An Autonomous Self-Adapting Conformal Array for Cylindrical Surfaces with a Changing Radius

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***Abstract*—Conformal antennas are being used more often in modern wireless communication systems. Because of this increased usage, novel self-adapting arrays have been developed for improving the performance of wireless communication systems that use conformal antennas on changing surfaces. Among the changing surfaces of interest is a cylinder with a varying radius and in this work, the properties of an autonomous self-adapting 4 × 4 conformal array for changing cylindrical surfaces is presented. A sensor circuit is used to measure the radius-of-curvature of the cylindrical surface and this information is used to control phased-shifters in the 4 × 4 conformal array for phase-compensation of the radiation pattern. This array has been denoted as the SELF-adapting FLEXible (SELFLEX) array. Finally, the self-adapting characteristics of the array are validated with measurements and simulations.**

I. INTRODUCTION

Because of new materials and manufacturing techniques [1], antenna designers have been turning to conformal antennas for wireless communication systems. However, the surfaces that the conformal antennas are attached to may change shape due to vibrations, wind or temperature fluctuations [2]. This can have a negative impact on the radiation pattern of the conformal antenna [3]. On the other hand, recent work on SELF-adapting FLEXible (i.e., conformal) arrays, denoted as SELFLEX arrays [3], has shown that phase-compensation techniques can be used to autonomously improve the radiation pattern of a shape changing conformal array. The objective of this work is to develop a new 4 × 4 SELFLEX array for cylindrical surfaces with changing radius-of-curvature values.

II. PHASE COMPENSATION FOR CYLINDRICAL SURFACES

The problem being considered in this work is shown in Fig. 1. The antenna elements located on the cylindrical surface are shown as black dots and the inter-element spacing is denoted as S_z and S_ϕ for the spacing in the z- and ϕ-directions, respectively. The cylinder has a radius of r, is along the z-axis and is non-conducting. Next, a reference plane is defined above the cylindrical surface in Fig. 1. Then, a direction of radiation is defined to be normal to the reference plane and for this work it is assumed that this direction is fixed. Note that the reference plane is shown above the surface for illustration purposes only. It could be defined to be touching the cylindrical surface along a line to give a tangential plane.

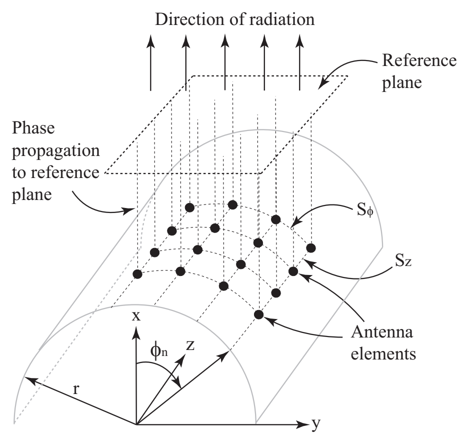

Fig. 1. Illustration of the 4 × 4 SELFLEX array on a cylindrical surface along the z-axis.

One method to achieve a radiation direction normal to the reference plane is to ensure that the field radiated from the antenna elements arrive at the reference plane with the same phase [3]-[4]. To compute the required phase shift that is to be introduced by the voltage driving each element, the distance from each antenna element to the reference plane must be determined. Then, the voltage phase can be advanced by a positive value equal to the negative value of the propagation phase. The distance from each antenna element to the reference plane can be determined by considering a cross-section of the cylindrical surface in Fig. 1 and evaluating the following [3]:

$$\Delta\phi_n^c = +kr|\sin(\phi_n) - \sin(\phi_{n-1})| \tag{1}$$

where r is the radius of the cylinder, k is the free-space wave number and ϕ_n is the angle of the n^{th} row from the positive x-axis. Notice that the value computed by (1) is independent of z, is written in general terms of the cylinder radius and element spacing, and is positive to cancel the propagation phase.

III. MEASUREMENTS AND SIMULATION RESULTS

To implement the phase compensation of (1), the prototype SELFLEX array shown in Fig. 2(a) was manufactured and a main pattern-lobe direction of $\phi = 0$ (i.e., along the x-axis) was assumed. The array had a 4 × 4 geometry of 2.45

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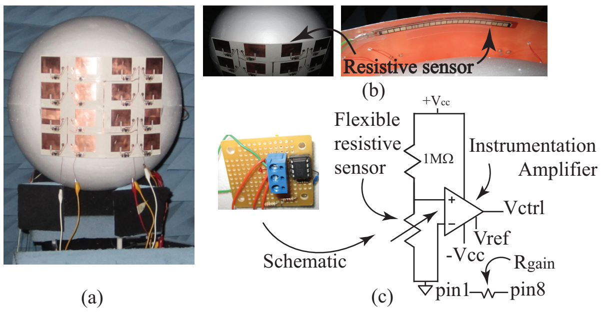

Fig. 2. (a) Prototype SELFLEX array attached along the equator of a non-conducting sphere to work as the shape of a cylinder; (b) top-view of the array and resistive sensor and (c) the sensor circuit (+V_{cc} = 15.0V, V_{ref} = -5.5V = $-V_{cc}$ and R_{gain} = 4.7KΩ).

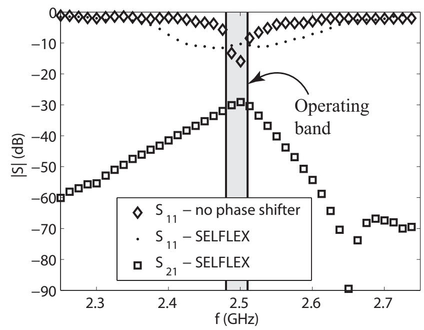

Fig. 3. Measured S-parameter values of the SELFLEX array.

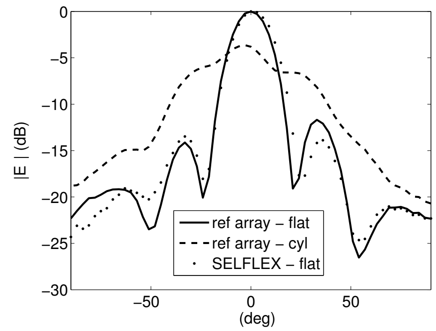

Fig. 4. Uncorrected radiation pattern in the x-y plane at 2.45 GHz for the reference and SELFLEX array.

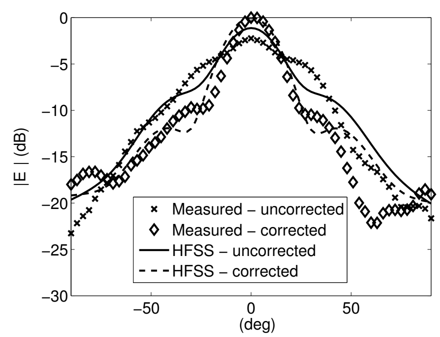

Fig. 5. Uncorrected and corrected radiation pattern in the x-y plane at 2.45 GHz for the SELFLEX array.

GHz microstrip patches designed for a 0.508 mm thick Rogers 6002 RT/duroid substrate [5] (ε_r = 2.94, tanδ = 0.0012). The design also consisted of the resistive sensor shown in Fig. 2(b) and the sensor circuit shown in Fig. 2(c). The inter-element spacing was S_z = 0.6 λ and S_ϕ = 0.45 λ and the radius of the non-conducting styrofoam sphere was r = 20.32 cm. It should be noted that the prototype was placed along the equator of the sphere to conform to the shape of a cylinder. The sensor circuit was used to measure the curvature of the surface, compute (1) and control the phase shifters (part number: HMC928LP5E [6]) for phase-compensation. The SELFLEX prototype was then placed in a fully calibrated anechoic chamber and measured.

In summary, the results in Figs. 3-5 show a good match, a maximum gain in the desired operating band, HFSS [7] validation and pattern correction. For comparison, a reference array with the same dimensions as the prototype SELFLEX array in Fig. 2(a) was manufactured without the phase-shifter circuitry. Since the reference array does not have phase-compensation capabilities, the effect that the cylinder has on the pattern can be illustrated and is shown in Fig. 4. Then, the results in Fig. 5 shows the radiation patterns for the SELFLEX array with phase compensation and a 3.0 dBi gain improvement. Finally, when comparing the flat SELFLEX curve in Fig. 4 to the corrected SELFLEX curves in Fig. 5, it can be seen that the SELFLEX array is autonomously correcting the radiation pattern.

IV. CONCLUSION

An autonomous self-adapting 4 × 4 array capable of compensation on a cylindrical surface has been presented. It was shown that with appropriate analytical computations, sensor circuitry and voltage controlled phase shifters, the radiation pattern of the array could be recovered. These results were validated with measurements and full-wave simulations.

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