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OFDM signal constellation processing on Radar applications

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Using QAM mapped OFDM signal in radar applications it is possible to get from the signal constellations both the target velocity and target distance from the radar station. When in the reflected signal constellation we get the rotated and distorted mapping that is mean that the signal is reflected from the moving target, while on the other hand, when the mapping is only rotated around the zero, we have a reflected signal from static target. Getting that signals and passing them through frequency and target distance filter banks we get the Doppler frequency and time shift and, consequently, the velocity and the distance of the target.

Key words: OFDM signal, Radar, constellation, target

1. Intorduction

Radar systems develop year by year. One of the latest approaches is using OFDM (Orthogonal Frequency Division Multiplexing) signals in radar systems. A lot of investigations had been done and different methods were designed to solve various OFDM-radar applications.

There are two major features of OFDM signals which make it applicable in radar applications, which are the signal long duration and the wide spectrum. The first one, signal long duration helps to determine Doppler shift very accurately. On the other hand, wide spectrum of the signal gives an opportunity to find a time shift of the received echo signal. Knowing these two values we can determine the velocity of the target and its distance from the radar station consequently. Several methods of OFDM radar signal processing have been proposed. One of the approaches was designed with using a correlation of received and transmitted signals [1]. Another metohod is called novel approach, where the proposed algorithm operates directly on modulated symbols [2,3].

In the present work it is shown that using QAM mapped OFDM signal in radar applications it is possible to get from the signal constellations both the target velocity and target distance from the radar station. When in the reflected signal constellation we get the rotated and distorted mapping that is mean that the signal is reflected from the moving target, while, on the other hand, when the mapping is only rotated around the zero, we have a reflected signal from static target. Getting that signals and passing them trough frequency and target distance filter banks we will get the Doppler frequency and time shift and consequently the velocity and the distance of the target.

2. OFDM in Radar processing

In Radar processing we can point two general parameters which describe the accuracy of the radar system: radar range resolution and relative velocity.

$$\Delta r = \frac{c_0}{2B}, \tag{1}$$

$$\Delta v = \frac{\lambda}{T}, \tag{2}$$

With$c_0$being the speed of light and Bbeing the total signal bandwidth in (1), while $\lambda = c_0/f_c$, where f_c is the carrier frequency.

OFDM signals consist of orthogonal parallel subcarriers. The whole signal will be

$$x(t) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} s_{mN+n} \exp(j2\pi f_n t), \tag{3}$$

where s_{mN+n} is a complex modulated symbols, N is the number of subcarriers, M is the number of consequtive symbols, f_n is the individual frequency of subcarriers and

$$f_n = \frac{n}{T}. \tag{4}$$

So, after inserting (4) in (1) and (2) we get.

$$\Delta r = \frac{c_0 T}{2N}, \tag{5}$$

$$\Delta v = \frac{c_0}{MTf_c}. \tag{6}$$

From (5) and (6) it is followed that more subcarriers we have, more accuracy will have radar system.

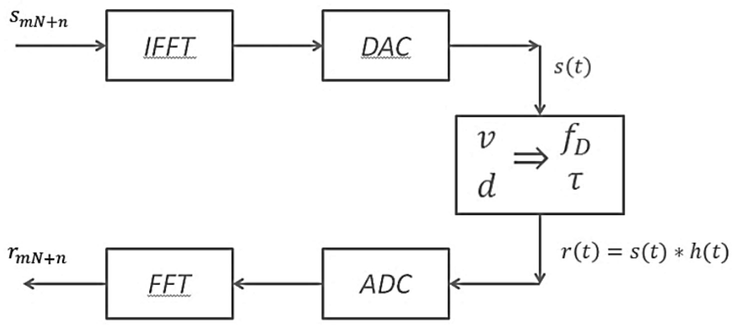
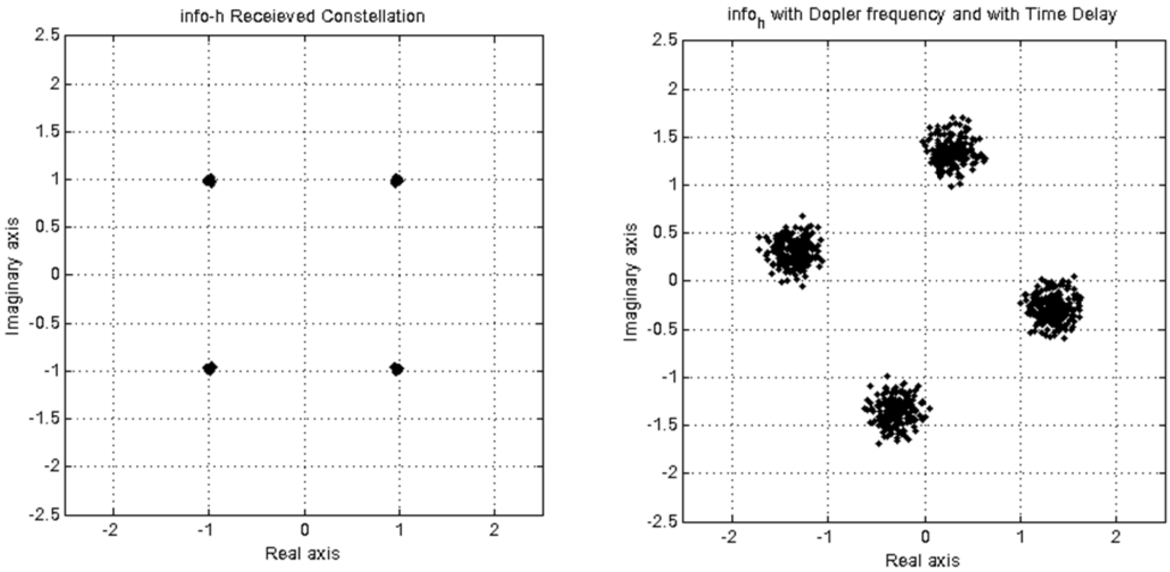


Fig. 1. OFDM Implementation by FFT.

OFDM transmission and reception can be implemented with Fast Fourier Transformation (FFT). As shown in Fig. 1, just performing an Inverse Fast Fourier Transform with the s_{mN+n} symbols and converting the data from digital to analog we will get $s(t)$ signal which will be transmitted from radar station. After reflecting from the target the echo signal gets a Doppler shift and time shift, which occur because of the velocity of the target and its distance from the radar station. The received signal will be the convolution of transmitted signal and the impulse response. So, to get the velocity and the distance of the target from the radar station firstly we should get the Doppler shift and the time shift, which are in the pulse response of our signal. By the way looking on Fig. 1, it looks very easy to implement and OFDM translation and reception by FFT, and it should work, because each block on the transmit site has its corresponding inverse on the receive site, so all the data should be perfectly recovered if our blocks work perfectly. We must satisfy the condition of orthogonality. In the picture it is hidden in the cover of Fourier transform theory, that's why erroneously it looks very easy to make it work correctly.

3. One target OFDM Radar simulation using constellations

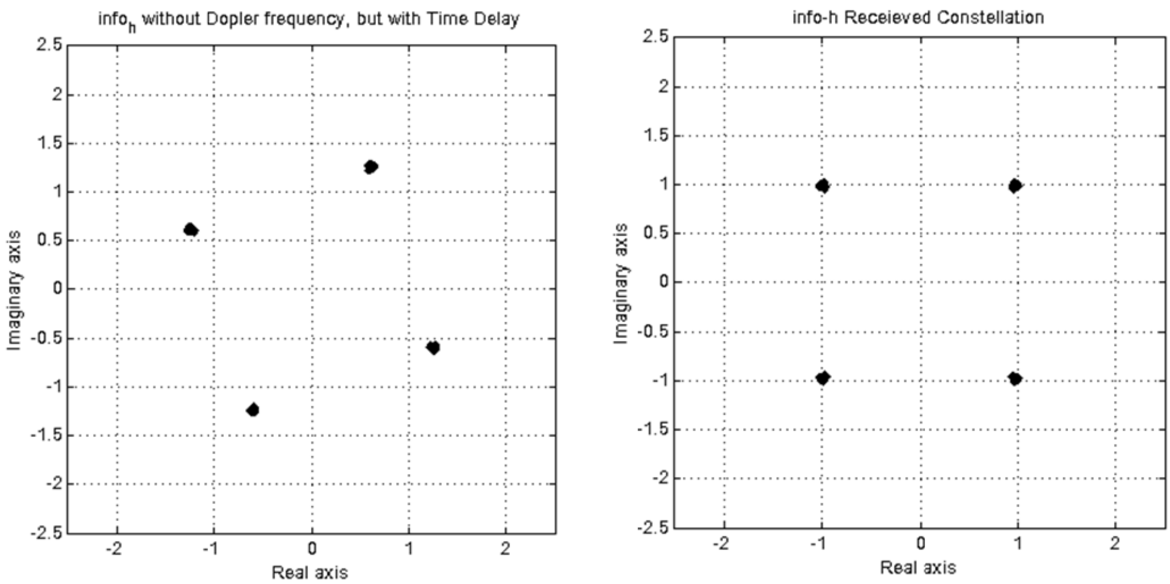
Representing OFDM signal in constellations, we found a very pretty results. In Fig. 2.a it is shown the transmitted signal constellation, while in Fig. 2.b we can brightly see what kind of changes get the signal after reflecting from a target.



a) b)

Fig. 2. (a) The constellation of transmitted OFDM signal, (b) The constellation of received OFDM signal with the existence of Doppler shift and time delay.

In Fig. 2.b we see that after the impact of Doppler shift and time delay our constellation graph have been rotated and scaled. Simulation results show that the Doppler shift makes our graph both to rotate and scale. On the other hand, the time shift just rotates the graph. So, itis obvious that first we must get the Doppler shifting and consequently the velocity of target and only then time delay and its corresponding distance from the radar station. In Fig. 3.a it is pictured the received signal without



a) b)

Fig. 3. (a) The constellation of received OFDM signal with the absence of Doppler shift and with the existence of time delay, (b) The constellation of received OFDM signal with the absence of Doppler shift and time delay.

Doppler shifting and in Fig. 3.b it is the received echo signal without Doppler shift and without time delay. So, during these two operations we have got two major measures and then we can easily determine both the velocity and the distance of target form the Radar station:

$$v = \frac{f_D c_0}{2 f_c}, \tag{7}$$

$$d = \frac{c_0 \tau}{2}. \tag{8}$$

Simulations were done in Matlab environment. The velocity range is took 2–62*km/h*, the carrier frequency$f_c = 16\ GHz$. The frequency bank of filters had a step $\Delta f_D = 60\ Hz$. So, it is found the Doppler velocity value` $f_D = 1.44\ MHz$ and consequently from (7) we obtain the velocity of simulated target velocity $v = 48.6\ km/h$.

In the same way, after getting the target velocity, we will make passed our signal through the time delay bank of filters and get the distance between the radar station. The maximum distance from the radar station is taken` $d_{max} = 8\ km\,.\Delta d = 300\ m$. Taking into account that $\tau = 2d/c_0$, we get $\tau_{max} = 52\ \mu s$ and $\Delta\tau = 2\ \mu s$. Simulations give the result$\tau = 40 \cdot 10^{-6} s$, and from (8) we obtain the distance of the target from Radar station $d = 6\ km$.

4. OFDM signal spectrum optimization

In communication systems transmitted data is not self-willed. That means that we will have discontinuities in our OFDM symbol waveform (Fig 4.a). Discontinuities make their influence on the signal spectrum, as it is shownin Fig 5.a where OFDM signal is generated from randomly symbols. On the other hand, if we have radar systems we can generate specified symbols, which have continuous waveforms as shown in Fig 4.b., in that case we will consequently have a significant spectral spreading in result (Fig. 5.b).So, it is extremely useful to generate that kind of waveform which make our spectrum with low level sidelobes and if in communication systems it is impossible due to the danger of disrupt transmitted data, in radar systems it’s acceptable. Also you can see the difference between two types of received signals constellations in Fig 6. When we have specified sinusoidal signal our constellation point distraction is more compact, so the measurement of Doppler frequency will be easier than in randomly generated signal case.

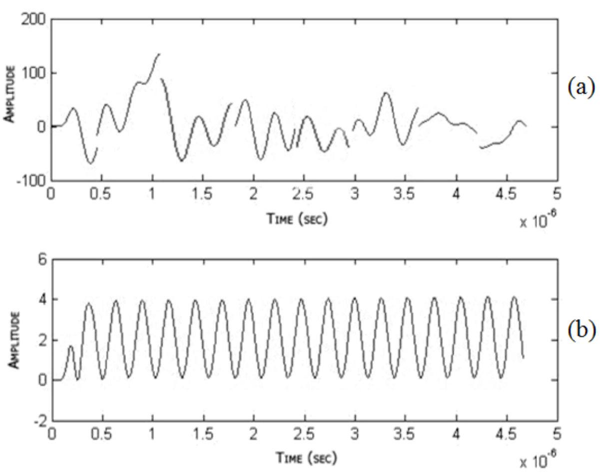


Fig. 4. (a) OFDM signal waveform with discontinuities, (b) OFDM signal waveform with continuous sinusoid

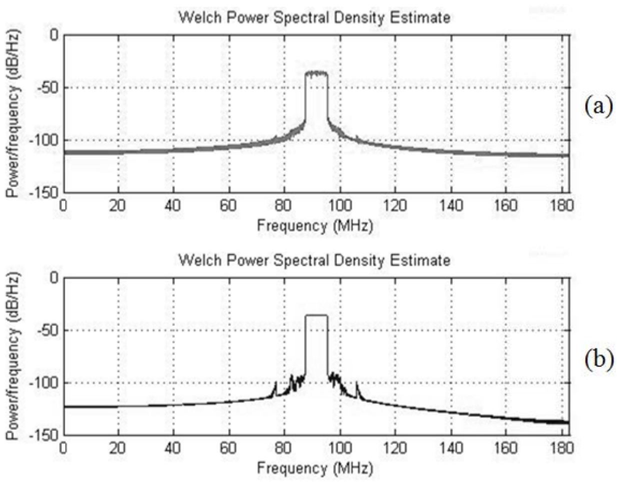
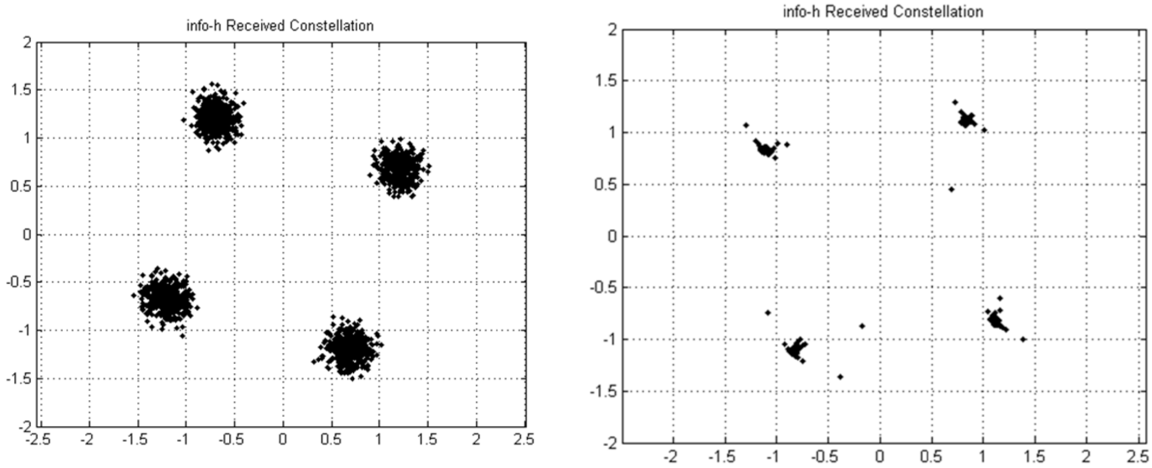


Fig. 5. (a) OFDM signal frequency response with random transmitted data, (b) OFDM signal frequency response with specified continuous waveform transmitted data



a) b)

Fig. 6. (a)OFDM received signal constellation with randomly generated data, (b) OFDM received signal constellation with specific generated data.

5. Conclusion

As we stated above this method it useful with one target, but it has another positive side. We saw that in the received signal's constellation, if we have only the rotation around the axis, that means that the target from which we get the reflected signal isn't moving, and only when we have an additional scaling with the rotation, in that case only we can assume that we have a movable target. So, constellations are also useful for MTI. As to using OFDM signals in radar applications, the results also gave the thinking that they are perfectly applicable and are able to solve many problems. Also we have seen that OFDM signal spectrum optimization made our processing more effective. Our next investigation will be the use of OFDM signals in addition with LFM signals, which is promising to solve the problems with multi target radars.

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