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OFDM Radar Signal Processing

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Abstract: OFDM in radar systems gives as an opportunity to generate all desired signals. It can overcome the problem of ambiguity function for distance and velocity of target, has an ability to detect multiple targets simultaneously and insert identification (IFF) bits for distinguish wanted targets.

Keywords: OFDM radar, identification bits, multi-frequency radar signal.

1. Introduction

As we already know, the Orthogonal Frequency Division Multiplexing (OFDM) method is widely used in 4G and 5G communication systems. There are some publications, which describe the usage of OFDM in Radar applications: Multi-frequency radar signals [1], Multi-frequency complementary phase-coded radar signal [2], OFDM signal constellation processing on Radar applications [3]. Some work have been done for target detection and tracking [4] [5], as well as direction of arrival estimation [6]. The research proves that the OFDM is ideal for both data transmission and radar sensing [7]. The research have also been done in automotive radar applications and an OFDM joint radar and communication system have been created [8] [9]. Most of this research work defines the Doppler and range separately.

Why we are using OFDM for radar applications?

1. Universality
2. It overcomes the problem of ambiguity function for velocity and distance.
3. Detects multiple targets simultaneously.
4. Identification (IFF) bits can be inserted in a frame of OFDM.

2. Theory

The OFDM is a universal method as already noticed in introduction. All radar signals can be generated using OFDM block. All is needed to do to make a FFT of this signals which will create complex coefficients for OFDM subcarriers and send these to OFDM block (figure 1).

In the output desired signal will be generated.

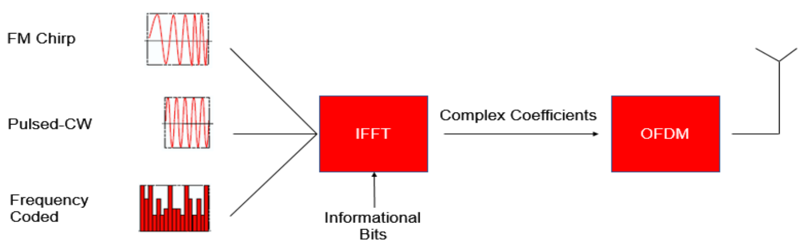


Figure 1. Universality of OFDM

The OFDM radar has an ability to include informational bits in a frame of signal, for example identification bits. The avionic radars require IFF signals to distinguish wanted targets. This means, that one module should be inserted into radar system, which will be responsible for this feature. In contrast, the OFDM radars can cope with without external module. These IFF signal bits can be inserted into the frame in certain pre-defined positions (figure 2). And only the own targets or objects can detect these bits and send reply message.

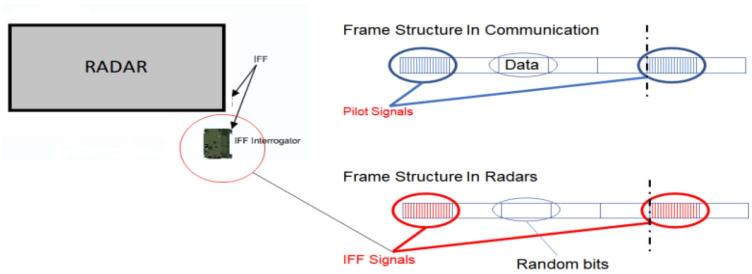


Figure 2. Avionic radar and OFDM frame with IFF bits

The radar application require high power signals. On the other hand, the OFDM require strong linearity. In that reason, the reference bits which will be generated are created by specified random method which will decrease the Peak to Average Power Ratio (PAPR).

The generated signal has following structure (figure 3):

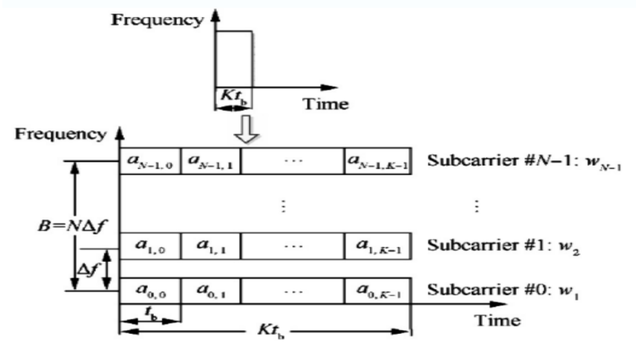


Figure 3. OFDM signal Structure In radars

In order to get appropriate OFDM parameters, we need to link them with radar parameters (Figure 4).

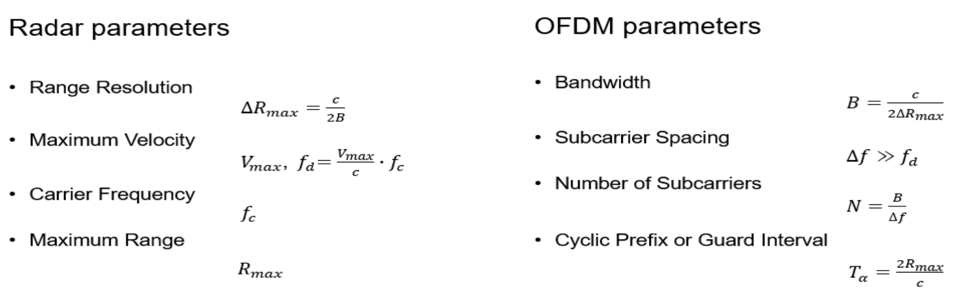


Figure 4. Link between Radar and OFDM signal Parameters

The received OFDM radar signal is represented by this equation

$$r(p,k) = \rho e^{-j2\pi f_0} \sum_{n=0}^{N-1} w_n a_{n,k} e^{j2\pi np/N_e} e^{-j2\pi f_d k t_b} e^{-2\pi n \Delta f \tau_0}, \qquad (1)$$

Where $e^{-j2\pi f_d k t_b}$ is the Doppler information and $e^{-2\pi n \Delta f \tau_0}$ is the range information.

The equation (1) can be represented in matrix form (Figure 5) [10].

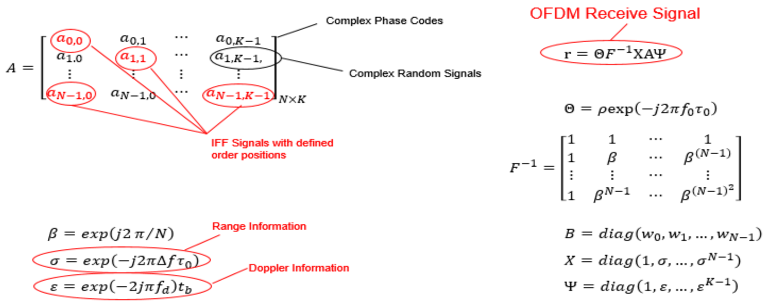


Figure 5. Matrix representation of OFDM Radar received signal

After receiving radar signal we need to do radar signal processing. The processing consists of following steps:

1. Multiplying the received signal with DFT matrix F

$$Fr = \Theta F^{-1} BXA\Psi \tag{2}$$

2. Multiplying both sides by B^{-1}

$$B^{-1} Fr = \Theta XA\Psi \tag{3}$$

3. Let $D = \Theta XA\Psi$

$$[D]_{n,k} = \rho a_{n.k} e^{-j2\pi f_0 \tau_0} e^{-j2\pi f_d k t_b} e^{-2\pi\Delta f \tau_0} \tag{4}$$

4. Taking element-wise division

$$[T]_{n,k} = \frac{[D]_{n,k}}{[A]_{n,k}} = \rho e^{-j2\pi f_0 \tau_b} e^{-j2\pi f_d k t_b} e^{-j2\pi\Delta f \tau_0} \tag{5}$$

5. Applying 2D-DFT with $N_r \times N_d$ points on T

The algorithm of generating and receiving OFDM signal is created in LabVIEW environment. Figure 6 demonstrate OFDM radar operation model which was realized on real OFDM radar prototype.

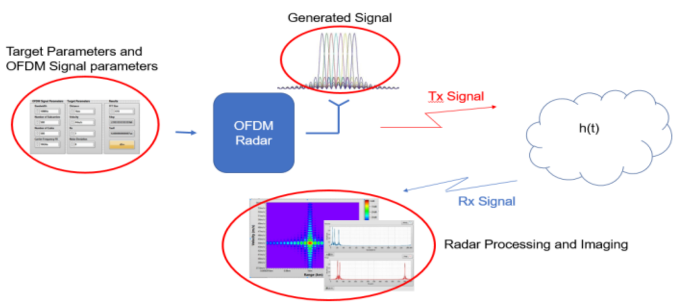
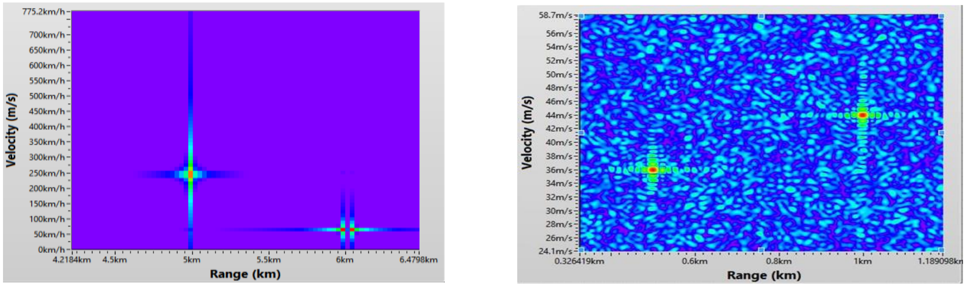


Figure 6. OFDM Radar operating model

The maximum number of simultaneously detected targets depends on number of OFDM subcarriers. The following figures demonstrate multi targets scenarios without noise (Figure 7. a) and with noise (Figure 7. b)



(a) (b)

Figure 7. Multi target scenarios in OFDM radar without noise (a), with noise (b).

3. Conclusion

The OFDM signal is a universal signal, which gives opportunity to generate all desired radar signals. It overcomes the problem of ambiguity function for distance and velocity of target and detect multiple targets simultaneously. As radar signal, OFDM generates mainly non-informational reference symbols, which gives opportunity to include identification symbols in a frame in pre-defined positions to distinguish wanted targets.

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