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Target Distance Direct Determination from QPSK Mapped OFDM Modified Radar Signal

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Strictly as per the compliance and regulations of :

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I. Introduction

OFDM signals are in focusfor radar applications due to high time bandwidth product[1, 2]. One of the main applications occurring during utilization of OFDM signals in radar systems is the signal processing which detect target parameters - distance and velocity. One of proposed method based on solving of matrix equations or 2D Fourier transform need high computing resources [3,4].

Previously it was presented new method based on QPSK-OFDM signal constellation processing which make possible to detect Doppler shift and accordingly target velocity [5]. Unfortunately that method couldn't be done directly, without solving target distance detection. It is presented below a new method again based on constellation processing which let to calculate target distance and make previous presented method more reliable and applicable.

II. Calculation Scheme of Time Delay from Modified OFDM Radar Signal

Target distance estimation in radar system is calculation of time, during which transmitted signal travel to the target and back to the receiver.

$$\tau = \frac{2D}{c} \tag{1}$$

where D-target distance, c speed of light.

Therefore target distance measurement is the same as timing offset estimation.

Let's consider the effect of timing offset on the OFDM signal constellation which is the representation of a signal modulated by digital modulation scheme, such as 4-QAM or in particularly QPSK.

For a set of N modulated orthogonal subcarriers f_n the transmitted signal can be represented as

$$S_t(t) = \frac{1}{N}\sum_{n=0}^{N-1} \dot{F}_n \exp\{j2\pi f_n t\} \tag{2}$$

where $\dot{F}_n$ are modulated symbols. For QPSK modulation modulated symbols will be

$$\dot{F}_n = \exp\{j(2k+1)\}, k = 0,1,2,3 \tag{3}$$

Consequently transmitted OFDM signal symbols points in constellation will have correspondent positions: $\varphi_1 = \frac{\pi}{4}, \varphi_2 = \frac{3\pi}{4}, \varphi_3 = \frac{5\pi}{4}, \varphi_4 = \frac{7\pi}{4}$(Fig.1).

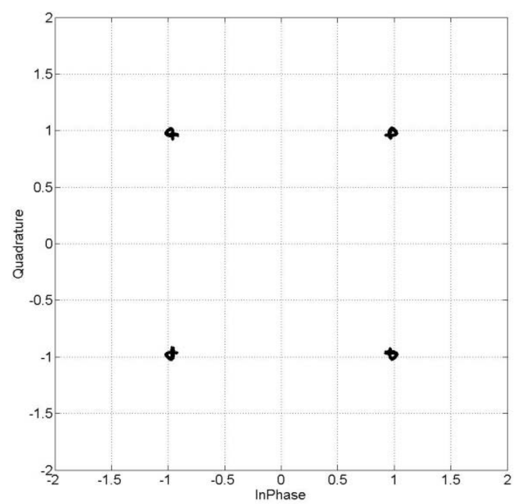

Figure 1 : OFDM transmitted signal constellation.

In communication systems phase difference of each two neighboring symbols could be $0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}$. In such applications when it is necessary to solve time offset, this initial phase difference between each consecutive symbols must be prevented. One of the ways of preventing that initial shift is raising phase to the 4th power [6].

Taking into account only time delay effect from target the received echo signal $S_r(t)$ will be time shifted version of the transmitted signal.

$$S_r(t) = S_t(t-\tau) \tag{4}$$

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So the received modulation symbols can be represented as

$$\dot{R_n} = \dot{F_n} \exp\{-j2\pi f_n \tau\} \tag{5}$$

As the phase of received symbol depended on subcarrier number, so with a large amount of subcarriers OFDM received symbols in constellation I/Q plane will spread all over plane in an interval $[0,2\pi]$(Fig.2).

To prevent this spreaded constellation, which doesn't give any opportunity to decide phase delay, we can simply take a divison of each consequitive symbols and make a new set of Q_k symbols.

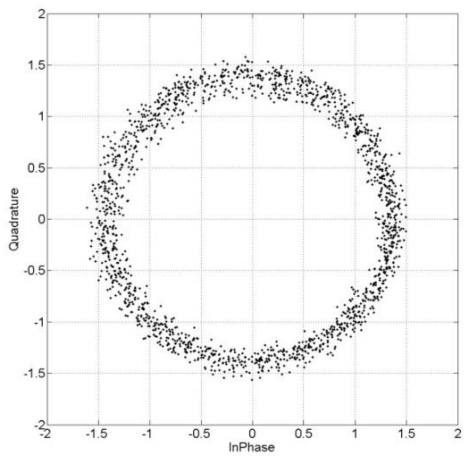

Figure 2 : OFDM received signal constellation consisting time delay.

$$Q_k = \frac{\dot{R_{n+1}}}{\dot{R_n}} = \frac{\dot{F_{n+1}}}{\dot{F_n}} \exp(-j2\pi f_{n+1}\tau + j2\pi f_n \tau) \tag{6}$$

where $k = 1,2,\dots,N-1$. As we stated before, OFDM stransmitted signal symbols can get phase values $\frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}and\frac{7\pi}{4}$, it is obvious that

$$\frac{\dot{F_{n+1}}}{\dot{F_n}} = \exp\left(\mu\frac{\pi}{2}\right) \tag{7}$$

$\mu = 0,1,2,3$.From (6) and (7) new modified OFDM signal can be represented as

$$Q_k = \exp\left(\mu\frac{\pi}{2}\right)\exp\left(-j2\pi\Delta f\tau\right) \tag{8}$$

where $\Delta f = f_{n+1} - f_n$ is subcarrier spacing. Expression (8) shows that time delay is independent from subcarrier number. That's mean that it is the same on all modified OFDM symbols anymore and it can be easily calculated.

$$\Delta\varphi = 360 \cdot \Delta f\tau \tag{9}$$

Fig. 3.a shows modified QPSK transmitted signal constellation while in Fig 3.b it is received modified OFDM signal constellation.

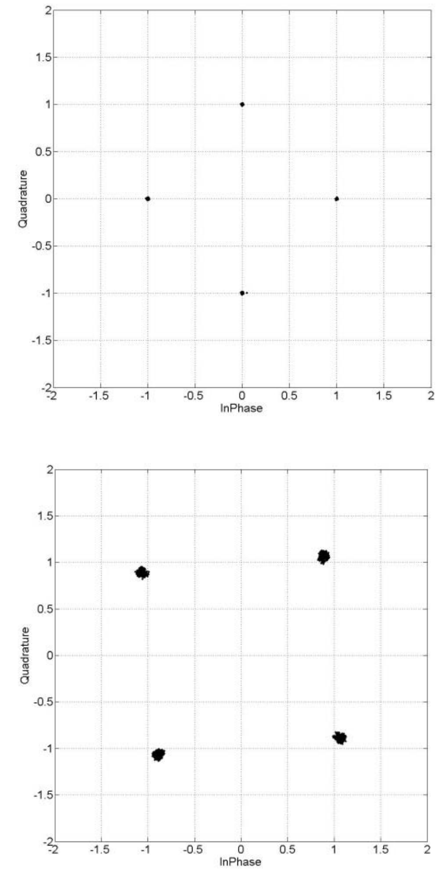

Figure 3 : (a) Modified OFDM transmitted signal constellation, (b) modified OFDM received signal constellation.

III. Distorted QPSK Mapped OFDM Radar Signal Time Delay Expected Value Calculation

In Fig. 3.b we can brightly see that even in all new modified OFDM symbols phase delay had the same impact, however there is still some distortion around the constellation poles. To prevent this distortion and calculate rotated angle more accurately, we simply have to extract an expected value of that rotated symbols (Fig. 4).

Simulations were done in Matlab environment with such parameterization: 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 target with randomly selected actual distance $R_{act} = 248.1m$. Then from modified OFDM received signal we calculate rotated angle Fig 4. We get $\Delta\varphi_{meas} \approx 50.2^{\circ}$and consequently from (9) and (1) we get measured distance of the target from radar station $R_{meas} = 230m$. For absolute error we get

$$E_{\tau,abs} = |R_{act} - R_{means}| = 18.1m \tag{10}$$

And therefore relative percent error will be

$$E_{\tau,rel,\%} = \frac{E_{\tau,abs}}{R_{act}} \cdot 100\% \approx 7\% \quad (11)$$

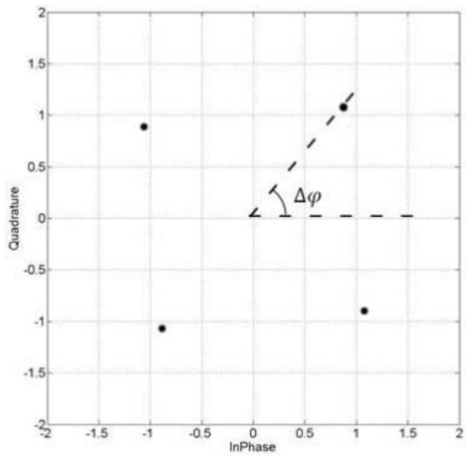

Figure 4 : The constellation of the modified OFDM received Q symbols estimated expected value.

IV. Conclusion

QPSK mapped OFDM modified signal processing let to solve target distance detection problem. Calculation process needs low computing resources because all processing could be done during one OFDM symbol.

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