A Frequency Reconfigurable Self-Adapting Conformal Array for Changing Surfaces

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Abstract: Conformal antennas placed on complex surfaces are receiving more attention as a method to increase the coverage of modern wireless communication systems. Furthermore, frequency reconfigurable antennas are being used in the development of multi-band multi-radio wireless platforms to simplify designs. In this project, theoretical development and a new 1 × 4 frequency reconfigurable self-adapting conformal antenna array that can be attached to changing conformal surfaces is presented. This conformal array consists of four reconfigurable microstrip patch antenna elements, a reconfigurable sensor circuit used to measure the curvature of the conformal surface and voltage controlled phase shifters. These phase shifters are controlled by the reconfigurable sensing circuit to implement phase-compensation to autonomously recover the pattern in both bands of the reconfigurable 1 × 4 array as the wedge- and cylindrical-shaped surface on which the array is attached upon changes shape. Throughout this project, analytical computations, simulations in CST and measurements are compared and shown to agree.

Target of the project: In this project, the benefits of self-adapting conformal antennas and reconfigurability are combined into one design. In particular, the objective of this project is to simulate the antenna array in CST by providing the correct phase at each element (when it is attached to the deformed surface as shown in Fig.2) and a prototype for validation. The antenna array consists of reconfigurable microstrip patch antennas each individually connected to voltage controlled phase shifters with identical SMA cables (flexible cables were chosen for placement on various surfaces). The wedge- and cylindrical-shaped surface deformation is measured by a new reconfigurable sensing circuit that does not require signal processing. The circuit then in turn provides an output voltage that drives the voltage controlled phase shifters to implement phase compensation [1] at both switching frequencies. By choosing the appropriate circuit design, the array in Fig. 1 can autonomously preserve the radiation pattern in both frequency reconfigurable bands using phase compensation. With the introduction of this array, designers will be able to develop wireless communication systems for much more complicated and compact structures. For example, in enclosures and the requirement of having a phased-array antenna on flat surfaces could be relaxed.

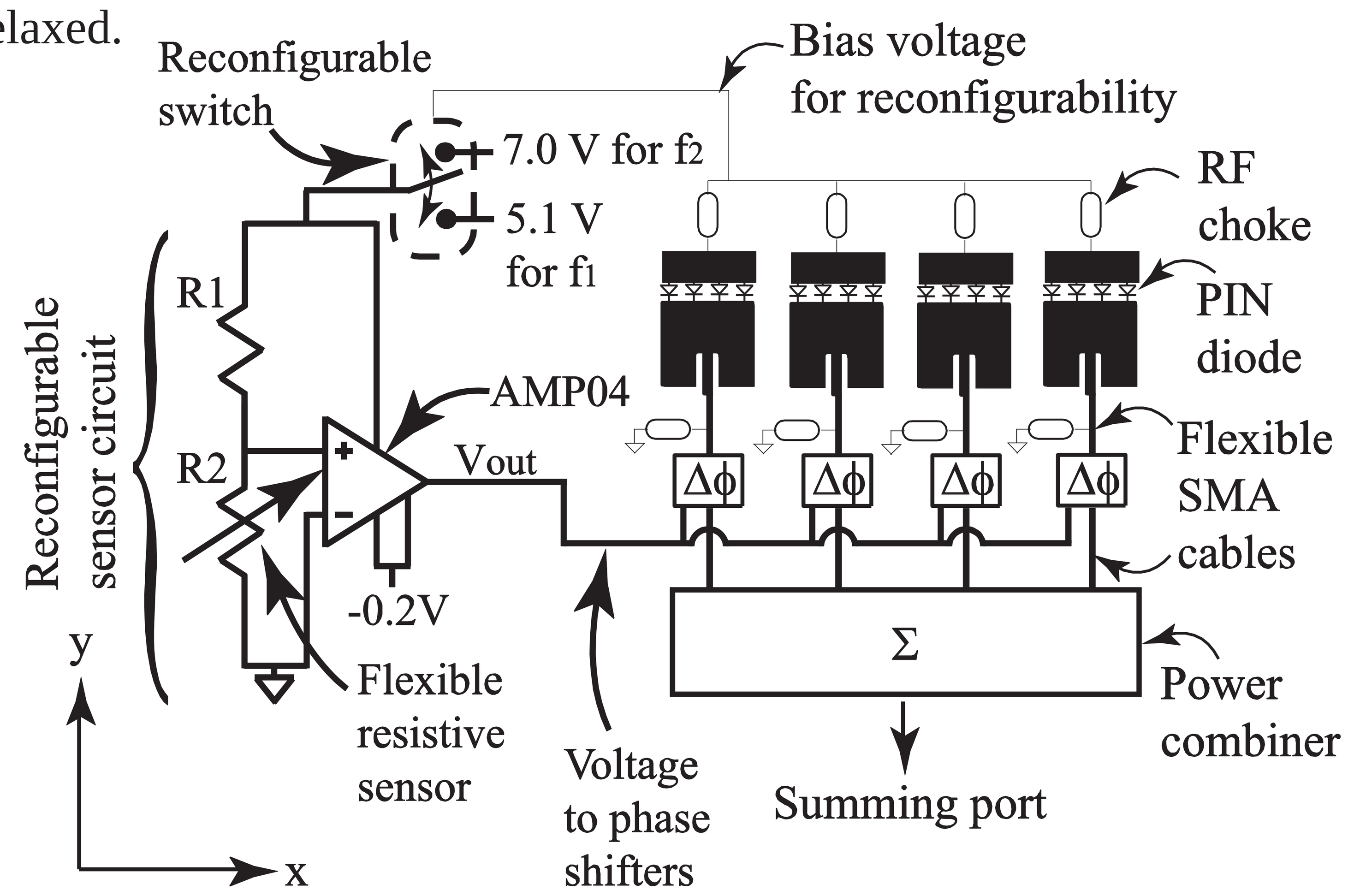

Fig. 1. Topology of the frequency reconfigurable self-adapting conformal antenna (R_1 = 1.0 MΩ, R_{gain} = 4.0 KΩ - connected between pins 1 and 8).

Results: A drawing with the dimensions of the reconfigurable patch is shown in Fig. 4(a). The reconfigurable antenna switches between f_1 and f_2 by changing the electrical length of the radiating patch. The antenna was simulated in CST [2] on a 1.524mm thick TMM4 Rogers Substrate [3] with five PIN diodes. The equivalent circuit of the biased and unbiased PIN diodes, shown in Fig. 4(b), were used in CST to compute the effects the diodes had on the input impedance of each patch. The PIN diodes were purchased from Skyworks [4] (part number: SMP1322) and the S-parameter results are shown in Fig. 3.

Next, the prototype array shown in Fig. 4(c) (shown attached to the wedge-shaped conformal surface) was manufactured. This array consisted of four of the frequency reconfigurable microstrip patches shown in Fig. 4(b) connected to four Hittite phase shifters through four identical SMA cables. The phase shifters were then connected to the port of a four-way power combiner (manufactured by Mini-circuits [5] with part number: WP4R+). Then, the reconfigurable sensor circuitry was connected to the voltage controlled phase shifters to create the frequency reconfigurable self-adapting conformal array. To validate the performance of the proposed reconfigurable self-adapting array, the wedge-shaped surface with the array attached was placed in a full anechoic chamber. The interelement spacing was $L_1 = 0.83\lambda_1$ and $L_2 = 1.0\lambda_2$. The pattern of the array was then measured at both f_1 and f_2 for θ_b = 30° and 45°. The results from these measurements are shown in Fig. 5 (a) - (d) for θ_b = 30°. For validation, these measurements were compared to the analytical computations using the Array Factor expressions presented in [1]. Good agreement can be observed and self-adapting characteristics at both

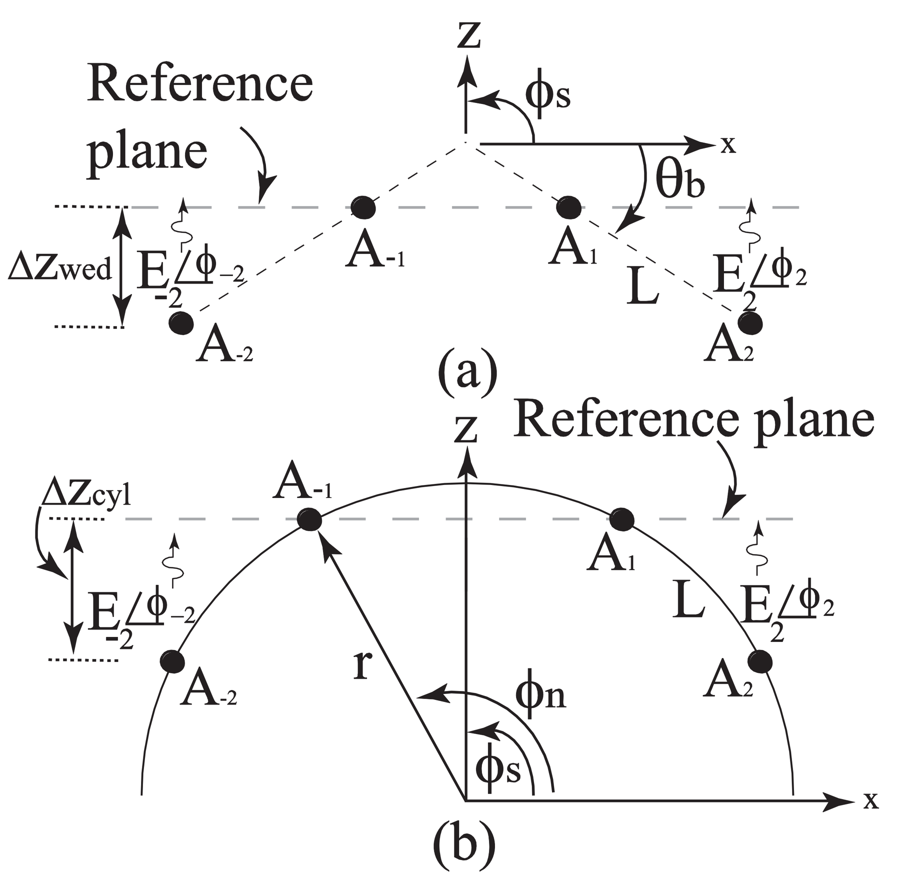

Fig. 2. An illustration of a 1 × 4 array on a (a) wedge- shaped and (b) cylindrical-shaped conformal surface.

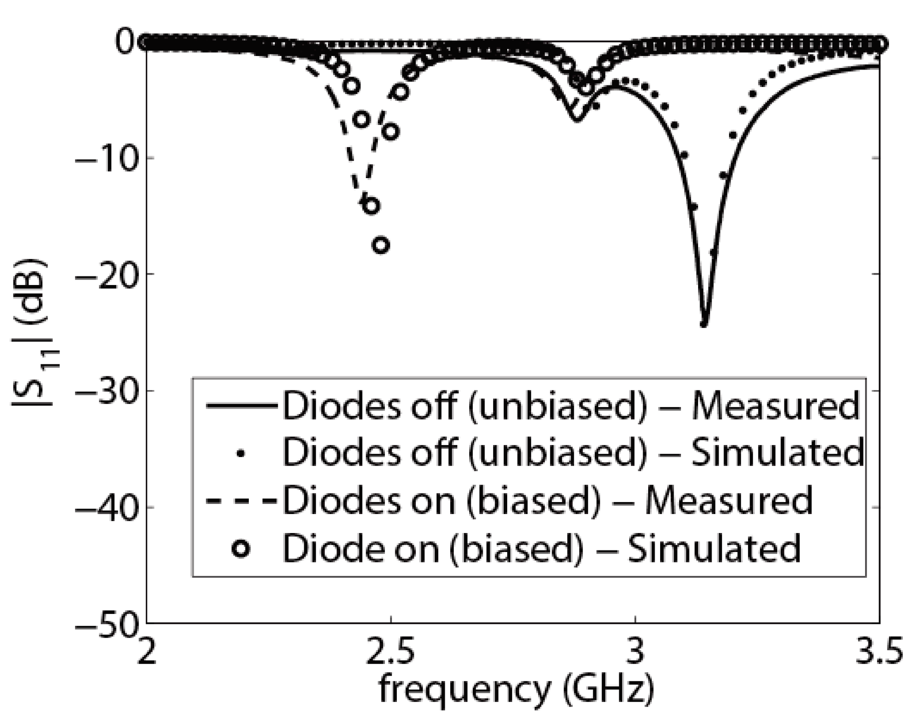

Fig. 3. Measured and simulated S-parameter values for the single frequency reconfigurable patch.

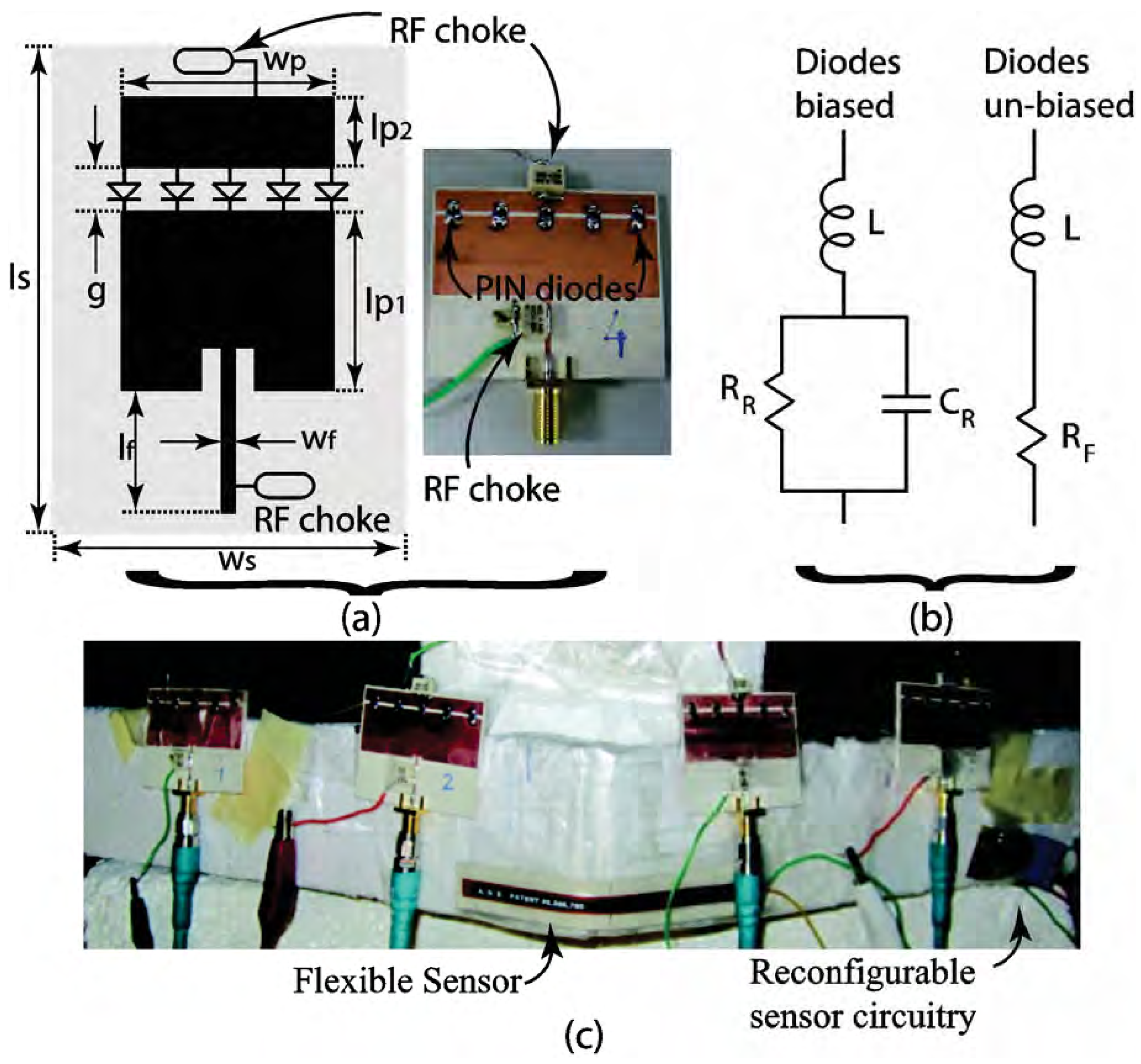

Fig. 4. (a) Drawing of the frequency reconfigurable microstrip patch element in the 1 × 4 array and a photograph of the prototype element (l_s = 42 mm, w_s = 50.5 mm, l_{p1} = 17.7 mm, l_{p2} = 4.8 mm, w_p = 49 mm, l_f = 17.6 mm and w_f = 1.3 mm); (b) circuit model of the biased and un-biased diodes in HFSS (L = 0.5 nH; R_F = 0.8 Ω; R_R = 1k Ω; C_R = 0.01 pF; C_B = 45 pF; L_C = 200 nH) and (c) photograph of the prototype array on the wedge-shaped conformal surface.

reconfigurable frequencies f_1 and f_2 are demonstrated. It should be mentioned that similar good agreement between measurements and computations was observed for θ_b = 45°. Next, the array was attached to a cylindrical-shaped surface with r = 16 cm and an inter-element spacing of $L_1 = 0.83\lambda_1$ and $L_2 = 1.0\lambda_2$. The results from these measurements are shown in Figs. 6 (a) - (d). Again, these measurements were compared to the analytical computations using the Array Factor expressions presented in [1]. Good agreement is also observed; indicating that the antenna is autonomously correcting the radiation pattern in both operating bands on three different conformal surfaces.

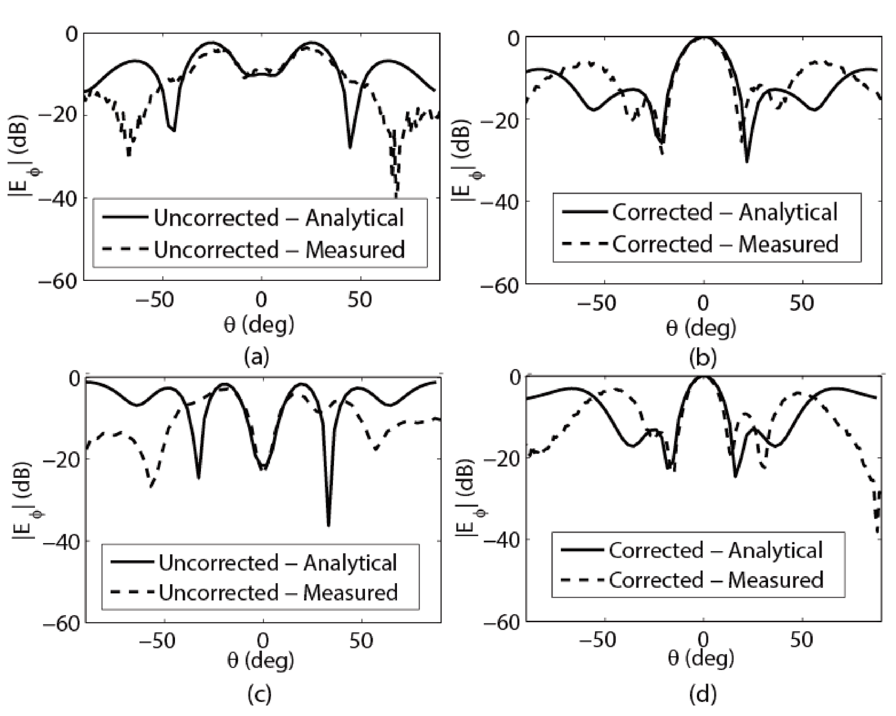

Fig. 5. (a) Uncorrected and (b) corrected analytical and measured patterns of the reconfigurable self-adapting array at 2.43 GHz (f_1) and (c) uncorrected and (d) corrected analytical and measured patterns of the array at 3.15 GHz (f_2). All results are in the x-zplane for the wedge-shaped conformal surface with θ_b = 30°.

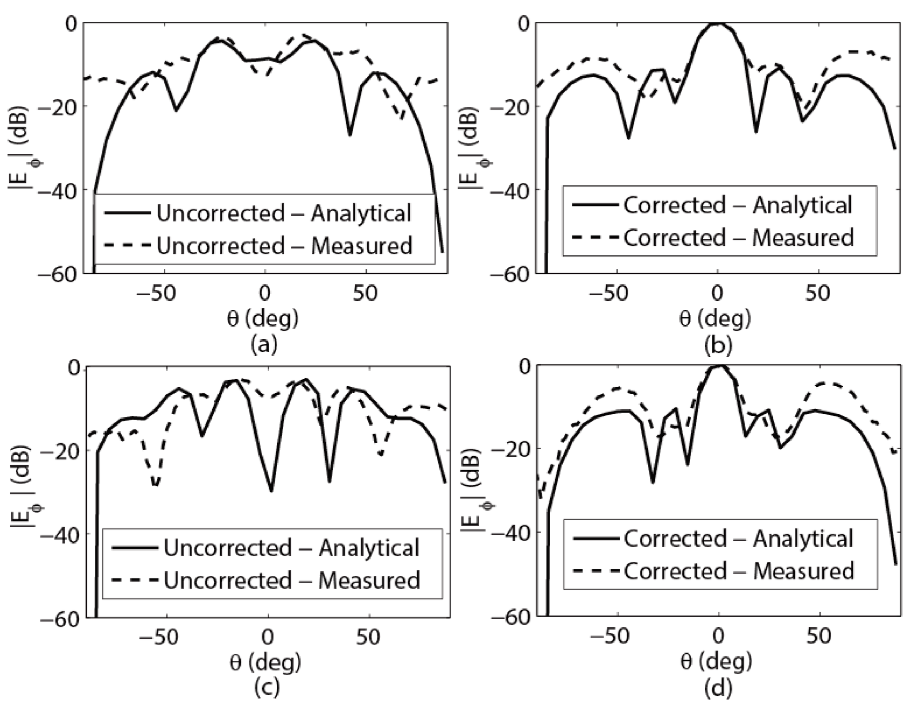

Fig. 6. (a) Uncorrected and (b) corrected analytical and measured patterns of reconfigurable self-adapting array at 2.43 GHz (f_1) and (c) uncorrected and (d) corrected analytical and measured patterns of the array at 3.15 GHz (f_2). All results are in the x-z plane for the cylindrical-shaped conformal surface.

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