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# Doppler Shift Extraction from QPSK Mapped OFDM Signal Constellation

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# Doppler Shift Extraction from QPSK Mapped OFDM Signal Constellation

A. Hakhoumian [α], Kh. Tovmasyan [σ] & E. Gabrielyan [ρ]

*Abstract-* Doppler effect gives a frequency offset on received OFDM signal in radar system. That offset can be seen as a distortion and rotation of reflected signals QPSK mapping vectors. It is possible to determine moving target velocity by estimating expected value of the distorted signal and then calculating the rotated angle. A mathematical relationship between Doppler frequency shift and rotated angle of QPSK mapping vectors was obtained. The recommended systems will require less computing resources, because Doppler frequency shift calculation could be done during one OFDM symbol.

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## I. Introduction

Utilization of OFDM (Orthogonal Frequency Division Multiplexing) signals in radar systems is trending higher on the year over year basis, so does the number of publications and investigations. Several methods and proposals has been designed and developed to solve various OFDM radar applications.

OFDM signals have two significant characteristics that make them usable in radar applications: their long duration and wide spectrum. Long duration helps to measure the Doppler shift with high accuracy. Its wide spectrum, from the other side, allows finding the time delay of the received echo signal. These two values will lead us to get both velocity and distance of the target from the radar station. The major advantage of the proposed method described in this paper is very low computing resource constraint, since the calculations could be done during one OFDM symbol of the signal.

Various OFDM radar signal processing methods has been proposed so far. First we would like to mention the method of the target velocity detection via OFDM signal constellation by passing reflected signal trough the bank of filters [1]. The main drawback of that method is that it needs huge computational and technical resources. In another presented proposal the frequency offset is initially estimated using an autocorrelation method, then it is further fine-tuned by applying an iterative phase correction by means of pilot-based Wiener filtering method[2].Recently a paper was published that introduced walking mobile user's Doppler shift calculation algorithm using 8-PSK modulation [3]. There is another method called novel approach, where the proposed algorthm operates directly on modulated symbols [4-5].In other technique both OFDM and CE-OFDM (Constant-envelope OFDM) are used to overcome peak-to-average ratio (PAPR) problem [6].

In this paper we illustrated the determination algorithm of the reflected signal's frequency offset caused by Doppler Effect. First paragraph presents the OFDM radar processing principles. Further we proposed a mathematical relationship of constellation vector angle and Doppler frequency. The target velocity detection algorithm and the simulation results are presented afterwards.

## II. OFDM in Radar Processing

Generally OFDM signal can be presented as

$$s(t) = \frac{1}{N}\sum_{n=0}^{N-1} F_n \cos(2\pi f_n t + \varphi_n) = \frac{1}{N} Re\left\{\sum_{n=0}^{N-1} \dot{F}_n \exp(j2\pi f_n t)\right\} \qquad (1)$$

Where $N$ is the number of subcarriers, $(\dot{F}_n)$ are complex modulated symbols, and $\dot{F}_n = F_n \exp(j\varphi_n)$ Orthogonality condition is fulfilled when

$$\int_0^T f_l(t) f_m(t) dt = \delta_{lm} \qquad (2)$$

Therefore $\Delta f = f_l - f_{l-1} = 1/T$. For QPSK modulated symbols $F = 1$ and $\varphi_1 = \frac{\pi}{4}, \varphi_2 = \frac{3\pi}{4}, \varphi_3 = \frac{5\pi}{4}, \varphi_4 = \frac{7\pi}{4}$. Taking into account the sufficiently large quantities of subcarriers, we can consider that the number of subcarriers with the same QPSK symbols will be the same $N_1 = N_2 = N_3 = N_4 = N/4$. So we will have four different sets of subcarriers $\{f_k\}$, $\{f_l\}$, $\{f_m\}$, $\{f_n\}$ with corresponding angles $\varphi_1, \varphi_2, \varphi_3, \varphi_4$.

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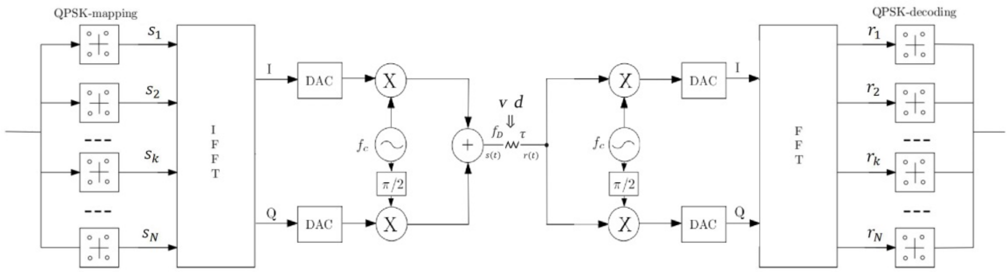


*Fig. 1 :* OFDM Radar transmission and reception system

OFDM transmission and reception can be implemented with Fast Fourier Transformation (FFT) [7]. As shown in Fig. 1, just performing an Inverse Fast Fourier Transform with $s_n$ symbols and converting the data signal from digital to analog format we will get the s(t) signal, which will be transmitted from the radar station [8]. After reflecting from the target object, the echo signal gets both Doppler frequency shift as well as a time shift, which occur because of the moving target velocity and its distance from the radar station. The received signal will be the convolution of transmitted signal and the impulse response. In order to get the velocity of the target we should first get the Doppler shift that is present in the pulse response of our signal. By looking at the Fig. 1, it is obvious that one can easily implement OFDM translation and reception by FFT, since each block on the transmitter has a corresponding inverse done on the receiver site, therefore all of the data will be perfectly recovered. The main condition would be to satisfy the orthogonality.

## III. Mathematical Relation Between Signal Phase Change and Doppler Frequency

Let´s consider the impact of the Doppler frequency shift of the reflected signal on the position of received signal modulated symbol vectors. We assume that$|2\pi f_d T| < \pi/4$, therefore $f_d < 1/(8T)$; $f_d < \Delta f/8$. For Doppler Effect we also have

$$f_d = 2\frac{v_r}{c} f_c \tag{3}$$

Where $v_r$ is the velocity of moving target, $c$ is the speed of light and $f_c$ is the carrier frequency. Since OFDM signal spectrum is $N\Delta f \ll f_c$ we can suppose that Doppler shift is the same for all subcarriers

$$f_{d_n} = (f_c + n\Delta f)\frac{v_r}{c} \approx f_c \frac{v_r}{c} = f_d \tag{4}$$

Reflected OFDM signal will be

$$s(t) = \frac{1}{N} Re\left\{\sum_{n=0}^{N-1} \dot{F}_n \exp\left(j2\pi(f_n + f_d)t\right)\right\} \tag{5}$$

It is important to call out that the Doppler shift will not affect the system orthogonality; instead it will lead to a spectrum shift. In-phase and quadrature parts on n-th subcarrier of the reflected signal which already has an impact of Doppler frequency are

$$I_n = Re\{g(t)\} \int_0^T [\cos 2\pi(f_n + f_d)t - \sin 2\pi(f_n + f_d)\, t] \cos 2\pi f_n t dt \tag{6}$$

$$Q_n = -Im\{g(t)\} \int_0^T [cos\, 2\pi(f_n + f_d)t + sin\, 2\pi(f_n + f_d)t]\, sin\, 2\pi f_n\, tdt \tag{7}$$

Considering any symbol, whose constellation point is in the positive side of both I and Q axis, we put √2/2 instead of Re{g(t)} and Im{g(t)}(in the other quarters of the coordinate system only the amplitude sign will change, but not the value). By doing some simple trigonometrical operations we will get both in-phase and quadrature components of the symbol we considered. In-phase component for n-th subcarrier will be

$$I_n = \frac{\sqrt{2}}{4}\Bigg[\frac{1}{2\pi f_d}(sin2\pi f_d T + cos2\pi f_d T - 1) + \frac{1}{4\pi f_n + 2\pi f_d}(\sin 2\pi(2f_n + f_d)T + (\cos 2\pi(2f_n + f_d)\, T - 1)\Bigg] \tag{8}$$

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and for quadrature we get

$$Q_n = -\frac{\sqrt{2}}{4}\Big[\frac{1}{2\pi f_d}(cos2\pi f_d T - sin2\pi f_d T - 1) + \frac{1}{4\pi f_n + 2\pi f_d}(sin2\pi(2f_n + f_d)T - cos\,2\pi(2f_n + f_d)T + 1)\Big] \quad (9)$$

Both (8) and (9) consist of two expression parts with similar denominators. $f_n$ is present in denominators of both second expression parts in (8) and (9); since $f_n = n/T$ and $f_n \gg f_d$ we can easily ignore them. Also it is obvious that existence of $f_n$ in sine and cosine components leads them to have random values, depending on subcarrier number. By estimating the expected values of both in-phase and quadrature components we will prevent their negligible dependency from the subcarrier number. That is the main reason why we can make the calculation during a single OFDM symbol. Picking another symbol from a different quarter of constellation axis led to the similar results (with possible negative sign when in-phase and quadrature components signs were different)

Therefore we get

$$E[I_n] = I = \frac{\sqrt{2}}{8\pi f_d}(sin2\pi f_d T + cos2\pi f_d T - 1) \quad (10)$$

$$E[Q_n] = Q = \frac{\sqrt{2}}{8\pi f_d}(sin2\pi f_d T - cos2\pi f_d T - 1) \quad (11)$$

To get Doppler shift phase change of reflected signal we have to calculate an arctangent of I and Q division.

$$\varphi = \tan^{-1}\left(\frac{sin2\pi f_d T - cos2\pi f_d T - 1}{sin2\pi f_d T + cos2\pi f_d T - 1}\right) \quad (12)$$

## IV. Distorted QPSK Mapped OFDM Radar Signal Expected Value Calculation

We achieved very positive results by reviewing the OFDM signal constellations. Fig. 2.a shows the transmitted signal constellation, while in Fig 2.b we can obviously see what kind of changes happen to the signal after reflecting from a target.

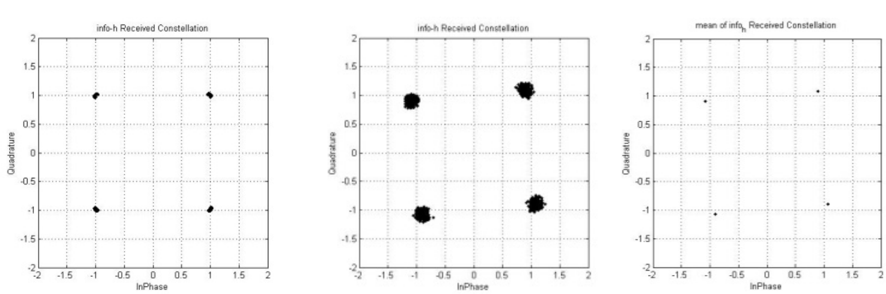
In Fig. 2.b we see that after the Doppler shift impact and time delay our graph has been rotated and scaled. Simulation results has shown that the Doppler shifting make the constellation graph to rotate and scale at the same time.

Simulations were done in Matlab environment. The carrier frequency $f_c = 24GHz$ OFDM symbol $T = 11\mu s$. Guard interval $T_G = 1.375\mu s$. During the simulation our system generated a moving target with randomly selected actual velocity $v_{act} = 59.4kM/h$. Then from the distorted signal constellation via our algorithm we calculated expected value of the signal (Fig 2.c). We get $\Delta\varphi \approx 5.44^{\circ}$ for phase vector rotation of signal. Using (12) we get Doppler frequency offset equal to 2440Hz. Consequently from (3) it is measured target velocity decided by proposed algorithm $v_{meas} = 54.9kM/h$. For absolute error we get

$$E_{abs} = |v_{act} - v_{meas}| = 4.5kM/h \quad (13)$$

And relative percent error will be

$$E_{rel} = \frac{E_{abs}}{v_{act}} \cdot 100\% = 7.57\% \quad (14)$$




a) b) c)

*Fig. 2 :* (a) The constellation of transmitted OFDM signal, (b) The constellation of received OFDM signal with the existence of Doppler shift, (c) The constellation of the distorted signal's estimated expected value

## V. Conclusion

Constellation of QPSK mapped OFDM signal expected value estimation gives an opportunity to easily determine Doppler frequency offset and consequently the target velocity. As we make Doppler shift extraction during one OFDM symbol we get very effective mechanism with very high performance and low computing recourses.

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