

Low cost phased array for mobile Ku-band satellite terminal

Stefano Vaccaro ⁽¹⁾, Daniel Llorens del Río ⁽¹⁾, Roberto Torres Sánchez ⁽²⁾ Rens Baggen ⁽³⁾

⁽¹⁾ JAST SA

PSE-C, CH-1015 Lausanne, Switzerland

stefano.vaccaro@jast.ch, daniel.llorens@jast.ch

⁽²⁾ Laboratory of Electromagnetics and Acoustics (LEMA)

Ecole Polytechnique Fédérale de Lausanne, Switzerland

roberto.torres@epfl.ch

⁽³⁾ IMST GmbH

Carl-Friedrich-Gauss-Str. 2, D-47475 Kamp-Lintfort, Germany

baggen@imst.de

Abstract— This article presents the design of a low cost fully active phased array antenna with specific emphasis on the realization of an elementary radiating cell. The phased array antenna is designed for mobile satellite services and dedicated for automotive applications. Details on the radiating element design as well as its implementation in a multilayer's build-up are presented and discussed. Results of the measurements and characterization of the elementary radiating cell are also presented and discussed. An outlook of the next steps in the antenna realization concludes this paper.

I. INTRODUCTION

Many present and future mobile applications require high data rate broadcasting systems with full continental coverage. Among existing satellite systems, Ku-band capacity is widely available all over the world and can easily handle, at low cost, rich multimedia multi-language broadcasting for both entertainment and information services. Ku-Band capacity can not only be exploited for broadcasting services but also for bidirectional links offering a competitive alternative to terrestrial networks.

One of the main limitations to commercial exploitation of Ku-Band in mobile services remains the lack of ground terminals and, in particular, cost-effective antennas with automatic tracking capability, able to track the satellite position while the vehicle is in motion.

The possibility to use phased array technology for mobile telecommunication applications would provide an effective and attractive solution for both service providers and the car industry. The major obstacle to a broad diffusion of phased array technology on the consumer market is the very high cost of active (typically GaAs) MMIC components. Therefore, a requirement for cost-effective phased arrays is to reduce the complexity and the number of active components.

The NATALIA project (New Automotive Tracking Antenna for Low-cost Innovative Applications), funded by ESA under contract number 18612/04/NL/US, is investigating the implementation of a compact, cost-effective, Ku-band, full electronically steerable (pointing and polarization) antenna for

automotive applications (see Fig. 1). Together with a high degree of cost effectiveness, another key item for the design of this antenna terminal is a compact size (around 20 cm in diameter and a height of a few cm's) so that it can easily be integrated within the profile of a car.

II. SYSTEM ARCHITECTURE

A detailed discussion about the system architecture is presented in [1],[2]. For the sake of completeness, we summarize the main aspects here. The main specifications to be satisfied by the NATALIA frontend are the following:

- Operating frequency: 10.7 GHz – 12.75 GHz
- Operation: Rx-only
- Polarisation: linear
- G/T: > -6 dB/K
- Aperture size: 20 cm in diameter (EU), 30 cm (USA)
- Estimated manufacturing price: <1000 Euro
- Scan range: 20°- 60° in elevation from horizon, 0°- 360° in azimuth

The analysis carried out during the project has resulted in a beam steering concept in which the beam pointing and the polarisation adjustment are combined using only two RF-phase shifting devices per array element.

The phase control and amplification are achieved using a GaAs based (M)MIC ([Monolithic] Microwave Integrated Circuits) LNA & phase shifter custom design.

The resulting global architecture shown in Fig. 1 is composed of two-port linearly polarized patches arranged in a triangular grid. The array consists of approximately 150 patches. Both linear polarizations are combined in order to achieve a single linear polarization with rotation agility. This rotation agility is achieved by using a 90° hybrid coupler and two phase shifting units. Good noise performance is achieved by using of an LNA located right in front of the phase shifter

and directly after the patch output. Both LNA and phase shifter are implemented in a single MMIC device.

The above described architecture allows performing beam pointing and polarisation adjustment simultaneously. The outputs from the different radiating elements are combined together using a corporate feed network that uses Wilkinson dividers. The summed RF-signal is then routed to the down converter whose output (L-band signal) is the input of the receiver system developed in a separate ESA project. The phase shifters are all digitally controlled by a microcontroller that interfaces with the receiver.

Fig. 2 shows a photo of the complete array.

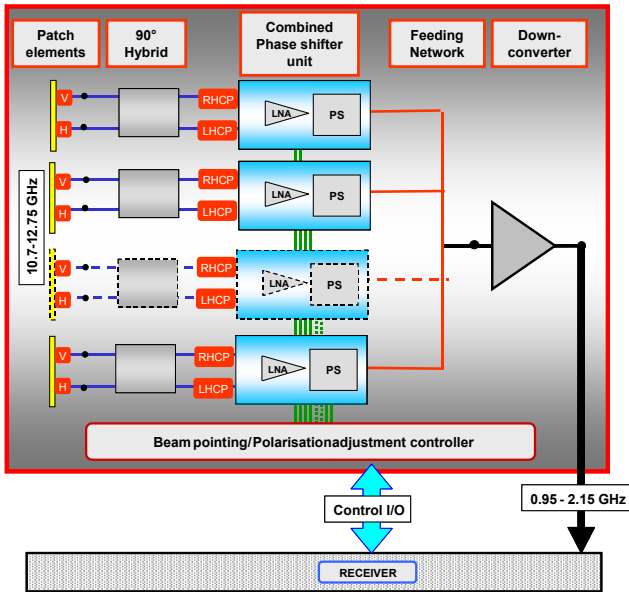


Fig. 1 NATALIA Frontend architecture

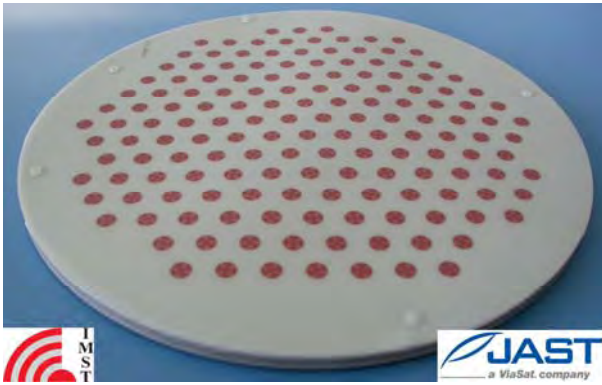


Fig. 2 NATALIA Frontend architecture

III. ARRAY CONFIGURATION

A triangular array lattice has been selected for the final antenna implementation. This is the most suitable array configuration for phased arrays with broad scan capabilities. It

results in the maximum distance between adjacent elements at the lowest elevation scan, before grating lobes start to appear. This distance determines the space available for the implementation of the Elementary Radiation Cell (ERC), i.e. one complete patch configuration, MMICs and other passive components included, which is of primary importance for an effective phased array implementation. If the ERC is too large, the elements have to be spaced further apart, resulting in limited scan capability.

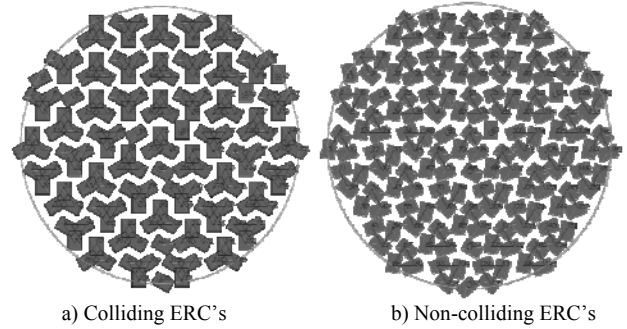


Fig. 3 Antenna array with different elements rotation schemes

Moreover, during the NATALIA project it has been found that the polarization characteristics of the array may be improved by rotating the elements in a particular way. However, depending on the size and shape of the ERC, it might not be possible to arrange the elements arbitrarily. Fig. 2(a) shows an example of an arrangement where, for a particular sequential rotation, a rectangular ERC does not fit within the specified element distance and overlaps ERCs.

By taking advantage of the multilayer substrate, it has been possible to reduce the ERC so that it fits in the required array lattice with the desired rotations. Fig. 2b depicts the configuration that was adopted for the final NATALIA phased array. The element rotations have been selected in order to improve the overall characteristics of the array, so that the requirements at the ERC-level can be relaxed (e.g phase shifters with less bits) resulting in overall cost savings for the whole array.

IV. RADIATING ELEMENT

The selected radiating element consists of two stacked patches fed by striplines through orthogonal coupling slots [2],[3]. Stripline technology has been selected in order to maximize the integration of the radiating element within the build-up and to allow integration with MMIC components.

Fig. 4 shows an exploded view of the radiating element's basic multilayer structure. This build-up is composed of four metallisation layers (stacked patches, slotted ground plane, feeding lines and lower ground plane), three kinds of dielectric materials (epoxy, polypropylene and Rogers RO4003C™) and six metallic posts (shorting pins), which

vertically cross part of the multilayer stack to connect both ground planes.

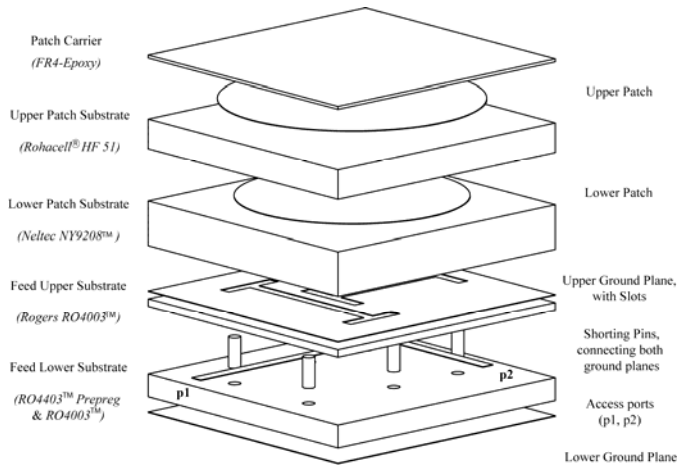


Fig. 4 Exemplary radiating element configuration

The stripline-based feeding structure defined between these two ground planes requires special precautions [5-6]. On the one hand, proper coupling between the feeding lines and the patch through the slot must be ensured. On the other hand, the unavoidable power leakage due to parasitic modes propagating in the parallel plate waveguide associated to the stripline configuration must be mitigated as much as possible.

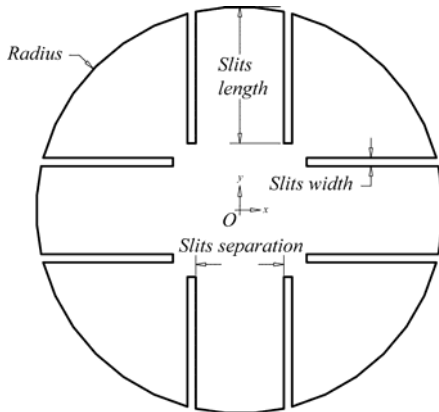


Fig. 5 Slitted patch layout (from [7]).

Finally, the patches were miniaturized by slitting their perimeter (see Fig. 5). This strategy was applied to both stacked patches in order to reach the desired reduction of the inter-element mutual coupling, without noticeably degrading the remaining performance parameters. Complete information can be found in [7].

V. ELEMENTARY RADIATING CELL (ERC)

The ERC is the basing building block of the whole array. It includes the radiating element, the hybrid, the different

interconnecting vias to the MMIC, and the final combiner to the Beam Forming Network (BFN).

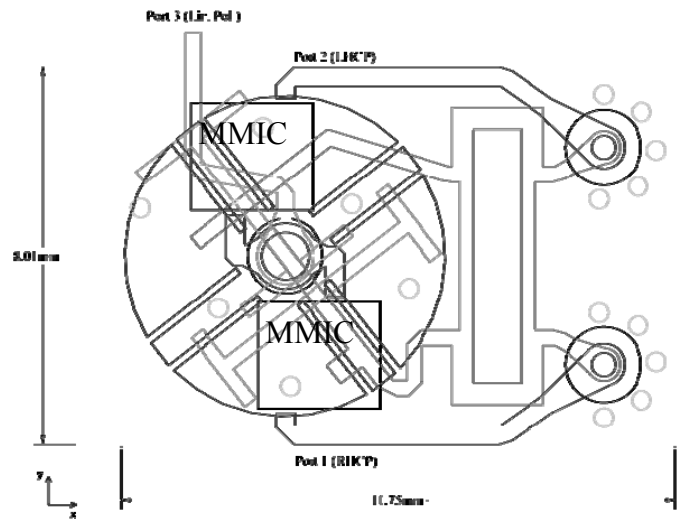


Fig. 6 Bottom layer layout of the complete elementary radiation cell (ERC)

Great effort has been invested in order to fit the complete ERC within the desired array lattice, for the reasons detailed in section III. The complete ERC has been realized in PCB-technology (Printed Circuit Board) and is depicted in Fig. 6. It has been implemented using different PCB-layers by interconnecting them using via holes. This type of implementation offers a large flexibility provided that it can be modeled in the correct way.

VI. REALISATION

The ERC presented in the previous section consists of a large number of components that require very careful analysis

and modelling. Therefore, it was of fundamental importance to be able to measure the ERC elements separately. To that effect, a 50 part breadboard panel of 18"x24" has been designed and manufactured as depicted in Fig. 7.

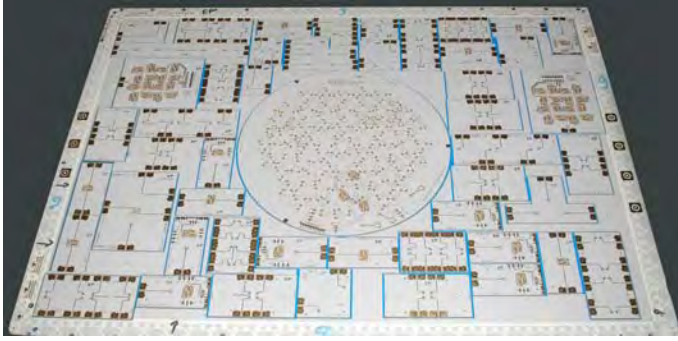


Fig. 7 Complete 24" x18" panel with 50 parts

VII. RADIATING CELL MEASUREMENT AND CHARACTERIZATION

The complete ERC has been manufactured and a very detailed measurement campaign has been carried out, also for different versions of some elements (blind and trough vias, variations in terms of hybrid resonant frequency and linear component phasing). In this paper we only summarize the main results of the measurement campaign. Fig. 8 shows the back side of one of the complete ERC measured.



Fig. 8 Picture of the complete ERC measured

A. S-Parameter measurements

Fig. 9 depicts the S parameters of the ERC. S_{11} and S_{22} correspond to the return loss at the two ports of the hybrid coupler, while S_{12} corresponds to the return losses of the radiating element as seen through the hybrid coupler. The S parameters have been measured with the reference planes located at the position of the coaxial connector port (see Fig. 8)

Considering the effects of the different transitions, the S parameters still show a good agreement with the simulations. Matching is below -10 dB for the required bandwidth.

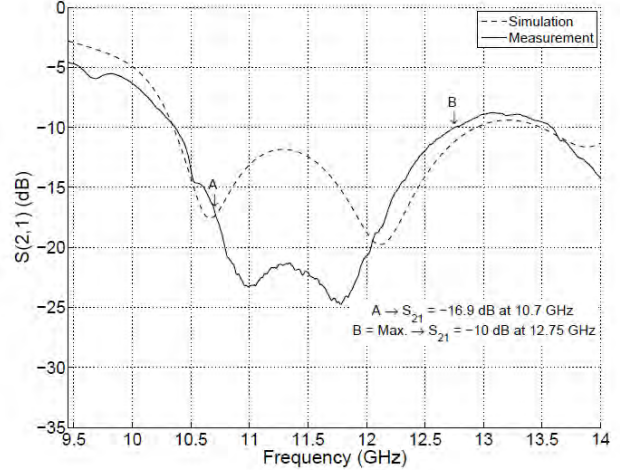
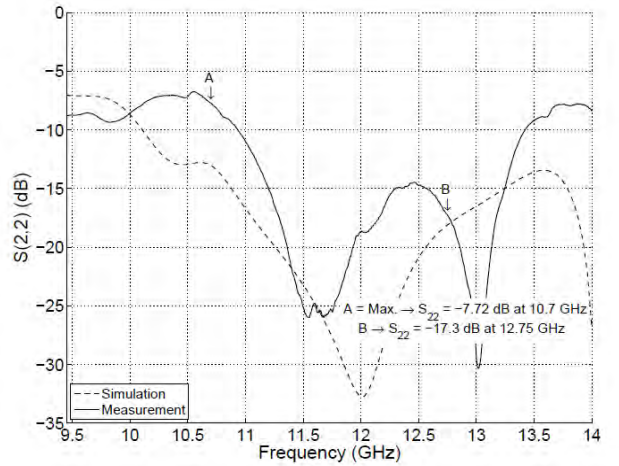
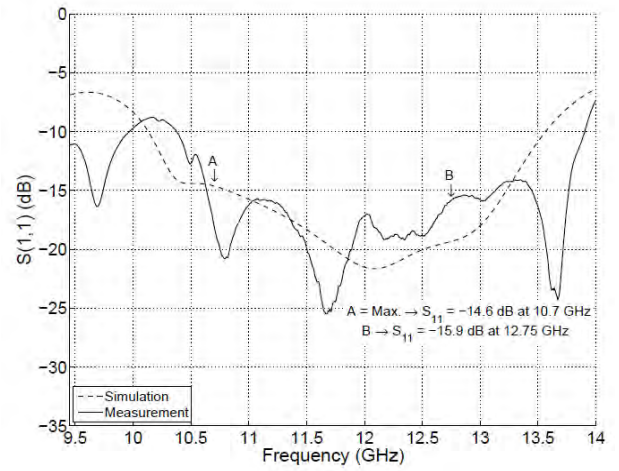


Fig. 9 Measured and simulated S parameters of the complete ERC

B. Radiation patterns

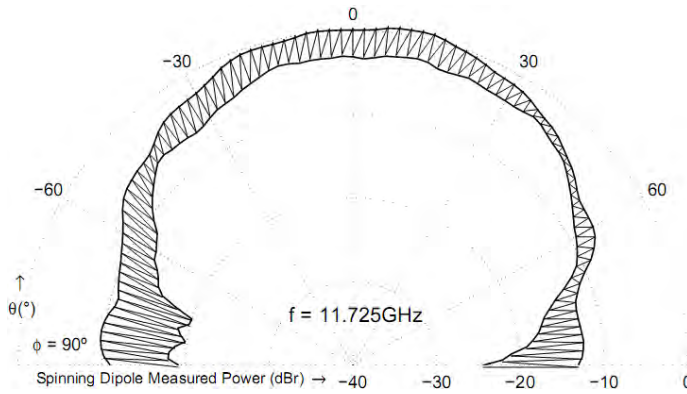
Fig. 10 shows the radiation pattern measurements for the complete ERC. The measurements have been performed using the spinning dipole technique in order to capture in the same chart the axial ratio and the radiation pattern shape. Fig. 10a shows the radiation pattern measured in the vertical plane

(normal to the plane of the connectors in Fig. 8) at the center frequency of 11.725 GHz, while Fig. 10b shows the radiation pattern measured on the horizontal plane (that contains the connectors in Fig. 8) at the same frequency. The patterns measured at other frequencies of the required bandwidth show a behavior that is similar to those presented here.

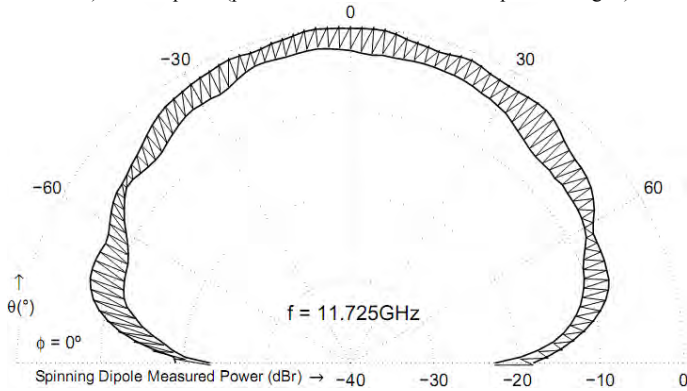
The patterns show good axial ratio for the required elevation range, generally below 3 dB, and both symmetry and directivity appear to match the array requirements.

A. Gain

The measured gain for the complete ERC remains in average between 5 and 5.5 dB in the frequency band of interest. Fig. 11 also shows a reasonable agreement between measurement and simulation. From these data the radiation efficiency of the linearly polarized radiating element is expected to be 72% in average.



a) vertical plane (plane normal to the connectors plane in Fig. 8)



b) horizontal plane (plane of the connectors in Fig. 8)

Fig. 10 Measured radiation patterns for the complete ERC

VIII. CONCLUSIONS

In this paper, general details of the design of a low cost phased array for mobile satcom services has been presented with a specific attention to the design and validation of an elementary radiating cell. The presented ERC opens the way to low cost implementation of phased arrays using a modular

approach and computer automated elements distribution. The maturity and reliability of the manufacturing process has also been demonstrated.

During the writing of this paper, the design of the complete array is reaching its end and first subarrays are being validated, hence the complete array is approaching its completion.

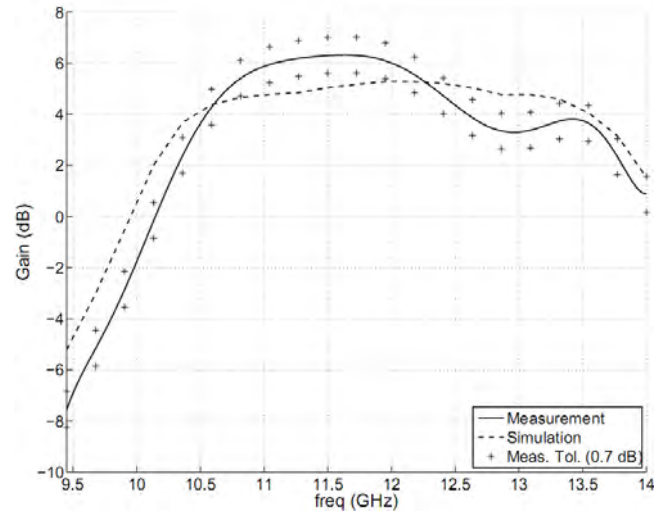


Fig. 11 Measured gain for the complete ERC.

ACKNOWLEDGMENT

The authors wish to thank the ESA for funding and supporting the NATALIA project, under contract number 18612/04/NL/US.

REFERENCES

- [1] R. Baggen, S. Vaccaro, D. Llorens del Río, "Design considerations for compact mobile KU-band satellite terminals", *2nd European Conference on Antennas and Propagation EuCAP*, Edinburgh UK, November 2007.
- [2] R. Baggen, S. Vaccaro, D. Llorens del Río, R. Torres Sánchez, G. Langgartner, "First Prototyping of a Compact Mobile Ku-Band Satellite Terminal", *4th European Conference on Antennas and Propagation EuCAP*, Barcelona, April 2010.
- [3] D. M. Pozar, "Microstrip antenna aperture-coupled to a microstripline", *Electron. Lett.*, vol. 21, no. 2, pp. 49–50, January 1985.
- [4] J.-F. Zürcher, "The SSFIP: A global concept for high performance broadband planar antennas", *Electron. Lett.*, vol. 24, no. 23, pp. 1433–1435, November 1988.
- [5] P. Brachet and J. M. Baracco, "Dual-polarization slot-coupled printed antennas fed by stripline", *IEEE Trans. Antennas Propagat.*, vol. 43, no. 7, pp. 738–742, July 1995.
- [6] R. Torres Sánchez, S. Vaccaro, and J. R. Mosig, "A compact and low cost radiating element for automotive satellite broadcasting reception arrays", *30th ESA Antenna Workshop for Earth Observation, Science, Telecommunication and Navigation Space Missions*, (ESA/ESTEC) Noordwijk The Netherlands, May 2008.
- [7] R. Torres Sánchez, J. R. Mosig, S. Vaccaro, and D. L. del Río, "On the design of a compact and low cost radiating element for satellite broadcasting automotive receiving arrays", *33rd Annual Antenna Applications Symposium AAS*, Monticello, USA, Sep. 2009.
- [8] R. Torres Sánchez, J. R. Mosig, S. Vaccaro, D. Llorens del Río, "A compact and low cost elementary radiating cell for satellite broadcasting automotive receiving arrays", *28th Progress in Electromagnetics Research Symposium PIERS*, Cambridge, USA, July 2010, to be published.

