SMART ANTENNA TERMINAL FOR BROADBAND AERONAUTICAL APPLICATIONS

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ABSTRACT

The growing demand for broadband multimedia services urges the aeronautical industry to provide bi-directional on-board communication services in near future. Today, first aircrafts are already being equipped with the technology to provide internet access for staff and passengers. Up to now, these solutions are developed to operate in L- and Ku-Band, due to the available satellite systems and affordable RF-components in these frequency range. Considering broadband multimedia applications, however, it is obvious that in near future, the technology will have to explore higher frequency regions like Ka-Band, where the bandwidth required can be provided.
Several studies show that for airborne broadband satellite communications, the terminal antenna is one of the key components in the system design. To compensate for the aircrafts movement, the terminal antenna must be steerable to provide satellite tracking. Due to limitations of mechanically steerable antennas, an electronically steerable array antenna based on digital beamforming is considered to be the most promising solution. Still, the development of such antenna arrays in Ka-Band technology faces high demands regarding performance, integration and, last but not least, component costs.
To push the development of this technology, a project called SANTANA (**S**mart **Ant**enna Termi**na**l) was initialised in 2001 with a two years time frame. This project, funded by the German government (BMBF) on behalf of the DLR, aims at developing a sub-module of an electronically steerable, bi-directional satellite terminal in Ka-Band technology.

This contribution reflects the status of the "SANTANA" project. It covers the system architecture, integration tasks, the aspect of the antenna array configuration as well as the principle of digital beamforming.

SYSTEM PARAMETERS

It is a well known fact that currently many planned broadband multimedia satellite systems suffer from postponed time schedules or rapidly changing system specifications due to their uncertain financial status. This makes the definition of reference system scenarios quite difficult. However, as will be shown later, the terminal concept presented here, is flexible enough to be adapted to different scenarios and applications.

Satellite System

Since it is unlikely that any LEO satellite system for broadband multimedia applications will be realised within near future, it seemed reasonable to base the system design on a geostationary satellite system, like EuroSkyWay [1]. EuroSkyWay is aiming at bi-directional broadband satellite communication in the Ka-Band (20/30 GHz) with data rates up to 32 Mb/s. While solutions for fixed terminals already exist, the SANTANA project focuses on the mobile use of the terminal, especially for aeronautical applications.

Polarisation

A mobile terminal antenna, based on a planar array, has to be electronically steerable to allow satellite tracking. Linearly polarised, electronically steerable antenna arrays suffer from the fact that besides beam steering, they also require polarisation tracking. Circularly polarised antenna arrays do not require polarisation tracking, and thus enable a less complex RF-circuitry. For this reason, the polarisation of the SANTANA terminal was chosen to be circular.

MODULAR CONCEPT

The terminal design is based on a modular concept. This means that on a given baseplate, the whole terminal can be assembled from sub-modules as depicted in Fig. 1.

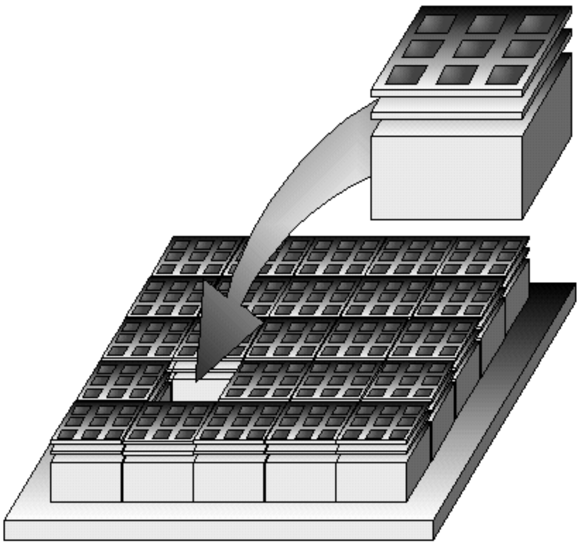

Fig. 1: Modular concept.

Each module comprises a small number of antenna elements (4-by-4 = 16 elements in the current concept) together with their dedicated analog receiver/transmitter circuits up to the AD/DA converters. The baseplate serves several cross-module functions such as digital signal processing for beamsteering and beamforming, power supply, distribution of LO/clock signals, and thermal management for the modules. The modular concept exhibits several advantages over a monolithic array. It offers a higher production yield and facilitates the

replacement of failed antenna channels or modules. Beyond that, the overall antenna size need not be specified from the outset because it is determined only by the layout of the baseplate. This allows the utilisation of the same module type for different applications.
To meet the different requirements for transmit and receive antenna, and due to the high integration density and associated problems of heat removal and interference the transmit and receive part of the terminal have been separated into different modules.

DIGITAL BEAM FORMING

The beam of an antenna array can be steered and formed electronically by applying different amplitudes and phases to the antenna elements. Traditionally, this task is performed by programmable attenuators and phase shifters connected to every single element.
In contrast to this, Digital BeamForming (DBF) is based on a direct up- or down-conversion of the transmitted or received signal at each antenna element. Fig. 2 depicts the principle of digital beam forming for the receive configuration. At each antenna element, the RF signal is converted into two streams of binary baseband signals representing I and Q channels. These digital baseband signals represent the amplitudes and phases of the signals received at each element of the array[2] [3].
The major advantage of digital beamforming is that once the RF information is captured in the form of a digital stream, it is possible to apply a multitude of digital signal processing techniques and algorithms. This allows a high flexibility in the generation of the array pattern. For example, it enables the suppression of sudden interferences or the generation of multiple beams for satellite handovers. Considering the transmitting scenario, moreover, the array pattern can be adapted to a fixed envelope for the antenna pattern prescribed by regulations.

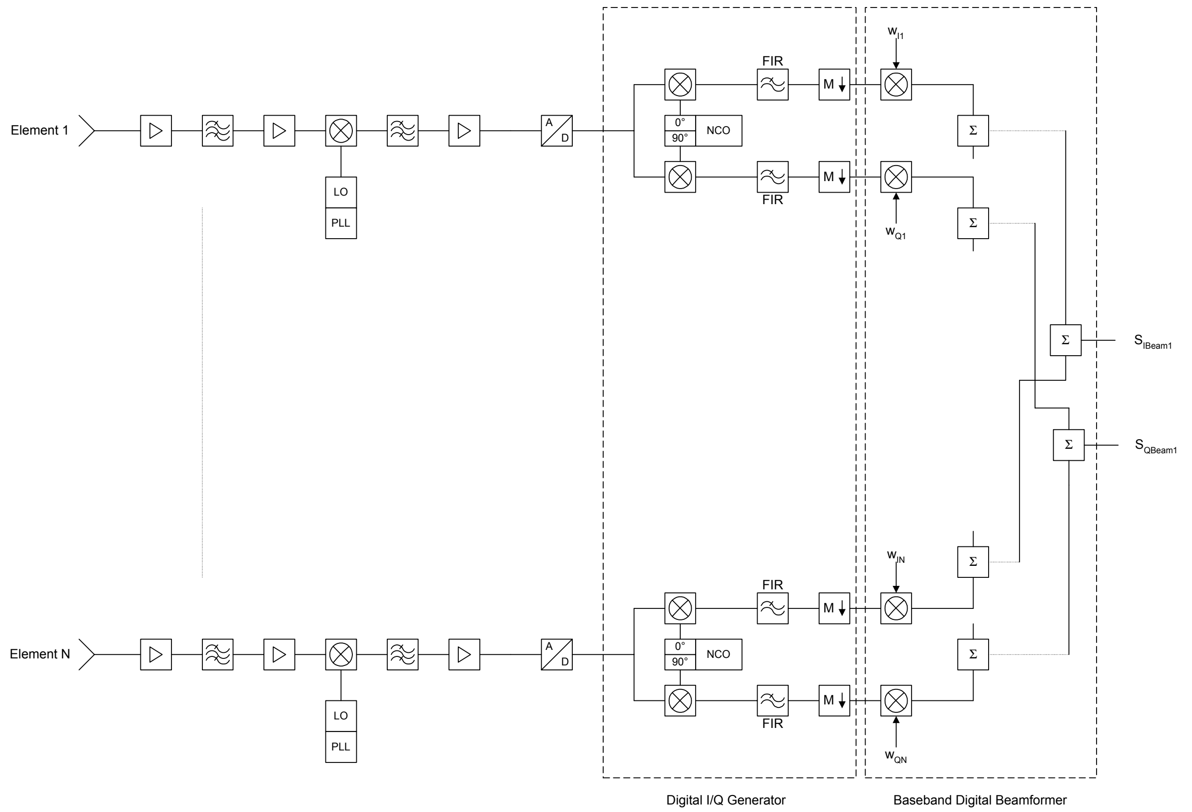

Fig. 2: DBF concept with digital I/Q generation.

ANTENNA DESIGN ASPECTS

The design of the transmit and receive antenna module is driven by different criteria: For both antennas, antenna gain and axial ratio are main design aspects, since in the transmit scenario, the output power needed to achieve a given EIRP (Effective Isotropic Radiated Power) level is limited by thermal dissipation aspects, and in the receive case, a minimum signal to noise ratio has to be guaranteed. For mobile terminal applications, in addition, a minimum gain has to be guaranteed over the defined steering range. Furthermore, for the transmit antenna, the antenna pattern has to fit to a defined envelope prescribed by regulations [4]. The radiation pattern of the receive antenna, in contrast, is driven by the maximum allowed noise level. The separation of transmit and receive part enables different concepts for the transmit and receive antenna.

Transmit Antenna

For the transmit antenna, a microstrip fed patch antenna element with truncated corners, operating at 29.5 to 30 GHz, serves as basic element. This element type only requires a single substrate layer, thus providing low cost and easy manufacturing of the antenna array. The antenna layer is mounted on a thick metal plate as shown in Fig. 3. On its backside, this metal plate supports the RF-layer. A dielectrically filled circular waveguide provides the interface from the RF-layer to the antenna layer using twin slots in the ground plane as field coupled transition to the microstrip lines.

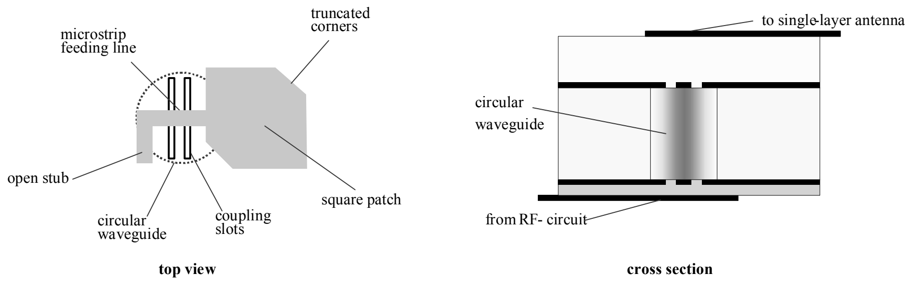

Fig. 3: Patch element with truncated corners and waveguide interface.

The antenna elements are sequentially rotated to achieve better polarisation performance of the complete array. To avoid grating lobes, the element distance is chosen to be half a wavelength. Since the array design is based on the digital beamforming concept, the phase and amplitude of each antenna element can be set digitally. The phase shift required for the sequential rotation of the elements as well as the for beam scanning can therefore be provided without any special feeding network. Fig. 4 shows the configuration of 2×2 sequentially rotated elements.

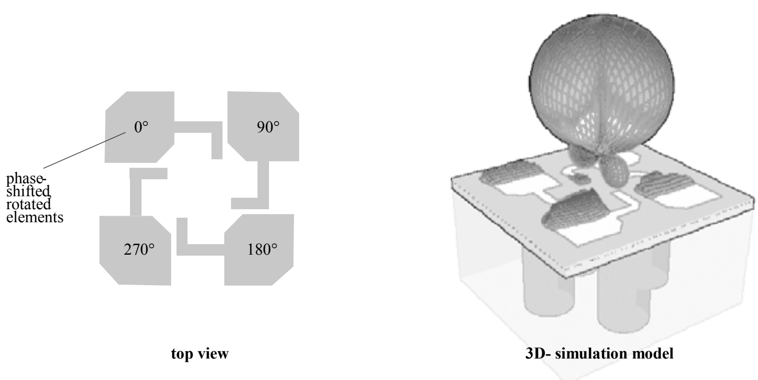

Fig. 4: Sequential rotated elements.

Receive Antenna

The basic element for the receive antenna is a linearly polarised patch operating in the frequency range from 19.7 to 20.2 GHz. It is fed by an arrangement of a circular waveguide with two slots (Fig. 5). A thick metal plate as ground plane is inevitable for heat dissipation, since the package density is very high and LNAs exhibit a very low efficiency in this frequency range.

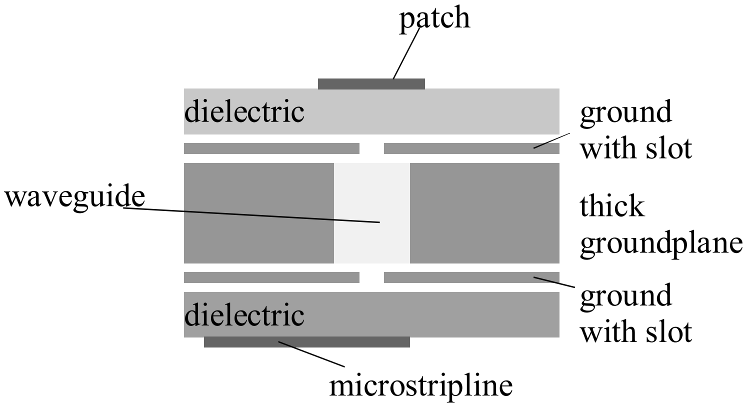

Fig. 5: Cross-section of single antenna element.

To obtain circular polarisation, the linearly polarised single elements are arranged in a sequentially rotated way (Fig. 6a). A modified subarray and the additional rotation of subgroups as shown in Fig. 6b are used to reduce the high grating lobe in the cross-polar component that appears when the beam is scanned away from boresight direction [5]. In this way, a suppression of more than 10 dB can be achieved.

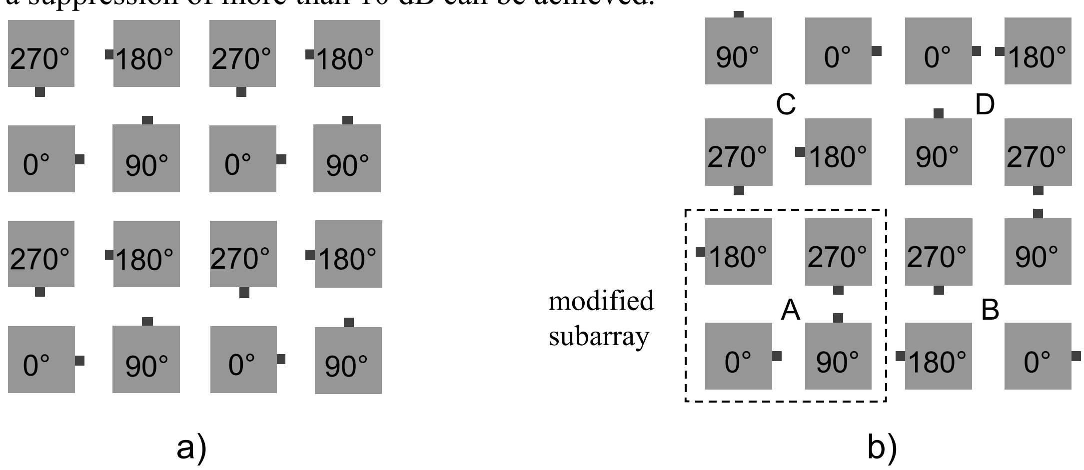

Fig. 6: a) 4x4 array with sequential rotation. b) Sequential rotation applied to modified subarrays.

ARCHITECTURE AND INTEGRATION

Fig. 7 depicts the module construction schematically. The antenna substrate carrying the microstrip patches and the frontend substrate for the Ka-band part of the electronic circuitry are bonded to either side of a thick brass plate. This configuration, with the antenna elements and the associated electronic circuitry mounted in parallel layers, is commonly referred to as *tile* configuration. The brass plate serves different purposes: it provides mechanical rigidity for the module and works as a heat spreader to remove heat from the active circuitry. At the same time it acts as an integral waveguide manifold, to interconnect the antenna elements and the electronic circuits.

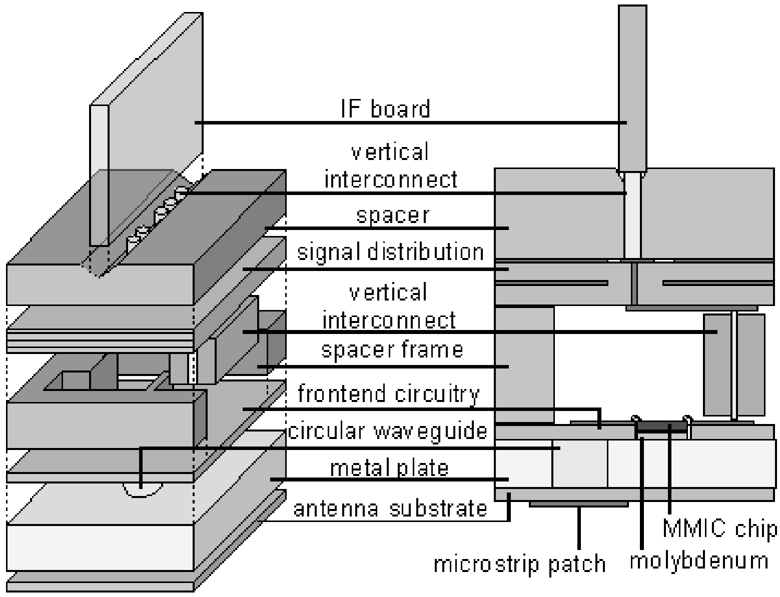

Fig. 7: Schematic view of the module construction (only one element channel shown).

A spacer frame provides cavities for the chips and separates the frontend substrate from a distribution manifold board, which routes DC supply power, LO signals, and IF signals to or from the frontend circuits. The frame accepts vertical interconnectors, such as elastomeric connectors or fuzz buttons to provide a solderless interconnection suitable for DC as well as for microwave signals. These connectors will allow the module to be disassembled for rework or repair or rework. In contrast to the *tile* configuration of the Ka-band part, described above, the IF boards are mounted perpendicularly with respect to the antenna surface and frontend substrate, resembling a *brick* configuration. The interconnection of the distribution manifold with the IF boards is established over the edges of the IF boards by solderless connectors inserted in a spacer.

The heat management must be handled differently for the transmitter and receiver module. For the receiver forced air cooling will be applied. To this end the cavities for the frontend circuitry provided by the spacer frame are ventilated with cool air supplied through air ducts and controlled from the module baseplate. The exhaust air flows back through the IF boards to still provide some air circulation. The transmitter will be cooled by a liquid cooling agent flowing directly through a single duct in the brass plate carrying the frontend chips. As in the case of the receiver the control and supply of cooling agent is also provided by the module baseplate. This ensures that the heat distribution over the whole array is constant, because the circulation can be adjusted independently.

OUTLOOK

In this paper the concepts of a Ka-band satellite terminal antenna front-end for aeronautical applications has been presented. Currently, first prototype components are designed, manufactured and tested. The fabrication and test of a 4×4-module, which will serve as a technology demonstrator, is scheduled for summer 2003.

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