# Nulls of a Conformal Beamforming Array on an Arbitrary Wedge-Shaped Surface

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***Abstract*—Beamforming is an integral part of modern wireless communication systems and a key component of beamforming is to have the ability to define specific nulls in the radiation pattern. Moreover, conformal antennas are being used in wireless systems to provide coverage in previously unavailable areas. This paper investigates the affects that a conformal surface may have on the specifically defined nulls associated with a desired beamformation. In particular, a 1×4 conformal array on a wedge-shaped surface is evaluated and analytical computations are validated with measurements.**

***Index Terms*—Conformal array; adaptive beamforming**

## I. INTRODUCTION

Conformal antennas, such as wearable, membrane and satellite antennas [1], have been applied to modern wireless communication systems to improve coverage. One desirable feature of antennas in wireless systems is to have the ability to define the radiation pattern dynamically (i.e., to have a smart antenna [2]-[3]). However, in much of the smart antenna work, it has been assumed that the elements of the array are fixed or attached to a rigid surface. Because of this assumption, when a conformal antenna is used as a beamformer, the shape of the pattern may not be as expected because the surface on which the conformal antenna is attached to may be changing shape. Thus, the objective of this work is to investigate the effects of that a wedge-shaped conformal surface may have on the radiation pattern of a beamforming array. In particular, the behaviour of the pattern nulls of the 1×4 beamforming array in Fig. 1(a) are investigated for various values of $\theta_b$ (i.e., wedge angles). It will be shown how the shape of the conformal surface changes the direction of a null in the radiation pattern; which can have a negative impact on the wireless communication system because this null may be associated with an unwanted user.

## II. COMPUTING THE ARRAY WEIGHTS FOR WEDGE-SHAPED CONFORMAL ARRAYS

The array in Fig. 1(a) consists of four antenna elements on a conformal surface in the shape of a wedge and each element is denoted as $a_n$ where $n$ = 1, 2, 3 and 4, and $\theta_b$ is the bend angle of the wedge. The angle in which the array communicates with the desired user (i.e., the signal of interest) is denoted as $\theta_{SOI}$ and the angle of the undesired user (i.e., signal not of interest or null) is denoted as $\theta_{SNOI}$. Furthermore, for this work the

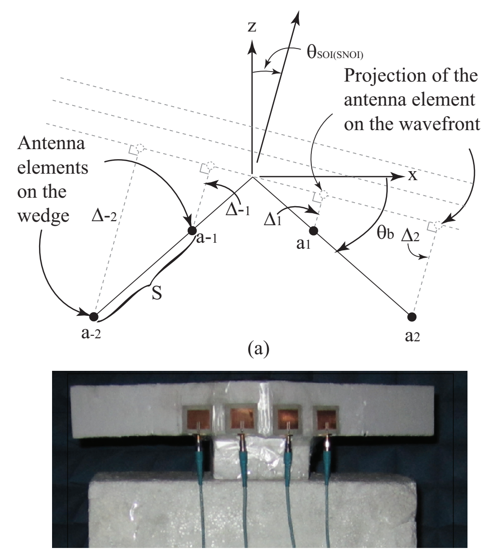


Fig. 1. (a) Illustration of the four-element conformal array on a wedge-shaped conformal surface with bend angle $\theta_b$ and (b) photograph of the four-element array used for testing in the full anechoic chamber.

TABLE I
SUMMARY OF THE BEAMFORMATION PATTERNS 1 AND 2.

| Variable | Pattern 1 | Pattern 2 |
|---|---|---|
| $\theta_{SOI}$ | 0° | 40° |
| $\theta_{SNOI_1}$ | −30° | −45° |
| $\theta_{SNOI_2}$ | 30° | −25° |
| $\theta_{SNOI_3}$ | 40° | 10° |

two beamforming patterns were defined for various values of $\theta_{SOI}$ and $\theta_{SNOI}$, and they are summarized in Table I.

To compute the desired complex array weights to support a desired propagation in the direction of $\theta_{SOI}$ or $\theta_{SNOI}$ (i.e. a specific beamformation), a projection plane was defined in Fig. 1(a) [2]. Then, the distance from each antenna element to the wavefront was computed and the following 4×4 matrices were used to solve for the array weights [2]:

$$\mathbf{W} = \mathbf{A}^{-1}\mathbf{C} \tag{1}$$

where **C** are the forcing functions for the array factor and **A**

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TABLE II
ARRAY WEIGHTS OF THE CONFORMAL ANTENNA ON THE WEDGE-SHAPED SURFACE.

| Pattern 1 weights | Pattern 2 weights |
|---|---|
| $\theta_b$ = 0° | |
| $w_{-2} = 1\angle{-32.15°}$ | $w_{-2} = 0.7462\angle{-176.1°}$ |
| $w_{-1} = 1\angle 32.15°$ | $w_{-1} = 1\angle 72.5°$ |
| $w_1 = 1\angle{-32.15°}$ | $w_1 = 1\angle{-72.5°}$ |
| $w_2 = 1\angle 32.15°$ | $w_2 = 0.7462\angle 176.1°$ |
| $\theta_b$ = 10° | |
| $w_{-2} = 0.8878\angle 21°$ | $w_{-2} = 0.5924\angle{-141.85°}$ |
| $w_{-1} = 0.5914\angle 53.85°$ | $w_{-1} = 0.9061\angle 91.27°$ |
| $w_1 = 1\angle{-11.73°}$ | $w_1 = 1\angle{-52.28°}$ |
| $w_2 = 0.7851\angle 84.66°$ | $w_2 = 0.8119\angle{-150.36°}$ |
| $\theta_b$ = 20° | |
| $w_{-2} = 0.8779\angle 74.77°$ | $w_{-2} = 0.4335\angle{-106.83°}$ |
| $w_{-1} = 0.2155\angle 79.65°$ | $w_{-1} = 0.7616\angle 111.56°$ |
| $w_1 = 1\angle 10.17°$ | $w_1 = 1\angle{-28.92°}$ |
| $w_2 = 0.6557\angle 136.25°$ | $w_2 = 0.8369\angle{-115.8°}$ |
| $\theta_b$ = 30° | |
| $w_{-2} = 0.9849\angle 128.76°$ | $w_{-2} = 0.3113\angle{-72.72°}$ |
| $w_{-1} = 0.2119\angle{-75.85°}$ | $w_{-1} = 0.5637\angle 135.57°$ |
| $w_1 = 1\angle 35.24°$ | $w_1 = 1\angle{-2.34°}$ |
| $w_2 = 0.5961\angle{-174.73°}$ | $w_2 = 0.8440\angle{-78.45°}$ |
| $\theta_b$ = 40° | |
| $w_{-2} = 1\angle{-178.72°}$ | $w_{-2} = 0.2649\angle{-37.21°}$ |
| $w_{-1} = 0.6034\angle{-4.38°}$ | $w_{-1} = 0.3506\angle 158.87°$ |
| $w_1 = 0.7615\angle 58.92°$ | $w_1 = 1\angle 25.78°$ |
| $w_2 = 0.5258\angle{-129.83°}$ | $w_2 = 0.8653\angle{-37.84°}$ |

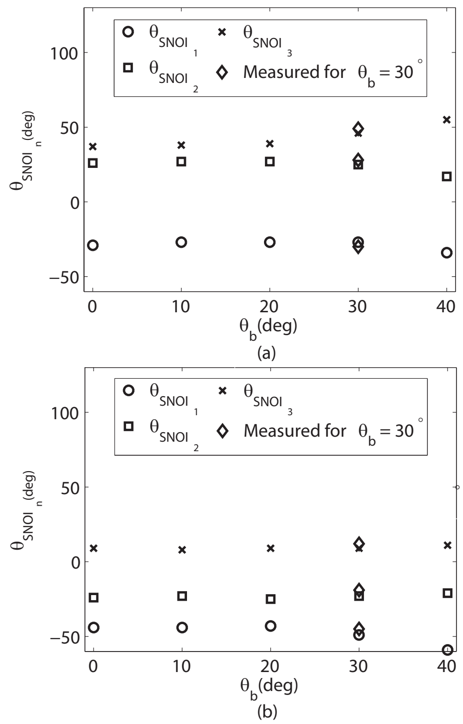


Fig. 2. Measured (for $\theta_b = 30°$) and simulated (for $\theta_b = 0°, 10°, 20°, 30°$ and $40°$) for (a) pattern 1 and (b) pattern 2.

is the array factor of the array on the wedge with the array-weights factored out. A summary of this matrix approach for computing (1) can be found in [2]-[3]. Since the array factor matrix **A** is written in general terms of the element spacing, source frequency and distance to the projection plane, the effect that the wedge-shape has on the beamformation can now be explored.

## III. WEDGE EFFECTS ON PATTERN NULLS

To investigate the effects of various bend angles on the nulls or $\theta_{SNOI}$, the four-element array in Fig. 1(a) was defined to have an operating frequency of 2.47 GHz and an inter-element spacing of $\lambda/2$. Then, the value of $\theta_b$ (i.e., wedge-angle) was defined to be 0°, 10°, 20°, 30° and 40° and (1) was used to compute the array weights for patterns 1 and 2 for each angle. The array weights are shown in Table II. Next, a four-element microstrip antenna array was simulated in HFSS [4] with the complex weights in Table II driving the elements. The values of $\theta_{SNOI_n}$ for $n$ = 1, 2 and 3 and bend angles $\theta_b$ = 0°, 10°, 20°, 30° and 40° are shown in Figs. 2(a) and 2(b) for patterns 1 and 2, respectively.

For validation, the prototype array shown in Fig. 1(b) was manufactured. The beamforming array consisted of four microstrip patches, four attenuators, four phase-shifters and a power divider. The patches on the wedge-shaped surface with $\theta_b$ = 30° were attached to the phase-shifters with identical SMA cables, and the attenuators and phase-shifters were used to provide the magnitude and phase, respectively, of the array weights to each individual element. Then, the nulls were measured and these results are shown to agree with the simulations in Figs. 2(a) and 2(b).

The goal of this work was to investigate the effects of various bend angles on the values of $\theta_{SNOI_n}$ for conformal antennas on wedge-shaped surfaces. The results in Fig. 2 indicate that the locations of $\theta_{SNOI_n}$ deviate from the desired values after a bend angle of $\theta_b$ = 20°. The deviations becomes more prominent as the surface becomes more deformed. This is a limitation thought to be due to the mutual coupling in the array and should be kept in mind during the design process.

## IV. CONCLUSION

The beamforming characteristics of a 1×4 conformal array on a wedge-shaped surface were investigated. In particular, the effects that the surface has on the nulls of the beamformation were determined, presented and validated with measurements. In summary, it was shown that for large enough surface deformations, the null locations deviated by as much as 15°.

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