Correction of Received Power for Doppler Measurements by FMICW Radars

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***Abstract* - This electronic document is aimed at the corrections of the received power through frequency modulated interrupted continuous wave radars. These corrections are important for the correct interpretation of the target characteristics. Power corrections, described in this paper, are modified for the measurement of the Doppler shifts. Doppler shifts are calculated by the using of the two dimensional fast Fourier transform. In practical part of this paper four types of windows were compared during calculation of the two dimensional spectra. We concluded that the correction coefficients should be determined for each window individually.**

***Keywords* – FMICW radar; Spectral analysis; Doppler measurements; Power corrections; Target reflectivity**

I. INTRODUCTION

FMCW (Frequency Modulated Continuous Wave) and FMICW (Frequency Modulated Interrupted Continuous Wave) radars are very often used for experimental measurements in the present. These radars are used for example at the TU Delft, or in the IAP CAS (Institute of Atmospheric Physics Czech Academy of Sciences) - radar PCDR 35 (Portable Cloud Doppler Radar). Data from these radars are used for scientific research of atmospheric properties. But if the data are wrong, results cannot be used for the research. FMCW radars do not have the problem with power. They are working continuously, FMCW radars are described in [1, 2 and 3]. But in the FMICW radar case the problem is caused by the difference between the real length of the received reflected signal and the length of the recorded signal. Principle of the FMICW radar is described in [4]. In this case the ionosphere is monitored (between the radar and the target is a very big distance) and a used frequency is low, there can be used the FMICW radar without corrections. The process of the transmitting and switching of the transmitter and the receiver is realized before incoming of reflected signal. In case of FMICW radar on the high frequency (increasing of free space attenuation) there must be longer pulse used and this pulse is not recorded totally for the short distances.

A modification of the power for the one dimensional spectral analysis was described in [5], but this method can be used only for the monitoring of the range. If we need to measure the Doppler shifts, we must do two dimensional spectral analyses and this process is described below. The purpose of this contribution is correction of a received power for the better estimation of the reflective area. Consequently, on this we expect better interpretation of the targets. Our aim is to evolve an algorithm for power correction for this radar. The model of this radar is described in [6]. The owner of this radar is IAP CAS.

II. FMICW RADAR PCDR 35

PCDR 35 is the meteorological radar at the 35.4 GHz frequency.

A. Description of the Radar

The principle of the FMICW radar is shown in Fig. 1. FMICW radar works in three steps, in the first step only the transmitter is open and reflected incoming signals are lost. The second step is blind zone time. In this time the transmitter and the receiver are switched off. The third step is receiving. In this time the signal for the spectral analyses is recorded. The calculation of the distance is described in (1).

Control unit of the radar PCDR 35 is shown in Fig. 2, this unit generates the inter frequency signal for the transmitter (pin 2) and the receiver (pins 1 and 3), the second function of this part is switching of the transmitter and the receiver (Rx and Tx). The signal trigger is used for the start of the signal recording. The 660 samples are recorded after the signal trigger. The transmitting part of this radar is shown in Fig. 3. The first block is the bandpass filter for the cancelation of the base signals from the generator. The second block is the circulator (blocking the reflected signals) and the PIN diode (driving the transmitter). In the next part the inter frequency signal is multiplied by 4, being amplified and connected to the antenna. The receiver is shown in Fig. 4. In the first step received the signal is transformed on the inter frequency, this signal is filtered, amplified and mixed on the base frequency. In the last step the signal is filtered and recorded by the computer. The next equation shows the distance calculation:

$$\delta f = \frac{\Delta f_{MAX}}{T} \cdot \frac{2 \cdot R}{c}, \qquad (1)$$

where Δf_{MAX} is the frequency range, T is the modulation time, c is the speed of the light and R is the distance of the target (δt in Fig. 1 is function of this target distance).

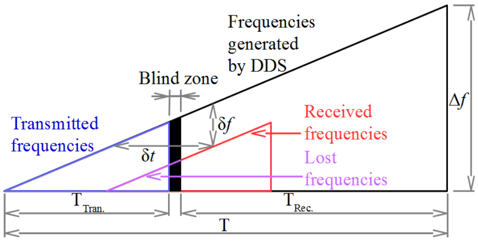

Figure 1. Timing diagram of FMICW radar [7].

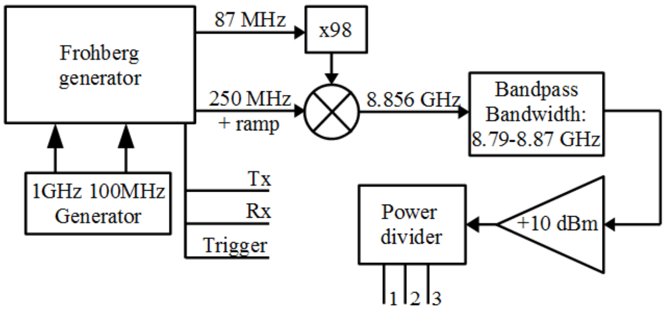

Figure 2. Control unit of the FMICW radar PCDR 35 and sweeping generator.

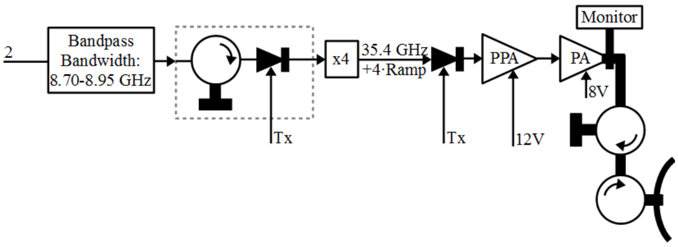

Figure 3. Transmitter of the FMICW radar PCDR 35.

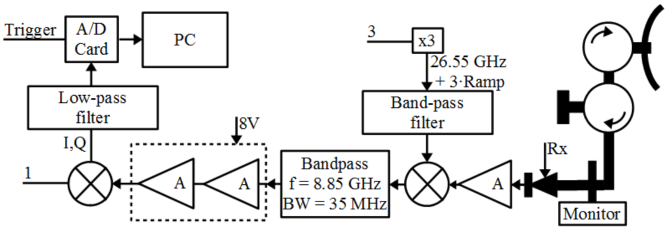

Figure 4. Receiver of the FMICW radar PCDR 35.

B. *Radar Signals Processing*

An example of the recorded signal is shown in Fig. 5. The signal is focused on the part with the reflected signal. In this recorded signal two reflected signals are available. The distance can be estimated from the samples of the last recorded points. But the estimation is problematic for more targets. The problem with the connection of the points and targets is evidential. A better description can be realized by the spectral analysis using. The spectral analyze can be made by the Fourier transform, multi signal classification method, auto regressive model and others. Methods for the spectral analysis of the signals are described for example in [8] and [9]. The spectral analysis of the signal from Fig. 5 is shown in Fig. 6. For the calculation, the FFT (Fast Fourier Transform) algorithm was used. In this figure the error in the power calculation can be observed. If you compare the longer signal (of a bigger distance) and the shorter signal (of a smaller distance) in Fig. 5, you can see that the power of the longer signal is lower. In the spectrum placed in Fig. 6 the power of remote target is “surprisingly” bigger - it is caused by the FFT principle.

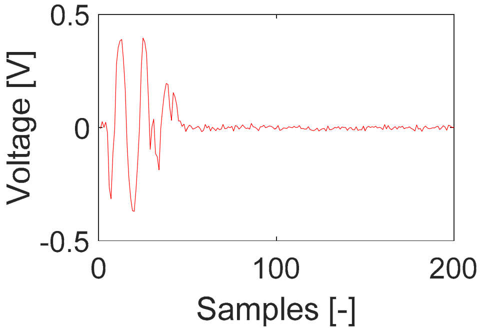

Figure 5. An example of the received signal from FMICW radar (PCDR 35), signal was obtained from the simulator.

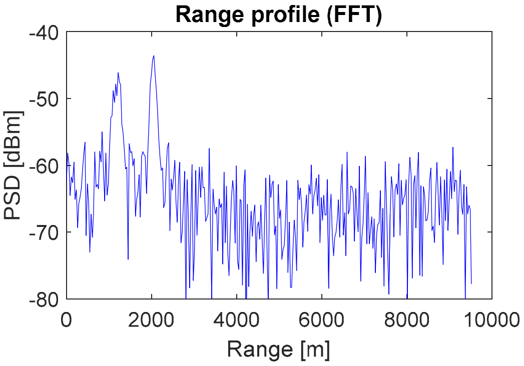

Figure 6. Spectrum of the received signal (Fig. 5) after transformation from frequencies to ranges.

III. CALCULATION OF 2D FFT

Using of the 1D spectrum is only for the distances and the powers analysis, but for the measurement of the Doppler shifts of the targets, 2D FFT must be used. This algorithm is shown in Fig. 7. For this analysis we need a matrix of measurements. In the first step the range spectra are made. These spectra (values must be complex) are placed to a matrix and the next spectra are realized for the distances. Before the second spectral analysis the actual spectra can be multiplied by the windows for the cancelation of the side lobes. It is important for the false alerts elimination.

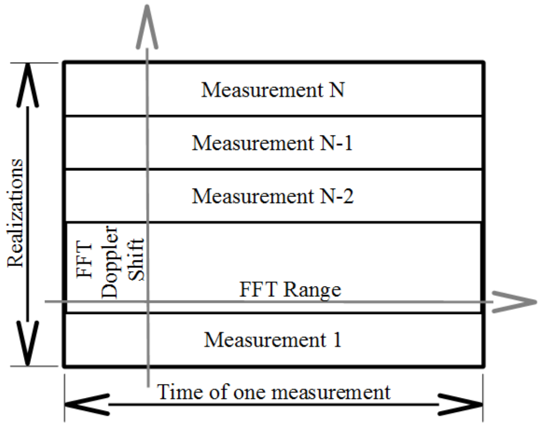

Figure 7. Principle of the 2D FFT [6].

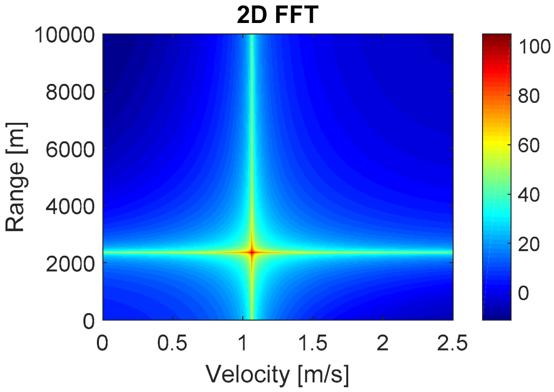

Figure 8. Analysis of the point target by the 2D FFT with using of rectangular window (detected object is approaching).

The incoming object is measured by the FMICW radar. The signal analyzed by the 2D FFT is shown in Fig. 8. The Doppler shift was recalculated to the velocity. The velocity is bigger than 1 meter per second.

IV. CORRECTION OF RECEIVED POWERS

The correction of the power is important for the estimation of the target type. For example, in the meteorology cells case (rain, clouds, snow and others) are estimated according to the reflective area and this area is calculated from the power. In this chapter sources of the errors and algorithm for correction of the power are described.

A. Sources of the Errors in Power Estimation

There are two main sources of the power errors. The first is caused by the principle of the spectral analysis, where spectral components are divided by the signal length, but in FMICW radar the effective signal is not available in the whole length of the recorded signal, it is shown in Fig. 5 and 6 (it is caused by physical principles and influenced by radar parameters). The second source is the placement of the sinusoid in the recorded data and the frequency. The dependence of the signal power on the frequency is in Fig. 9. The error is in this case in the range from +1 dB and –3 dB (for a median value). These loses are caused by the side lobes - energy is namely spread in main lobe as well as in side lobes. According to Fig. 9 we can estimate that dependence on the frequency is periodical.

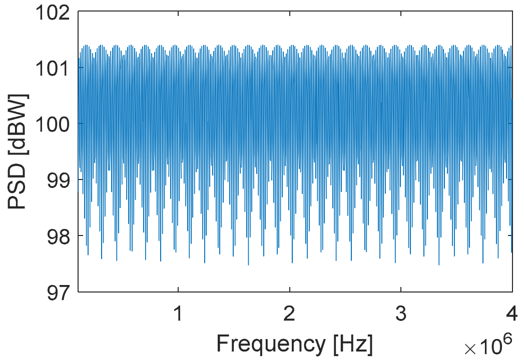

Figure 9. Dependence of the received power on the frequency (rectangular window is used for the Doppler spectra).

Statistical parameters in the dependence on the frequency for the different windows, used by the second FFT, are shown in the Tab. 1. From this table we can estimate the range of the frequencies and difference between these four windows. We can see that the biggest difference is between rectangular and Blackman window (approx. 8 dB).

TABLE I. STATISTICAL PARAMETERS OF SINUSOIDS POWERS OBTAINED FROM 2D FFT FOR DIFERENT WINDOWS USED ON THE RANGE SPECTRA IN DEPENDENCE ON THE FREQUENCY

Parameter over frequencies	Hamming window [dBW]	Blackman window [dBW]	Rectangular window [dBW]	Hanning window [dBW]
Maximum	101.3990	99.2142	106.7624	100.7286
Median	100.4938	98.3090	105.8571	99.8234
Minimum	97.4769	95.2920	102.8402	96.8064

B. Experiment and Algorithm for Correction of the Powers

For our test the training signals were simulated, these signals were processed by the 2D FFT with four different windows. All signals were of the same amplitude, but lengths of the effective signals were different. Data from this simulation were placed to Tab. 2. From this table we can see that the power is four times smaller if the effective signal is reduced to the 50 percent. Data for the rectangular window were drawing in Fig. 10. Points were interpolated by the power curve.

TABLE II. DEPENDENCE OF THE POWER ON LENGTH OF THE EFFECTIVE SIGNAL AND LENGTH OF THE RECORDED SIGNAL RATIO BY USING OF THE 2D FFT

ESRSLR[a]	Hamming's window [dBW]	Blackman's window [dBW]	Rectangular window [dBW]	Hanning's window [dBW]
2.27%	68.535	66.35	73.898	67.865
10%	81.504	79.319	86.867	80.834
20%	87.451	85.266	92.815	86.78
30%	90.949	88.764	96.312	90.278
40%	93.472	91.287	98.835	92.801
50%	95.377	93.192	100.74	94.707
60%	96.979	94.794	102.342	96.308
70%	98.309	96.124	103.673	97.639
80%	99.4628	97.278	104.826	98.792
90%	100.497	98.312	105.861	99.827
100%	101.398	99.213	106.761	100.727

a. Effective signal to recorded signal length ratio

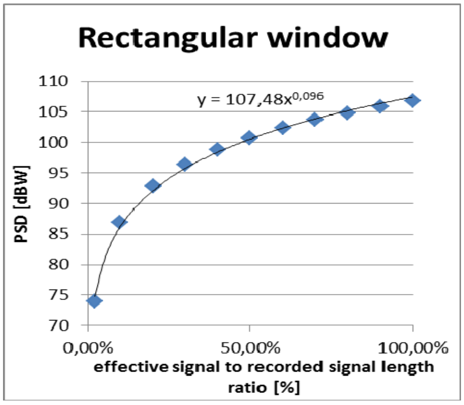

Figure 10. Dependence of the power error on the length of the effective signal length in the recorded signal (rectangular window is used).

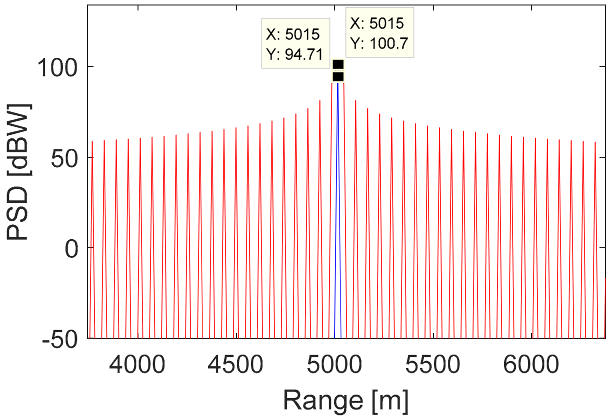

Figure 11. Comparison of two signals spectra with different lengths of effective signal (2D FFT with rectangular window).

The Algorithm for the whitening of the powers is following one. In the first step the training signals are processed by the 2D FFT and these points are used for a creation of the power equation (in our case equations (2) for the rectangular window). From this equation the whitening equation is created (in our case (3)). These equations must be modified for every window.

$$y = 107.48 \cdot x^{0.096} \ , \tag{2}$$

$$y = x^{-0.096} \ , \tag{3}$$

where x is the length of the effective signal and the recorded signal ratio (since 0 to 100) in percentages.

The ratio between lengths of the effective signal and the recorded signal is a function of the target distance. The correction coefficient is calculated from the target distance and this coefficient is multiplied by the power in dB to obtain the correct power.

Examples of two cases are placed in Fig. 11. The red spectrum is for the shorter effective signal (50 %) and the blue is for the longer signal (100 %), both signals have the same voltage. The correction coefficient for the red spectrum (50 %) was estimating according to the equation (3) - value 1.074. The corrected power is obtained from the multiplying of the power (97.71 dBW) and the correction coefficient (1.074). This new power is 101.7 dBW. The estimation power error is reduced from 6 dB value to 1 dB value now. We can see that algorithm is successful as it was shown in this paragraph and in Fig. 11.

V. CONCLUSION

In this paper the algorithm for the FMICW radar power receiving correction was described. The error of the power is caused by the different length of the effective signal and the length of the recorded signal for the spectral analysis. This algorithm is important for the correct interpretation of the monitored targets. This algorithm can be used for example in meteorological radars. In these applications the received power is used for the estimation of the reflective area. A wrongly estimated power produces bad estimation of the monitored target type.

In this paper four types of windows used for the Doppler shift calculation were compared. As we showed in this paper, these windows have different influences on the received powers. You can see that the different whitening curves must be used for every window. And every window gives a different maximal power. The static modification must be realized for the correct interpretation of the signal. The difference between tested windows is up to 8 dB. The best variant for a power correction is the rectangular window, amplitude is not affected there. If we are using other window types, the power must be modified according the Tab. 1.

Our future intention is the whitening curve modification for the frequency influences suppression. In present this process makes an error in the range from +1 dB to -3 dB. Our aim is to implement this algorithm for PCDR35 radar. This method is possible to utilize in the radar signal processing only after some target detection. If we use this step beforehand, it can produce new false alerts. These false targets can be suppressed by the using of a variable threshold value. Consequently, the radar signal processing is more complicated.

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