A LoRa Receiver with MATLAB/Simulink and the RTL-SDR

HOCHSCHULE SCHMALKALDEN
UNIVERSITY OF APPLIED SCIENCES

Carsten Roppel, Schmalkalden University of Applied Sciences
Blechhammer, D-98574 Schmalkalden, E-Mail: c.roppel@hs-sm.de

MATLAB
EXPO 2025

LoRa

- LoRa is the physical layer of a long-range wide area network (LoRaWAN)
- Chirp spread spectrum (CSS) modulation allows for long-range communication over several kilometers with low-power devices
- In a typical application sensor nodes transmit their data to a gateway connected to a server network, e. g. The Things Network (TTN)

LoRa sensor nodes from Dragino, SenseCAP and Arduino

- In Europe LoRa uses the frequency plan EU863-870 with eight carrier frequencies 867.1 MHz, 867.3 MHz, …, 868.5 MHz

Chirp Spread Spectrum (CSS) Modulation

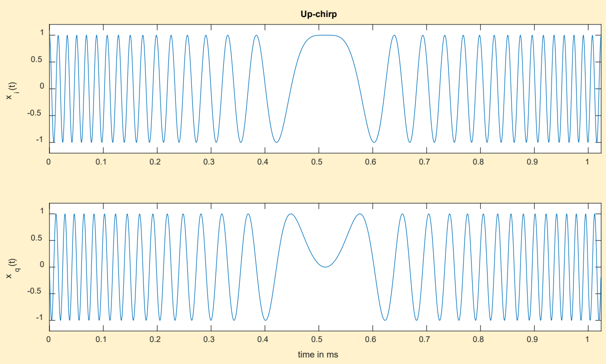
- Symbol time: $T_s = 2^{SF}/B$
  SF: Spreading factor, $SF = 6 \ldots 12$
  B: Bandwidth 125 kHz or 250 kHz
  $T_s = 1.024$ ms for $SF = 7$, $B = 125$ kHz
- Forward error correction with code rates $R_c = 4/5, 4/6, 4/7$ or $4/8$
- Bitrate $r_b = SF\, R_c/T_s = 5468.75$ bit/s ($SF = 7$, $B = 125$ kHz, $R_c = 4/5$)
- Up (down)-chirp: The frequency increases (decreases) linearly within ± B/2, the complex baseband representation is:

$$c_{up}(t) = \exp\left(j2\pi\left(f_0 + \frac{B}{2T_s}t\right)t\right)$$

- The symbol a_k determines the start frequency:

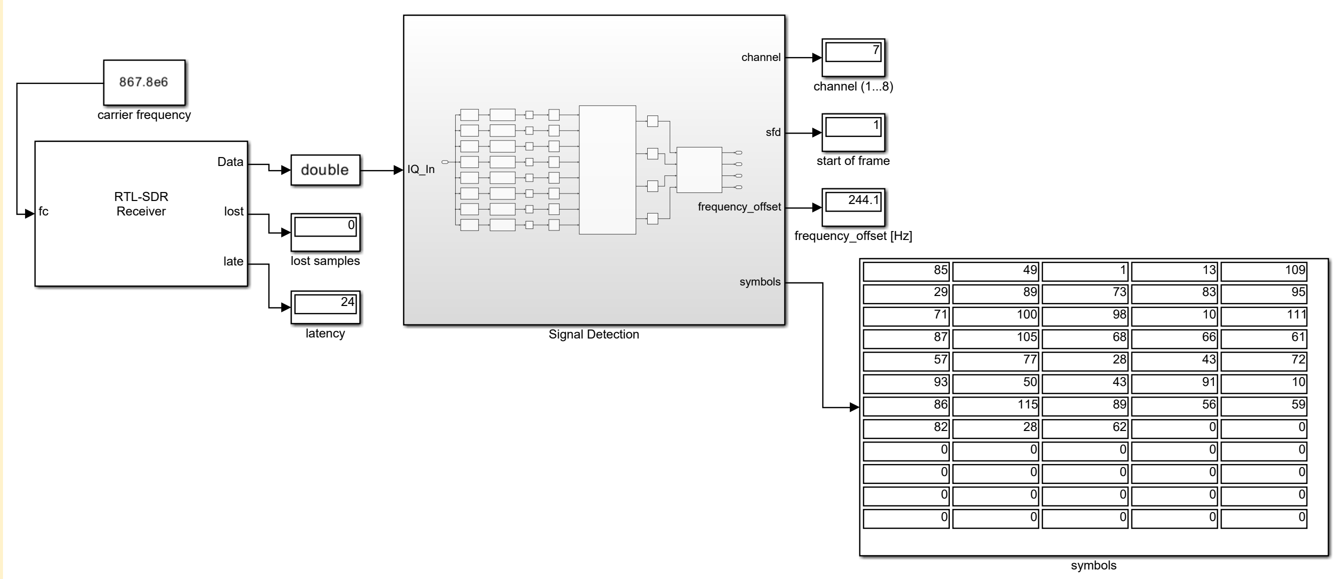
$$a_k \in \{0, 1, 2, \ldots, M\}, \qquad M = 2^{SF}$$

$$f_0 = -\frac{B}{2} + \frac{a_k}{M}B$$



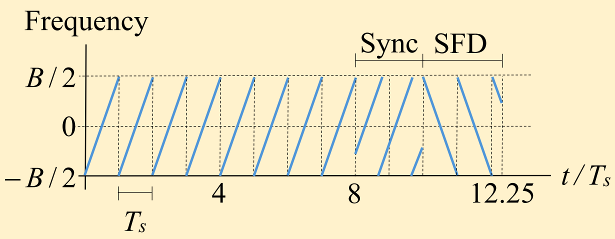
Quadrature components of a basic up-chirp ($f_0 = -B/2, T_s = 1.024$ ms)

- Demodulation: By multiplying each symbol with a down-chirp a signal with constant frequency f_0 is obtained (dechirping)



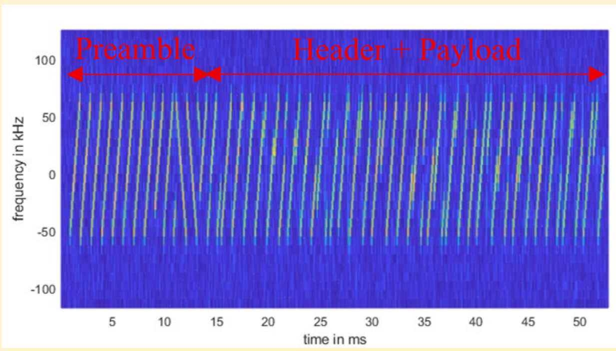
LoRa Receiver with the RTL-SDR

- The receiver allows to monitor the activity of LoRa nodes
- RTL-SDR (Software Defined Radio):
  - Low-cost receiver, frequency range 25 MHz to 1.7 GHz
  - Converts the RF signal to baseband, the quadrature components are further processed with MATLAB/Simulink
  - Hardware Support Package available
- LoRa packets are composed of a preamble with several consecutive up-chirps, a sync field, a start of frame delimiter (SFD) composed of 2.25 down-chirps, a header and a payload



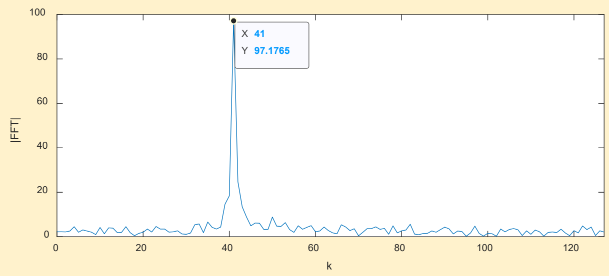
Preamble of a LoRa packet

- Processing steps for $SF = 7$, $B = 125$ kHz:
  - Filtering and frequency shifting according to the channel frequency ($f_s = 2$ MHz)
  - Downsampling by 8 ($f_s/8 = 2B = 250$ kHz)
  - Correlation with the up-chirp
  - If an up-chirp is detected: Search for SFD
  - Carrier frequency offset correction
  - If SFD detected: Downsampling by 2 ($f_s/16 = B = 125$ kHz), demodulation



Spectrogram of a LoRa packet ($f_s = 250$ kHz)

- When $f_s = B = 125$ kHz and $T_s = 1.024$ ms, we have 128 samples/symbol
- The symbol is found by calculating the 128-point-FFT and finding the maximum peak

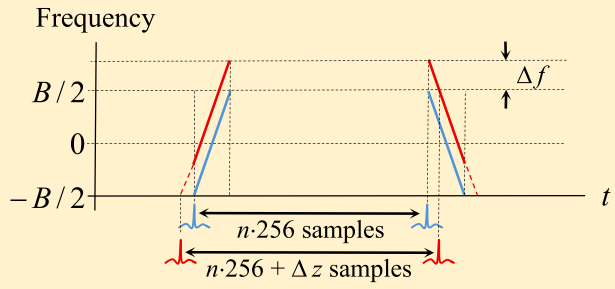


128-point FFT of symbol $a_k = 41$

Carrier Frequency Offset Correction

- A maximum frequency offset Tx-Rx of $\Delta f = 0.25\,B$ is allowed
- For $f_s = 250$ kHz, we have 256 samples/sym.
- When correlating the preamble with an up and a down-chirp, the number of samples between the correlation peaks is $n{\cdot}256$ for $\Delta f = 0$
- If the number of samples differs by Δz, this corresponds to a frequency offset of

$$\Delta f = \Delta z\;\; 125\,\text{kHz}/(2 \cdot 256)$$



Up- and down-chirps in case of a frequency offset

- A frequency offset correction with a resolution of ±244 Hz ($\Delta z = \pm 1$) is possible

References

Semtech Datasheet SX1276/77/78/79, Rev. 7, 2020.

Zhenqiang Xu, Shuai Tong, Pengjin Xie, Jiliang Wang: *From Demodulation to Decoding: Toward Complete LoRa PHY Understanding and Implementation*. ACM Trans. on Sensor Networks, Vol. 18, No. 4, Dec. 2022.

Robert W. Stewart, Kenneth W. Barlee, Dale S.W. Atkinson, Louise H. Crockett: *Software Defined Radio using MATLAB & Simulink and the RTL-SDR*. Strathclyde Academic Media, 2015.

Carsten Roppel (2025): *FM RDS Receiver with the RTL-SDR* (https://www.mathworks.com/matlabcentral/fileexchange/100316-fm-rds-receiver-with-the-rtl-sdr), MATLAB Central File Exchange. Abgerufen 7. September 2025.

Carsten Roppel: *Grundlagen der Nachrichtentechnik*. Hanser-Verlag, 2. Aufl., 2023.