# INTEGRATED 5.8 GHZ PHASED ARRAY ANTENNA FOR ELECTRONIC TOLL COLLECTION

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## ABSTRACT

An integrated 3x8 element phased array receiving antenna combined with a 4x8 element transmit antenna for 5.8 GHz DSRC Dedicated Short Range Communication has been built. The number of analog phaseshifters and antenna elements has been optimized to meet the specific requirements of the application and of the DSRC-standard. A sophisticated concept for the integration of analog beamformer, RF-chain, and array antenna has been developed to enable a design of the complete antenna system on a thin multilayer structure. The size of the whole antenna is 280mm x 400mm x 20mm.

## INTRODUCTION

In automatic toll collection it is important to determine the position of the communicating vehicles to enable selective enforcement. Fig. 1 illustrates the existing solution, which achieves this localization by several receiving antennas with 5 spot beams for each lane and the proposed solution, which utilizes a phased array antenna. The major advantage of the presented integrated phased array antenna system is its cost efficiency in comparison to the existing one with 5 receiving antennas and one transmitting antenna per lane. A solution with one phased array antenna for each lane results in a high cost reduction and simplification of the whole system. A typical scenario consists of 15 receiving units and 3 transmitting units controlled by one computer. Using the new approach it would be possible to replace this 18 transceiver units by 3 phased array antenna systems. Due to the fact of a compact design with low cost SMD components the phase array antenna won't be more expensive as one very complex multilane fixed beam antenna, which results in cost reduction of about 75%. Another very important advantage of this system is the reduced data transfer between the transceiver units and the control unit which results in a simplification of the complete control unit.

As illustrated earlier [1],[2] a first prototype of a phased array antenna evaluates the performance of such a system. However, this prototype is large and bulky and does not meet the DSRC-standard. Therefore, an integrated antenna system according to the standard has been developed, which reduces the cost compared to the first prototype by a large factor.

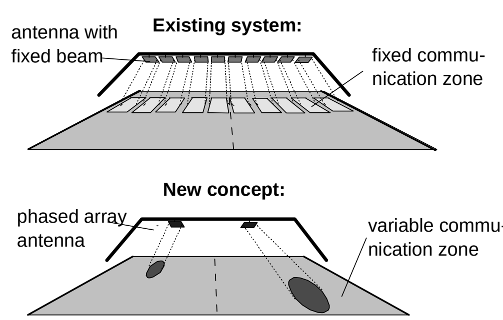


Fig.1: Comparison of automatic toll collection systems with fixed beam antennas and phased array antennas.

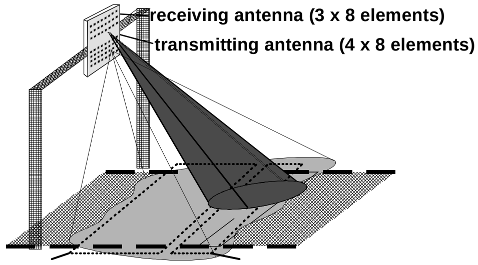


Fig.2: Phased Array Antenna system including fixed beam Tx antenna and steerable Rx antenna

To enable integration on a thin multilayer structure, the number of phaseshifters has been optimized and a sophisticated layout concept has been developed. The integrated design of the phased array results in a low cost antenna system and opens the way to its commercial use and mass production. The complete antenna system is shown in Fig.3.

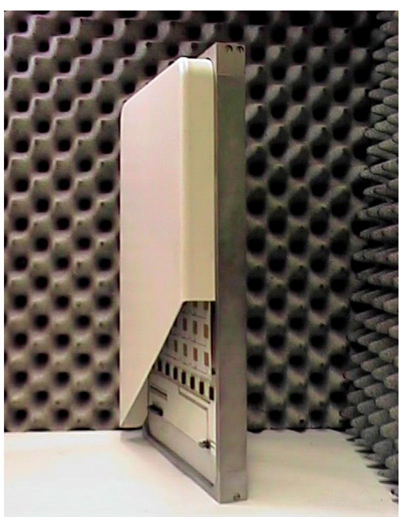

Fig.3: Phased array antenna system

## TECHNICAL CONCEPT AND SYSTEM DESIGN

The realized system consists of a phased array receiving antenna ( 8x3 elements) with steerable main beam with reduced sidelobe levels and of a transmitting antenna (8x4 elements) with a fixed radiation pattern shaped to cover one lane as shown in Fig.: 2, which meets the DSRC specification. With the new phased array antenna the main beam can be steered in three positions in azimuth and more than eight positions in elevation. The complex receiving antenna design is now reduced from 128 to only 56 phaseshifters which are implemented with pin-diodes.

The receiving antenna consists of 8 sub-arrays with 3 vertically stacked microstrip antenna elements shown in Fig. 4 designed to obtain left handed circular polarization with XPD ( crosspolarization discrimination) of -15 dB. The eight ports are combined using a tapered 1:8 power splitter. The DC decoupling of different phaseshifters are implemented with coupled line filters in microstrip technology. To meet the low cost and small size requirements a multilayer design as shown in Fig. 5 has been chosen.

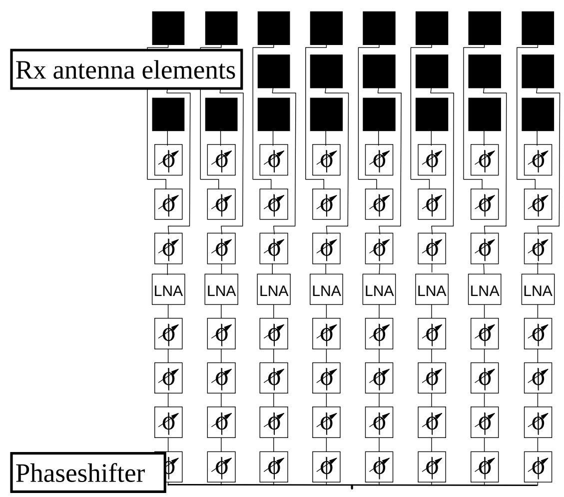


Fig.4: Phased array receiving antenna system design

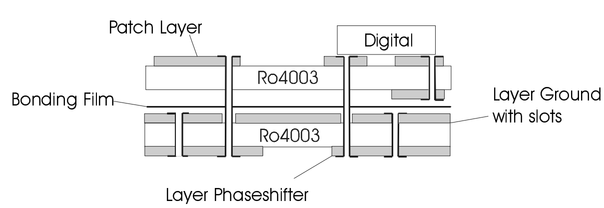


Fig.5: Multilayer design of the phased array receiving antenna

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With this compact design it is possible to build the phased array antenna and the needed digital control unit on only one multilayer. Each subarray consists of 7 phaseshifters, three 1-bit phaseshifters for elevation scan and a 4-bit phaseshifter for horizontal scan and one LNA ( low noise amplifier). The phaseshifters are realised as branchline coupled hyprid phaseshifters with low cost pin diodes. The reproducibility of the phaseshifters is very high, thus there is no need for an off-line calibration procedure, which reduces the cost of the whole system. For the LNA's a low cost PHEMT transistor HPATF36163 with very low noise figure values has been chosen. The input of the LNA is matched for optimum noise figures, whereas the output is matched for maximum gain resulting in a good signal to noise behavior of the complete antenna system.

## REALIZATION AND MEASUREMENTS

The complete receiving antenna has been built on two low cost dielectric substrate layers bonded with a standard multilayer bonding film. The performance of the phaseshifters concerning transmission loss at different phase values as well as the realized phase values itself are essential for the correct funktion of the whole antenna system. Fig.6 shows the transmission losses of the 4-bit phaseshifter at different phaseshift values. The maximum difference over the concerned area is about 0.9 dB. Fig.7 shows phaseshift values of the 4-bit phaseshifter in comparison to ideal values.

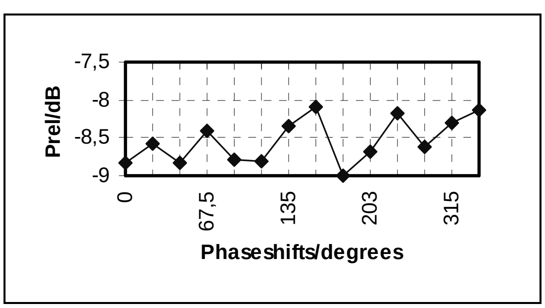


Fig.6: Losses of the 4-bit phaseshifter

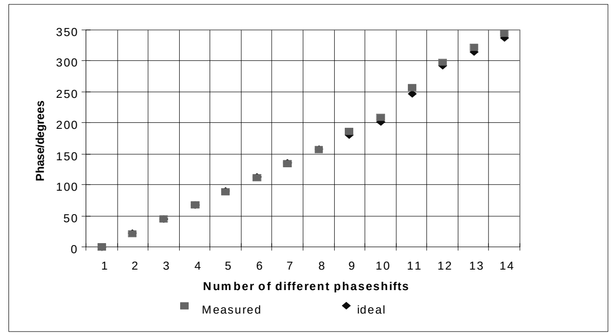


Fig.7: Phaseshift values of the 4-bit phaseshifter in comparison to ideal values

The radiation patterns have been measured in a anechoic chamber in the azimuthal and horizontal plane with different scan positions. Beam steering performs as expected and is shown in Fig.7 and Fig.8 for elevation and azimuthal scan.

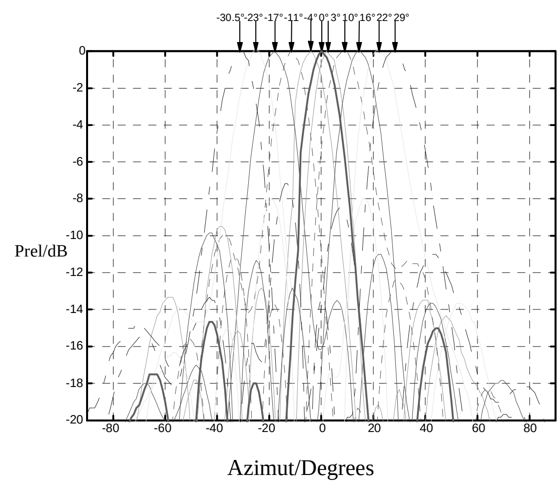


Fig.8: Measured radiation pattern in azimuth plane for 11 different scan angles between +/- 30°.

The 3dB beamwidth at the 0° scan is about 14°, which decreases to 18° at the 30° scan for azimuth. The scan loss, due to the fact of an effective smaller aperture at high scan angles, is about 1.5-1.6 dB. The measured gain of the receiving antenna is 19.4 dBi The measured values for the main beam steering angle corresponds good to the expected values. The scan accuracy is about 1.5°, which is more than enough for this application. Thus, an accurate localization of the communicating vehicles is guaranteed. The sidelobe suppression is about -15 dB for the 0° scan, and decreases to -8 dB at the 30° scan.

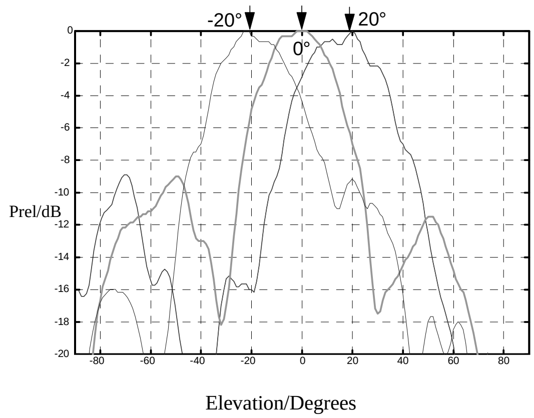


Fig.9: Measured radiation pattern elevation plane for 3 different scan angles 0°, +/-20°

The measured values for the main beam steering angle corresponds very good to the expected values of +/-20°. The higher sidelope values correspond to the equal excitation coefficients of the elevation plane.

## CONCLUSION

An integrated 5.8 GHz phased array antenna with an optimized number of phaseshifters has been presented as an improved antenna concept for Electronic Toll Collection. Integration of the complete antenna as well as the digital control unit on one multilayer opens the way to a cost effective solution. Measurements of the realized system show very accurate funktion without any calibration procedure. The presented antenna system has the ability to reduce the cost of a multilane arrangement for electronic toll collection by 75 %.

## REFERENCES

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