Design and Development of an Active Printed Cylindrical Antenna Array for Radar Applications

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ABSTRACT

An active printed cylindrical antenna array for radar applications is designed and developed. The radiation pattern synthesis algorithm is based on the orthogonal method and is capable of handling both single and multi-ring geometries. A "Switched beam" approach is employed for the beam steering, enabled by activating in-turn a different sub-group of antenna elements. The whole system design assumes a separate Transmit (Tx) / Receive (Rx) module feeding each vertical sub-array, a fixed RF-beamformer to shape the beam in the vertical direction and an IF-beamformer to shape the beam in the azimuth direction. The development of the Tx and Rx modules is not considered herein. Finally, commercially available vector modulators are used for the IF beamformer, allowing the digital control of both magnitude and phase of the signals exciting the antenna elements.

INTRODUCTION

Active phased arrays are of primary importance in modern radar applications [1]. Some of their impressive features include the beam pointing agility offered by their electronic scanning, selectable target dwell time and simultaneous tracking of multiple targets. Also, the employment of solid state microwave technology improves the system reliability, previously caused by the low reliability of microwave tube transmitters. Moreover, the MMICs (Monolithic Microwave Integrated Circuits) technology is matured enough to allow the development of Transmit/Receive (Tx/Rx) blocks (modules) that can be placed directly behind the antenna array surface. This is particularly compatible with printed array technology, where the Tx/Rx modules are placed behind the ground plane. Moreover, these antenna arrays can be made conformal to the host platform. The cylindrical geometry is of particular interest, since this is the shape of a lot of airbone platforms (as a whole or parts of them). Also, the cylindrical array provides beam direction agility through a relatively simple switch matrix, as will be described latter. Recognizing, the above important features a European Consortium was formed in the framework of "THALES JP1.3, Conformal Array Antenna Technology" project. This paper describes a part of the research effort undertaken by the Greek group that participated this project, which follows the above described directions.

DESIGN OF THE CYLINDRICAL ARRAY

A detailed system design was carried out aimed at an active conformal antenna array printed on the surface of a cylinder with radius 0.5m. Only azimuthal beam scanning covering an angular section of 120^o was considered, based on a "switched beam approach". The half power beamwidths are specified as $HP_a=6^o$ and $HP_e=30^o$ in the azimuth and elevation angular directions respectively. In order to achieve this beamwidths at least 21 patch antenna elements are required in the azimuth and 4 elements in the elevation direction. When this 4-rings array with 21 elements per ring is printed on the surface of the 0.5m hosting cylinder, the beam maximum will be oriented along the middle (11^{th} element) radial direction. In order to enable the beam steering, 69 elements per ring are considered, as shown in Fig.1. Activating the first 1-21 elements the beam points in the radial direction of the 11^{th} element. Likewise, activating the elements 2-22 the beam points along the 12^{th} element and so forth (the angular difference between successive beam orientations is 2.5^o). In this manner, the beam maximum can be oriented toward any desired azimuthal direction within the 120° angular sector by just activating the corresponding 21 elements using a switch matrix. A pattern synthesis software tool [3] based on the orthogonal method [4] for the design of the cylindrical array is used. In order to achieve the required side lobe level (SLL<-30dB) a non-uniform array excitation is employed, namely both the amplitudes and phases of the currents exciting the patch elements are allowed to vary.

A fixed printed RF beamformer provides the proper excitation amplitudes and phases of 4 vertical patch elements shaping the radiation pattern in the elevation direction. The RF-BFN is designed and fabricated in microstrip technology on a separate substrate to be placed behind the cylindrical substrate on which the patch elements are printed. The RF-BFN and patch antenna substrates will be placed back to back with their ground planes soldered together. According to this approach the 4x69 array is fed by 69 RF-BFNs with each one of them exciting the corresponding 4 vertical elements. The input of each RF-BFN is to be driven by a separate Tx/Rx module and the beam pointing is reduced to the activation of the corresponding 21 successive Tx/Rx modules.

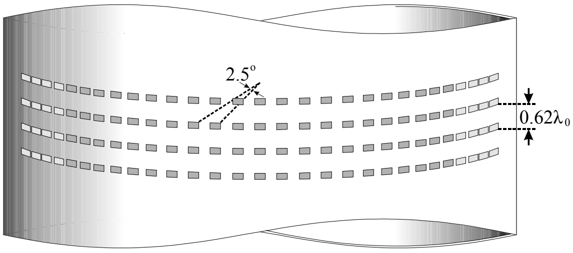

Fig.1. Geometry of the 4-ring x 69 elements cylindrical array.

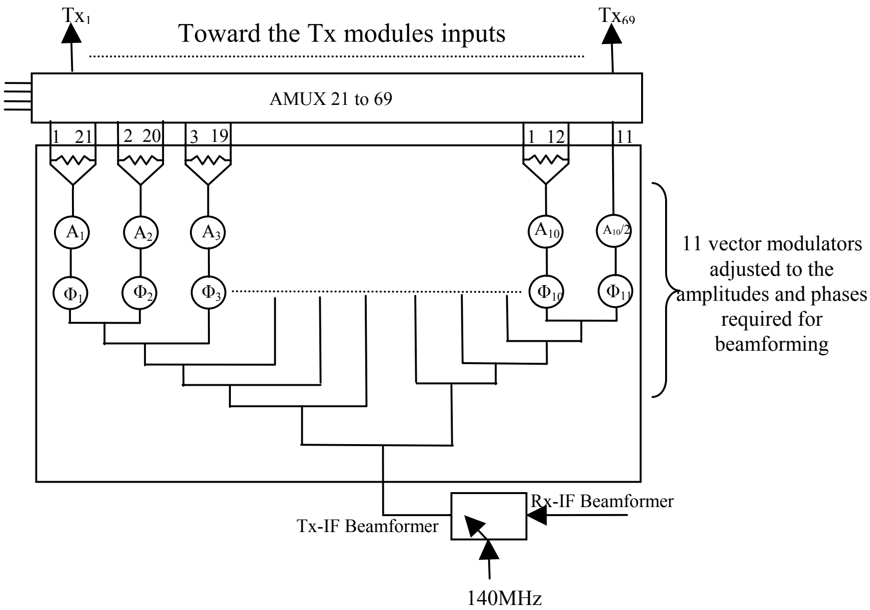

Fig.2. Block diagram identifying the details of the transmit IF-beamformer.

The beam shaping in the azimuth direction can be obtained by applying the proper weighting factors (amplitudes and phases) to each one of the 21 active Tx/Rx modules. It was decided to implement this circuit at the IF stage in order to obtain faster beam steering, while simultaneously the required IF beamformer becomes simpler and easily controllable. A commercially available I/Q vector modulator integrated circuit (specifically the HP2005) is employed for the development of the IF beamformer to be introduced at the input of each Tx and at the output of each Rx module. The block diagram of the Tx IF beamformer is shown in Fig.2. Its 21 outputs are connected to the corresponding 21 active Tx modules through a 21 to 69 switch matrix. A similar topology is adopted for the Rx IF-beamformer. The proper choice of two digital words, to be applied to the I and Q inputs of the vector modulator, provide simultaneously the desired amplitude and phase. In the actual implementation the proper digital words are created and stored in a look up table. A microcontroller selects and applies the proper digital words during the radar operation.

One of the major difficulties resulting from the employment of an IF beamformer is the increased calibration requirements since every Tx/Rx module should be made identical (amplitude and phase). However, this can be overcome if all Tx channels which includes the Tx module and IF vector modulators are made identical. The arbitrary differences between the channels are compensated or absorbed by a corresponding change in the I and Q digital control words. Likewise, the same is applied to the Rx channels in combination with their IF vector modulator.

NUMERICAL AND EXPERIMENTAL RESULTS

As described above the antenna array activated at each instant of time consists of 4 rings x 21 elements in the vertical and azimuth directions respectively. The developed pattern synthesis software tool is applied aiming at a non-uniform cylindrical patch array with SLL<-30dB and half power beam-widths of 30^0 in the elevation and 6^0 in the azimuth directions. The resulting magnitudes and phases of the patch elements excitation currents are shown in Fig.3, while the calculated radiation pattern in the azimuth direction is shown in Fig.4. The latter shows a sidelobe level better than –35dB (below the main beam maximum).

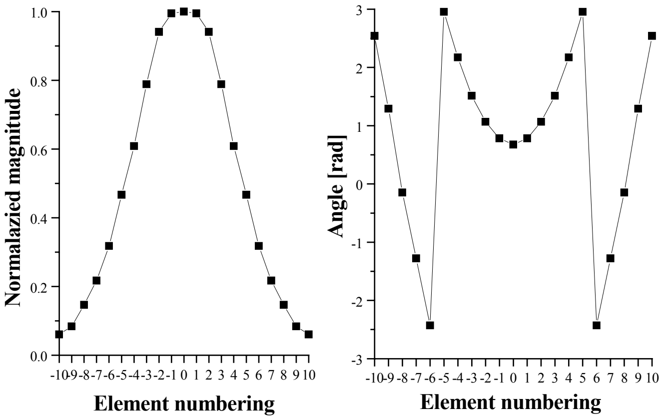

Fig.3. Magnitudes and phases of the currents exciting the elements in the azimuth direction.

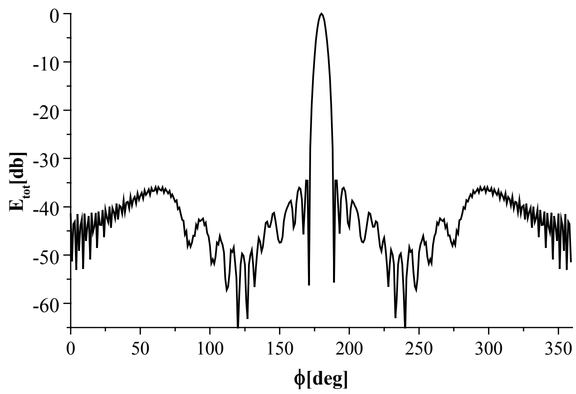

Fig.4. The calculated radiation pattern of the designed array, in the azimuth direction.

As shown in Fig.1, the distance between the patches (centre-to-centre) is $0.62\lambda_O$ *=18.6mm* in the vertical direction and 2.5^0 or $0.727\lambda_O$ *=21.82mm* in the azimuth direction. The normalized excitation current amplitudes for the vertical elements are 1 for the two inner patches and 1.5/8=0.1875 for the two outer ones, while their phases are identical. These are in turn realized with the aid of the printed RF-beamformer (on a Rogers RO-4003 substrate) to be placed back-to-back with the printed antenna substrate. The excitation currents (weighting factors) for the azimuth direction are provided by the if-beamformer, which also offers a system calibration feature. A photograph of a part of the developed if-beamformer is shown in Fig.5. The phase shift and the desired amplitude variation provided by each vector modulator is controlled through two 12 bit digital words applied to its I and Q input channels. The desired excitation amplitudes (dB) and phases (degrees) are achieved with an accuracy better the 1% and 4% respectively. The patch antenna array is also printed on a Rogers's RO-4003 substrate. An example of the measured input impedance of an element to be fed by a Tx/Rx module is shown in Fig.6. The desired 10GHz resonant (operating) frequency with a $50\,\Omega$ input impedance are achieved with high accuracy.

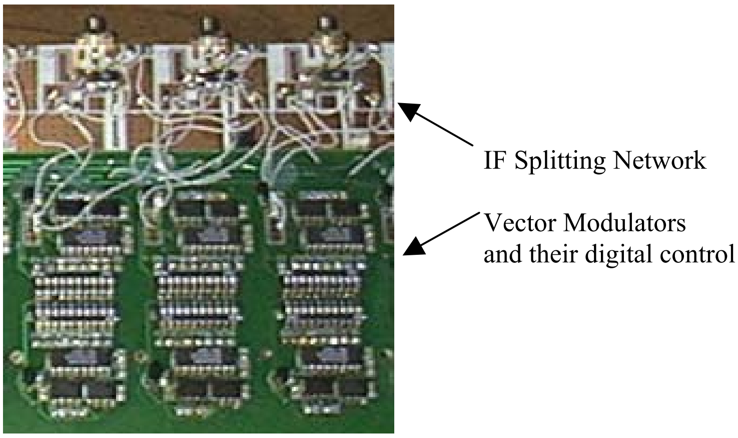

Fig.5. Photograph of a part of the fabricated IF-beamformer.

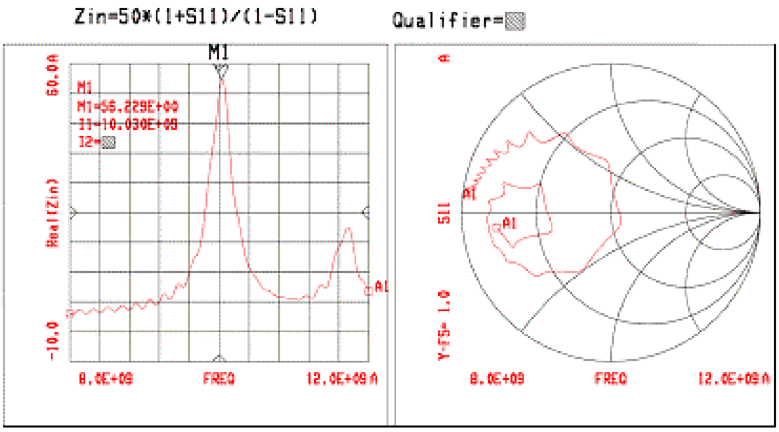

Fig.6. Measured input impedance of a printed antenna element.

CONCLUSIONS

A printed cylindrical phased array for radar applications was designed, fabricated and tested. The orthogonal method is employed for the non-uniform array synthesis. The vertical beam shaping is realized with the use of a fixed-printed RF-beamformer, while the azimuth beam shaping is provided by digitally controlled vector modulators. Also, beam steering is achieved based on a switched beam array approach.

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