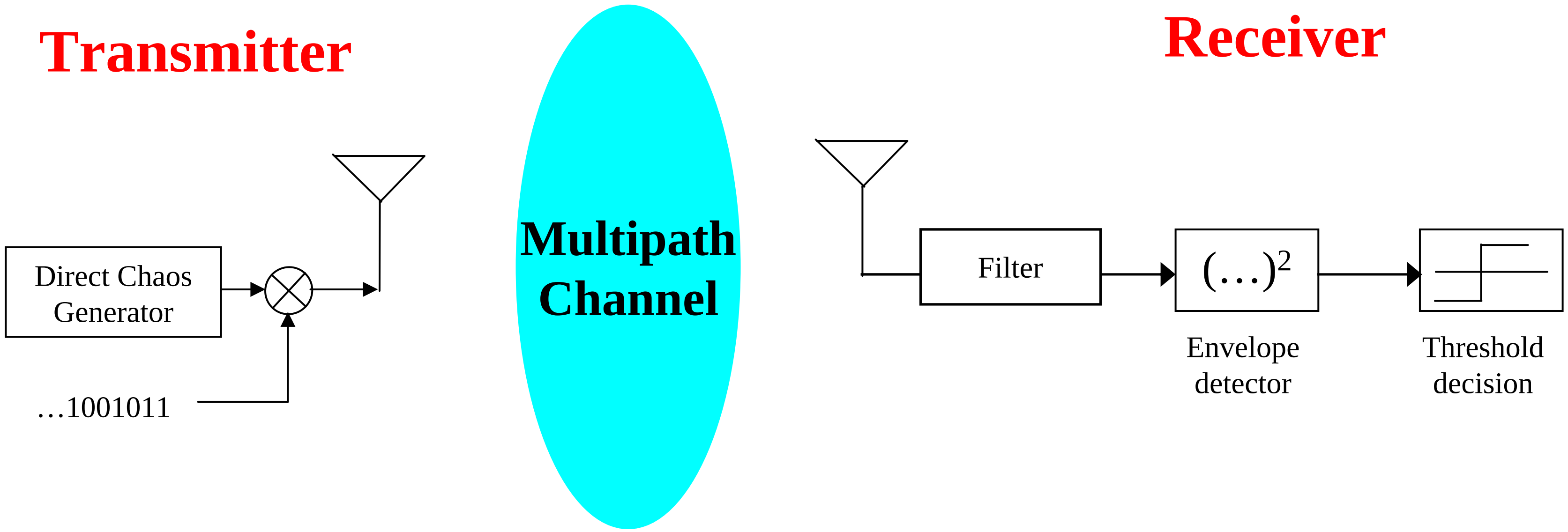
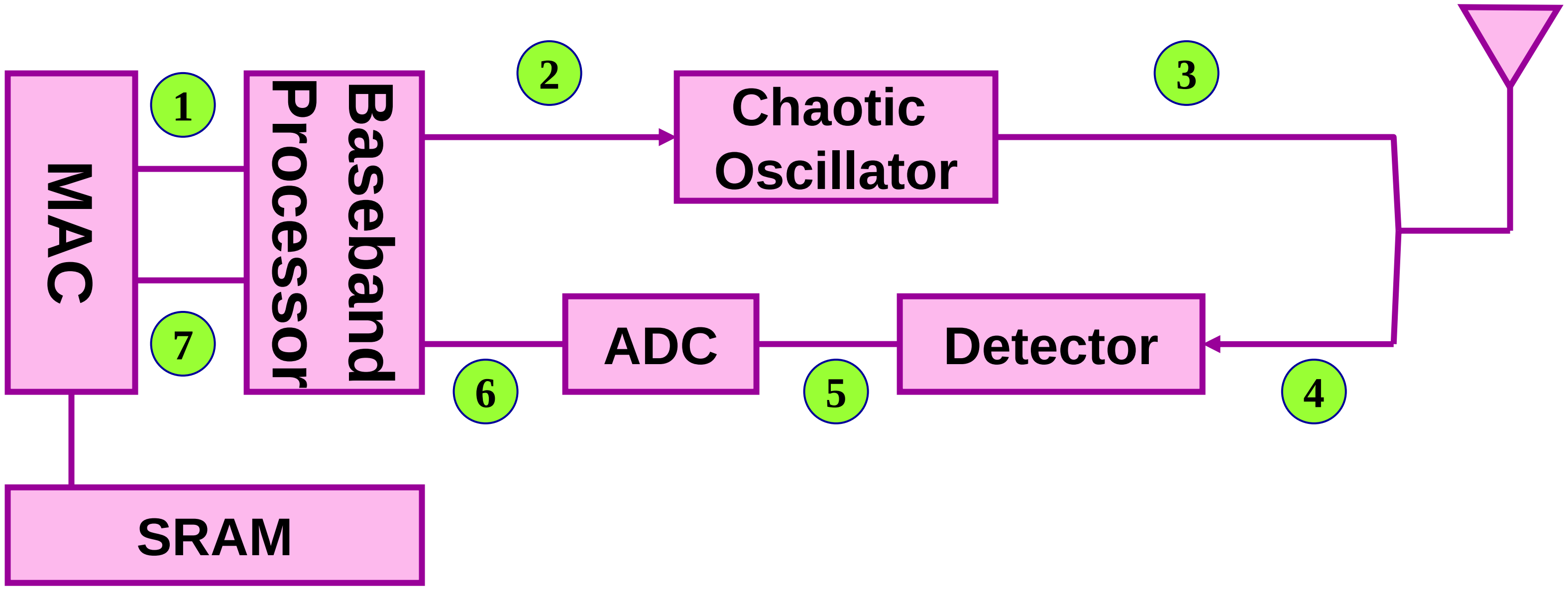
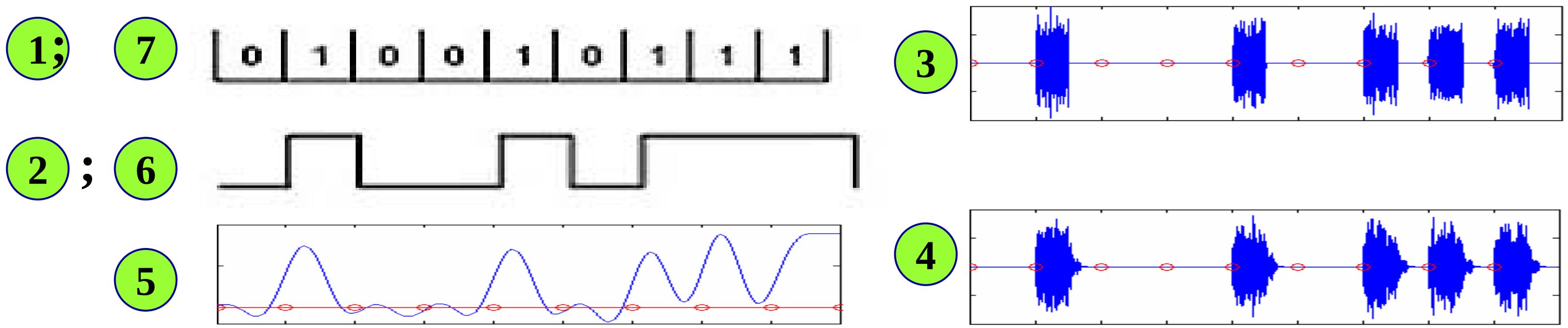
DC-OOK Transmitter & Receiver



DC-OOK Transceiver Architecture

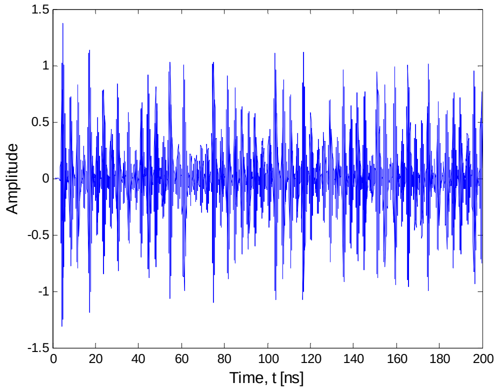


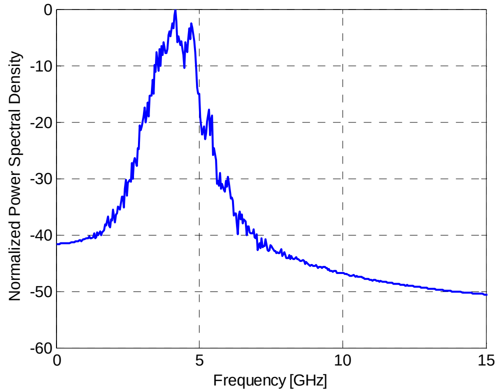


- Very simple modulation scheme: on-off power supply is used for modulation (OOK)
- Additional power saving

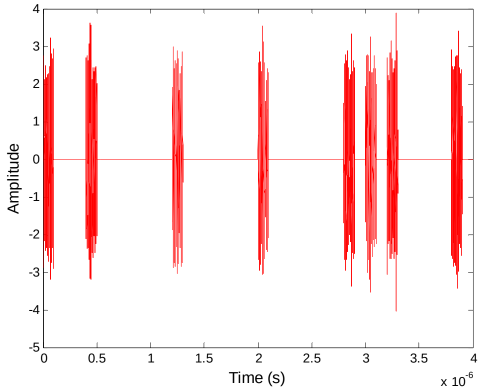
Signal Waveforms and Spectrum

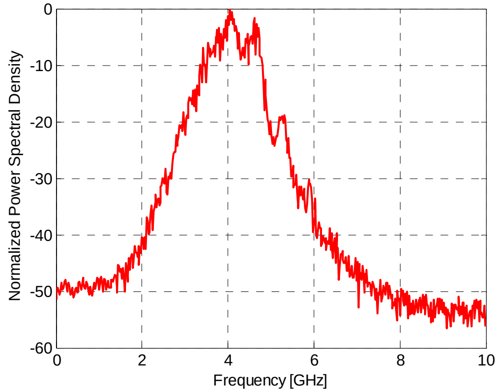
Signal of chaotic generator





Modulated signal

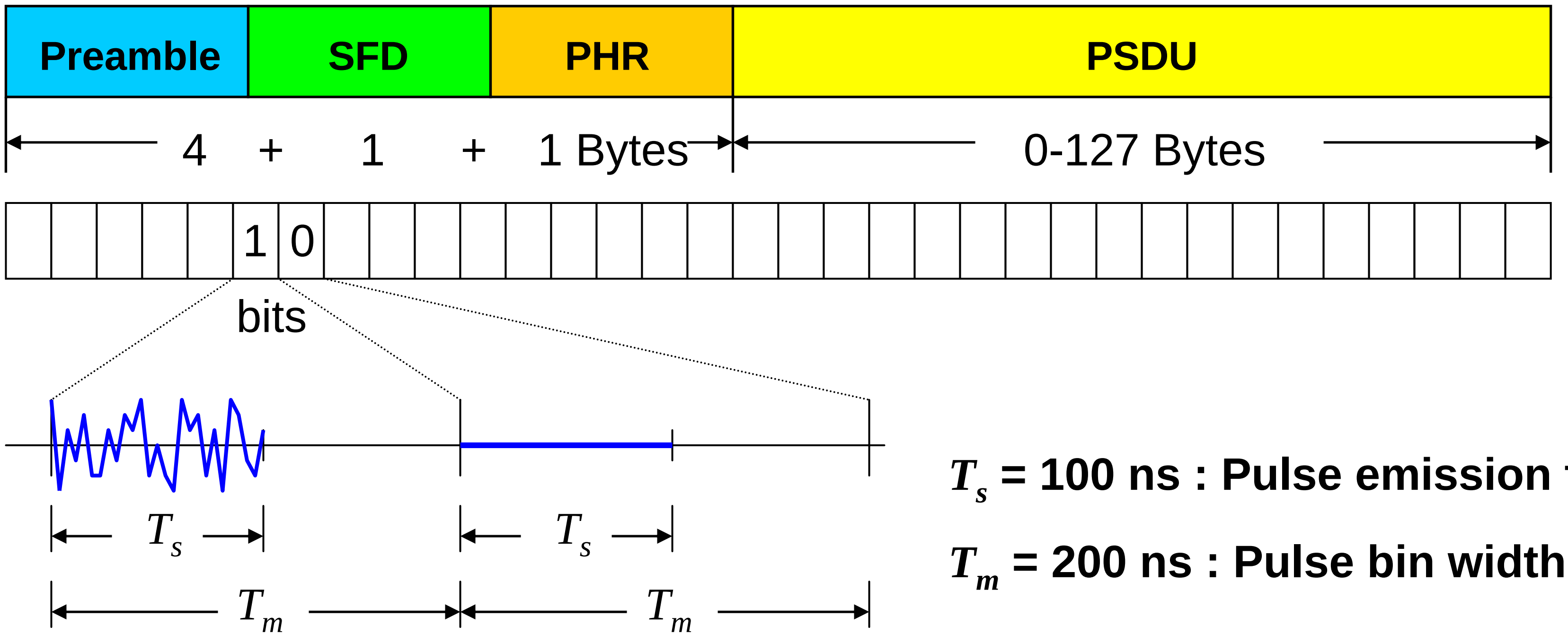




PHY Frame Structure

PHY Packet Fields

- Preamble (32 bits) – synchronization
- SFD (Start of Frame Delimiter) (8 bits) – specifies frame type
- PHR (PHY Header) (8 bits) – Sync Burst flag, PSDU length
- PSDU (PHY Service Data Unit) (0 to 127 bytes) – Data field

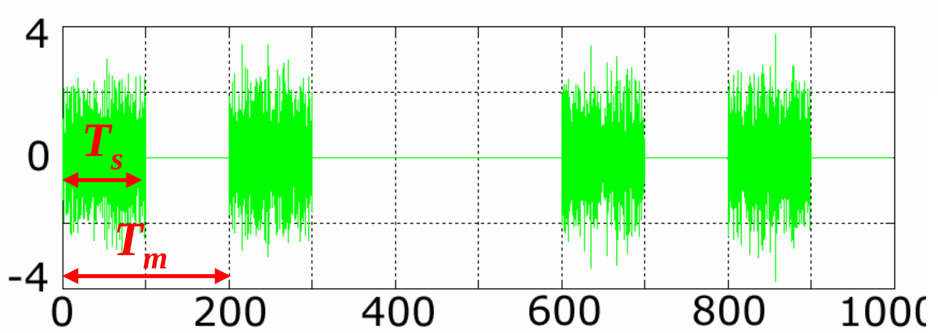


T_s = 100 ns : Pulse emission time

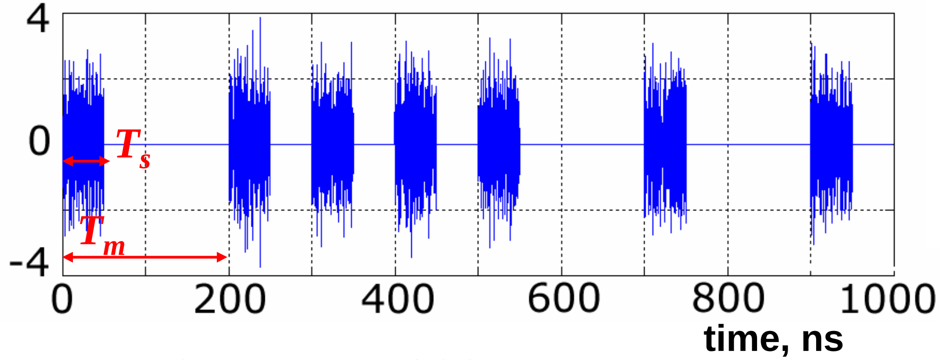
T_m = 200 ns : Pulse bin width

System Performance

Signal structure (COOK)

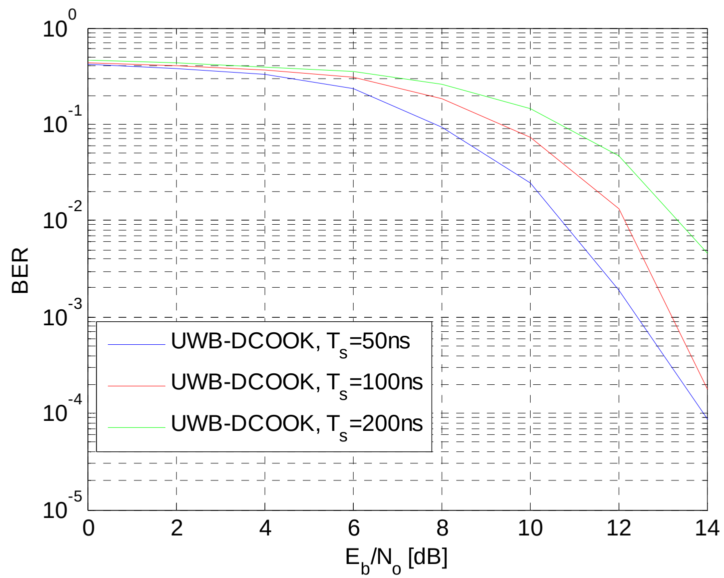


T_s = 100 ns, T_m = 200 ns



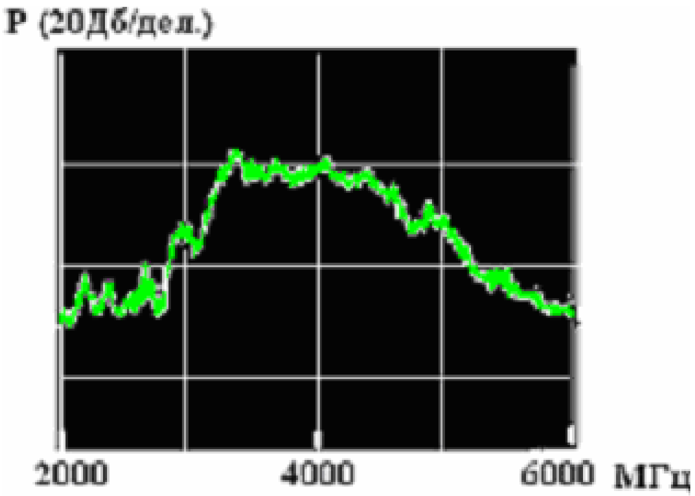
T_s = 50 ns, T_m = 200 ns

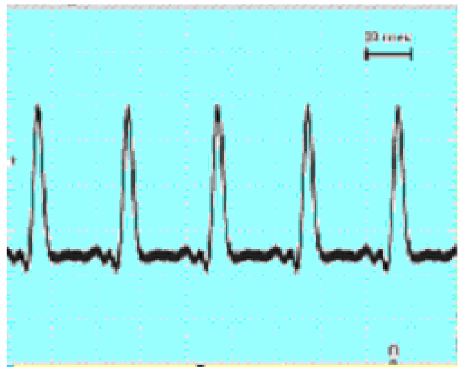
AWGN channel

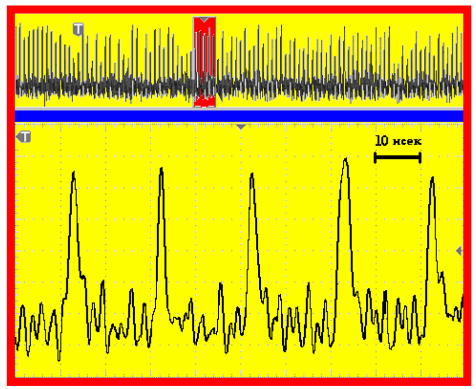


UWB-DCC System Test Bed (3.1–5.1 GHz)

UWB-DCC Experiments: 3.1–5.1 GHz







Conclusions

- Chaotic communications meet the low power, low cost & low complexity requirements.
- Proposed UWB-DCC-COOK compliant with FCC PSD regulation.
- The implemented test bed demonstrated that the feasibility of DCC technology.
- Current investigation issues:
  - UWB-DCSK modulation scheme for more robust performance.
  - Suitable location awareness techniques.
  - Multiple access solution for simultaneous operating piconets (SOP).