History of Automotive Anticollision Radars

and

Final Experimental Results

of a

MM-Wave Car Radar Developed

by the

Technical University of Munich

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ABSTRACT

The history of development of automotive radars in different countries since 1972 is described using a short comparison of radar types in Table 2, on page 17. Table 1, next page, indicates the planning of introduction of car radars in the near future according to information supplied by car companies.

The purpose of the development of an automotive radar in our university was to test different signal processing procedures both for distance and Doppler evaluation and also for a digital wavefront reconstruction to find out the angle position of a target. The block diagram, the main properties, the technical data of the radar system, the used antennas and the multiplexing of two transmitting antennas is described in the following. Finally some experimental results have been obtained under real traffic conditions.

(Editor's Note: We have not revised the author's language.)

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This is a revised and updated version of a paper presented at the 1996 CIE International Conference on Radar (CCIR-96), Beijing, China, October 8-10, 1996.

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HISTORY OF AUTOMOTIVE RADARS

The first car radars using an active frequency doubling reflector on the backside of "target" cars were constructed in the early '60s in the US. But shortly it was realized, that in case of heavy accidents, these reflectors could be in a wrong position. So, the next series of car radars were designed to detect all passive obstacles in front of a car. In the first time they used only one antenna beam to distinguish any lateral positioning of targets. To reduce antenna size, the frequency was increased from 10 GHz at the beginning to 34 and 50 GHz in the mid-'70s [1, 2] and to 60, 77 and 94 GHz in the '90s [19]. Both FM, pulse and FSK modulation is used and the new systems have a minimum of three antenna beams. One proposal is using a pure noise generator [17]. Some antennas have 3 feed horns, which are switched in short time periods. Both mechanically moved feed horns and electronic scanning systems are used. A survey of the different radar types is shown in Table 1 (next page). The biggest series of car radars until now was mounted 1992 in 1500 Greyhound busses. 3,000 drivers worked with this system in 1993 over a distance of 250 million miles. During this time, the number of accidents was reduced by about 25% and it was the lowest accident year in Greyhound history. In spite of this positive result the drivers

Table 1. Different Types of Automotive Radar Systems [19, 20]

Year	Frequency	Modulation	Beams	Antennatype or Technology	Company
1972	10 GHz	FM-CW	1	2 Horns	RCA (USA.)
1974	34 GHz	Pulse 10 ns	1	2 Parabolas	Telefunken
1976	50 GHz	Pulse 10 ns	1	2 Parabolas	Telefunken
1978	18 GHz	FM-CW	1	2 Parabolas	SEL
1978	24 GHz	Pulse	1	?	Nissan (Jap.)
1991	77 GHZ	FM-CW	1	Metal.-Plastic-Waveguide-Bloc	Philips, (NL.)
1992	60 GHz	FM-CW	1	?	Fujitsu (Jap.)
1992	94 GHz	FM-CW	1	MMIC	TRW (USA.)
1993	24 GHz	FM-CW	1	2 Patch-Antennas	Eaton, VORAD Greyhd., (USA.)
1993	60 GHz	Pulse	1	?	Nissan (Jap.)
1993	60 GHz	PN-Code Ph.M. (FSK)	4(8)	5 Rectang. Horns + Dielectr. Lenses	TU-München
1994	77 GHz	FM-CW	5	?	Plessey, (UK.)
1995	77 GHz	?	3	?	Militech, (USA.)
1995	77 GHz	FM-CW	3	Fresnel Lense + 3 Horns	Daimler Benz Aerospace
1995	77 GHz	Pulse-Doppler	3	Fresnel Lense	Dornier
1995	77 GHz	FM-CW+Sp.	1	2 Horns	TU-Braunschweig
1995	77 GHz	FM-CW	Mech.Scan	Cassegrain	Celsius (Sweden)
1995	77 GHz	FM-CW	?	?	HIT (Israel)
1995	77 GHz	FM-CW	3	MMIC	Raytheon (USA.)
1995	77 GHz	FM-CW	3	4 MMICs	Thomson CSF (France)
1995	77 GHz	FSK	?	?	VORAD (USA.)
1995	35 GHz	Noise	1	2 Parabolas	Acad.Kharkov (Ukraine)

union was able to remove the radars from the busses again. There were two reasons: the first was the combination of the radar processor with a data storage system, which provided vehicle and driver data reports and had an accident reconstruction capability; and the second reason was, that the bus radars had the same frequency as the police radars and interfered with the radar warning devices in private cars. [19]

The new automotive radar systems, which have been developed during the last two or three years, are now in the state of introduction by different car companies. The main purpose of its application is the use for the so-called "Autonomous Intelligent Cruise Control," (AICC) on highways. This means, that the distance to the proceeding car will be automatically controlled by the radar measured values of speed and distance using both the accelerator and the brakes. The maximum value for braking should not exceed 2.5 m/s^2. In Germany for this system also the phrase "Intelligent Tempomat" is used.

EXPERIMENTAL CAR RADAR OF TU. MUNICH

Principal Configuration

A new collision avoidance system was under study for six years at the Technische Universitat Munchen within the European Prometheus project. The choice of the modulation method depends mainly on the application, which must be resistant to interferences between a great number of cars,

Table 2. Introduction of Automotive Radars

Year	Car-Company	Radar-Manufacturer
1996	Frightliner	VORAD
1997	Chrysler	VORAD
1998	Mercedes-Benz	Millitech
1998	BMW	VDO/HIT
1998/99	Volvo	Celsius/Philips
1998/99	Opel (GM)	?
1998/99	Volkswagen	VDO/HIT/Rockwell

which can be equipped with such radars. A PseudoNoise (PN) code modulation is used, where the code and the repetition frequency can be changed. The code has a length of 1023 chips. With a repetition frequency of 196 kHz the unambiguous range is 767 m. The width of one bit of the code is 5 ns, which leads to a distance resolution of 0.75 m. The PN-code is not generated by shift registers, as usual, but read out from a memory. All codes, both for the transmitted signal and for the 1023 reference codes, which are shifted by one bit, are stored in EPROMs. The access to a desired range gate can be made via a code shift by simple address selection. The theoretical gain of the system is 60 dB. It is possible to detect a target of 1 m^2 reflective cross section in a distance of 150 m with a single sideband power of only 1.6 mW. To measure the relative

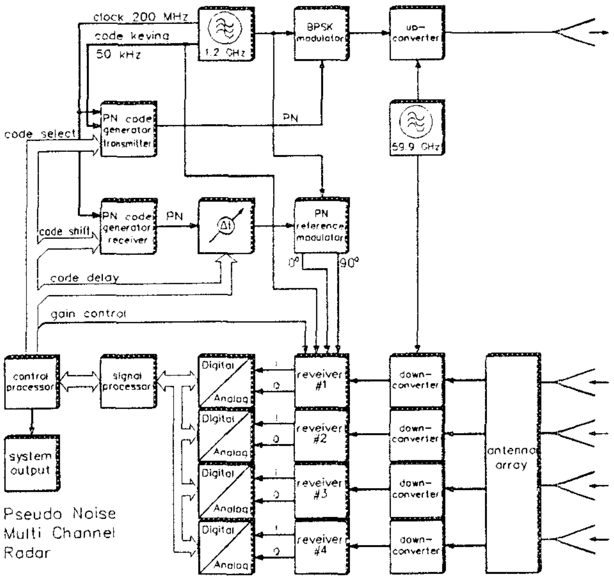

Fig. 1. Block Diagram of the System

velocity of cars the Doppler frequency must be evaluated, which needs a coherent system. In Figure 1 the block diagram of the system is shown.

The mm-wave front-end, which is made in conventional waveguide technique, now has a transmission frequency of 61 GHz. In the future, the frequency for such systems will be 77 GHz in Europe. For a change to another frequency only the front-end has to be exchanged. For the angular allocation, an antenna array with 5 antennas is

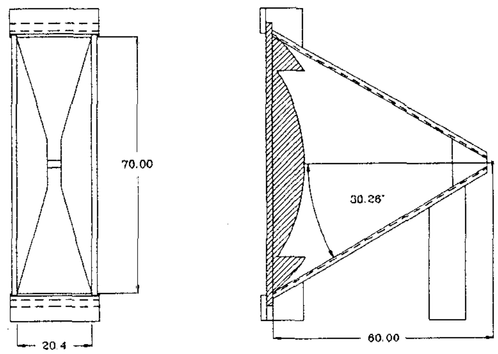

Fig. 2. Dimensions of the Horn Antennas

used, where the phase discrimination is made between the four receiving channels digitally. This seems to be cheaper than a conventional phased array. The necessary field of view according to the usual dimensions of motorways is characterized for our experimental system in a horizontal opening angle of 12°. For this angle, three lanes, which are usually 3 to 3.5 m wide, can be covered in a distance of 75 m and for a distance of 100 m corresponds to the field of view to five lanes. The vertical angle of the radiation is only 3,° to avoid reflections from bridges and tunnel entrances. In the first step the horizontal angle was divided in four angular resolution cells by use of four receiving antennas and a digital wavefront reconstruction. One resolution cell has an opening angle of 3°. The antennas consist of rectangular horns with cylindrical dielectric lenses. See Figure 2, where dimensions are shown for a one horn antenna. The overall horizontal size of all five antennas (4 receiving and 1 transmitting horn) is 110 mm and the vertical dimension is ca. 80 mm. The mm-wave front-end is the same size and is combined directly with the antenna array, so the installation of this unit on the frontside of a car is easy.

Radar Data Evaluation

After construction and testing of the four channel system in the laboratory it was mounted in an experimental vehicle. Together with the radar setup a video camera and facilities for data recording are provided in the car. The purpose was to make simultaneous recordings of typical sequences of radar data and video pictures, which show the traffic conditions on the road during the recording, and their superposition. The radar data are stored in digital form on a hard disk. All the video pictures have a number and can be compared easily with the data, which belong to the measuring time of the video image. So the evaluation of suitable signal processing methods could be made later in the laboratory.

Transmitter Location Multiplexing

The next step was the investigation of a higher angular resolution by transmitter location multiplexing. In case of shifting the location of the transmitting antenna it is possible besides the existing receiving antenna array to add another array of so-called "synthetic" antennas, which increases the synthetic aperture of the array and improves the angular resolution, as indicated by the sketches of Figure 3 or 4, next page. There are two possibilities: as shown in Figure 3, one can

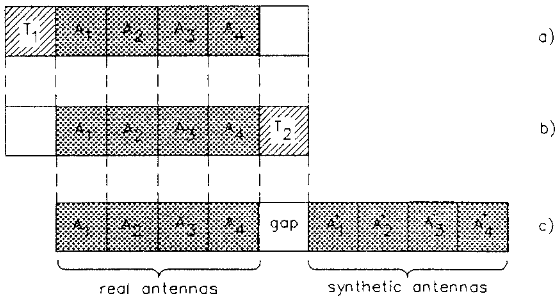

Fig. 3. The "Six-Antenna" Configuration
A. Antenna T_1 Transmits
B. Antenna T_2 Transmits
C. Effective Aperture

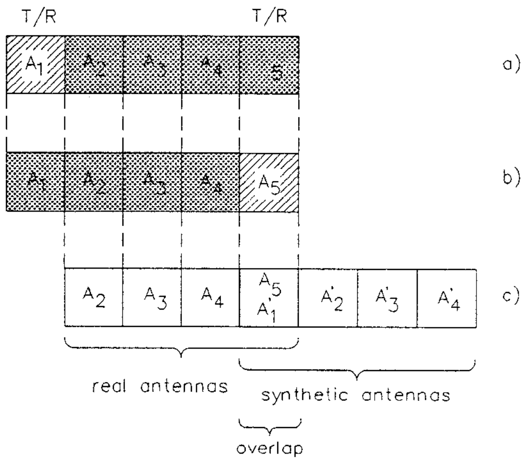

Fig. 4. The "Five Antenna" Configuration
A. Antenna A_1 Transmits
B. Antenna A_5 Transmits
C. Effective Aperture

use an additional transmitting antenna, which increases cost and real size; in case of the arrangement in Figure 4 with only five antennas one can switch the antenna between transmitting and receiving. In the first case the angular resolution will have 4/9 of the value with a four receiver system; in the second case the new resolution is 4/7 of the original value. After simulating the two different ways of transmitter location multiplexing it was decided to realize the "Five-Antenna" configuration. The switching between transmitting and receiving was performed in the baseband frequency channel of Antenna 5. This was made possible by using the mixer in this channel both for up- and down-converting.

Experimental Results

Finally both antenna diagram measurements (like in Figures 5 and 6) and also some practical test rides were performed with this new antenna configuration. The measured curve of Figure 5 shows, that the 3 dB beamwidth of the system is about 1.7°. The resolution between two targets is shown in Figure 6. A displacement of 2.4° originates a minimum of 12 dB.

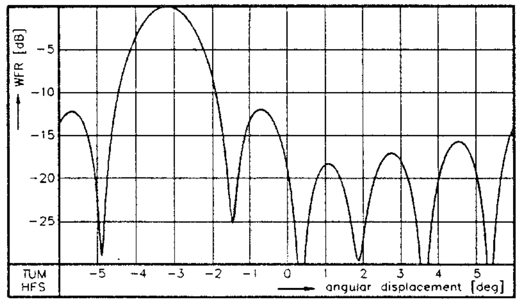

Fig. 5. Measured Lateral Response for One Target. Angular Displacement –3.2°

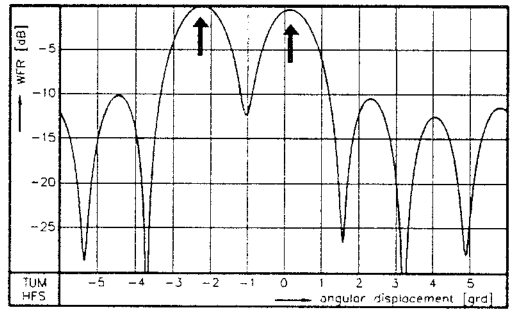

Fig. 6. Measured Lateral Response for Two Targets. Angular Displacement 0.2° and –2.2°

REFERENCES

[1] Lindner, K. and Wiesbeck, W., (1976), 35-GHz-Impulsradarsensor zur Verwendung in Abstandswarngeräten für Kraftfahrzeuge. (35-GHz Pulse Radar for Car Distance Warning Applications), Nachr. Techn. Z. 29, Germany, p. 667.

[2] Neininger, G., (October 1977), An FM/CW Radar with High Resolution in Range and Doppler Application for Anti-Collision Radar for Vehicles, IEE Conf. Pub. No. 155: Radar 77, London, pp. 526-530.

[3] Rozmann, M., Detlefsen, J. and Lange, M., (1989), Phasencordiertes Dauerstrichradarbei 1 GHz mit hoher Empfindlichkeit und Auflösung, (CW-Radar with Phase Code Modulation at 1 GHz with High Sensitivity and Resolution), 7. Radarsympos. DGON, Ulm, Germany, Verlag TÜV Rheinland, Köln 1989, pp. 377-387.

[4] Detlefsen, J. and Rozmann, M., February 8-9, 1990, PN-Code Millimeter-Wave Radar, Proc. 1990 German MTT/AP Chap. Workshop Microw. Components and Subsystems, Schloß Reisensburg, Germany.

[5] Rozmann, M., Lange, M. and Detlefsen, J., May 14, 1990, Collision Avoidance Radar Using Wavefront Reconstruction, Proc. 3rd PRO-CHIP Workshop., Paris, France, pp. 251-256.

[6] Zeblinger, W., Zundl, T. and Detlefsen, J., September 13, 1991, A Collision Warning Radar Using PN Code Ranging and Wavefront Reconstruction, Proc. Workshop. 21st Europe. Microwave Conference, Stuttgart, Germany, pp. 153-158.

[7] Detlefsen, J., Troll, T. and Zellinger, W., May 1992,
Collision Avoidance Radar Using Wavefront Reconstruction,
Proc. 6th PRO-CHIP Workshop.,
Kista, Sweden,
pp. 113-115.

[8] Detlefsen, J., Troll, T., Rozmann, M. and Zellinger, W., June 1992,
System Aspects and Design of an Automotive Collision Warning
PN Code Radar Using Wavefront Reconstruction,
IEEE MTT-S. Digest,
Albuquerque, New Mexico, Vol. 2.,
pp. 625-628.

[9] Detlefsen, J., Rozmann, M., Troll, T. and Zeilinger, W., May 1993,
Auffahrwarnradar für Kraftfahrzeuge - Evaluierung des Systemkonzepts,
(Anticollision Car Radar - Evaluation of the System),
Proc. MIOP-Conf.,
Sindelfingen, Germany,
pp. 394-398.

[10] Detlefsen, J. and Kees, N., September 14-16, 1993,
Genauigkeltsvergleich von Doppler-Signalverarbmeiturgsalgorithmen zur
2 D-Geschwindigkeitsmessung,
(Comparison of the Accuracy of Different Signal Processing Algorithms
for the 2 D-Speed Measurement),
Proc. 8. Radar Symp.,
DGON, München, Germany,
pp. 25-30.

[11] Troll, T., Detlefsen, J., Rozmann, M. and Zeilinger, W., September 14-16, 1993,
Dopplerfestigkeit eines phasencodierten Dauerstrichradars für
KFZ Anwendungen.
(Doppler-Tolerance of a Phase Code Modulated CW-Radar),
Proc. 8. Radar Symp.,
DGON, München,
pp. 31-36.

[12] Groll, H., Detlefsen, J., Rozmann, M. and Troll, T., December 15-18, 1993,
Car Collision Avoidance Radar Using mm-Waves With PN-Code
Modulation and Digital Wavefront Reconstruction,
Proc. 4th ISRAMT 93 Conf.,
New Delhi, India,
pp. 735-738.

[13] Detlefsen, J., Kees, N. and Schmidhammer, E., 1995,
Improvement of Angular Resolution of a mm-wave Imaging System
by Transmitter Location Multiplexing,
MTT-S 1995,
Internat. Microwave Symp.,
Orlando, Florida, USA., Vol. 2,
pp. 969-972.

[14] Groll, H., Detlefsen, J., Kees, N. and Schmidhammer, E., September 11, 1995,
Transmitter Location Multiplexing for an Automotive Collision Warning
System in the mm-Wave Range,
Proc. 5th ISRAMT 95 Conf., Vol. 1,
Kiev, Ukraine,
pp. 31-34.

[15] Schmidhammer, E., Kees, N. and Detlefsen, J., May 30 - June 1, 1995,
Evaluation of a 4 Respect. 8 Channel Phase Coded Collision Warning Radar,
Proc. MIOP 95 Conf.,
Sindelfingen, Germany,
pp. 618-622.

[16] Kees, N., Schmidhammer, E. and Detlefsen, J., May 30 - June 1, 1995,
Realization of Transmitter Location Multiplexing for Angular
Resolution Enhancement of a Collision Warning Radar,
Proc. MIOP 95 Conf.,
Sindelfingen, Germany,
pp. 375-381.

[17] Lusk, A.K, September 4-7, 1995,
Noise Radar with Correlation Receiver as the Basis of Car Collision
Avoidance System,
Proc. 25th European Microwave Conference,
Bologna, Italy,
pp. 506 - 507.

[18] Detlefsen, J., Kees, N. and Schmidhammer, E., 1995,
Improvement of Angular Resolution of a Millimeterwave Imaging System
by Transmitter Location Multiplexing,
MTT-S 1995,
International Microwave Symposium,
Orlando, Florida, USA, Vol. 2,
pp. 969-972.

[19] Meinel, H., April 11, 1996,
Radarwarnsensoren und intelligenter Tempomat Übersicht im internat.,
Bereich
(Radar Warning Sensors and Intelligent Cruise Control - International Survey),
DGON-Sitzg. Kfz-Radarsysteme,
Braunschweig, Germany.

[20] Meinel, H., September 9-12, 1996,
Millimeterwaves for automotive applications,
Proc. 26th European Microwave Conference,
Prague, Czech Rep.,
pp. 830 - 835.

Specifications — They are Eternal!!

The US Standard railroad gauge (distance between the rails) is 4 feet 8.5 inches. That's an exceedingly odd number. Why was that gauge used? Because that's the way they built them in England and the US railroads were built by English expatriates. Why did the English people build them like that? Because the first rail lines were built by the same people who built the pre-railroad tramways, and that's the gauge they used.

Why did "they" use that gauge then? Because the people who built the tramways used the same jigs and tools that they used for building wagons, which used that wheel spacing. Okay! Why did the wagons use that odd wheel spacing? Well, if they tried to use any other spacing the wagons would break on some of the old, long distance roads, because that's the spacing of the old wheel ruts.

Who built these old rutted roads? The first long distance roads in Europe were built by Imperial Rome for the benefit of their legions. The roads have been used ever since. And the ruts? The initial ruts, which everyone else had to match for fear of destroying their wagons, were first made by Roman war chariots. Since the chariots were made for or by Imperial Rome they were all alike in the matter of wheel spacing.

Thus, we have the answer to the original question. The United States standard railroad gauge of 4 feet 8.5 inches derives from the original specification for an Imperial Roman army war chariot. Specs and bureaucracies live forever. The next time you are handed a specification and wonder what horse's ass came up with it, you may be exactly right, because the Imperial Roman chariots were made to be just wide enough to accommodate the back-ends of two war horses.

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