A Digital Beam-Forming Antenna Module for a Mobile Multimedia Terminal in LTCC-Multilayer Technique

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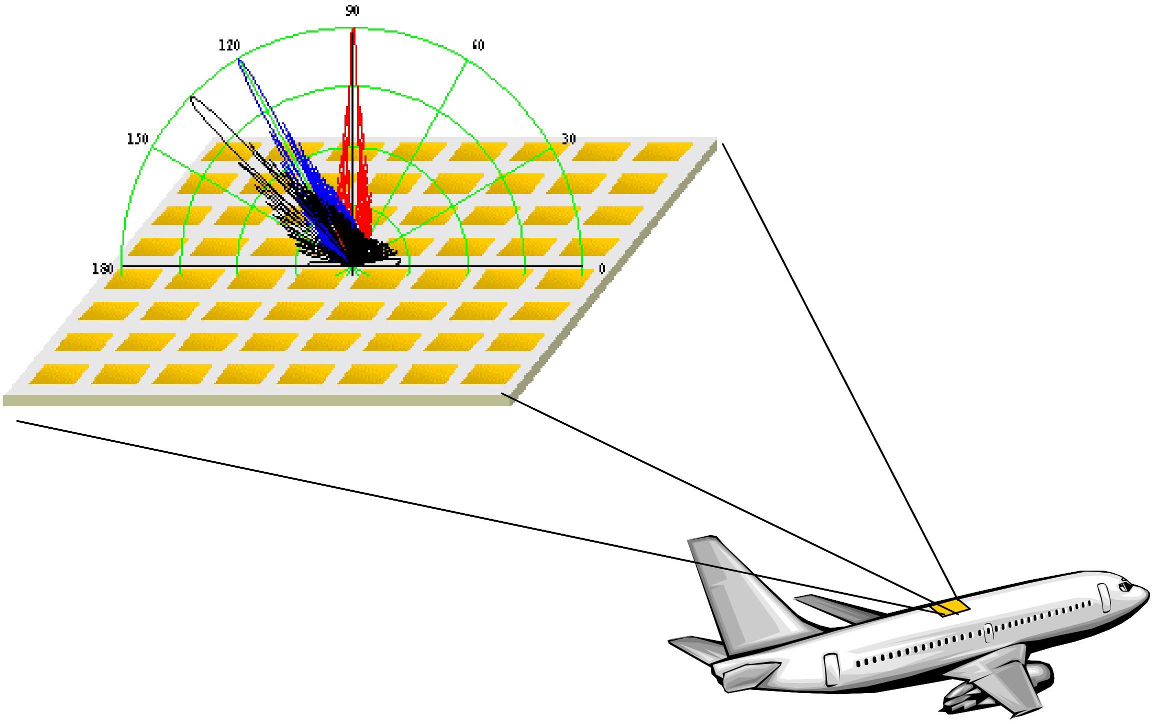
Abstract

The increasing demand for mobile access to fast data services is one of the driving forces behind future broadband satellite systems. In-flight data exchange between aircrafts and satellites for real-time Internet access is a prominent example for this kind of applications. Electronically steerable antennas employing Digital Beam-Forming provide fast and flexible reconfigurability capabilities required for such systems. The antenna module presented here, represents a 4 x 4 patch element array module for the up-link at 29.75 GHz. The polarisation of the antenna is circular, and because of digital beam-forming every single antenna element has to be equipped with its own RF-circuitry (up-converter, etc.). The area for this complex circuitry is however limited to the grid defined by the cell size of one element (about one by one wavelength). In addition, the array requires a complex calibration network. This results in a highly integrated microwave network that can be achieved by means of vertical integration in Low Temperature Cofired Ceramics (LTCC)-Multilayer technology.

Key words: Satellite Antenna, Digital Beam-Forming, LTCC-Multilayer



Introduction

Future broadband satellite communication systems are highly suitable for mobile access to fast data services. Among the many applications, the in-flight data exchange between aircrafts and satellites for real-time Internet access is the most promising one, especially for frequencies up to Ka-band.

For such applications, antennas employing Digital Beam Forming (DBF) [1] are well suited, since they offer fast and flexible beam reconfigurability. The SANTANA antenna concept is based on a 4x4 element array module (transmit and receive modules respectively), which can be used to build high-gain DBF antenna arrays for multimedia applications.

Within the SANTANA projects, highly integrated transmit/receive modules are being developed to demonstrate the technology of Ka-band multimedia terminals employing DBF. Current investigations aim at the realisation of a medium size system to demonstrate the system functionality by establishing communication links between a SANTANA system and mobile platforms.

The antenna concept will firstly be introduced and explained. Some of its key features will be discussed. Thereafter, the multilayer architecture is described in detail, and the RF circuitry is presented. The major RF building blocks are then discussed, and the first prototypes in LTCC are shown. A summary will conclude this paper.

Antenna Concept

Phased array antennas have control over the beam direction and shape by distributing the signal to each of the antenna elements (or a small subgroup), and then controlling phase and amplitude individually. The combination of the radiated fields of each of the array elements results in the desired radiation pattern. Christiaan Huygens' theory on the nature of light with wavelets (representing the elementary radiators) and resulting wave front, gives a very nice visualisation of the basic principle [2]. If all the elementary radiators are excited in phase, the resulting wave front is parallel to the plane in which the elements are arranged, and the wave is propagating perpendicular to it. A phase gradient across the antenna array will tilt the plane of the wave front and thus change the direction of propagation. The application of an amplitude taper on the antenna array allows control of the shape of the beam. Traditionally phased arrays are fed by power distribution networks followed by phase shifters and amplifiers / attenuators for every element to control phase and amplitude respectively. DBF means that phase and amplitude shifts are applied at baseband level using a direct up- or down-conversion of the signal transmitted / received by each element being a patch here. Therefore, each antenna element is equipped with a complete RF front-end, IF circuits, DA- and AD-converters respectively, and dedicated digital logic. In conjunction with fast algorithms for beam forming and beam steering this defines a very flexible and versatile system for broadband mobile communication.

Linear polarised antennas require, besides the standards tracking capabilities, also polarisation tracking for maximum performance. Circular polarisation eliminates the necessity of polarisation tracking in mobile platforms. For the antenna presented in this paper, circular polarisation of the antenna elements is achieved by a hybrid ring coupler [3].The antenna transmit & receive modules consist of 16 (4 x 4) patches each, arranged spatially according to the sequential rotation principle[4].

Multilayer Architecture

LTCC-Multilayer technology has been selected because it provides the necessary degree of vertical integration for the high-density microwave circuit presented here. The area defined by the cell size of one antenna element accommodates the transmit hybrid coupler feed and the complete RF-circuitry thereof. In further layers the complex calibration network is located. Terraced cavities for the antenna patches with conductive walls (via fences) improve the accuracy of the calibration (off-line as well as on-line), and the radiation pattern by reducing unwanted mutual coupling between adjacent patches. A "lossy line termination" for the hybrid coupler provides a good match without having to trim the buried resistors. Furthermore, it is essential to have a low loss material with good microwave performance for this application. Low permittivity is certainly an advantage for microwave antennas.

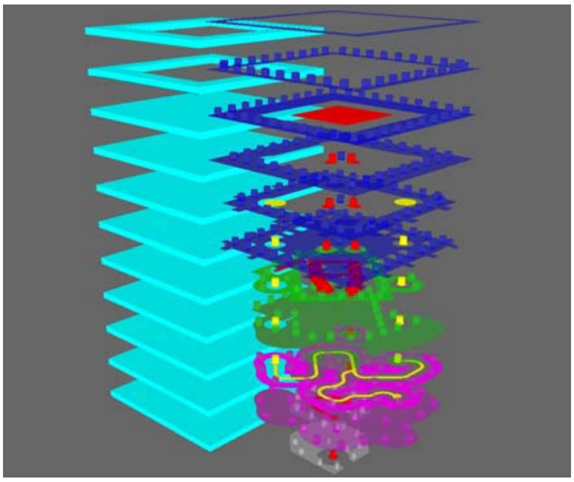


Fig. 1: Exploded view of the 11-layer structure.

Fig. 1 shows the complete architecture of one multilayer antenna element incorporated in FERRO A6S LTCC. The structure consists of 11 layers. Four different functional blocks can be identified: the antenna block is depicted in blue, the green block marks the hybrid ring coupler, the violet parts form a part of the calibration network, and the RF-to-antenna interface is shown in grey. The transmit signal path is marked in red, while the yellow indicates the calibration signal path. In Fig. 2 the 4x4 array, consisting of 16 of such antenna cells, is visualised.

Fig. 2: 4x4 array.

Starting with the top layer, the functional blocks are described in more detail in the following sections.

Antenna Element

One of the special features of the antenna patch element is that it is counter sunken in a cavity, as depicted in Fig. 1 and, in more detail, in Fig. 3. The patch element is operated in a frequency range from 29.5 to 30 GHz. It has two excitation ports. The phase shift between these ports is 90° to ensure circular polarisation. In close proximity to the antenna element there are two via near field probes. These probes are receiving a small part of the antenna signal for the calibration network without disturbing the antenna significantly.

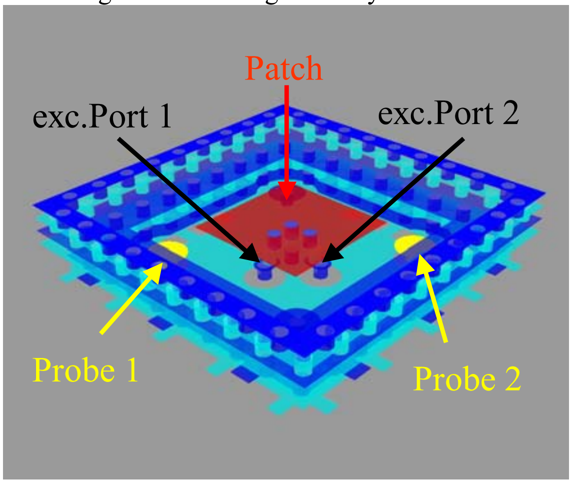


Fig. 3: Patch antenna iso view.

Hybrid Coupler

The hybrid ring coupler is used to excite the circular polarisation of the patch, while absorbing the cross polar components of the antenna. This is an important feature; in particular for antenna arrays with high element count.

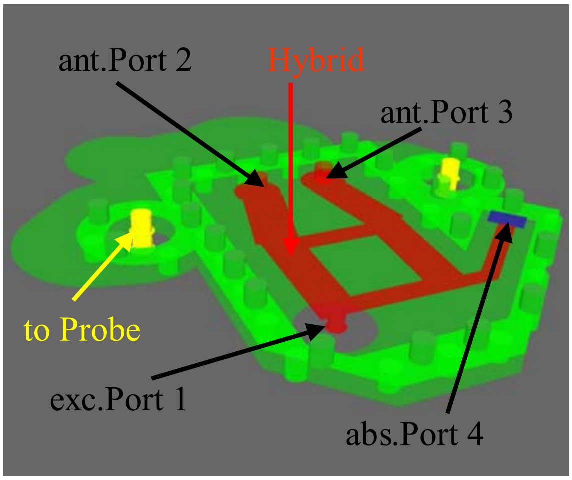


Fig. 4: Hybrid coupler iso view.

The 3D EM simulation model of the hybrid ring coupler within the EMPIRE™ field solver [5] is shown in Fig. 4. Located beneath the antenna block, the hybrid ring is a stripline circuit layout. A good reflection coefficient can be stated in combination with an equal power division between the two antenna feeding ports. Only a negligible amount of power has to be absorbed by port 4, which is matched by a buried thickfilm resistor.

Calibration Network

The complete calibration network of the 4 x 4 array is visualised in Fig. 6 on a larger scale. Fig. 5 depicts the first t-junction of this network. For the calibration process, one single receiver is used for the 16 elements. Due to the symmetrical structure of the network, every calibration probe is connected with equal path length to the receiver. This ensures that every calibration probe signal has identical phase and attenuation.

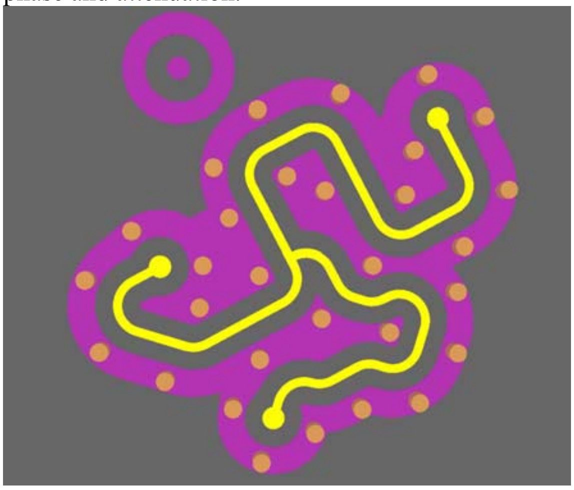


Fig. 5: Calibration network first T-junction.

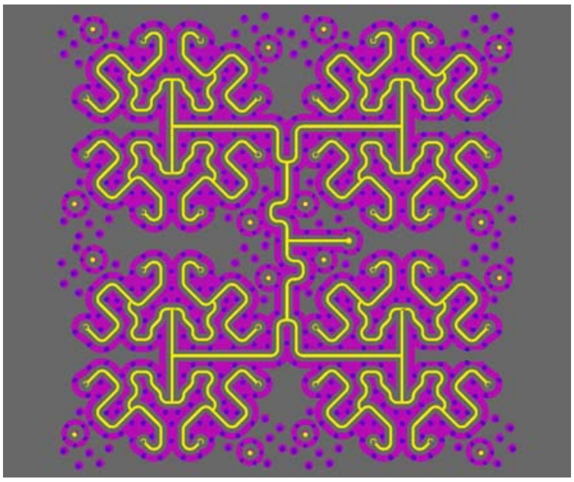


Fig. 6: Whole calibration network for the 4x4 array.

Prototyping

First prototypes using FERRO A6S LTCC have been realised as depicted in Fig. 6. Several test structures like striplines located in different layers, specific transitions, the hybrid ring coupler, and antenna elements with and without the hybrid ring coupler (see Fig. 6 upper half) have been realised for measurements and testing. In the lower half of the picture, the complete 4x4 modules are clearly visible. First measurements show promising results, and indicate that LTCC appears to be a valid solution for this kind of application.

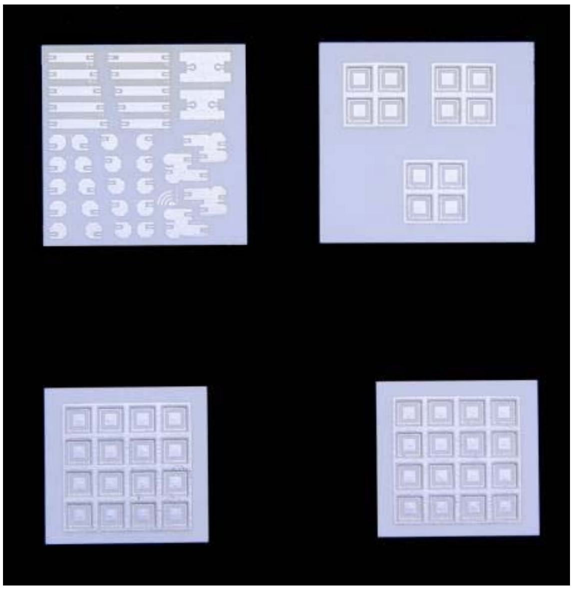


Fig. 7 LTCC Test Tile

Summary

A promising design of a 30 GHz highly integrated LTCC antenna module for digital beam forming arrays has been presented. Simulation results of the different functional blocks and RF-measurement of the module show that the design allows for a good suppression of the cross-polar component of the radiated field.

These are the promising first steps towards a compact low profile module for future multimedia communication via satellite where fast and flexible beam reconfigurability is essential.

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