

# Beamforming Analysis on a Broadband Antenna Array for the Galileo System

E. S. Neves\*, M. V. T. Heckler, A. A. Selga and A. Dreher

*German Aerospace Center (DLR), Institute of Communications and Navigation,  
Oberpfaffenhofen, D-82234 Wessling, Germany*

## 1. Introduction

Future navigation services provided by the upcoming Galileo satellite system will require corresponding improvements on the navigation receiving systems. The first part of any navigation receiving system is the antenna or antenna terminal. In order to obtain the best possible navigation accuracy, exploiting the full capabilities offered by this new system, design of state-of-the-art antenna systems must be pursued.

In this work, beamforming analyses on a broadband antenna array designed for the whole Galileo frequency band [1], [2] are shown. The beamforming software [3] was developed by the DLR antenna group and employs a combination of an optimized Chebychev pattern [4] with the Sample Matrix Inversion (SMI) algorithm [5].

This paper begins with a description of the antenna array used for the simulations and its antenna element, and then the construction concepts are presented and commented. Finally, the results of the beamforming analyses are shown and discussed.

## 2. Antenna Array Setup

The single element for the Galileo antenna array [1], [2] consists of a circular microstrip patch antenna fed by means of capacitive coupling. The element has been designed with an integrated feeding system composed of a  $180^\circ$  hybrid (rat-race) and two  $90^\circ$  hybrids in order to generate a progressive phase shift of 90 degrees at the four feeding points. A schematic of the antenna element as well as a first prototype are shown in Fig. 1.

The impedance bandwidth of this element is approximately 31% (full Galileo band) in which the axial ratio is below 3 dB for elevation angles from  $90^\circ$  down to  $30^\circ$ .

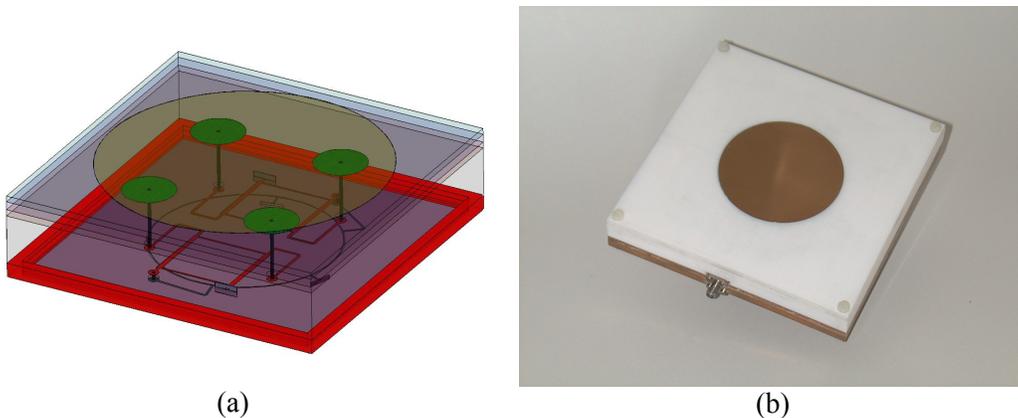


Fig. 1. Single element (a) schematic and (b) prototype.

Fig. 2 shows the antenna array schematic in a perspective and a side view. The array size is 4x4 elements and it is mounted using a modular concept, i.e. each antenna element is a module itself. Based on the capabilities of a 4x4 antenna array using the element described above, a set of desired specifications was made as follows:

Table I. Antenna array specifications

Parameter	Specification
Bandwidth	1164 MHz to 1591 MHz (31%)
Return loss	-10 dB min
Polarization	RHCP
Azimuth scanning	360°
Elevation scanning	from 30° to 90° (from 0° to 30° desired)
Gain	10 dBi min. over all scan angles (30° to 90° elevation)
Axial ratio	3 dB min. over all scan angles (30° to 90° elevation)
Cross-polarization	15 dB minimum, 25 dB or better is desirable

The overall antenna array surface is 38 cm x 38 cm, since each module measures 95 mm x 95 mm. The feeding of each element is performed by means of phase-stable coaxial cables. The adopted mechanical concept provides flexibility to the array prototype, allowing real time electronic steering as well as passive switched beamforming tests on the same platform by means of switching modules. In addition, any part of the antenna array may be easily tested isolated from the others.

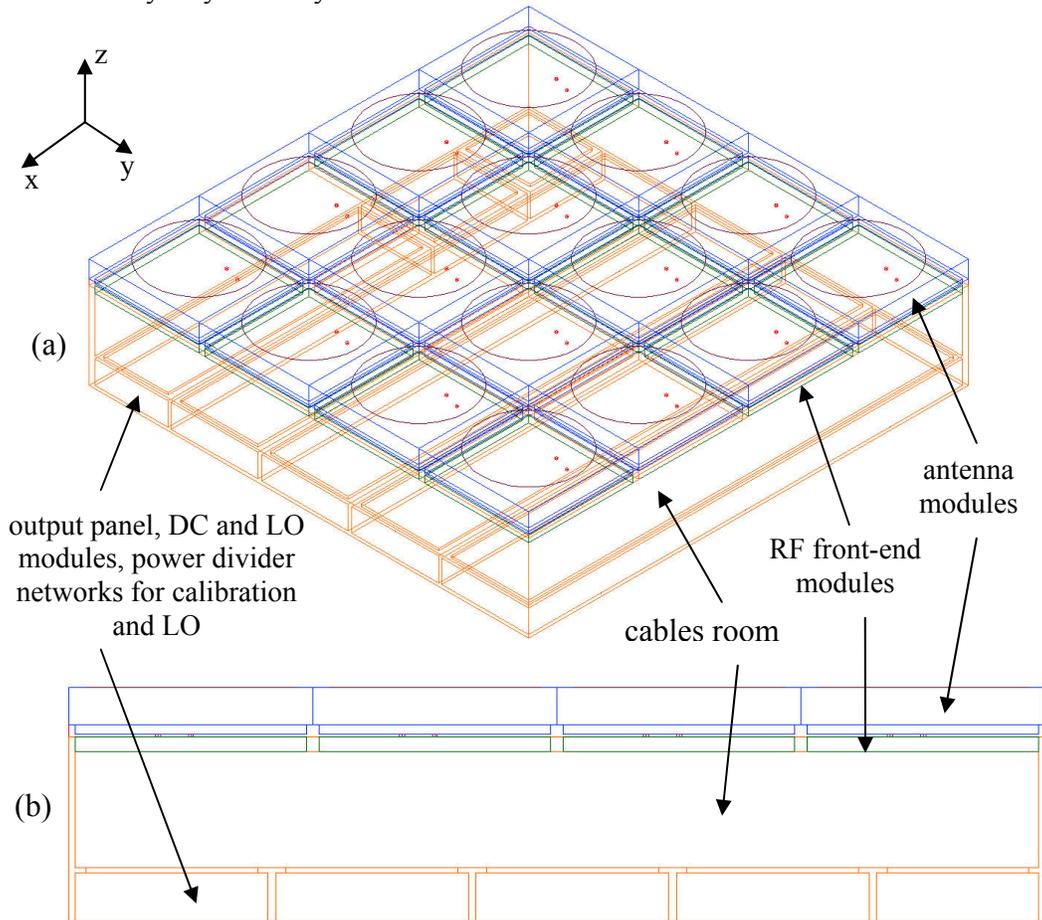


Fig. 2. Antenna array frame structure. (a) Perspective view. (b) Side view.

### 3. Beamforming Simulation Results

In order to verify the array performance, simulations have been carried out for different beamforming conditions and frequencies. The computations have been performed using a simplified model of the antenna to suit the available computational resources. It did not consider the feeding system under each array element ( $180^\circ$  and  $90^\circ$  hybrids). Therefore, the vias feeding the four plates shown in Fig. 1(a) have been directly fed with the appropriate amplitudes and phases.

Beamforming simulations including mutual coupling have been performed. For this purpose, the radiation characteristics for each array element were determined using the Planar EM Simulator from Ansoft Designer<sup>®</sup>. A decoupling algorithm was applied according to the procedure described in [3]. The dielectric layers and ground plane were considered infinite in extension. Further details related to these simulations will be given at the symposium.

Since the array is designed to operate at the entire Galileo band, computations have been performed for frequencies located at the lower and upper parts of it. The first observable effect when working with a broad band is that the directivity, as well as the side lobe level (SLL) related to the main lobe, may vary significantly from the lower to the upper frequencies. For instance, when pointing the main beam to broadside and without applying any SLL suppression, a directivity of 15.65 dBi is observed at 1.19 GHz in contrast with 17.98 dBi at 1.57 GHz. One reason for that is the electrical inter-element spacing, which is  $0.38 \lambda_0$  for the first and  $0.5 \lambda_0$  for the second frequency respectively. Moreover, the simulated gain for an isolated element in the boresight decreases from the upper to the lower part of the frequency band.

Simulations pointing the main beam to an azimuth angle of  $45^\circ$  and different elevation angles with SLL suppression of 20 dB were performed. With this setup, the main beam could only be steered down to an elevation angle of  $47.5^\circ$  at 1.19 GHz due to the physical characteristics of the array. The calculated directivity in this case was 14.09 dBi. All lobe levels are 20 dB under the main beam, as shown in Fig. 3. Under these conditions, the directivity at an elevation of  $30^\circ$ , the minimum acceptable according to the specifications, is estimated to be 12.12 dBi. At 1.57 GHz, the main beam could be steered down to an elevation angle of  $40^\circ$  with a directivity of 15.99 dBi considering the same SLL suppression and azimuth angle as in the former case. However, two grating lobes appear with levels greater than  $-20$  dB, as it can be seen in Fig. 4.

The ratio between the  $E_{\text{right}}$  and  $E_{\text{left}}$  components, observed in Fig. 3 and Fig. 4, shows a reasonably good axial ratio, below 5 dB, for elevation angles down to  $30^\circ$ .

### 4. Conclusions

Beamforming simulations for a broadband antenna array have been presented in this work. The results showed that the radiation characteristics, especially in terms of directivity and grating lobes excitation, may present significant variations within a broad frequency band demanding careful array design.

Grating lobe excitation occurred in both frequencies simulated. In the 1.19 GHz case, the side lobe levels are all below 20 dB the main lobe. However, for other simulated beamforming conditions where the electrical inter-element spacing is bigger, lobes with higher levels have been excited.

Finally, a reasonable performance in terms of axial ratio was achieved.

## References

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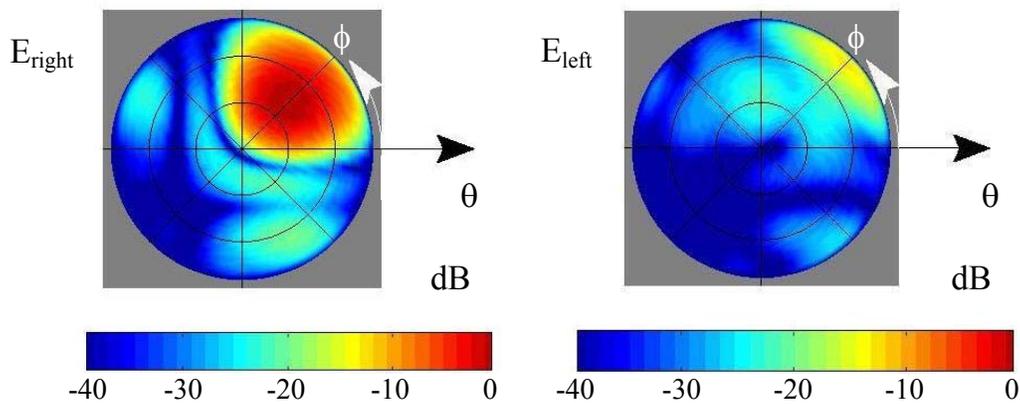


Fig. 3. Normalized Fields radiated by the antenna array at 1.19 GHz.

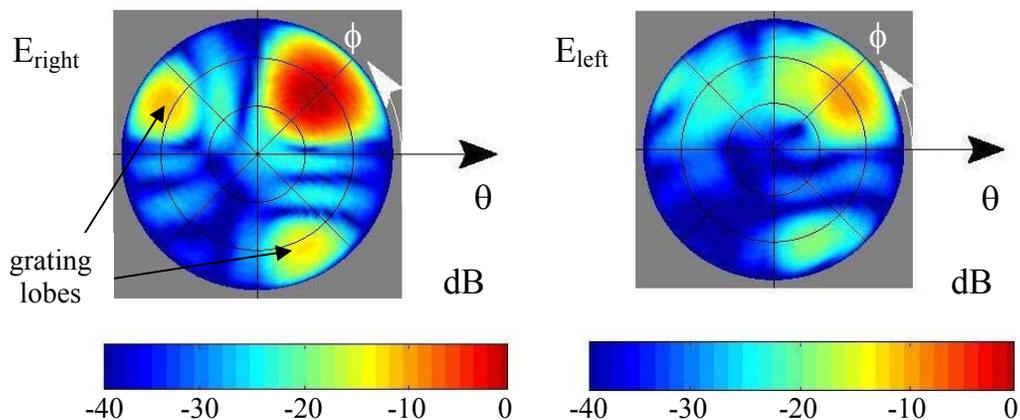


Fig. 4. Normalized Fields radiated by the antenna array at 1.57 GHz.