A Prototype Digital Beamforming Antenna for Future Satellite Communications

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Abstract — **In this paper a fully adaptive digital beamforming antenna system for receiving in the L-Band is described. The system consists of a 25-element planar array for circular polarisation, 25 parallel receiving channels realising a double down-conversion to the base band or a very low frequency, a multiplexer followed by a state-of-the-art A/D-converter-card and a fast PC for the processing of the received signals. This allows the highest degree of flexibility for various tests of different digital beamforming algorithms.**

The different subunits of the array system and the overall antenna system design is explained in conjunction with the special demands due to an application in future satellite communications. The demonstration system is used to obtain experience in digital beamforming technology and to investigate and evaluate different beamforming algorithms. As an additional objective of the work, a performance demonstration in the communication environment of LEO-satellites is scheduled.

I. INTRODUCTION

The application of smart antenna systems in terrestrial communication systems has been emphatically discussed in the past. Possible benefits of this kind of antenna techniques are increased link efficiency, opportunities against multipath effects and interference as well as the possible realisation of space-division-multiple-access (SDMA). A lot of resarch results were presented to show possible improvements in system perfomance in terrestrial communication scenarios based on practical results as well as on theory. However, up to date only a few puplications focus on the application of antenna arrays to satellite systems especially for ground terminals in communication and navigation systems. Nevertheless the practical benefits of beamformed array antennas in the satellite environment are widely accepted [1].

The most promising approach to adaptive beamforming is the use of a digital beamforming (DBF) antenna system. This provides the highest degrees of freedom for beamforming and array signal processing, of course based on a very high expenditure and thus overall system cost. As a result of the recent major advances in the field of monolithic microwave integrated circuits (MMICs) at L- and S-band frequencies as well as for digital signal processing components, the establishment of DBF concepts becomes feasible. The reasonable practical implementation is also closely related to an appropriate packaging and integration technology for active antenna systems.

To address the numerous challenges caused by the discussed antenna technology, we are engaged in a project supported by the DLR in Bonn, Germany, that focuses on the realisation of a fully adaptive digital beamforming system suitable for a future transfer to mobile satellite communications. The primary objectives of the work are obtainment of experiences in the developement and application of digital beamforming systems and the practical investigation and evaluation of the potential performance of different signal processing algorithms. For this purpose we developed a digital beamforming antenna system for reception in the L-Band that is described in detail in this paper. This is done in conjunction with the special demands due to an application in future satellite communication systems. The demonstration system consists of a planar antenna frontend build up of aperture coupled patches and a 25-channel receiver. For data aquisition a multiplexer board followed by a state-of-the-art A/D-converter card in a high performance personal computer was chosen. This allows maximum flexibility for the necessary signal processing during our test phase.

II. PLANAR ANTENNA FRONTEND

The antenna elements are carried out as planar radiators, which are well suited as part of a digital beamforming

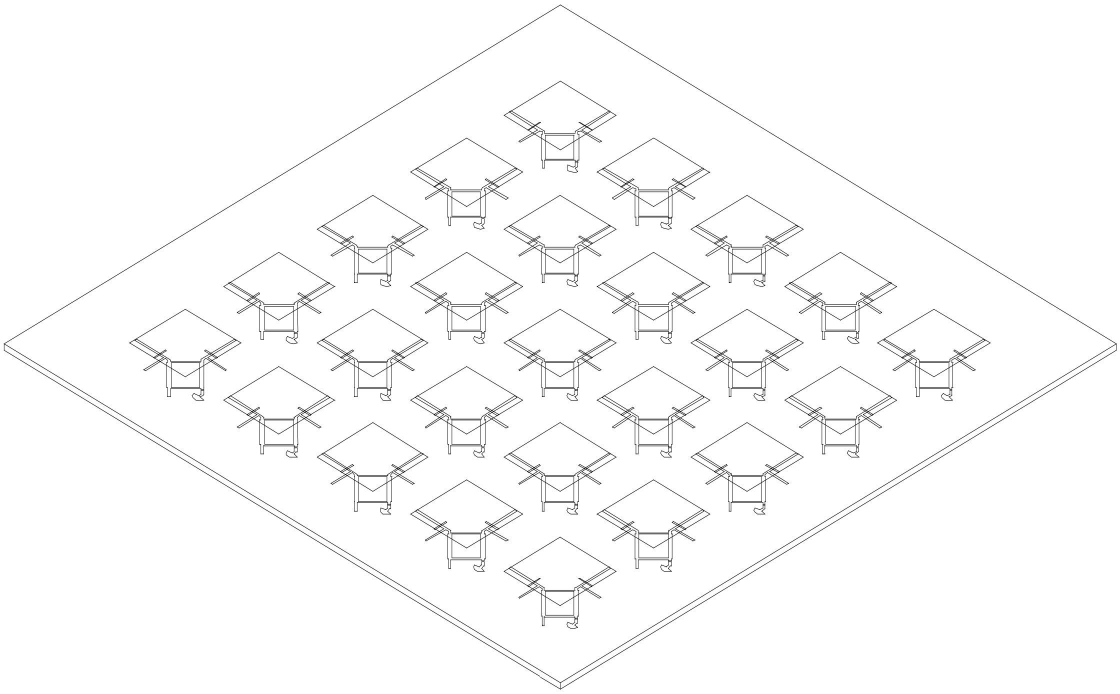

Figure 1: Antenna array setup with aperture coupled patch elements and branchline-couplers for RHCP

antenna, because they can easily be integrated with active elements in a multilayer structure. This forms the basis for future highly integrated circuits to be used in terminals of satellite communication systems.

In order to provide the required RHCP with cross polarization below -15 dB over at least 2% bandwith, single feed circulary polarized radiators can not be used due to their narrow bandwith behavior. In order to minimize the interaction between the feed network and radiator elements an aperture-coupled patch solution was preferred.

To integrate the antenna frontend (Fig.1) in a multilayer structure, each single patch is excited with a perpendicular slot arrangement and symmetric stripline feed-network [2]. The required power splitting and 90° phase shift for RHCP is performed with a 3-dB-branchline-coupler. Number and distance of the patches are determined to achieve a gain of minimal 10 dB at 75° for scan angles up to 60° while keeping grating lobes as low as possible.

At the design frequency of approx. 1.6 GHz, a viable compromise has been found between requirements and expenditure esp. for signal processing and processor performance in designing a 5×5 array with $\lambda_0/2$ distance.

Thus, network and slot radiation at the backside are avoided and a good shielding between patches and RF/digital electronics is achieved. For the suppression of inevitable parallel-plate modes a special technology with no suppression pins around each slot is used [3].

A rigorous optimization was carried out on method-of-moment based software to meet a tradeoff between de-coupling level and VSWR.

Rogers RO 4003 dielectric material (ε_r=3.38) is used with 0.51 mm thickness for the radome and with 1.52 mm thickness for the feed substrate. To achieve the required bandwith Rogers U-LAM 2000 (ε_r=2.5) with 1.52 mm thickness is inserted between the slotted ground plane and the patch radiator.

III. MULTICHANNEL RECEIVER

The complete receiving antenna system including the double-superhet receiver for signal conversion to an appropriate frequency range and the signal processing units is depicted in Fig. 2. The elemental receivers perform amplification and filtering of the received signals in the L-Band followed by the first mixing stage. The LO is provided by an active distribution network which is used to split the signal of a programmable frequency source into 25 parts. At the IF stage of approximately 140 MHz additional amplification with a fixed and a variable gain amplifier is realized. To determine the receiver channel bandwith a 1 MHz-SAW-filter is inserted. The subsequent IQ-mixer can provide the final signal conversion to the base band. This is necessary for

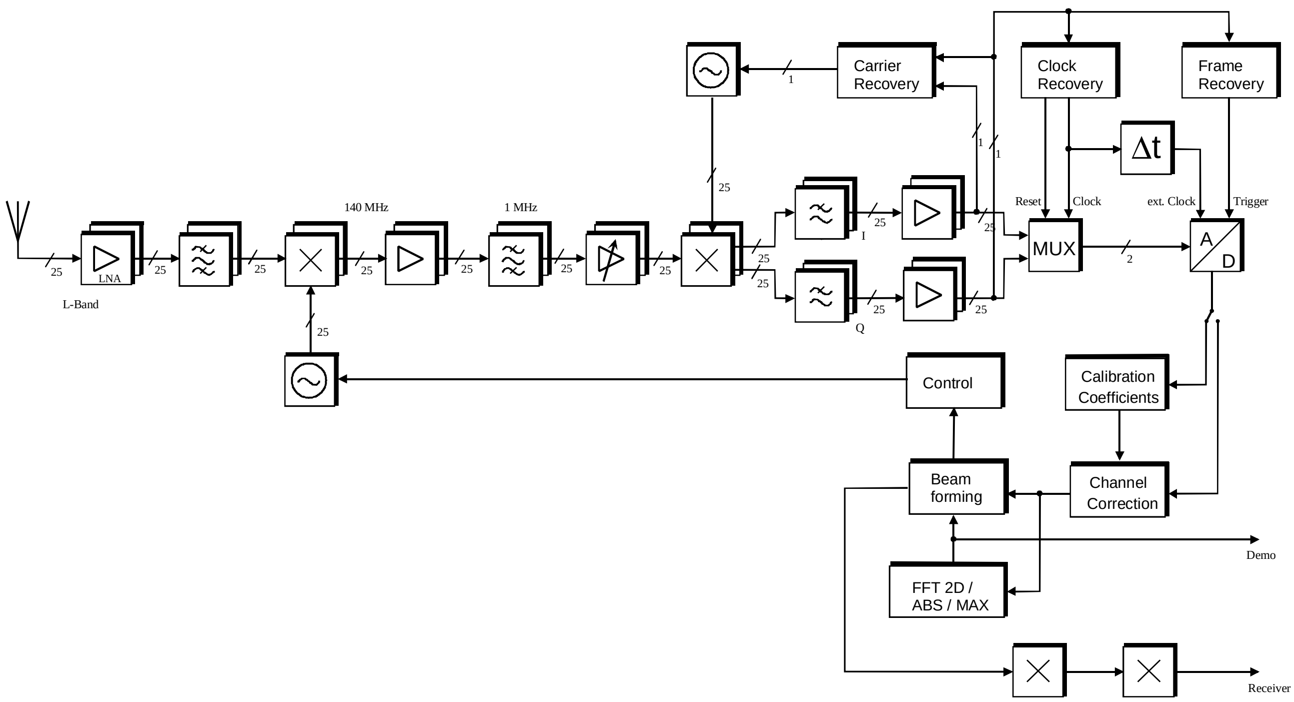

Figure 2: Schematic circuit diagramm of the complete system

an operation in conjunction with the carrier recovery loop, wich is described in further detail in the next chapter. For a rather complete digital reception mode, it can also be used to perform a signal conversion to a very low frequency for an LF-sampling of the signals. The necessary LO signals for the mixing process are again distributed by an active network. To obtain appropriate signals for data aquisition baseband- / LF-amplifiers and low pass filters are implemented at the end of the receiver chain.

The seperate receivers are optimized for an overall noise figure of about 2.5 to 3.5 dB and a gain range between 65 and 110 dB providing enough potential for different scenarios for our test phase. They are also suitable for the conditioning of LEO satellite signals.

For temperature stable and reliable operation each elemental receiver as well as each of the distribution networks features his own active bias network.

A very crucial and sensitive issue during the design and development phase is the packaging technology and the great number of interconnects necessary in digital beamforming systems. The packaging has to provide a mechanical robust housing for the individual subsystem units that also adresses the need for electromagnetic compability of the seperate system parts while the interconnects are expected to not degrade the RF- and IF-performance of the system. To cope with this problem, the elmental receivers are arranged in a honeycomb structure depicted in Fig. 3, providing excellent rigidity and electromagnetic shielding of the components. This also eliminates unwanted mutual coupling of the separate receiving branches.

The active distribution networks for the first and second LO-signals are mounted on one side of the structure. The feeding topology is divided into 5 strips, each carrying a distribution network for the first and the second LO. The strips for each row are feeded by the LO sources succeded by predividers. This separtion was chosen to account for an easy system setup and service purposes. The planar antenna frontend is arranged on the opposide side of the structure. The interconnects on both planes are realized by special modified SMB-connectors which inherit a good signal performance up to a few GHz. Although the

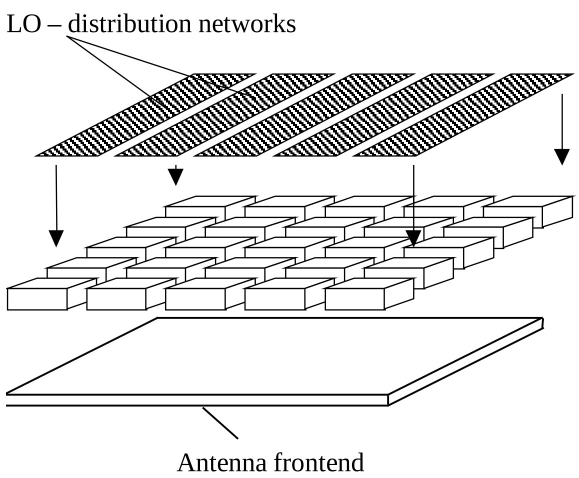

Figure 3: Schematical explanation of the packaging technique

described realisation is a highly reliable and robust solution, additional work concerning a complete integration of the whole system together with the antenna frontend will be very important in the future. This will of course demand for a very expensive and highly sophisticated technology.

IV. SIGNAL PROCESSING UNITS

The system is intended to demonstrate feasibility and performance of adaptive LEO satellite signal reception. Besides complete digital reception an analog carrier recovery operating on a single channel is also provided in order to reduce the problems of handling the large data stream while being still able to demonstrate and obtain experience with the various methods for digital beamforming. For this purpose a single channel is selected for carrier recovery. A costas loop serves to synchronize with the carrier frequency removing the effects of the Doppler shift on the incoming signals by adjusting the frequency of the second LO.

This procedure also enables the system to recover clock rate and frame period of the satellite system. Using this information, those timeslots of the TDMA signals can be selected which are permanently available for down link transmission. A defined time delay, which is realized by a field programmable gate array (FPGA), is used to choose suitable positions of the sampling bursts with respect to the frame period and also to enable a data synchronous digitising of the signals.

Parallel to the single channel carrier- and clock recovery the baseband signals of the 25 antennas are digitised sequentially. A multiplexer connects the inphase and quadrature components of the signals in parallel to two 12-bit A/D converters. The data are stored in a 8 Msample memory at a rate of 1.3 MS/s. As only a part of the frame period of this TDMA system is used for down link transmission, the remaining time can be used for data reduction and for the transfer of the data to the PC-RAM via PCI-bus. The task of the PC microprocessor is to take into account the calibration coefficients of the array, to estimate the directions of arrival (DOA) and to implement the beamforming algorithms.

The calibration coefficients are obtained from an additional calibration procedure, which is necessary to cope with mutual antenna coupling and the imperfections of the array. It is based on the information obtained by the reception of plane waves in a well defined environment. In future extensions these coefficients will be updated regularly by monitoring changes of a test signal which will be fed to the array at certain intervals.

In a first step direction finding will be realized by a 2-dimensional FFT followed by a search for maximum magnitudes of the 2D angular response. The angular information is used for conventional beamforming. In a second step a spectrum of more sophisticated and thus more time consuming methods of DOA estimation and adaptive and optimum signal processing will be evaluated with respect to their effectiveness to produce beams and signal streams of low BER for the given application.

V. CONCLUSIONS

In this paper the realisation of a new concept for digital beamforming antennas for future satellite ground terminals was presented. A complete test system for the L-Band was built that was described in detail concerning the different system parts, the building technique and the signal processing strategy. Crucial system issues are highly integrated components, a high performance digital signal processing and a reliable packaging technology in conjunction with appropriate interconnects. Especially this last topic appears to be one of the major problems for a practical implementation of digital beamforming systems for future satellite ground terminals.

The test phase of the overall system on test ranges and in a LEO-satellite scenario is currently in progress. The results provide new valuable information concerning the problems and the feasibility of different digital beamforming techniques in connection with LEO-satellite systems as well as the application of smart antennas in future satellite communications.

VI. ACKNOWLEDGEMENT

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