# SEVENTH FRAMEWORK PROGRAMME
# THEME FP7-ICT-2007-2
# Information and Communication Technologies

Project # 224197 – TUMESA

## MEMS Tuneable Metamaterials for Smart Wireless Applications

Deliverable 3.7

Test and evaluation of the novel smart steering reflective surface at a radar front end level and evaluation of the overall performance

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**Abstract:**

Following the design, simulation and optimization of the high-impedance surfaces (HIS) for beam steering, large scale HIS chips have been fabricated and measured. The fabrication of the HIS was not successful in order to fulfill tuneability operation. This is mainly because some of the normal fabrication facilities were not available during the fabrication process. Due to the limited time frame of the project, processes from other facilities were used instead, but these were not optimized for the fabrication of HIS prototypes. In this report simulation results are briefly presented and the overall capability of the HIS for the radar application is evaluated using the knowledge obtained in the TUMESA project.

**Keyword list: high impedance surface, beam steering, MEMS, integration capability, 77-GHz automotive radar front-end.**

## Executive Summary

In this deliverable, the simulation results of the high-impedance surfaces for beam steering are briefly reviewed. The requirements to be taken into account while implementing the HIS-based antenna within a 77-GHz radar front-end are presented.

# Full description of deliverable content

# 1 High-impedance surfaces for beam steering

## 1.1 Introduction

During TUMESA project several fabrication runs were carried out at KTH for the fabrication of large MEMS-based high-impedance surfaces (HIS) for beam steering. Within the final fabrication run, two key processes were not available in the time constraints of the TUMESA project. KTH went to other fabrication facilities but processes there were not sufficiently developed to meet the fabrication specifications, despite efforts to rework the unsuccessful material. Additional rework activities were performed with large arrays from previous fabrication runs which were then additionally sent to AALTO for further quasi-optical measurements. However, these backup large arrays from previous fabrication runs were not deemed fit for tuning on array level, and thus could not be used to test the beam steering system. The fabrication runs are described and the measurement results of the backup large arrays are presented in deliverable D1.6. In this section, simulation results for the high impedance surface are briefly reviewed. More details are in deliverable D1.6.

Figure 1 shows the operation principle of the beam steering with the high-impedance surface.

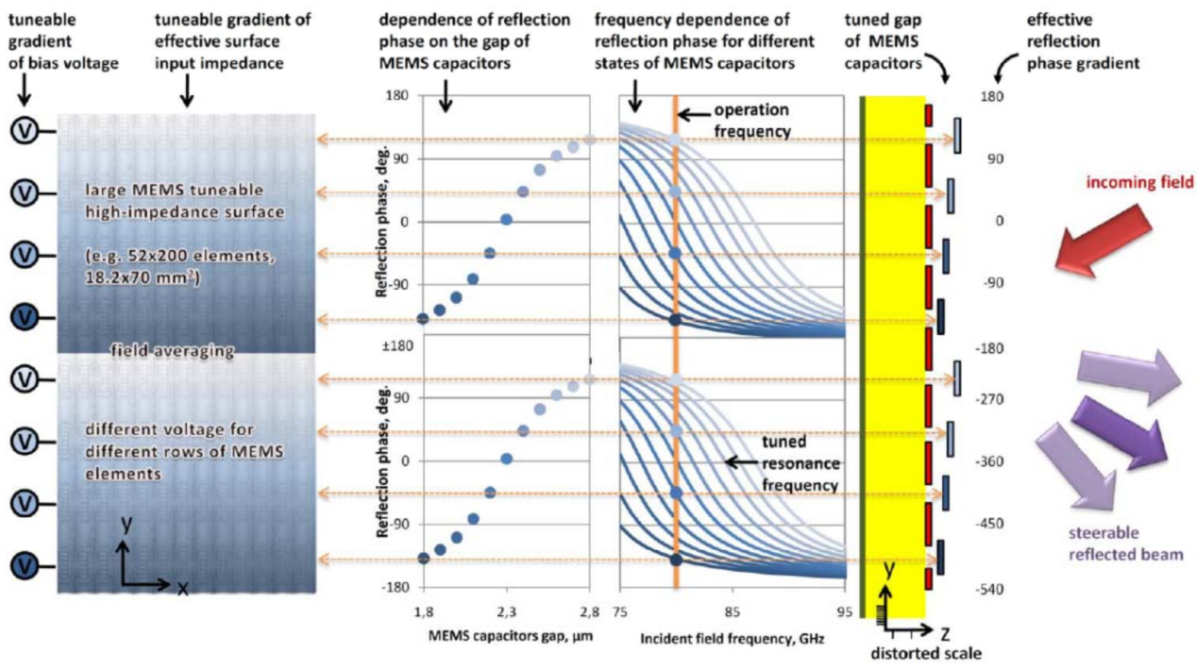


Figure 1. Operation principle of tuneable high-impedance surface for beam steering.

## 1.2 Simulation results

Simulated normalized radiation patterns for 45° steering angle are shown in Figure 2. As a reference, we have also simulated the radiation pattern of the surface with equal impedance (50 ohm resistance). For oblique incidence of 45° the strongest lobe is the main steering lobe according to the programmed reflection angle, i.e. 0°. A strong forward reflected wave side lobe can be observed through these simulation results, which is due to the specular reflection occurring, when a wave impinges to a flat surface. The tuning range of the phase is not fully from $-\pi$ to $+\pi$ due to the MEMS restriction. The limited tuning range does not produce a perfectly linear phase gradient, as the phase is truncated at extreme values. The details of the simulation are presented in deliverable D1.6.

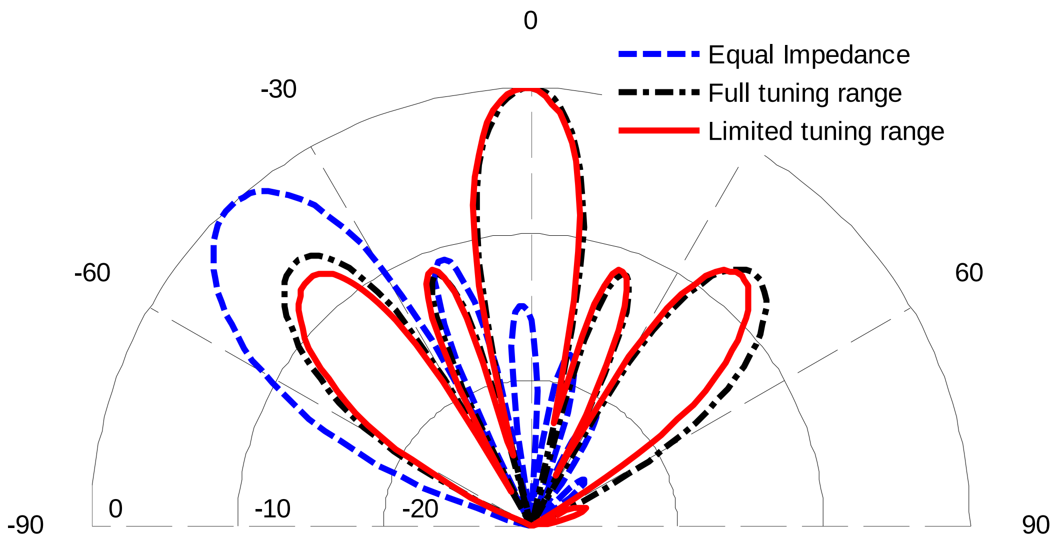


Figure 2. The normalized radiation pattern at 80 GHz with incident angle from 45° for the surface, which is programmed for a beam at the direction of 0°.

# 2 Antenna implementation in 77-GHz automotive radar front-end

## 2.1 Introduction

In this section, we will show how the implementation of the antenna prototype will look like in 77-GHz automotive radar front-end. A synoptic presentation of the radar system with the scanning antenna is shown in Figure 3. The presentation of the antenna implementation is already introduced in deliverable D3.6, but this is repeated here as a reminder. Also the specifications presented in section 2.3 and in its subsections are repeated from deliverable D3.6. The specifications are discussed with respect to the high-impedance surface for beam steering.

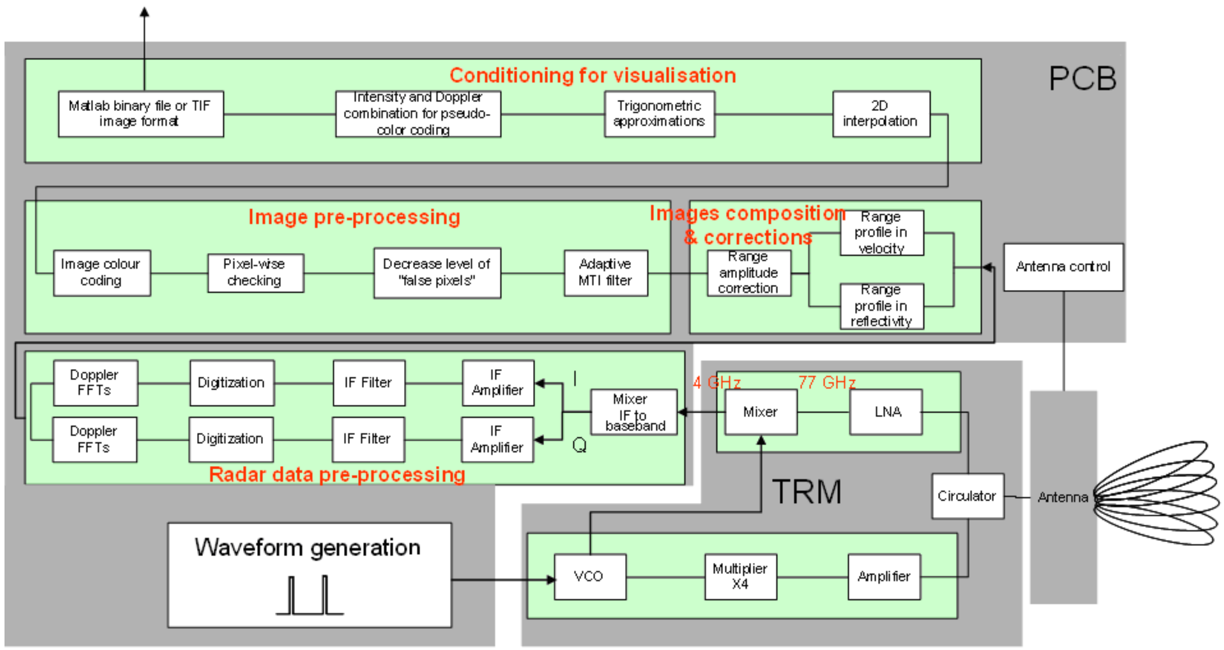


Figure 3. Synoptic presentation of the radar system.

## 2.2 Architecture of the RF transceiver

The architecture of the RF transceiver is directly related with the antenna concept. For example, the configuration shown in Figure 4 uses a bistatic architecture associated to an array of antenna elements to realize the beamforming in RX.

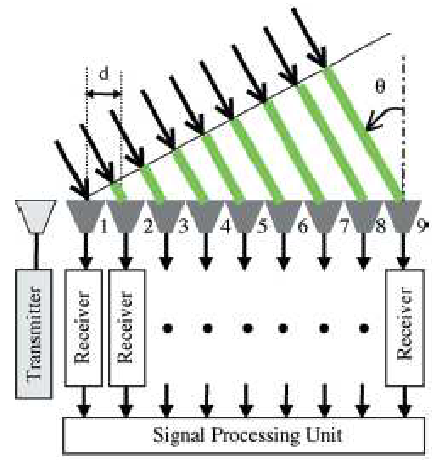


Figure 4. Multi-channel architecture [1]

Since a separate RX-channel is required for each antenna element, this approach exhibits high cost and is difficult to integrate using GaAs technology. This problem can be solved with the emergence of the new SiGe / CMOS technologies which offer the capability of higher integration and lower cost.

In our case, one of the advantages of the developed MEMS-based HIS chip is that the beam scanning can be realized using a single antenna element. Therefore, only one RF-channel is required in RX and the RF transceiver can be realized in a simple monostatic architecture using GaAs technology (Figure 5).

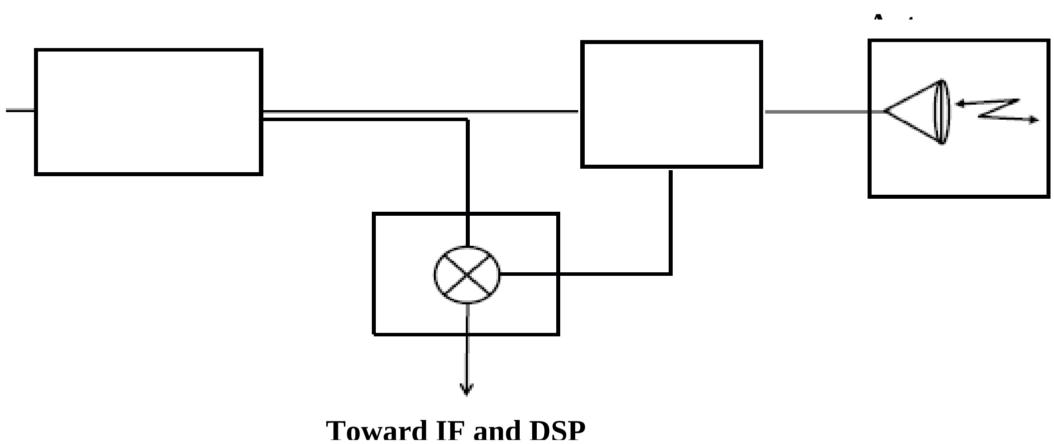


Figure 5. Proposed transceiver architecture for the antenna based on high-impedance surface.

The core of the RF transceiver is composed of MMICs operating at 77 GHz. The connection between the MMICs and the antenna is realized via RF substrate. As the antenna operates in monostatic mode, the transition between the transceiver and the antenna mainly affects the following performances:

- TX power,
- Noise factor in RX,
- Isolation between TX & RX,

Consequently, the transition losses and the matching have to be optimized with a low cost and compliant technology.

## 2.3 Interconnection and packaging issues

The selection of the most suitable assembling and packaging technique for the antenna depends on the antenna & transceiver architectures and technologies. The main criteria are:

- Cost
- Integration capability
- Thermal dissipation
- RF performances in the temperature range
- Mechanical compliance between material versus temperature
- Maturity and reliability of the technologies
- Sensitivity versus process dispersion, assembling, …
- Leading time for the assembling
- Life time
- Protection versus external environment

Best compromises have to be found between these criteria. Some criteria are mandatory and no compromise can be accepted.

### 2.3.1 Cost

The cost is a main criterion in the automotive industry. It is set to <200€ per unit and the antenna part has to be <20€. The RF part is a big contributor of the radar cost. The latter depends on:

- Basic material: substrates
- Processes to realize the "component"
- Steps for the component assembling in the global structure
- Accuracy requirement of the assembling
- Lead time for all the processes and final integration
- Packaging if needed for environment protection

The priority must be given to simplicity, which is not often easy.

The volume manufacturability of the MEMS high-impedance surfaces is investigated in deliverable D4.5. In conclusion, the volume manufacturability and process control/uniformity of this process was considered as very good and even better than other RF MEMS processes. However, the costs were seen as a drawback of the novel process flow, as two SOI wafers are required, which are very costly, also in higher volumes, as compared to blank silicon wafers. In high volume production, the first SOI wafer could be eliminated by designing the high-impedance surfaces for a larger dielectric layer thickness (currently 100 µm), and then a full wafer could be used for the bonding, which would drastically reduce the cost, but also reduce the accuracy of nominal frequency control (in non actuated state), as the wafer thickness has higher tolerances (+/-25 µm) as compared to the typical device layer thickness of an SOI wafer with thick device layer (+/-1..10 µm). When also the 2$^{nd}$ SOI wafer is tried to be eliminated, the process loses its robustness (in terms of stress control) and reliability, and has no benefit in that respect over conventional RF MEMS devices.

### 2.3.2 Integration capability

Figure 6 shows the schematic of the integration of RF components. The radar integration is mainly driven by the antenna dimensions. The latter must be kept below 100 mm × 60 mm × 40 mm. This requires a high integration level the following components:

- Integration of MMICs
- RF substrate to connect MMICs with antenna
- 3D transition between antenna and RF substrate
- DC components and lines for MMICs biasing
- antenna control
- antenna device
- global packaging

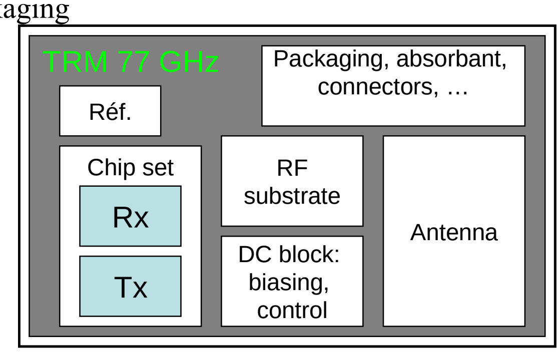


Figure 6. Integration of the RF components.

Use of the MEMS-based HIS as a reflective surface makes it very challenging to meet the requirement for the overall antenna dimensions. The focal length, i.e. the distance between the feed antenna and the reflective surface, has to be large enough in order to provide appropriate illumination for the feed. Also, a sufficient feed offset is needed in order to avoid blockage of the steered beam by the feed antenna.

### 2.3.3 Thermal dissipation

Thermal dissipation is a critical factor for high level integration issues: SiP, wafer level integration etc. The operating temperature range of the radar sensor is set according to standards from -40°C to 125°C and the storage temperature (no power) from -40°C to 130°C. MMICs are main contributors to power consumption (around 250 to 500 mA).

Consequently, the employed technology and the packaging technique must provide a good thermal dissipation coefficient.

### 2.3.4 Effect of the packaging on the antenna performance

The antenna integration in the radar system must be considered at the beginning of the development. The addition of packaging for environmental protection could also affect the antenna efficiency (e.g. protection of the MEMS components of the high-impedance beam steering surface).

The antenna specifications are deduced from the radar link budget: transition losses must be kept less than 1dB and matching below -15 dB in the frequency band of operation. As in any reflector antenna, there are some spill-over losses in the current antenna scheme. Moreover, with current fabrication techniques there is 0.5-1 dB loss in reflection from the smart surface. A significant amount of the radiated power from the MEMS-HIS is directed to the specular reflection lobe (see Figure 2). It affects the antenna beam efficiency but it may also have effect on the matching.

Therefore, the specular reflection has to be also terminated with, e.g., absorbing material. The simulation results show (see Figure 2) that there is a side-lobe towards the angle of incidence. This may cause some deterioration of the matching.

### 2.3.5 Mechanical properties vs temperature

The stacking of the different components (antenna, RF substrate, plate etc.) has to ensure good mechanical thermal expansion coefficient in the 3 axes. For example, a bad mechanical thermal expansion of the substrate in the z direction might create non flat and non regular ground continuity if the substrate is glued on a metallic plate. This effect is more problematic with large substrate dimensions, which is also the case with the MEMS-HIS antenna.

### 2.3.6 Maturity and reliability of the technology

The technological choices must be coherent with the antenna concept and its integration and packaging process. In our case, GaAs technology seems to be a good choice due to its maturity, high performance and the simplicity of the transceiver architecture (1 RF-channel in RX).

The volume manufacturability of the MEMS-HIS is investigated in deliverable D4.5. In the D4.5 conclusions, the volume manufacturability and process control/uniformity of this process are considered as very good and even better than other RF MEMS processes

### 2.3.7 Sensitivity versus process dispersion and assembling

The antenna integration has to be robust versus technology, processes and assembling spread. Hence, the deviations from the nominal process have to be evaluated and the worst cases have to be considered in order to analyze the antenna performance in its real environment. For example Monte Carlo simulations can be realized to see if the performance remains in the specified envelope.

### 2.3.8 Leading time for the assembling

The leading time depends on the assembling and the steps required for the antenna integration within the radar system. This criterion impacts the cost of production. Thus, the priority is to reduce the assembling steps as much as possible.

### 2.3.9 Life time

A typical radar warranty is 8000 hours at a mean speed of 37.5 km/h (300000km).

### 2.3.10 Environmental protection

The protection of the radar components against external environment should not affect their performance. For example, the radom and the plastic bumper must be transparent regarding the antenna radiation, electromagnetic perturbations, high frequency devices, chocks, thermal aspects, pollution etc.

## 3 Bibliography

[1] Y. Asano, S. Ohshima, T. Harada, M. Ogawa, and K. Nishikawa, “Proposal of millimeter-wave holographic radar with antenna switching,” *IEEE MTT-S International Microwave Symposium Digest,* Phoenix AZ, USA, May 20- 25, 2001, vol. 2, pp. 1111–1114.