PROCEEDINGS OF ISAP '89

3B1-4

NEAR-ZONE OPTIMIZATION OF ANTENNAS FOR TRUE GROUND SPEED SENSING

J. Detlefsen, Lehrstuhl für Hochfrequenztechnik,
M. Weinberger, Lehrstuhl für Mikrowellentechnik,
Technische Universität München, Munich, FRG

Introduction

Remote sensing of vehicular speed can be implemented using small solid-state microwave Doppler radars, alleviating problems of conventional speed sensing such as wheel slip, wheel lock and variable rolling radius. A lot of the problems involved are surveyed in [1]. Within the context of this task the question of the speed measurement accuracy in a given time interval is of concern. This paper discusses this problem with respect to antenna design. The solution of the problem for different antennas involves the consideration of their near-zone field characteristics and their optimization.

Analysis

Fig. 1 shows the geometrical configuration used for the calculation of the near-zone field and the pertaining Doppler signal. Apart from the specific antenna to be chosen, the problem in principle can be described by a planar antenna aperture, radiating an antenna beam, that is incident at an angle to the ground. In the case of automotive applications to be considered here the distance between antenna and ground is in the order of magnitude of the antenna dimensions, so the resulting Doppler signal is determined by the near-zone field characteristic of the antenna differing essentially from well-known radiation field properties. The near-zone field of concern is in the case of a planar ground surface a two dimensional distribution of the electric field in the plane given by $y = h$ (h height above ground) using the coordinate system of Fig. 1.

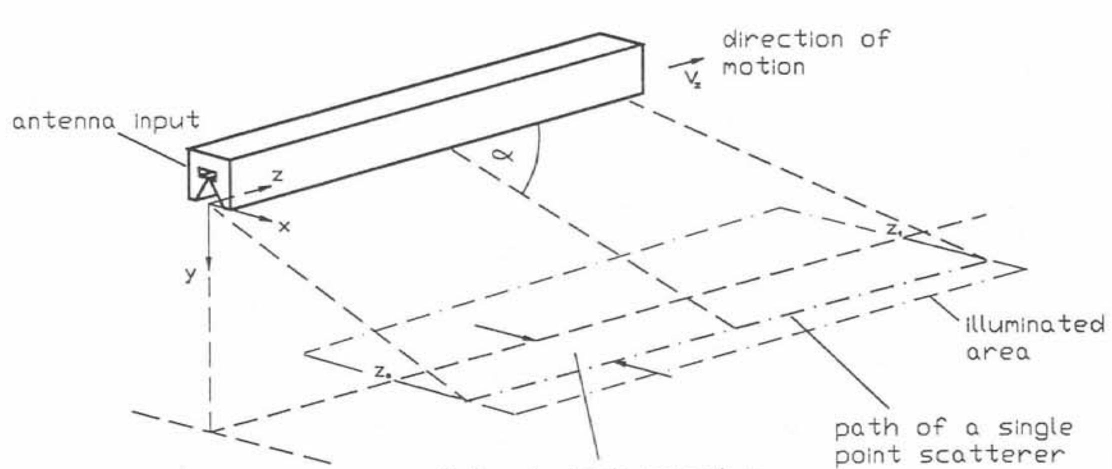

Fig. 1: Geometrical Configuration

As the antenna design has to be such that specular reflections from the ground surface are suppressed by choosing a suitable incident angle, the illuminated ground area can be considered to consist of a variety of single point scatters, which are randomly distributed. As antenna near-zone field characteristics and not the scattering properties of the ground are of consideration in this context, each of these point scatterers is assumed to be the source of an isotropically scattered wave, parts of which are recollected by the antenna aperture causing the Doppler signal. The intensity of the scattered field is assumed to be proportional to the incident total electric field strength by a factor k. If the propagation between antenna input and individual scatterer at location x,z can be described by a complex transmission factor $\underline{t} = t \exp\{j\varphi\}$, the total transmission path which is effective for the Doppler signal is characterized by

$$\underline{t}_t = kt(x,z)^2 \cdot \exp\{j2\varphi(x,z)\}, \tag{1}$$

using the reciprocity theorem. If the antenna is moved in z direction with the velocity v_Z relative to ground, each point scatterer gives rise to a complex Doppler signal

$$s_i(t) = s_o \cdot k \cdot t(x,z)^2 \cdot \exp\{j2\varphi(x,z)\} \tag{2}$$

where $z = z_o + v_z t$.

For ground speed sensing the pertaining Doppler spectrum is of concern. A Fourier transform of $s_i(t)$ yields $S_i(x,f)$ for the single scatterer.

$$S_i(x,f) = \int_{-\infty}^{+\infty} s_i(t) \cdot \exp\{-j2\pi ft\}\, dt \tag{3}$$

Introducing the Doppler shift normalized to the maximum Doppler frequency $f_d = 2v_Z/\lambda$ and relating the z-coordinate to the wavelength eq. (3) can be rewritten independently of v_Z:

$$S_i(x,f/f_d) = \int_{-\infty}^{+\infty} s_o \cdot k \cdot t(x,z')^2 \cdot \exp\{j2\varphi(x,z')\} d(z') \tag{4}$$

using $z' = z/(\lambda/2)$

The Doppler spectrum of a variety of randomly distributed independent scatterers can be obtained by a superposition of the power spectra of individual scatters, which are identical for a given lateral displacement x. To account for all possible displacements the individual Doppler power spectrum $S_i(x,f/f_d)^2$ has to be integrated over all possible x resulting in the total Doppler spectrum P which can be used to characterize the antennas speed measurement capabilities.

$$P(f/f_d) = \int_{-\infty}^{+\infty} |S_i(x,f/f_d)|^2\, dx \tag{5}$$

Thus the total Doppler spectrum can be interpreted as the projection of the individual power spectra along the x-axis.

Waveguide Slot Antenna

In the specific example of the waveguide antenna, which is in principle a leaky wave antenna, using a longitudinal radiating slot of many wavelength length. From the excited slot field, which is given by

$$I(z) = I_o \exp\{-j\beta_{10} z\}, \qquad (6)$$

β_{10} : propagation constant of TE_{10}-mode

the field distribution on the rectangular limited aperture II and in turn at a ground surface point is calculated using Kirchhoffs principle retaining near-zone field terms. As can by anticipated from near aperture considerations, the position of the illuminated footprint in longitudinal direction can be approximately obtained by projecting the aperture using the angle , which is related to free space and waveguide wavelength by

$$\cos(\alpha) = \beta_{10}/k, \qquad (7)$$

k: free space wavenumber

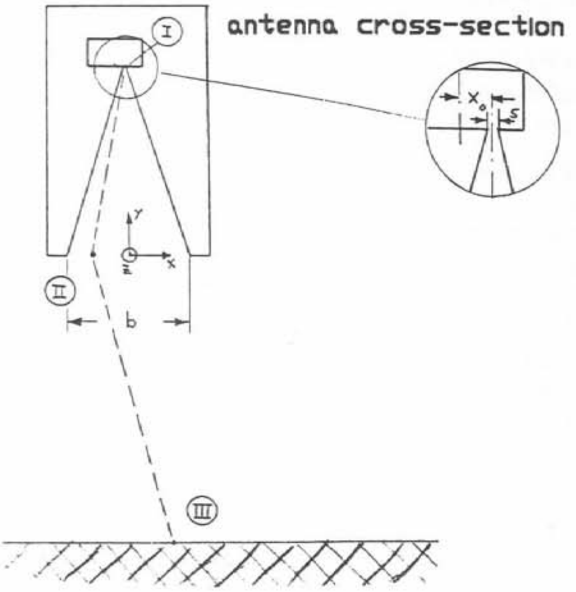

Fig. 2: Steps of Analysis

if the waveguide is operated in its fundamental TE_{10}-mode. This statement is supported by Fig. 3, which indicates calculated and measured field in longitudinal direction for x = 0. With an antenna height of 20cm above ground, which is convenient for vehicular use this near-zone field distribution shows that the rectangular longitudinal source distribution with linear phase at the antenna aperture still can be approximately observed at this distance, which allows to expect a narrow Doppler spectrum. In fact, using this antenna design, the width of the Doppler spectrum is inversely proportional to the antenna length, which can at least in principle be chosen arbitrarily long. The remaining important question therefore is the broadening of the Doppler spectrum due to the lateral width of the antenna field.

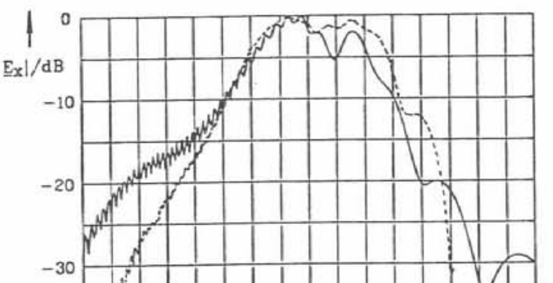

Fig. 3: Longitudinal Field Distributions for a waveguide antenna (length 270mm) a) calculated (solid) b) measured

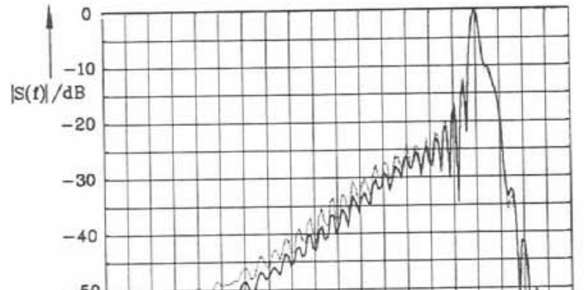

Fig. 4: Doppler-Power-spectra
a) Point Scatterer (x = 0),
b) Total power spectrum (solid)

To look into this problem, the single point scatterer Doppler power spectrum $S_i(x,f/f_d)^2$ and total Doppler power spectrum $P(f/f_d)$ have been calculated for an antenna of the same dimensions and are given in Fig. 4, indicating that there is no major difference between both in the main lobe area.

This result can be augmented by looking at the width of the total Doppler spectrum, obtained for waveguide antennas of different lateral extension b of aperture II. The results which fully agree with experiment and are given in Fig. 5 indicate that this width nearly remains constant and that this is in contrast to conventional horn antennas used for comparison.

The reason for this favourable characteristic of the waveguide antenna can be explained using Fig. 6. The main lobe footprint on ground of this antenna can be characterized by a hyperbolic shape, which is in full agreement with the lines of constant Doppler frequency [2] projected on the ground plane. The increase of lateral beam width extends the illuminated area to region of same Doppler frequency giving no spectral broadening. The use of a pyramidal horn antenna instead leads to a ellipsoidal footprint on the ground plane. Increasing this footprint incorporates more and more areas of different Doppler frequencies, resulting in an increase of spectral width.

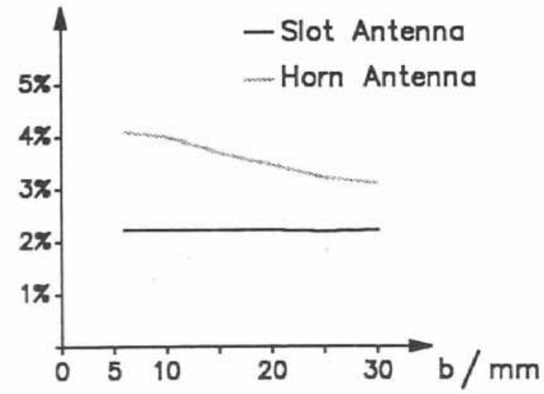

Fig. 5: 3 dB-Spectral Width dependent on lateral aperture width b, λ = 8.57mm. a) Waveguide Antenna b) Pyramidal Hornantenna

Conclusion

The near-zone field characteristics of a waveguide slot antenna of leaky wave type have been investigated with respect to its suitability for precise Doppler measurements for vehicle true speed sensing. Besides the fact that an antenna of this design can be made without restrictions in mechanical dimensions in principle as long as required for a sufficient narrow Doppler spectrum, there is in contrast to conventional horn antennas also no restriction for the lateral beam width. This is because the foot print only comprises areas of approximately constant Doppler frequency which are illuminated. Using this antenna the beam width therefore can be optimized only with respect to SNR considerations. This is the reason for the known excellent Doppler measuring capabilities of this antenna [3].

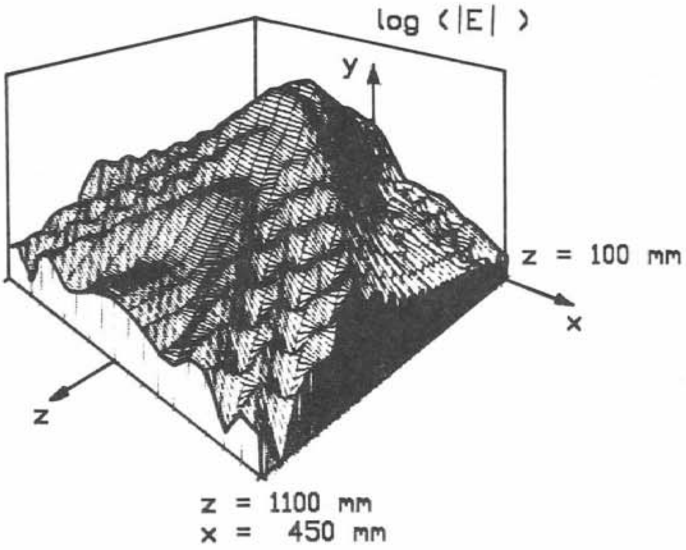

Fig. 6: Two-dimensional Field distribution of the waveguide Antenna

References

[1] Hyltin, T.: Vehicular Radar Speedometer, SAE Int. Automotive Eng. Congress and Exposition, 8.-12.1.1973, Detroit, USA

[2] Skolnik, M.: Radar Handbook, New York: McGraw-Hill 1970, 19-8

[3] Groll, H.; Detlefsen, J.; Schuck, W.: Doppler-Radargerät zur Messung der Eigengeschwindigkeit eines Fahrzeugs, Patentapplication No. DE 2237139 C2, FRG, 28.7.72

Acknowledgement: The authors are grateful to the Deutsche Forschungsgemeinschaft for financial support.