A Doppler Wheel in Radar Calibration

Jukka Ruoskanen (1) **Pekka Eskelinen** (2)

(1) ***Finnish Defence Forces Technical Research Centre***
PVTTEIOS, PL10, 11311 Riihimäki, Finland
Email:jukka.ruoskanen@mil.fi

(2) ***Helsinki University of Technology***
PL3000, 02015 TKK, Finland
Email:pekka.eskelinen@tkk.fi

INTRODUCTION

Modern test instrumentation with enhanced computer control features has long ago pushed mechanical Doppler targets [1] up to the museum of radar engineering. However, phenomenologically speaking, the frequency domain radar response from selected rotating targets or from targets containing rotating parts remains of continuous interest [2]. Such geometries and dynamic characteristics are found for example in artillery munitions, low-flying missiles and as parts of rotating wing aircraft.

Millimeter wave radar returns from cylindrical targets such as artillery shells or helicopter rotor shafts can be experimentally evaluated with the classic Doppler wheel which also makes a simple autonomous calibration tool for radar development and field-testing. Measured Doppler spectra for up to 3000 rpm speeds with a Ka-band radar against a 100 mm diameter flat cylinder are presented. We also show less apparent wheel-return characteristics found in practical measurements.

This research was motivated by the brief description in [1] giving no details about the results but illustrating a real physical device. Furthermore, it is in our need to have an autonomous Doppler evaluation target for millimeter wave radar work out in the field.

MEASUREMENT SETUP

The test installation consists of a monostatic battery-powered coherent Ka-band CW radar, an anechoic range and the rotating wheel itself. The radar has an output power of +10 dBm and a circular horn antenna with a dielectric lens add-on giving an overall 3dB beamwidth slightly below 5°. The receiver utilizes a simple biased diode mixer and a low-noise audio amplifier together with a high pass filter.

The target is a hollow cylinder manufactured of electric-grade copper and machined to give a rotational symmetry better than 0.1 mm. The cylinder diameter was 120 mm and an axial height 40 mm. A DC motor was used as a rotator giving useful speed range from 180 rpm to 3000 rpm. High quality millimeter wave absorbers are used to cover all critical regions of the 2-meter test range, see illustration in Fig. 1.

Data was recorded with a high-speed four channel digital oscilloscope that also provided the FFT (Fast Fourier Transform) results. An adequate frequency resolution was obtained with time domain records extending over several consecutive target turns.

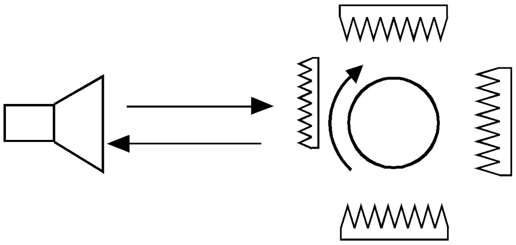

Figure 1: *Illustration of the test setup.*

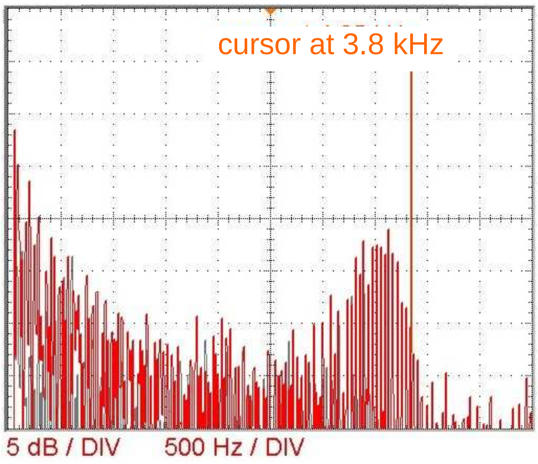

Figure 2: *Measured Doppler spectrum (n=2400 rpm, left edge illuminated, with turbine blade added) of a receding blade.*

TEST RESULTS

Four different main illumination cases where evaluated with the rotating wheel. The starting point was a full illumination coverage of the metal skin and then three alternative masks of arbitrarily chosen width were tried in turn covering either the center part, both edges or everything else but one edge of the wheel surface as seen from the radar. Additionally, to get an idea about the influence of surface irregularities, we purposely added a 2x2 mm^2 bump just above the cylinder rim and also tried a miniature turbine blade with main dimensions of 6x12 mm^2.

Our main findings are the following. When measuring with a practical CW radar, signal components of meaningful amplitude do exist up to the maximum frequency defined by the cylinder's rim speed - a result not completely in line with [3]. Contrary to our initial assumptions we found that absorber-based shadowing of illumination does not remove all "masked" frequencies, but for example at a speed of 3000 rpm and just 5 mm wide illuminated outer segment we could measure Doppler components down to 1200 Hz. An approximative theoretical Matlab-model, using basic geometric- and physical optics, fails to explain the components at the lower end of the spectrum. The high end of the measured spectrum shape e.g. in the case of approaching or receding blade can be simulated with satisfactory accuracy. The origin of the low frequency components will be studied further using more elaborate RCS prediction methods.

References

[1] R. L. Ferranti, "Widgets and wonders: Lincoln Laboratory's unique radar hardware legacy," *MIT Lincoln Laboratory Journal*, vol. 12, no. 2, p. 425, 2000.

[2] C. W. Chuang, "Backscatter of large rotating conducting cylinder of arbitrary cross section," *IEEE Transactions on Antennas and Propagation*, vol. AP-27, pp. 92-95, January 1979.

[3] J. K. Christensen, M. J. Underhill, "Doppler measurements of smooth and rough surface high frequency scattering from spinning steel cylinders," *IEEE Aerospace and Electronic Systems Magazine*, vol. 19, pp. 11-14, December 2004.