On the Design of a Circuit for Phase Compensation of Self-Adapting Conformal Arrays

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***Abstract*—A simple circuit capable of measuring the shape of a conformal antenna in real-time and using this information to apply phase-compensation to correct the radiation pattern is presented in this paper. More specifically, using three desired sensor output values, the necessary circuit components in the control circuit can be analytically evaluated. The accuracy of the proposed analytical technique has been validated by comparison with published literature, simulations and analytical computations of a 1X4 conformal array on a wedge-shaped surface.**

***Index Terms*—Conformal antenna, AMP04, analog phase shifter.**

I. Introduction

Conformal antennas have recently gained popularity among researchers because wireless systems for wearable networks, antennas mounted on vibrating surfaces in the aerospace industry and implantable sensors can be significantly improved if the antenna is allowed to change shape [1]-[3]. In related work [1], it has been shown that a circuit consisting of weighting functions, flexible strain gauges, amplifiers and various discrete components can be used to measure the surface deformation of a conformal antenna and introduce appropriate phase compensation. However, considering the versatile applications of conformal arrays, the circuit reported in [1] is restricted to a single type of conformal resistive sensor.

One of the challenges in designing a self-adapting conformal array is to retain its original direction of radiation irrespective of its curvature of surface in real time. One technique to overcome such issues is to sense the changes in the surface of the array and adjust the phase of the voltages driving each element accordingly (i.e., autonomous phase compensation). For this work, the 1X4 array on the wedge-shaped surface shown in Fig. 1(a) was considered. The antenna elements are denoted as A_1, A_2, A_3 and A_4. The array in the flat position is shown along the line with the solid box. Then, the array on the wedge-shaped surface with angle θ_w is illustrated with the elements in the wedge-shaped box with the dotted lines. Also, for this work, the direction of radiation is assumed to be in the +z-direction. Therefore, one method of supporting radiation in the +z-direction when the array is flat (i.e., outlined by the box with the solid line) is to drive each element with the same phase. However, when the array is on the wedge-shaped surface and each element is driven with the same phase, the main lobe moves away from the +z-direction

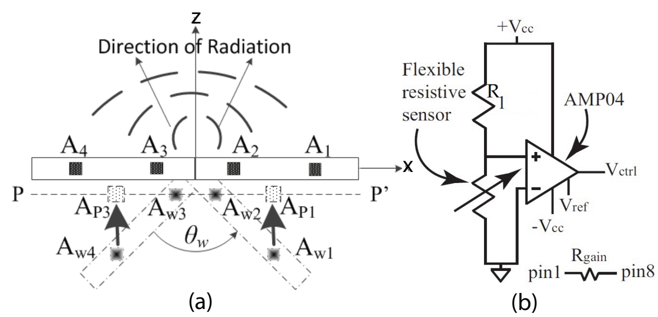

Fig. 1. (a) the 1x4 conformal antenna array on planar and wedge-shaped surfaces and (b) schematic of the control circuit used to measure the conformal surface and implement phase compensation.

in an undesired manner. To move the radiation back to the +z-direction, a positive phase on the voltages driving elements A_{w1} and A_{w4} to cancel the negative propagation phase can be introduced. This will result in a field radiated from A_{w1} and A_{w4} that will arrive at the reference plane P in Fig. 1 with the same phase as the fields radiated from elements A_{w2} and A_{w3}, thus resulting in broadside radiation to the reference plane. Therefore, the objective of this paper is to derive the necessary equations to compute the components of the sensor circuit shown in Fig. 1(b) capable of implementing autonomous phase-compensation into a conformal array. Furthermore, the design equations used to compute the component values of this circuit will not be restricted to a single resistive sensor and will be written in terms of the surface on which the conformal array is attached to, operating frequency and the element spacing.

II. Derivations of the Design Equations

For this work, the AMP04 instrumentation amplifier is chosen and the first step is to derive an expression for the the control voltage V_{ctrl} in Fig. 1(b). This control voltage is used to implement phase compensation by driving the voltage controlled phase shifters in the conformal array. According to the data sheet, the following equation can be used to find V_{ctrl}:

$$V_{ctrl} = \frac{100V_{cc}}{R_{gain}} \left(\frac{R_{sensor}}{R_1 + R_{sensor}} \right) + V_{ref} \qquad (1)$$

where all resistors are in KΩ and R_{sensor} is the arbitrary resistance of the sensor used to measure the conformal surface

TABLE I
COMPARISON BETWEEN ANALYTIC AND SIMULATED VALUES

Angle of Wedge	Analytic Value	Simulated Value	Normalized Phase
θ_w = 0°	3.6 volt	3.63 volt	0°
θ_w = 30°	5.45 volt	5.49 volt	61°
θ_w = 45°	6.5 volt	6.36 volt	96°

the array is attached upon. Next, for this work a flexible resistive sensor manufactured by Spectra Symbol [4] was used and an expression for R_{sensor} in terms of the bend angle of the wedge θ_w (in degrees) can be expressed as:

$$f(\theta_w) = R_{sensor} = \frac{6}{35}|\theta_w| + 16. \tag{2}$$

Notice that the resistor value in (2) has been denoted as a function in terms of θ_w. This was done to emphasize the generality of the expression. Next, to determine the values of the unknown components, V_{cc} should be defined and the calculation of three phase compensation voltages (denoted as $V_{ctrl,1}$, $V_{ctrl,2}$ and $V_{ctrl,3}$) is required. These three compensation voltages are needed to produce three (3) equations with three (3) unknowns where the unknowns are R_{gain}, R_1 and V_{ref} in (1). Also, $V_{ctrl,1}$, $V_{ctrl,2}$ and $V_{ctrl,3}$ are associated with the bend angles θ_{w1}, θ_{w2}, θ_{w3}, respectively. To compute $V_{ctrl,n}$ (n = 1, 2 and 3), general knowledge on the array spacing, operating frequency and associated bend angles is required and the expressions to find $V_{ctrl,n}$ used for this work are reported in [2]. Next, substituting (2) into (1), using the three voltages and corresponding wedge angles, and algebraically solving yields the following quadratic equation to solve for R_1:

$$R_1{}^2 a + R_1 b + c = 0 \tag{3}$$

where

$$a = p - q, \tag{4}$$

$$c = a f(\theta_{w1}) f(\theta_{w2}), \tag{5}$$

$$p = \frac{1}{100}\left(\frac{V_{ctrl,3} - V_{ctrl,2}}{f(\theta_{w3}) - f(\theta_{w2})}\right), \tag{6}$$

$$q = \frac{1}{100}\left(\frac{V_{ctrl,2} - V_{ctrl,1}}{f(\theta_{w2}) - f(\theta_{w1})}\right), \tag{7}$$

and

$$b = f(\theta_{w2})a + f(\theta_{w3})p - f(\theta_{w1})q. \tag{8}$$

Then, R_{gain} can be solved using $R_{gain} = \frac{100}{G}$ where

$$G = \frac{r(V_{ctrl,2} - V_{ctrl,1})}{100} \tag{9}$$

and

$$r = \frac{f(\theta_{w2})}{R_1 + f(\theta_{w2})} - \frac{f(\theta_{w1})}{R_1 + f(\theta_{w1})}. \tag{10}$$

Lastly, V_{ref} can be determined with the following:

$$V_{ref} = V_{ctrl,1} - 100G\left(\frac{f(\theta_{w1})}{R_1 + f(\theta_{w1})}\right). \tag{11}$$

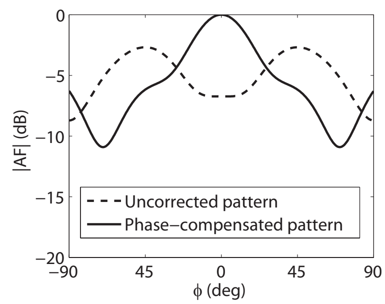

Fig. 2. Analytically computed array factor for the four-element conformal array on a wedge-shaped surface with θ_{w3} = 45°.

III. RESULT AND VERIFICATION

For verification of (1) and (2), the four element array on the wedge-shaped surface in Fig. 1(a) was evaluated. The spacing between the elements was 0.5λ and the operating frequency was fixed at 2.45 GHz. To get three equations with three unknowns, the three wedge angles chosen were $\theta_{w1} = 0°$, $\theta_{w2} = 30°$, and $\theta_{w3} = 45°$. Then, using a Hittite phase shifter (part number: HMC928LP5E [5]), the required voltage for the phase compensation for each wedge angle was 3.6 V, 5.45 V, and 6.5 V, respectively. Considering $V_{cc} = 15$ volt, the evaluated values of the circuit components using (3) - (11) were found to be R_1 = 98.5KΩ, R_{gain} = 30KΩ, and V_{ref} = -3.4 V. For an initial validation, these values were used in a SPICE simulation of the circuit in Fig. 1(b) and the results are shown to compare well in Table I. Finally, the normalized angles in the fourth column of Table I were used to compute the array factor of the conformal array on the wedge in Fig. 1(a) for $\theta_{w3} = 45°$. The results in Fig. 2 shows pattern correction (i.e., phase-compensation) and compares well with the values reported in [2]. Similar agreement was shown for $\theta_{w2} = 30°$.

IV. CONCLUSION

In this paper, a new analytical technique to evaluate the circuit components of an autonomous phase-compensation circuit for conformal self-adapting arrays has been proposed. Overall, it was shown with simulations, array factor computations and comparison with published results that the proposed circuit design technique can be used successfully.

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