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Comparisons Between Doppler Signal Orthogonal Transformations

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Abstract: This paper presents expansion and the behavior of the radar Doppler signals. As the experimental basis for this research work measurement results of the Federal Physical Engineering Bureau, Germany are used. The exposed problem is analyzed from the metrological and the identification point of view, taking the vehicle as the small velocity target under the scope. The comparative analysis of the Doppler signal orthogonal transformations is also presented, comparing the spectrums of different vehicles moving in the electromagnetic field of the Doppler radar with proposed velocities, under strictly defined circumstances. The short time spectrums are related to the photographic picture series taking the optical lenses with the same space angle as the Doppler radar main lob space angle.

Keywords: Doppler signal, orthogonal transformation, short time spectrum, long term average spectrum, vehicle spectral characteristic

1 Introduction

The consideration of the Doppler signal properties will start by diffusion scattering of the incident wave from the moving of the three dimensional object, which is an exceptionally complex process. With definite simplifications [1] which essentially do not affect result, Doppler signal spectrum at the output may be represented as:

$$B(\omega) = G(\omega) \cdot F(\omega) \quad \ldots \tag{1}$$

Where $F(\omega)$ is the spectral characteristic of the moving object and $G(\omega)$ is the spectral characteristic of the antenna.

The derived expression is based on a fact that the process of the vehicle which is passing through the EM radar beam is a convolution process. Each elementary reflector on the vehicle surface passes through same EM beam, naturally at different time moments. On the basis of this knowledge separate considerations of the object properties and the antenna's spectral characteristics was enabled.

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It is also known [2] that the spectral characteristic of the vehicle $F(\omega)$ is an asymmetrical curve with maximum at which, in general case, differ from Doppler frequency. In the Doppler signal spectrum considerable components may appear under the influence of the of the vehicle spectral characteristic. Due to their possible influence on the process of speed measuring of the vehicle, they were named „error signals“.

On Fig.1 is shown flat conducting surface which is moving in the EM radar beam. The frequency characteristic of the object has a maximum which produce ”error signal” whose relative position with respect to the Doppler frequency may be expressed as:

$$\varepsilon_r = \frac{\tan(\alpha)}{\tan(\alpha_s - \alpha)} \quad \cdots \tag{2}$$

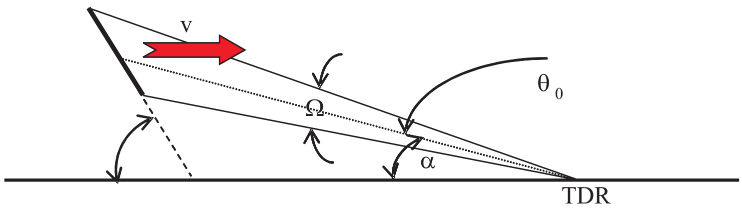


Fig. 1. Flat conducting surface moving in the EM radar beam.

As we see, the ”error signal” has the position which is a function of the angle of the surface slope with the respect to the direction of motion.

Fig. 2 displays three Doppler signals from same vehicle (Porsche) which is moving with three different speed (around 20, 40 and 60 km/h).

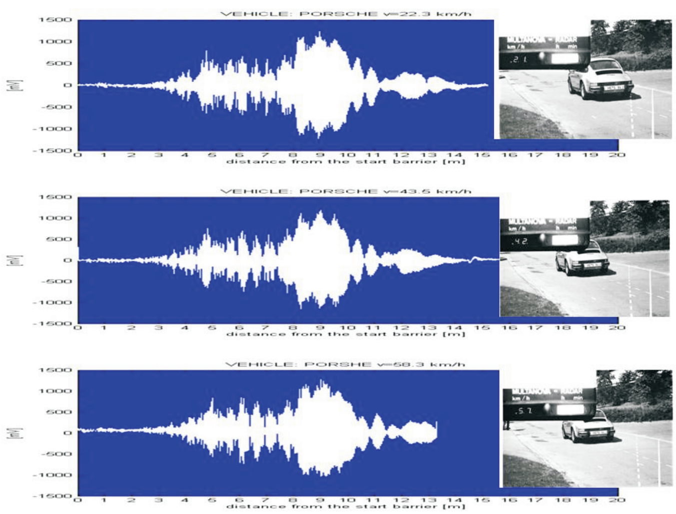


Fig. 2. Flat conducting surface moving in the EM radar beam.

2 Orthogonal functions

Infinite set of non-zero real functions:

$$\varphi_0(t),\ \varphi_1(t),\ \varphi_2(t), ..., \varphi_n(t), ... \quad ... \tag{3}$$

is said to be orthogonal on $a \le t \le b$ if

$$\int_a^b \varphi_n(t) \cdot \varphi_m^*(t) dt = 0 \quad (n \neq m) \quad ... \tag{4}$$

Each continuous function $f(t)$ which satisfy condition:

$$\int |f(t)|^2 dt < \infty \quad .. \tag{5}$$

can be representing with sum:

$$f(t) = c_0\varphi_0(t) + c_1\varphi_1(t) + c_2\varphi_2(t) + ... + c_n\varphi_n(t) + ... = \sum_{n=0}^{\infty} c_n\varphi_n(t) \quad ... \tag{6}$$

Set of coefficients can be obtained:

$$c_n = \frac{1}{\|\varphi_n\|^2} \int_a^b f(t) \cdot \varphi_n^*(t) dt \quad ... \tag{7}$$

where

$$\|\varphi_n\| = \sqrt{\int_a^b \varphi_n^2(t) dt} \quad ... \tag{8}$$

is a norm of a function $\varphi_n(t)$.

Discreet signal can be presented as:

$$f(kT) = \sum_{n=0}^{\infty} c_n\varphi_n(kT), \ \ k = 0, 1, 2, 3, ... \quad ... \tag{9}$$

The energy of a function $f(t)$ is closely related to the energy of its transform (Eq. 6):

$$E = \sum_{n=0}^{\infty} c_n^2 \|\varphi_n\|^2 \quad ... \tag{10}$$

For orthonormal set of functions $\varphi_n(t)$ energy of signal is:

$$E = \sum_{n=0}^{\infty} c_n^2 \tag{11}$$

DFT (Discrete Fourier Transformation) is a transform for Fourier analysis of finite-domain discrete-time functions. The input to the DFT is a finite sequence of real or complex numbers created by sampling a continuous function line Doppler signal. The sequence of N complex numbers $f(n)$ $n = 1,2,...,N$ is transformed into another sequence of N complex numbers according to DFT formula:

$$f(n) = \sum_{k=0}^{N-1} c_k \varphi_N^{kn}, \quad n = 0,1,2,...,N-1 \tag{12}$$

$$c_k = \frac{1}{N}\sum_{n=0}^{N-1} f(n)\varphi_N^{-kn} \quad k = 0,1,2,...,N-1 \tag{13}$$

Function of orthogonal basis is:

$$\varphi_N = e^{j\frac{2\pi}{N}} \quad ... \tag{14}$$

According to Parseval theorem power spectrum is:

$$P_k = |c_k|^2, \qquad k = 0,1,...,N-1 \quad ... \tag{15}$$

Walsh - **H**adamard **T**ransform (WHT) is an example of generalized class of Fourier transforms. It performs an orthogonal, symmetric involutional linear operation on 2^m real numbers (or complex numbers, although the Walsh – Hadarmard matrices themselves are purely real.

WHT can be defined in finite length Hilbert space, where signal

$$\{f(m)\} = \{f(0), f(1), \ldots, f(N-1)\}, \qquad N = 2^m$$

is defined and orthonormal set of Walsh – Hadamard functions Wal(j,k):

$$f(k) = \sum_{j=0}^{N-1} c_j \cdot Wal(j,k) \qquad k = 0,1,...,N-1 \tag{16}$$

$$c_j = \frac{1}{N}\sum_{k=0}^{N-1} f(k) \cdot Wal(j,k) \qquad j = 0,1,...,N-1 \quad ... \tag{17}$$

In mathematics and signal processing, the **Z-transform** converts a discrete time-domain signal, which is a sequence of real or complex numbers, into a complex frequency-domain representation. It can be considered as a discrete-time equivalent of the Laplace transform. This similarity is explored in the theory of time scale calculus.

Z-transform of discrete-time function

$$\{f(k)\} = \{f(0), f(1), ..., f(n))\}, \quad 0 \leq n \leq N-1$$

which is calculated in different points of contour $z = AW^{\alpha}$, where $\alpha$is a parameter:

$$z_k = A \cdot W^{-k} \quad k = 0,1,...,N-1$$

is:

$$F(z_k) = F_k = \sum_{n=0}^{N-1} f(n) A^{-n} W^{nk} \quad ... \tag{18}$$

3 Long term average spectrum of Doppler signal

In this part long-term average spectrum (LTAS) performance in task of describing properties of TDR signals is studied. LTAS is statistical feature that any digital signal possesses. It answers the general question about the average signal power distribution over frequency band [10]. The main goal is to compare the efficiency of different orthogonal transformations to make a sharp difference between Doppler signals from different types of vehicles.

Using LTAS for Automatic Recognition can be promising for large enough TDR Doppler signals since this feature collects the average general information about the speaker.

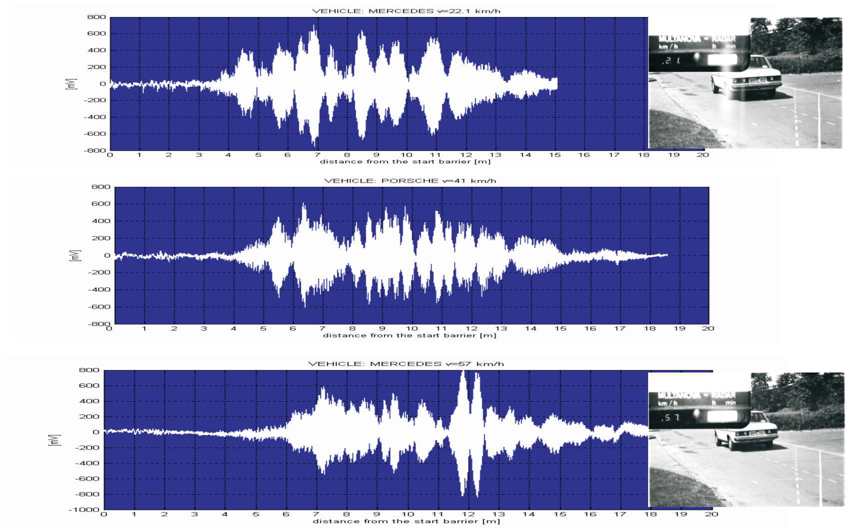


Fig. 3. Three Doppler signals from same vehicle (Mercedes) with different velocity.

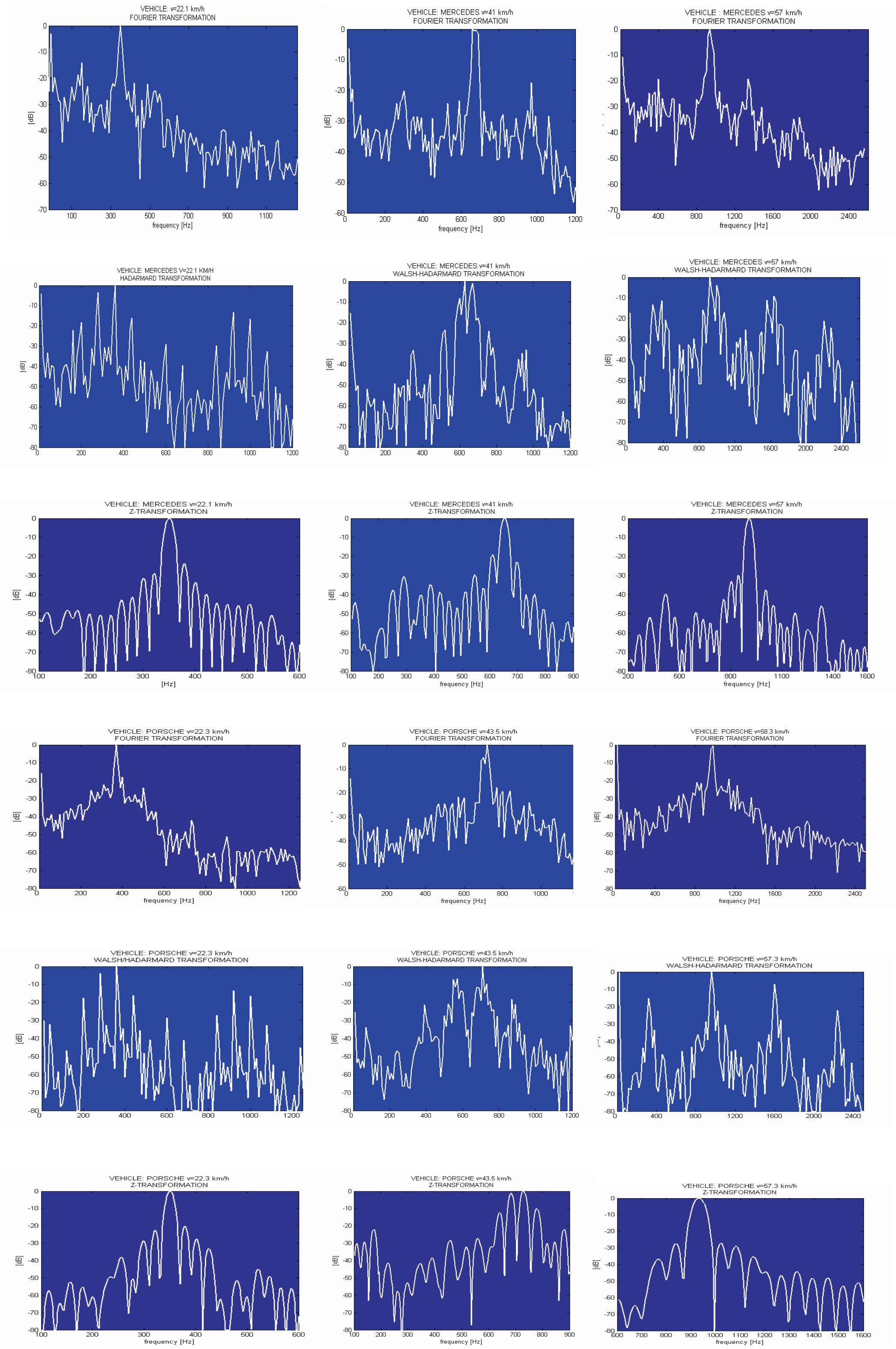
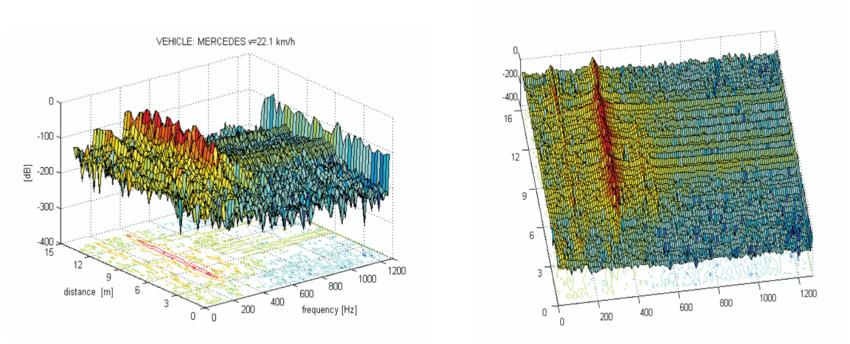


Fig. 4. Long-term average spectrum (LTAS) for different orthogonal basis.

4 Short-time spectrum of Doppler signal

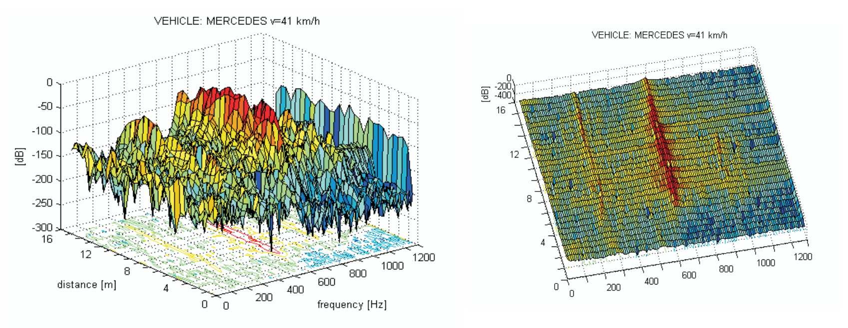
The concepts of short-time Fourier analysis are fundamental for describing any quasi-stationary (slowly time varying) signal such as Doppler signal or speech [1]. This time of spectrum is obtained by using the Doppler signal samples belonging to one part of it, and which were obtained by windowing of the signal by windows of the definite form and time.

Figures from 5a to 10b display the development of short-time spectrums when vehicle is passing EM beam of TDR. On Fig.11 is shown measuring disposition.



a) b)

Fig. 5. Different view angle (a, b) of short time spectrums, when vehicle MERCEDES is passing TDR EM beam with velocity $v = 22.1$ km/h.

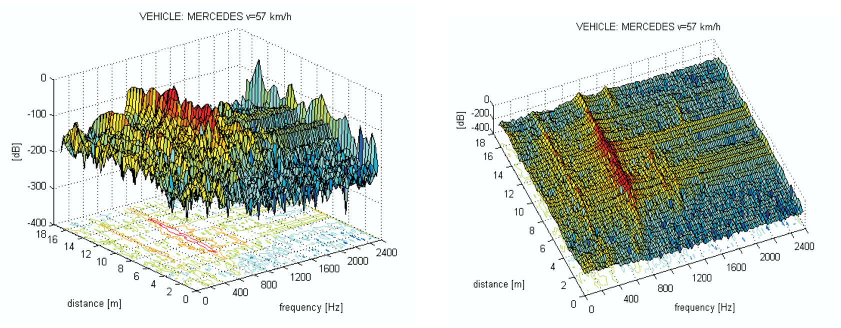


a) b)

Fig. 6. Different view angle (a, b) of short time spectrums, when vehicle MERCEDES is passing TDR EM beam with velocity $v = 41$ km/h.

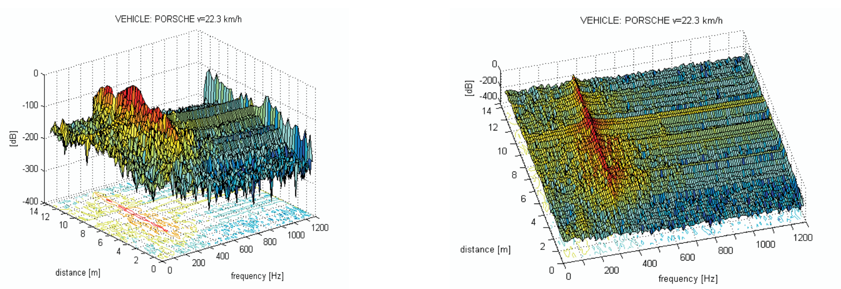
In this example we have two type of vehicle MERCEDES and PORSCHE. Recorded signal were when this two vehicles passed with three desired velocities (about 20,40 and 60 km/h).

At the distance of 5 m. from the barrier, the vehicles start entering by their front part into main EM beam. The signal levels are at that point low, while simultaneously there are very strong error signals which sometimes can overcome the spectral component on



a) b)

Fig. 7. Different view angle (a,b) of short time spectrums, when vehicle MERCEDES is passing TDR EM beam with velocity $v = 57$ km/h.

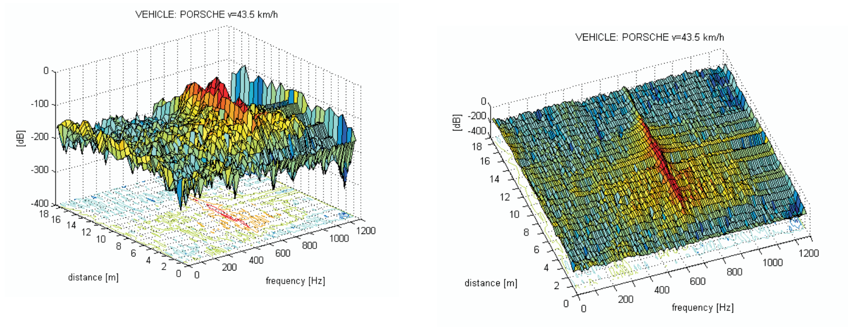


a) b)

Fig. 8. Different view angle (a,b) of short time spectrums, when vehicle PORSCHE is passing TDR EM beam with velocity $v = 22.3$ km/h.

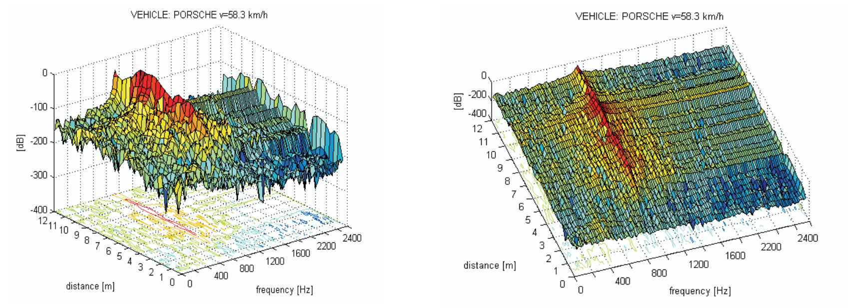
the Doppler frequency. At that time the signal is mainly formed thanks to side lobes of the antenna's characteristic. As we can see from figures 5 to 7, short-time spectrums from vehicle MERCEDES are relative wide with pronounced error signals at the left and right side of the spectral component on Doppler frequency. This component is quite strong at very entrance of the vehicle into EM beam. However, there are also error signals on the frequencies of 273 and 937 Hz when vehicle has velocity about 40 km/h. If we look more carefully and compare these spectrums than we can notice that the mentioned error signals occur even in the long time spectrum. It is therefore clear that the error signals in long time spectrum occur mainly in the early phase of entering vehicle in measuring region (between two piezoelectric contacts), but that their presence is visible at the time when vehicle is in the main EM beam. Even when vehicle is come out of main EM beam those error signals are present.

For vehicle PORSCHE error signals are located very near to Doppler frequency and can overcome main component. Constant presence and a power of spectral components around Doppler frequency may produce huge problems during the speed measuring process for this type of vehicle. We may expect that the width of the spectrum main lobe is wider sometimes with multiple peaks as on the Fig.4.



a) b)

Fig. 9. Different view angle (a,b) of short time spectrums, when vehicle PORSCHE is passing TDR EM beam with velocity $v = 43.5$ km/h.



a) b)

Fig. 10. Different view angle (a,b) of short time spectrums, when vehicle PORSCHE is passing TDR EM beam with velocity $v = 58.3$ km/h.

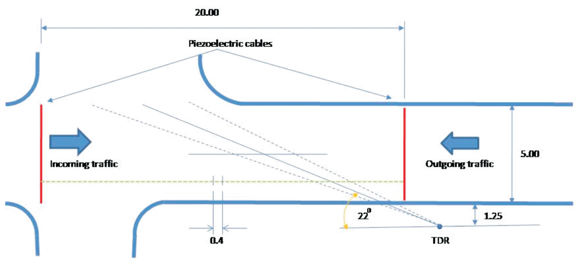


Fig. 11. Measuring disposition

5 Spectral characteristic of the vehicle $F(w)$ and the error signals

A number of methods for identifying the radar target are based on the detection of significant spectral components in the so-called "spectral signature" of the received radar signal from the target. These spectral components which are also called error signals (from the speed measuring point of view) are representing local maximums in Doppler signal spectrum. Their presence and position are for each type of vehicle is unique and describe spectral characteristic of vehicle. Relative position of these components is independent from the vehicle speed. Therefore, from different orthogonal transformations of the radar Doppler signals obtained from various vehicle types, we can estimate useful information for identification process. From set of figures from 5a to 7b for vehicle MERCEDES we observe that the relative position of the error signals, i.e. of the significant spectral components with respect to the spectral component at the radar Doppler frequency is constant irrespective of the vehicle speed. We can expect that for other types of vehicles position of significant spectral components (if they exist) is specific. The same measurements we have for another four types of vehicles (BUS, VW, GOLF, Motorcycle) [8,9] with results of orthogonal transformations which confirms our theory.

Though the vehicles did not in all three cases (v=20,40 and 60 km/h) have the identical trajectory, the position of the presented spectral components in Doppler signal spectrum remains approximately constant. The theoretical assumption derived in the introduction section of this paper, that the process of the vehicle identification may be performed on the basis of the error signals, whose positions and levels are related to the spectral characteristic of the vehicle by the experiments performed is proved.

6 Conclusion

On the basis of theoretical assumptions derived in this paper we first compare the efficiency of different orthogonal transformations to make a sharp difference between Doppler signals from different types of vehicles. On the example of two vehicles (MERCEDES and PORSCHE) it was shown that the long term average spectrum of Doppler signal (LTAS) may contain in the specific way distributed spectral components on which we can base the identification process of TDR target. Also with estimation of short time spectrum it was shown that the particular shapes of the vehicle may at definite moments create extremely strong error signals. From the development of short time spectrum of TDR signals, appearing and disappearing some spectral components we can estimate important information for identification process.

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