Semi-Circular Microstrip Array on a Planar Reflector with Extended Beam-Scanning Range

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Abstract

For wide-angle scanning applications, this contribution investigates a semi-circular microstrip array on a planar metalic reflector. To assess its beam scanning properties, the achievable directivity is determined for different main-lobe directions. For this particular array configuration, the main lobe can be scaned in an angular range of ±82° with a slightly reduced directivity compared to a corresponding planar linear array, indicating an angular scan range of ±50°. As a proof of this concept two array antennas with fixed main-beam directions are realized at an operating frequency of 10 GHz. The experimental results are compared with our simple analytical model using Matlab and simulations using the commercial tool Clementine.

Introduction

Wide-angle scanning capabilities of array antennas are often desirable. E.g. a scanning range of nearly 180° is aimed for a wireless LAN base station array antenna mounted on a wall or a near-range radar sensor in an automotive application. Most beamforming algorithms assume that the elements of an array antenna are all isotropic omnidirectional point sources or sensors. However, in practice, the scan properties of an array of identical elements are determined, among other parameters, by the pattern of the applied array element. To overcome this limitation, arrays of elements with different element pattern may be used, e.g. conformal microstrip arrays. The investigated Semi-Circular Microstrip Array antenna (SCMA) on a planar metallic reflector, as shown in Fig. 1 combines the favorably beam-scanning properties of cylindrical microstrip arrays [1] with the typical microstrip low-cost fabrication and the potential of integration in a planar environment or the possibility of combination with common microstrip-circuit components.

For the presented SCMA, the spacing of the elements along the circumference is chosen to be approximately $\lambda_0/2$ and the cylinder radius is $R=5/3\lambda_0$. Hence, the investigated array consists of nine patch rows, forming the elevation pattern, which is not within the focus of this work. The shape of the azimuth pattern is determined by the excitation of the patch rows. This excitation may be generated by a simple power divider or an adaptive beam-former, depending upon the application.

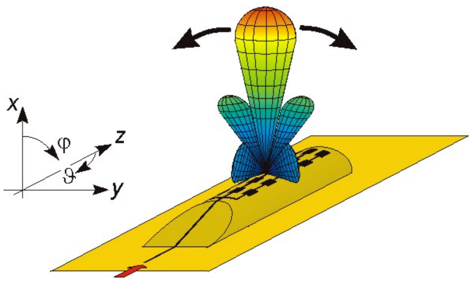


Fig. 1: Semi-Circular Microstrip Array (SCMA) on a planar metallic reflector.

The analysis of microstrip antennas on cylindrical sector multilayer structures with arbitrary sector angles has been presented in [2]. However, in our special case, it is analyzed by a simple analytical model using Matlab and with the commercial simulation tool Clementine, which is applicable for cylindrical single layer microstrip structures [3].

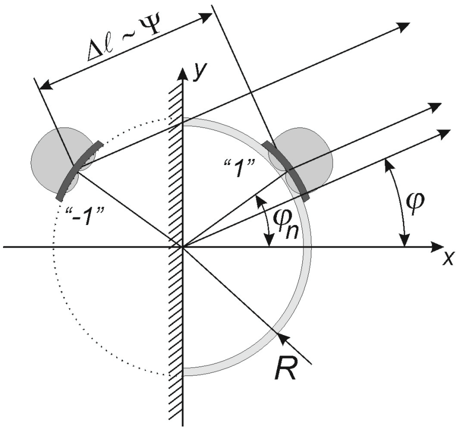


Fig. 2: Patch element on the semi circular surface with the infinite planar reflector and the corresponding image source.

Individual Element Patterns

In conformal arrays no common element factor exists, since the antenna elements do not point towards the same direction. The contribution of each radiator has to be considered individually to the total radiation pattern.

For the azimuth pattern synthesis, an approximation is used for the element pattern, taking into account an image radiator because of the metallic reflector. The reflector is large compared to the wavelength λ_0 and thus, can be assumed as an infinite perfect ground plane. Hence, the pattern of an individual patch at the position φ_n according to Fig. 2 is:

$$\underline{C}_n(\varphi) = \left|\cos\left(\frac{\varphi-\varphi_n}{2}\right)\right|^5 \cdot e^{-j\pi\cdot\cos^6\left(\frac{\varphi-\varphi_n}{2}\right)} - \left|\sin\left(\frac{\varphi-\varphi_n}{2}\right)\right|^5 \cdot e^{-j\pi\cdot\sin^6\left(\frac{\varphi-\varphi_n}{2}\right)} \cdot e^{j\Psi} \qquad (1)$$

with $\Psi = -2\pi \dfrac{R}{\lambda_0}\cos(\varphi)\cos(\varphi_n)$ and $R = 5/3\lambda_0$.

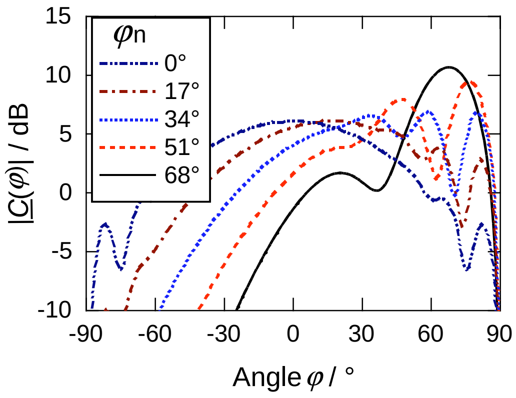


Fig. 3: Modified element patterns for element positions φ_n on the cylindrical surface with a radius R=5/3λ_0.

Fig. 3 depicts the element patterns for the five patches on the upper quadrant (φ_n=0°...68°) of the investigated nine element array. Because of symmetry, the patches on the lower quadrant show the same, but mirrored characteristic.

Beam-Scanning Properties

The excitations for each element, i.e. the weighting vectors for different scan directions can be generated by applying beam-forming algorithms [4]. Fig. 4 shows radiation patterns for different scan directions φ_0 calculated from the corresponding optimized element weighting vectors. It can be seen that scan angles of more than ±80° are possible with side-lobe levels below –15dB.

To evaluate the beam-scanning capability of this array antenna the achieved directivity in dependence of the scan angle φ_0 is calculated and shown in Fig. 5. In addition, the directivity as a function of φ_0 for a corresponding linear array is shown for comparison.

The achived average directivity of the SCMA is about 12.5 dBi within an angular scanning range of ±82°. Assuming the same directivity value, the angular scan range of the linear array is reduced to about ±50°. Hence, for the SCMA, the scan range is extended by 64%, while the mean directivity value is only sligthly degraded by about 2 dB compared to the linear array. Thus, this cylindrical arrangement is particularly well suited for wide-angle scanning applications.

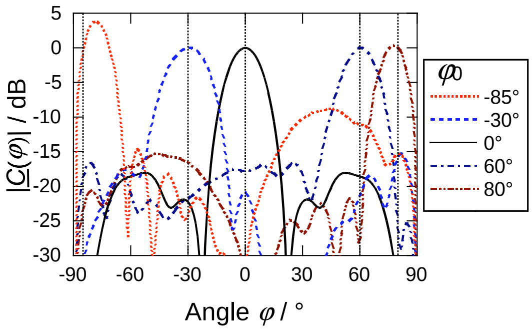


Fig. 4: Total radiation patterns for optimized element weights and different main-lobe directions φ_0.

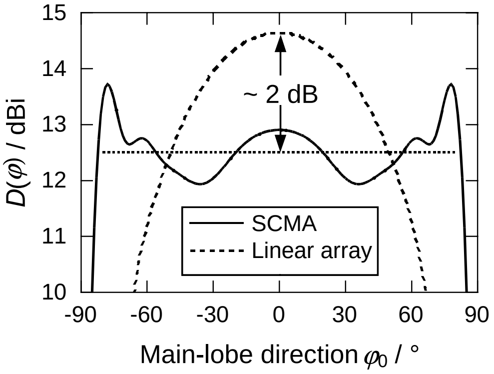


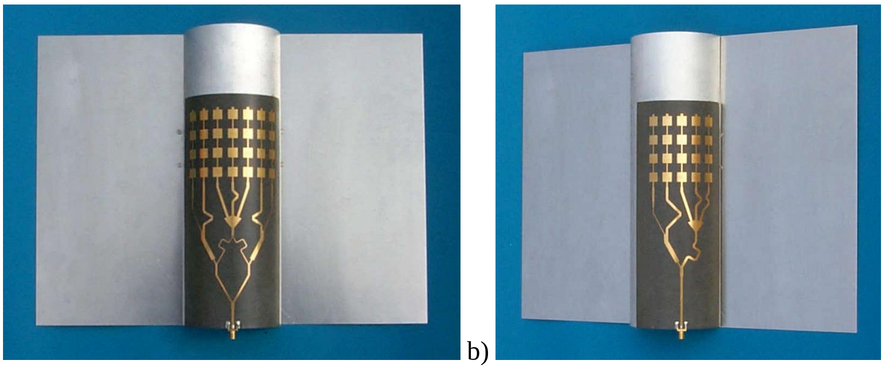
Fig. 5: Directivity for a SCMA on a planar reflector and a linear array.
SCMA: 9 elements, R=1.66λ_0,
φ_n={-68 -51 -34 -17 0 17 34 51 68}.
Linear array: 9 elements, λ_0/2 spacing.

Experimental Results

To measure the directivity in dependence of the scan angle, a digital beamforming receiver has been build up. These measurements are currently prepared and hence, the corresponding results will be presented on the conference. For a first verification of the simulation results, two SCMA configurations with fixed main beam directions φ_0=0° and φ_0=60° have been realized at an operating frequency of 10 GHz. For the antenna substrate we used RT-Duroid 5870 with a thickness of 31 mil. Patch rows with four elements in z-direction (elevation) with a uniform power distribution are used to increase the antenna gain. For the synthesis of the series-fed patch rows, the transmission-line model is utilized.

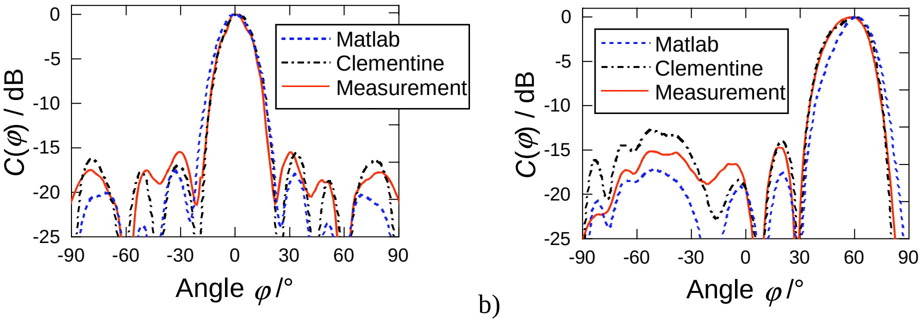
Since the calculated element weights of some patch rows are very smal compared to the maximum weight, only seven instead of the proposed nine patch rows are used in the case of the array with φ_0=0° and only five rows are used in the case of the array with φ_0=60° to minimize the realization expenditure. The desired excitation of the patch rows is provided by suitable microstrip power dividers as shown in Fig. 6.

The experimental results in Fig. 7 exhibit very good agreement with our analytical model (Matlab) and with the MoM-calculation (Clementine). These results validate the made assumptions and our simple analytical model, which allows a good and fast characterization of this special arrangement.



a) b)

Fig. 6: Two SCMA-configurations with feeding network mounted on a metallic reflector ($13\lambda_0 \times 10\lambda_0$) for fixed scan directions a) φ_0=0°, b) φ_0=60°.



a) b)

Fig. 7: Experimental and simulated radiation pattern for the two SCMA-configurations with the scan directions a) φ_0=0°, b) φ_0=60°.

Conclusion

For wide-angle scanning applications we investigated of the scanning capabilities of a SCMA on a planar reflector. For this, the directivity is determined in dependence of the scan angle. The calculations are based on a simple analytical model and an approximation for the element pattern of a single element in the SCMA mounted on a planar metallic reflector. It is shown that the average directivity of this array of nine patch rows is 12.5 dBi, within an angular scanning range of ±82°. Taking this directivity value as a measure, the scanning range of a comparable planar linear array is only about ±50°. Hence, this range is extended by 64%, while the mean directivity value is only sligthly degraded by just 2 dB compared to the corresponding planar array. The simulation results are successfully verified by the experimental data of two realized conformal array antenna configurations with fixed scan directions.

The results show that the SCMA on a planar reflector is particularly well suited for wide-angle scanning and hence, very interesting for many applications in wireless communications and radar sensor systems.

References

[1] Löffler, D.; Wiesbeck, W.: A Comparison of Measured Performance Data for Different Conformal Antenna Geometries. 1st European Workshop on Conformal Antennas, pp. 42-45, Karlsruhe, Germany, October 29th, 1999.

[2] Thiel, M.; Dreher, A.: Microstrip Antennas on Cylindrical Sector Structures. 2nd European Workshop on Conformal Antennas, Le Hague, The Netherlands, April 2001.

[3] Ansoft Corporation: Handbook Clementine V1.0, 1997.

[4] Krim, H.; Viberg, M.: Two Decades of Array Signal Processing Research. IEEE Signal Processing Magazine, July. 1996, pp. 67-94.