5.8 GHZ PHASED ARRAY ANTENNA FOR ELECTRONIC TOLL COLLECTION IN ROAD TRAFFIC APPLICATIONS

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ABSTRACT

Concept and realization of a phased array antenna for road traffic applications based on the 5.8 GHz dedicated short range communication standard is presented. Localization and tracking of vehicles is possible even at high velocities and under critical signal situations. Measurements confirm a robust system performance and high reliability.

INTRODUCTION

In order to ensure individual mobility in future and to reduce especially road traffic problems, several research programs in Europe, USA and Japan work on new and efficient services for an Intelligent Transportation System (ITS). Such new services are electronic toll collection on freeways and automatic access control to restricted areas, e.g. parking lots. They provide financing of new roads, tunnels and bridges and their maintenance, high driver comfort, fluent traffic, reduction of manual operation and reduction of toll plaza size. Only a standardized system design can lead to a widespread implementation of compatible infrastructure and vehicle equipment and thus opens a mass market with low prices for the necessary vehicle equipment. In Europe, an important step in that direction has been achieved by CEN TC 278 standardization body, where the pre-standard for 5.8 GHz dedicated short range communication (DSRC) was passed in spring 1995.

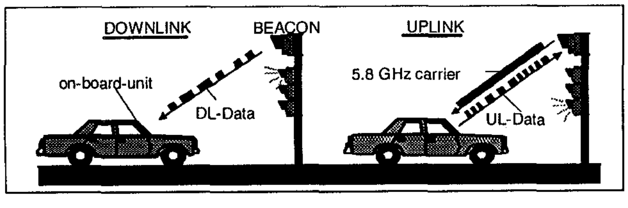

Fig. 1: Dedicated Short Range Communication

In automatic toll collection and access control systems an exact allocation between the transmitted data and the position of the communicating vehicles is important for an enforcement of unauthorized ones. According to the approach in [1], this can be achieved by several receiving antennas with spot beams for each lane. As illustrated earlier by simulations [2], a phased array antenna is a more flexible solution and is well suited to substitute several fixed beam antennas. Now an appropriate phased array antenna system has been realized.

TECHNICAL CONCEPT OF DSRC

The DSRC-standard defines a system for a bidirectional data communication between beacons located in close vicinity to a road and on board units (OBUs) behind the windshields of vehicles (Fig. 1). In the downlink mode the beacon transmits data via amplitude modulation of a 5.8 GHz carrier to the OBU. In the uplink mode the OBU receives an unmodulated carrier from the beacon, modulates it with a PM-subcarrier and then transmits it back to the beacon. The advantage of this transponder principle is a very low circuit complexity which

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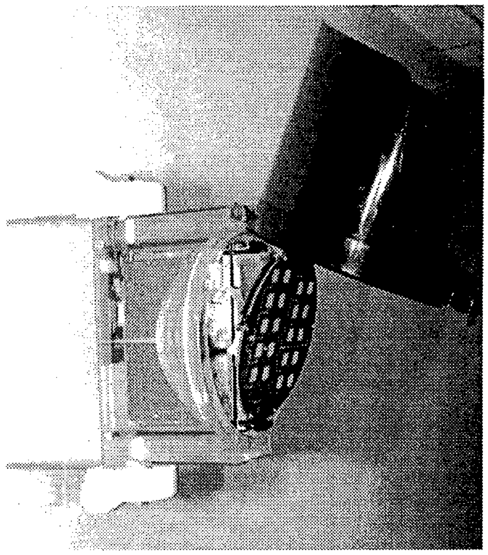

Fig. 2: Beacon in a traffic light housing

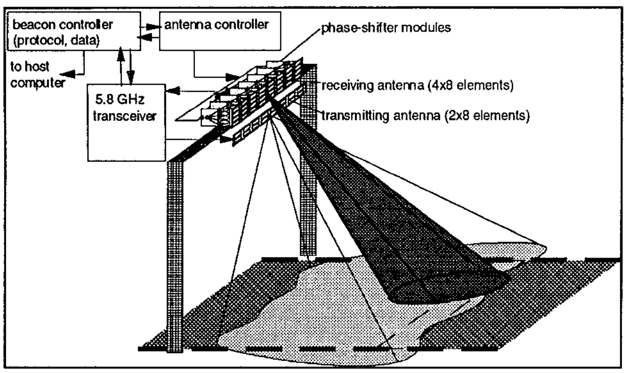

Fig. 3: Schematic system setup of the phased array system

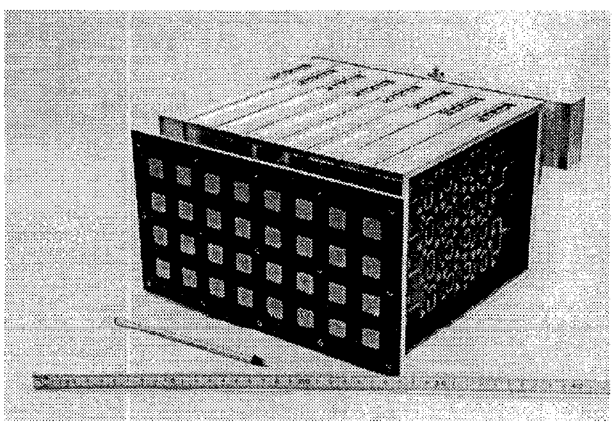

Fig. 4: Receiving antenna

does not need any frequency generating or converting components and therefore is well suited for a low-cost mass production [3]. Circular polarization and diversity techniques help to improve the communication behavior [4]. Theoretical and experimental investigations have shown adequate reliability of 5.8 GHz DSRC [5].

Figure 2 shows a realization of a beacon that fits into a traffic light housing and therefore can easily be installed on existing poles for traffic lights. The design is fully compatible to the new standard and presents a cost-effective solution. The communication zone is fixed and especially shaped to cover one vehicle on a single lane. Thus, this beacon is well suited for systems for automatic access control and permission to e. g. parking lots, factories, residential areas.

For applications with free-flow traffic as on highways, where an enforcement of unauthorized traffic has to be performed (e. g. with a video camera system), the beacon transceiver can be extended by the presented phased array antenna system. This enables a clear localization of vehicle postions in a large area, and allows high vehicle speeds in multi-lane environments.

TECHNICAL CONCEPT AND REALIZATION OF THE PHASED ARRAY ANTENNA

The realized system consists of a phased array receiving antenna with a steerable narrow main-lobe and a transmitting antenna with a fixed radiation pattern shaped to cover one lane as shown in figure 3. Both antennas are planar microstrip patch arrays for left-handed circular polarization, with 4x8 and 2x8 elements for receiving and transmitting, respectively. Sidelobe suppression is attained by a fixed amplitude tapering of the element weighting factors. Phase-shifter modules containing low-noise amplifiers, 4-bit phase-shifters and a 4-way power combiner are connected to each column of the receiving antenna. These modules have

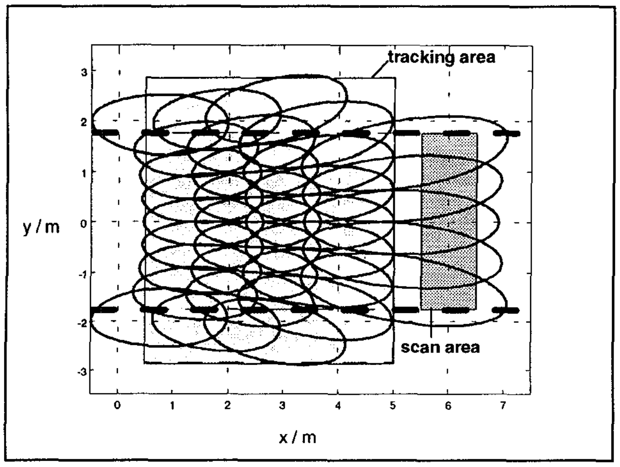

Fig. 5: Communication zones covering a scan and a tracking area

been developed in microstrip technique utilizing surface-mount components to ensure a simple and low-cost production. An 8-way power combiner summarizes the output signals of eight phase-shifter modules. Data communication with OBUs and a host computer is managed by a beacon controller. A separate antenna controller adjusts the 4-bit phase shifters and thus can steer the main lobe to different communication zones on the lane.

System parameters are dimensioned such that these communication zones overlap and cover a scan area and a tracking area on the lane (fig. 5). While no vehicle is detected the antenna scans the main lobe through the scan area. By measuring the power level of the received signal for different main-lobe configurations and detecting a correct data transmission with an OBU, the antenna is able to locate the position of a vehicle entering the scan area. Due to the transponder principle in the OBU the Doppler shift of the received signal can be measured and the velocity of the vehicle can be retrieved. This information is used to calculate an estimate position of the vehicle over communication time and to track the main lobe according to the vehicle motion. Thus the antenna is able to handle the CEN TC 278 data-transmission protocol up to very high vehicle speeds.

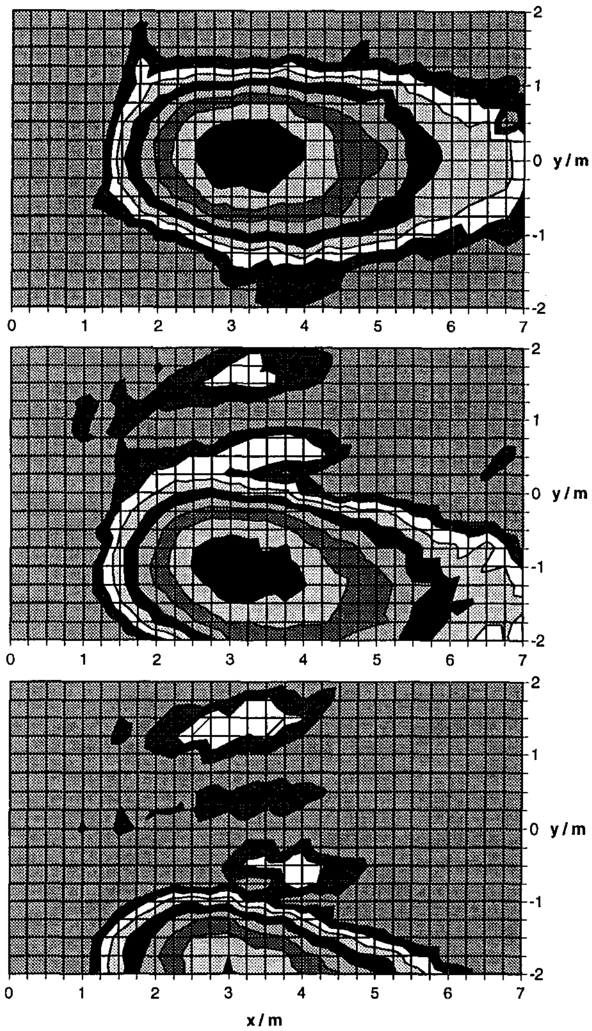

Fig. 6: Typical measured uplink communication zones in a realistic environment isolines in 3-db-steps

MEASURED ANTENNA PERFORMANCE

As a first step to evaluate the performance of the phased array the radiation patterns have been measured in an anechoic chamber. Beam steering performs as expected and a minimum side-lobe suppression of at least 15 dB is achieved. More relevant for the performance evaluation is the forming and the size of the communication zones on the lane. The antenna has been set up for a toll collection application according to figure 3 and the power levels of the uplink signal at the beacon for different OBU positions in a plane one meter above and

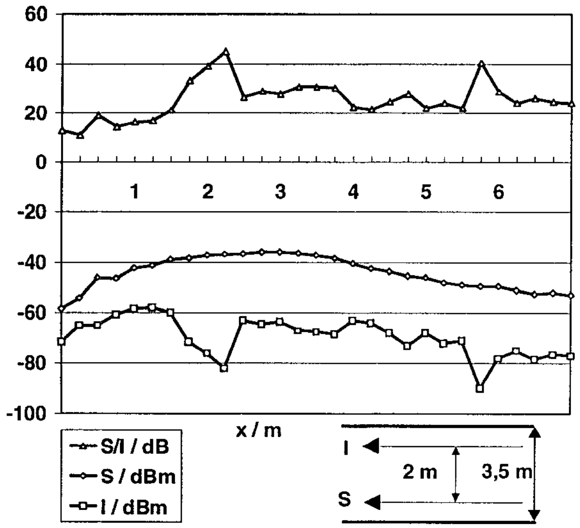

Fig. 7: S/I measurement

parallel to the lane have been measured. Figure 6 shows typical measurements of three communication zones, where the main lobe has been steered towards different directions in the azimut. It can be seen that the power levels are high only in a small zone in the center and descend with a steep slope towards the sides of the lane. This is important for a reliable localization of OBU signals in presence of interfering signals from other OBUs.

Figure 7 shows a signal-to-interference ratio (S/I) measurement, where two OBUs move parallel with a distance of 2 meters along the lane, one representing the wanted and the other the interfering signal. The main beam of the radiation pattern is always directed to the wanted signal. Over a wide range the resulting S/I is better than 20 dB. Thus, a reliable datatransmission and localization is guaranteed.

CONCLUSION

Concept and realization of a 5.8-GHz-DSRC-system with phased array antenna for toll collection and automatic access control applications in a free-flow multi-lane environment have been presented. Measurements of the realized system confirm small communication zones and good side-lobe suppression. The antenna has the ability to safely suppress interferers and manage critical signal situations. Clear localization of vehicle position is possible even if OBUs are very close to each other. The presented antenna system meets strong specifications for automatic toll collection and access control applications and is now prepared for field trials in 1996.

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