Array Antenna for Body-Worn Automotive Harmonic Radar Tag

S. Cheng[#1], P. Hallbjörner[#*2], A. Rydberg[#3]

[#]*Uppsala University, Microwave Engineering, Box 534, SE-751 21 Uppsala, Sweden*
[1]shi.cheng@angstrom.uu.se
[3]anders.rydberg@angstrom.uu.se

**SP Technical Research Institute of Sweden, Box 857, SE-501 15 Borås, Sweden*
[2]paul.hallbjorner@sp.se

Abstract — **A W-band four-by-four microstrip patch array antenna for body-worn automotive harmonic radar tag is presented in this paper. The antenna is fabricated on 100 µm thick liquid crystal polymer flex foil, using commercially available printed circuit board manufacturing processes. Port impedance and radiation patterns of the antenna are studied numerically and experimentally. The measured results are in good agreements with the numerical simulations. Experimental results indicate that a 2.5 GHz impedance bandwidth (S_{11}=-10 dB) and a 16.4 dBi maximum antenna gain are achieved, at a center frequency around 80 GHz. Experiments with various types of dry and wet textiles are performed in order to study the effect of integration in clothes.**

I. Introduction

Automotive radar systems have been identified as a critical technology for the improvement of road safety. Short and long range radar sensors are under development, for features such as collision warning, lane change assistance, and blind spot monitoring. Automotive radars [1]-[4] at W-band are designed to detect vehicles, persons, and fixed objects, at ranges up to 150 m. An improvement to the radar functionality would be to single out persons among "dead" targets and clutter. Within the EC funded project ADOSE, the harmonic radar (HR) [5]-[6] technique is studied as a means to accomplish this. With the HR technique, nonlinear radar reflectors, so-called tags, are carried by the person. They enhance the visibility of the person on the radar because they reflect a specific intermodulation product frequency that can be detected by the radar. Radar tags for this application should be easily carried by a person. Consequently, they should be small and inconspicuous, preferably mechanically flexible and easily integrated in clothes. They should also be low-cost in order to gain acceptance on the market.

A nonlinear tag consists of an antenna and a nonlinear load. The nonlinear load is in effect a reflective mixer, which can be realized with for instance Schottky diodes. The antenna should have an optimal combination of gain and beamwidth, in order to meet the system requirements on detection range and full azimuthal coverage of the carrier.

It is tempting to use the Van Atta retrodirective array concept [7] to combine high gain with broad coverage. However, as illustrated in Fig. 1a, a retrodirective array uses several nonlinear loads over which the received power is divided, whereas a standard antenna array with a single port concentrates the received power in a single load. Dividing the power means that the power at each load is reduced. Thereby, the conversion loss in the mixing increases drastically, and hence the range of operation is significantly reduced. An array antenna with a single load (Fig. 1b) is therefore the preferred choice.

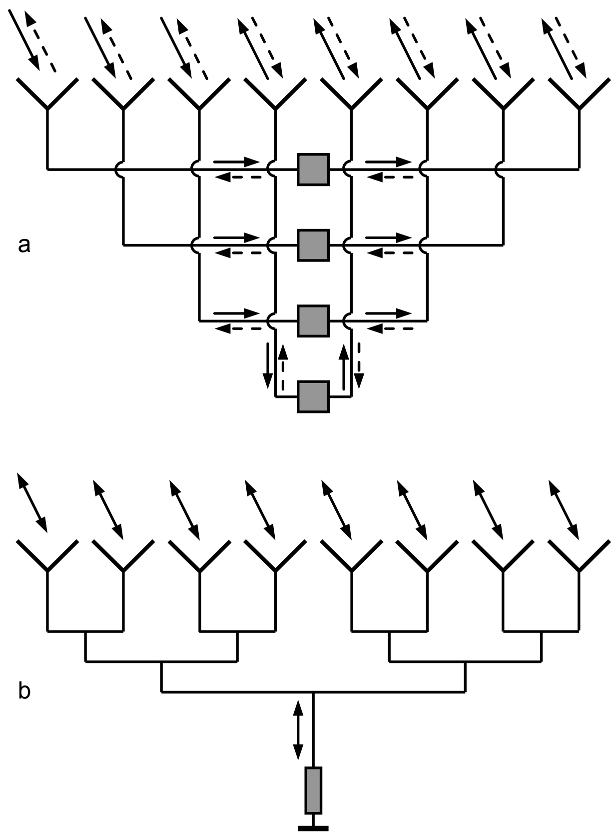

Fig. 1. Comparison between the principle operations of (a) Van Atta array with several transmission-type nonlinear loads and (b) standard array antenna with a single reflective nonlinear load. The Van Atta array gives broader coverage but divides the received power between several loads.

Antennas at millimetre-wave frequencies are usually small, and can easily suffer from poor electrical performance due to difficulties in manufacturing them accurately enough. Achieving highly efficient antennas at low cost is even more challenging. A successful design needs a substrate material with low cost and favourable electrical performance at millimetre-wave frequencies. Design issues such as how to suppress unwanted substrate modes or reduce losses in the feed network have to be taken into account as well. Furthermore, much effort has to be put in minimizing the loss in inter-chip connects (if a monolithic solution is not feasible).

This paper presents an antenna design for integration in clothes. Measured performance is presented, as well as a discussion on wave propagation aspects, mechanical and environmental issues. As such nonlinear tags are to be integrated in clothes in real applications, experimental studies on the effect of various types of dry and wet textiles on the antenna performance are also carried out.

II. Tag Antenna Design

The physical size of the tag sets a limit for its electrical performance, and also has a strong impact on its cost and suitability for integration in clothes. In order to match existing automotive radars, the center frequency should be in the W-band, e.g. 77 GHz, and the polarization should be linearly vertical. From system calculations, the electrical requirements for the tag antenna are found to be a bandwidth of >1 GHz, a gain of >15 dBi, and a vertical beamwidth of >20º. Given this, the horizontal beamwidth should be as large as possible.

Production cost is targeted at 1 Euro/person. Since the human body provides efficient shadowing at W-band, each person should carry several tags distributed around the body for full coverage in azimuth. A possible ground reflex also has to be considered. With a direct signal path and a ground reflex, there will be variations in signal strength over tag height on the body. Fig. 2 illustrates this for typical ranges and different ground reflectivity. Because of the ripple, and the fact that the locations of the peaks vary, several tags should be spread vertically on the body, over a few decimeters. The multiplicity of tags of course further limits the allowed cost per antenna.

All these aspects lead to the choice of a single layer microstrip array antenna, etched on a Rogers liquid crystal polymer (LCP) Ultralam 3000 flex foil substrate [8]-[9] with 100 μm thickness, see Fig. 3. The LCP substrate is chosen for its attractive merits, e.g. excellent high frequency properties, extremely low moisture absorption, favourable mechanical characteristics, and relatively low-cost. Owing to its excellent flexibility, the tag antennas built on LCP flex foil are easily integrated into clothes or on body surface. Moreover, the antenna can be fabricated using commercially available printed circuit board manufacturing processes. This leads to a cost effective solution for large volume production.

The antenna consists of four identical linear arrays and a one-to-four feed network. Each linear array comprises four identical patch elements excited in phase, resulting in a high antenna gain and symmetrical radiation patterns in the vertical plane. More patch elements can of course be employed to increase the antenna directivity. However, the vertical beamwidth as well as the impedance bandwidth of the antenna decrease with the increasing number of the patch elements. In order to achieve maximum directivity, the linear arrays are uniformly excited through the feed network. The feed network consists of three identical 3 dB power dividers, as shown in Fig. 3.

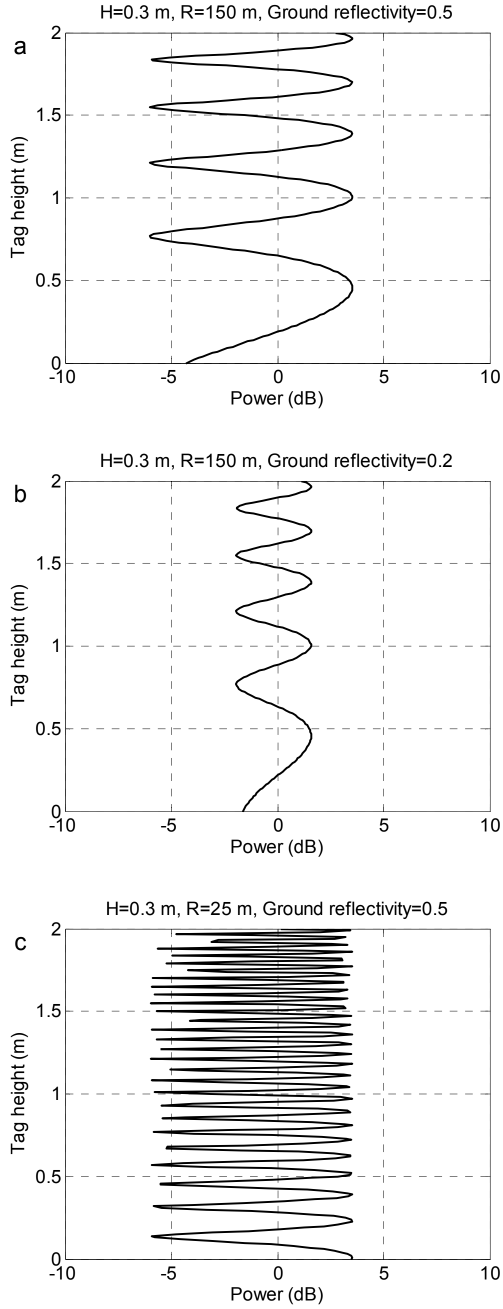

Fig. 2. Variations in received power at the tag as a result of ground reflex. *H* is the height above ground of the car radar antenna, *h* is the tag height, and *R* is the distance between car and tag.

III. Antenna Characteristics

Numerical simulations of the tag antenna are performed using Ansoft HFSS. The presented antenna is simulated and measured with a finite ground plane of 2 cm × 2 cm. Port impedance and radiation characteristics are measured to verify the numerical results.

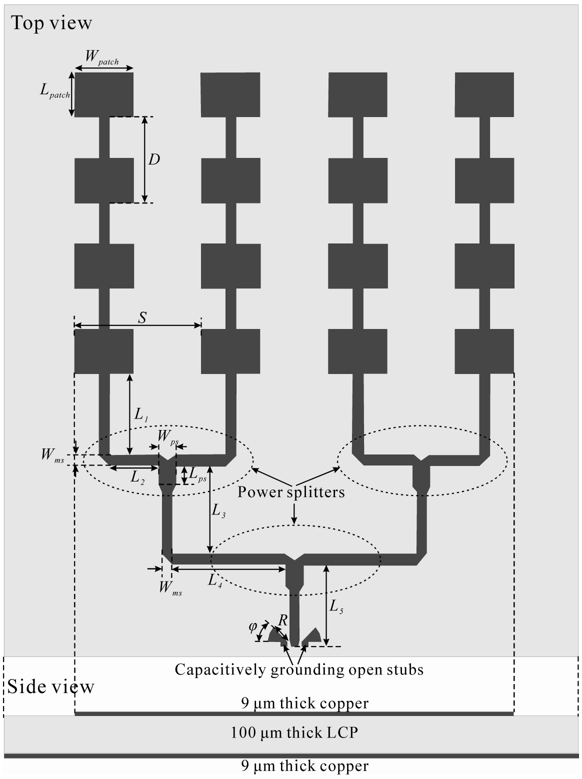

Fig. 3. Layout of the presented tag antenna. Dimensions are: L_{patch}=1.04 mm, W_{patch}=1.40 mm, D=2.00 mm, S=3.00 mm, L_1=2.00 mm, L_2=1.12 mm, L_3=2.18 mm, L_4=2.69 mm, L_5=1.81 mm, L_{ps}=480 µm, W_{ps}=395 µm, W_{ms}=234 µm, R=460 µm, and φ=45°.

A. Port Impedance

Reflection coefficient measurement is performed using a network analyzer (Agilent Technologies E8364B, PNA series) and millimeter wave VNA extender from OML INC (V10VNA 2-T/R). A ground-signal-ground (GSG) Picoprobe @ Model 110H with a pitch distance of 150 µm is used to feed the tag antenna. Prior to the measurement, an open-short-load one-port calibration is performed with a calibration substrate (GGB CS-5). Simulated and measured port impedance of the antenna is shown in Fig. 4. Measured results indicate that the antenna achieves a 2.5 GHz impedance bandwidth (S_{11}=-10 dB) around 80 GHz.

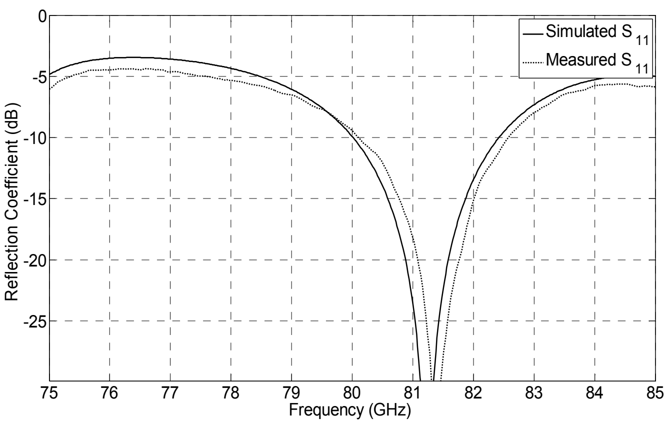

Fig. 4. Simulated and measured reflection coefficients of the array antenna.

B. Radiation Characteristics

Radiation properties of the demonstrated antenna are characterized using the measurement setup illustrated in Fig. 5.

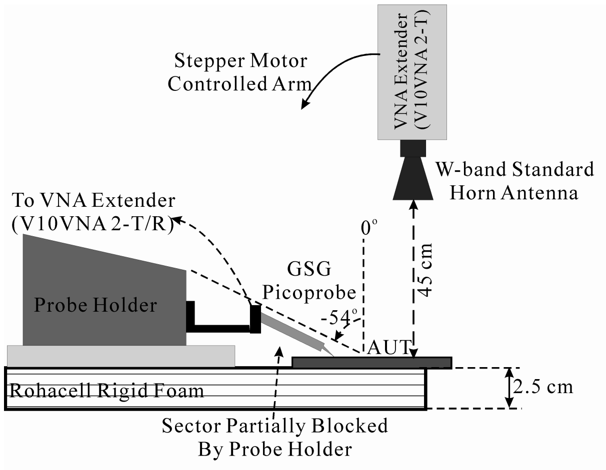

Fig. 5. Measurement setup of antenna radiation properties.

Fig. 6 presents the vertical and horizontal plane simulated and measured radiation patterns. Measurements show a gain of 16.4 dBi, beamwidths 21º (vertical) and 16º (horizontal). With 16º beamwidth in azimuth, at least 23 antennas are needed for full coverage.

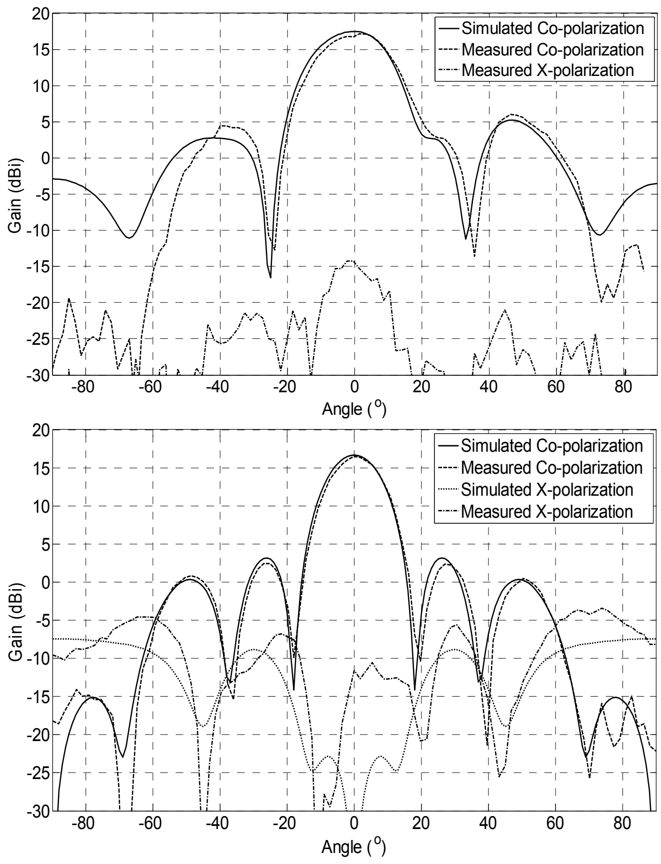

Fig. 6. Simulated and measured radiation patterns, in the vertical plane (upper) and horizontal plane (lower).

Because of irregularities in placement and alignment, the use of at least 50 antennas is suggested for full coverage. Overlapping coverage from several tags would only be an advantage. On the reverse link, signal addition from several tags gives a ripple in the power level with peaks a few dB above the average power. By detecting at the peaks the radar range can be further increased.

IV. Integration In Clothes

The chosen flex foil is smooth and soft but does not crease easily. Regarding bending, simulations indicate that 0.5 mm deflection at the antenna edges compared to the center gives no more than 0.5 dB in gain reduction. The foil can be stitched or glued to a textile layer or the lining of a jacket or coat. LCP is a rather non-hygroscopic material, compared to other millimeter-wave substrate materials. Moisture is therefore not expected to change the electrical performance of the substrate. Since the back side of the substrate is metallized, textile or any other object behind the antenna will not affect its performance. Anything in front of the antenna might have an impact, though, mainly with two possible effects: detuning of the antenna resonance frequency, and attenuation due to reflection and absorption.

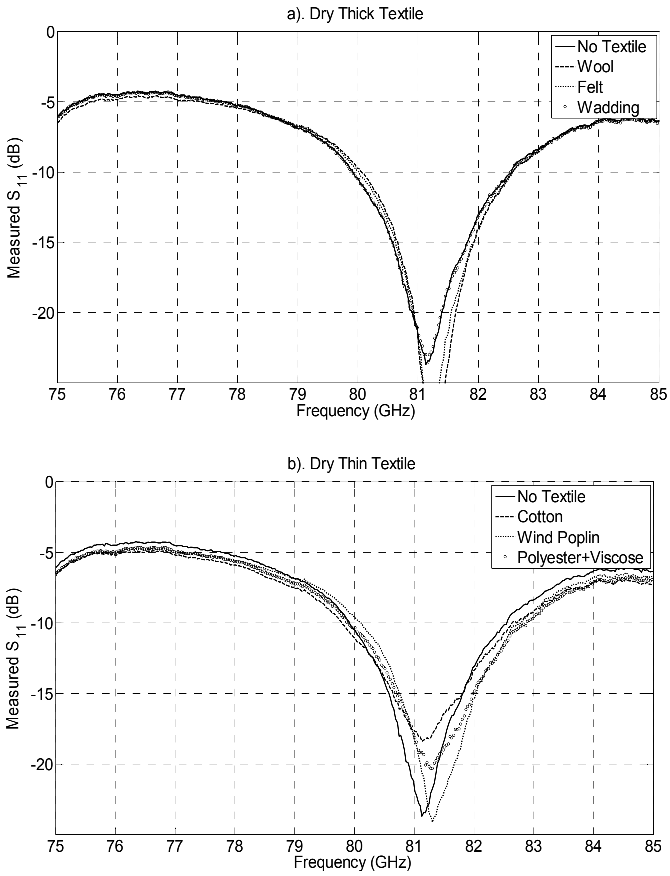

Fig. 7. Measured reflection coefficients of the presented tag antenna with various dry textile layers in front of it.

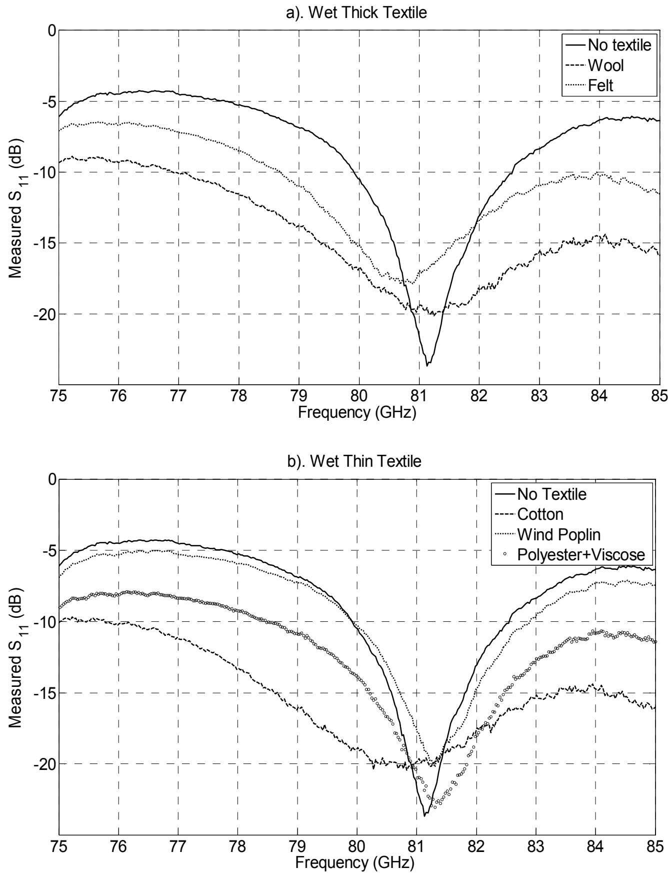

Fig. 8. Measured reflection coefficients of the presented tag antenna with various textile layers in front of it, all soaking wet.

Port impedance of the tag antenna is characterized with various types of textiles, both dry and wet, see Figs. 7 and 8. In the wet case each textile contains as much water as the textile can hold. The dry and wet cases thus represent two extremes. The measurement results indicate that the detuning effect is negligible. Due to the high losses of the wet textile, the antenna exhibits a much wider impedance bandwidth with a thick wet textile than with a thin wet or a dry textile.

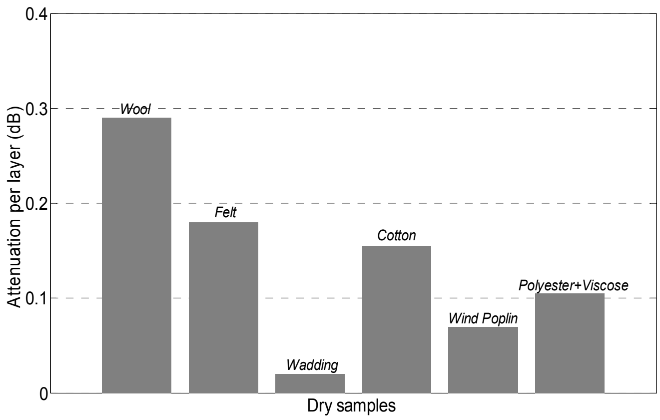

Fig. 8. Attenuation (gain reduction) due to of various dry textile layers in front of the antenna.

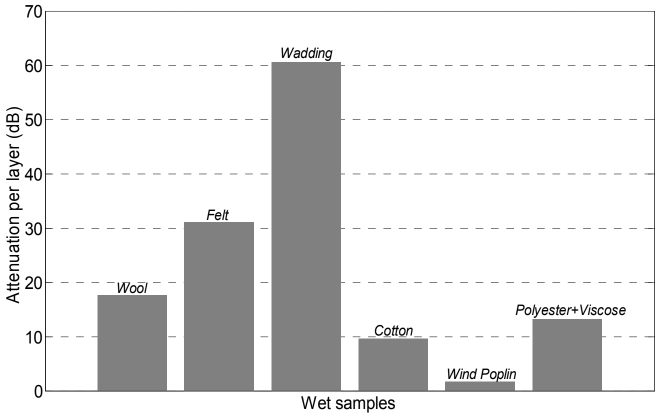

Fig. 9. Attenuation (gain reduction) due to of various textile layers in front of the antenna, all soaking wet.

The attenuation of various dry and wet textiles is measured. As shown in Fig. 9, the attenuation with dry textiles is small (<0.3 dB). Textiles soaked with water on the other hand cause severe attenuation, cf. Fig. 9. Differences in attenuation are due to differences in thickness and ability to absorb water. Tests are performed to verify that the attenuation of medium wet textiles can be derived from the presented extreme cases through interpolation based on the water contents.

V. Conclusions

An antenna solution for automotive harmonic radar body-worn tags is presented. The antenna is an array antenna etched on LCP flex foil, 2 cm x 2 cm wide and 100 µm thick. It has 2.5 GHz bandwidth and 16.4 dBi gain. It can be glued or stitched to textiles, and integrated in e.g. a coat. The antenna can bend to a certain degree without significant performance degradation. Textile layers in front of the antenna have negligible effect on its electrical performance as long as they are dry. Slightly wet textiles can be tolerated, but soaking wet textiles in front of the antenna cause severe attenuation. The antenna is insensitive to anything behind the antenna, e.g. the body. Its production cost is estimated to 0.1 Euro/antenna for volumes of ten thousand, and lower for larger volumes. Approximately 50 tags should be evenly placed around the body for full coverage at all azimuth angles. They should be distributed vertically over a few decimeters in order to make maximum use of the ground reflex effect.

Acknowledgment

This work was supported by the EU Commission under the contract FP7-ICT-2007-1-216049 of the ADOSE project.

References

[1] K. Solbach, R. Schneider "Antenna Technology for Millimeter Wave Automotive Sensors," 29th European Microwave Conference, October 1999, Session MF-TuB 3, pp. 139-142.

[2] V. F. Fusco, D. Salameh, T. Brabetz, "Integrated Antennas for Millimeter-Wave Asset Tracking," IEE Seminar on Integrated and Miniaturised Antenna Technologies for Asset Tracking Applications, IEE London, Digest No. 00/065, November 2000, pp. 7/1-7/4.

[3] N. Yamada, "Radar Cross Section for Pedestrian in 76 GHz Band," R&D Review of Toyota CRDL, Vol. 39, No. 4, pp. 46-51.

[4] N. Yamada, Y. Tanaka, K. Nishikawa, "Radar Cross Section for Pedestrian in 76 GHz Band," 35th European Microwave Conference, 3-7 October, Paris, France, Session EuMC49.

[5] G. L. Lövei, I. A. N., Stringer, C. D. Devine, M. Cartellieri, "Harmonic Radar - A Method Using Inexpensive Tags to Study Invertebrate Movement on Land," New Zealand Journal of Ecology, Vol. 21, No. 2 , 1997, pp. 187-193.

[6] M. E. O'Neal, D. A. Landis, E. Rothwell, L. Kempel, D. Reinhard, "Tracking Insects with Harmonic Radar: a Case Study," American Entomologist, Winter 2004, pp. 212-218.

[7] L. C. Van Atta, "Electromagnetic Reflector," US Patent 2.908.002, 1959.

[8] www.rogerscorporation.com, Rogers Corporation, Ultralam 3000 Data Sheet.

[9] S. L. Smith, V. Dyadyuk, "Measurement of the Dielectric Properties of Rogers R/flex 3850 Liquid Crystalline Polymer Substrate in V and W Band," IEEE 2005, pp. 435-438.