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System Aspects and Design of an Automotive Collision Warning PN Code Radar Using Wavefront Reconstruction

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Abstract:

A collision avoidance system for automobiles to be used in freeway and similarly structured traffic environments is under study at the Technische Universität München (TUM). In principle a two-dimensional imaging problem has to be solved, because the mere detection of objects in front of a vehicle is not sufficient as potential paths of collision can only be recognized by assigning objects to their surroundings. While digital wavefront reconstruction is used for angular discrimination, a high resolution pseudonoise code radar applying a binary phase modulation to a continuous carrier has been implemented for longitudinal (range) resolution. As the system has been designed as an experimental platform rather than a prototype, provisions for recording and evaluation of online radar data have been implemented. The paper reports on concepts, the state of realization and on first experimental results.

1. Introduction

A collision avoidance system for automobiles to be used in freeway and similarly structured traffic environments is under study at the Technische Universität München (TUM) within the European PROMETHEUS [1] project. In principle a two-dimensional imaging problem has to be solved, because the mere detection of objects in front of a vehicle without relation to their environment is not sufficient to classify them as dangerous. To identify potential paths of collision, objects and their actual and expected future trajectories have to be estimated and additionally assigned to individual lanes. This seems to be a very demanding task which makes it necessary in a first step to restrict the application to better structured environments found in motorway scenes. This justifies to set up first an experimental platform to collect and evaluate radar data related to realistic scenarios.

2. System Concept

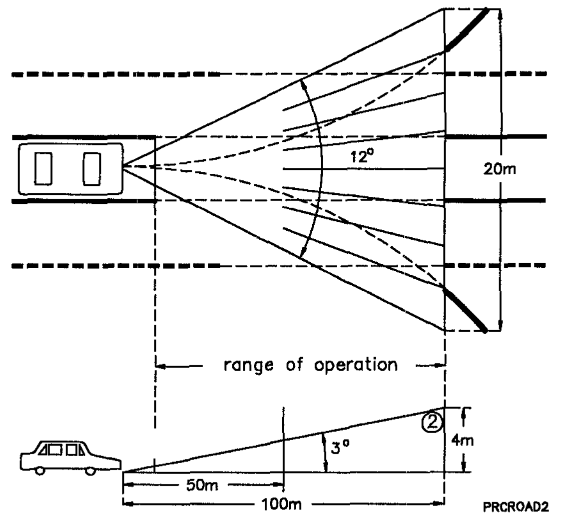

Fig. 1: Field of view.

According to Fig. 1 the experimental system was designed to cover a reasonable field of view taking into account usual dimensions of motorways and their curvature. Fig. 1 indicates the necessary field of view chosen for this experimental system which is characterized in a distance of 100 m by a width of five lanes divided into four and in a second step into eight angular resolution cells. In radial direction an operating range of about 100 m starting at a distance of 20 m is covered by 128 radial resolution cells of 75 cm width. The total field of view is illuminated by a single transmitting antenna while four real or later eight effective receiving antennas are used to sample the reflected fields.

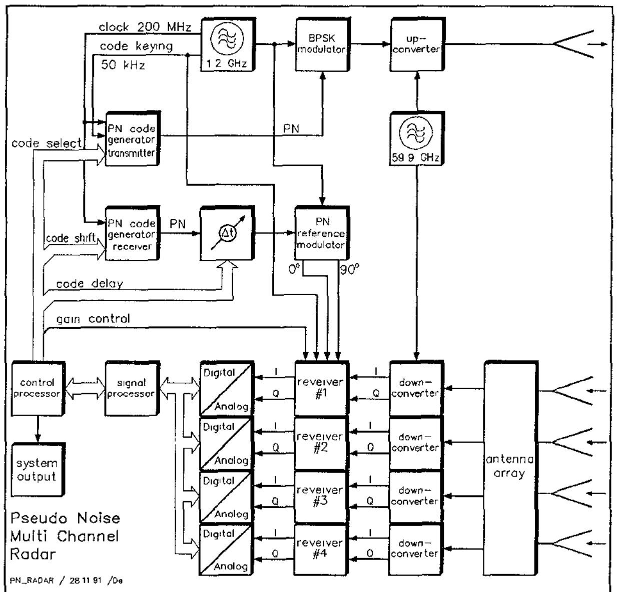

Fig. 2: Block diagram of the PN code radar set-up with four receiver channels.

2.1 Range Resolution

To obtain a longitudinal (range) resolution of 75 cm, a 200 MHz clockrate pseudonoise code radar has been designed and built. According to Fig. 2, which shows the set-up of four receivers, a binary phase modulation using maximal-length pseudo-noise code sequences is applied to a continuous wave subcarrier of 1.2 GHz. As the phase modulation acts upon the subcarrier the resulting signal can easily be upconverted to any desired mm-wave frequency, offering a great flexibility with respect to the choice of frequency. In this case a frequency of 61 GHz has been allocated by the German PTT. The system uses the homodyne reception principle in combination with unstabilized solid-state sources. As shown in Fig. 3, which gives details of the up- and downconverting technique, the oscillator frequency of 59.9 GHz is upconverted by the subcarrier pseudo-noise signal to the transmitted frequency band at 61.1 GHz, while the LO power necessary for the four receivers is obtained by injection locking from a second Gunn source. To enable only the transmission of the upper sideband a waveguide structure of appropriately reduced width is used as a high pass filter. Preliminary experiments have confirmed [2] that the use of these principles allows to keep the system unsophisticated while maintaining sensitivity to cover distances up to 150 m using a transmitted single sideband power of about 1.6 mW.

In contrast to conventional designs the PN code is not generated instantaneously by shift registers but read out from a memory at the necessary rate. This concept offers the advantage of giving direct access to any desired range gate via a code shift by a simple address selection. The access is always to one range gate at a time, determined by the address offset between the transmitter and receiver code generator. By sequentially processing all range gates of interest at a rate of 10000 range cells per second, the whole field of view of about 128 range gates (100 m) can be covered within 13 ms which is sufficient for real time demands. Fig. 4 displays the return signal of a point scatter obtained by correlation between a transmitted and a received signal which has been 22 dB below thermal noise level before processing.

2.2 Angular Resolution

In contrast to other possible concepts using mechanically scanning antennas or expensive phased array techniques wavefront reconstruction [3] is used for angular discrimination by generating calculated beams. Four suitably weighted samples of the complex field distribution received by the antennas are transformed by a FFT into the response of an equal number of antenna beams of about 3° width creating digitally four angular resolution cells.

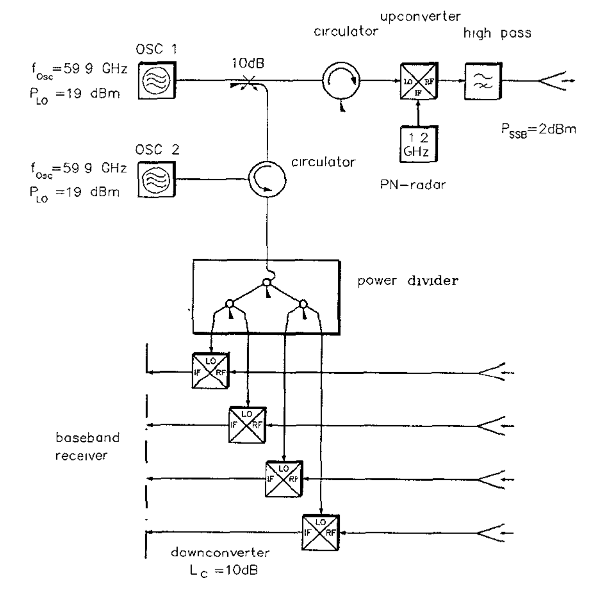

Fig. 3: Block diagram of the millimeter wave front end.

carrier frequency	61 GHz
subcarrier frequency	1.2 GHz
range resolution	0.75 m
unambiguous range	767 m
maximum range	150 m
modulation	BPSK
code	maximal length PN sequence
code length	1023 chips
chiprate	200 Mchips/s
code repetition frequency	196 kHz
angular resolution	wavefront reconstruction by FFT
angular resolution cells	4 / 8
angular resolution cell width	3° / 1.5°
field of view	12° x 150 m
RF - power	1.6 mW
maximum Doppler frequency	+/-20 kHz

Table 1: System parameters.

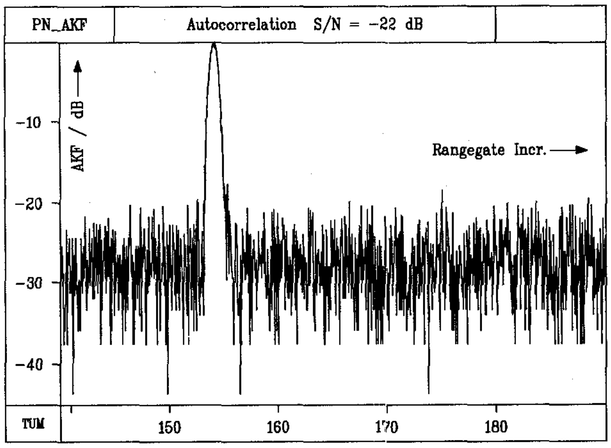

Fig. 4: Correlation function of a PN code signal received from a point scatterer.

The extension to a configuration of eight receivers as planned in the second step can be obtained by sequentially selecting two suitably spaced transmitter antennas. The field distribution of the incoming wavefronts, which is sampled by the receivers, can alternatively be evaluated by the more sophisticated methods of spectral estimation. Depending on SNR this can increase the effective angular resolution beyond the classical limits. Because the reconstruction is completely carried out by digital signal processing, the number of resolution cells and the width of the area to be surveyed can be adjusted according to distance and depending on traffic requirements.

3. System Evaluation

The four channel system with system parameters given in Table 1, which had been fully evaluated in the laboratory assembly shown in Fig. 5, has now been mounted on an experimental vehicle. The project objectives are directed towards the recording of radar images for various traffic scenarios, comprising also different environmental and road conditions. For this purpose facilities for the simultaneous recording of typical sequences of radar and video images and their superposition have been implemented. This allows to evaluate and optimize the data processing routines in the laboratory on the basis of signals measured in realistic highway environments. On this basis suitable CFAR algorithms can be constructed and verified, resulting in

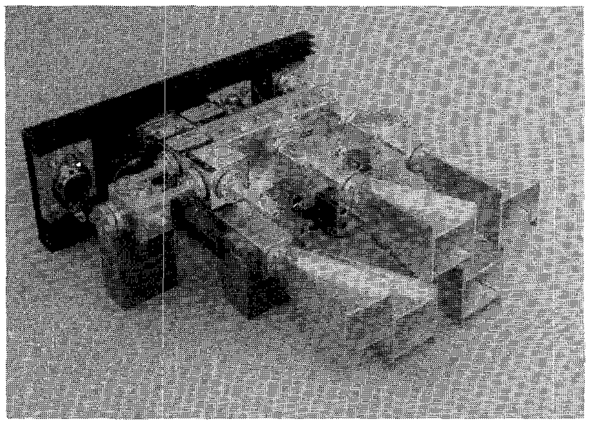

Fig. 5: Laboratory assembly of the radar front end

realistic specifications of false alarm rates and probabilities of detection. Further the capabilities of tracking and trajectory estimation will be evaluated for typical scenarios. The results will be used to test and improve warning algorithms for dynamic scenarios for a later direct incorporation into the system. Fig. 6 shows the typical radar response obtained from a stationary outdoor scene using one antenna beam of the non moving radar system which had been mounted on the experimental vehicle.

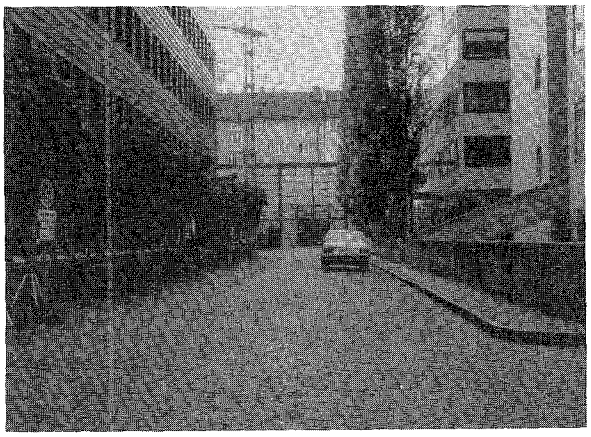

Fig. 6a: Photograph of a stationary scene.

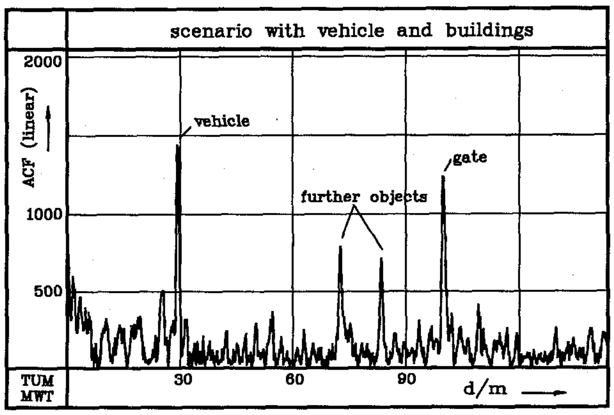

Fig. 6b: Radar response of the stationary scene.

4. Conclusion

The paper reports on the novel system concept, the design and system realization of a automotive collision warning PN code radar using wavefront reconstruction for angular discrimination. The laboratory evaluation of the system has confirmed the specifications regarding essential system parameters such as radial resolution and sensitivity. The memory readout concept for PN codes enables the expected fast access to radially separated range gates and allows on-line tracking of several objects. The concept of data processing and validation is presented and first experimental results are reported.

References

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[3] M. Bockmair, J. Detlefsen: A Multistatic Two-Dimensional Millimeter Wave Imaging System at 35 GHz, 13th Europ. Microwave Conf., Nürnberg 1983, pp. 540 - 545.