A 76 GHz Folded Reflector Antenna for True Ground Speed Measurement

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***Abstract*— A 76 GHz multibeam folded reflector antenna for true ground speed measurement applications is presented. The antenna radiates four independent beams with 30° radiation angle. Antenna far and near field measurement results are given. 3dB-width of the antenna beams is between 3.2° and 3.9°. The antenna was used in a continuous wave doppler radar sensor. Results of the measured velocity and slip angle during a counterclockwise circular driving are presented.**

I. Introduction

Radar sensors for automotive applications have become of great interest during the last years. Especially sensors in the 24 and 76 GHz bands for applications like adaptive cruise control, parking aid and lane change assistants have been investigated thoroughly. Some of them are commercially available, whereas others are still in research and development.

Another application that is of high importance is true ground speed measurement of vehicles. Driver assistance systems like the electronic stability program, the antilock braking system or the traction control system depend on the exact knowledge of the state of vehicle movement. It is characterized as shown in Fig. 1 by its speed vector v and yaw rate $\dot{\psi}$. The side slip angle β is defined as the angle between speed vector v and the longitudinal axis of the vehicle. It is very important in vehicle stability considerations. However, at the moment, only the yaw rate can be measured directly at reasonable costs in series vehicles. Longitudinal speed is measured by using wheel speed sensors. Unfortunately they suffer from uncertainties when the wheels are blocking or skidding or when the size of the wheel changes. The side slip angle is not measured at all.

Radar sensors that measure only longitudinal true ground speed have been investigated by numerous authors [1]–[7]. Such sensors are commercially available as reference measurement systems for vehicle tests or for special applications e.g. in agricultural machinery. For cost reasons they usually work in the 24 GHz frequency band.

Radar sensors that are additionally capable of measuring side slip angle are not available commercially. Some research has been done by a few authors [2], [4]–[7], but limited accuracy and high costs have prevented these sensors to be commercially successful.

In this paper we present a 76 GHz antenna arrangement for true ground speed and side slip angle measurement radar sensors. It is very compact and manufacturable at potentially low costs.

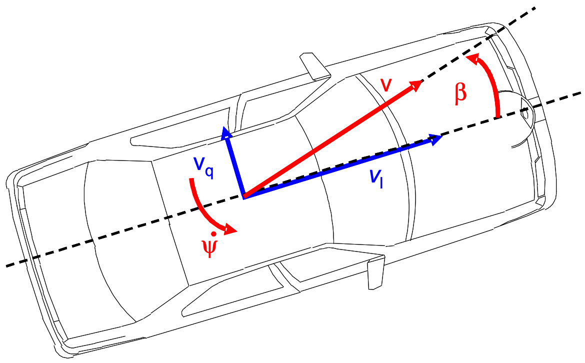


Fig. 1. Velocity and side slip angle of an automobile.

II. Radar Sensor Topology

Speed measurement by means of radar is done by radiating an electromagnetic wave towards the road and measuring the doppler-shift of the backscattered wave. The basic principle is shown in Fig. 2. The doppler-shift f_d can be calculated by

$$f_d = 2\frac{f_0}{c_0}\sin\theta\,(v_x\cos\varphi + v_y\sin\varphi) \quad , \tag{1}$$

where f_0 is the frequency of the radiated wave, c_0 is the speed of light, v_x and v_y are the speed vector components and θ and φ are the radiation angles in elevation and azimuth. The vertical speed v_z ist assumed to be zero. In order to measure the speed vector two orthogonal beams are needed. If, in addition, one wants to compensate for nick or roll angles of the sensor, two more beams are advantageous [4]–[7]. The sensor topology with four beams is shown in Fig. 3.

Radiating four beams can be done in several ways. It is most obvious to use four independent antennas. However, this needs much space and alignment of the antennas might be difficult. Other possibilities are using bifocal lens [6], [7] or leaky wave antennas [2], [4]. In this paper we propose to use a bifocal folded reflector antenna [8]. This kind of antenna is very compact to build, has very low losses and is easy to manufacture. As we will show below, it has the ability to radiate four beams with only one physical aperture.

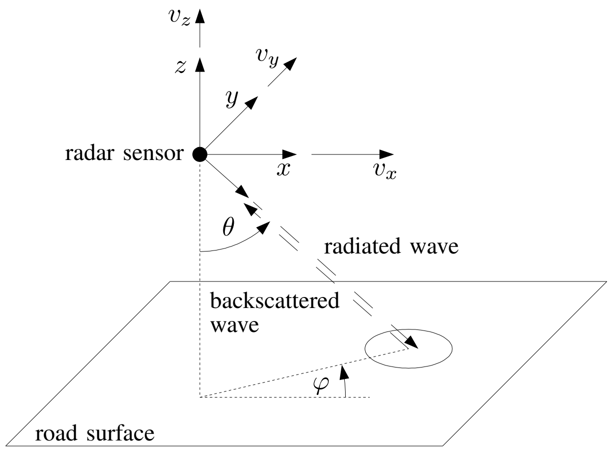


Fig. 2. Basic principle of radar ground speed measurement.

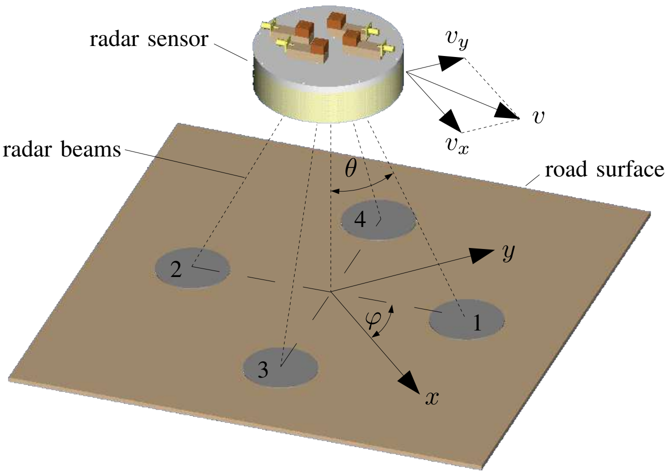


Fig. 3. Radar sensor topology.

III. Antenna Design

The basic principle of the bifocal folded reflector antenna can be found in [8]. Fig. 4 depicts the cross section of the antenna that was realized. It mainly consists of two parallel reflect-arrays and four circular waveguide feeds. The feed waveguides with horn openings are inserted into an alloy mounting plate. The RF energy is radiated from the horn to the upper reflector. There it is reflected by the polarizing grid and phase shifted by patches printed on the reflector. The wave then propagates to the lower reflector where it is once again reflected and phase shifted. Additionally, the polarization is twisted by 90°. Finally, due to the twisted polarization, the wave can pass the polarizing grid. As outlined in [8] the phase shifting on both reflectors controls the focus points and the radiation characteristics. The phase shifting on both reflectors of the antenna ist symmetric with respect to the midpoint. Thus, it is possible to radiate similar beams from all four feed points.

The realized antenna has an outer diameter of 150mm, a distance between the two reflectors of 35mm and four feed

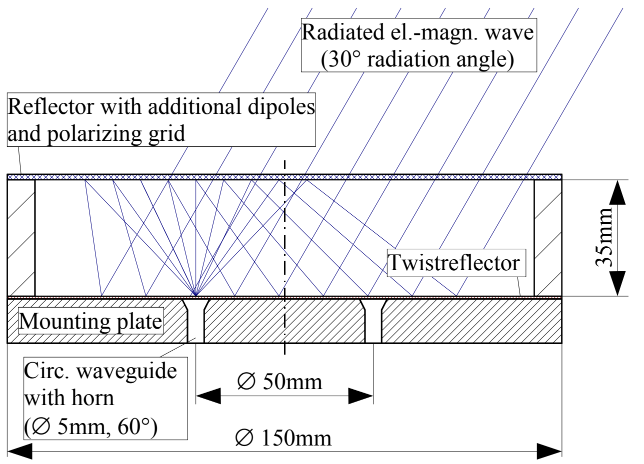


Fig. 4. Functional principle of 4-beam folded reflector antenna (antenna cross section).

points on a circle with a radius of 25mm. The reflector diameter is 120mm. However, as can be seen from Fig. 4, not the entire aperture can be used for each beam. The large tilting angle of 30° leads to shadowing effects at the wall and limitations in phase shifting properties. Thus the effective aperture is somewhat smaller than the physical aperture. A photograph of the antenna can be seen in Fig. 5.

IV. Antenna Measurement Results

A. *Far Field Measurements*

Radiation diagrams have been measured at 76.5 GHz for each port in two planes (E-Plane and H-Plane). Results of Port 1 and 2 are shown in Fig. 6. Beams are radiated at an angle of 30° in one plane and 0° in the other plane. 3dB-beamwidths are between 3.2° and 3.9° and side lobe level is around -14dB. Port 3 and 4 show similar characteristics.

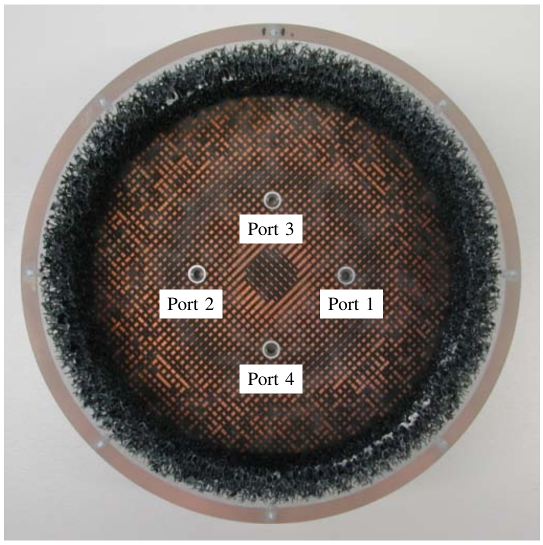
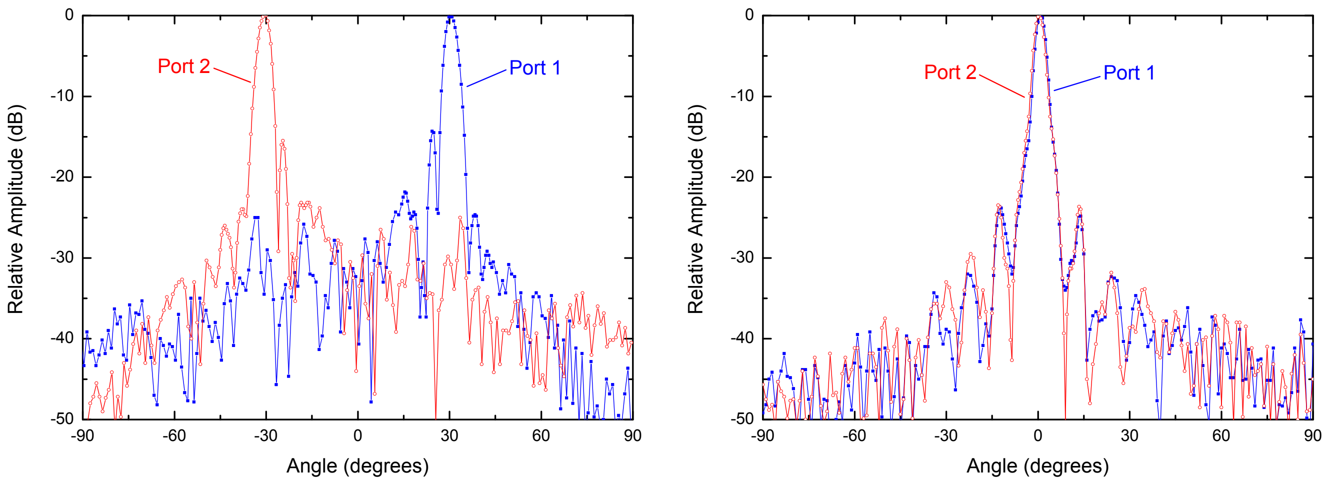
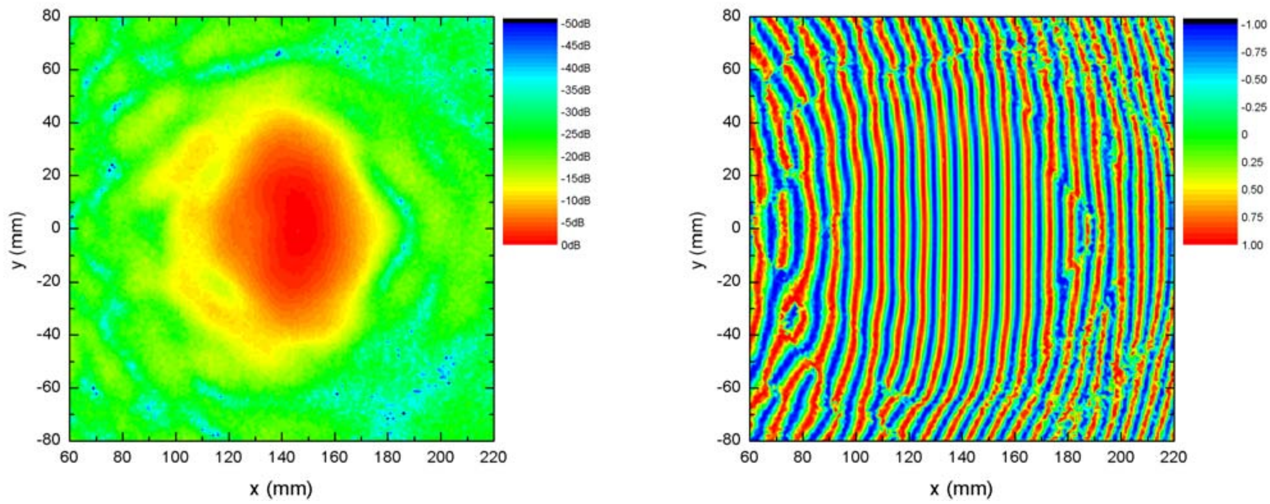


Fig. 5. Photograph of the 4-beam folded reflector antenna (upper reflector removed).



(a) H-plane (b) E-plane

Fig. 6. Measured H- and E-plane radiation diagrams (76.5 GHz, Port 1 and 2, 3dB-beamwidths: 3.9°/3.9° resp. 3.2°/3.3°)



(a) Normalized Amplitude (b) Sine of Phase Angle

Fig. 7. Measured near field amplitude and phase characteristics (76.5GHz, RF input at port 1, other ports left open, 25cm distance between twistreflector and measurement plane, (160x160)mm2 area, data points measured every 1mm in x- and 1.04mm in y-direction)

B. Near Field Measurements

Although far field measurements are rather important for antenna characterization and verification, they are not very representative for the desired application of the antenna as a ground speed sensor. More insight into the characteristics as a speed sensor is gained by measuring the field properties on a plane parallel to the antenna aperture. This plane represents the road surface where the radiated field of the antenna is incident when used as a true ground speed sensor. Both components, amplitude and phase, of the field need to be measured. Fig. 7 shows the near field characteristics of Port 1 measured at 76.5GHz on a plane in a distance of 25cm to the twist-reflector of the antenna. The antenna was moved in steps of 1mm in x-direction and 1.04mm in y-direction using a xy-linear table. An open waveguide was used as illuminating antenna. The amplitude characteristic shows an elliptical spot on the measurement plane. Within this spot, the phase characteristic is close to a plane wave characteristic. The phase fronts consist of evenly spaced almost straight lines. This is important in order to get a small spectrum of the doppler signal for accurate speed measurements. Measurements of the other ports show similar results.

V. True Ground Speed Measurement

The antenna was used in a continuous wave doppler radar sensor for true ground speed measurement. It was mounted at

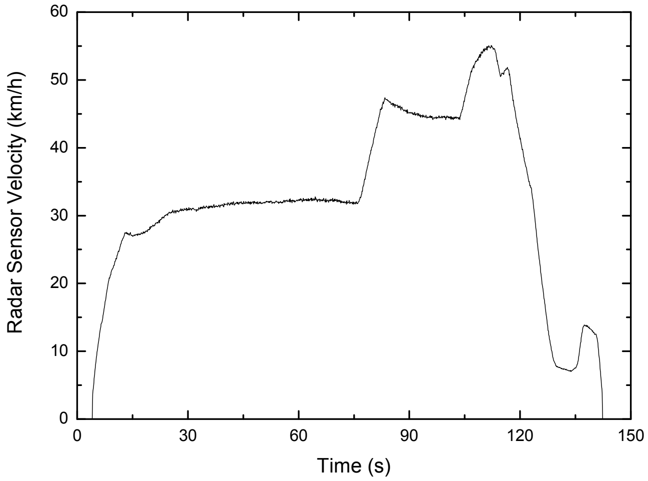


Fig. 8. Measured absolute velocity at sensor position (counterclockwise circular driving, 100ms measurement-time)

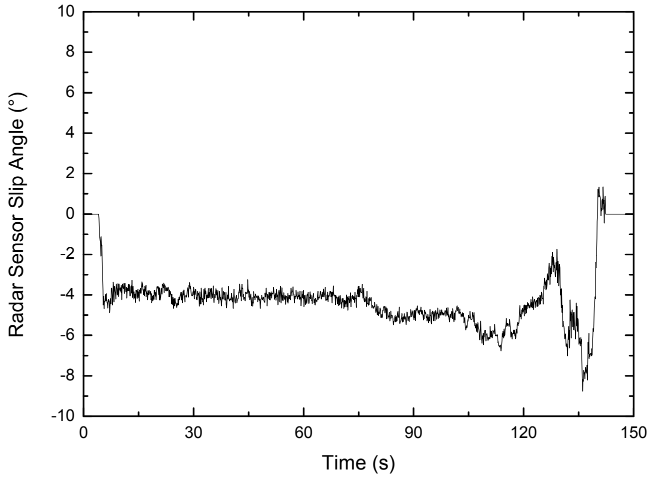


Fig. 9. Measured slip angle at sensor position (counterclockwise circular driving, 100ms measurement-time)

the rear bumper of a car and driving tests have been performed. Fig. 8 and 9 show the measured velocity and slip angle of the car at the sensor position. In order to get the side slip angle β one would need to transform those values to the center of mass by using the yaw rate $\dot{\psi}$ and the sensor position. Also, a compensation for an inaccurate mounting angle of the sensor would be needed. The measured velocity shows the variations in vehicle speed very clearly. After an acceleration to about 30km/h the speed was kept constant while driving counterclockwise on a circlular course with 30m radius. The measured slip angle during this phase is about -4°. Later, the speed was increased to about 45km/h, still driving on the same circular course. The slip angle changes to about -5°. When the speed is increased even further to about 55km/h, the slip angle increases to approximately -6°. During the last phase the speed is decreased. The slip angle decreases accordingly. The following increase in slip angle ist due to leaving the circular course by driving a sharp curve. It has to be noted that the measured slip angle shows very little variation due to measurement noise. Depending on the speed of the vehicle the standard deviation of the slip angle is in the range of 0.1° to 0.2°.

VI. Conclusion

A 76 GHz folded reflector antenna with 4 beams and 30° radiation angle has been presented. The antenna employs a bifocal principle to radiate 4 independent beams with only one physical aperture. It has a very compact size and it can be manufactured very easily. 3dB beamwidths between 3.2° and 3.9° for the four lobes have been demonstrated. Near field measurements have shown the incident field properties on the road, when the antenna is used for true ground speed radar sensors. Road tests have shown the potential of the antenna for accurate true ground speed and slip angle measurements.

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