Antenna Design and Architecture for RF-MEMS based Electronically Steerable Phased Antenna Array at 9.5 GHz

William Gautier[1], Armin Stehle[1], Christian Siegel[1], Bernhard Schönlinner[1], Volker Ziegler[1], Ulrich Prechtel[1], Wolfgang Menzel[2]

[1] EADS Deutschland GmbH, EADS Innovation Works, IW-SI, 81663 Munich, Germany, +49(0)8960722767, William.Gautier@eads.net
[2] University of Ulm, Dept. Mikrowellentechnik, Albert Einstein Allee 41, 89069 Ulm, Germany, +49(0)7315026350, Wolfgang.Menzel@uni-ulm.de

***Abstract*—In this paper, the first development steps of an RF-MEMS based electronically steerable antenna at 9.5GHz are presented. The architecture of the complete phased antenna and the way the different elements, feed network, phase shifters, and antenna array are integrated in a stand alone demonstrator are described. The design of the 4x8 patch antenna array is presented and the corresponding simulated and measured radiation characteristics as well as the return loss of the fixed beam antenna are shown. A very good agreement between simulation and measurement validates the antenna design.**

***Index Terms*—antenna array, microstrip antenna, phased arrays, phase shifters, RF-MEMS.**

I. Introduction

Modern aeronautic communication applications rely to a large extent on low profile, high efficiency reconfigurable antennas and the need for such antennas is constantly increasing. However, the weight and the bulkiness of mechanically steerable antennas and the relatively low efficiency of phased antennas based on active circuitry such as PIN-diodes or transistors are limiting factors for a wide use of reconfigurable antennas in microwave and millimeter-wave communication front ends. To overcome this situation, some alternative technologies like RF-MEMS and ferroelectric materials are now implemented to realize low cost and low insertion loss phase shifters. However, even if such phase shifters have been presented and show very good performances [1], just few active antennas making use of such technologies have been demonstrated [2] [3] [4].

The antenna front-end presented in this paper is an RF-MEMS based electronically steerable phased antenna array designed for 9.5GHz. It includes a microstrip antenna array and a feed network printed on a soft substrate and four 3-bit RF-MEMS phase shifters realised in silicon technology.

The antenna itself assumes a broadside pattern in both E- and H-planes and will be later on electronically steered in the H-plane. This beam steering capability is achieved by four phase shifters integrated between the antenna and the feed network, which allow for a controlled relative signal delay between the different sub-arrays of the antenna and thus for a control of the main beam direction in the H-plane. A sketch of the proposed antenna is shown in Fig. 1.

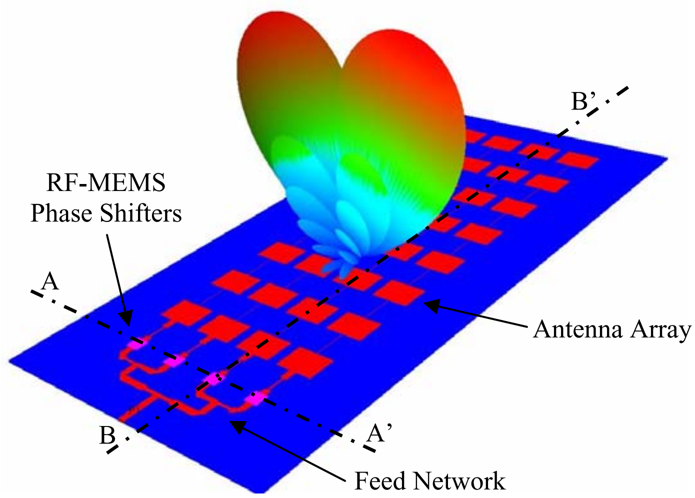

Fig. 1. Principle of the proposed phased antenna array

II. Architecture of the Antenna Front-End

The different elements of the antenna are integrated on an aluminium holder providing the necessary rigidity since the antenna is realised on a soft substrate Rogers RT/Duroid 5880. A side view of the complete antenna architecture is shown in Fig. 2.

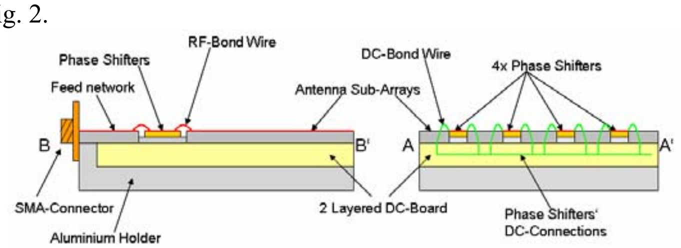

Fig. 2. Architecture of the antenna front-end

The DC-control board is realised on a low cost FR4 substrate. It is a two layered substrate containing the DC-connections necessary for the control of the phase shifters. The DC-signal lines are realised in the middle Cu-layer and the top Cu-layer of the board is almost fully metallised to provide a proper common ground to the different elements realised in microstrip technology integrated on top of it. The feed network, the phase shifters, and the antenna are placed on top of the FR4 board using conductive epoxy and they are connected using RF-bond wires.

The control lines of the phase shifters are connected to a computer controlled switch matrix through a parallel bus. A Labview program implemented on a computer allows for the control of the different phase shifters in order to achieve the desired angle for the main beam direction.

The antenna is fed by an SMA connector. The measured insertion loss of the transition between the SMA connector and the microstrip line on Rogers RT/Duroid 5880 is 0.17dB at 10GHz. The measured S-parameters show that the transition could be used up to at least 15GHz with a measured return loss better than -20dB.

III. Design and Measurement of the Antenna

The antenna and the feed network are realised on a low loss soft substrate Rogers RT/Duroid 5880 (ε_r=2.2, tanδ=0.002). The antenna is formed by four patch antenna sub-arrays connected in parallel by a corporate feed network. Each one of the four sub-arrays is built with eight patches connected in series by a microstrip line. The length of the microstrip line between two neighbouring patches is chosen such that the eight patches of each row are fed in phase, which is a necessary condition for the radiation of a broadside pattern in the E-plane. The width of the microstrip line connecting the patches is 200µm. This width has been chosen as small as possible to prevent the fields radiated at the edges of the patches from being disturbed by the feeding microstripline. A photograph of the realised antenna is shown in Fig. 3.

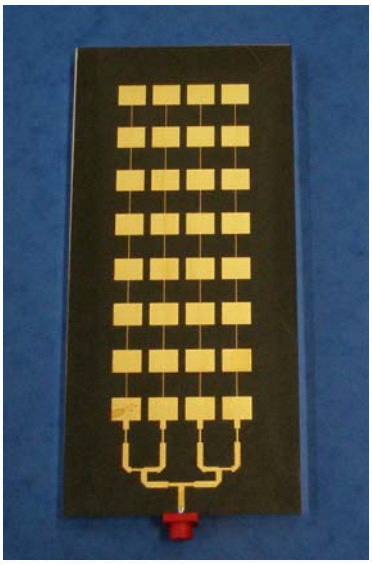

Fig. 3. Photograph of the fixed beam 4x8 patch antenna array

The corporate feed network is designed incorporating asymmetrical T-junction power dividers in order to feed the four sub-arrays with an aperture distribution. This aperture distribution has been computed by an iterative Remez-type algorithm [6] and allows for a reduction of the side lobe level of the pattern radiated in the H-plane. The simulated and measured far field patterns of the antenna in both, E- and H-planes, are shown in Fig. 4 and Fig. 5, respectively.

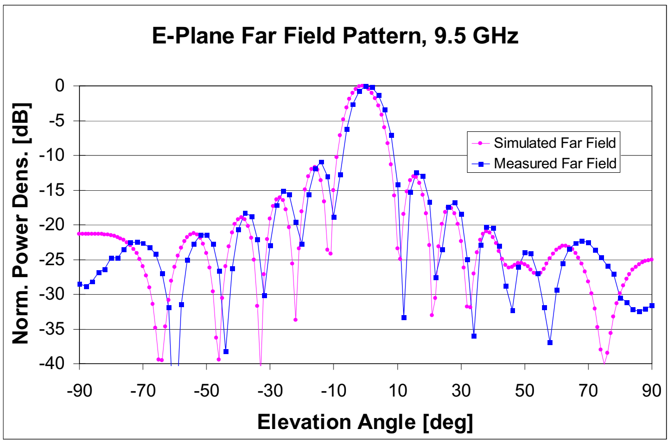

Fig. 4. Simulated and measured far field pattern (E-plane)

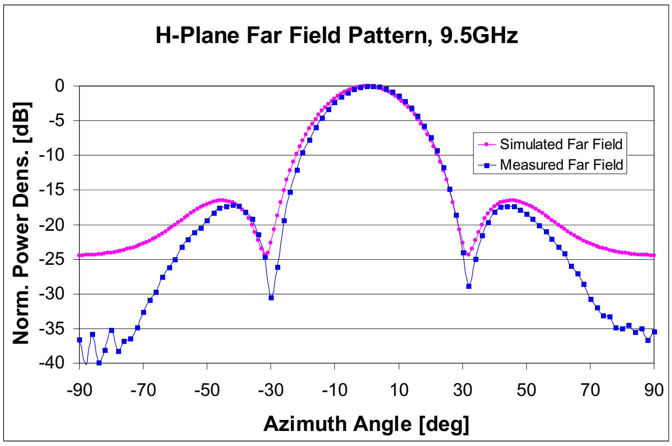

Fig. 5. Simulated and measured far field pattern (H-plane)

They show a good agreement between measurement and simulation. The measured gain of the antenna is 17dB at the design frequency of 9.5GHz. The measured -3dB beam width is 10° in the E-plane and 22° in the H-plane and the side lobe level is better than -11dB and -17dB, respectively. A measurement of the radiation pattern over a larger frequency range shows a satisfactory behaviour between 9.3GHz and 9.7GHz. This bandwidth limitation is due to the principle of the serially fed patch antenna array itself. Above or below the design frequency, the electrical length of the microstrip lines connecting the different patches of each sub-array is not equal to half of the wavelength anymore and the patches are not fed in phase. As a result, the radiated pattern shows an off-axis main beam in the E-plane and the secondary lobe level increases.

The measured and simulated return loss of the antenna is shown Fig. 6.

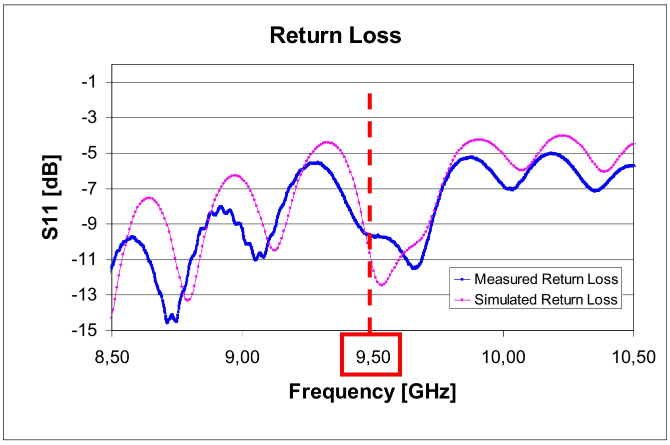

Fig. 6. Measured and simulated return loss of the antenna

It shows good agreement between simulation and measurement. The matching is better than approximately -10dB between 9.45GHz and 9.72GHz, which gives a relative band-width of the antenna of about 2.8%. The measurement of the far field pattern of the antenna versus frequency shows that the off-axis angle of the main beam in the E-plane is smaller than 4° over this frequency range.

IV. The Phase Shifters

The RF-MEMS phase shifters to be integrated between the feed network and the antenna are realised in a microstrip technology on a 300µm thick high resistivity silicon wafer. The phase shifting is achieved with 3 bits: 45°, 90° and 180° all implemented in switched-line topology. The different transmission lines are switched either by two SP2Ts (Single Pole Double Throw) RF-MEMS serial switches for the 90° bit or by two SP4Ts (Single Pole 4 Throw) for the 45° and 180° bits. The parallelisation of the 45° and 180° bits imply the use of a 225° bit to overcome the fact that the two bits can not be added as in a standard serial configuration of the 3 bits. This configuration of the phase shifter presented in [7] allows for miniaturisation of the phase shifter. The overall size of the chip presented here is about 7.5mm x 8.5mm, which is not yet pushed to the limit of the miniaturisation of this phase shifter. A layout of the phase shifter is shown in Fig. 7.

The RF-MEMS switches are realised in the low complexity EADS Innovation Works technology presented in [8]. The basic SPST serial switch, the SPDT switch and the SP4T switch have been processed separately in a first development step. The SPDT switch has been realised using two SPST serial switches. It has then exactly the same performance than the SPST serial switch it is realised with, in terms of matching, isolation and insertion loss. The SP4T switch has been completely redesigned to allow for a higher space efficiency of each switch necessary to get the four switches as close as possible of the line they have to be connected to. The measured performances of these switches at 9.5GHz are shown in Tab.1.

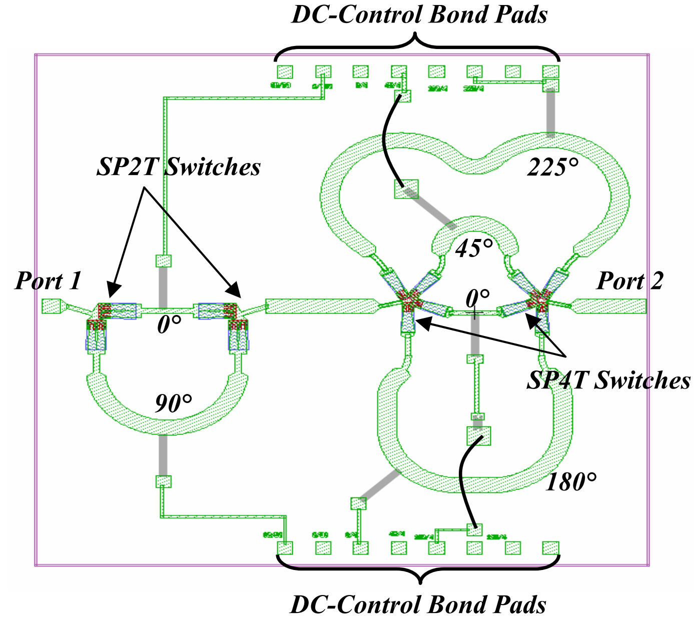

Fig. 7. Layout of the 3 bit RF-MEMS Phase Shifter

	Basic Serial Switch	SP4T
Ins. Loss	-0.2dB	-0.4dB
Isolation	-19dB	-25dB
Matching	-25dB	-27dB

Tab. 1. Measured performances of the basic serial switch and SP4T at 9.5GHz

The insertion loss is equal or better than -0.4dB for both switches, the matching is at least -25dB and the isolation is -19dB or better at the design frequency of 9.5GHz. These performances are really good at the design frequency and remain extremely satisfactory over a large frequency range.

The entire phase shifter has been designed and simulated with the simulator AWR Microwave Office. The simulated insertion loss is better than -1.7dB and the simulated return loss is better than -20dB at the design frequency of 9.5GHz. Thanks to the switched line topology chosen to implement the phase shifter and to the broadband behaviour of the serial switches presented above, the phase shifter shows a satisfying behaviour between 8GHz and 11GHz.

These phase shifters have been processed and will be integrated between the antenna and the corporate feed network in the way previously described in a further development step.

V. Conclusion

In this paper, a low cost and low complexity architecture for an RF-MEMS based phased antenna array at 9.5GHz is presented. In the proposed integration concept, the phase shifters, the antenna, the feed network, and the DC-control board are mounted on a rigid holder providing a stand alone phased antenna array demonstrator. The design of the antenna and the feed network is presented and validated by a very good agreement between simulation and measurement. The measured gain of the antenna is 17dB at the design frequency of 9.5GHz and its relative bandwidth is 2.8%. The processing of the phase shifters has been successfully performed. The next development step will be the assembly of the complete antenna array and the subsequent measurements.

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