

FM RDS Receiver with the RTL-SDR

Carsten Roppel, University of Applied Sciences Schmalkalden, October 2021

Simulink model: *FM_RDS_Receiver_with_RTL_SDR.slx* (MATLAB Rel. R2020a)

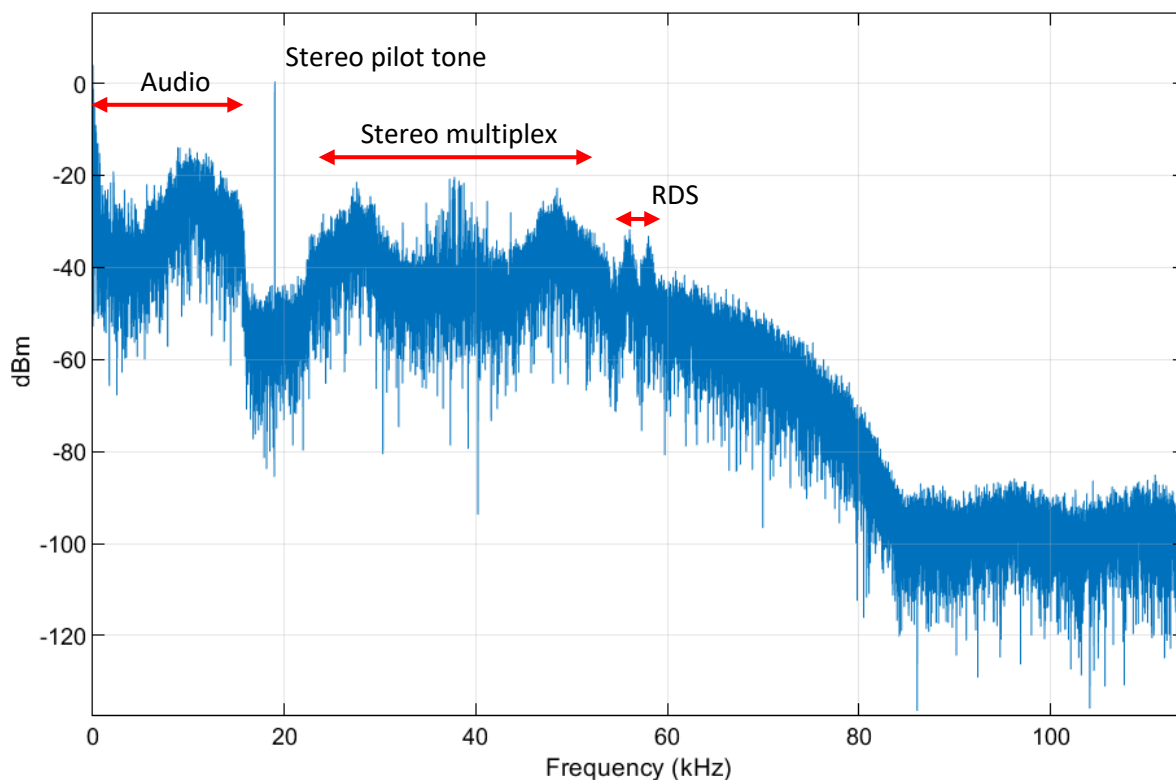
This Simulink model is used for teaching analog and digital modulation in a real-world application using a low-cost hardware, the RTL-SDR [1].

FM Demodulator and Audio Output

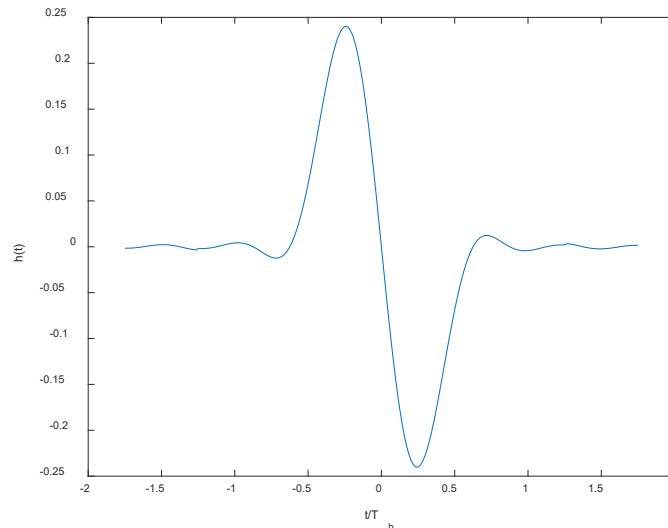
The FM demodulator calculates the derivative of the phase of the FM signal [2]. The sampling rate is 912 kHz. In the audio subsystem, the signal is filtered by a 15 kHz lowpass filter and downsampled by 19, resulting in a sampling rate of 48 kHz. Finally, the signal is passed through a 3.2 kHz FM deemphasis filter.

RDS Demodulator

The RDS signal, a BPSK signal with a bit rate of 1187.5 bit/s, is transmitted at 57 kHz. After downsampling by 4 the sampling rate is 228 kHz = 4·57 kHz. The figure below shows the spectrum of the signal at the FM demodulator output and its components.

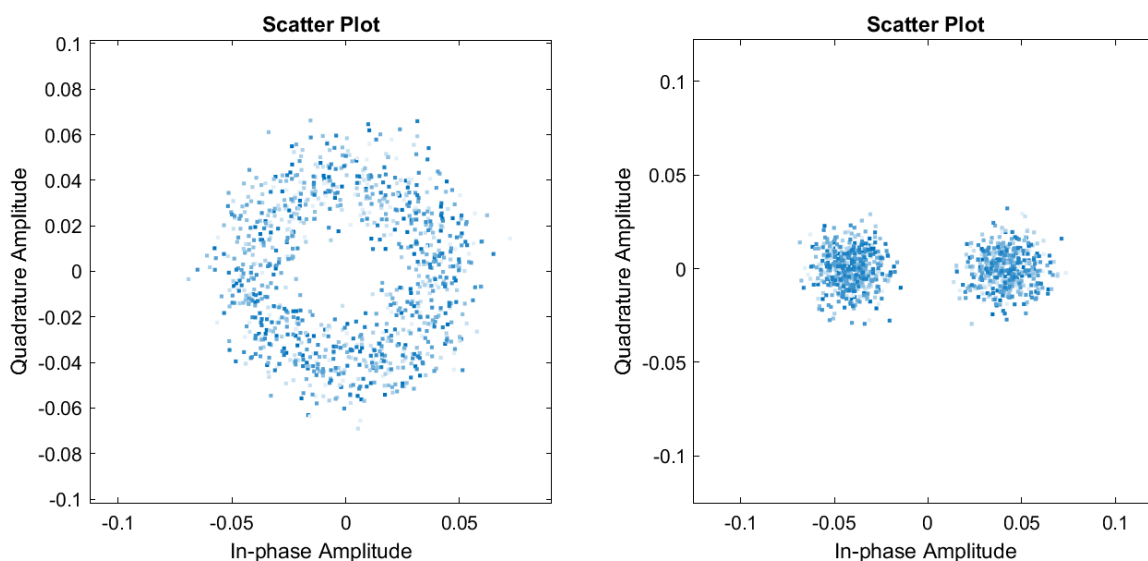


Next, the RDS signal is filtered and demodulated with a quadrature demodulator [2] and again downsampled by 3, resulting in a sampling rate of 76 kHz or 64 samples per bit. The matched filter follows, its impulse response is shown below. It is matched to the baseband pulse, a bi-phase pulse with square-root raised cosine shape and a roll-off factor of 1 [3].

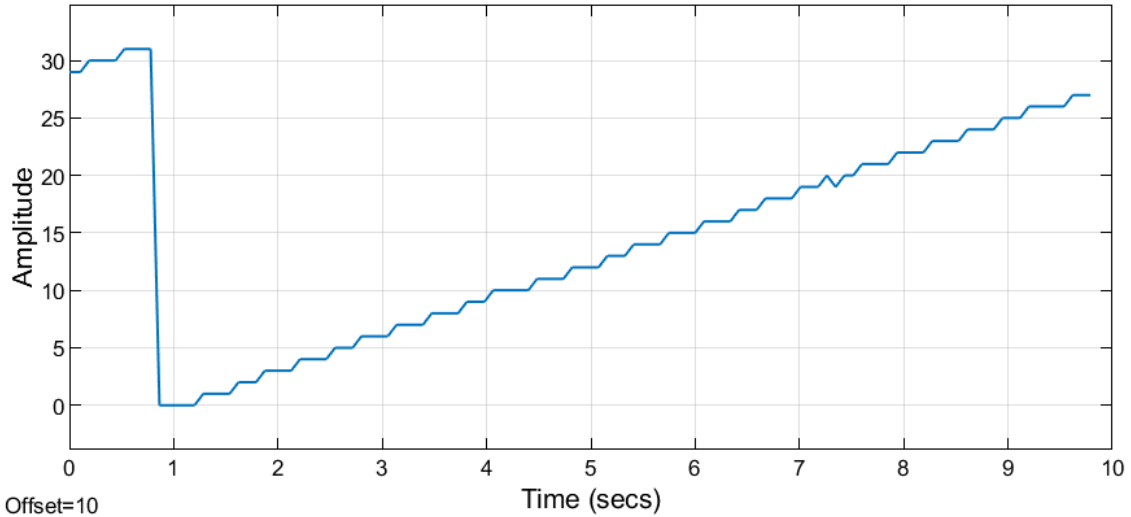


After downsampling by 2 we have 32 samples per bit. For symbol synchronisation, we have to find the sample for maximum vertical eye opening. Because we have many samples per bit, we do not need an interpolator. We take 3200 samples, downsample by 32 with offset $i = 0 \dots 31$, and calculate the signal power. The optimum sample is the sample resulting in the maximum signal power. The symbol synchronisation function returns one sample per bit.

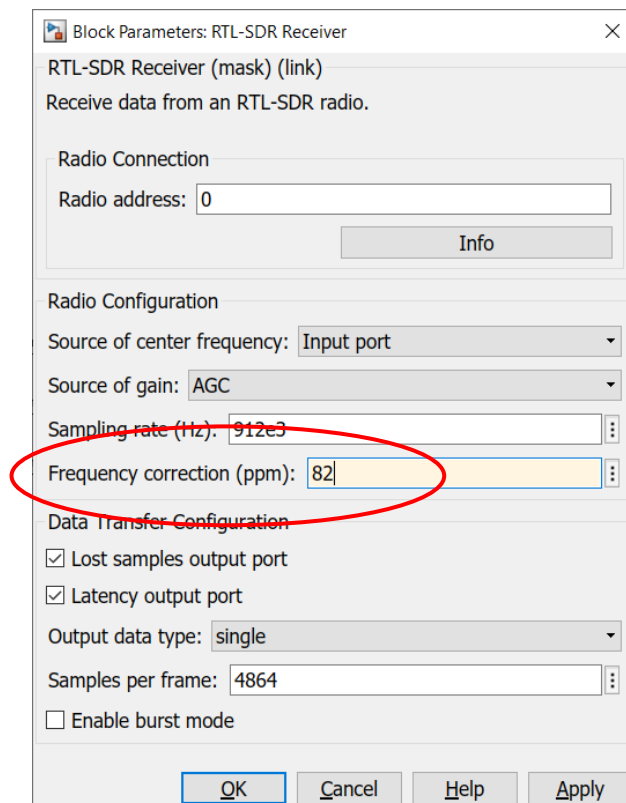
It is followed by a Viterbi & Viterbi carrier synchronisation, which is able to operate at one sample per bit [4]. The figures below show the signal constellation after symbol synchronisation (left) and after carrier synchronization (right).



A typical plot of the sample offset over time as determined by the symbol synchronisation function is shown below. From this plot we can estimate the frequency offset of the local oscillator in the RTL-SDR.



Here, the sample offset increases from 0 to 25 in 8 seconds. The sampling period is $T = 1/(38 \text{ kHz}) = 26.31 \mu\text{s}$, and the frequency offset is $25 \cdot T / (8 \text{ seconds}) = 82 \cdot 10^{-6}$ or 82 ppm. In the RTL-SDR Receiver block, we can enter this value to correct the frequency. This helps to avoid bit slips, which occur when the sample offset wraps.



RDS Decoder

After differential decoding, 10400 bit are buffered. Because RDS data is organized in 26 bit blocks, this corresponds to 399 blocks (plus two incomplete blocks at the beginning and the end).

RDS information is transmitted in groups of 104 bit. A group comprises 4 blocks of 26 bit. A block is composed of a 16 bit information word plus a 10 bit CRC. Offset words A, B, C and D are added modulo 2 to the CRC.

The block synchronisation function searches the bit stream for blocks with a valid CRC. A matrix with the information words and a number indicating the block type is passed to the text decoding function. This function extracts the Program Service Name transmitted in type 0A groups and radio text transmitted in type 2A and type 2B groups.

References

- [1] C. Roppel, M. Kruhme, M. A. Muhammed Nor: Ein FM/RDS-Empfänger mit MATLAB/Simulink und RTL-SDR (Software Defined Radio) – eine ideale Kombination für die Lehre. MATLAB EXPO 2016, München.
- [2] C. Roppel: Grundlagen der Nachrichtentechnik. Hanser, 2018.
- [3] EN 50067: Specification of the radio data system (RDS) for VHF/FM sound broadcasting in the frequency range from 87,5 to 108,0 MHz. CENELEC, 1998.
- [4] A. J. Viterbi, A. M. Viterbi: Nonlinear Estimation of PSK-Modulated Carrier Phase with Application to Burst Digital Transmission. IEEE Trans. Inform. Theory, vol. 29, pp. 543-550, July 1983.