An Active Phased Array for Mobile Satellite Communication at Ka-Band in LTCC Technology

L. A. Greda*, W. Elmarissi, M. V. T. Heckler, and A. Dreher

Institute of Communications and Navigation
German Aerospace Center (DLR), D-82334 Wessling, Germany
E-mail: Lukasz.Greda@dlr.de

Introduction

To transfer broadband services to mobile users by satellite communication a large bandwidth is required. Since the spectrum at lower frequencies is already densely occupied with different services, free broad frequency bands can be found only at Ka-band or at even higher frequencies. However, in this case a high antenna gain is necessary to compensate for the free-space loss. The user terminal antenna should preferably have low profile so that it can be conveniently mounted on e.g. an aircraft, ship or vehicle. The aerodynamic profile of reflector antennas usually is too high for this purpose. Lower profiles can be achieved with antennas based on the microstrip array technology. They can be fully electronically steered or offer a combination of electrical and mechanical scanning in elevation and azimuth, respectively. The lowest profile and the best surface integration can only be obtained with fully electronically steered antennas.

Two types of fully electronically steered antennas can be distinguished: digital beamforming (DBF) antenna and phased array. While the DBF antenna is superior to the phased array in terms of pointing and tracking accuracy and the possibility of determining the direction of arrival (DoA), it is also more complex and, for broadband satellite communication, requires processing of data rates that are far too high for today's hardware. By performing beamforming in analog domain, the phased array needs to process only a tiny part of the data rate of the DBF antenna and, therefore, this type of antenna seems to be the best choice for affordable broadband mobile satellite communication for the near future.

In [1] a concept for an active circularly polarized phased-array terminal antenna for satellite communication at Ka-band was presented. The main parts of this concept were positively verified and it was shown that the proposed antenna is suitable for delivering high data rates to mobile users. One drawback of this concept is the necessity to feed the RF-signal for each patch through a thick cold plate that is located between high power amplifiers (HPAs) and phase shifters. The cold plate has a thickness of about 5 mm and, therefore, a transition through it has comparatively high losses. Additionally, due to very high packaging density, there is only little place for this transition.

For this reason a modified concept was developed in which both HPAs and phase shifters are placed above the cold plate and only the RF-signal for each module of the array (4x4 elements) is fed through the cold plate. Fig. 1 shows the cross-sectional view of this concept.

For the fabrication of the proposed antenna, LTCC technology was chosen. It offers several advantages e.g. low cost in mass production, high number of usable signal

978-1-4244-3647-7/09/$25.00 ©2009 IEEE

layers and ease of fabricating vias. The drawbacks of LTCC technology include poor thermal conductivity and substrates only with high permittivity.

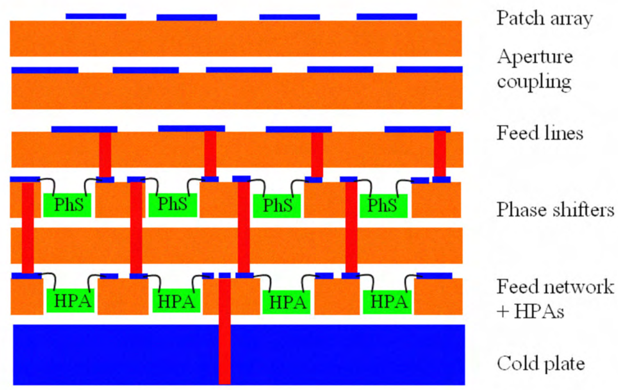


Figure 1: Cross section of the proposed concept in LTCC technology.

New phased array concept

Design of a single element of the phased array

The 3D-view of a single element of the designed phased array is shown in Fig. 2 [2]. The array is supposed to operate in the frequency range from 28.8 to 29.3 GHz. As in the previous concept, the radiator is a square patch with truncated corners for circular polarization. The patch is fed by aperture coupling with a single feeding line.

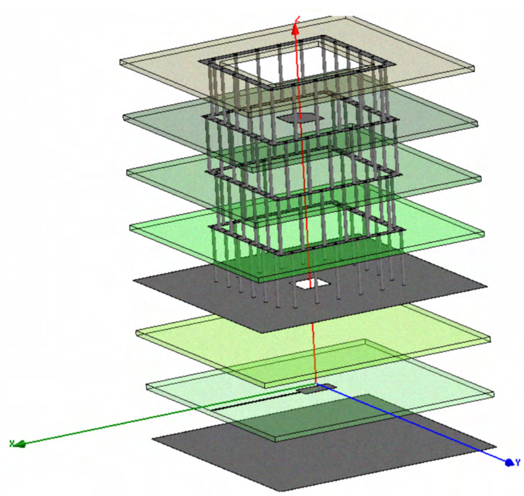


Figure 2: 3D-view of the passive part of the designed patch antenna in LTCC technology.

As a substrate, LTCC tape Dupont 951 AX with $\epsilon_r = 6.8$ was used. To suppress the surface wave propagation, each radiator is surrounded by a shield [3] which aims at preventing coupling between adjacent radiators in the array. The shield consists of horizontally placed square frames on different layers that are vertically connected (short circuited) by metallic vias. It extends from the ground layer, where the slot for aperture coupling is located, to the top layer (see Fig. 2).

Design of the whole array

One disadvantage of the previous concept [1] is the necessity to transmit the signal for each radiating element through the thick cold plate located between the phase shifters and the amplifiers. In the new concept, only the signal that feeds the whole module of 4x4 elements needs to pass the cold plate. Then, this signal is distributed to a layer on which power amplifiers are located (see Fig. 1). Since the amplifiers are soldered to the cold plate and there are less cut outs in the cold plate than in the previous concept, cooling of the antenna is also much easier and can be done e. g. with the help of heat pipes.

Because power amplifiers are located before phase shifters, their maximal output power is limited by the maximal input power that can be handled by the phase shifters. For the 5-bit phase shifters TGP2100 EPU from TriQuint, the maximal input power is 100 mW and, therefore, the power amplifier CHA3092 from UMS with 100 mW output power was chosen. The selected amplifier requires only two 100 pF capacitors and, contrary to the amplifier used in the previous concept, suits in the tiny space that is available for each radiating element (5.3 x 5.3 mm^2).
It is a big challenge at higher frequencies to lead a signal from one layer to another with low insertion loss. For better leakage suppression quasi coaxial transitions consisting of a signal via surrounded by grounds vias [4] were used.

Results

To start the validation of the proposed design, a single passive patch antenna was manufactured. Fig. 3 shows photographs of the top and the bottom layers of the fabricated structure. Not only the single patch antenna but also the quasi-coaxial transitions that are used to lead the signal between different layers of the phased array are fabricated. The transitions are located on the rear side of the structure and should not influence the behavior of the antenna.

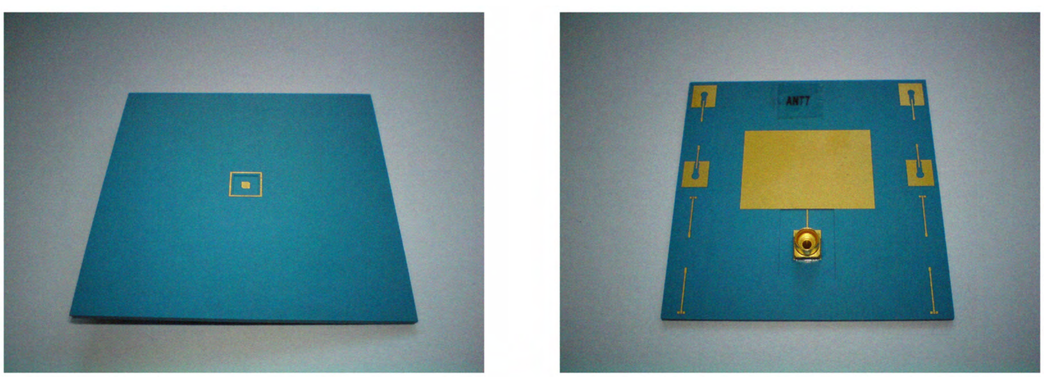


Figure 3: Photographs of the fabricated structure.

Fig. 4 depicts the simulated (using Ansoft HFSS) and measured return loss for the fabricated antenna with and without connector. The reflections introduced by the connector were removed by means of time domain gating. Both measured and simulated results are below -15 dB in the desired frequency range. Fig. 5 shows the comparison between the measured and simulated radiation patterns of the antenna at 29.0 GHz. The ripples in the radiation pattern that appear especially in the plane $\phi = 90°$ are probably caused by the radiation of the slot and by the propagation of

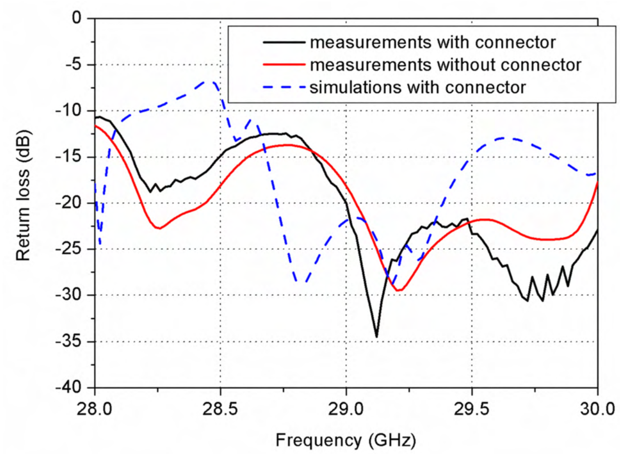
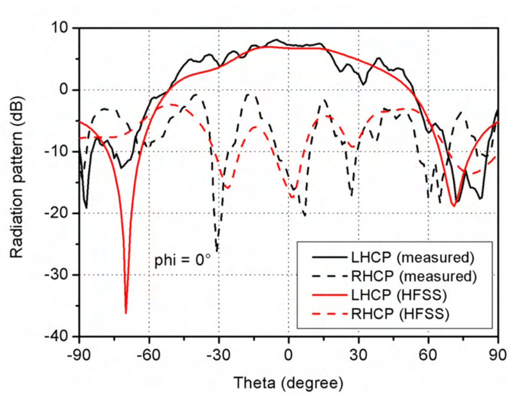


Figure 4: Simulated and measured return loss of the patch radiator.

substrate waves that partially pass the shield that surrounds the patch. Additional investigations must be performed to confirm these assumptions.



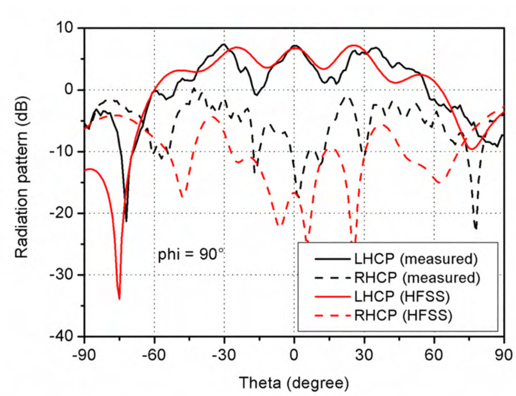


Figure 5: Radiation patterns of the single patch for $\phi = 0°$ (left) and $\phi = 90°$ (right)

Conclusions

A novel concept for an active transmit phased array for satellite communication has been proposed. It improves the main drawbacks of the previous one presented earlier. Important parts of the new concept have been positively verified. Additional validation of the remaining parts and of the whole concept is still to be done.

References

[1] L. A. Greda and A. Dreher, "Tx-terminal phased array for satellite communication at Ka-band", *37th European Microw. Conf., Munich, Germany*, Oct. 2007, pp. 266-269.
[2] J.-C. Rannou, "Development of an active patch antenna array in LTCC technology", *Internal Report DLR-IB 554-07/02*, 2007.
[3] R. L. Li et al., "Radiation-pattern improvement of patch antennas on a large-size substrate using a compact soft-surface structure and its realization on LTCC multilayer technology",*IEEE Trans. Antennas Propag.*, vol. 53, no. 1, Jan. 2005, pp. 200-208.
[4] J. Kim, H.-Y. Lee and T. Itoh, "Novel microstrip-to-stripline transition for leakage suppression in multilayer microwave circuits", *IEEE 7th Topical Meeting on electrical performance of electrical packaging*, 1998.