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Pedestrian Micro-Doppler Signature Disclosure as a Carrier Suppressed Amplitude Modulated Signal Detection

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Abstract – The analysis of the signal using the power spectrum and autocorrelation function is insufficient. We do not have complete information about such signals, because of the loss of the phase information in the power spectrum and autocorrelation function. In that case it is very important using higher order statistics (HOS). The subject of higher order statistics (HOS) has received much attention in recent years [1]. We are using higher order statistics to differ useful information from noise which looks like carrier suppressed amplitude modulation. Matching of these two signals is described below.

Keywords: HOS, bispectral estimating, cumulants, micro-doppler, phase coupling, object detection

1.Introduction

Availability of radars gives huge opportunities in different areas. One of these areas is detection. Radars could be used for observation of huge areas for unwanted moving objects detection. The main detection methods are based on received signal energy spectrum estimating. As it is known, second order statistics, such as autocorrelation function and power spectrum provide only information amplitude information, but that information isn't enough for biological object detection. For more information about moving biological object, such as pedestrian, we need more deeply analysis of received signal.

The reflected signal from narrative moving object with constant velocity estimation shows that in power spectrum there is only one useful frequency. That frequency is Doppler shift frequency. In case, then the object is moving with acceleration, there is spectrum correlation. The peaks are appearing. It becomes more difficult to separate useful peaks from noise. For example, separate carrier suppressed amplitude modulated signal useful peaks from noise. So it is very important to estimate phase information. In this case it is very important to use more powerful tool such as higher order statistics.

As it is known second order statistics, i.e. autocorrelation, power spectrum and etc. are phase blind [2]. That is why cumulants and its Fourier transform, known as higher order statistics, become very important. The phase information can be provided by higher order statistics such as third-ordered autocorrelation function and third-ordered spectra known as bispectrum [3].Using of higher order statistics gives opportunities to find not only amplitude information, but phase information in addition. We are using higher order statistics to disclose pedestrian micro-Doppler signature.

Receiving signals from moving objects, especially from pedestrian, are classified in special group. The pedestrian global motion consists of several micro-motions. He has center of gravity and his hands are moving concerning that center. Pedestrian hands are moving opposite sides. The speed of pedestrian hands is allocated between null and double of pedestrian body moving speed. So we have two mathematical pendulums with opposite phases but with the same frequencies. This means that we have Doppler shift to different sides [4, 5]. In general, they are micro-Doppler shifts, because the pedestrian motion includes different body parts with different motion structure [6, 7] (figure 1).

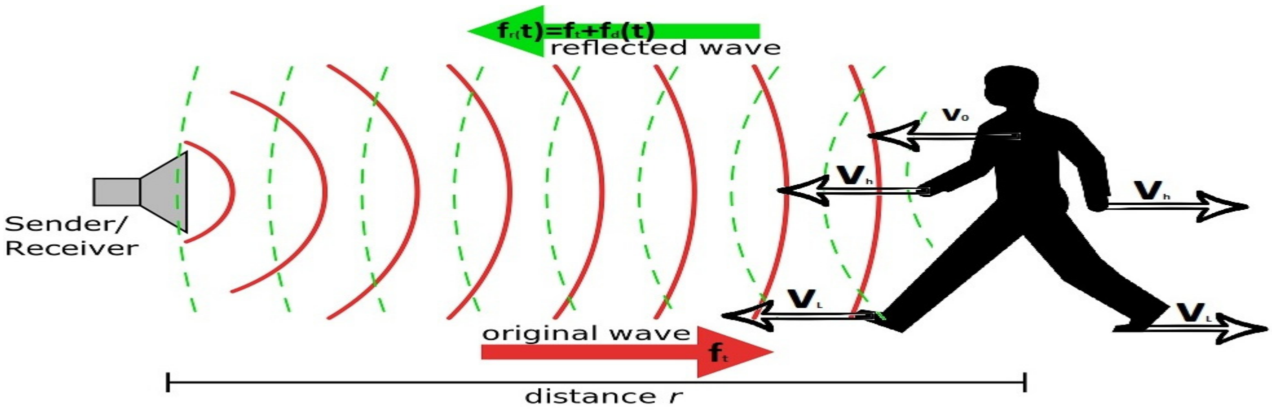


Figure 1: The pedestrian global motion with several micro-motions.

Namely, by first approximation we have amplitude modulation [8].Besides, in received signals can be a noise, which in power spectrum, will be looks like amplitude modulation. The only difference of useful and background signals is coupled phases of frequencies received from pedestrian.

In this paper we have two types of carrier suppressed amplitude modulation. In first case we have signal looks like carrier suppressed amplitude modulation. That signal was generated using two free running generators. In another case we have carrier suppressed amplitude modulation from one source, i.e. received signal from pedestrian [9]. At first sight both of signals are the same in power spectrum and in time domain. There are no differences. But deeply analysis using HOS can show huge differences between these two signals.

2.Bispectrum processing

Cumulants have the same meaning as moments. The moments of a random process are derived from the characteristic function$\Phi_x(\omega)$, and the cumulant generating function $c_x(\tau_1, \tau_2, .., \tau_{r-1})$ is defined as the logarithm of the characteristic function. For a real-valued stationary discrete process $\{x(i),\ i = 0,1,2, ...\}$ the joint cumulants of r^{th}order can be defined as [10]

$$c_x(\tau_1, \tau_2, .., \tau_{r-1}) = -i^r \left[\frac{\partial ln\Phi(\omega_1, \omega_2, \dots, \omega_r)}{\partial\omega_1 \partial\omega_2 \dots \partial\omega_r}\right]_{\omega_1=\omega_2=\cdots=\omega_r=0}, \tag{1}$$

where $\Phi(\omega_1, \omega_2, \dots, \omega_r) = \langle \exp\left[i(\omega_1 x_1 + \omega_2 x_2 + \cdots + \omega_r x_r)\right]\rangle_x$ is multidimensional characteristic function, $\omega_1, \omega_2, \dots, \omega_r$ are the frequencies, $i = \sqrt{-1}$, $\langle \dots \rangle_x$ denotes ensemble average procedure and $\tau_1, \tau_2, .., \tau_{r-1}$are the integer-valued shifts.

The *(r-1)* - multidimensional Fourier transform of the r^{th} order cumulant is the r^{th} order spectrum of a signal *x(i)* and defined as [10]

$$C_x(\omega_1, .., \omega_{r-1}) = \frac{1}{(2\pi)^{r-1}} * \sum_{\tau_1=-\infty}^{\infty} \dots \sum_{\tau_{r-1}=-\infty}^{\infty} c_x(\tau_1, .., \tau_{r-1}) e^{-i(\omega_1\tau_1 + \cdots + \omega_{r-1}\tau_{r-1})} \tag{2}$$

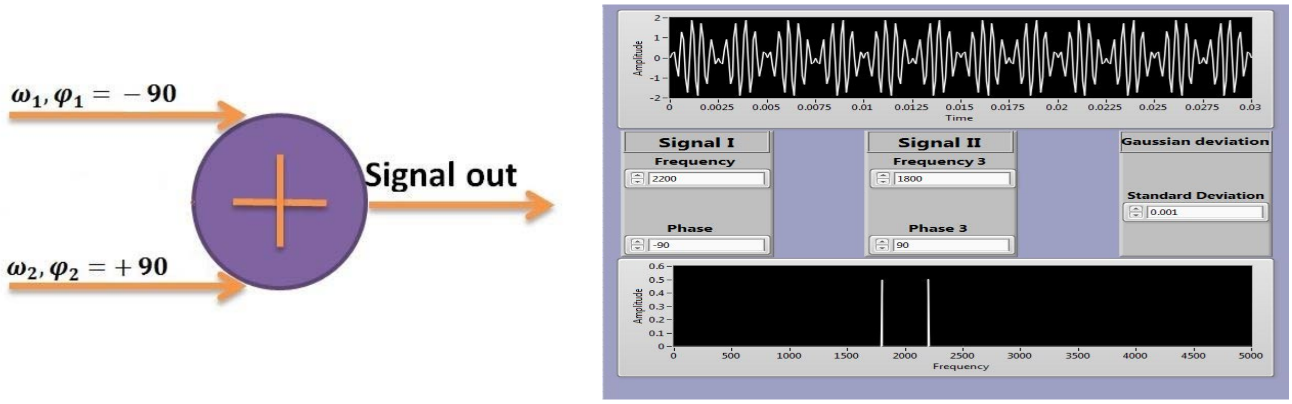
Formula (2) permits to define the bispectrum $B_x(\omega_1, \omega_2), (r = 3)$ in the formula (3)

$$B_x(\omega_1, \omega_2) = \frac{1}{(2\pi)^2} \sum_{\tau_1=-\infty}^{\infty} \sum_{\tau_2=-\infty}^{\infty} c_x(\tau_1, \tau_2) e^{-i(\omega_1\tau_1 + \omega_2\tau_2)} \tag{3}$$

where $c_x(\tau_1, \tau_2) = \langle x(i)x(i+\tau_1)x(i+\tau_2)\rangle$ is 3rd order cumulant. The equation (3) contains the cumulant function the properties of are very interesting. The most important one the Gaussian noise suppression was worth considered in detail in [8].

3.Career suppression using HOS or bispectrum estimation

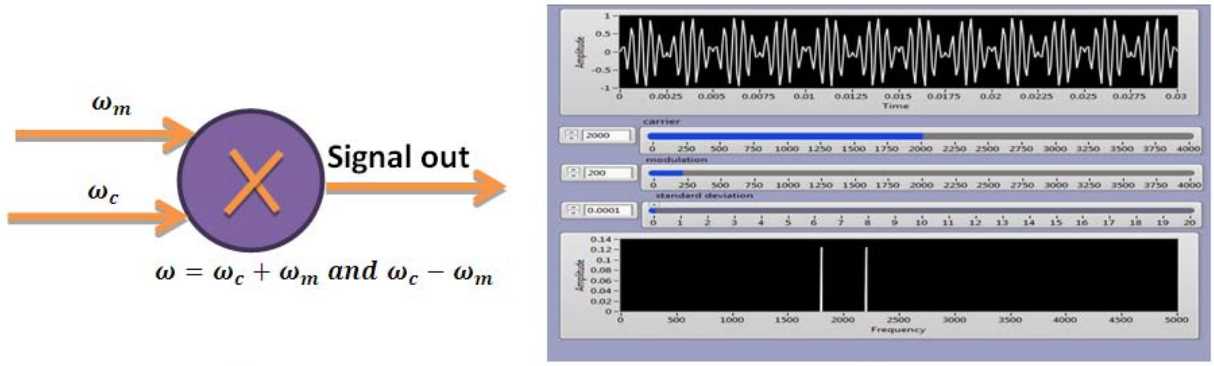
As it was said in introduction in this paper we have carrier suppressed amplitude modulation and noise which are same in power spectrum. One of signals is generated usingt wo free running generators with different phasesφ_1, φ_2 and different frequencies ω_1, ω_2. The only conditions are that $\varphi_1 = -90$ and $\varphi_2 = 90$. In this case we havenoise looks like amplitude modulation in power spectrum and time domain (figure 2):



a) **b)**

Figure 2.Noise, which was generated using two free running generators: **a)** schematic illustration of method; **b)** simulation result.

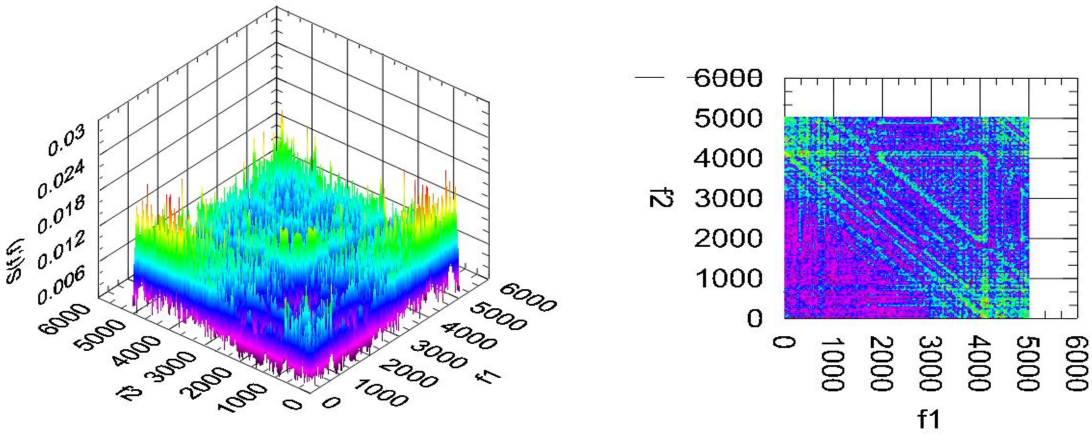
On Figure 3 it is illustrated carrier suppressed amplitude modulation, which was generated using two signals multiplication.



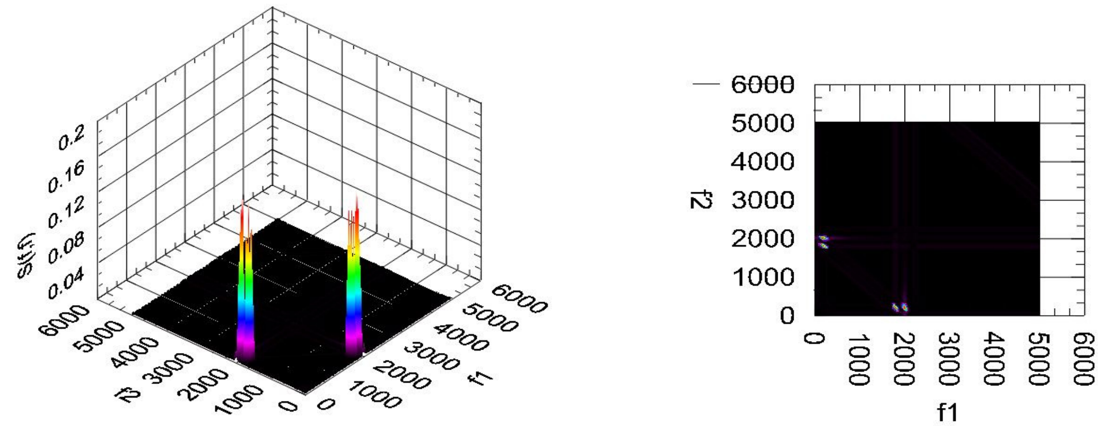
a) **b)**

Figure 3.Carrier suppressed amplitude modulation: **a)** schematic illustration; **b)** simulation result.

As it is shown in figure 2 and figure 3 results are the same but generated with different ways. There are the same peaks and the same frequencies, the same time domain and the same power spectrum. So comparing and differ this two signals in time domain or in power spectrum practically ineffectually. On the other hand if compare this two signals using bispectrum estimating, it will show clearly different signals in bispectrum domain. The result is shown on figure 4:



a)



b)

Figure 4. Bispectrum estimation: **a)**Noise, which was generated using two free running generators: default view (left) and top view (right); **b)**carrier suppressed amplitude modulation: default view (left) and top view (right).

As it is shown on figure 3(a) when there is noise, which was generated using two free running generators, in bispectrum domain there is signal looks like noise. On the other hand (figure 3 (b)) there are 4 peaks of carrier suppressed amplitude modulation in bispectrum domain. Bispectrum is a multi-dimensional Fourier transform of signal that's why in bispectrum domain peaks have been appeared in cross of two frequencies. For this case there are 4 frequencies:

- $\omega_m = 200$MHz (modulate signal)
- $\omega_c = 2000$MHz (carrier)
- $\omega_{right\ sideband} = \omega_c - \omega_m = 1800$MHz (right sideband)
- $\omega_{left\ sideband} = \omega_c + \omega_m = 2200$MHz (left sideband)

All peaks are phase coupled i.e. all are from the same source [5]. Peaks are appearing in frequencies which phases are connected with each other. Phase coupled frequencies are shown below on table 1.

Frequencies		**Phases**
$(\omega_{right\ sideband}, \omega_m)$	$(1700MHz, 300MHz)$	$\varphi_{right\ sideband} + \varphi_m = \varphi_c$
(ω_c, ω_m)	$(2000MHz, 300MHz)$	$\varphi_c + \varphi_m = \varphi_{left\ sideband}$
$(\omega_m, \omega_{right\ sideband})$	$(300MHz, 1700MHz)$	$\varphi_m + \varphi_{right\ sideband} = \varphi_c$
(ω_m, ω_c)	$(300MHz, 2000MHz)$	$\varphi_c + \varphi_m = \varphi_{left\ sideband}$

Table 1. Amplitude modulated signal peaks in bispectrum domain

4.Conclusions

In this paper was shown one of the most important property of HOS i.e. phase-coupled frequencies finding. In particular, phase information finding using high order statistics has been examined. The most important points of HOS and bispectrum estimation are given and it has been shown that they can provide information which second order statistics cannot. Finally, a new signal detection method was presented. It gives opportunity to detect and find signals which are generated from the same source i.e. the signals are phase coupled. The simulation early results are very promising.

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