35-GHZ-DOPPLERRADAR FOR LAW ENFORCEMENT AGENCIES IN EUROPE

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ABSTRACT

The accuracy of stationary Ka-band-doppler-radars for law-enforcement agencies is discussed as a function of numerous parameters.

The experimental setup for the studies comprises a dual channel 35-GHz-CW-dopplerradar with selectable transmit polarization, direction of motion sensing capability and a signal recording system. The results of the experiments provide basic data to design law-enforcement radars at Ka-Band. The dominant scatterers and their location on the vehicle will be determined.

INTRODUCTION

For more than 25 years law-enforcement agencies all over Europe used X-band-CW-dopplerradars for remote speed measurement of urban traffic and on highways.

Since 1982 there is a tendancy towards higher frequencies, thus allowing industry to design smaller radars with improved accuracy. A Ku-band-CW-dopplerradar (13.45 GHz) is the interim step towards Ka-band.

Meanwhile a commercial 35-GHz-CW-dopplerradar that operates at 34.3 GHz is in service at least with the German and Swiss authorities. However, until recently no comprehensive study on radar reflectivity of moving vehicles existed for the Ka-Band to support the radar designers, bureaus of standards and the traffic courts in terms of system accuracy and reliability.

STATE OF THE ART

The law-enforcement radars approved in the Federal Republic of Germany (F.R.G.) operate with horizontal polarization and a quadrature homodyne receiver to sense the direction of motion. Parabolic dish antenna beamwidths vary from 7 degrees (9.41 GHz) to 5 degrees (34.3 GHz).

The beamwidths of waveguide slot antennas are wider in elevation, as beamwidths are in the United States (app. 15 degrees).

The different designs of the signalprocessing presently in use are based on limited empirical rules gained through the use of X-band-radars operating with single polarization. The designated frequencies in the U.S.A. are 10.525 GHz and 24.15 GHz.

Due to a lack of knowledge in the reflectivity of moving motor vehicles as an ensemble of scatterers in the nearfield of the antenna of a stationary mmW-radar it is difficult to define system parameters like antenna aperture, polarization, signalprocessor architecture, algorithms and system accuracy.

FIELD TESTS WITH 35-GHz-CW-DOPPLER-RADAR

This paper reflects part of the extensive work that has been done with the Technical University of Darmstadt to investigate the accuracy of radar measurements on moving motor vehicles at 35 GHz based on the experience gained during field tests at X-Band.

A polarimetric Ka-Band-CW-dopplerradar including data acquisition was designed, built and calibrated against standard reflectors. The temperature-stabilized Gunn-oscillator has an output power of 20 mW.

The beamwidths of the conical horn are app. 7 degrees in both planes, to comply with the beamwidths used at X-Band. The target's copolar and crosspolar dopplerreturns are received simultaneously and recorded on magnetic tape including a reference signal.

By means of light barriers and a specific data recording procedure the vehicle's velocity and position within the antenna beam was determined for reference.

A typical setup of a roadside measurement is shown in figure 1.

A comprehensive experimental program was conducted to investigate the reflectivity of moving motor vehicles at Ka-Band as well as the accuracy of speed measurements as a function of numerous parameters such as antenna polarization, beam illumination, side distance, multipath, antenna height, signal to interference ratio and aspect angle.

SIGNALPROCESSING OF DOPPLER SIGNALS

The vehicle's velocity has been determined by different methods to determine the doppler frequency. These are

- 1. zero counting
- 2. period counting
- 3. FFT

The results of each individual measurement are weighted by the normalized energy of the doppler signal in a related timevariant intervall ($s = v * Tm$ = app. 0.5 m).

Figure 2 shows the FFTs for an approaching motor vehicle and a receeding car (nonsymmetrical FFT) and the relative doppler errors for the copolar (Inphase) and crosspolar (Quadrature phase) signals.

RESULTS OF ROAD MEASUREMENTS

Velocity measurements were conducted on 700 receeding and 700 approaching cars. Up to three light barrier systems were installed for reference. The maximum errors obtained in the copolar and crosspolar channels for these 1400 trials are between - 3.8 % and + 3.7 % and related to antenna beamwidth as predicted by theoretical evaluations.

The mean and standard deviation of the velocity errors for motor vehicles as a function of side distance d, polarization and horizontal aspect angle have been measured.

The means of the velocity error are less than +/- 2 % for a Volkswagen Rabbit, standard deviation is not range dependent.

SYSTEM ACCURACY DUE TO ANTENNA BEAMWIDTH

In order to study the influence of antenna gain 100 additional measurements on vehicles closing towards the radar at an aspect angle of 22 deg. were conducted with a radar having an antenna gain of app. 34 dB at vertical polarization. The beamwidths were 2.8 deg. (E-plane) and 2.6 deg. (H-plane).

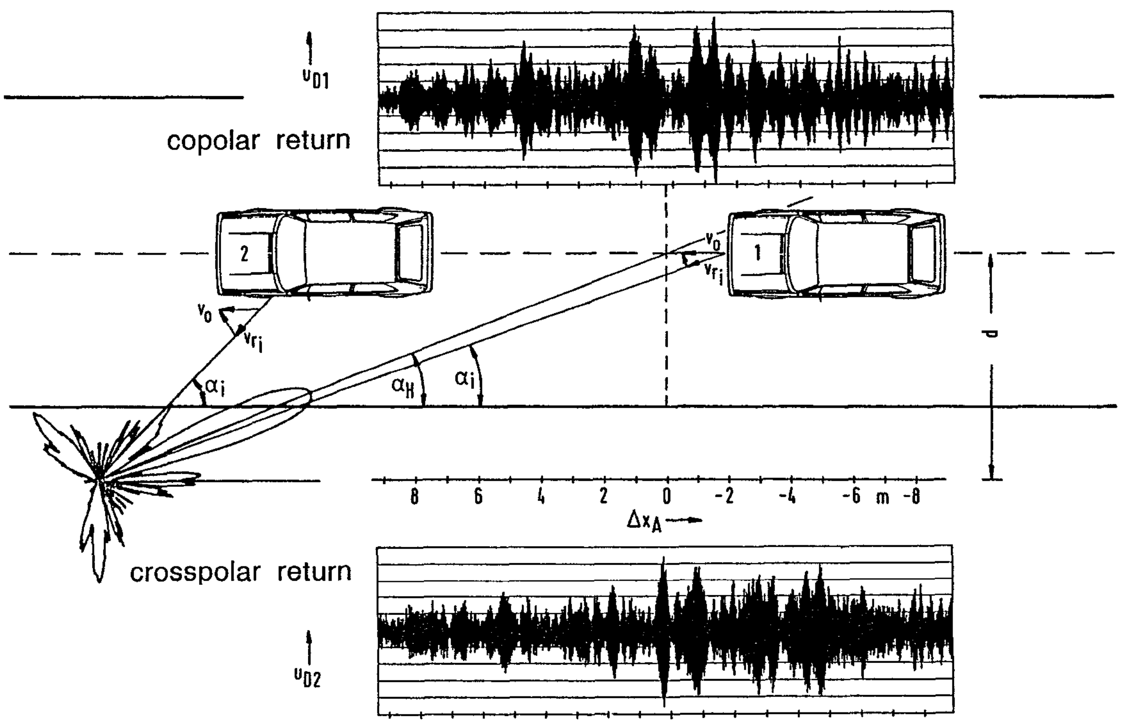

Fig. 1: Velocity measurement of a closing car

Less interferences with slower amplitude fluctuations were observed on the doppler-signal and the maximum velocity errors calculated were between - 2.6 % and + 0.5 %.

These errors are a function of the motor vehicle's position at the occurence of the maximum energy of the doppler return.

If the front of the vehicle is before the intersection of antenna beam and median of the road (refer to figure 1 at 0 m) the velocity error is positive in most cases. Doppler measurements at max. signal energy normally are more accurate than frequency measurements at maximum doppler amplitude. Accuracies will be improved by calculating the weighted mean over several time intervalls. The weighting factor is the normalized doppler energy during the speed gate. whose length is variable with target speed

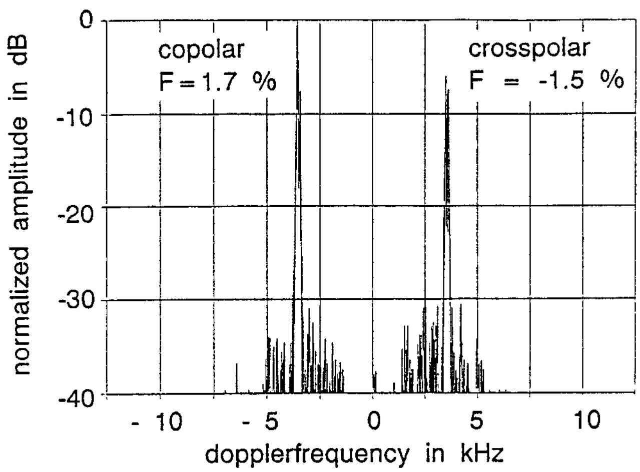

Fig. 2 a: FFT of complex dopplerreturn from a closing motor vehicle

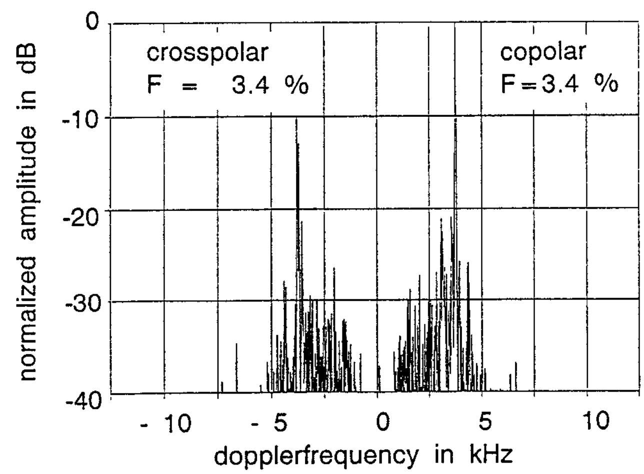

Fig. 2 b: FFT of complex dopplerreturn from a receeding car

PROCESSING OF CROSSPOLAR RETURNS

The maximum errors presented occured at the peaks of the doppler energy. Weighted combining of the two dopplerreturns in the signal processor and the use of appropriate weighting factors improves system accuracy.

Due to the multitude of scatterers on a vehicle and the high likelihood of multipath over asphalt (r is app. 0.6 at 35 GHz), the doppler returns fluctuate in amplitude and the accuracy of zerocounting the doppler to determine the vehicle's velocity suffers. This effect can be reduced by averaging the doppler frequency over a number of counting intervalls including weighting by energy.

CAMOUFLAGED CAR

The velocity of an approaching FIAT 128 AC was determined with an accuracy of better than 1 %.
The analysis indicated the right front fender to be the strongest scatterer, second were the headlights. The interaction of the right front fender and the rear fender caused strong interferences. Therefore the radar reflectivity of the car was changed by covering the headlights, motor grill and right front fender with absorbing material.

Now the maximum of the doppler energy occured + 2.5 m later (towards the radar), indicating the right rear fender as the most dominant scatterer. The velocity error determined for weighted averaging of the frequency measurements still remained within the 1 % boundary.

CONCLUSIONS

The RCS of motor vehicles is approximately 2 dB to 6 dB higher than the values known from X-Band. The RCS of approaching vehicles is up to 10 dB stronger than those of receeding cars. The dominant scatterers are the headlights, the grill and the fenders.

Radars with antenna beamwidths of 7 degrees achieve reasonable accuracy. but beamwidths of 5 degrees and smaller are preferable.

Dopplermeasurements should be done within the - 10 dB boundaries of the dopplerreturn with respect to the maximum of the doppler-energy. The minimum S/I-ratio at maximum of the doppler energy should be min. 10 dB.

The antenna polarization has minor impact on system accuracy. Processing the crosspolar return does improve system accuracy,direction sensing can be done simultaneously.

A 35-GHz-CW-Dopplerradar, properly designed will be a suitable and accurate system for speed law enforcement purposes.