Project:

RETINA

Aeronautics & Space
FP6 – 2003 – AERO 1
516121

Deliverable #: D7.5

Public report on project results

16 June 2010

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Summary:

Project Number	:	FP6 – 2003 – AERO1: # 516121
Project Title	:	RETINA
Dissemination level	:	PUB

Deliverable Number	:	D7.5
Contractual Delivery Date	:	02 2008
Actual Date of Delivery	:	03 2008
Title of Deliverable	:	Public report on project results
Contributing work package	:	WP7
Nature of Deliverable	:	Report
Responsible partner	:	EADS
Author(s)	:	Volker Ziegler, The RETINA consortium

Abstract:
This report provides an overview about the results obtained during the three years of the project.

Keyword list:
SatCom antennas, Ku-Band, RF-MEMS, ferroelectric, switch, tunable capacitor, phase shifter, reflect array, demonstrator, reliability**.**

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1 Original project background

Today, aeronautical broadband services enabled by satellites are becoming a reality. The services, which are and will be offered using these broadband data links range from increasing passenger comfort (Live-TV, Internet on-board) to providing real-time ATM functions (in-flight monitoring) and improving safety / security aspects (live video-connection to ground). Currently existing aeronautical antenna solutions show drawbacks in terms of costs (active phased arrays) or drag (dish antennas).

2 Original project objectives

The project aimed at developing a reliable and low cost solution for electrical beam steering in Ku-band on-board mobile platforms. It is based on the global concept called reflect array and the industrial implementation is clearly a lower cost alternative compared to active phased array antennas. In addition, the quasi-planar integration of these antenna types will produce almost no additional drag. For the key building block of the antenna, the phase shifter, two solutions will be considered in parallel until a decisive milestone is reached after two years to choose the most suitable technology for the final reflect array demonstrator:

- High-power handling RF-MEMS technologies
- High-power handling ferroelectric materials

They are considered by the consortium to be the best technical alternatives for phase shifters up to Ka-band today and are foreseen to level up the performances while keeping the costs at the lowest level, because of their full compatibility with collective fabrication processes. Finally, a partial reflect array demonstrator will be assembled using the most suitable technology.

The following picture illustrates the principal arrangement for the RETINA SatCom antenna on top of an aircraft fuselage.

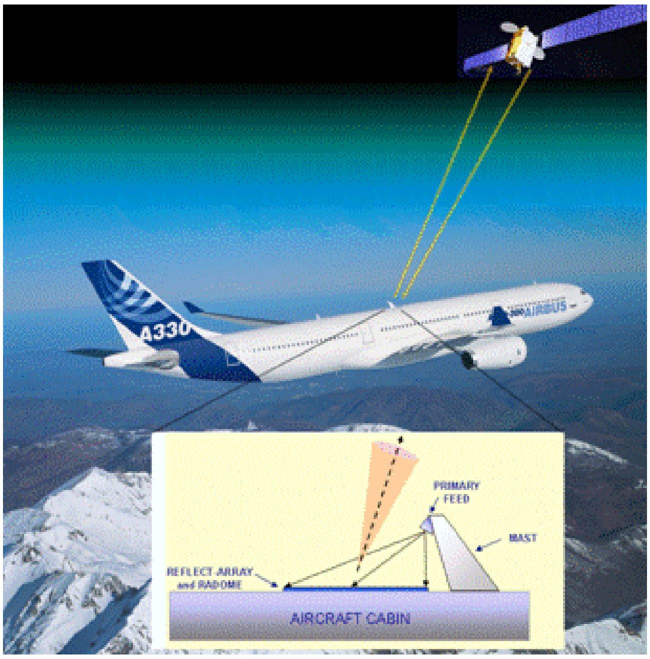

Figure 1: Arrangement of the RETINA SatCom antenna on top of an aircraft fuselage

The RETINA demonstrator itself will consist of 20 to 30 unitary cells, compared to around 1000 cells envisioned for the future target product. The main commitment for this demonstrator is to be representative for the low cost collective fabrication process and assembling method developed throughout the project.
As the demonstrator is for aeronautical applications, high attention is paid during the whole project to the issue of reliability under these demanding conditions in terms of temperature, vibrations, and signal strength. Therefore, extensive tests on the reliability of both technologies will accompany the different stages of the project and extra efforts will be spent with respect to the proper modelling of the main reliability aspects by developing a suitable software tool.

3 Description of work

3.1 System requirements and reflect array antenna architecture

Initially, the complexity of the application was addressed from a global view of the potential applications of a broadband SatCom link, down to the requirements of the most suitable antenna system and finally to the technological specifications of the key building blocks: the phase shifters.
Therefore, first of all, an analysis of the benefits of using a permanent broadband SatCom link was made by reviewing all potential applications concerned. From this knowledge a synthesis on the data rates and characteristics of each application was deduced.
Then a review of the aeronautical and space markets was performed to identify the compatibility and convergence between the requirements of the system proposed in the project and the two afore mentioned domains. A major outcome of this investigation was to develop a Ku-band antenna system rather than a Ka-band one.
The next step was to quantify and summarize the complete link in terms of its primary performances (e.g. bandwidth, which is the most critical parameter) and operational requirements, different scenarios (aircraft size and passenger mixture) were analysed.
After having gained these insights and having defined the global communication and system aspects, the technical system analysis was started and preliminary conclusions on the antenna system specifications (electrical as well as environmental) were drawn. Different implementation scenarios of the ReflectArray antennas were analysed to fulfil the requirements. The principal arrangement and the basic architecture of the reflect array approach is shown in the following picture.

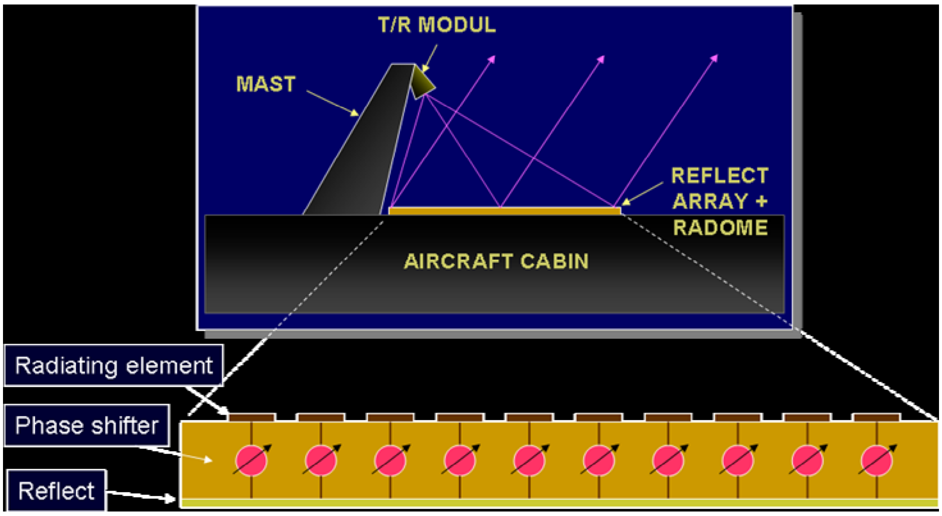

Figure 2: Principal arrangement of the ReflectArray antenna system on top of an aircraft and basic antenna architecture

After the definition of the target solution for the antenna system in detail, it was possible to define the array layout, describe and define the requirements of the unitary cells of the phased array antenna and determine the specifications for the key functions: the phase shifters.

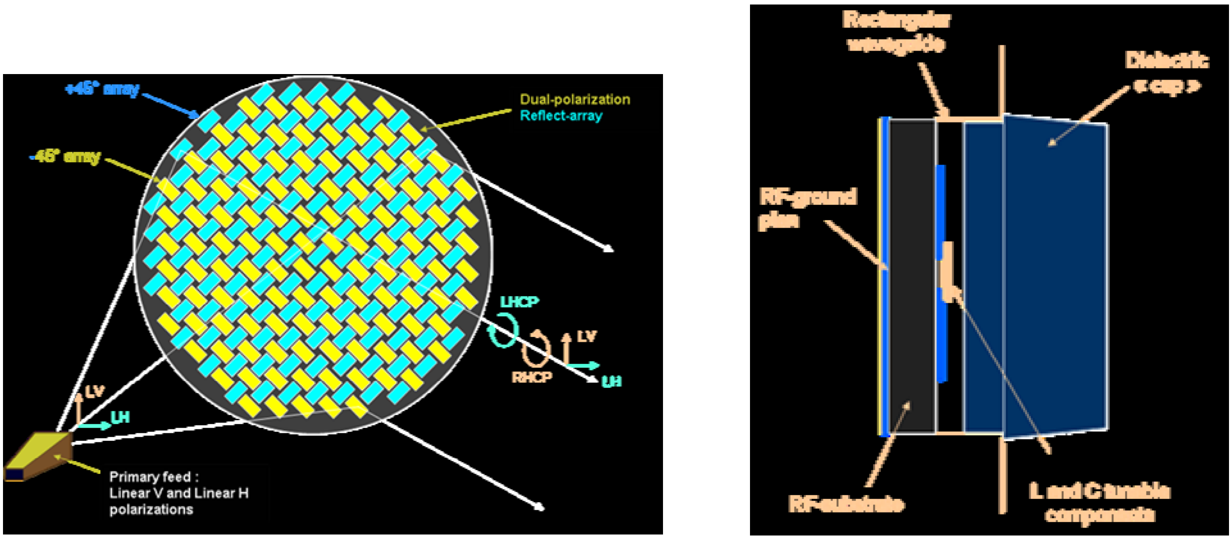

Figure 3: Arrangement of the unitary cells within the ReflectArray (left) and possible layout of a unitary cell (right) including phase shifting elements (tunable or switchable components)

Within the market analysis, meetings and discussions were held with people from AIRBUS, satellite manufacturers and ESA and reports from Euroconsult were analysed. From intensive discussions with the end-user AIRBUS, the specifications for the SatCom antenna system were derived together with Thales and merged into the requirements for the project's demonstrator.

3.2 Phase shifter design, fabrication and characterisation

The definition of specifications for the phase shifting devices was followed by three cycles of modelling and electrical-mechanical design, processing and subsequent characterisation of the two key technologies under investigation (RF-MEMS and ferroelectric material) in the first two years of the project. The first two processing runs were mainly dedicated to test structures and single devices, like ferro-electric tunable capacitors, RF-MEMS tunable capacitors and RF-MEMS switches. The following pictures show some of the fabricated devices.

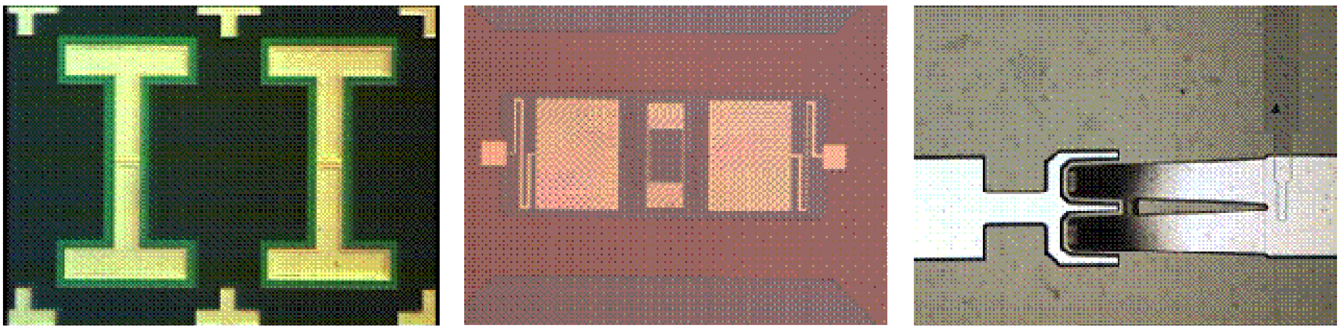

Figure 4: Fabricated phase shifting devices. Ferroelectric tunable capacitor (left), RF-MEMS tunable capacitor (middle) and RF-MEMS switch (right).

The devices demonstrated very nice performances in terms of tunability of the capacitances (up to 3.5) and low insertion losses (-0,2dB) of the switches.

The third processing run was aiming at the fabrication of devices that will be assembled in demonstrator unitary phase shifting cell, which will be used to assess the suitability of each technology to be implemented into the demonstrator. The phase shifting unitary cells were designed for both technologies and the devices were successfully assembled in the unitary cells as shown in the subsequent pictures.

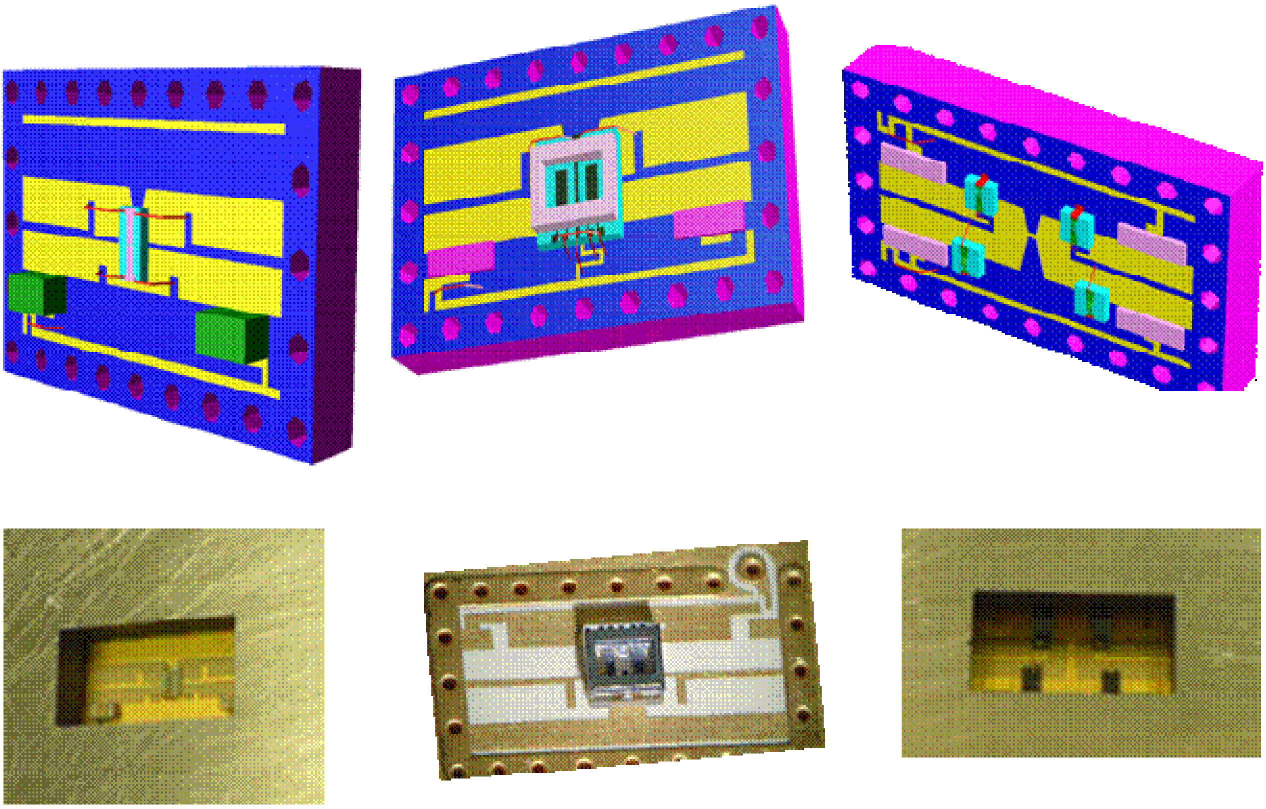

Figure 5: Top pictures: Layouts of the phase shifting unitary cells with the phase shifting devices (ferroelectric tunable capacitor (left), RF-MEMS tunable capacitor (middle) and RF-MEMS switches (right). Bottom pictures: Fabricated phase shifting unitary cells of the respective technologies.

These waveguide phase shifters were then successfully characterised and the results obtained were part of the basis for the decision on the optimum technology for the phase shifter. Other important parameters for the decision were summarized in a complex matrix addressing all topics of each technology, from RF-performance to reliability, assembling issues and fabrication costs.
The main technical requirements, for the phase shifting devices to be chosen, were to exhibit low losses, the phase shift needed and a high bandwidth to be used in both, receive and transmit antennas. Both technologies demonstrated very nice performances, but each had its own challenges remaining to fulfil all requirements. The RF-MEMS showed very broadband behaviour with acceptable losses, while not achieving the necessary phase shift in the waveguide configuration. On the other hand, the ferroelectric capacitors demonstrated good phase shifting capabilities with decent losses, while having only a narrow-band performance. It seemed to be possible to solve the challenges for both technologies in the third year of the project. But since a decision had to be made, two key arguments were considered most important to produce a demonstrator as valuable as possible: the best fit between measurements and simulations of the assembled waveguide phase shifters in year 2 and the most simple fabrication process. Therefore, the decision was to use the ferroelectric tunable capacitor for the RETINA demonstrator.

In the further ongoing of the project, the work to be done on the chosen technology differed from the one to be performed on the non-chosen technology. The latter one, RF-MEMS, was optimized in terms of minimizing the geometrical size of the component and to develop a low-dielectric package for it. Both tasks were aiming at the improvement of the phase shifting performance of the waveguide phase shifter.

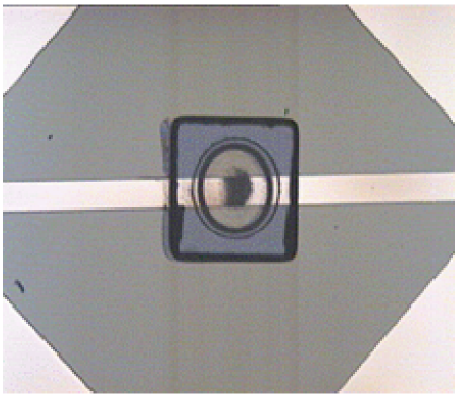

Figure 6: Miniaturized RF-MEMS switch with low-dielectric packaging

Both tasks were successfully performed and the RF-MEMS switches are now ready for the implementation into the RETINA application.

In terms of the ferroelectric components and the realisation of the demonstrator, the first step was the optimization of the ferroelectric capacitor with respect to its tunability and therefore its operational bandwidth. These aspects were successfully addressed in a forth technological fabrication run, which produced the devices needed to realize an optimum phase shifter and afterwards to assemble the demonstrator. In addition to this, the low-cost fabrication approach for this technology was further improved by moving successfully from 1” wafers in 2005 to 4” wafers in 2008.

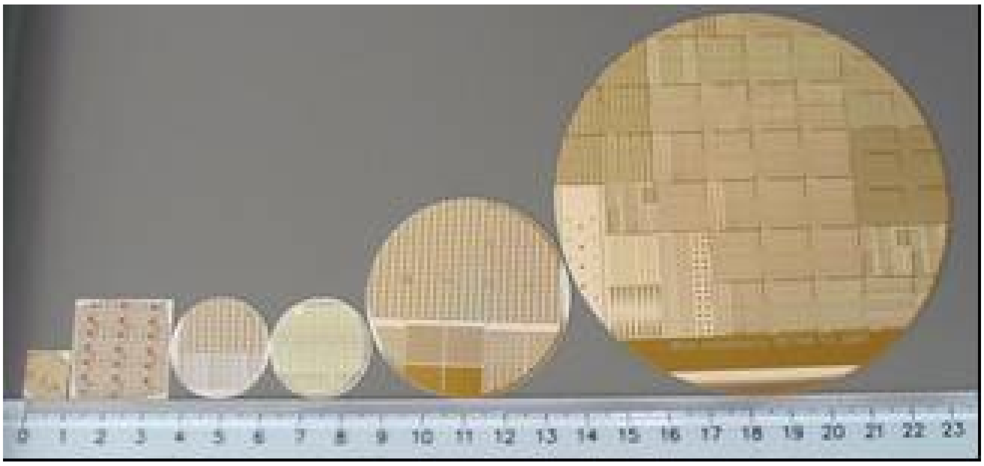

Figure 7: Successful scaling up of the wafer size used for the fabrication of the ferroelectric capacitors. From 1” wafers in 2005 to 4” wafers in 2008.

3.3 Reliability assessments and simulation tool development

As the demonstrator was designed for the aeronautical application, high attention was paid during the whole project to the issue of reliability under these demanding conditions. Therefore, a test plan was set-up for the ferroelectric technology (for which little was known about its reliability at the beginning of the project) and for the RF-MEMS technology. One major step towards a reliable RF-MEMS technology was the testing of the creep sensitivity of the metallisation layers. The results of these tests and the following developments led to the stabilisation of the RF-MEMS switches for reliable operation up to 130°C and 10^9 switching cycles without failure. Lifetime tests on the ferroelectric capacitors indicated $3*10^8$ switching cycles without failure.

The next picture shows an example for the reliability testing of a ferroelectric capacitor.

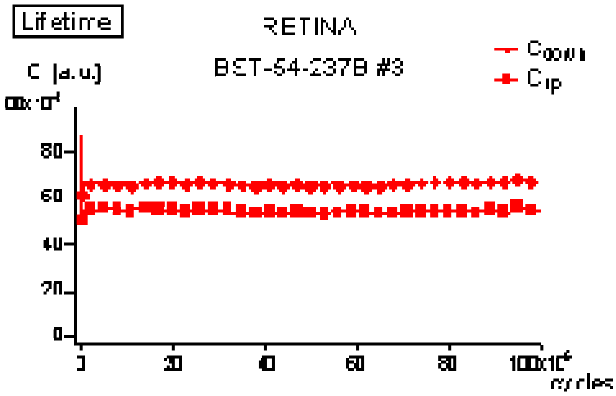

Figure 8: Lifetime testing of a ferroelectric tunable capacitor

Since, a significant portion of the time involved in the commercialization of MEMS enabled products is devoted to improving the reliability. It is interesting that a decade ago the challenge was to produce designs that were manufacturable (by adopting a concurrent engineering approach as opposed to a build-and-test approach) in a minimal number of fabrication starts. Today the challenge is to produce reliable MEMS, which perform to specification with minimal number of fabrication starts. Therefore, this key issue was addressed by the development of a suitable software tool “Design for Reliability”.
It is now capable of performing rapidly simulations of complete RF MEMS switch cycles considering reliability relevant issues such as residual stresses, temperature cycles and stiction. Virtual shock testing improves the insight in the device performance. Using concurrent engineering practices, it is possible to simultaneously model the relevant subsystems and their interactions. Complete system analysis can be carried out considering not only the MEMS structure itself but also its packaging, the RF performance and the surrounding electronics.

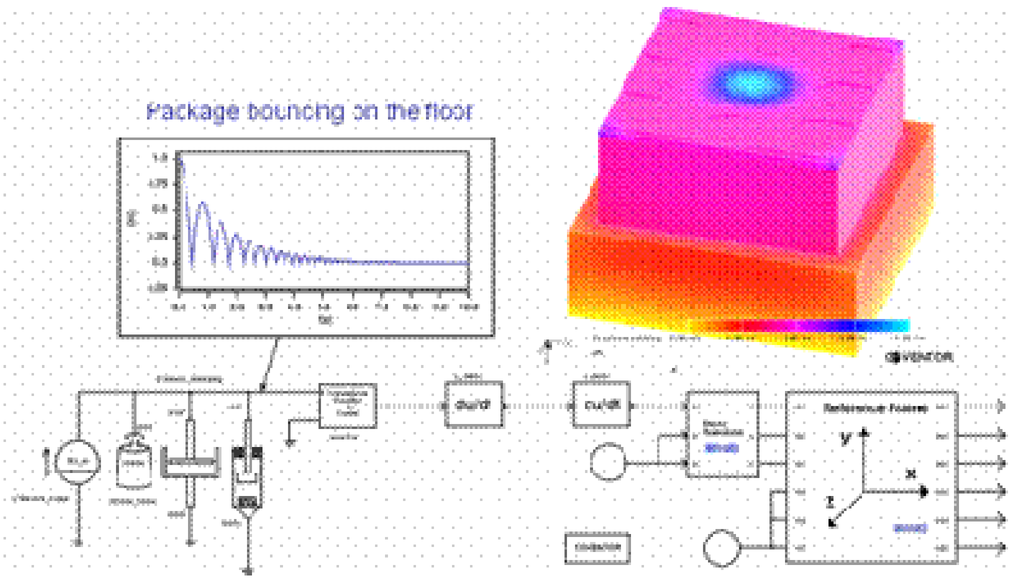

Figure 9: Virtual drop test – Calculation of the stiffness of the package, chip and concrete floor; followed by injection into the system reference frame

3.4 Demonstrator architecture and assembly

The partial reflect demonstrator was chosen to be a 1D reflect-array structure (i.e. linear array) where the elementary cell corresponds to the optimised ferroelectrics bipolarisation cell and where the spacing between cells has been optimised in order to verify steering versus large incident angle. In order to be representative (reproducibility, pattern level), this demonstrator consists of 24 cells.

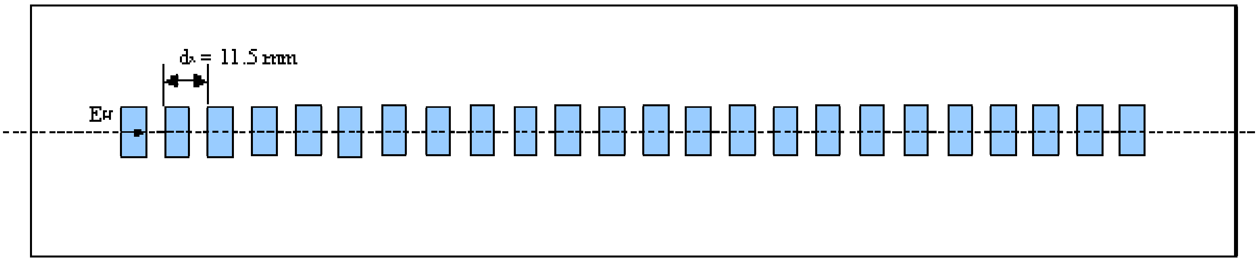

Figure 10: Layout of the RETINA partial reflect array with 24 unitary cells

The ferroelectric capacitor of each cell is driven using specific electronics. The electronic control circuit board, which may be considered as the Digital / Analogue interface between the computer in charge of the demonstrator command (through a serial link) is mounted directly onto the physical antenna, with metal corner plates, so that the antenna plane and the PC board plane are 90° oriented, as represented in the next figure.

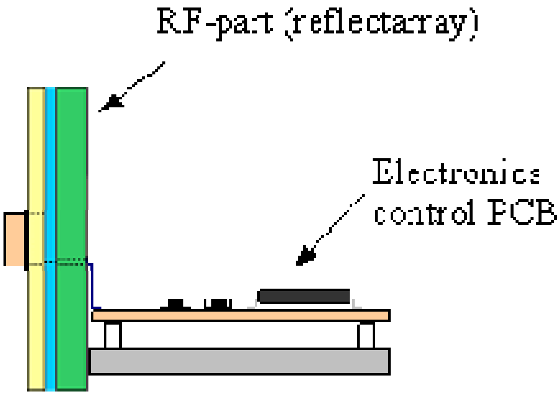

Figure 11: Layout of the complete demonstrator. Reflect array and control electronics

This demonstrator assembly consisting of 24 identical unitary cells with ferroelectric capacitors and the control electronics board was successfully realized and is depicted in the subsequent picture.

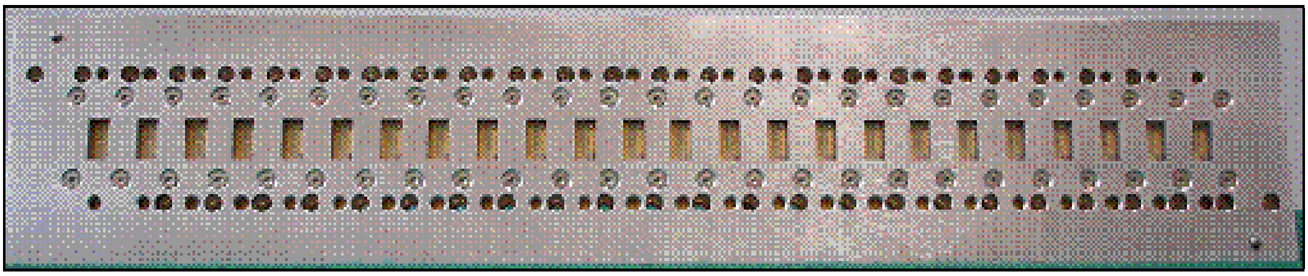

Figure 12: View of the metallic grid of the reflect array (including the phase shifting devices) mounted on the RF-PC board.

The demonstrator was characterised in an anechoic chamber and showed the foreseen one-dimensional electrical beam-steering within the operational bandwidth.

The real-size mock-up of the RETINA demonstrator inserted into a complete antenna arrangement is shown in the following picture.

Figure 13: Real-size SATCOM antenna mock-up with inserted demonstrator array (see arrow in the left picture)

3.5 Conclusions

Within the RETINA project, a successful development of advanced phase shifting technologies (RF-MEMS and ferroelectric capacitors) was performed, which led to the realisation of a partial reflect array antenna, demonstrating electrical beam steering in the operational SatCom bandwidth.
The project has built the foundation for the development of a full-scale Ku-Band SatCom antenna, with the potential of advanced electrical beam-steering using low-cost fabrication processes.

4 Project Consortium

The project duration was from February 1st of 2005 to February 29th of 2008 and the project was co-ordinated by EADS Innovation Works - Germany. The partners of the project and their major roles were the following:

Partner	Country	Major role
EADS Innovation Works	Germany	System requirements. Design, fabrication and test of RF-MEMS switches and transmission line phase shifters.
Thales Systèmes Aéroportes	France	System requirements and analysis, design and characterisation of the wave-guide phase shifters and of the demonstrator
Interuniversitair Micro-Elektronica Centrum	Belgium	Reliability characterisation of RF-MEMS and ferroelectric devices
Swiss Federal Institute of Technology at Lausanne, Ceramics Laboratory	Switzerland	Design, fabrication and characterisation of ferroelectric capacitors and transmission line phase shifters.
Coventor SARL	France	Development of software-tool “Design for reliability”
Chambre de Commerce et d'Industrie de Paris (CCIP), ESIEE Group	France	Design, fabrication and characterisation of RF-MEMS tunable capacitances and inductances.
Jozef Stefan Institute	Slovenia	Development of low-cost chemical solution deposition (sol-gel) process for ferroelectric thin films, fabrication of ferroelectric capacitors, technology transfer to the industry
HYB proizvodnja hibridnih vezij, d.o.o.	Slovenia	Assembling of the phase shifters and of the demonstrator, fabrication process transfer from JSI

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5 Dissemination activities

Besides the organization of two workshops on ferroelectric microwave components and on RF-MEMS power handling and reliability, the project results led to the publication of 41 articles and conference contributions.

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